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LOW HEADROOM TRANSFER CHUTE FOR UNDERGROUND BELT CONVEYORS:

Analysis of Coal Flow through Ninety Degree Transfer Point & Preliminary Design

FINAL TECHNICAL REPORT as of MAY, 1978

This report represents completion by the Interior Department's Bureau Of Mines of a part of a program that was transferred to the Department Of Energy on October 1, 1977.

Terrell L. Holliday

Fairchild Space & Electronics Company
Germantown, Maryland 20767

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16. Abstract (Limit: 200 words)

A study program combining computer math modelling and scale model tests has evolved a preliminary design for a 90-degree transfer chute for belt conveyors in underground coal mines. The principal design objective was to achieve chute flow characteristics that minimize coal spillage, dust generation, and belt wear. This preliminary design will serve as a conceptual baseline for detailed design, fabrication, and testing---both above ground and in a coal mine---of a full size, 90-degree transfer chute between a 36-inch wide, input belt conveyor and a 42-inch wide, receiving belt conveyor.

The study concludes that a double curvature-type surface will most nearly achieve the performance objectives for the 90 degree belt conveyor transfer chute. The surface recommended for full scale, above-ground testing resembles a portion of a 90 degree smoke pipe elbow, corresponding to a jointed approximation of a basic torus geometry. For the 36 inch wide belt, 450 fpm, feed conveyor case, the torus has a 36-inch major radius and an 18 inch minor radius.

Work performed under this study includes 1) technology surveys of transfer point design, bulk flow theory, and underground coal mine operations; 2) math modeling and associated computer programming of free fall, impact, and frictional flow dynamics; 3) evolution and evaluation of several candidate chute geometries; 4) construction and laboratory testing of one-sixth scale models; and 5) preliminary design of the recommended chute.

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Bulk Handling
Chutes
Coal Dust
Coal Mining
Coal Mines
Mine Haulage

b. Identifiers/Open-Ended Terms

Transfer Point Design
Pseudo Plastic Flow
Torus
Smoke Pipe Torus

c. COSATI Field/Group Earth Sciences and Oceanography/Mining Engineering

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2.0 EXECUTIVE SUMMARY

2.1 INTRODUCTION

This report summarizes the results of a study program to evolve a preliminary design for a 90-degree transfer chute for belt conveyors in underground coal mines. This preliminary design is intended to provide a conceptual baseline for detailed design, fabrication, and testing---both above ground and in a coal mine---of a full size, 90-degree transfer chute between a 36-inch wide, input belt conveyor and a 42-inch wide, receiving belt conveyor.

2.2 PROJECT SUMMARY

Consistent with the above objective of this program, this study has addressed candidate chute configurations from the standpoint of flow characteristics that will minimize coal spillage, dust generation, and belt wear. In order to achieve this, the work performed in this study has included the following:

1) Technology surveys of transfer point design, bulk flow theory, and underground coal mine operations, the last including visits to several mines.
2) Math modeling and associated computer programming of dynamics covering both free fall and impact, as well as frictional flow.
3) Evaluation of several candidate chute geometries, including mathematical formulation of the most promising ones for analysis.
4) Construction and laboratory testing of one-sixth scale models of preliminary chute concepts.
5) Preliminary design of the recommended chute configuration, including installation interfaces.

FSEC's work in evolution, analysis, and testing of chute surfaces was initiated by an extensive bibliography study into pertinent subject areas related to underground belt conveyor transfer points and was further augmented by specific consultant support in transfer point technology, bulk flow theory, and mine operations. In this last-mentioned area, FSEC inspected transfer points in a total of eight underground mines. This overall survey phase of the study program is covered in Section 4.0.

Math modelling effort during the program involved mathematical definition and associated computer programming in two basic areas: 1) dynamic flow; and 2) mathematical definition of specific chute geometry to support the flow study.

Two distinct dynamic phases were modelled, namely, those of free fall and frictional flow. Provision was made in these models for introduction of three principal groups of parameters: 1) conveyor interface characteristics; 2) material characteristics; and 3) the chute itself. Definition of the dynamic phases of the modelling is covered in section 5.0 while the chute configuration model is developed in section 6.0, following evolution and screening of candidate chute surface concepts.

The free fall portion of the dynamic model was uniformly successful in providing locations and angles of impact of the initial trajectory. The frictional flow portion of the model, however, involved a considerable period of shakedown and debugging that was not entirely resolved in this program. The problems were ultimately related to mathematical convergence problems in the incrementally defined velocities and shapes of the several stream flow elements, into which the mass cross section was divided to establish the effects of deformation. As a result of this, modifications of the math model were dictated until the end of the program, and the results in the area of frictional flow are limited to a few dynamic parameters.

In the math model of the torus, a broad flexibility is provided for parametric variation both of details of the surface configuration and of rotational and translational definition relative to the feed conveyor pulley.

The results of the flow analysis utilizing the above math models, covered in Section 7.0, includes development of design definition data utilized in Section 3.0. derived from dynamic trajectories generated during the free fall and functional phases.

The basic toroidal surface configuration was selected from a number of candidate surface geometries evaluated during preliminary analysis and testing. The details of this conceptual development phase, other configurations evaluated, and the tradeoffs involved are discussed in Section 6.0. The torus geometry was not the simplest type of those considered, and extensive consideration was given to the question of producibility, as ultimately reflected in Section 3.0. It was, however, evident from the tradeoffs involved that the potential performance of the torus offered the best opportunity for advancing the state of the art in transfer point design, particularly from the standpoint of minimized turbulence, scatter, and --- thereby --- dust evolution.

Construction of one-sixth (1/6) size scale models for laboratory testing involved about seven preliminary candidate designs, which were included in the conceptual evolution and tradeoff analysis discussed above. These configurations, which included basic conical and cylindrical geometries, as well as several iterations of the torus shape, are described and shown in Section 8.0.

Laboratory testing of the scale models provided ultimate insight into several critical phases of flow characteristics. The most important of these were 1) the behavior of flow at impact, 2) the tendency toward convergence/divergence during the frictional phase; and 3) the output direction of the flow trajectory relative to the receiving conveyor. In the first-mentioned area, several trial positions and attitudes for many chute model configurations were dictated to achieve impact flow that did not 1) fork or divide, as a result of variable angle of impact at different areas in the impact zone; and 2) interfere with the subsequent frictional flow. Extensive photographic coverage was provided of this work, which is summarized in Section 9.0.

2.3 CONCLUSIONS AND RECOMMENDATIONS

Analysis and testing conducted in this study program indicates that a double curvature-type surface will most nearly achieve the performance objectives for the 90 degree belt conveyor transfer chute. The surface specifically recommended for full-scale, above-ground testing approximates the outer portion of a 90 degree smoke pipe elbow. This elbow is itself a jointed approximation of a basic torus geometry, which for the 36 inch wide belt, feed conveyor case, has a 36-inch major radius and an 18 inch minor radius. The chute configuration specified herein for a nominal feed conveyor input velocity of 450 fpm is shown in Figures 3-2a and 2b, while the overall transfer point layout is shown in Figures 3-1a, -1b, and 1-c.

The basic conceptual approach taken in this preliminary design is fourfold:

1. Establish the location of initial contact of the free fall trajectory with the chute as close as possible to the feed conveyor to initiate the 90 degree turn of the material early and minimize the headroom utilized for the turn. This location can be varied at installation along three axes of translational adjustment.

2. Orient the initial contact surface approximately tangential to the free fall trajectory vector to minimize turbulence and scatter originating at impact. This is achieved both by the surface shape as well as provisions for three degrees of rotational adjustment for the chute at installation.

3. Provide a vertical curve frictional trajectory in the direction of the receiving conveyor to achieve the most efficient geometry from a headroom standpoint, to maintain and/or accelerate flow. This vertical curve is parallel to the major radius of the torus geometry.

4. Provide converging curvature crosswise to the above vertical curve in order to contain random movement and spillage as well as to direct and center the flow mass relative to the receiving conveyor. This convergence curvature corresponds to the minor radius of the torus.

The smoke pipe approximation of the torus geometry was chosen in order to achieve both producibility, as well as maintainability of worn portions of the chute surface. The surface is built up of single-radius-of-curvature, or cylindrical, segments. These segments can be either cut from a flat pattern and formed individually or else cut from a common piece of rolled stock. The design provides for assembly and replacement of the segments as individual pieces by means of bolted attachment. Details of fabrication and assembly are provided in Section 3.0.

The base support structure defined for the chute provides for floor mounting and is primarily related to requirements of above ground testing. While this configuration is applicable to a below-ground installation, the particular requirements of mines vary, involving in some cases either or both vertical or lateral support from the feed conveyor boom structure of else from the floor roof, via roof bolts. In this context the chute base support structure will require review during planning for below-ground testing, as well as during production design.

3.0 PRELIMINARY DESIGN

This section describes the preliminary design of a transfer point chute which has evolved from the studies performed in this program. It addresses alternate configurations for different feed conveyor input velocities. The basic chute surface approximates a portion of a torus. It is constructed of a series of jointed cylindrical surfaces and resembles therefore a cutout from a "smokepipe" 90 degree elbow.

3.1 STRUCTURAL DESCRIPTION

3.1.1 General

The overall transfer point configuration is shown in Figures 3-1a, -1b, and -1c, which include side, end, and top views, relative to the two interfacing conveyors. The basic dimensional parameters cited are the following:

- Input Belt Width - 36"
- Receiving Belt Width - 42"
- Input Belt Velocity - 450 FPM (For the particular chute position shown)

The two principal structural elements in the design are the following:

1. The Chute Assembly (Figures 3-2a and 3-2b)
2. The Base Support Structure (Figures 3-1a, -1b, and 1c)

The Chute Assembly consists of a series of cylindrically curved plate segments mounted in a multiple-ring,plate segment support structure weldment. (Figures 3-3a and 3-3b.) The inside radius of curvature of each plate segment is 18 inches, while the orthogonal, or major, radius approximated by the series of plates is 54 inches.

This ring support structure weldment, which in part resembles a boat hull skeleton, (Figure 3-3b), includes a wheelbarrow handle-like extension (Figure 3-3c, that pivotally attaches the aft end of the entire Chute Assembly to the Base Support Structure. The opposite end is also supported by the Base Support Structure, suspended by a wire rope-type loop. This permits the Chute Assembly to move up around the aft-located pivot, relative to the receiving conveyor direction, when large run of mine coal lumps arrive from an upstream feed point.

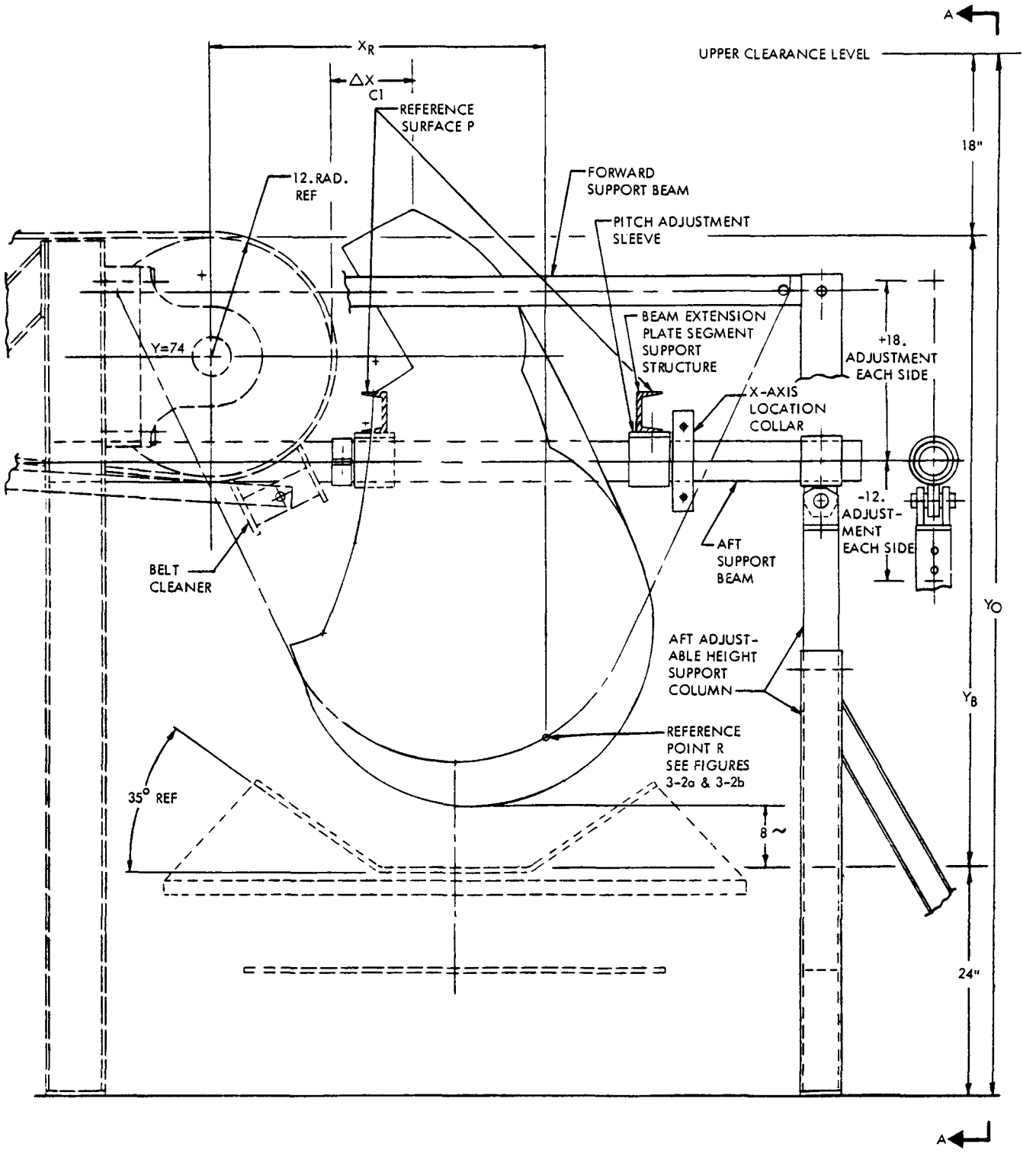


Figure 3-1.a. Chute Installation Layout-Front View
(Looking Parallel to Down Stream Conveyor)

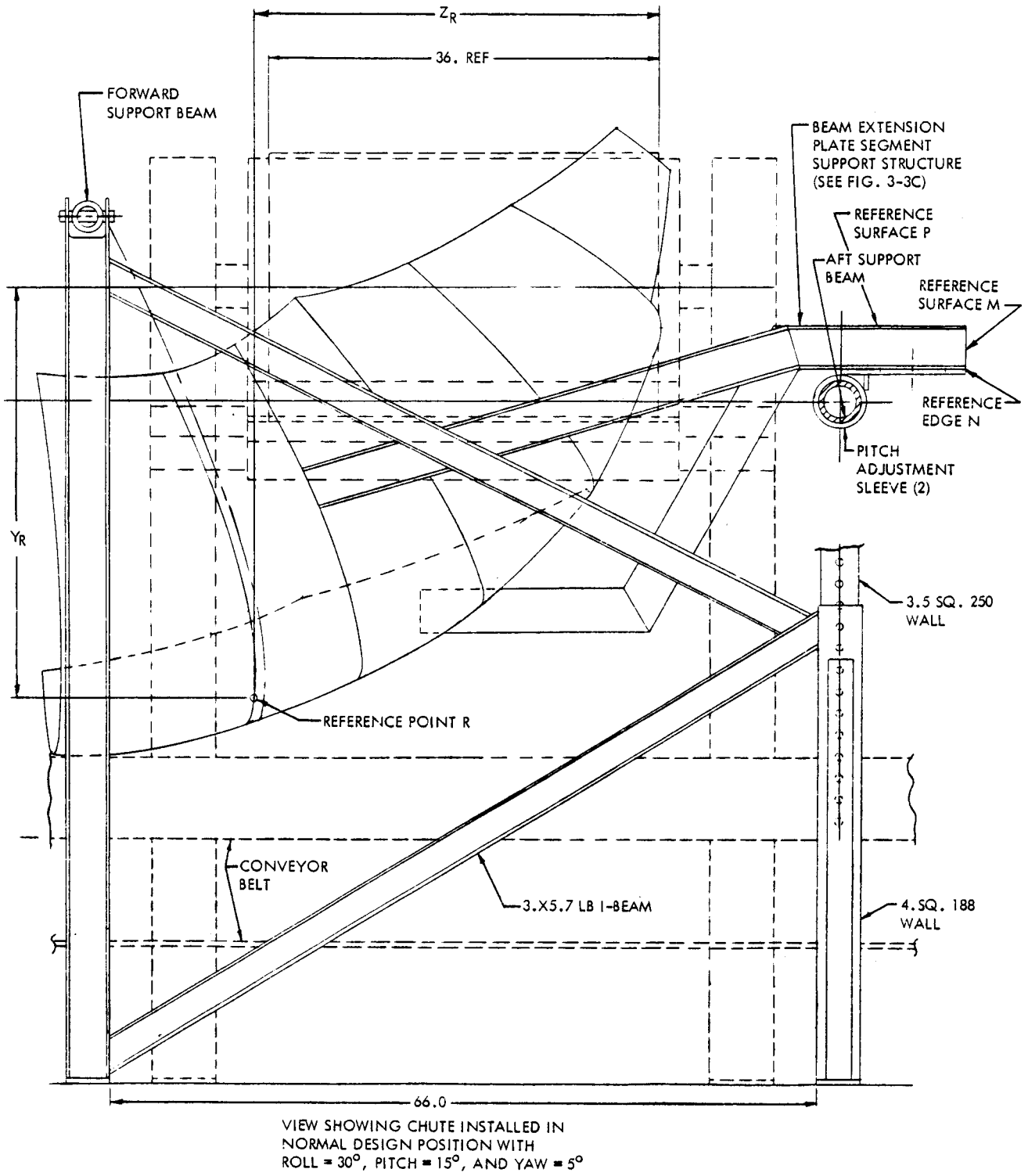


Figure 3-1b. Chute Installation Layout - Side View, Looking Parallel to Upstream Conveyor (View A-A in Figure 3-1a)

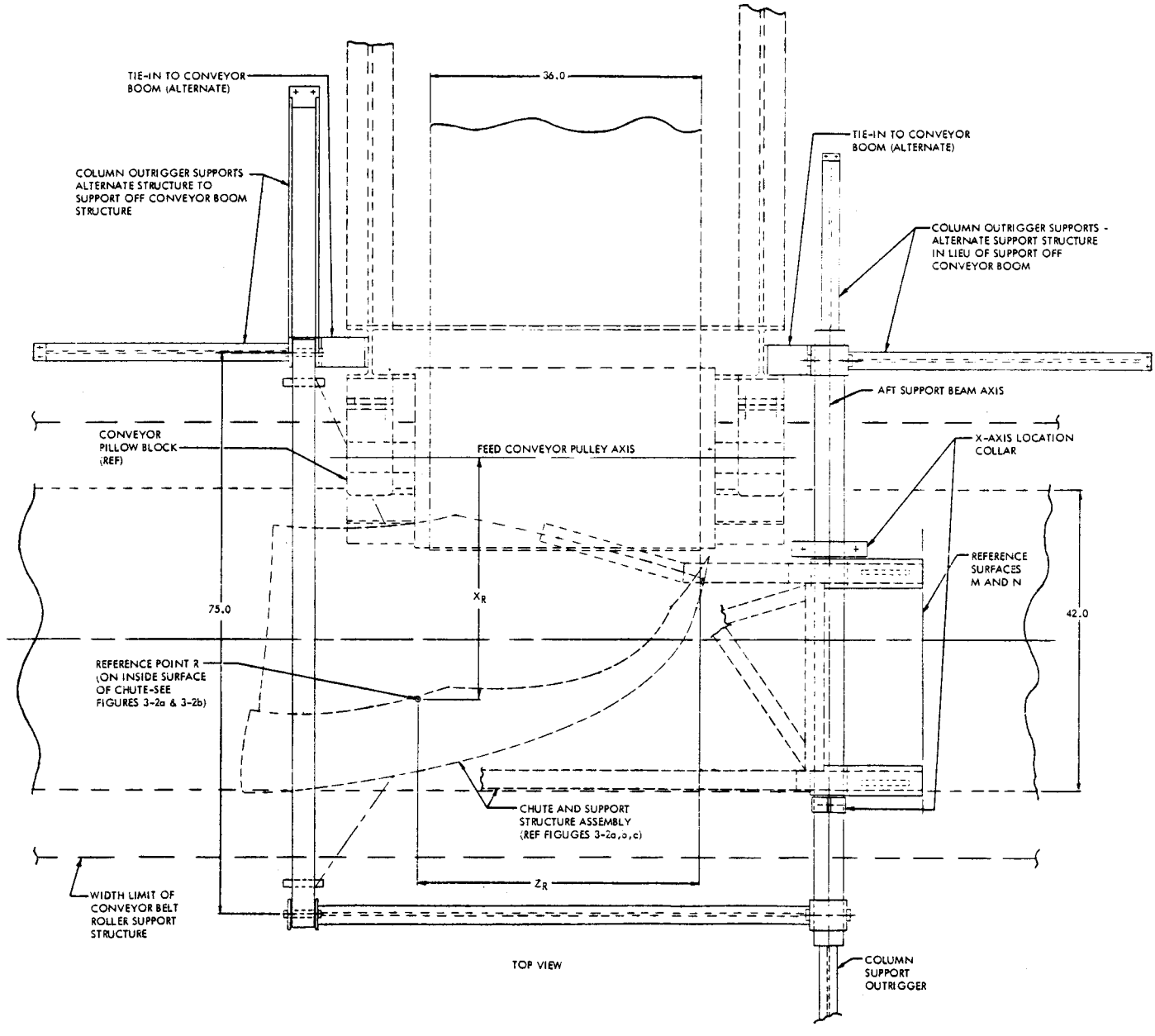
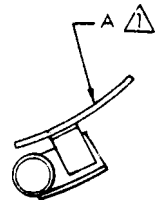


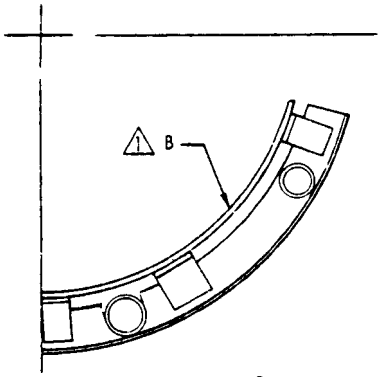
Figure 3-1c. Chute Installation Layout - - Top View

NOTES:

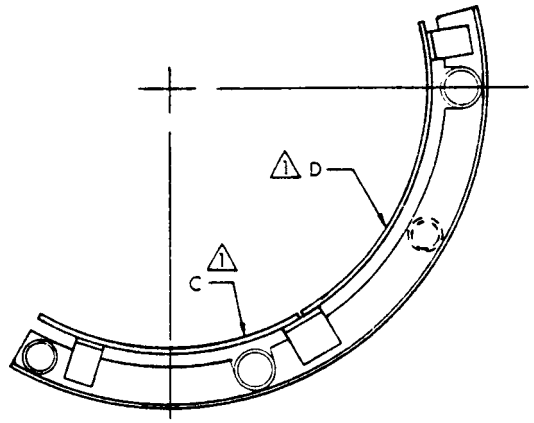
1. SEE FIGURE 3-5 FOR PLATE LETTER DESIGNATIONS.
2. SEE FIGURE 3-2a FOR SECTIONS A, B, & C.



SECT F-F (ROTATED 73-30° INTO PLANE)



SECT E-E (ROTATED 60° INTO PLANE)



SECT D-D (ROTATED 45° INTO PLANE)

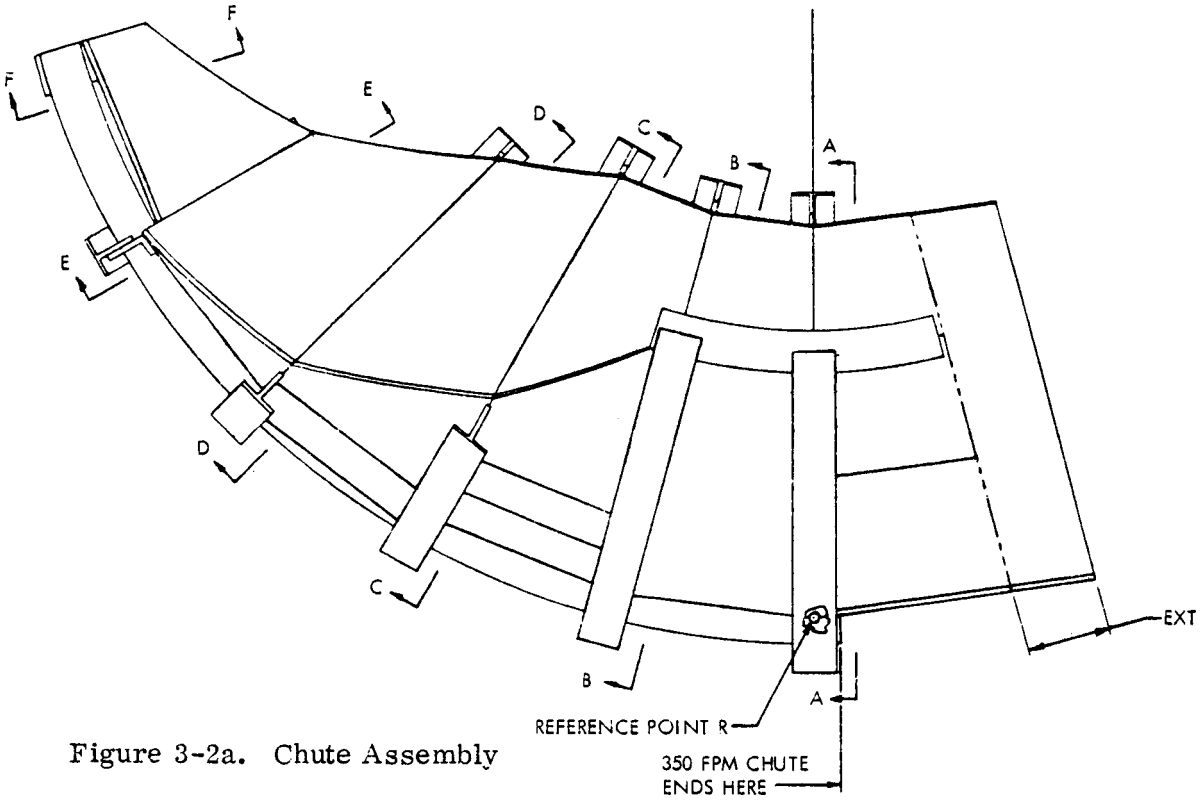


Figure 3-2a. Chute Assembly

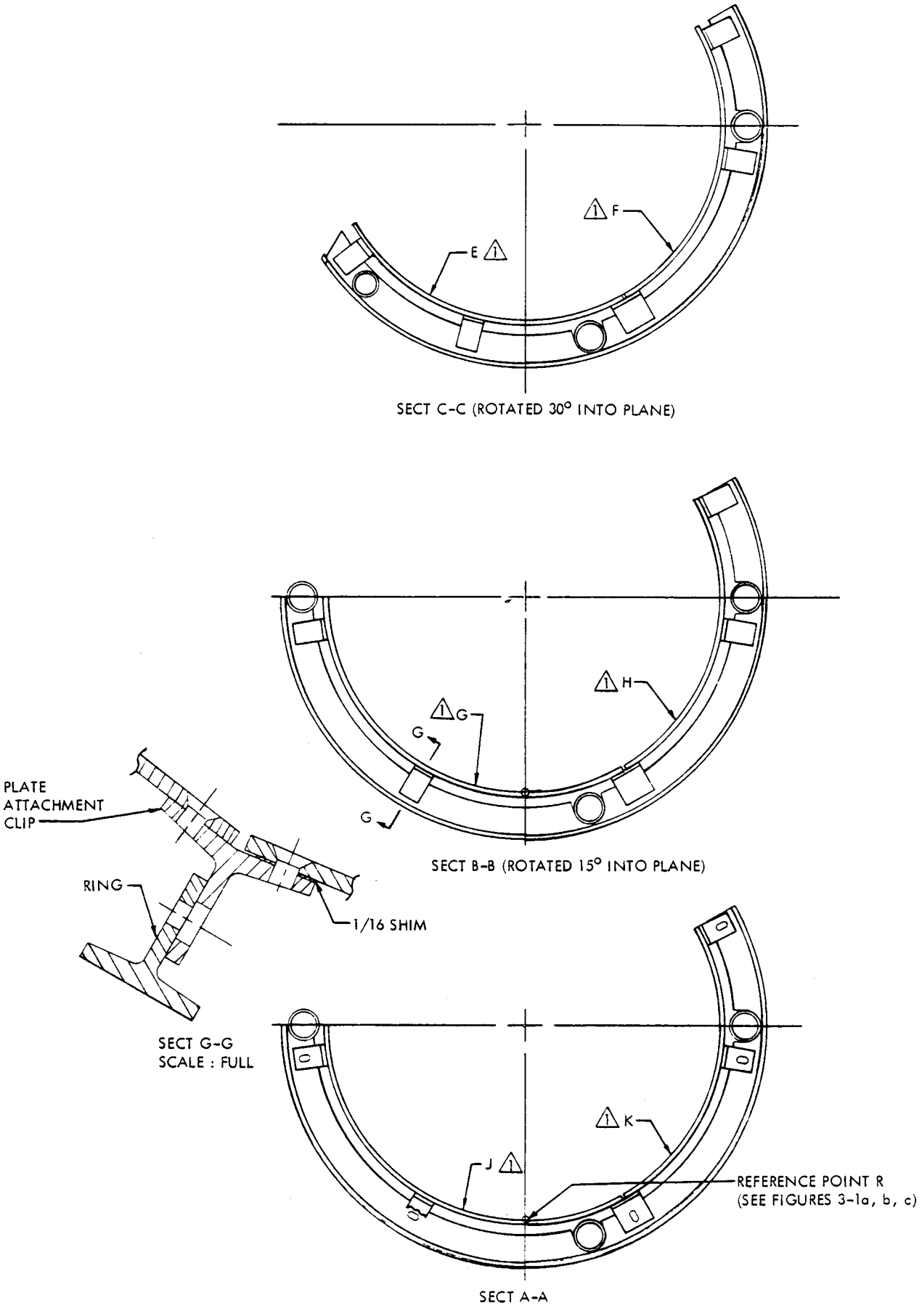
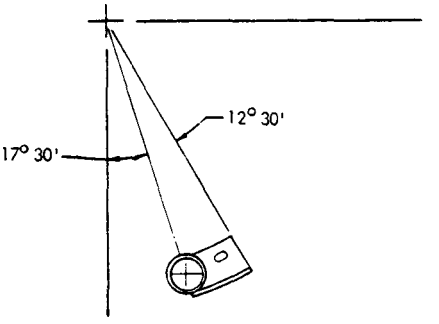
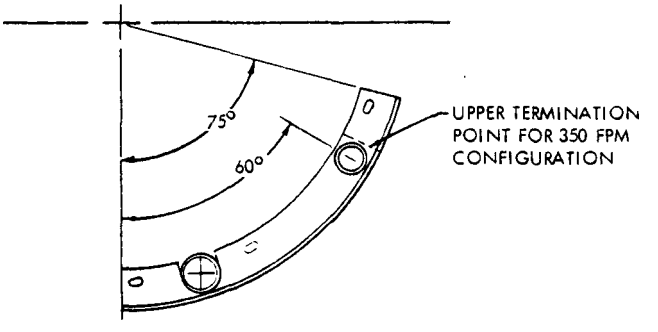


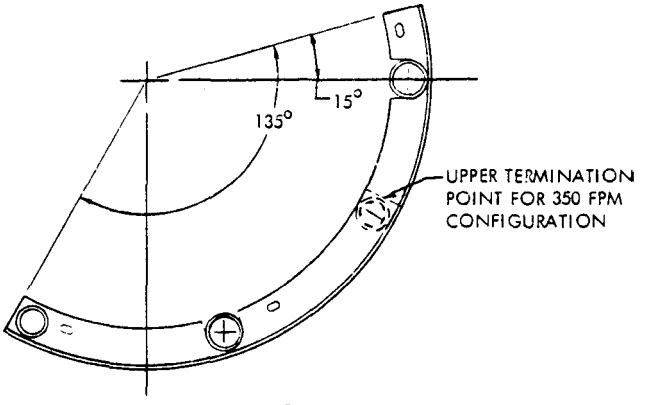
Figure 3-2b. Chute Assembly - Continued (Additional Sections)



SECT F-F (ROTATED 73° 30' INTO PLANE)



SECTION E-E (ROTATED 60° INTO PLANE)



SECT D-D (ROTATED 45° INTO PLANE)

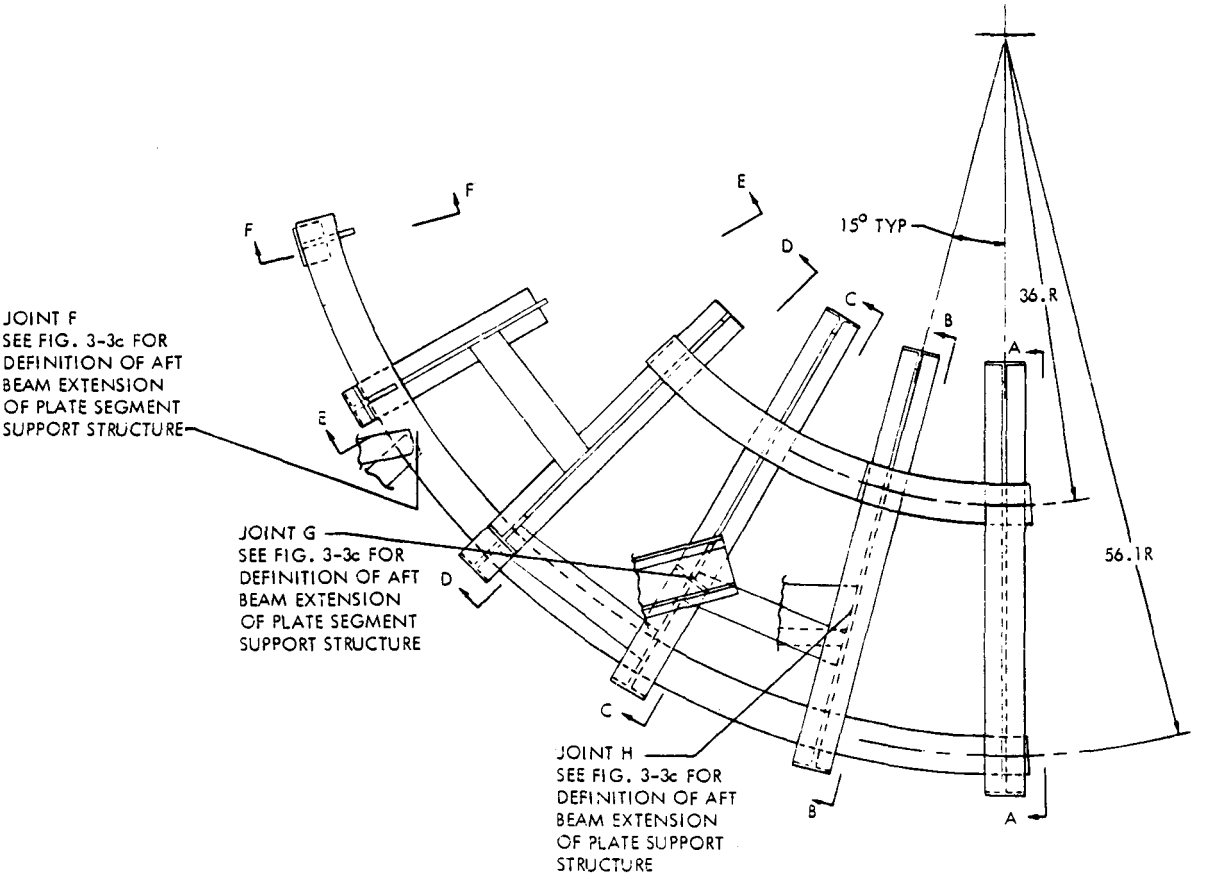
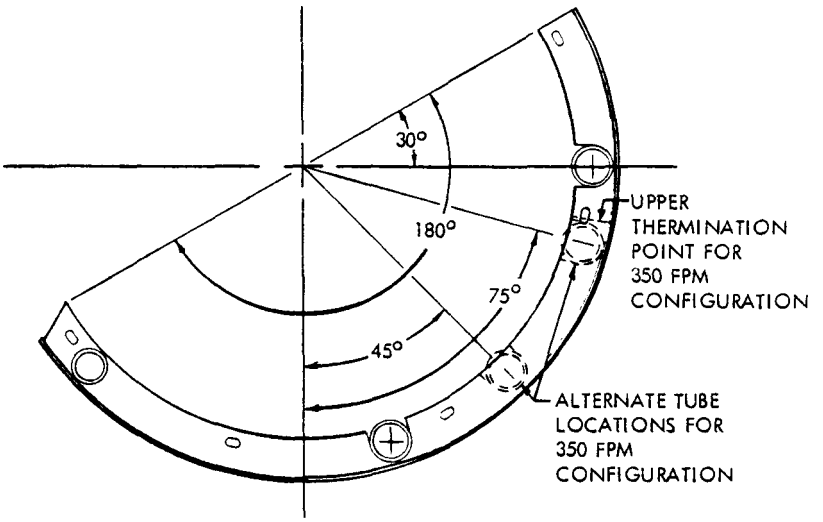
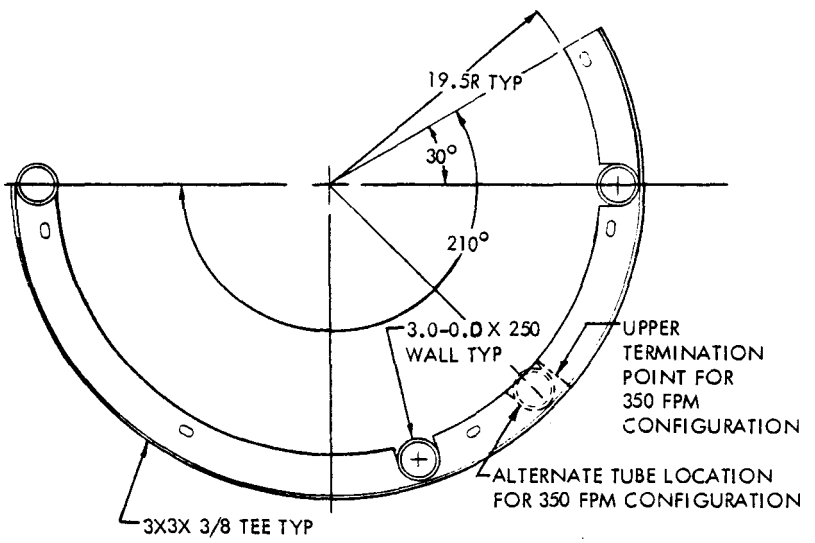


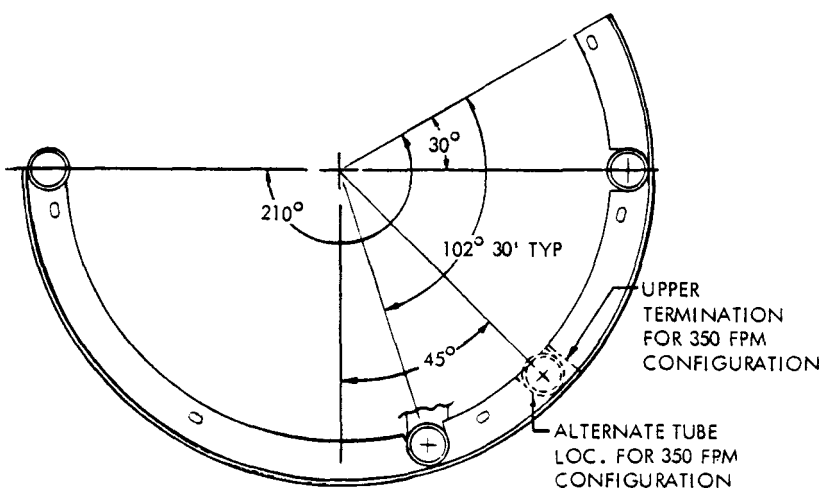
Figure 3-3a. Ring Support Structure Weldment - Forward Portion



SECT C-C (ROTATED 30° INTO PLANE)



SECT B-B (ROTATED 15° INTO PLANE)



VIEW A-A (PARTIAL)

Figure 3-3b. Ring Support Structure Weldment, Forward Portion (Additional Sections Taken in Figure 3-3a)

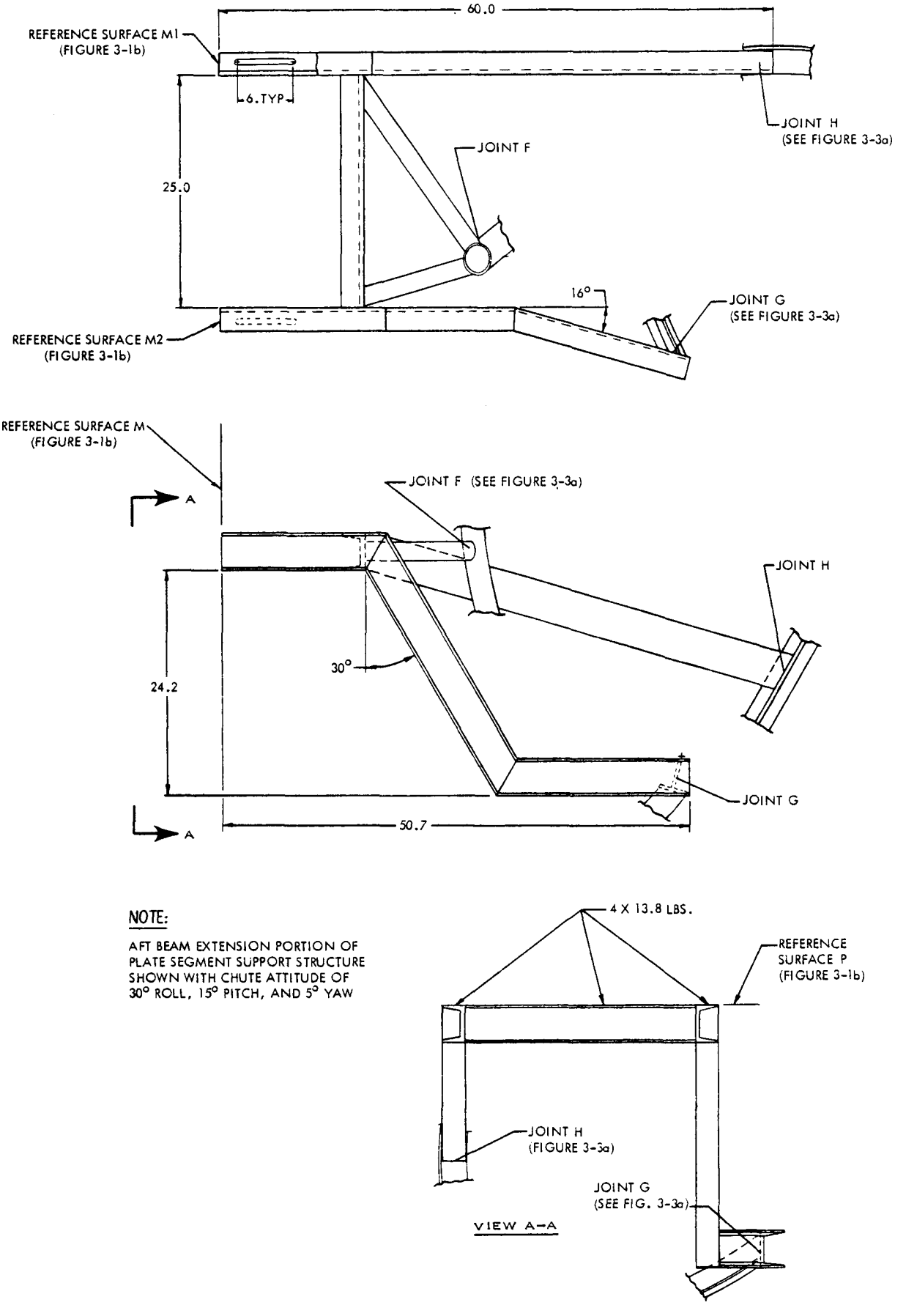


Figure 3-3c. Ring Support Structure - AFT Extension Structure

3.1.2 Design Details

3.1.2.1 Surface Plate Segment

3.1.2.1.1 Basic Configuration

Figure 3-4 shows a typical curved plate element of which the frictional flow surface of the Chute Assembly is constructed. Defined here as a basic flat pattern as well as a curved section, the surface segments are machine-torch cut from 3/8 inch steel plate. Tolerances of $\pm$ 1/16 inch, which are achievable by this cutting method, will be adequate for matching of the plates at assembly into a continuous flow surface.

Definition of an entire chute surface, in terms of the initial flat patterns for all plate segments required, is provided in Figure 3-5. The solid, phantomed, and dashed outlines correspond to the dynamic conditions involved for input conveyor velocities of 450, 600, and 350 feet per minute, respectively. The patterns shown are for the plate neutral planes, but can be readily extrapolated in the direction of curvature to outside surface dimensions. This alternative is mentioned in connection with a proposed spares philosophy wherein basic stock is obtained with the 18 inch curvature for local mine inventory, and then cut to specific flat pattern shapes when worn pieces are to be replaced. The plate width dimensions are 1/4 inch less than the nominal corresponding to a edge-to-edge-fit.

In the flat patterns defined, the upper edge of the plates on the outboard side have a minimum "ΔXC" clearance with the extreme end of the conveyor pulley, corresponding to the specific numbered points in the respective flat pattern (Figure 3-6). The important feature of these clearances is that they increase along the directions of the 90 degree turn and that of the receiving conveyor. These clearances are specified in Section 3.4.

The chute segments, when rolled up, correspond approximately to 15^{o} sections in a 90 degree smoke pipe elbow. In the case of the 450 and 600 FPM configurations the lower most sections (from flat patterns J and K) include a tangential extension beyond the 15 degree central angle, required to center the flow prior to discharge. The tangential extension distance EXT, will involve some final sizing during above ground tests as a function of the coefficient of friction, but six inches is judged to be a good nominal starting value.

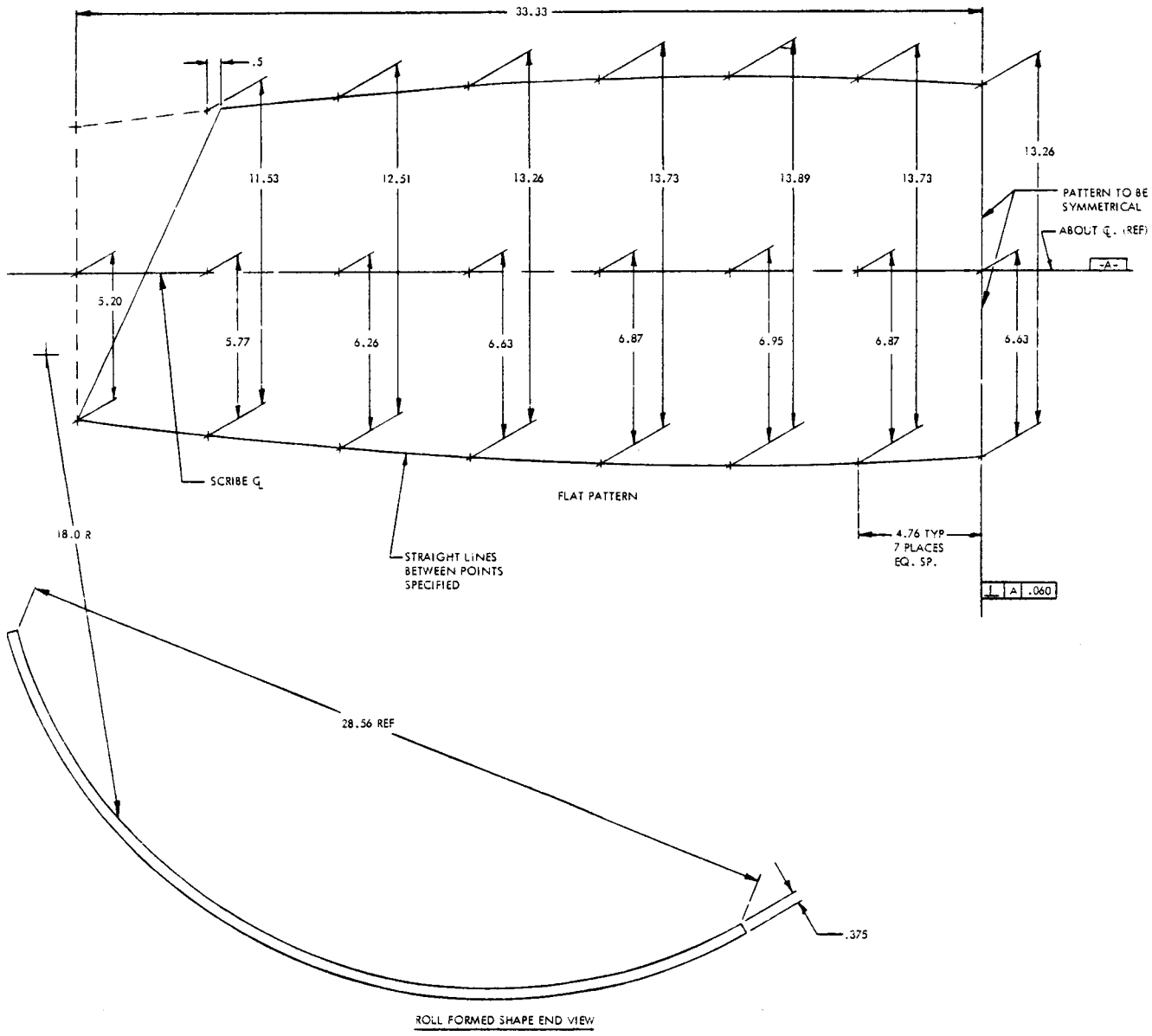


Figure 3-4. Plate Segment, Typical

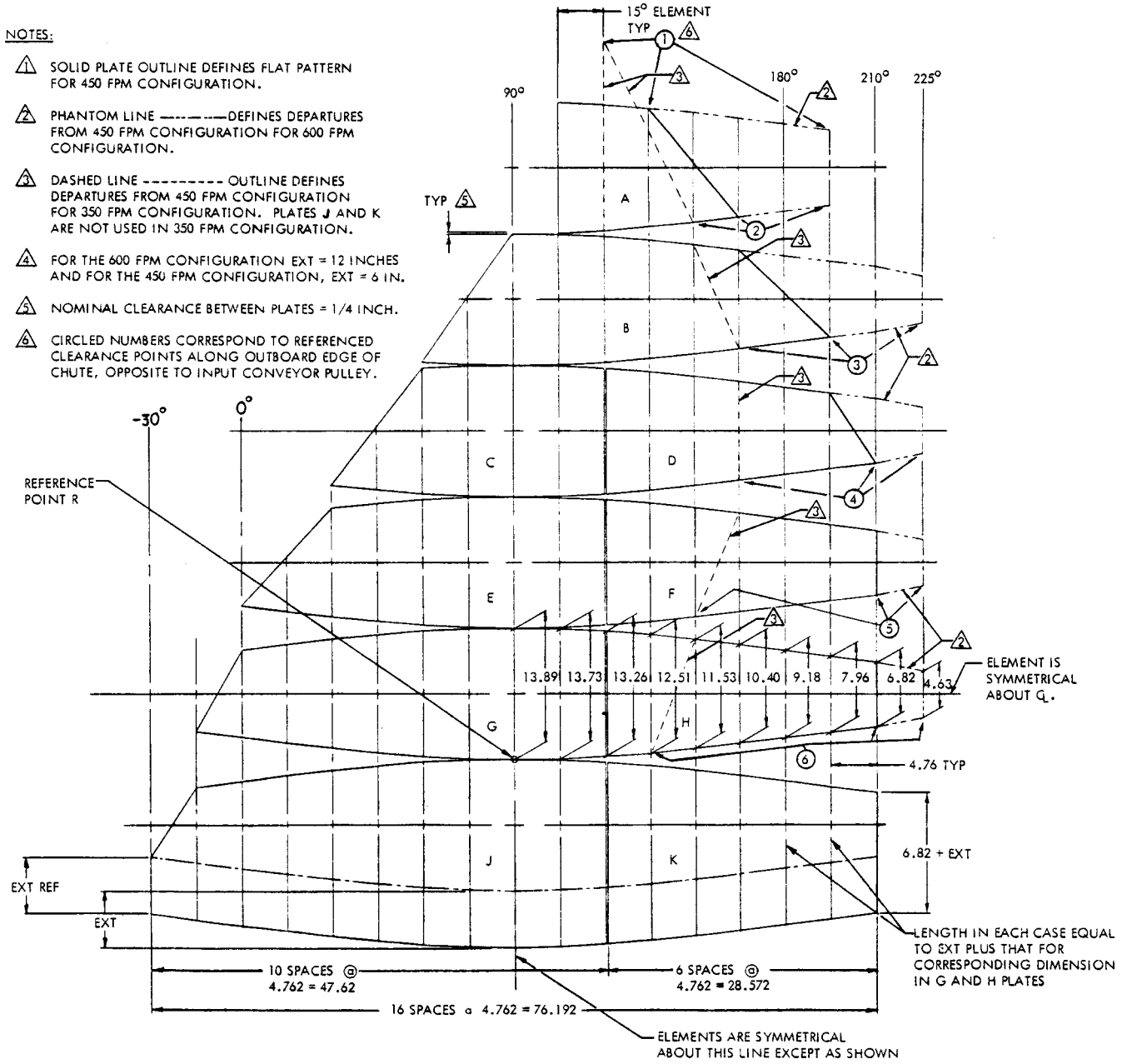


Figure 3-5. Flat Pattern Layout for Chute Segments

3.1.2.1.2 Materials

Some very pertinent design tradeoffs are involved in defining the specific surface material. Five basic alternatives, relative to the surface wear enviroment, are identified here:

- An austenitic stainless steel
- A high abrasion resisting steel, such as US Steel T-1 (various brinell hardnesses) or Jones and Laughlin Jalloy
- A nonmetal, such as ceramic or UHMW
- A standard carbon steel, which will wear out most quickly.
- A standard carbon steel surface treated with a plasma spray-on material such as tungsten carbide

The choice must be made in the context of initial cost and replacement considerations as well as of performance.

Apart from its cost, stainless steel is evidently not presently favored by the mining industry as an option for a chute liner material because of the relative difficulties involved in cutting and welding in under field conditions. However, stainless is attractive because of its relatively low coefficient of friction with run of mine coal (Table 4-1), and may necessarily be considered in the case of very sticky flow cases.

UHMW and ceramic have often been suggested for use in high abrasion environments, such as for a coal chute surface. Potential questions concerning UHMW in the areas of flammability and associated toxic gas by products have been partially addressed by means of additives to the basic mix. These additives, however, are known to degrade the abrasion resistant properties of the material. Consideration of UHMW was, in this regard, put in limbo during the survey on this subject, when it was determined from MESA that new criteria on permissibility of materials in underground mines were in the process of being prepared. In that these criteria were expected, in the area of flammability, to involve performance against specific tests, it was evident that no early resolution concerning UHMW was likely, and it was dropped from further consideration.

Use of ceramic bricks for aboveground coal hopper and chute liners has been introduced, according to industrial literature. However, it is indicated that the brick or "tile" thickness must be quite large to avoid impact-type fractures. Moreover, introduction of tile mosaic configurations into underground mine environments, while literally feasible, raises questions concerning maintenance and inspection that are beyond the scope of this program to resolve. The key factor that seems to militate against enthusiasm over this option for the present design under consideration is that the provision for ready quick replacement of plate segments makes it possible to use materials with less wear life with minimum penalty.

The high abrasion resisting steels are an obvious candidate for the chute plate surface, having already experienced wide use in coal mines for this application. The cylindrical forming requirement for the plates in this present design involves a potential problem here, however. A major fabricator contacted concerning use of these steels indicates that some initial sample rolling fabrication should be performed to insure that the plate's "springiness", inherent in the heat treated condition, does not cause the radius of the formed segments ultimately to relax due to shipping or handling shock. It is recommended that such tests be performed on a full size sample plate segment in Phase II of the program. Assuming that the results are favorable in the area of dimensional stability, a high abrasion resisting steel is the recommended plate segment material for this chute design, except where friction dictates stainless.

A fall-back choice of materials is a standard, low carbon steel. While replacement of worn pieces will be dictated more frequently, this requirement is inherently well-addressed for in the proposed design, which provides for bolted attachment of the individual plates to the Plate Segment Support Assembly.

A fifth plate design alternative considered was a low carbon steel with a plasma-sprayed coating of a high abrasion-resisting quality, such as tungsten carbide. A process commercially identified as Metco flame spraying was studied in this connection. This option is inherently attractive from the standpoints of 1) the potential economics relative

to initial cost and mine maintenance and 2) the geographically widespread availability of the flame spraying process, as well as the number of very hard coating materials available. However, its typical application has characteristically not involved the broad plate areas under consideration here; and it is also indicated that the surface roughness of a plasma coating such as tungsten carbide will typically exceed 200 RMS, resembling a sand paper configuration. Altogether, it is clear that some developmental work in this area would be required to confirm its feasibility here.

3.1.2.2 Plate Segment Support Structure

The plate segment support structure consists of 6 radially - formed, three inch deep, T sections of various lengths (as shown in Figures 3-3a and 3-3b) welded to orthogonally curved, 3 inch O.D. tubular sections. Viewed prior to any chute rotation*, this support structure has a main tubular section securing all six T-section ring segments at an outboard radial location about 60 degrees down from the horizontal at each ring cross section. A second outboard tubular section, located on the horizontal of each cross section, secures the lowest four ring segments, while a second tubular segment at 60^{o} ties the fourth and fifth rings. A series of shorter tubular sections join pairs of adjacent rings together along the inboard side. As indicated in Figures 3-3a and 3-3b, the Plate Segment Support will be configured slightly differently for the 350 fpm configuration.

The plates are secured to the ring sections by means of T-shaped clips. When plates meet going around the principal radius of the torus, the upstream plate edge is shimmed as required so that its surface is flush or slightly above the downstream plate edge (Detail G-G in 3-2b). The T-clips, which are all identical, have slotted holes for their attachment to the ring sections, in order to provide assembly flexibility. The corresponding ring section holes are also slotted at 90^{o} to the above slots for additional adjustment flexibility.

*See 3.2

The aft beam extension of the Plate Segment Support Structure is configured so that the nominal rotational attitude of the chute, prior to utilizing the adjustment features, are the following:

- Roll - 30^{o}
- Pitch - 15^{o}
- Yaw - 5^{o}

The adjustment provisions are discussed in the next section and the required chute attitude requirements are introduced in Section 3.3.

Standard structural steel materials are proposed for all elements of the Plate Segment Support Structure. A number of alternatives exist for fabricating the basic cross section defined for the T clip. Immediate options involve welding a 3/8 plate stem to a cap which has been dihedrally break-formed to the 15 degree angle required. Another involves bending the cap ends on a standard structural Tee section, each by 7 1/2 degrees, in opposite directions.

3.1.2.3 Base Support Structure

3.1.2.3.1 Structural Interface

The Base Support Structure (Figures 3-1a, -1b, and -1c) has been defined primarily in the context of preliminary, above ground testing requirements and without final specification of a feed conveyor to dictate an interface requirement. The support approach is, accordingly, entirely floor-mounted. It is clear, however, that other alternatives in the underground coal mine industry include 1) provision of either or both vertical and lateral support from the ceiling or 2) support on the chute inboard side (relative to the feed conveyor pulley) directly from the pulley boom. These alternatives must be addressed for individual mine installation requirements.

It will be seen that the principal support interface to the chute assembly (Figures 3-2a and 3-2b) involves forward and aft support tubular beams, supported on individual columns. The columns on the outboard side are braced together for lateral support, parallel to the receiving belt conveyor; and the aft column is supported with an outboard stanchion or outrigger. The two inboard columns have outrigger supports also, although it is envisioned that alternate, lateral support to the conveyor head pulley structure may be feasible.

3.1.2.3.2 Adjustment Features

Adjustment procedures and requirements relative to chute position and alignment are discussed in 3.3 and 3.4, respectively. The structural features involved in these adjustments are identified here.

The aft pair of support columns consist each of a pair of square tubes, sized so that the upper tube sections, which are pivotally attached to the aft beam, slide inside the lower tube sections and can be fixed at various heights by means of a pin-through connection. By this means the chute can be either 1) raised or lowered, or 2) rotated when seen in Figure 3-1a, (pitch rotation).

The forward end of the chute assembly can be raised or lowered by means of shortening or lengthening the loop length of a wire-rope provision attachment to the forward beam. The details of the rope and the attachments are not defined in the preliminary design. The movement inherent here is either vertical adjustment, in conjunction with the previous adjustment, or else rotation of the chute, when seen in Figure 3-1b.

The structural interface between 1) the aft extension structure, or "wheelbarrow handle" portion of the chute assembly, and 2) the aft tubular beam consists of two "pitch adjustment sleeves", as identified in Figure 3-1b. This feature permits the following relative movements:

1) Rotation of the chute around the aft beam axis.
2) Sliding of the chute along the aft beam axis, as constrained by the X-axis adjustment collars. (The wire rope loop must be correspondingly capable of being slid along the forward beam).

In addition, the "pitch" adjustment sleeve is slotted at the attachment point with the aft extension structure of the chute assembly. This permits two further adjustments:

3) Movement of the chute assembly relative to the aft tubular beam, parallel to the axis of the feed pulley.

4) Rotation of the chute assembly when viewed in Figure 3-1c.

It should be noted that the nature of the adjustment features inherently involves some cross coupling of rotations and translational adjustments, since they are not independent of each other. Relatively small angular and translational adjustment ranges are involved, however, as noted in the following paragraphs. Furthermore, because of the inherent interim nature of these provisions relative to full scale testing, more sophisticated adjustment features are not warranted.

3.2 CHUTE POSITIONAL ADJUSTMENT PROCEDURES

In order to provide for the range of dimensional and dynamic parameters associated with the transfer point configuration, as well as design uncertainties at this stage of the program, provision in the support design has been described for six-degree of freedom adjustment of the chute assembly. Figure 5-1 defines the ultimate coordinate system for these adjustments. The procedure recommended for achieving the required adjustments involves first setting the required rotational attitude of the chute about the midpoint of the aft support beam, and then achieving the required translational position in terms of coordinates X_R, Y_R, Z_R.

3.2.1 Rotational Adjustment

As defined in Figures 3-1a, -1b, and -1c, the position of the chute shown corresponds to the following geometry.

	Physical Condition	Corresponding Angular Attitude
1.	Surface P (See also Figure 3-3c) is horizontal in X direction, or as viewed in Front View of Figure 3-1a.	Roll Angle = 30^{o}

3.2.1 (contd)

	Physical Condition	Corresponding Angular Attitude
2.	a. Aft support beam axis is perpendicular to pulley axis (vertical as viewed in Fig. 3-1c).	Yaw Angle = 5^{o}
	b. Reference surface M (M1 and M2 in Figure 3-3c) is flush or parallel to Reference Surface N in Fig. 3-1b.	
3.	Surface P is horizontal in Z direction, or as seen in side view of Fig.	Pitch Angle = 15^{o}

As previously discussed, adjustments can be made relative to the designated surfaces. A bubble type inclinometer is required for measuring roll and pitch adjustments, while a scale is needed for yaw adjustments.

Prior to making any of the rotational adjustments, the required vertical clearance distance between the lowest point of the chute assembly and the receiving conveyor should be approximately set, using the forward end wire rope support. It is suggested that 8 inches be used here.

3.2.1.1 Roll Adjustment

The roll adjustment is performed by raising and lowering the upper ends of the aft support columns, in opposite directions, as required, by equal amounts. For the 75 inch separation between columns shown, the simultaneous raising/lowering increment is 0.65 inches per degree of roll, or a total vertical movement of ± 6.5 inches on each side for achieving a range of 15 ± 10 degrees of roll. The angle can be monitored by a bubble inclinometer on surface P.

3.2.1.2 Pitch Adjustment

This adjustment is achieved by raising or lowering the aft columns in the same direction, by equal amounts. Based on the approximate 60 inch diagonal separation between the aft pivot axis and the forward support point on the chute assembly, and an initial angle of this diagonal with the horizontal of 30°, the additional height adjustment required in the aft columns for achieving a range of $15 \pm \frac{5}{10}$ degrees of pitch is approximately $\pm\frac{5}{10}$ inches or 15 inches, total.

Since the wire rope attachment should be secured at the forward-most support ring, raising of the aft pivot axis to increase pitch will have the net effect of raising the forward end slightly, while lowering the aft pivot axis (decreasing pitch) will have the effect of lowering the forward end slightly. This is because the horizontal distance between the lower attachment point and the aft support axis will be changing, causing the angle of the wire rope to the lower support point also to change. This vertical movement will be a second order effect, however.

Once again, an inclinometer will be used on surface P to measure the desired pitch angle

3.2.1.3 Yaw Adjustment

Yaw adjustment is achieved by turning the chute crosswise in the top view (Figure 3-1c) so that the distances between edge surfaces M and N on back side change by equal amounts in opposite directions. At the 25 inch baseline between surfaces M1 and M2 (Figure 3-3c), this corresponds to 0.21 inches per degree of yaw change, or about $\pm$ 1 inch for a $5 \pm 5^{\circ}$ yaw range.

3.2.2 Translation Adjustment

A point along the axis of the pulley, even with the belt edge on the upstream side is chosen as the translation (X, Y, Z) origin. (Figure 5-1).

The initial 90° point R on the chute surface between plates G and H (Figures 3-2 and 3-5) is chosen as the common chute reference point for any input velocity chute configuration. The X, Y, and Z distances, then become those indicated in Figures 3-1a, -1b, and -1c, as X_R, Y_R, and Z_R.

3.2.2.1 X-Adjustment

X adjustment is achieved by relocating the X-adjustment collars and sliding the chute along the aft beam shaft until X_R is achieved. (The wire rope loop will simultaneously slide in the X-direction.

3.2.2.2 Y-Adjustment

Y adjustment is achieved by simultaneously adjusting the heights at the forward and aft support locations, the former by changing the wire rope loop length and the latter by adjusting the aft tubular support columns. The remaining adjustment length available in the aft columns, starting with a total available range of $\pm\frac{18}{12}$ inches and subtracting ± 6.5 inches and $\pm\frac{5}{10}$ inch for the previously defined roll and pitch adjustments, respectively, is $\pm\frac{6.5}{1.5}$ inches.

It is not anticipated that the chute will be lowered toward the receiving belt appreciably once the initial 8 inch clearance is set.

3.2.2.3 Z-Adjustment

Z adjustment is accomplished by means of the same adjustment provision as for the yaw angle. The attachments between the chute assembly aft beam structure and the pitch adjustment sleeves are loosened and reference surface M is moved relative to reference surface N, in the required Z direction.

3.3 NOMINAL CHUTE POSITION AND ATTITUDE

For the three designated input conveyor velocities, Table 3-1 gives the nominal rotational and translational requirements for the chute position, in terms of the six reference parameters, roll, pitch, yaw, and X_R, Y_R, and Z_R.

Table 3-1

Chute Locational Parameters

Parameter		Input Conveyor Velocity, FPM		
Name	Units	450	600	350
Roll	Degrees	30	30	25
Pitch	Degrees	15	20	0
Yaw	Degrees	5	10	0
X_R	Inches	33.6	39.3	23.12
Y_R	Inches	-38.0	-37.3	-37.8
Z_R	Inches	37.9	30.7	52.8

3.4 TRANSFER POINT INSTALLATION CLEARANCES

Two other primary dimensional parameters for the chute involve 1) the clearance ΔXC between points along the outboard edge of the chute and the end of the feed conveyor head pulley and 2) the net head room clearances ΔY_B and ΔY_O, dictated at the transfer point. Table 3-2 summarizes these parameters for the chute configurations proposed for the 350, 450, and 600 fpm input belt velocities.

The chute outboard points referenced in the table are defined in Figure 3-5, being seen to occur at the joints between the plate segments.

Their ΔX_C clearance with the pulley, which assume a 12 inch pulley radius, increase to a minimum of 20 inches in the direction of the turn, and are considered adequate for the large lumps of coal and (or rock encountered in undergound mining operations (See 4.2.1.5).

The overall clearance, Y_O, assumes a minimum 18 inch clearance above the input feed conveyor surface.

The headroom clearances, ΔY_B and ΔY_O, are defined in Figure 3-1a and -1b. The overall clearance Y_O assumes a minimum 18 inch clearance above the input feed conveyor surface and a 24 inch distance from the lower belt surface down to the floor.

Table 3-2

Transfer Point Installation Clearances

Clearance		Feed Belt Velocity Case		
		350 fpm	450 fpm	600 fpm
1. "ΔX" Clearance Between End of Feed Conveyor Pulley and Chute Out Board Edge at Following Chute Points:				
Point*	At Plate Joint			
0	A (350 Case)	3.0	-	-
1	A (450/600 Case)	-	7.8	2.5
2	A/B	12.7	16.7	18.4
3	B/D	16.0	18.8	20.1
4	D/F	19.	18.6	23.2
5	F/H	20.8	20.5	25.6
6	H/K	20.4	21.5	27.3
2. Headroom				
Belt/Belt Y_B		59.4	62.9	64.1
Overall Y_O		101.4	104.9	106.1

*See Figure 3-5.

4.0 DATA SOURCES

Data sources for this program were of two types: 1) consultant support and 2) state-of-the-art surveys, involving literature searches and visits to underground coal mines. The details of the information gained from these sources are summarized in this section.

4.1 CONSULTANT SUPPORT

FSEC retained the following consultant support in Phase I:

	Consultant	Field
1.	Jenike and Johanson North Bellerica, Massachusetts	Bulk Material Flow
2.	Hendrik Colijn Monroeville, Pennsylvania	Transfer Point Design
3.	Reese E. Mallette Assoc. Birmingham, Alabama	Mining Operations
4.	John T. Boyd Co. Pittsburg, Pennsylvania	Mining Operations

Dr. Jerry Johanson of Jenike and Johanson defined the basic model of mathematical equations that describes the dynamic effects of both internal and external boundary friction of a deforming mass as it moves across a surface under gravity. The details of this work and its application in a general math model of overall transfer point dynamics is discussed in Section 5.

Mr. Hendrik Colijn provided support in 1) technology and design practice associated with belt conveyor transfer points and 2) in laboratory test characterization of run of mine coal properties, related to parameters pertinent to flow dynamics (See 4.2.2).

Reese E. Mallette Associates and John T. Boyd Company assisted FSEC in gaining specific insight into operational details and constraints at belt conveyor transfer points in underground coal mines. This involved the primary activity of identifying, and conducting survey trips to, a series of underground mines where a range of transfer point configurations and constraints could be observed. John T. Boyd Company was retained for the last four mine trips when Reese Mallette was not able to support an additional series of mine visits by FSEC. The data obtained from the mine site survey are discussed in 4.2.1.

4.2 STATE-OF-THE-ART SURVEYS

4.2.1 Mine Site Survey

4.2.1.1 Mines Visited

FSEC studied belt conveyor transfer point configurations in a total of eight underground mines, located in eastern and midwestern states. These sites, for which trip reports were included in monthly contract progress reports, were located in the following geographic areas:

1. Alabama, Birmingham vicinity
2. Illinois, western
3. Kentucky, western
4. West Virginia, Charleston vicinity
5. Pennsylvania, western

4.2.1.2 General Techniques of Right Angle Transfer

Provisions for turning the flow through 90 degrees at the transfer points observed by FSEC can be classified in three types, in order of hardware sophistication:

1. No Chute: Flow trajectory impacts belt directly

2. Deflector Plate: Flow trajectory impacts vertical backboard plate, which is parallel to second belt motion, and either suspended above the center of this belt or located alongside this belt and opposite the feed conveyor head pulley.

3. Chute: Flow channeled by plate structure down a slide incline, after its initial direction has been deflected by an impact surface (see next section).

It is worth noting that the third type of provision was made for transfers from 36 inch to 42 inch belt transfer points in only five of the eight mines visited. In one of the mines with the most sophisticated conveyor haulage systems, chutes were used only for 42 inch belt feed cases, while the 36 inch to 42 inch transfer points were served by the deflector plate technique.

4.2.1.3 Chute Configurations Observed

As implied above, chute configurations observed generally had a channel-type cross section to converge flow to the area above the receiving belt. Most of these channel sections had a flat inclined bottom, with vertical or sloped flat side walls, ranging from elementary, two-plate shapes to multiple flat plate configurations. In two instances, the side wall was curved, following the 90° turn.

The other general design class was characterized by curved bottoms cross wise to flow. In some cases the curved surface, a cylinder, was bounded by flat side walls, while in another mine visited the chutes were virtually 180° cylindrical sections.

4.2.1.4 Performance Characterization

Of principal interest to FSEC during the site visits were the following performance characteristics at the transfer chutes:

- Spillage
- Dust
- Belt Wear

4.2.1.4.1 Spillage

In general, loss of material at the transfer points with chutes was successfully controlled, any accumulation on the mine floor being very gradual and due primarily to bouncing around the periphery of the mass flow cross sections as it made initial contact with the chute. There were cases where the flow in the chute tended to back up and spill over the back or sides, owing principally to an insufficient slope angle of the slide base. In this case the material generally still landed on the belt.

Major spillage was observed only at one site, where transfer was attempted onto the tail end of the receiving conveyor, without even a backboard provision A three sided frame-type structure, slightly raised above the belt surface, was the only converging device. It was evident in all transfer points not using a chute that tolerable operation depended on generally low flow conditions, and that occurrence of peak flow for more than a few seconds would have resulted in sometimes significant spillage.

4.2.1.4.2 Dust

With few exceptions, measurable levels of dust were generated at the transfer points, even with water spray suppression devices in use. The exceptions were in cases where the flow itself had a high moisture content. At the opposite extreme, an unusually heavy dust condition at one particular transfer point was attributed by mine personnel in part to the dryness of the air, corresponding to climatic conditions for that time of year.

It appeared that the exposure of the mass cross section periphery during the airborne or free fall, phase of the transfer is a factor in dust generation approaching that of the impact and frictional flow phases. In the heavy dust condition case identified above, mine personnel indicated that the reason for not using grizzly bars (see 4.2.1.11) was to preclude segregation of the fine material from the coarse. Segregations renders this fine material vulnerable to scattering by air currents during the period of gravity descent to the receiving belt.

One mine employed a dust suppression device known commercially as Roto-Clone at its mainline transfer points. This involves covering the transfer point under a hood and vacuuming the dust as it is generated. The dust is then mixed with water and expelled on the receiving belt.

4.2.1.4.3 Belt Wear

Observations in the area of belt wear provided no quantitative means for relating this parameter to chute evaluation. Even on a qualitative basis a measurable reference in this area was not available, in that worn surfaces were not clearly discernable at any of the mines visited. Evidence of sensitivity of mine personnel to this type of wear mechanism was correspondingly absent. At one of the most up-to-date mines visited, technologically speaking, means of turning flow at the 36 inch to 42 inch transfer points involved only a deflector plate, identified in an earlier paragraph. This required the flow to drop vertically to the second belt, there to be accelerated from zero to full belt speed while sliding on the belt.

There appears to be some question among experienced people in this area concerning the criticality of the belt wear mechanism. That impact with the receiving belt at a direction other than approximately tangential and at a speed other than that of the belt surface involves some wear function is clear. Certainly a chute configuration that most nearly produces a flow output velocity matching that of the receiving belt constitutes a design objective, all other considerations being equal. On the other hand, an issue that has been raised by at least one consultant to FSEC in this area is that belt failure and/or replacement due to belt wear of this type is comparatively insignificant to those of 1) catastrophic events and 2) belt edge wear.

4.2.1.5 Flow Materials Characterization

Principal flow constituency parameters of interest include maximum size; size distribution; moisture content; internal and external coefficients of friction; hardness; and basic definition from a materials constituency standpoint. Detailed data in several of these area was developed during the literature survey, and is covered in 4.3.

Of note here are observations defining anomalies in run of mine coal from the standpoint of maximum size and makeup. While not specifically observed by FSEC during the field visits, the maximum lump dimensions was, according to interviews of mine personnel, judged to run up to 18 to 20 inches. This usually involved roof rock, sandstone, etc., rather than coal. The most unusual article observed was a roof bolt.

Refuse, or non-coal constituents in the flow, ran typically 30 to 40 percent.

4.2.1.6 Chute Frictional Slope Angles

Slope angles, relating to the inclination of the chute bottom when viewing the receiving belt from the side, ranged from 32 degrees to 49 degrees, or slightly higher, with the horizontal. The steeper cases yielded, of course, positive dynamics from a self cleaning standpoint, but the shallowest angles noted appeared to work reasonably well during the period of observation, even when the flow material characterized a mud slide. Some potentially marginal conditions existed, however.

4.2.1.7 Construction Details

Quarter to 3/8 inch-thick steel plate was in normal use for chute configurations observed. High-abrasion resisting alloys, including U. S. Steel T-1 and Jones and Laughlin Jalloy were frequently used.

Welded construction for joints between principal chute sections was the typical means of fabrication. Replacement of worn sections was ordinarily accomplished piecewise by torch cutting and welding in a filler piece or else simply welding over patch pieces. In one mine visited significant use was made of bolted-in sections of predetermined size for replacement. The original plates were attached by means of flat socket head cap screws, making quick replacement possible.

One of the reasons cited for the absence of stainless steel construction for the chutes at any of the transfer points visited was the comparatively greater difficulty, over other steels, in torch-cutting and welding stainless on site.

4.2.1.8 Mine Interfaces

Mine interface details are grouped in four areas here: chute structural support; elevation distance between conveyors at the transfer point; chute clearance above the belt; and roof clearances at these points.

Methods of chute structural support, in the typical case of chutes located at intermediate points along the receiving belt, included as a general rule a pivotable mounting at the aft, or upstream end of the chute and cable or chain suspensions, sometimes with shock springs, at the forward, or downstream end. The pivoted end is hinged on a shaft in varying configurations, the shaft itself having simple beam supports on opposite sides of the receiving conveyor. On the feed conveyor side, attachment is typically to the head conveyor structure itself, while on the opposite, or outboard end, support is provided by a column. Similar two point support is provided for a cross beam above the downstream end of the chute, from whence hang the cable supports identified above.

Less common means of support for the aft pivot shaft and forward cross beams involved attachment to roof bolts or attachment to cantilevered beams extending across from the head pulley structure.

The distance between conveyor surfaces at transfer points utilizing chutes ranged from 79 inches down to about 45 inches, with a mean estimated at about 60 to 66 inches. For deflector plate type transfer points, this elevation difference was as little as 30 to 36 inches.

Clearances between the bottom of the chute and the receiving conveyor belt ranged from 6 to 18 inches, with 12 inches being common.

In connection with the chute to receiving conveyor interface, mine operation practice observed uniformly stressed the need for aligning in plain view the flow discharge vectorparallel to the receiving belt motion, in order to prevent belt mis-tracking.

No attempt was evident at the vast majority of transfer points witnessed to minimize roof height or headroom. This height was rarely less than seven feet at 36 inch to 42 inch belt transfer points and frequently was up to 9 to 10 feet, giving a more than adequate distance above the feed conveyor.

4.2.1.9 Conveyor Data

The maximum pulley radius observed for the 36 inch feed conveyor was 12 inches, corroborating catalogue data.

Input conveyor speeds, where known, ranged between 450 to 500 feet per minute, with catalogue data defining a probable maximum range of 350 to 600 fpm. Receiving belt speeds, often not known at specific sites, were most commonly estimated at 550 to 600 fpm.

At all transfer points visited, the elevation angle of the feed conveyor belt was essentially zero, i.e., horizontal, although it was evident from the head pulley structure configuration that this angle was variable up to 10 to 15 degrees above the horizontal.

All feed conveyors utilized belt cleaning devices of various configurations of a factory or local design. The effluent from this cleaner is normally caught on an inclined surface and fed onto the receiving conveyor. This surface is sometimes steel but is more commonly old conveyor belting or an elastomer material.

4.2.1.10 Transfer Point Operations

Transfer points for 36 to 42 inch belt cases are moved, according to personnel interviewed, at frequencies as little as every 4 months up to 2 years or more. A typical period required for movement of both the conveyor head section and the transfer chute is one week.

4.2.1.11 Ancillary Equipment

Some of the most common types of ancillary equipment at transfer points included skirt boards, dust suppression spray systems and grizzly bars. The function of these items are well understood in the industry. In particular, the purpose of grizzly bars --- which are in reality a part of the transfer chute --- is to lay a protective bed of fine material on the belt, by virtue of falling between the bars, prior to impact of the

larger, heavier lumps which cannot drop to the belt prior to reaching the end of the grizzly bars. It was noted earlier, however, that the view on the value of this provision, at least among some mining personnel, is divided, owing to the increased vulnerability of the now isolated fines to be scattered by air currents.

4.2.1.12 Other Data From Mine Site Surveys

FSEC performed photographic coverage of all but two of the mines visited. In conjunction with this work, FSEC's mining consultant assisted in gathering and identifying geologically samples from about five coal mine operations.

4.2.2 Other Surveys

In addition to mine site inspections, extensive data gathering in the areas of mining technology, transfer chute design, bulk flow theory, and run of mine coal properties was undertaken through the routes of literature surveys and consultant contacts. This section summarizes 1) bibliography accession from the literature survey and 2) run of mine coal properties applicable to bulk flow, gained from both literature and consultant sources.

4.2.2.1 Program Bibliography

In Appendix A are identified reports, books, magazine articles, and correspondence from consultants, which were obtained and reviewed during this program. They are organized by subject matter in the following areas:

1. Chute design, general
2. Chute materials
3. Coal mining at face
4. Underground haulage
5. Dust
6. Specific coal mines
7. Safety
8. Bulk flow, general
9. Bulk flow, theory
10. Coal properties
11. Sampling
12. Scale modelling

4.2.2.2 Materials Properties

Table 4-1 summarizes several test-derived properties for various types of coal samples from a total of 11 mine sites. While "cleaned" coal samples as well as raw coal are included, the properties cited are not found to vary significantly, and this is confirmed by the consultant source for this data. While the actual test data for samples given by site letter code cannot be identified, one (J) has given such permission, and the test report data from which the tabulated friction and moisture figures for Site J are taken is included herein as Figure 4-1.

Partly based on the above data and partly based on consultant experience, the following mean property values are given:

1.	Moisture, percent	6-7
2.	Sliding Friction Angle, degrees	
	Stainless Steel	20
	Rusted Carbon Steel	35
	UHMW	20
3.	Effective Angle of Internal Friction, Deg.	55
4.	Angle of Internal Friction, Deg.	38

The profile distribution of lump sizes in run-of-mine coal depends initially on whether it has been mined with convential or continuous mining equipment. Figure 4-2 shows a logarithmetically plotted size distribution for typical distributions using each method. Mean average sizes are seen to be less than a half inch for continuously mined coal and close to 3/4 inch for conventionally mined coal, with mean peak sizes of 4 1/2 and 8 inches, respectively. The maximum sizes here are superseded by the 18 to 20 inch sizes observed during the mine visits, however.

4.3 CHUTE DEVELOPMENT GUIDELINES

Table 4-2 summarizes guidelines, derived from the various data surveys reported in this section, to serve as a baseline in this program for the development of chute configurations and associated mine interfaces.

Table 4-1

Applicable Coal Properties From Test Data

Site Code	Type of Coal	Effective Angle of Friction δ, Deg.	Angle of Internal Friction Ø Deg.	Moisture Content %	Angle of External (Wall) Friction		
					UHMP* Deg.	Rusted Steel Deg.	Stainless 304-2B Deg.
A	Clean	50	36	3.5		35	21
		60	40	13.0		39	23
B	Clean	50	39	23	19	33	20
		50	40	31	19	35	20
C	Raw	50	38	6	18	23	20
D	Clean	50	39	8			24
		52	39	11			29
		55	40	15			30
		60	41	18			26
E	Clean	50	40	5		32	22
		53	40	9		33	22
F	Clean	49	39	12	16	33	16
		50	40	15	18	33	18
G	Clean	54	40	10	17	30	15
		56	40	13	18	34	20
H	Clean	56	38	8	23	40	21
I	Clean	58	39	18	20	35	19
	Raw	53	39	15	21	35	21
J	Raw	50	39	12	16	34	16
K	Raw	60	45	7 1/2	20	36	17
	Clean	51	37	7	18	36	20
		55	40	9	20	37	23
		60	40	15	22	44	28
L	Clean	56	38	10	19	36	18
	Raw	58	40	7	21	35	20

*Ultra High Molecular Weight Polyethylene

Figure 4-1a

FLOW PROPERTIES OF RAW COAL SITE J

12.0% MOISTURE CONTENT

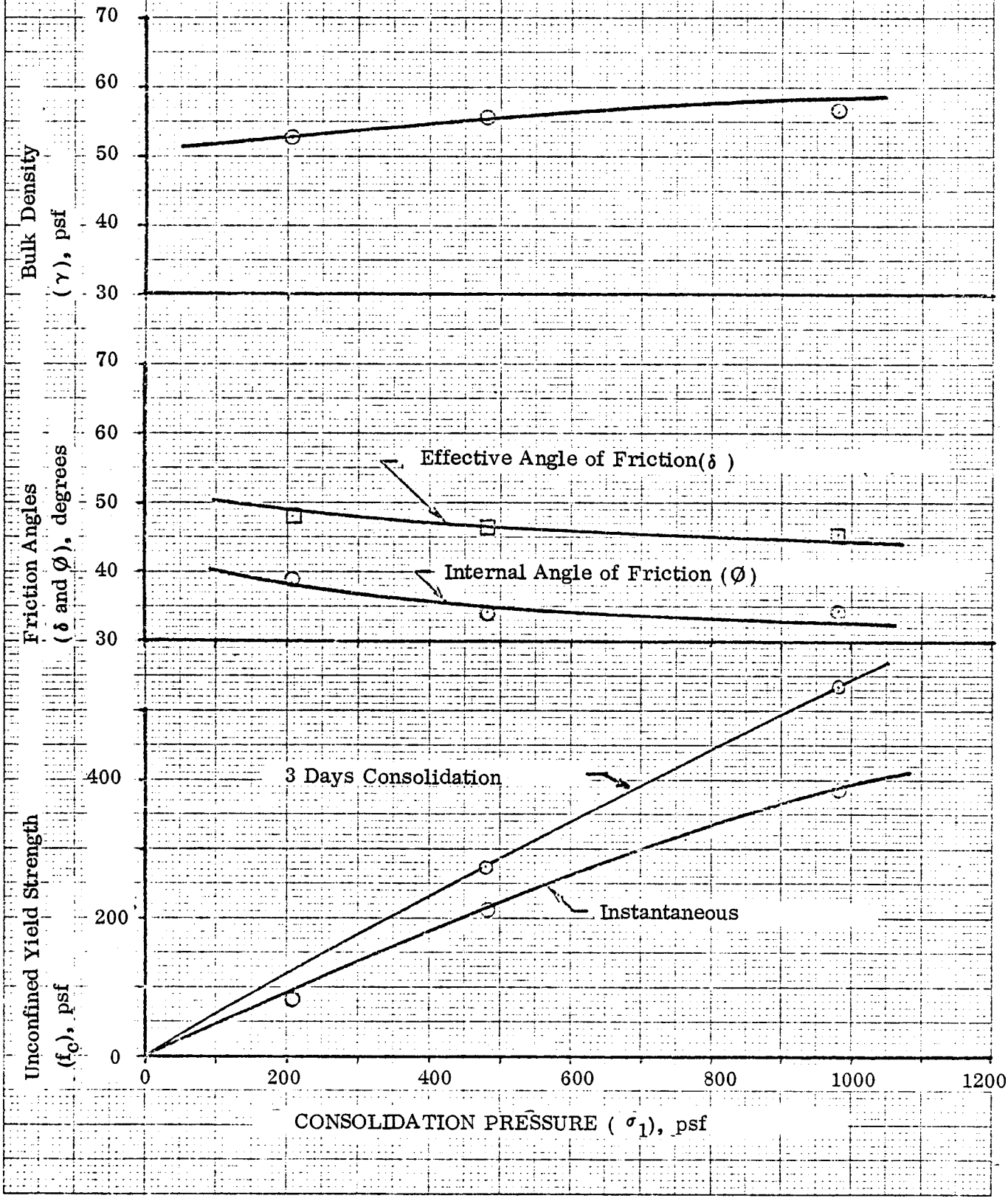
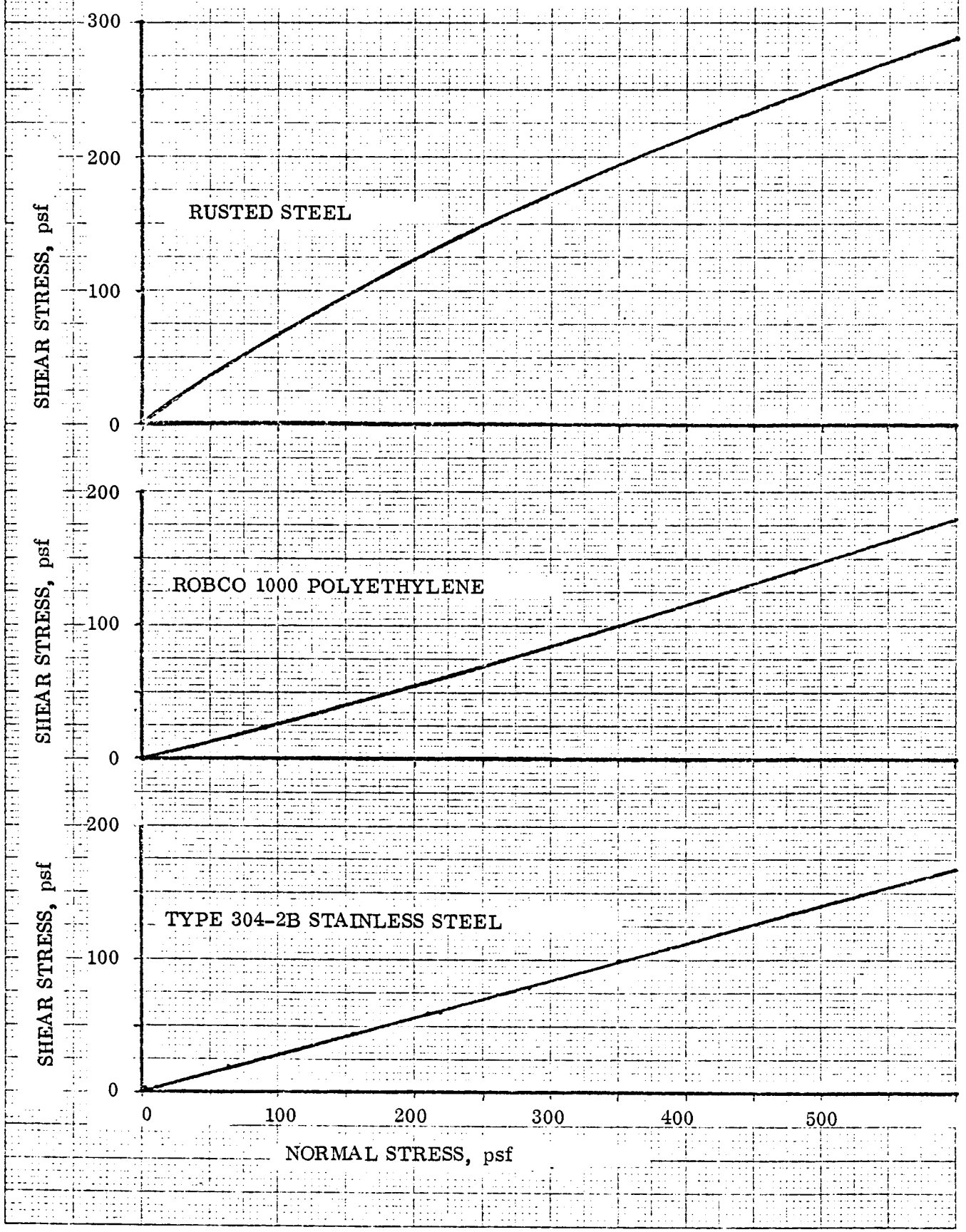


Figure 4-1b

WALL YIELD LOCI OF RAW COAL SITE J

12.0% MOISTURE CONTENT



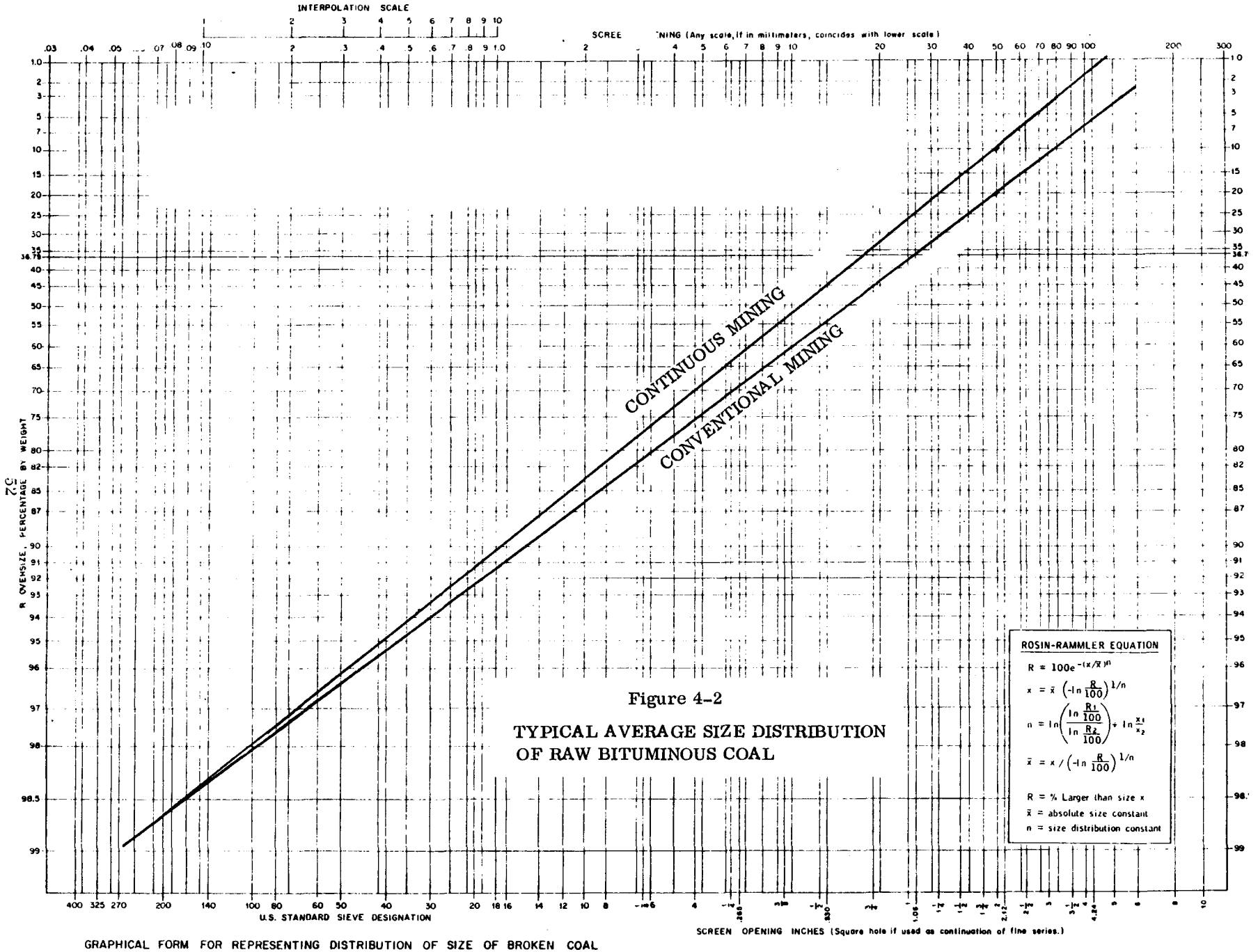


Figure 4-2

TYPICAL AVERAGE SIZE DISTRIBUTION OF RAW BITUMINOUS COAL

GRAPHICAL FORM FOR REPRESENTING DISTRIBUTION OF SIZE OF BROKEN COAL

Table 4-2

Low Headroom Chute Development Guidelines

GUIDELINE			REFERENCE SOURCE REQUIREMENT					
				MAINTENANCE			SAFETY	
GENERAL	PARAMETER SPECIFIC	REQUIREMENT	FUNCTIONAL PERFORMANCE	SPILLAGE	WEAR	OTHER	DUST	OTHER
1. Bulk Material Characteristics	a. Moisture Range Raw Coal, Percent		X	X		X (Corrosion)		
	Peak	15						
	Average	6						
	b. Sliding Friction Φ' Degrees (for 6% moisture)							
	1) Mild Steel, Rusted	29^{o}-40^{o}	X	X	X			
	2) Stainless, 304 2B	15^{o}-29^{o}	X		X			
	c. Effective Angle of Friction δ							
	• Average	50^{o}-60^{o}	X					
	• Maximum	40^{o}-65^{o}	X					
	d. Angle of Internal Friction Φ		X					
	• Average	35^{o}-40^{o}						
	• Maximum	12^{o}-43^{o}						
	e. Coefficient of Restitution, Chute Wall with Coal	Function: 1) Angle of Incidence 2) Run of Mine Particle Size and Material; 3) Chute Wall Thickness	X	X	X			
2. Dynamic Constraints	a. Pulley Diameter		(Influence on Trajectory)					
	• Maximum	24"	X					
	• Minimum	16"	X					

Table 4-2, cont'd

Low Headroom Chute Development Guidelines

GUIDELINE			REFERENCE SOURCE REQUIREMENT					
GENERAL	PARAMETER SPECIFIC	REQUIREMENT	FUNCTIONAL PERFORMANCE	MAINTENANCE			SAFETY	
				SPILLAGE	WEAR	OTHER	DUST	OTHER
2. Dynamic Constraints (Cont'd.)	b. Belt Speeds (FPM)							
	1) Feed Conv. (36")							
	• Minimum	350	X					
	• Average	450-500	X					
	• Peak	600	X					
	2)Recv. Conv. (42")							
	• Minimum	500	X					
	• Average	550-600	X					
	• Peak	800	X					
	c. Feed Trajectory Angle (above horizontal, climbing)	0^{o}-15^{o}	X	X				
	d. Impact Location on Receiving Belt						X	
	• Crosswise to Recv. Belt (Convergency)	Center 1/3 of Belt Width, Approx.		X		X (Tracking)		
	• Lengthwise to Recv. Belt	Centered Between Idlers Approx. (Max. Idler Pitch of 18" to 30")		X	Belt			
	e. Elevation Drop							
	(From Top of Feed Conveyor to Top of Receiving Conveyor)							
	Goal	42"	X					
	Current Mean Range	60" -66"						
	f. Stream Cross Section							
	• Cohesion	Avoid:						
		1)Stream Splitting	X	X			X	
		2)Peripheral Scatter						
		3)Impact Bounce						
		4)Chute Flow Buildup						
		5)Impact Interference with Sliding Stream						

Table 4-2, cont'd

Low Headroom Chute Development Guidelines

GUIDELINE			REFERENCE SOURCE REQUIREMENT					
				MAINTENANCE			SAFETY	
GENERAL	PARAMETER SPECIFIC	REQUIREMENT	FUNCTIONAL PERFORMANCE	SPILLAGE	WEAR	OTHER	DUST	OTHER
2. Dynamic Constraints, Cont.	g. Final Flow Vector at Impact							
	• Direction of Horizontal Component	Parallel to Receiving Conveyor		X	X	X (Tracking)	X	
	• Magnitude	Near-Match to Receiving Conveyor Velocity (See also 4. a.)		X	X		X	
3. Construction Details	a. Materials							
	1) Surface	High Abrasion Resistance in Wear Areas (See also 3. b.)			X (Chute)			
	2) Plastics (UHMW, etc.)	Ruled Out Peremptorily for Present Design Consideration because of Uncertainty Pending MESA Action on Materials Permissibility Standards for Underground Mines						oFlame spread oToxic by-products when burnt
	3) Weldability	1) Weldability Underground Desirable; 2) Torch Cuttable 3) Low Skill Req'd.				X (Minimum) Downtime Underground		X
	b. Fastening	Bolted Replacement of High Wear Surfaces Desirable			X	X (Minimum Downtime Underground)		
4. Ancillary Constraints	a. Impact Control on Receiving Belt	Provide Grizzly bars, to provide initial bed of fine material for cushioning of impact by large pieces			X			

Table 4-2, cont'd

Low Headroom Chute Development Guidelines

GUIDELINE			REFERENCE SOURCE REQUIREMENT					
				MAINTENANCE			SAFETY	
GENERAL	PARAMETER SPECIFIC	REQUIREMENT	FUNCTIONAL PERFORMANCE	SPILLAGE	WEAR	OTHER	DUST	OTHER
4. Ancilary Constraints (Cont'd)	b. Skirtboard (If Required)							
	1) Belt Interface	Minimum Gap •Support Skirtboard on Idlers •Minimize Idler Pitch Along Skirt-Board Length (18")		X			X	
	2) Material	Elastomer Wearstrip			X			
	3) Length	Sufficient to Contain Material During Deposition on Belt						
	c. Belt Cleaner (Accommodation, clearances for)							
	1) Location Around Pulley	135° from Top, Approx.		X				
	2) Feeds	Receiving Belt		X				
	d. Troughing Angle (Both Conveyors)	27°; 35°	X					
	e. Overflow	Consider Cutoff Switch for Feed Conveyor Based on Overflow Sensor	X	X			X	
	f. Dust Control							
	1) Water Spray	Use at Impact Area						
	2) Active System (At 42" and 48" feeder transfer points only)	Consider hood & exhaust which mixes dust with water and dumps on receiving conveyor						
	g. Min. Clearance Between Bottom of Chute and Conveyor Belt	8" to 18" (Also, chute to be Pivoted for Large Pieces)	X	X				

Table 4-2, cont'd

Low Headroom Chute Development Guidelines

GUIDELINE			REFERENCE SOURCE REQUIREMENT					
				MAINTENANCE			SAFETY	
GENERAL	PARAMETER SPECIFIC	REQUIREMENT	FUNCTIONAL PERFORMANCE	SPILLAGE	WEAR	OTHER	DUST	OTHER
5. Acceptance in Industry	Producibility	• Fabrication by Standard Manufacturing Techniques						
		• Readily Assembled and Installed						
	Adaptability	• Definable and Adjustable to local constraints within design limits						

5.0 DYNAMIC THEORY AND MATH MODELLING

Two distinct dynamic phases are involved in analytically modelling the mass flow of material at a right angle conveyor belt transfer point:

1. The free fall phase, from the instant of leaving the input conveyor until contact with the chute.
2. The frictional phase, from initial contact with the chute until departure from the lower end.

Section 5 is concerned with 1) the identification of the applicable dynamic theory in these areas; 2) the structuring of a mathematical model adequate to represent the physical conditions; and finally 3) the creation of a computer program covering these phases, suitable for parametric analysis of the candidate chute model or models. In order to define entirely these areas, the method for representing mathematically a generalized chute surface will also be introduced. However, parametric analysis of specific geometric configurations will be addressed in section 7, following the presentation of candidate chute concepts and mathematical representation of a specific concept in section 6.

5.1 PHASE 1. FREE FALL TRAJECTORY AND IMPACT

5.1.1 General Definition

In Phase 1, the principal objectives involve tracking of the periphery of the mass cross section in terms not only of location but of the direction of the velocity vector. It is necessary to know the trajectory location in order to insure that the chute is positioned to intercept the flow; while it is equally important to know the trajectory direction, in order to monitor the angle of impact with the chute surface. Subject to verification by testing in both laboratory scale models and full-size configurations, one goal for the analytical task is to maintain this impact angle with the chute surface as small as possible, in order to minimize the tendency for bouncing and ricocheting. It is also necessary to know the angle and magnitude of the velocity vector at impact in order to calculate the initial velocity of the flow in the friction phase.

5.1.2 Math Model of Free Fall Phase

Appendix B summarizes the equations involved in the free fall trajectory phase. The main steps involved are the following:

1. Division of the total flow cross section into piece-wise segments across the head pulley, for purposes both of defining a chute impact trace and for tracking the later frictional movement.
2. Determination of the position and direction of the trajectory when it leaves the head pulley.
3. Mathematical representation of the subsequent trajectory path at the top, center of gravity, and bottom of the flow segments.
4. Solution for the impact point by means of simultaneous solution of mathematical equations for the trajectory, found above; and for the chute surface.
5. Computation of the following additional impact data:
   - Impact angle between velocity vector and normal to plate, and the complement of this angle.
   - Stream velocity immediately before and after impact

Some general points concerning the math model theory are addressed here.

Definition of the direction of the stream segments and their position on the head pulley at the instant of departure is taken from the chapter on discharge trajectories from the CEMA Bulk Materials Handbook. The theory here, briefly, assumes the trajectory of all elements of the flow mass follows that of a point mass located at the center of gravity of the flow cross section. This theory assumes a relatively smooth, tangential departure from the pulley radius, and does not address a phenomenon sometimes referred to as "humping", wherein the material does not reach the pulley perimeter tangentially, but rather

experiences an impact component with the pulley. A review of this subject was undertaken with one of FSEC's consultants, whose joint conclusion, with two other sources especially contacted on this matter, is that the effect referred to is not significant for conveyor speeds less than 800 to 900 feet per minute. This range is considerably above the peak speed of 600 fpm defined for this study.

As shown in Parts 1 and 2 of Appendix A, determination of the initial velocity and location of the piece-wise-defined segments, or streams, of the flow cross section entails introduction of the following parameters:

1. Belt speed, V
2. Conveyor belt inclinator with the horizontal $\emptyset$
3. Idler configuration angle
4. Surcharge angle
5. Pulley radius (belt thickness is disregarded) R
6. Number of stream subdivisions assumed, n
7. Belt width, b
8. Edge distance, from belt to flow mass, e

Tracking the free fall trajectory of the flow cross section thus becomes a straightforward mathematical exercise. In the matter of defining the chute impact location and velocity for each stream, however, the model becomes closely dependent on the means of representation, as opposed to the specific shape, of the chute. As will be discussed later, this involves initial approximation of the chute surface by a mosaic of finite, rectangular, flat plate segments.

This representation is independent of whether the chute configuration actually consists of a smooth curved surface or is segmented in flat plates. As shown in part 4 of Appendix B, this convention leads to the solution of two simultaneous equations: 1) that of the second degree trajectory path for a given stream and 2) the line defining the intersection

between the plane of this stream trajectory, and the plane of the plate segment of the chute. In order to utilize a means convenient for computer solution for the specific plate impacted and the coordinates of the impact point, each rectangular plate is divided into a pair of discretely identified triangular sections. This permits the actual determination of the impact point to be broken into two phases, involving a test of each predetermined, triangular segment in the chute to determine whether it satisfies two conditions:

1. Where, if at all, does the trajectory intersect the plane in which the triangular segment lies?
2. Does the computed hit point lie within the triangle?

In both the free fall trajectory phase of the analysis and the subsequent frictional phase, the coordinate convention for locating stream positions and chute plate locations is that defined in Figure 5-1. In particular, the convention involves an XYZ axes system wherein the origin is on the pulley axis, even with the edge of the belt on the upstream side, relative to the motion of the receiving conveyor.

5.1.3 Computer Program for Free Fall Phase

The math model developed in Appendix B was written in FORTRAN lanuage as a computer program, which is presented in Appendix C. As an aid to following the detailed steps in the program compilation, it will be seen that extensive use therein is made of annotations in the form of comment statements. Figure 5-2 is a flow chart of the basic logic in the Phase 1 computer program.

As an aid both to design and analysis of various chute configurations, the FSEC computer has a routine available called NASTRAN which prepares in each of three orthagonal views, and also a perspective view, a plot of the X, Y, Z coordinates of all corners of the flat plate mosaic representation of the chute. In addition to these points, the NASTRAN routine will also store the coordinates of the hit points on the chute, as well as other useful data, such as the relative location of the feed conveyor head pulley. (Figure 5-1).

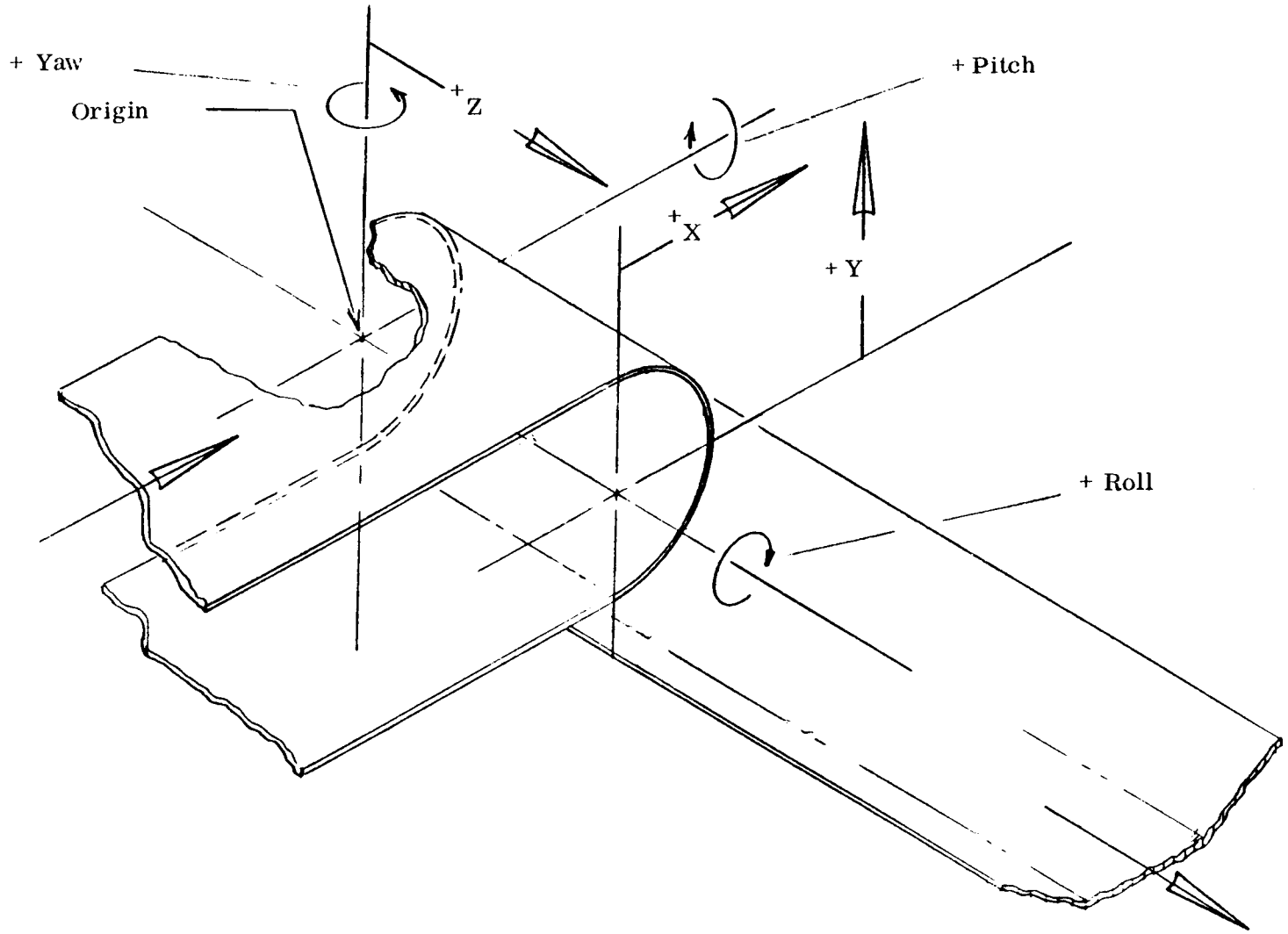
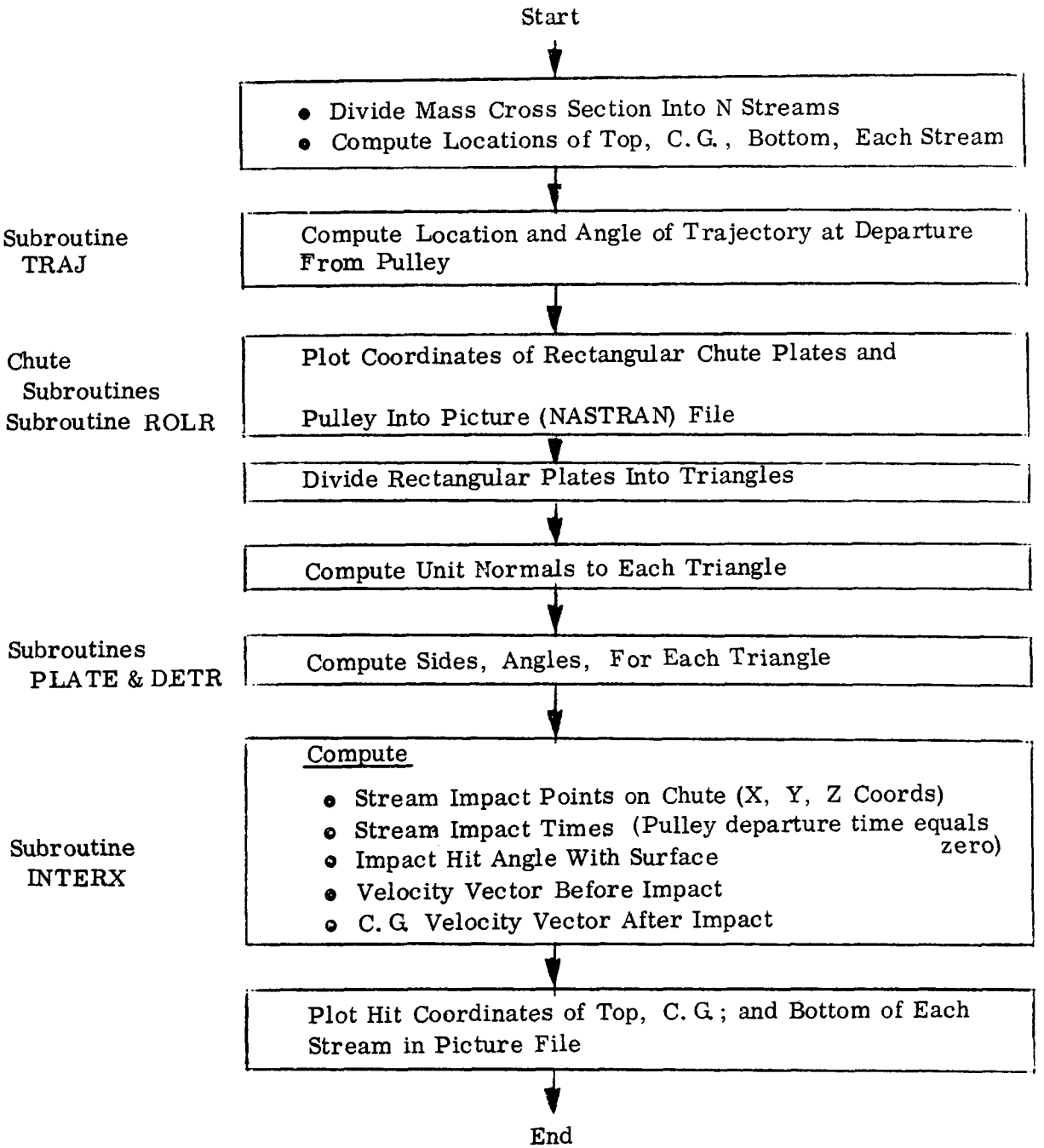


Figure 5-1 , Coordinate Axes
Translation and Rotational Sign Convention



** See Section 6.2

Basic Flow Diagram
Phase 1 (Free Fall/Impact) Computer Program

Figure 5-2

5.2 FRICTIONAL FLOW PHASE

5.2.1 General

The frictional flow math model covers the phase of the transfer beginning immediately after impact with the chute and extending down to exit of the flow from the chute. The basic theory accounts for the dynamic effects upon flow both at the periphery and within the interior of the flow mass cross section, the latter case arising because of deformation of the mass cross section.

5.2.2 Math Model

Briefly outlined, the theory treats the flow cross section in a series of piece-wise segments, whose mass in each case is concentrated at its center of gravity. After chute impact, these point masses are treated initially as independent dynamic entites. The velocity after impact for each stream is in a phane which is defined by the impact vector and the unit normal vector to the chute plate surface at the point of impact.

Because the moving c.g's represent streams of finite width and height, however, they must interact. Their relative locations and motions are traced in the model as they are combined into a stream net during initial movement down the chute. Before and after the net formation phase, the dynamic interaction at hypothetical interface planes or "dividing planes between the streams is analyzed in terms of normal and shear forces. Together with 1) normal and friction forces at the chute wall; 2) gravity; and 3) centrifugal forces associated with chute curvature, these internal, interactive forces are applied iteratively to a stream "cell" of unit length during a series of stepwise movements down the chute surface. At the end of each step, which has a predetermined length, the velocity, shape, and boundary conditions for each stream are recomputed. The cells along a given cell wavefront of the streams are "locked" together, in that each is advanced some variable distance during each step, as a function of its velocity, width, and height, relative to those of adjacent streams.

The details of this model, including explanatory theory, are covered in Appendix D.

The flow theory utilized in this math model is sometimes referred to as the "pseudo-plastic" theory in bulk dynamics study. In a broad sense it assumes that the flow is governed primarily by dynamic mechanisms involving the fine particles in the mass cross section. Flow criticality, that is, is a function of what the fines "do", and, generally speaking, analysis of this type will give a conservative cast applied to cases where large lumps predominate, without a significant presence of fines.

The major premise of this conclusion relates to the fact that the independent parameter of record utilized in pseudo plastic analyses, the effective coefficient of friction delta (δ), is a test-derived data point, obtained in tests where the maximum particle size is about a number 8 mesh size, or about one tenth of an inch. The reason for this is that shear tests involving maximum particle size significantly larger than the number 8 mesh size have historically exhibited considerable scatter in the results. FSEC is advised by its consultant in the bulk dynamics theory area, however, that obtaining test data for using uniformly graded material of about 1/8 inch should be achievable with some laboratory equipment now in use. Because the effect of the fines would have therefore been isolated from the material tested, the data obtained would be immediately extrapolable to uniformly graded sizes much larger than the 1/8 inch material, since the inter angular mechanisms involved in the shear measurements would not be dependent on a specific particle size.

The use of the mathematical model defined herein is not, then, ultimately limited to fine particle-governed dynamics. On the other hand it is judged,from observations of the flow material at the transfer points visited by FSEC, that the prevalence of fines is sufficiently common that this conservative approach is entirely justified, and in fact is the only approach justified, in order to ensure that flow is maintained. It is recognized, in this connection, that observations by experienced people in the field show that some segregation of the fines and coarse particles occur in transit to the transfer points, and that as a result the coarse pieces at the top of the flow cross section leaving the feed conveyor

head pulley may reach slide portions of the chute where flow is not pseudo-plastic, owing to the absence of the fines. This is still considered to be a nonconservative approach, however; the mechanism of the fines elsewhere on the slide will still be the pacing case from the standpoint of maintaining flow. The path of the coarse pieces must, of course, also be confined.

5.2.3 Frictional Flow Computer Program

Appendix E contains a compilation of the computer program for the Phase 2 frictional phase of the 90 degree transfer analysis. The program is extensively annotated and can be followed by one familiar with FORTRAN IV after he familiarizes himself with the friction flow math model (Appendix D) and the following discussion.

5.2.3.1 Phase 1 Interface

The Phase 2 computer program is run in sequence with the Phase 1 program, which provides it, in the form of a punched computer deck or else in disk or tape memory, the following data for a given set of chute configuration, mass properties, and feed conveyor characteristics:

1. The X, Y and Z coordinates of the corners of the rectangular plates of the chute (See section 6.2).
2. The X, Y, and Z coordinates of the corners of the triangular subdivisions of each plate.
3. The X, Y, and Z directional cosines of the unit normal to each plate surface.
4. The lengths of the sides and the vertex angles of each triangle.
5. The coordinates of each stream impact point and the identification of the plate/triangle hit.
6. All eight parameters defined in paragraph 5.1.2.
7. Run-of-mine coal properties, including angle of dynamic wall friction and effective angle of internal friction.

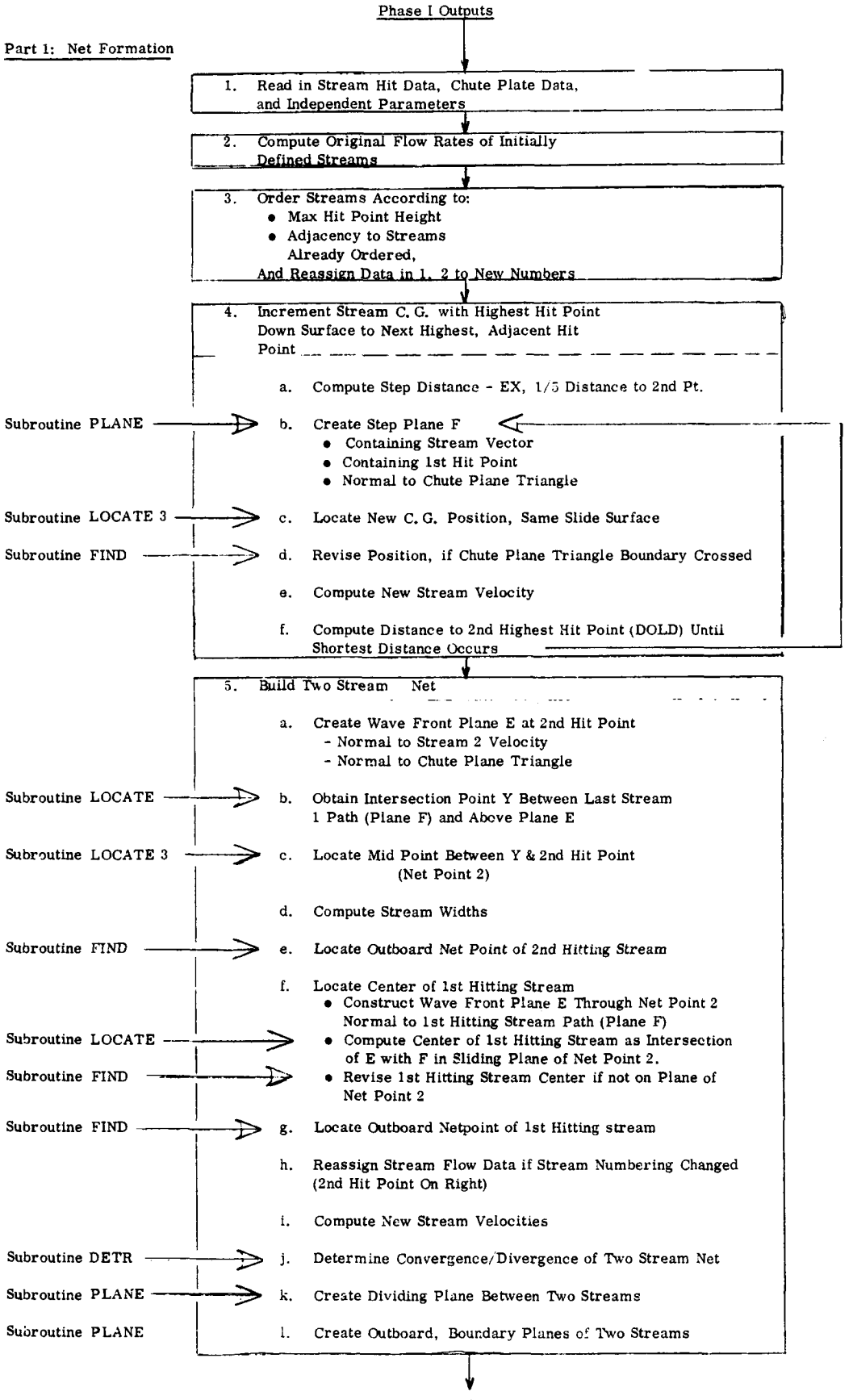
5.2.3.2 Program Sequence

Figure 5-4 is a flow chart summary of the basic steps involved in the Phase 2 computer program shown in Appendix E, identifying also major subroutines and their functions.

It will be seen that the Phase 2 frictional program is itself divided into two parts: the first tracks the flow as the individual streams are sequentially incorporated into a common net; the second part then tracks the flow down to the point where the end of the chute is reached. In the second part, the fact that the identities of the original independent streams have been maintained discretely, for the previously discussed purpose of measuring internal normal and shear forces, is utilized to track the incremental departure of the flow from the chute, as various portions across its width reach the chute edge in that area.

Figure 5-4

Phase 2 Math Model Computer Program Flow Chart



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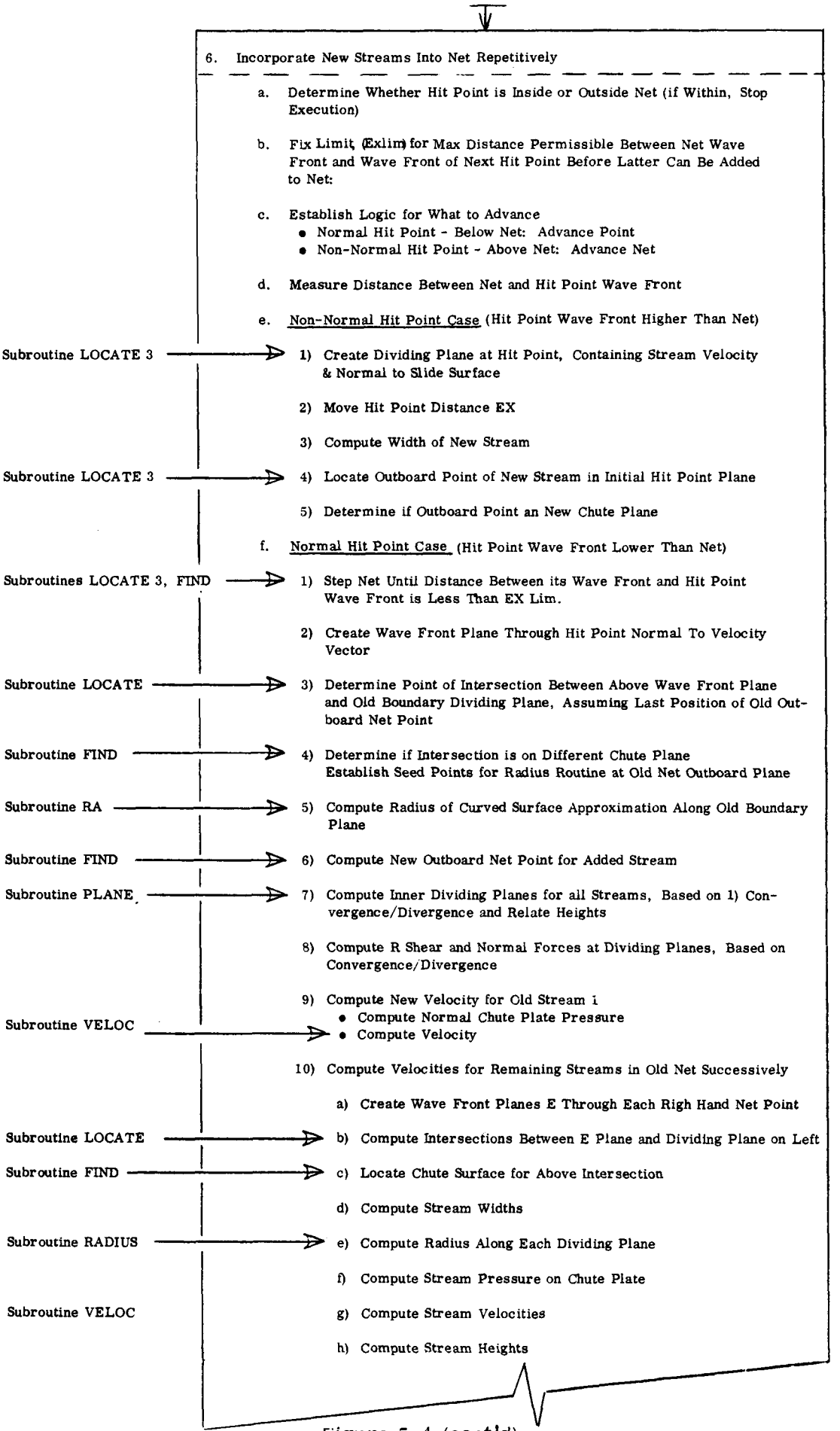


Figure 5-4 (cont'd)

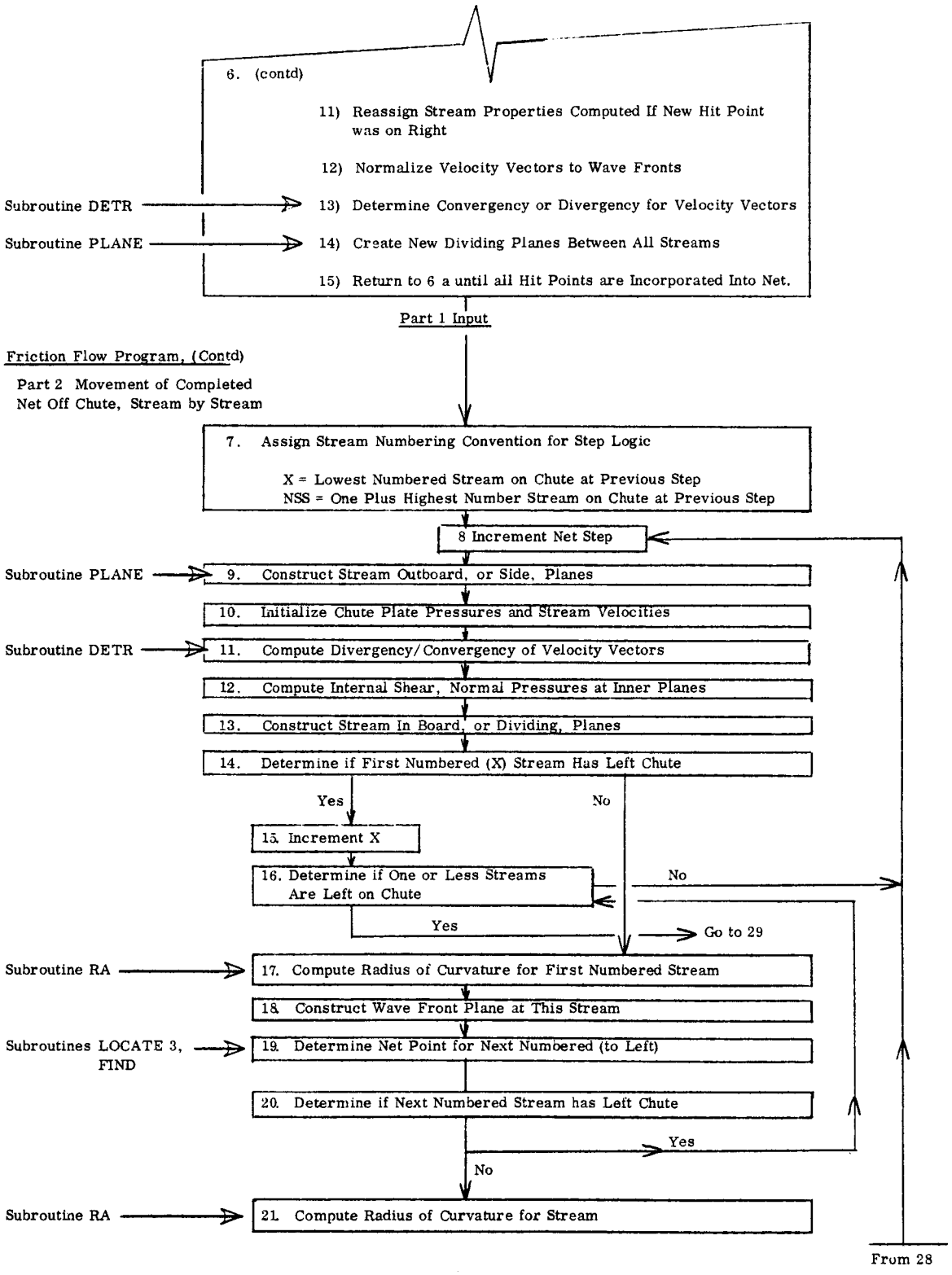


Figure 5-4 (cont'd)

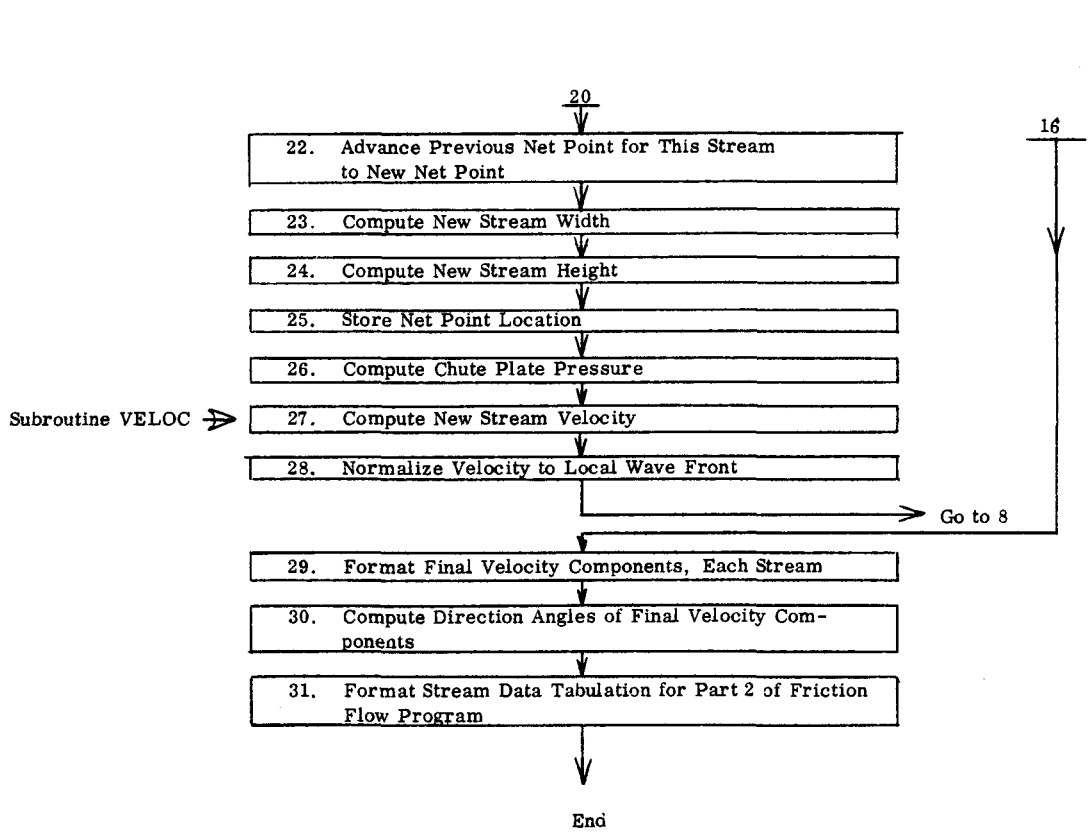


Figure 5-4 (cont'd)

6.0 CHUTE DESIGN CONCEPTS AND MATH MODELS

Prior to mathematically analyzing flow on specific chute surfaces, a series of concepts were evolved and evaluated as candidate configurations for the ninety degree transfer chute. The most promising concepts were screened by early lab testing (see Section 8 and 9); and in two cases chute math models were developed, namely, for toroidal and conical geometries. The torus geometry was selected for detailed analysis.

6.1 CONCEPTUAL DESIGN AND EVALUATION

Of numerous concepts considered, above seven distinct shapes were evaluated in detail. The seven configurations are derived from three basic geometries, namely, a cone, a cylinder, and a torus:

Item	Basic Geometry	Concept Designation	Reference Figure
1	Cone	Opening Half Angle	6-1
2	Cone	Flat Impact Plate	6-2
3	Cone	Zero Half Angle	6-3
4	Cylinder	Single Surface	6-4
5	Cylinder	Compound Surface	6-5
6	Torus	True (Smooth)	6-6
7	Torus	Smoke Pipe (Jointed)	6-7

These candidate concepts were screened in a tradeoff analysis against the following ten criteria, covering the three general areas of performance, compatibility with mine operations, and economics.

1. Stream (Mass Cross Section) Cohesion
2. Belt Impact Vector
3. Freedom of Flow
4. Convergence
5. Jam Clearance
6. Minimum Headroom
7. Installation Complexity
8. Maintainability
9. Producibility

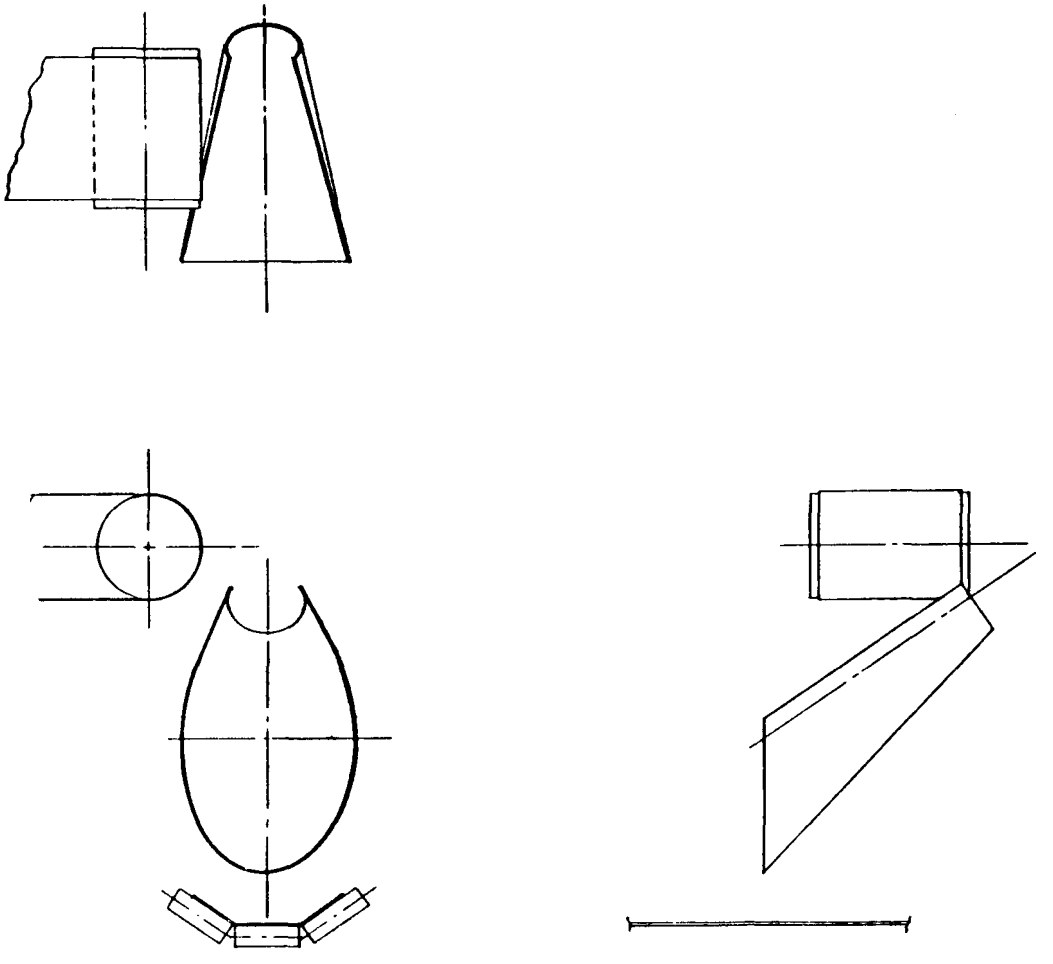


Figure 6-1 Cone, Opening Half Angle Concept

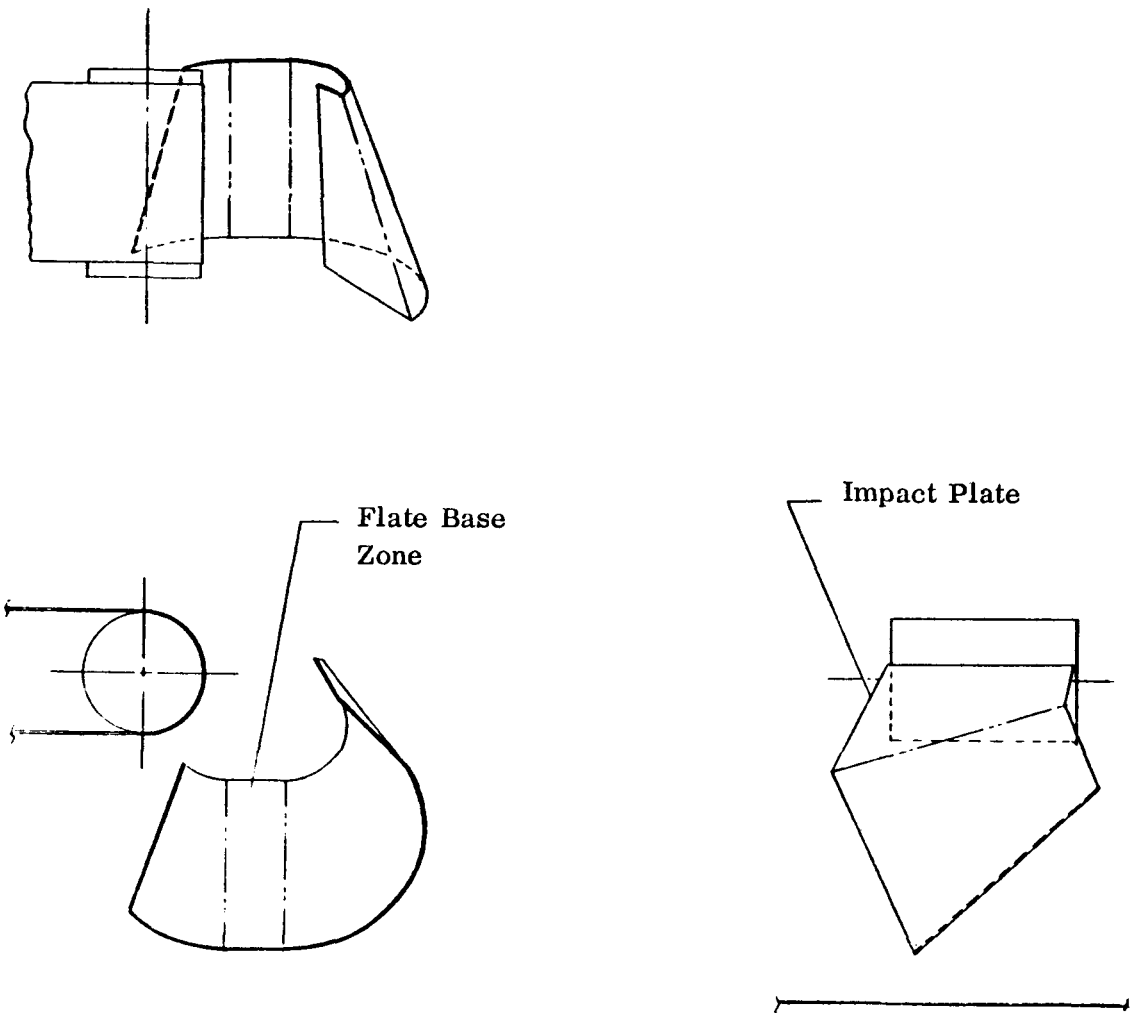


Figure 6-2, Cone Concept With Flat Impact Plate

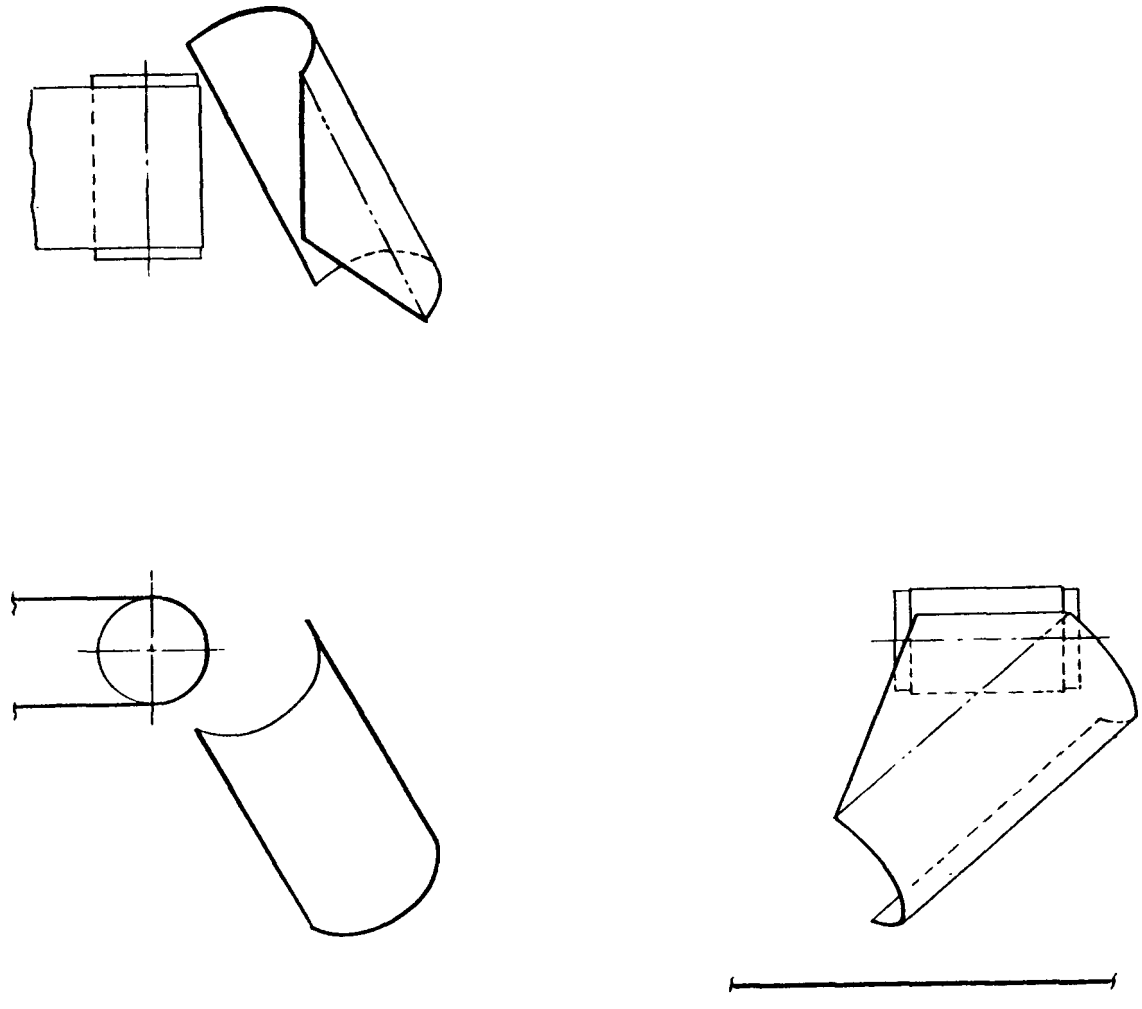


Figure 6-3, Zero Half Angle Cone Concept

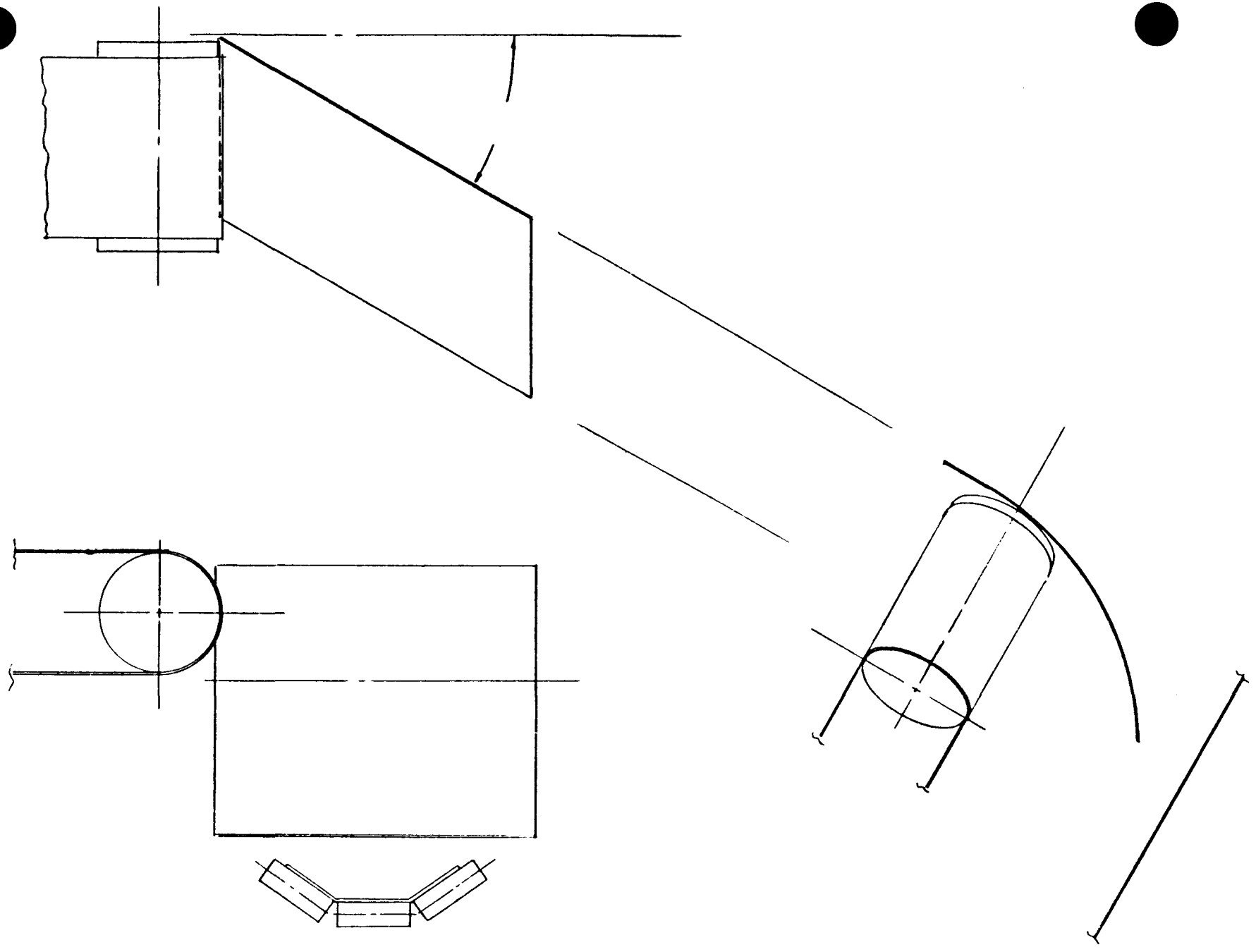


Figure 6-4, Cylinder Concept, Single Surface

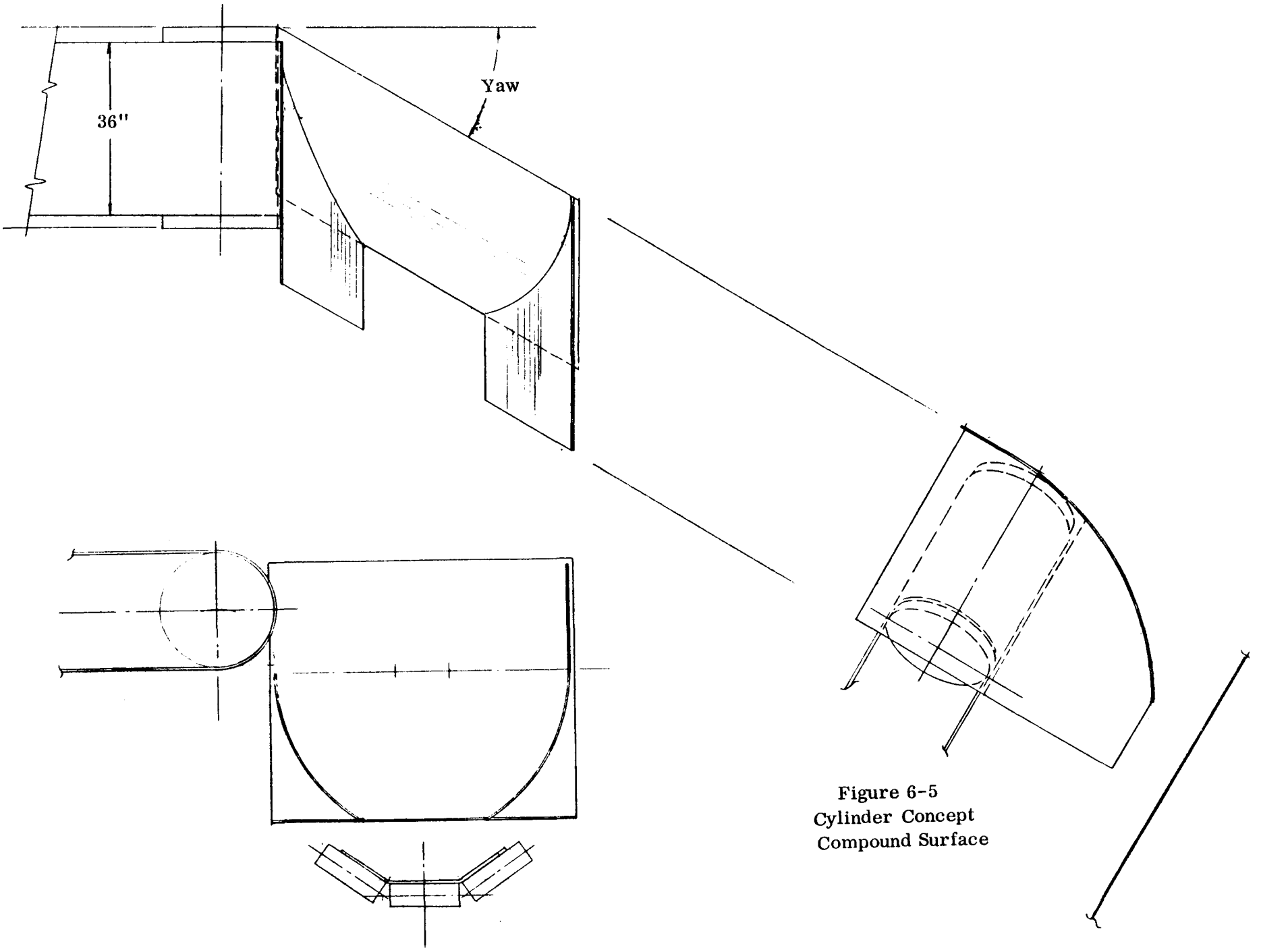
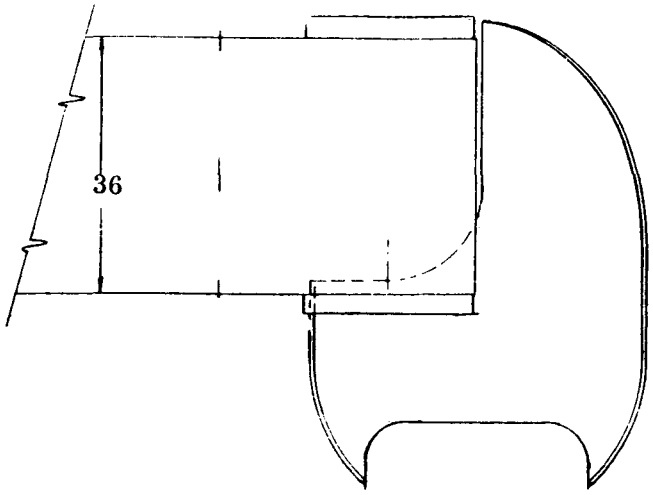
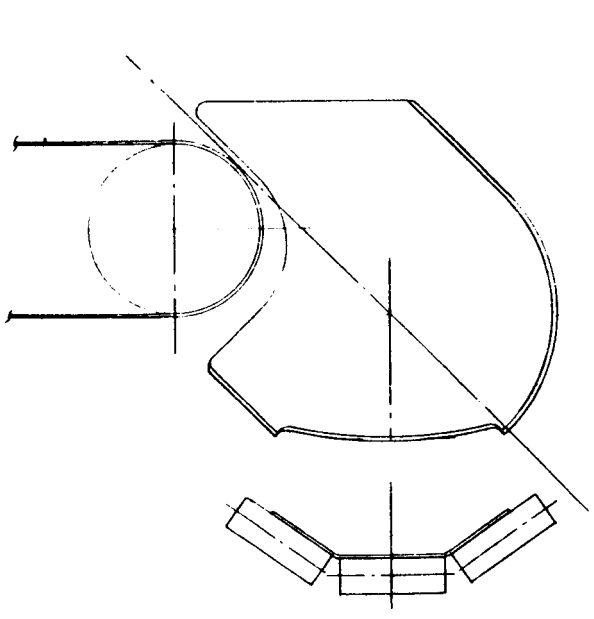
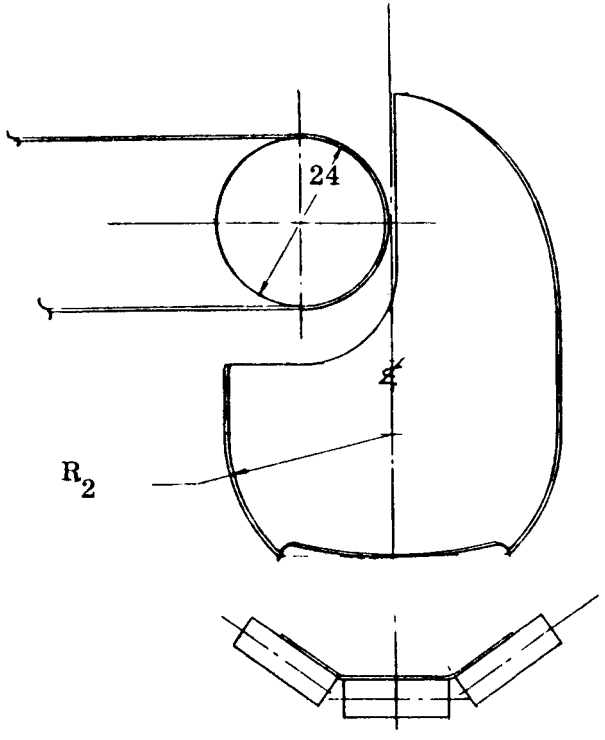


Figure 6-5
Cylinder Concept
Compound Surface





Alternate Roll Position



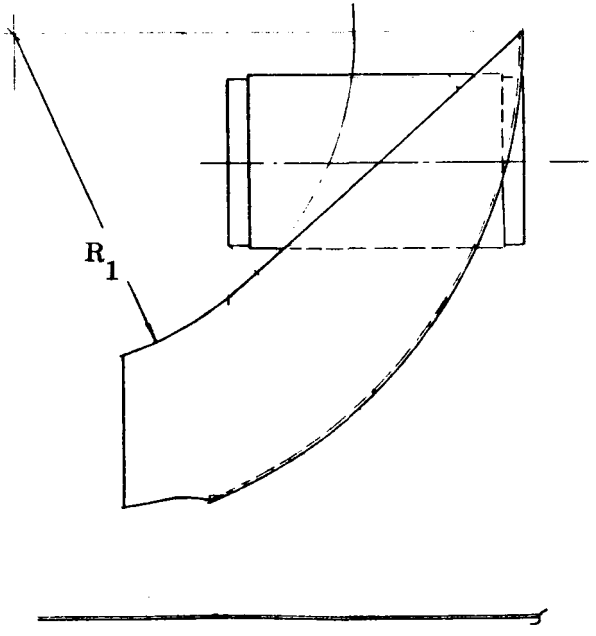


Figure 6-6 True Torus Concept

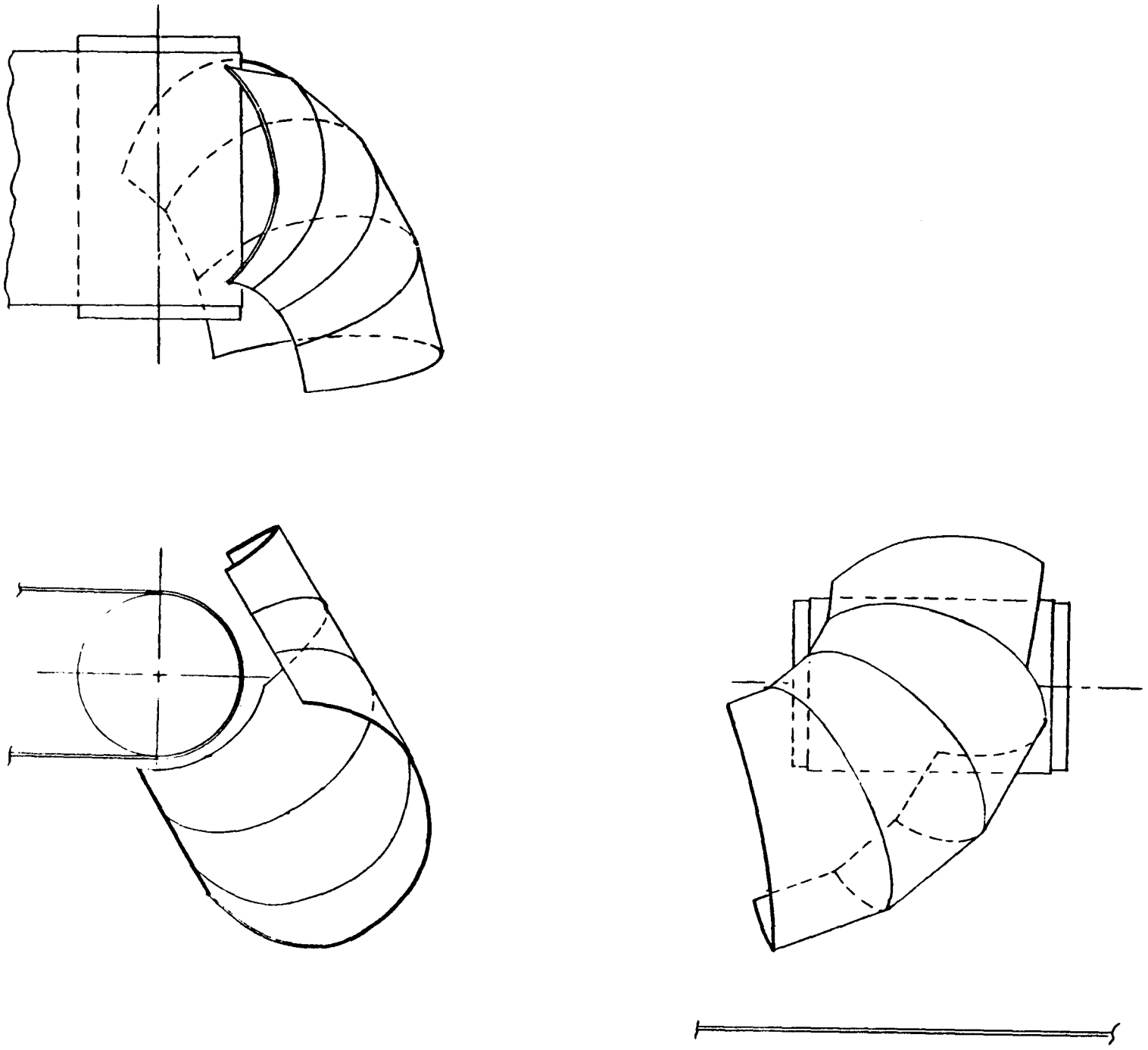


Figure 6-7, Smoke Pipe Torus Concept

Appendix F is a report of the tradeoff analysis performed. In addition to a discussion of both the candidate concepts and above criteria, it provides a rationale for application of a numerical weighting to these criteria in terms of relative importance.

The conclusion of this tradeoff analysis is that the smokepipe torus achieves the best overall rating in performance, mine compatibility, and economics. Moreover, because of one or more prohibitive drawbacks found to characterize each of the other concept configurations, the smokepipe torus is the only one judged to be suitable for detailed analysis and preliminary design.

6.2 CHUTE MATH MODEL

As discussed in Section 5, the general math model for flow analysis introduces the chute configuration effectively as an independent group parameter, along with sets of parameters relating to 1) the feed conveyor and pulley; 2) flow material parameters. This introduction is achieved by means of a specific chute subroutine to Phase I of the flow analysis computer program, given in Appendix C.

The chute subroutines provided are TORUS and CONE. They are capable, with prespecified modification, of generating in mathematical space three dimensional representations of any of the correspondingly designated chute surfaces listed in previous section 6.1. These surface representations are defined by flat plate-subdivided approximations of the nominal geometrical curved surface, where the degree of approximation can be achieved to any degree of precision simply by specifying a finer subdivision.

One purpose of the chute subroutine, then, is to supply to the two main routines of the flow analysis program the locating X, Y, Z, coordinates of the four corners of each rectangular subdivision. These plate definitions are immediately subdivided into triangles by the program for the purposes both of locating initial free fall trajectory hit points and of tracing the subsequent frictional flow path.

A second, prior function of the chute subroutine is to compute the space location of these plate coordinates, given basic independent parameters relating 1) to the particular geometrical shape and 2) to the location and attitude of the chute relative to the feed conveyor pulley. Thus in the case of the torus, the following base parameters would be specified for a given run:

1. Major Radius RT 1
2. Minor Radius RT 2
3. Number of Flat Plat Subdivisions Along Major Radius of Curvature NT1
4. Number of Flat Plate Subdivisions Along Minor Radius of Curvature NT2
5. Coordinates of top, aft edge of torus section from pulley origin : X_T, Y_T, Z_T (See Figures G-1 and G-2 of Appendix G)
6. Attitude of chute, relative to pitch, yaw, and roll angles, about the principal axes through origin (Figure 6-8).

The torus math model whereby the computer programs subroutine develop the corner coordinates of the subdivided rentangular plates is provided in Appendix G. A similar math model is available for the cone computer program subroutine (Appendix C), but is omitted here in the interests of brevity, since this subroutine is not utilized in the proposed configuration. (Some of the cone chute models generated by this subroutine are shown in Figures 1B, 2B, and 3B of Appendix F).

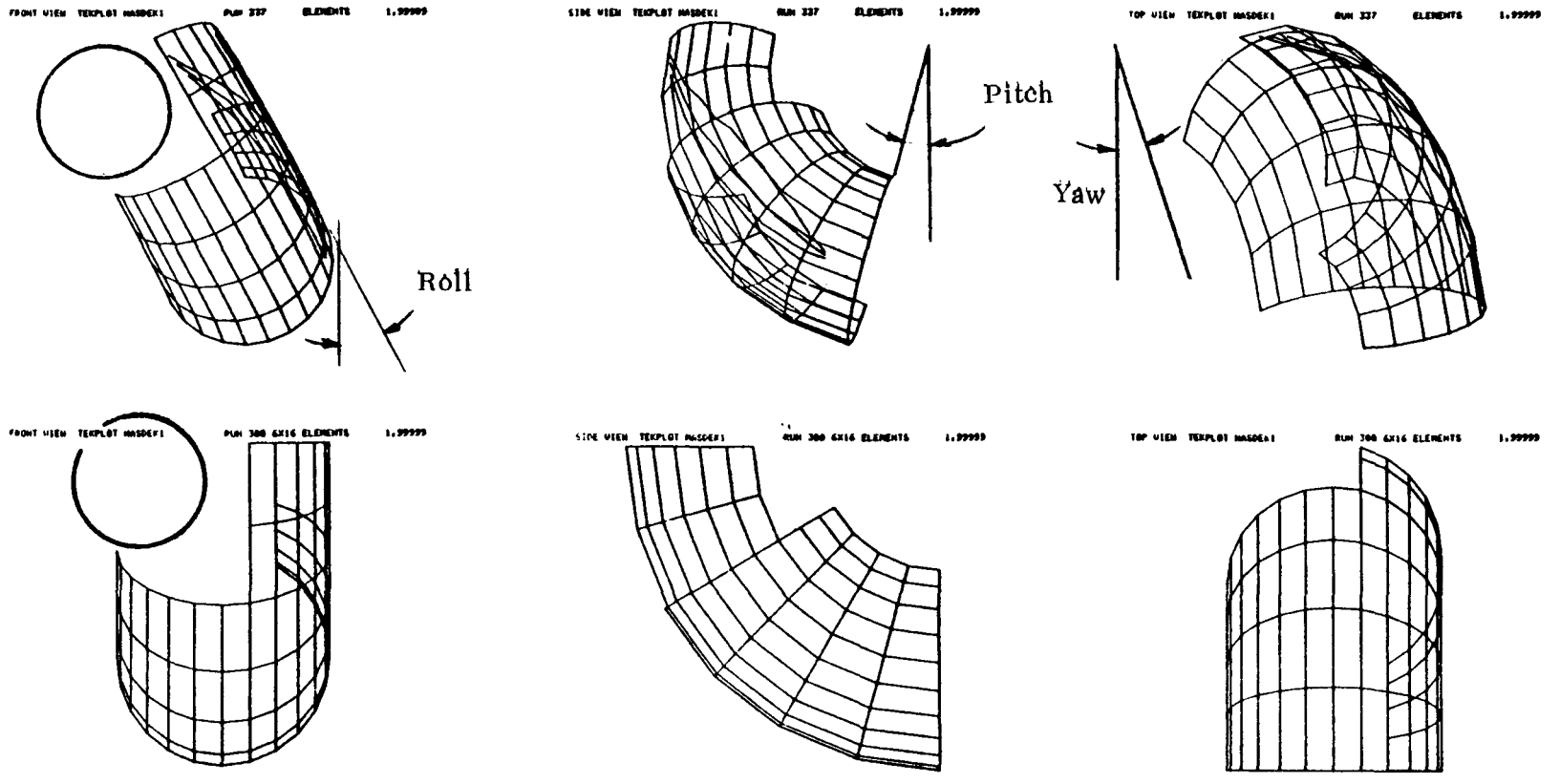


Figure 6-8. Computer Plate and Rotation Definition

Some other considerations in the actual chute geometry involve the fact that the surface is toroidal down to the last section, but at this point the plates in the final section developed in the model are each extensions of the adjacent plates in the previous section. This tangential departure from the "donut" shape is provided with a computer-designated length factor "EXT", to center the flow in the chute for some flow cases.

Another provision in the computer subroutine torus is the capability of specifying removal for clarity and appearance of particular flat plates from the basic mosaic pattern computed (Figure 6-8).

As shown in Figure G-4 of Appendix G, nominal plate numbering is along each cross section segment of the torus in sequence, beginning with the top section and going to the lowest. The numbering along each cross section begins on the side nearest the pulley and goes to the outboard side. When plates are removed, the numbering simply skips those plates. In the final configuration the entire top row of plates and the left side of the second row are so eliminated, since no streams impact in that upper area of the torus math model.

A "sub" subroutine called DIST is used to compute basic plate dimensions, depending on the number of subdivisions and the total angular lengths chosen for (NT1) X(NT2)plates. This is a design aid and the subroutine is not called for every parametric run.

7.0 DYNAMIC ANALYSIS RESULTS

For convenience of presentation, the results of the computer studies are included as Appendix H, in Volume II. Sections H-1 and H-2 of this Appendix cover the free fall/impact and the frictional flow studies, respectively. Discussions in this section, which addresses the 350, 450 and 600 fpm input belt velocity cases, will be in reference to Appendix H. The free fall/impact studies include chute configuration data which is used extensively as a design aid.

7.1 FREE FALL/IMPACT PHASE

1. 350 FPM Trajectory Case

   The results of the free fall/impact analysis for a given trajectory vs chute orientation case are presented in Appendix H in the following formats, making illustrative reference here to Run 626, which corresponds to the nominal chute orientation:for the 350 fpm trajectory.

   - Input Data (Page H-4), covering parameters on the feed conveyor, the torus chute, run of mine coal, and run convention constants
   - Output Data, (Page H5 to H10), covering 1) basic geometry outputs; 2) the X, Y, Z coordinates of the four corners of each of the plates into which the chute is subdivided; and 3) the hit data, which includes for each stream into which the flow mass is subdivided: the time of impact, its angle of impact with the chute surface, and the X, Y, Z coordinates of the hit point. Because of bulk, the output information for all run cases except the nominal ones will be limited to the hit data.
   - Design Plots , (Pages H11-H14) covering four (4) computer-plotted views of the conveyor pulley, the chute, and the hit pattern on the chute surface.

Run 626 corresponds to the nominal design orientations presented for the 350 fpm trajectory in section 3.3. The "Y min" value, which is the Y coordinate of the lowest point on the chute, is used to determine the belt-to-belt clearance Y_B in Table 3-2 of section 3 by adding the 12 inch radius above the pulley centerline, plus 8 additional

inches of clearance below the chute. Similarly, the roll, pitch, and yaw rotations specified in Table 3-1 are taken directly from the input data sheet of the computer run (H-4). This same procedure is used for establishing locational and rotational parameters for the nominal chute positions in the 450 and 600 fpm cases.

The X_R, Y_R, and Z_R coordinate locations for the 350 fpm trajectory case are taken from the fourth corner of the 33rd plate, which corresponds to the bottom edge of the chute prior to any rotation..

The chute position here defines approximately that in run number 72 in section 9.0, where the X, Y, Z locating coordinates of -0.2, -2.0 and -0.5 in Table 9-5, correspond within a quarter of an inch to the first corner of plate 1 (page H-4), if the 0.305, 11.176 and -1.427 are divided by 6 to correspond to the 1/6 scale of the lab chute.

It will be seen with few exceptions that the hit angles at the c.g., top, and bottom of each stream are less than 30 degrees.

The chute outboard edge, shown by dashed lines in the side view plot of page H-16 was located to clear the upper impact trace by approximately 6 inches, in the event that final translational or rotational adjustment causes this impact line to rise. The corresponding side view in Run 627 shows, for example, the change in the location of the top of the impact zone if the R point on the chute is lowered about a half inch and brought in toward the pulley about 1 inch. The allowance for material above the final hit zone must be minimized to obtain maximum clearance with the pulley.

It will be seen from the front view plot (H-12) that material corresponding to approximately two plates, must be removed in the chute design. In that each plate corresponds to a 30 degree segment, and that the left edge of the cutout shown in H-12 is at the centerline, the final left edge should be at 30 degrees to the right of this centerline. Referring to the flat pattern for the 350 fpm plate segment flat pattern in Figure 3-5, it will be seen that this is where the left edge lies, including a additional triangular area about the upper segment, which corresponds to the second row of plates in the H-12 figure.

2. 450 FPM Trajectory Case

Run 746 corresponds to the nominal design chute position for the 450 fpm trajectory. Reference point R in Table 3-1 corresponds to the fourth corner of plate 29, which is numbered differently from that in the 350 fpm case because the latter contains an additional row of four plates at the upper end. Run 746 also ties in approximately with test runs 481 and 482, whose locational coordinates in Table 9-6 correspond to those at the fourth corner of plate 32, the latter being at full scale.

The outboard edge of the chute wall, as shown in the side view plot of Run 746, is well above the hit zone, and will accommodate shifts of this zone due to rotational ranges introduced during the testing phase, such as that shown in Figure 706. The peculiar hump at the lower end of the hit zone in the Figure 706 side view is an anomaly due to the coarseness of the plate subdivision chosen. When the subdivision is 15^{o} plate segments instead of 30^{o}, as shown on the page immediately following for a shorter chute at the same location and orientation, the hit zone is seen to smooth out.

3. 600 FPM Trajectory Case

Run 846 corresponds to the nominal design chute position for the 600 fpm trajectory. Reference point R in Table 3-1 corresponds to the fourth corner of plate 29, as in the 450 fpm case. This run also corresponds to Test run 462, for which the locating coordinates given in Table 9-6, tie to the fourth corner of plate 32, at full scale.

The location of the outboard edge above the hit zone is shown in the side view plot, where again the top of the former shows perturbations due to the coarseness of the plate subdivision..

7.2 FRICTIONAL FLOW PHASE

A problem of wave front stability still existed in final computer runs of the model for frictional flow down the surfaces of the nominal chute configurations defined in the previous section. A number of steps were taken regarding the modification of the initial math model (Appendix D) to correct the problem, including changing the logic as to the direction of the hypothetical dividing planes between stream subdivisions of different height. Various step increment sizes were tried for the moving of the net down to the surface. It was found also that additional work was required on the surface radius computation, upon which the centrifugally derived friction effect depends.

Page H-66 and H-67 show one of the typical computer log formats for maintaining the dynamic parameters of each stream during its stepwise movement. In addition, the right hand four (4) columns present the successive locations of the stream wavefront, given, respectively, in terms of X, Y, Z coordinates, and plate number location (referring to H-4 to H-8, for example).

The balance of Appendix H-2 presents computer plots taken from preliminary friction flow runs at 0 and 20 degrees, for various trajectories. It will be seen that, for the most part, the general flow directions are evident, despite the random perturbations associated with point location, which correspond to computer overflow conditions due to the remaining math model instabilities. Some of the random data in the runs has been removed from the plots for clarity.

Prior to attempting higher wall friction coefficients (tan ($\emptyset'$)), it would be necessary to model a smoother inter-relationship between adjacent streams, as well as improve the radius subroutine.

It will be noted that the plot data shown, as well as the tabular data identified above, relates to the movement of the stream net, once all streams have been incorporated into this common net, after initial impact. The net formation phase, which is documented in a cumbersome computer printout format not presented here, is a very smooth process, ranging up to 40 steps in itself, prior to the step sequence in the table on H-66, 67. The computer plots shown record wavefronts at every tenth step after the full net is formed.

8.0 LABORATORY CHUTE SCALE MODELS AND TEST EQUIPMENT

FSEC constructed a number of one-sixth size scale models of chutes during this study program. The modeling efforts related to two different activities: 1) the development and evaluation of various concepts, which were screened in the tradeoff analysis discussed in Section 6; and 2) to testing of that chute geometry identified for detailed study, the torus. This section describes the various scale models fabricated and tested, together with basic test equipment utilized, and the scaling considerations involved.

8.1 SCALE MODEL CONSIDERATIONS

8.1.1 Dimensional Analysis

Two groups of parameters are involved in addressing options and constraints relative to scale model testing: 1) material flow characteristics applicable to free, open channel flow; and 2) chute geometry and associated material trajectories.

Because free, open channel flow characterizes the functional flow mechanism of interest in transfer point chutes, all of the materials flow characteristics applicable to the analysis are effectively dimensionless. In particular, because steady velocity profiles in a mass-flow configuration characterize chute flow, only two material parameters are involved:[1]

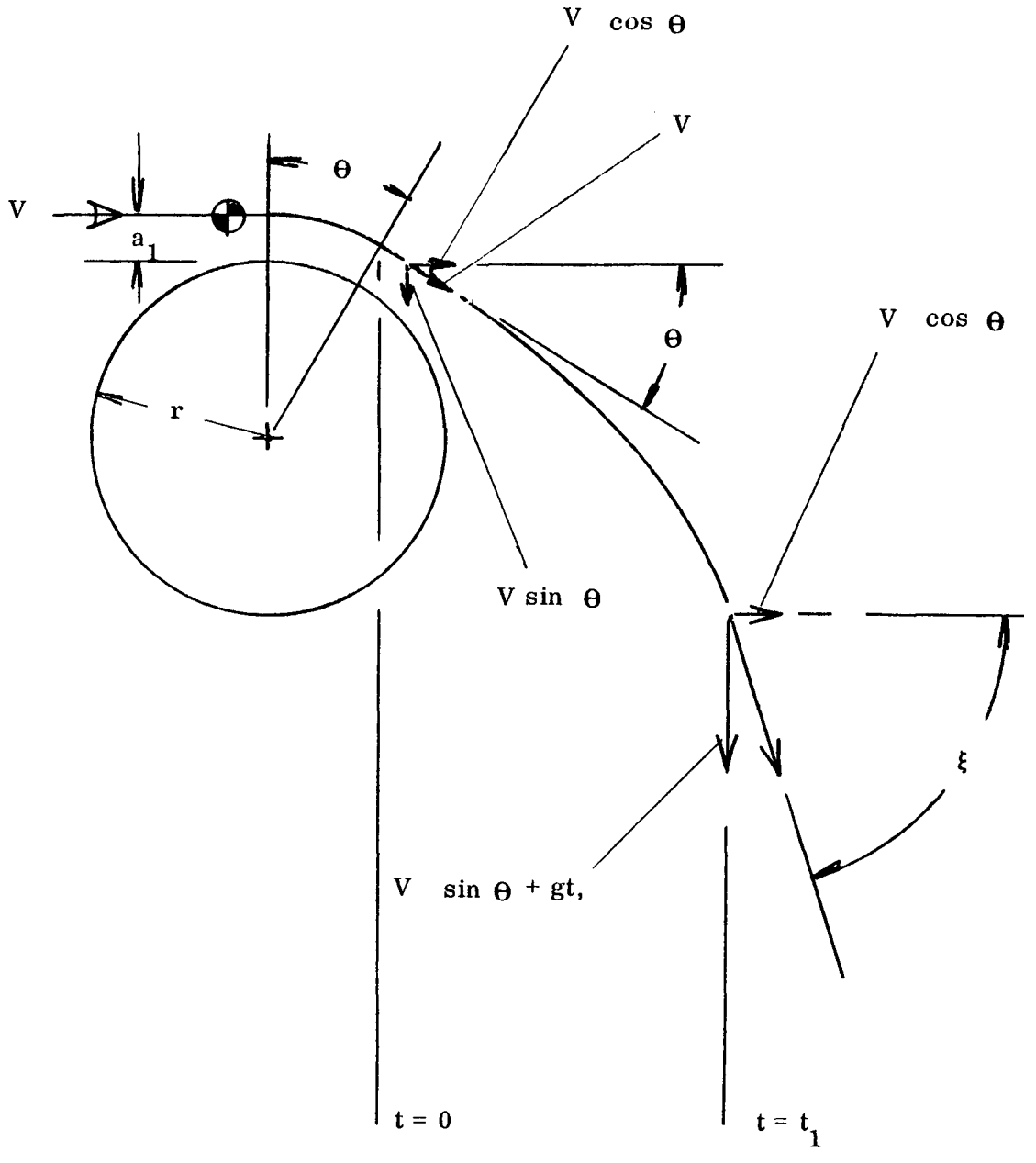
1. Effective angle of internal friction δ
2. Kinetic angle of wall sliding friction ϕ'

In an actual laboratory size scale test, one additional constraint applied to materials parameters is that the largest lump size should not be greater than about 1/4 to 1/3 of the belt width, relating to the idler trough.

In the pre-friction flow phase of the transfer point analysis, it is necessary to duplicate the shape of the free fall trajectory relative to the chute scale size selected, as well as the pulley diameter applicable. Referring to Figure 8-1, the relationship required between the scale size selected (s) and the full size configuration (f) is

$$\xi_s = \xi_f$$

[1] Modelling Flow of Bulk Solids, J. R. Johnson, Powder Technology, May 14, 1971



$$\theta = \text{Cos}^{-1}\left(\frac{V^2}{g\,(r + a_1)}\right)$$

Figure 8-1 Free Fall Trajectory Parameters

That is,

$$\frac{V_s \sin \theta_s + gt_s}{V_s \cos \theta_s} = \frac{V_f \sin \theta_f + gt_f}{V_f \cos \theta_f} \tag{2}$$

or

$$\tan \theta_s + \frac{gt_s}{V_s \cos \theta_s} = \tan \theta_f + \frac{gt_f}{V_f \cos \theta_f} \tag{3}$$

By definition of equivalency of trajectory shape,

$$\theta_s = \theta_f \tag{4}$$

Also, in the horizontal direction, for either case,

$$t = \frac{X}{V \cos \theta} \tag{5}$$

Hence, substituting equations (4) and (5) in equation (3) and clearing common terms

$$\frac{X_s}{V_s^2} = \frac{X_f}{V_f^2} \tag{6}$$

This can be expressed in the form,

$$\frac{V_s}{V_f} = \sqrt{\frac{X_s}{X_f}} \quad , \tag{7}$$

indicating that for any scale factor X_s / X_f chosen, the ratio of the velocities must be the square root of this ratio.

It will be seen from section 2 of Appendix B, that because the following relationship holds

$$\theta = \cos^{-1} \left[\frac{V^2}{g(r + a_1)} \right]$$

the above dimensional relationship between the velocity and the pulley size holds identically to that for the velocity and the chute size.

8.1.2 Laboratory Test Scale Size

Because relatively minor dynamic constraints govern selection of the scale size for laboratory testing, it is possible to chose one where the cost and inconvenience of handling and storing large amounts of bulk materials can be minimized and also where the most readily available conveyor test equipment can be chosen. In the case of the 1/6 scale model chosen, it will be seen that the normal peak flow rate, at full scale, of about 18 tons per minute on a 600 fpm, 36 inch belt conveyor reduces to

$$Q_s = (18 \times 2000 \text{ lbs}) \times \begin{pmatrix}\text{Cross Sectional}\\ \text{Area Scale Factor}\end{pmatrix} \begin{pmatrix}\text{Velocity}\\ \text{Scale Factor}\end{pmatrix}$$

$$= 36{,}000 \times (1/6) \times \left(\sqrt{1/6}\right)$$

$$= 408 \text{ lbs/min}$$

For a test run of one minute, this figure corresponds to the following volumetric requirements;

Material	Density	1-minute Flow Volume
Coal	55 lb/ft^3	7.4 ft^3
Sand	100 lb/ft^3	4.1 ft^3

8.2 LABORATORY TEST EQUIPMENT

8.2.1 Test Conveyors

The most practical means of producing flow volumes with the required trajectory shapes and uniformly reproducible flow rates was judged to be a 1/6 scale size conveyor, i.e., with a 6 inch wide belt. One further critical feature required, in order to obtain the trajectory shape, is that the radius to the belt surface also be 1/6 that of the full size case in order to duplicate the full scale radial angle of departure θ of the flow mass from the pulley. For 24 inches the largest size pulley diameter available for a 36-inch wide belt conveyor, the exterior scale size radius must then be 2 inches for the feed conveyor.

Figure 8-2 shows the scale model conveyors utilized in testing, together with a typical scale mode chute (see 8.3.5). The feed conveyor has a 6 inch wide, slider bed-type, troughed conveyor and is 10 feet in length. Its 3 1/2 inch pulley diameter and

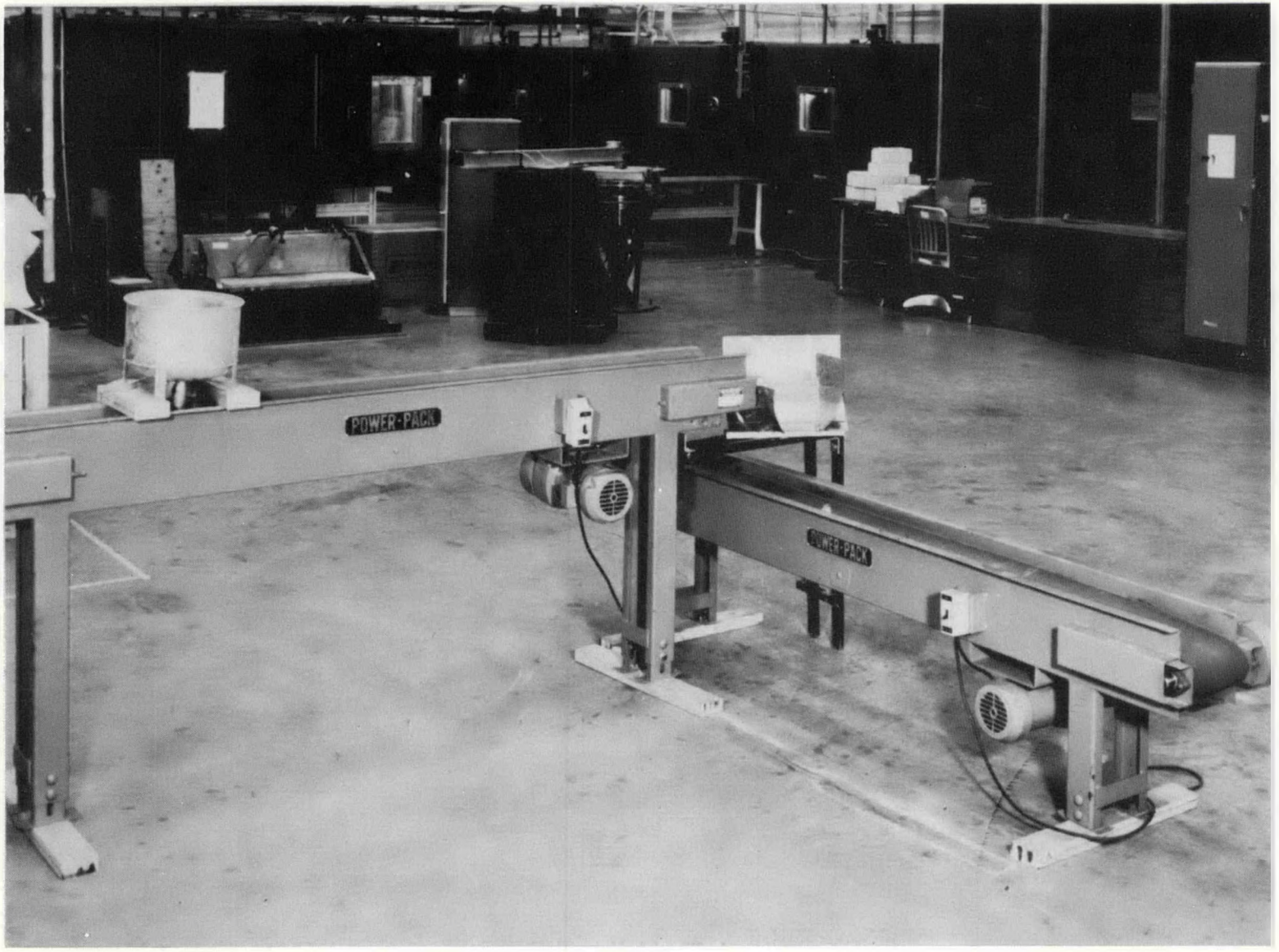


Figure 8-2. 6-Inch & 8-Inch Test Conveyors

1/4 inch thick belt yields the required exterior 2 inch radius.

The receiving conveyor, also 10 feet long, has an 8-inch belt width. For the 1/6 scale factor, this corresponds to a full size conveyor of 48 inches.

Each conveyor is driven by a 1/3 hp motor, utilizing a chain sprocket drive reduction to the pulley shift to obtain the required belt speed. Provision was made in the chain drive assembly to adjust the belt speeds to values which are average value and limiting values for the applicable range at full scale. Table 8-1 summarizes the details of this provision:

Table 8-1
Belt Speed Variation Provision in Scale Model Conveyors

Scale Model Conveyr	Speed Range Value	Sprocket Provision			Belt Velocity, Fpm	
		No. Teeth Drivr Spkt	No. Teeth Drvr Spkt	Ratio	Scale Model	Full Size Equiv. (X 6)
6" (Input)	low	14	26	1.84	143	350
	average	14	20	1.43	184	451
	high	14	15	1.07	246	602
8" (Output)	low	16	21	1.29	204	500
	average	16	17	1.07	245	600
	high	16	14	.88	301	737

8.2.2 Flow Feed Provision

A conical hopper with about a 4.5 cubic foot capacity was constructed to provide about a minute's flow at peak capacity for test sand, Figure 8-3 shows the hopper in place above the feed conveyor. After filling, the hopper is raised to the position shown on a hydraulic fork lift. (Figure 8-3a).

8.3 CHUTE SCALE MODELS

8.3.1 Conceptual Scale Model Phase

The following models were developed during the conceptual development phase. Conceptual rationale for the various iterations is also discussed in 9.2 and 9.3.

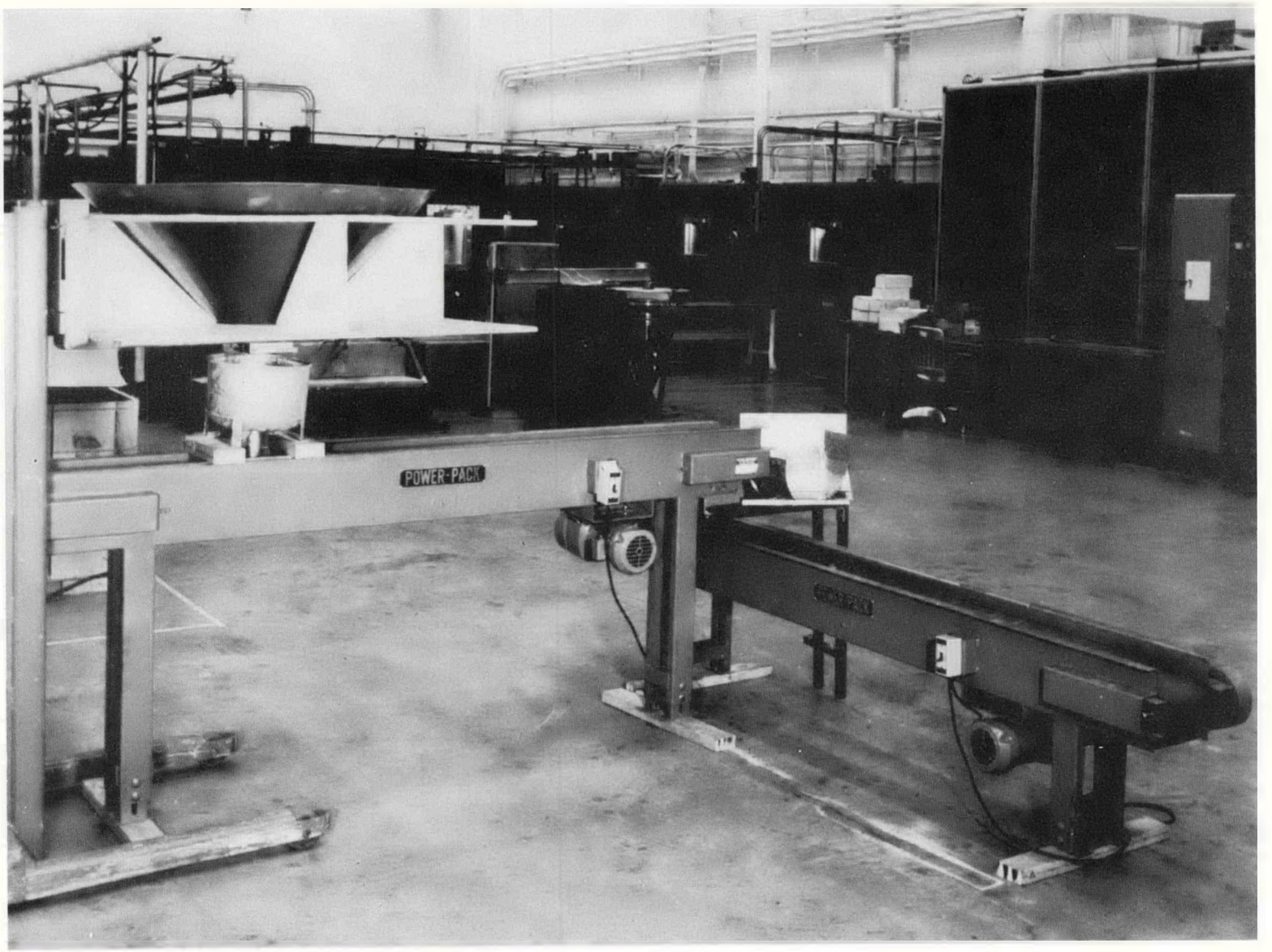


Figure 8-3. Transfer Point Test Setup

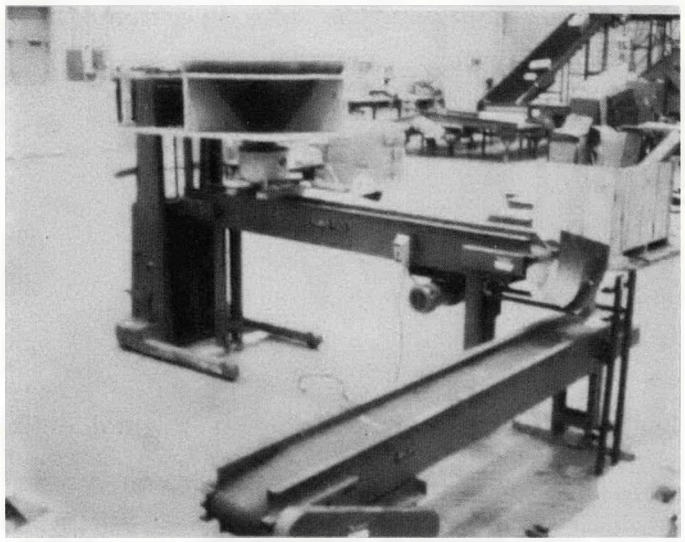


Figure 8-3a. Hopper Lift

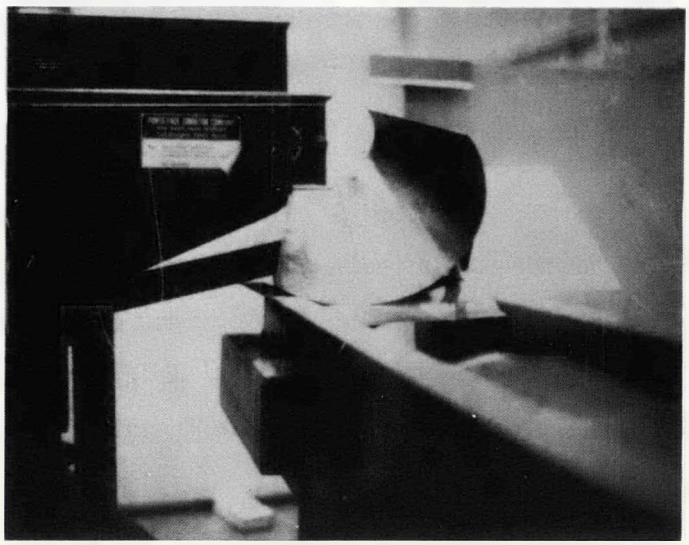


Figure 8-4. 15° Cone Scale Model

8.3.1.1 Conical Models

Two different types of cone scale models were designed and constructed. The first was an multi-section assembly, with a fifteen degree opening angle (Figure 8-4). It consists of the following elements:

- Piece 1 (Figure 8-5)
  A base section, containing the curved portion of the cone on the inboard (to the pulley) cone side and a flat section located along the lowest quadrant, which is capable of being varied in width by sliding Piece 2 on it.
- Piece 2 (Figure 8-6)
  The lower outboard quadrant of the cone.
- Piece 3 (Figure 8-7)
  The upper, outboard section of the cone, which defines a variable cone arc above piece 2 by varying its degree of overlap therewith.
- Piece 4 Figure 8-8)
  A flat, initial impact plate, which is an optional attachment to Piece 3.

A second type of cone section is depicted in Figure 8-9. Nominally called a cone because of its similarity to the previous configuration in the manner of its alignment orientation, the opening angle of this cone is zero degrees.

8.3.1.2 Cylindrical Models

Two basic cylindrical geometries were defined and constructed. The first is an approximately 90 degree cylindrical quadrant, terminating at the upper end with a flat vertical wall (Figure 8-10). The second configuration is a compound version of the first, consisting of a pair of additional cylindrical quadrants, which are provided as side constraints on the flow as it slides down the main cylindrical section. (Figure 8-11)

8.3.1.3 Toroidal Models

Two groups of torus chute scale models were designed and fabricated

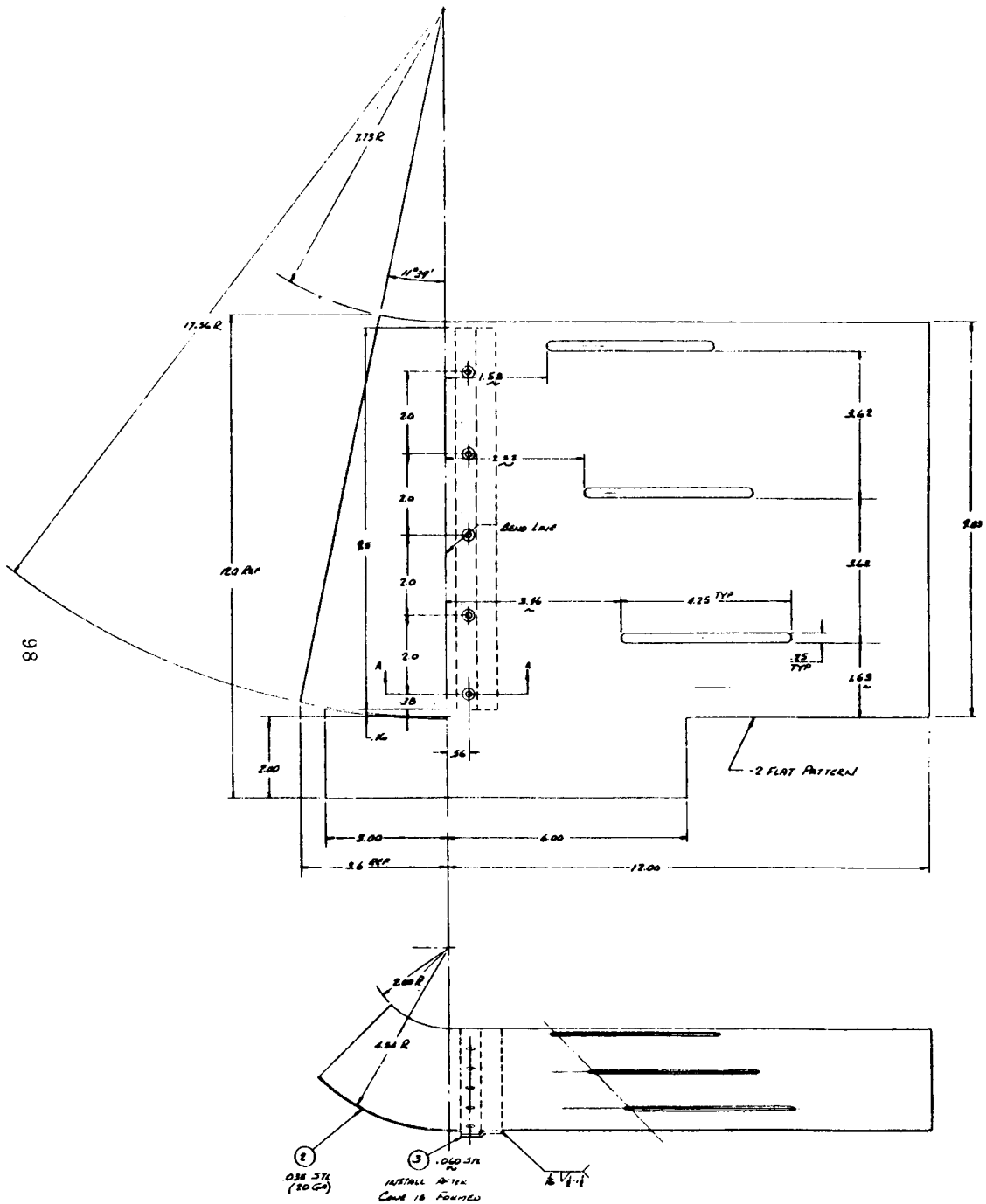
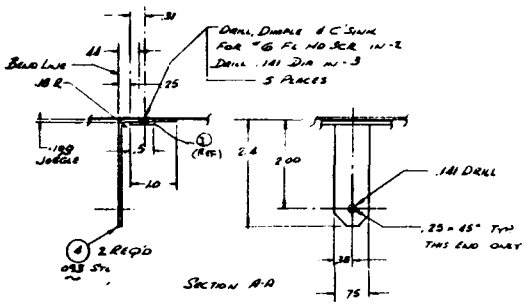


Figure 8-5, Cone Baseplate



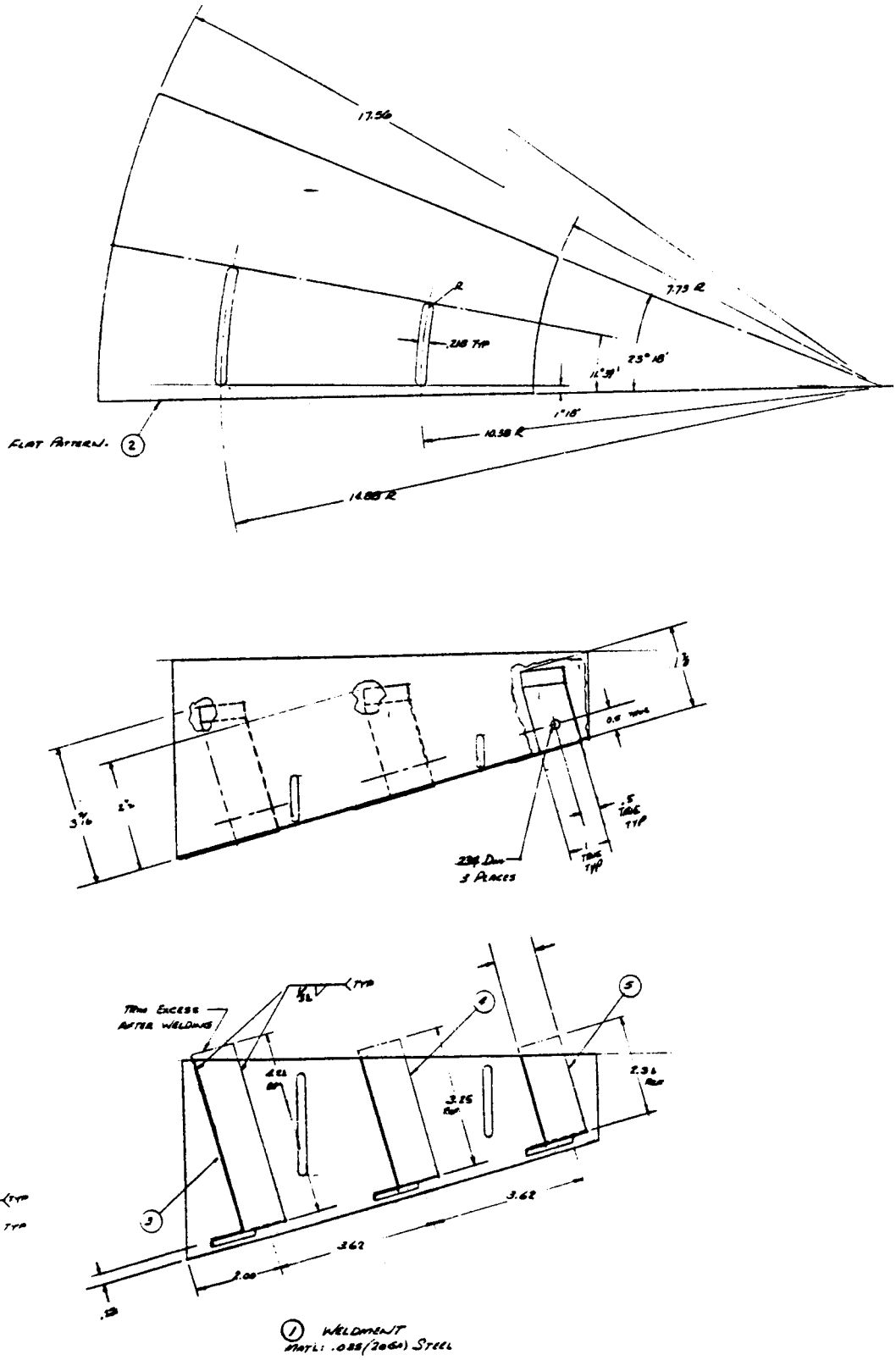


Figure 8-6. Lower Quadrant, Cone Model

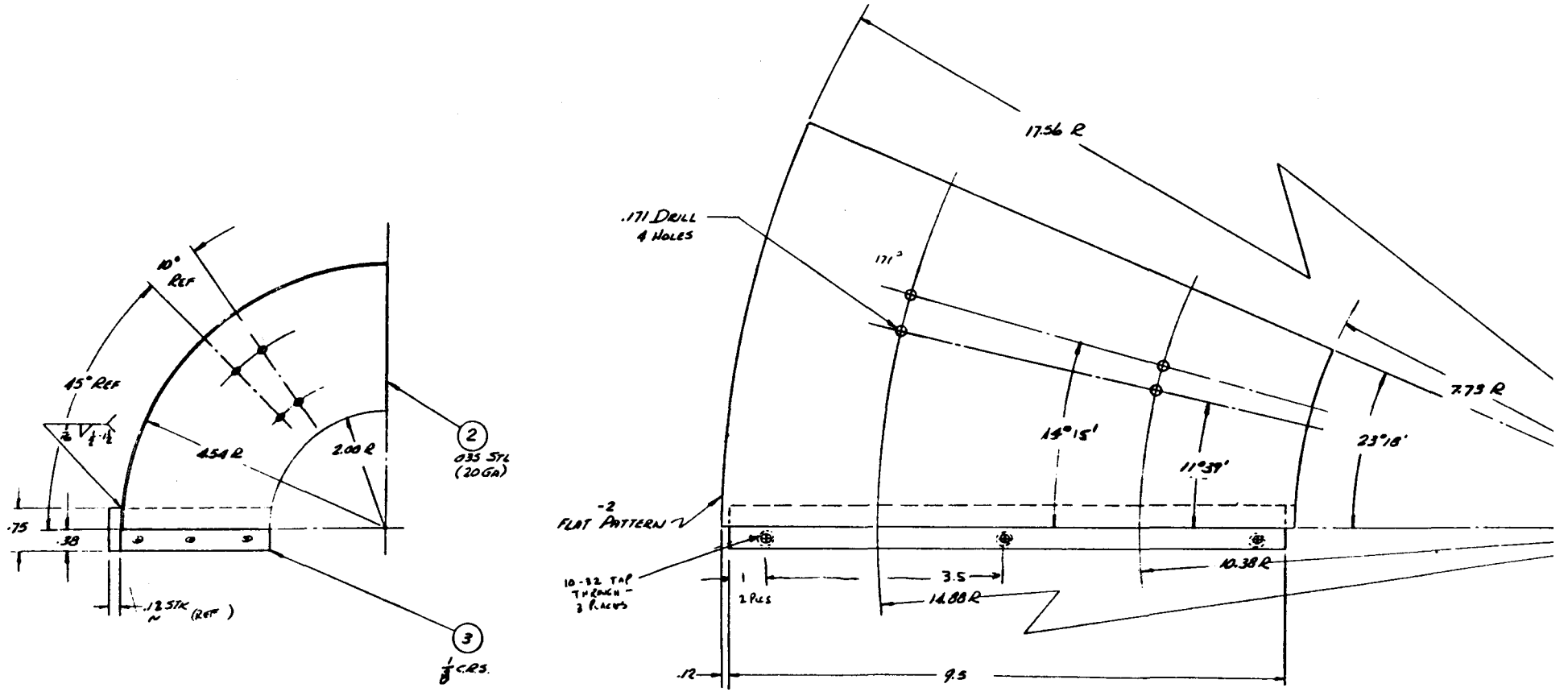
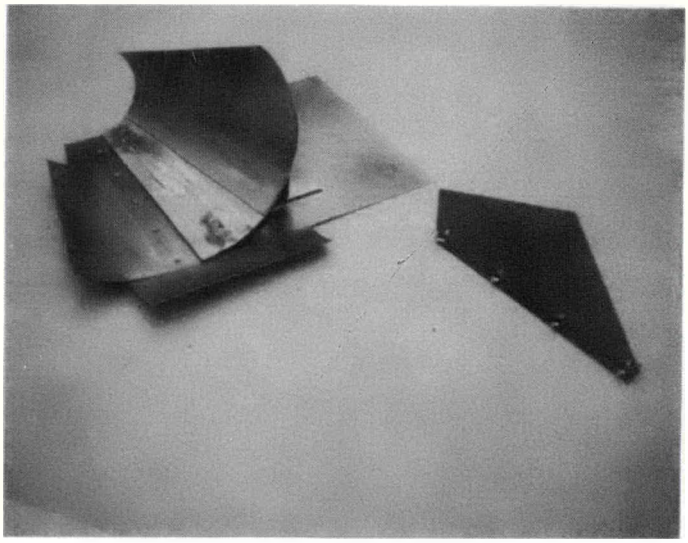
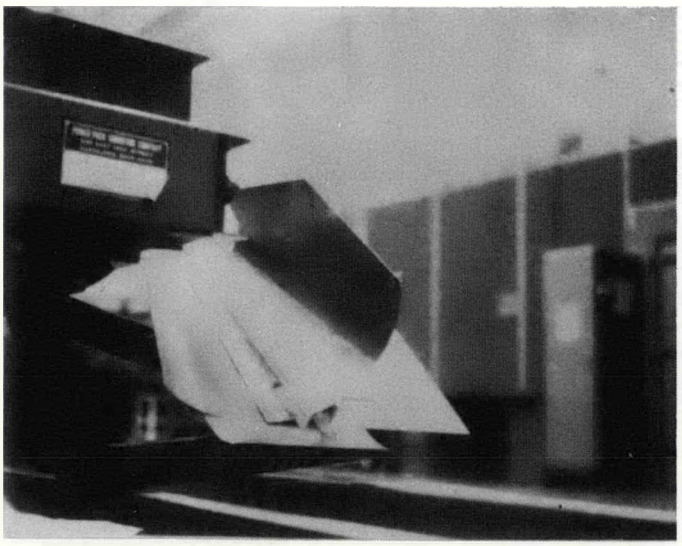


Figure 8-7. Upper Quadrant, Cone Model

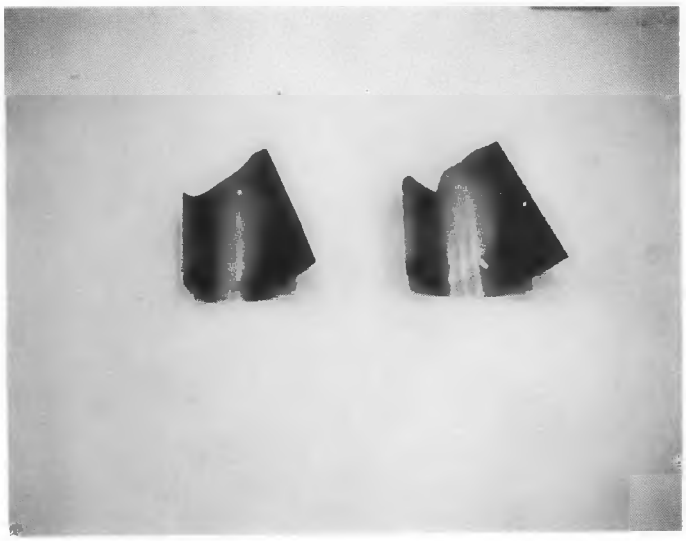


Impact Plate Separate

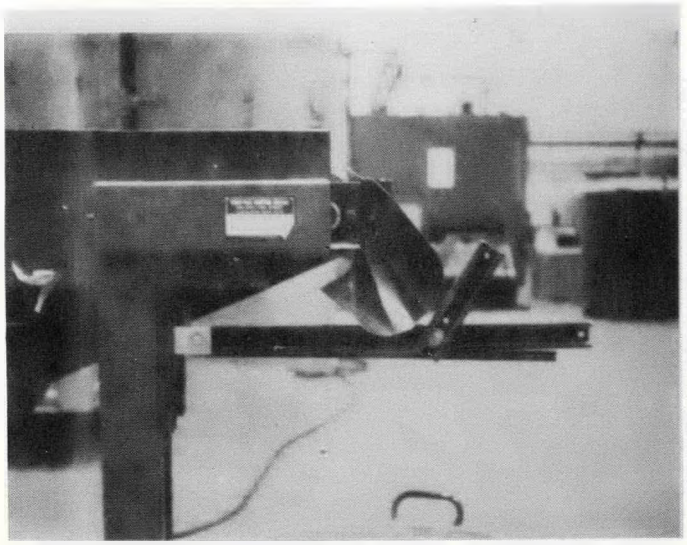


Installation

Figure 8-8. Cone Model with Flat Impact Plate

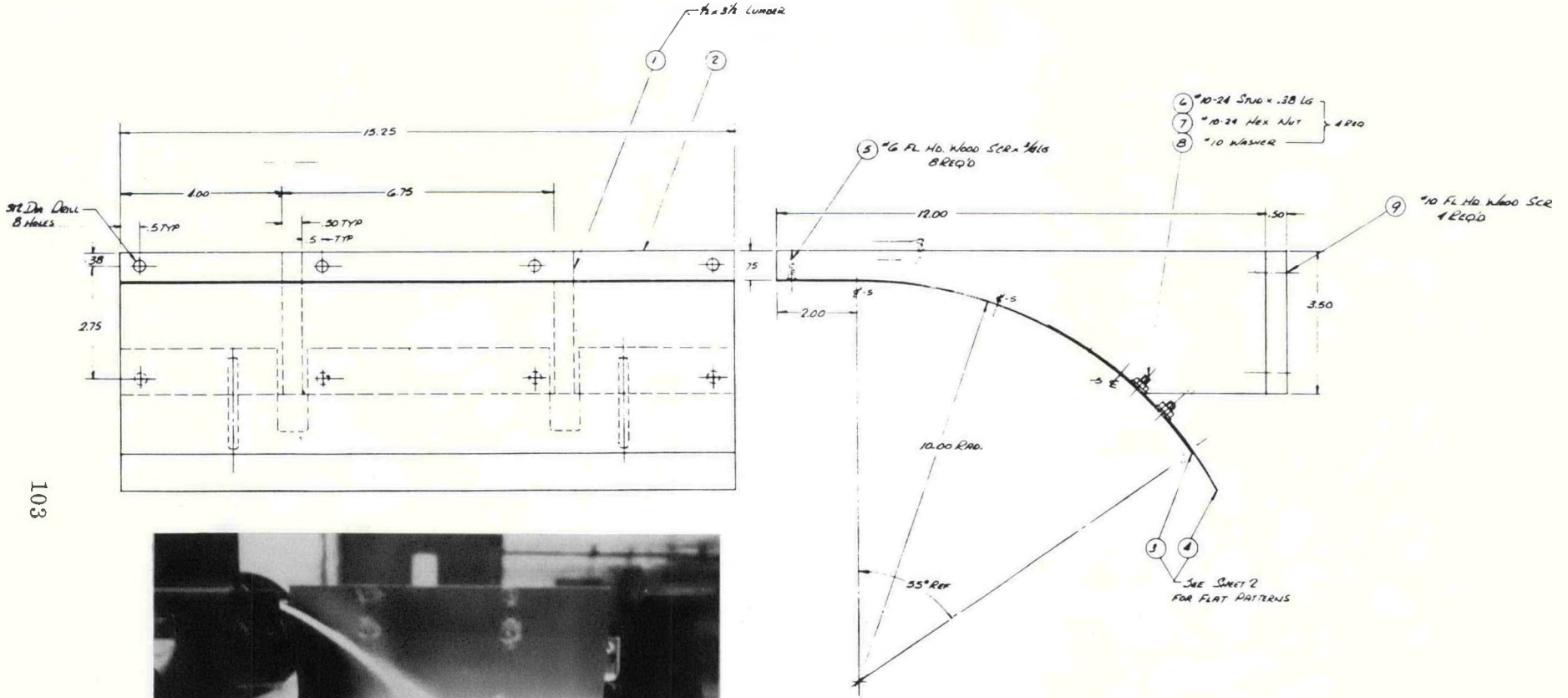


6" Dia. 8" Dia.



Installation, 6" Dia.

Figure 8-9. Zero Opening Angle Cone



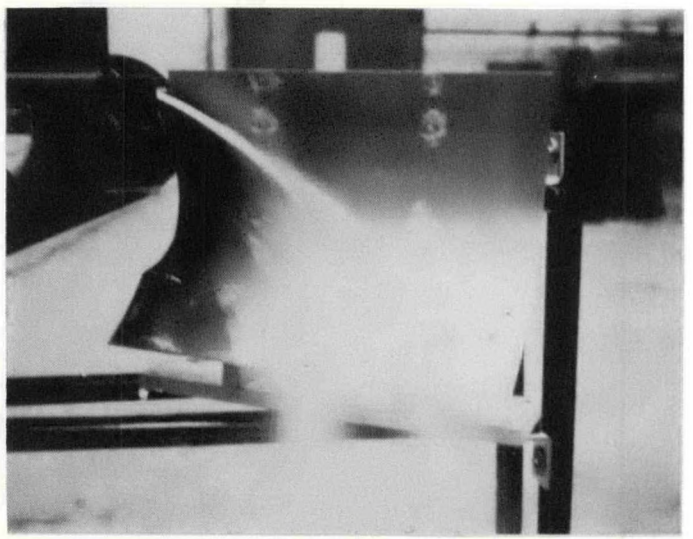


Figure 8-10. Quarter Cylinder Model, Single Surface

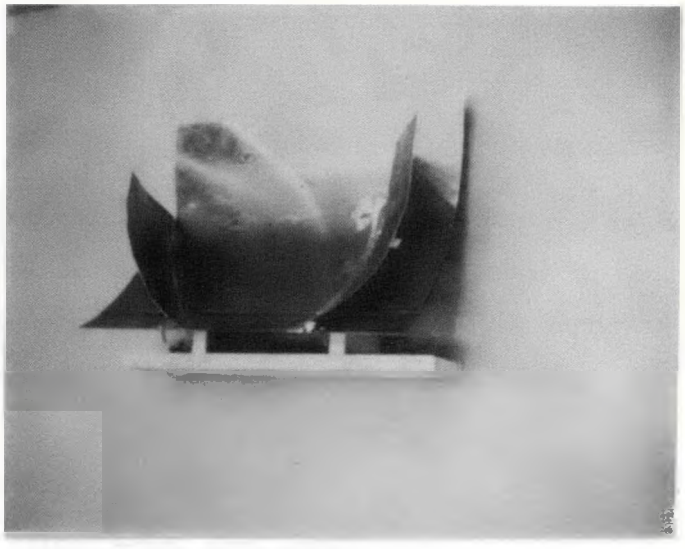
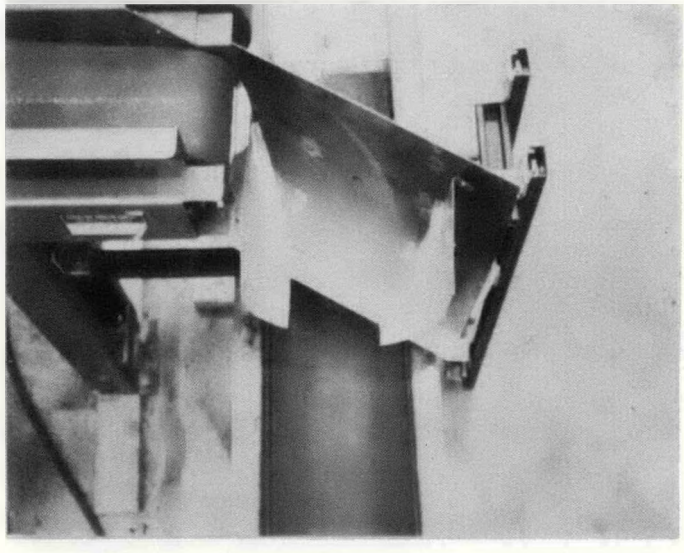


Figure 8-11. Compound Quarter Cylinder Model



iteratively during the initial conceptual stage. The first group involved a series of smooth toroidal surfaces, corresponding to sections cut from 90-degree welding elbows. The second group were similar in basic geometry, except that they were cut from 90-degree, "smoke pipe " elbows, or hot air ducts. The fabrication of the second group involved very informal methods, the purpose of these models being to determine whether significant departures in flow pattern occurred when a smooth toroidal surface is broken into series of intersecting cylinders.

8.3.1.3.1 Smooth Torus Configuration

Smooth torus configurations were constructed in 6 inch and 8 inch minor scale size diameters. The first set designed are shown in Figure 8-12. Their outboard wall, relative to the pulley side was found during testing to be cut too low. The length of the vertical curve along the major radius was similarly made too short.

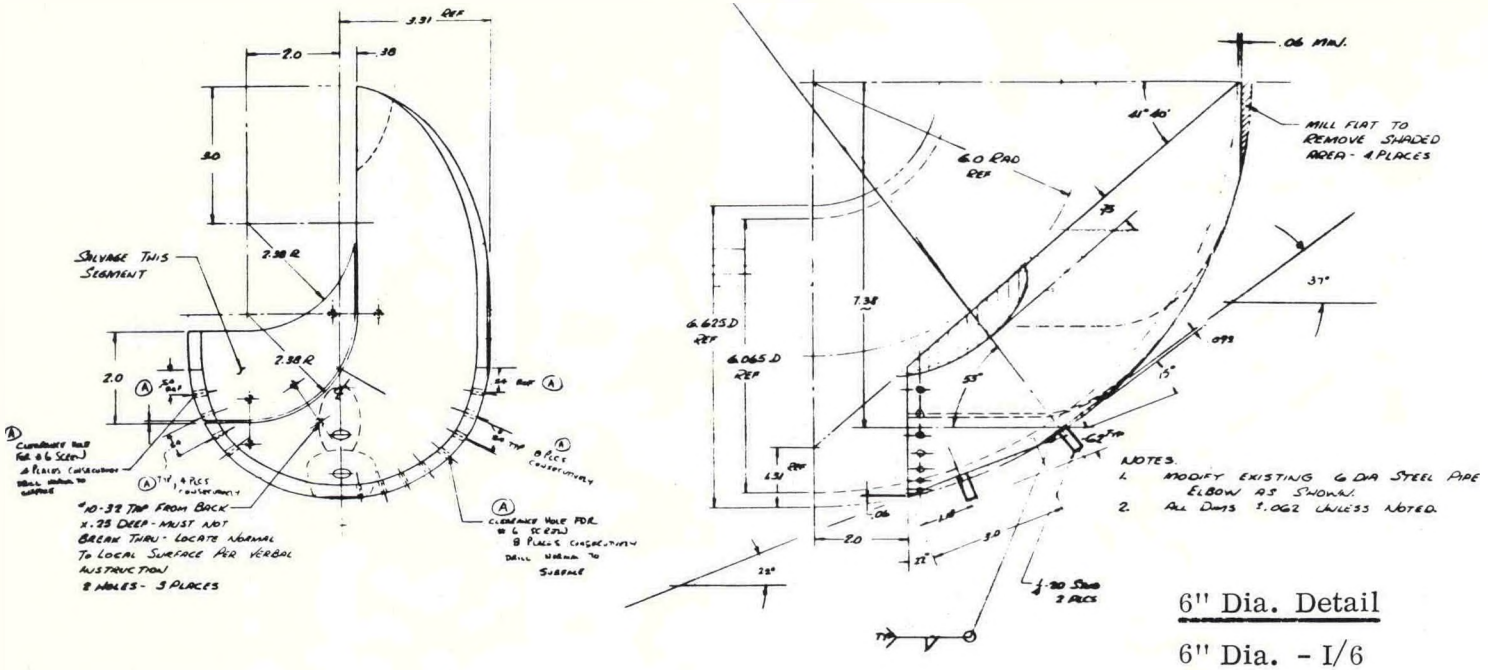
A second torus configuration was built to redeem the shortcomings of the first. Shown in Figure 8-13, it consisted of a much higher outboard wall; and its vertical curve length was extended by virtue of a two piece construction. The lower section was provided to guide the final flow vector leaving the end of the torus. The lower section is a rotatable attachment to the upper one, provided to realign the slot opening with the bottom of the first section as its roll position varies.

8.3.1.3.2 Smoke Pipe Torus Configurations

The smoke pipe torus configurations modelled involved various modifications of basic 90 degree, 4-section, hot air duct elbows. Although a number were investigated, the most typical ones are shown in Figure 8-14. They include modifications of both 6-inch and 8-inch minor diameters, where once again the variations involved pertain to the amount of outboard sidewall retained as well as to the length of the vertical curve.

8.3.2 Additional Torus Configuration Scale Models

Subsequent to selection of the torus shape as the preferred chute geometry, an additional design iteration was performed to define configurations suitable for 350 fpm



6" Dia. Detail

6" Dia. - I/6

8" Dia. - I/8

Figure 8-12. Torus Model I, 6" Dia.

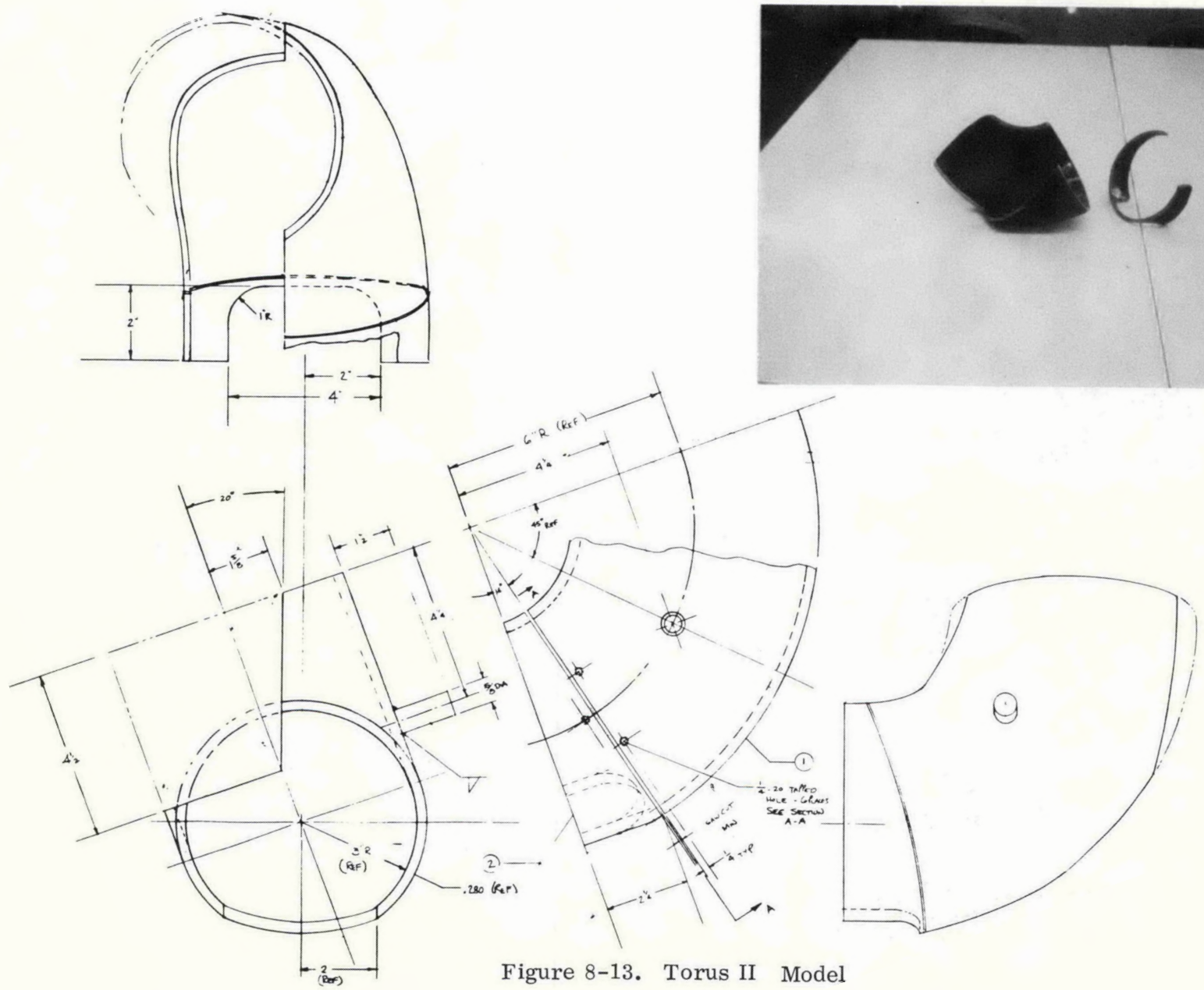
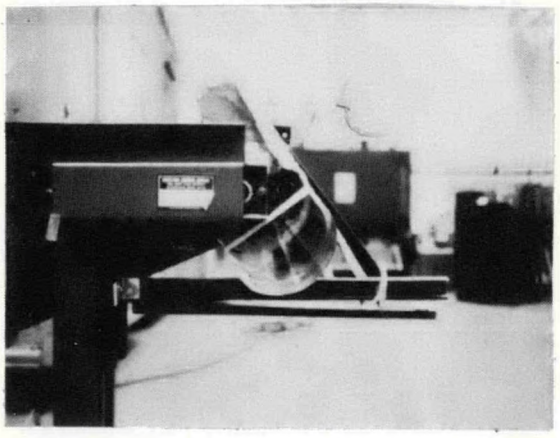
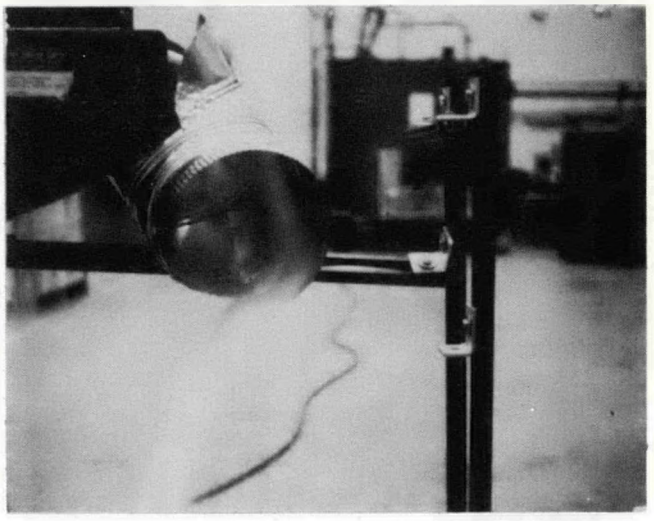


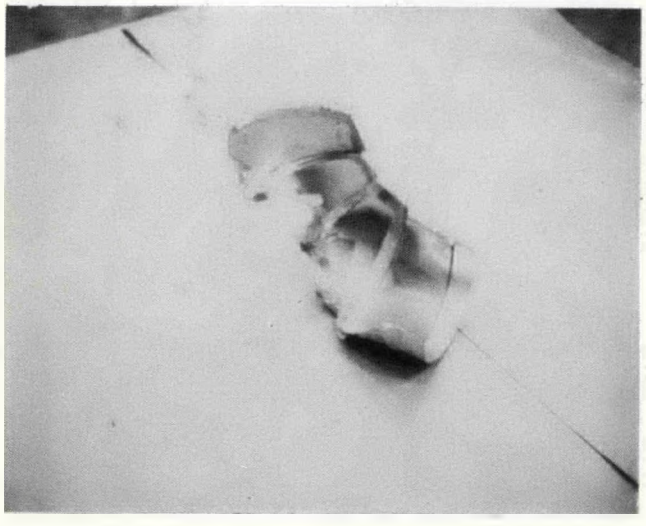
Figure 8-13. Torus II Model



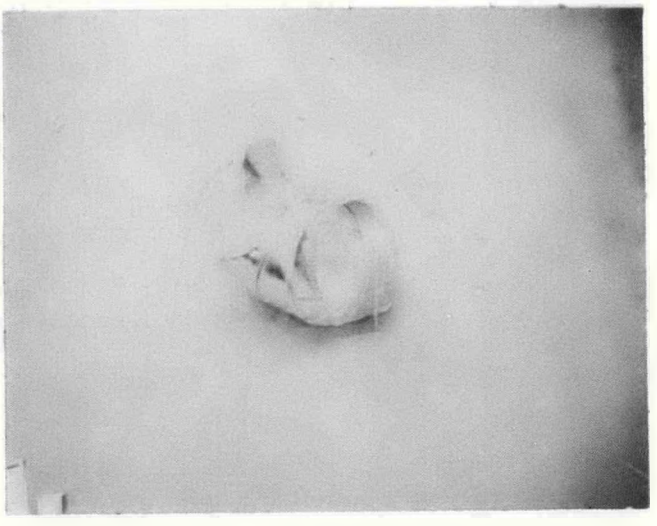
Installation: Run 126



Installation: Run 111

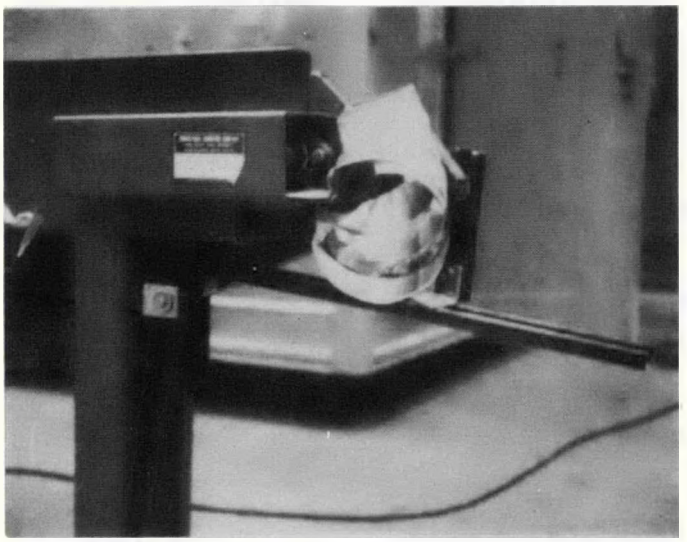


8" Minor Dia. High Configuration

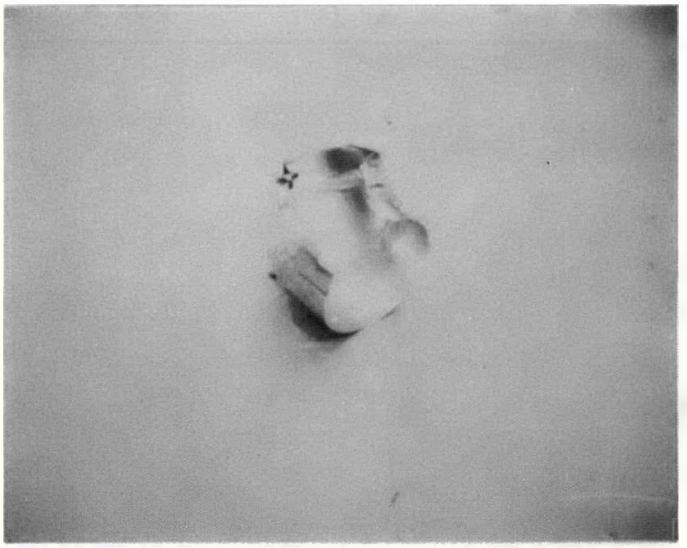


8" Minor Dia. Low Configuration

Figure 8-14a Smoke Pipe Torus Models - 8"



Installation: Run 131



6" Minor Dia.

Figure 8-14b Smoke Pipe Torus Model - 6"

and 450 fpm input flow velocities, as well as the 600 fpm figure used in the conceptual screening phase of the work. This resulted in the configuration shown in Figure 8-15, covering the specific 450 and 600 fpm cases and generally an approximate range between 400 to 600 fpm, for which the angle Θ of trajectory departure from the pulley surface is 0 degrees. In addition, the configuration for the 350 fpm case, covering up to about 400 fpm is shown in Figure 8-16. This last scale model is the one defined in the drawing depicted in Figure 8-13.

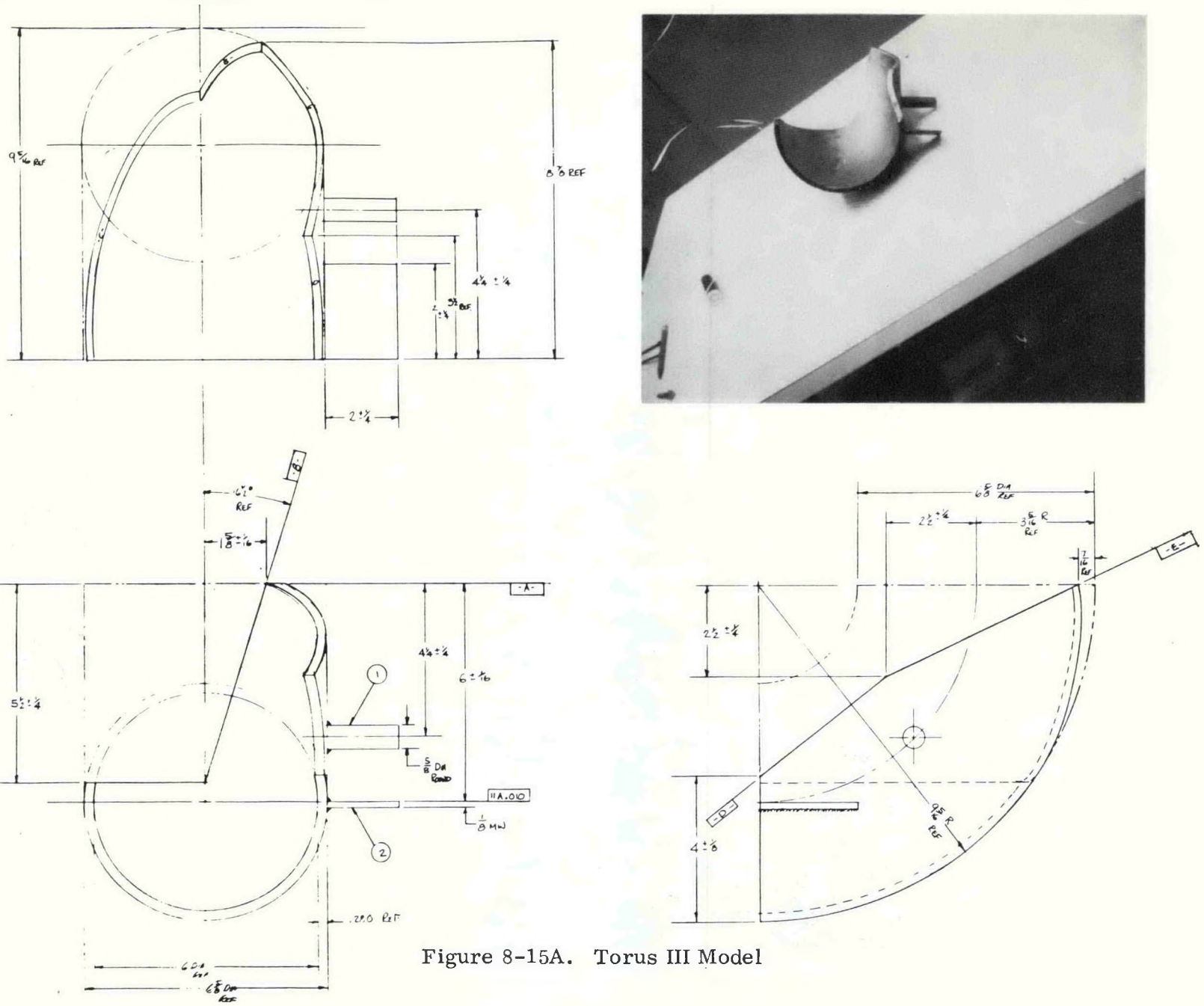


Figure 8-15A. Torus III Model

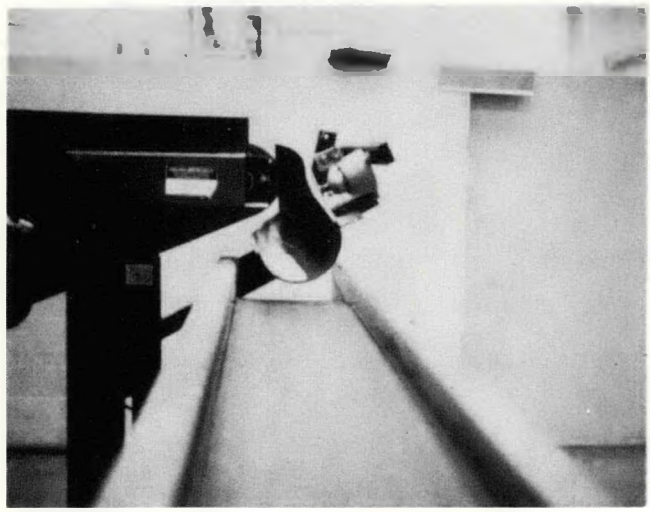


Figure 8-15C. Torus III Installation

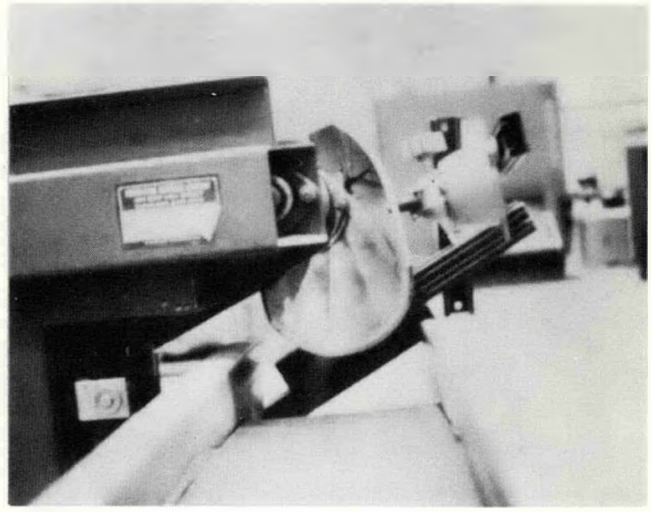


Figure 8-16. Torus I Installation for 350 FPM Feed

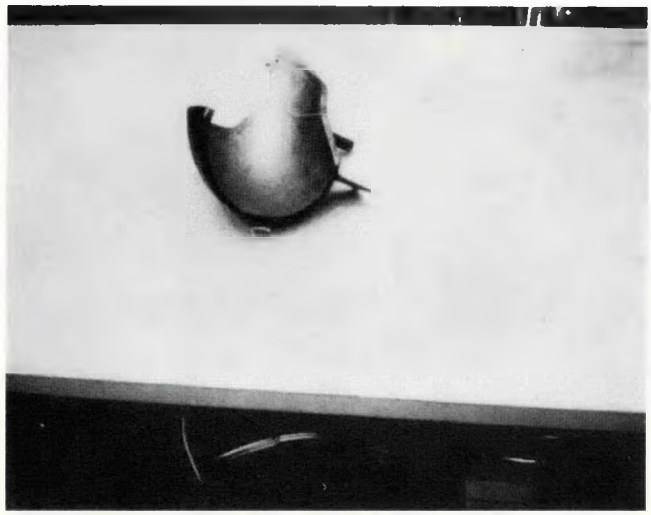


Figure 8-15B. Torus III Model

9.0 LABORATORY TESTING

9.1 FLOW MATERIALS UTILIZED

Flow materials utilized at different phases during scale model testing included primarily Ottawa sand,with occasional use of run-of-mine coal, including rock. Apart from the advantages of cleanliness and consistency of flow through the hopper test fixture, the Ottawa sand was the most useful material from the standpoint of tracing flow patterns --- particularly at the impact area.

Table 9-1 summarizes the data on the specific mixtures utilized in testing, in addition to the original Ottawa sand grade constituents of the mixes. The majority of testing was performed with the Code C mix. This contains four different Ottawa grades covering the range of about 15 available, wherein Flint Shot and F-140 are the coarsest and finest, respectively. This mix gives a well-proportioned profile of particle sizes.

Figure 9-1 shows some coal samples made available to FSEC during the

Table 9-1

Sand Mixtures Used in Scale Model Testing

Item	Description	Test Use Code	% Retained on (Sieve #)								Remarks
			30	40	50	70	140	200	270	Pan	
1	Flint Shot	A	30	65	5						Ottawa Std
2	Crystal	-	1	31	51	13	3	T			Ottawa Std
3	#17 Silica	-			45	29	13	4	1	T	Ottawa Std
4	F-140	-		T	2	8	36	31	12	11	Ottawa Std
5	Items 1&2	B	16	48	28	7	1	T			Equal Parts
6	Items 1, 2, 3, 4	C	8	26	26	12	13	9	4	2	Equal Parts

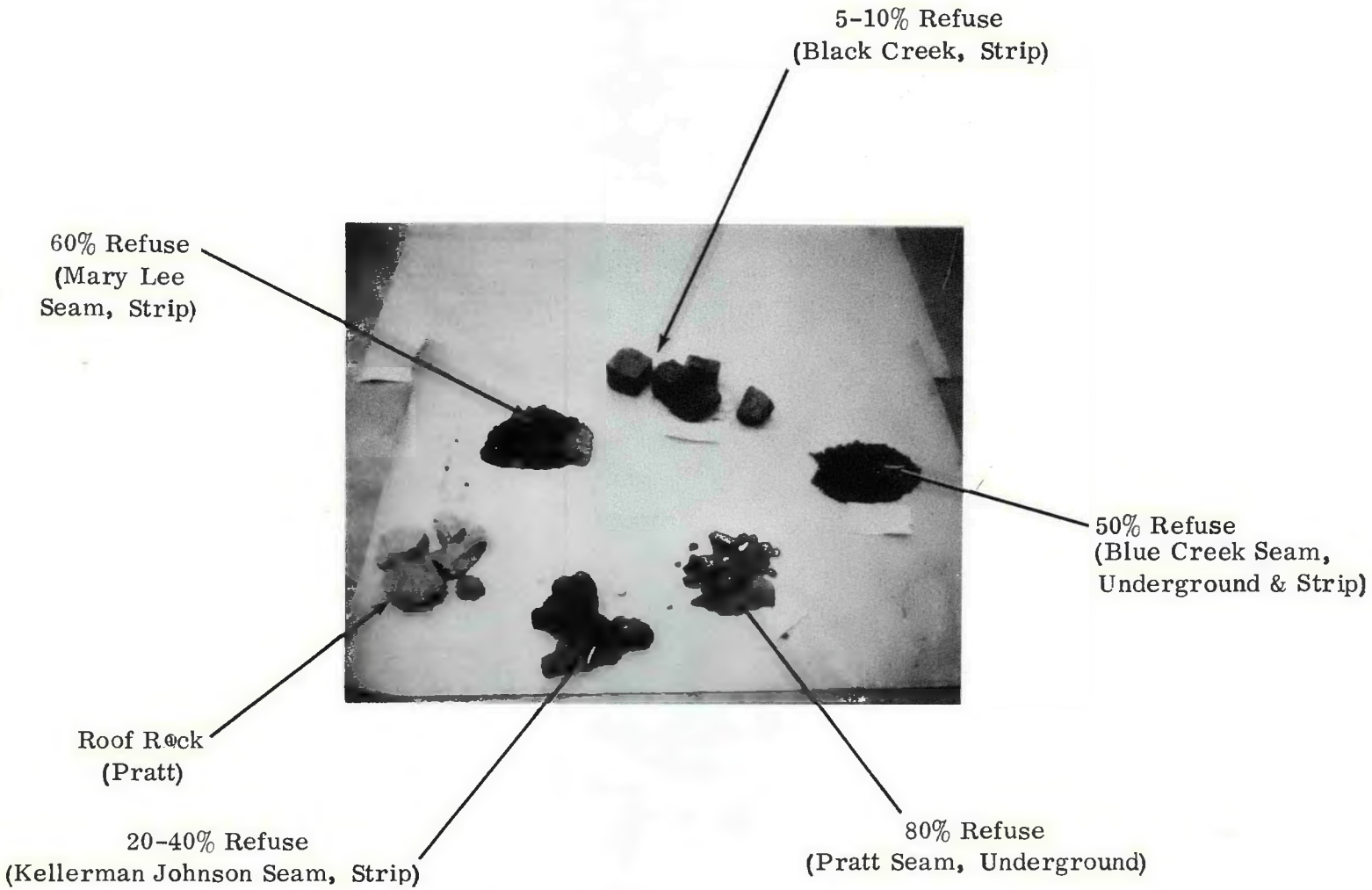


Figure 9-1. Run of Mine Coal Samples

study program. Informal lab testing was performed with a number of these; and the results, within the limitations of the method of feeding this coarse material, did not appear to deviate significantly from those for the sand flow pattern. Close hand observation of the coal frictional flow, because of the variation in particle size and the scale size used, was not an efficient method for parametric optimization of the chute performance; and on this account sand was the preferred test material for scale model testing.

Periodically during testing, roof rock (Figure 9-1) was introduced onto the feed belt (Figure 9-7), to verify chute clearance with the head pulley.

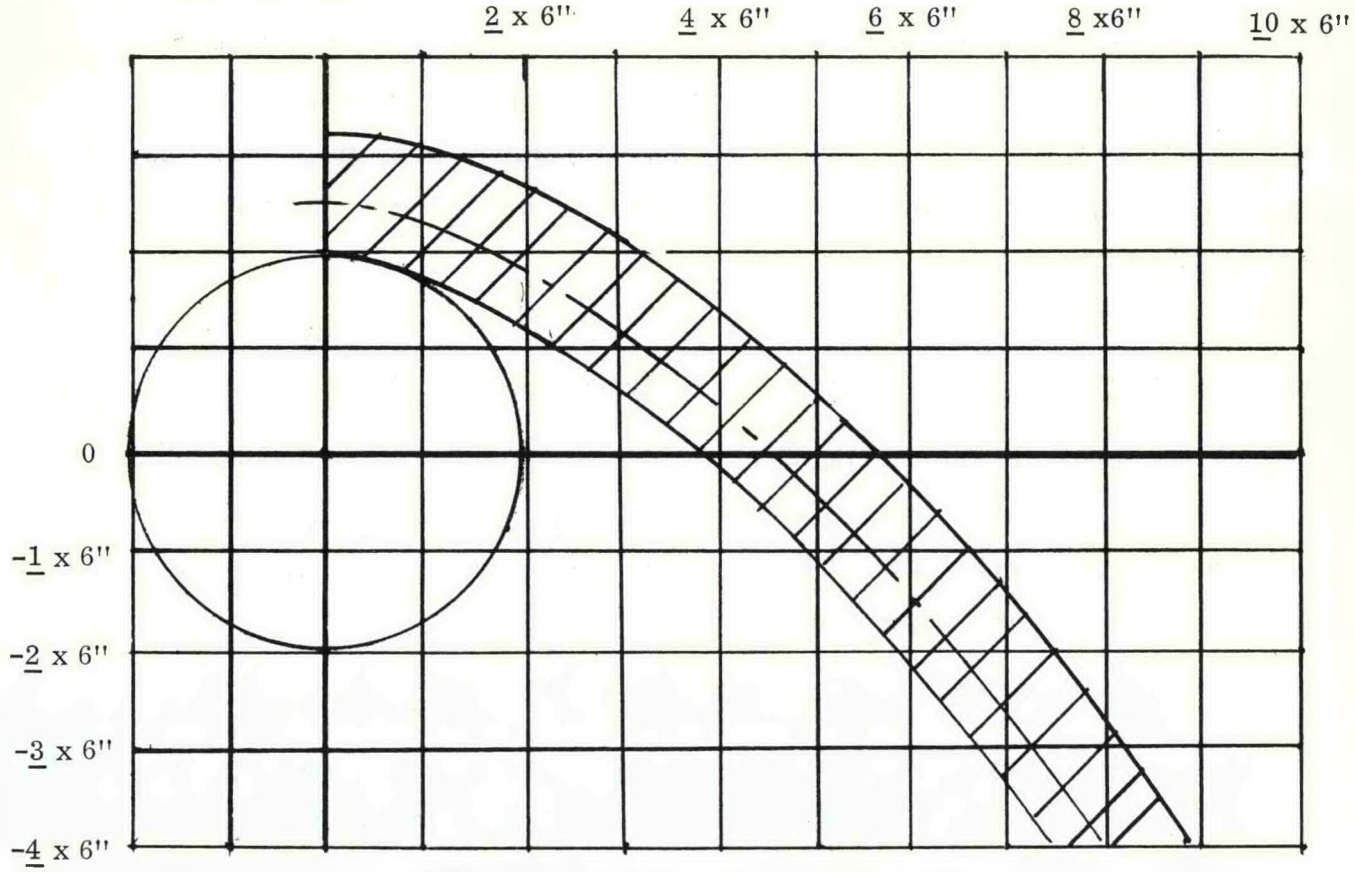
At the beginning of the laboratory testing program, a confirming comparison was made between the CEMA trajectory theory (5.1.2) and the velocity scale down theory (8.1.1). As shown in Figure 9-2, very good agreement was found between the two trajectory shapes.

9.2 INITIAL LAB TESTING OF DEVELOPMENT CONCEPTS

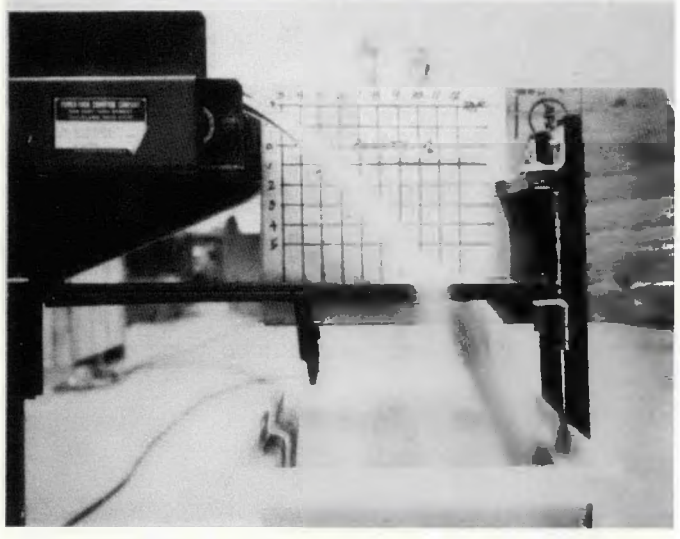
Laboratory scale model testing results constituted a major criterion in screening of initial chute configuration concepts, which is covered in Appendix G. This section covers the details of the test results. The test run data are provided in the form of tables and in photos referenced to the run numbers.

9.2.1 Cone Model Tests

The tests of the various cone configuration are summarized in Table 9-2, and in Figures 9-3 to 9-11. The overriding disadvantage with the opening angle cone configurations was inherent divergence of flow during descent (Runs 201-206). Although repositioning of the cone relative to the free fall trajectory made it possible to prevent the impact split, the divergence problem could not be resolved. (Next text page: 9-9).



600 FPM Trajectory (CEMA Theory)



246 FPM Test Trajectory (1/6 Scale)

Figure 9-2. Correlation Between Theoretical and Test Trajectory Shapes

TABLE 9-2

SCALE MODEL TEST RESULTS FOR CONE CHUTE CONFIGURATIONS

Run No.	Chute Config.		Flow Material	Locating Coord*			Y Min. In.	$\mathcal{L}_L$ Attitude			Deviation From 90° Turn	Remarks		
	Half Angle	Other Features		X In.	Y In.	Z In.		Roll o	Pitch o	Yaw o		Figure No.	Cohesion	Spillage
201	15°	Flat Impact Pl.	Sand - A**	4.8	1.6	0	-	0	25.5	0	20	9-3	Impact Split	Considerable Scatter
201A	15°	Flat Impact Pl.	ROM ***	4.8	1.6	0	-	0	25.5	0	20	9-4	Poor	Major Scatter
202	15°	No Impact Pl.	Sand - A	4	0.3	0	-	0	25	0	20	9-5	Impact Split	Slight Improvement
203	15°	No Impact Pl.	Sand - A	3.5	0.3	0	-	0	25	0	20	-	Divergence	No Change
204	15°	No Impact Pl.	Sand - A	3.5	0.3	0	-	0	25	11.5	0-5°	9-6	Improved	Some Scatter
205	15°	No Impact Pl.	Rock	3.5	0.3	0	-	0	25	11.5	0-5°	9-7, 8	-	None
206	15°	No Impact Pl.	Coal	3.5	0.3	0	-	0	25	11.5	-	9-9	Poor	Major Scatter
151	0	8" Dia. (Cyl.)	Sand - C	-1.9	6.2	2.4	-7.5	37.5	22.5	27	0	9-10	Good	-
152	0	6" Dia. (Cyl.)	Sand - C	-1.2	6.2	1.8	-7.0	44	30	23	0	9-11	Good	-

*$\mathcal{L}_L$ at top end, Runs 201-206
Aft outboard corner, Runs 211, 212
**See Mix Description, Table 9-1
*** Mary Lee, Figure 1

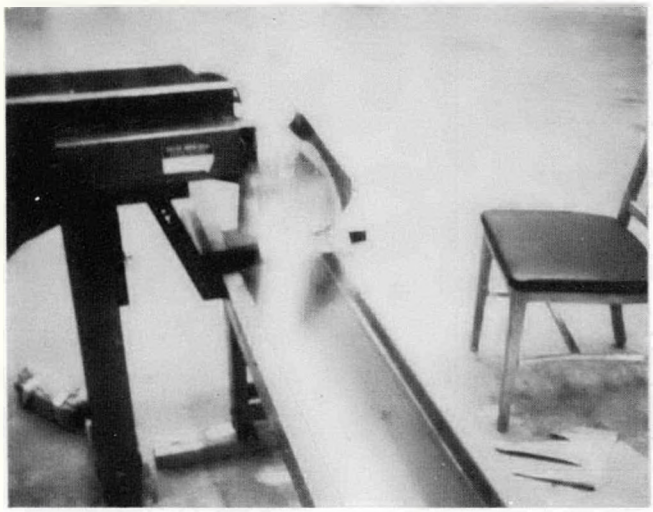


Figure 9-3. Run 201

Figure 9-4. Run 201A

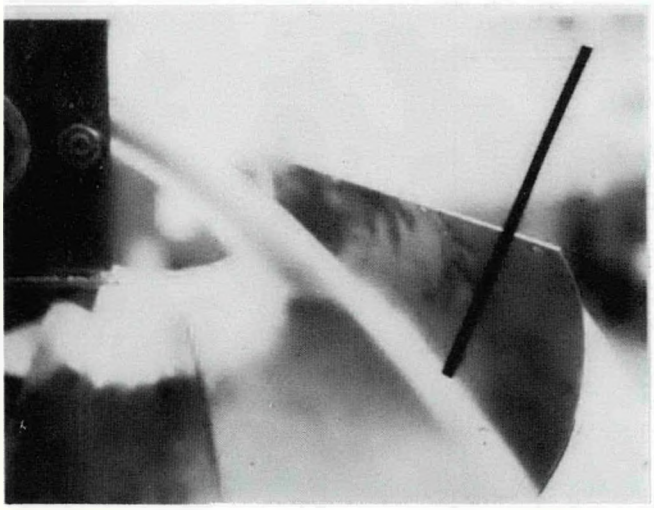


Figure 9-5. Run 202

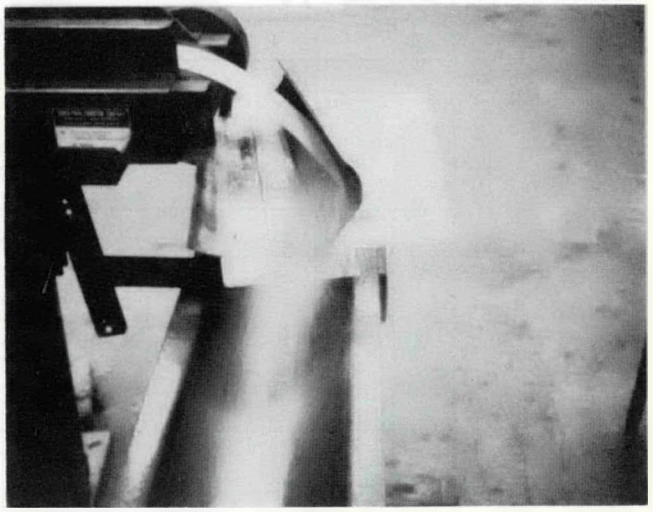


Figure 9-6. Run 204

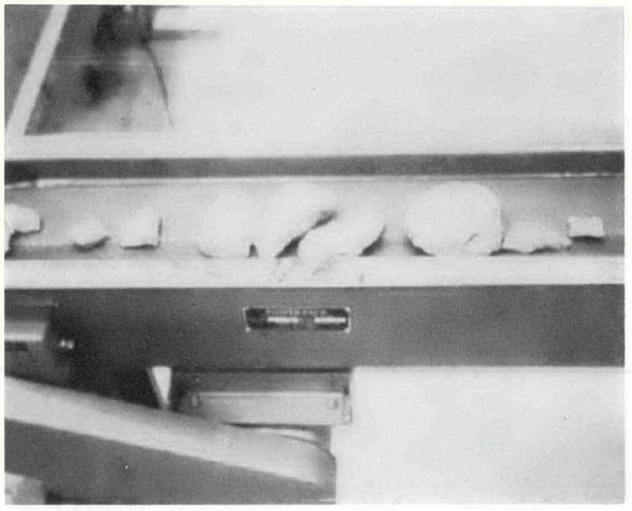


Figure 9-7. Run 205

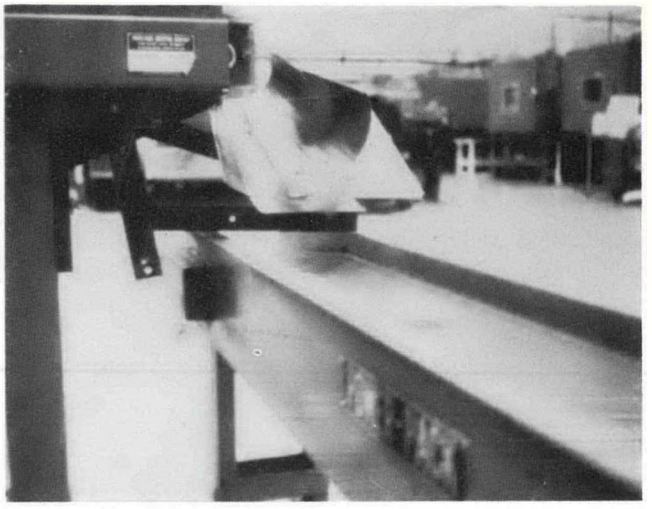


Figure 9-8. Run 205

Figure 9-9. Run 206

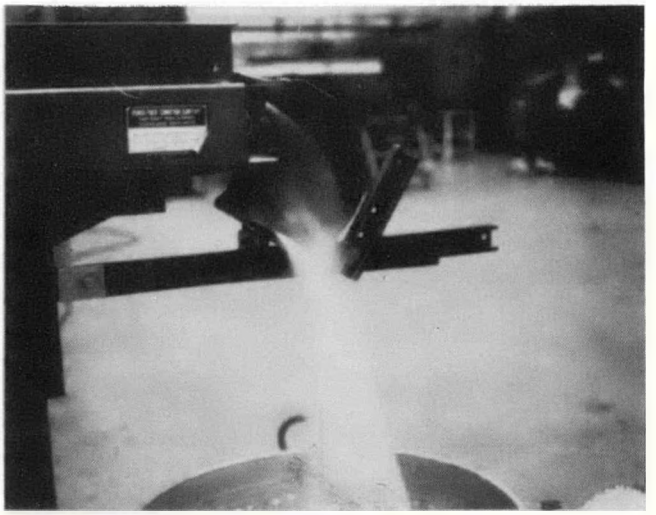


Figure 9-10. Run 151

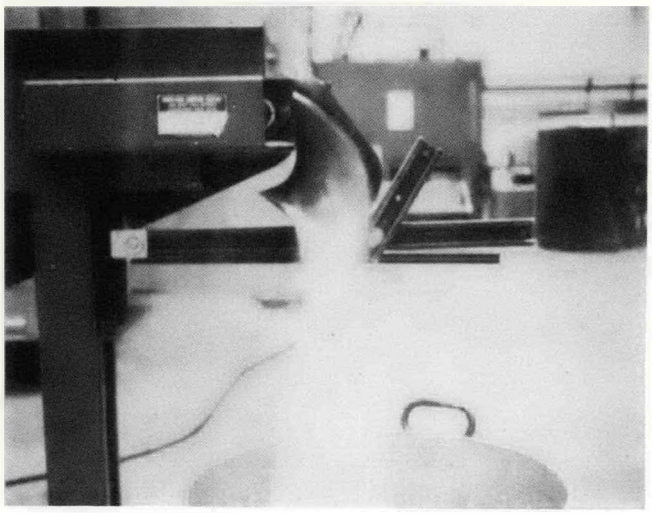


Figure 9-11. Run 152

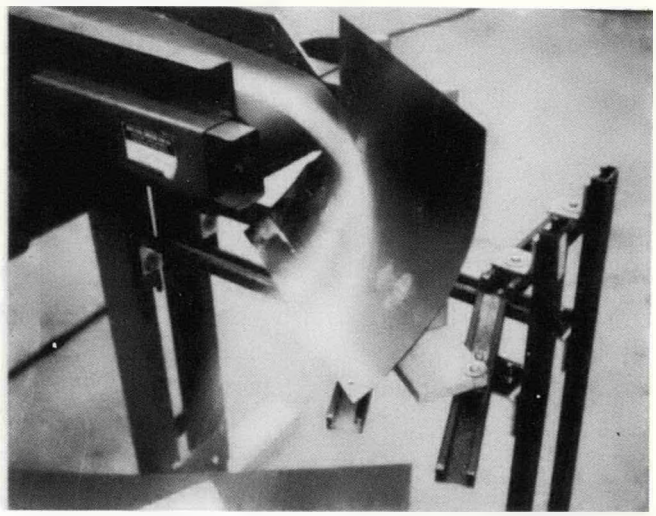


Figure 9-12. Run 1

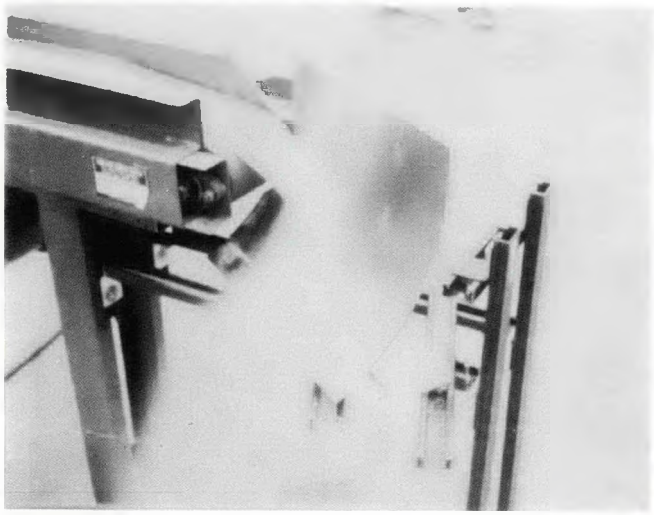


Figure 9-13. Run 3

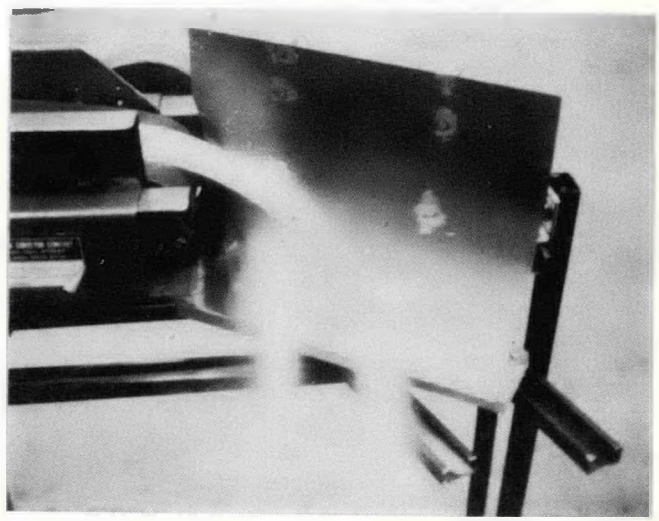


Figure 9-14. Run 4

This consideration led to the origin of the so-called "zero opening angle" cone, wherein the divergence was inherently eliminated. An unforeseen characteristic of this configuration, however, was the need for moving it too close to the head pulley, in order to provide a smooth (non-forking) impact condition (Runs 151, 152).

9.2.2 Cylinder Model Tests

Tables 9-3 and Figures 9-12 to 9-25 summarize the results of tests on the cylindrical configurations. The first tests, 1-8, were devoted to attainment of the optimum yaw angle of the cylinder axis with the input direction of flow, relative to achieving a 90^{o} turn. This angle was found to be about 30 degrees.

The single surface cylinder (Test Runs 1 to 8) exhibited scatter, due partly to the absence of side constraints, but basically due to the constantly changing angle of impact of the free fall trajectory, at different points across the flow mass width. This resulted in a characteristic forking of the stream into two parts, or at least into a generalized fan pattern. Testing of the chute model at a variety of height positions relative to the feed conveyor yielded the same result. Control of the spillage feature of this forking phenomenon was attempted by the side walls provided in the compound cylinder configuration (Runs 9 to 13). While this attempt was successful, it was still apparent that the forking, which still persisted, corresponded to an undesirable, dust-producing turbulence in a full scale configuration.

In a final search for a non-forking impact flow, cylindrical radii tighter than the 10 inch one used in the above tests were tried. These included 6 and 8 inch radii (Runs 21 - 25).

9.2.3. Initial Torus Configuration Tests

The early torus chute tests are detailed in Table 9-4 and in Figures 9-27 to 9-50. (Next text page: 9-22).

TABLE 9-3

SCALE MODEL TEST RESULTS FOR CYLINDRICAL CHUTE CONFIGURATIONS

Run No.	Chute Config.			Flow Material	Height, Horiz. Cylindrical Axis Above Belt	Y Min.	℄ Attitude			Deviation From 90° Turn	Remarks		
	Cylind. Descr.	Rad (In.)	Arc o				Roll o	Pitch o	Yaw o		Figure No.	Cohesion	Spillage
1	Plain	10"	64	Sand A	1.75	-7.2	0	0	38	15°	9-12	Sharp* Impact Fork	Scatter
2	Plain	10"	56	Sand A	1.75	-6.6	0	0	38	0-5	-	Sharp* Impact Fork	Scatter
3	Plain	10"	56	Sand A	1.75	-6.6	0	0	31	5°	9-13	Sharp* Impact Fork	Scatter
4	Plain	10"	64	Sand A	1.75	-7.2	0	0	31	5°	9-14	Sharp* Impact Fork	Scatter
5	Plain	10"	56	Sand A	0.12	-8.2	0	0	31	0°	9-15	Sharp* Impact Fork	Scatter
6	Plain	10"	56	Sand A	-1.31	-9.6	0	0	31	0°	9-16	Sharp* Impact Fork	Scatter
7	Plain	10"	56	Sand A	-4.31	-12.6	0	0	31	0°	9-17	Sharp* Impact Fork	Scatter
8	Plain	10"	56	ROM	-1.19	-9.5	0	0	30	0°	9-18	Less Pronounced Fork	Scatter
9	Compound	10"	64	Sand A	-1.0	-10.0	0	0	30	0°	9-19	Fork Recombined on Belt	Controlled
10	Compound	10"	64	ROM	-1.0	-10.0	0	0	30	0°	9-20	Not Visible	Dusting
11	Compound	10"	64	Sand A	1.0	-8.0	0	0	30	0°	9-21	Fork Maintained	None

* Trajectory Impacts into Frictional Flow Path

TABLE 9-3 (Continued)

SCALE MODEL TEST RESULTS FOR CYLINDRICAL CHUTE CONFIGURATIONS

Run No.	Chute Config.			Flow Material	Height, Horiz. Cylindrical Axis Above Belt	Y Min.	℄ Attitude			Deviation From 90° Turn	Remarks		
	Cylind. Descr.	Rad (In.)	Arc o				Roll o	Pitch o	Yaw o		Figure No.	Cohesion	Spillage
12	Compound	10"	64	Rock	2.0	-7.0	0°	0°	30°	0°	9-22	-	None
13	Compound	10"	64	Sand A	2.0	-7.0	0°	0°	30°	0°	9-23	Fork	Controlled
21	Plain	6"	90	Sand A	2.25	-7.8	0°	0°	30°	0°	-	Fork	Scatter
22	Plain	6"	90	Sand A	4.0	-6	0°	0°	30°	0°	9-24	Fan-Out	Scatter
23	Plain	6"	90	Sand A	-1.0	-11	0°	0°	30°	0°	9-25	Fan-Out	Scatter
24	Plain	8"	90	Sand A	-1.0	-11	0°	0°	30°	0°	-	Fan-Out	Scatter
25	Plain	8"	90	Sand A	3.62	-6.8	0°	0°	30°	0°	9-26	Fork	Scatter

Table 9-4

Scale Model Test Results for Initial Torus Chute Configurations

Run #	Chute Config.	Flow Material	Locating Coord*			Y min	Attitude			Dev. from 90° Turn	Fig#	Remarks	
			X in	Y in	Z in	in	Roll °	Pitch °	Yaw °	°		Cohesion	Other
101	Torus I/6	Sand-A	-	-	-	-	30	0	0	30	9-27	Impact Break	Outboard Scatter
102	Torus I/6	"	-	-	-	-	42	0	0	30	9-28	"	"
103	Torus I/8	"	-	-	-	-	45	0	0	0 avg	9-29	Impact Fork	Diverge
104	"	"	-	-	-	-	45	0	0	10 avg	9-30	"	"
105	Torus I/6*	"	-	-	-	-	30	0	0	0 avg	9-31	"	"
106	Torus I/8*	Sand-A	-	-	-	-	30	0	0	10 avg	9-32	"	"
111	S/P I/8	Sand-B	3	-3.2	3.6	-	30	24.5	28	20	9-33	No Impact Split	Too tight
112	S/P II/8	"	5	-4	0	-	5	15	5	0	9-34, 35	Impact Fork	Clear OK
113	"	"	6	-5.4	5.1	-	10	23	9	0	-	"	Scatter
114	"	"	6.5	-4.2	4.2	-	0	30	20	30	9-36	Major Fork	Broad Scatter
115	"	"	4.8	-5.1	5	-	14	25	15	15	9-37	Smaller Fork	Some Scatter
116	"	"	4.8	-4.9	5.4	-	12.5	29	11	5°	9-38	Large Fork	Scatter
117	"	"	5.4	-4.5	5.4	-	5.5	30.5	10	25°	9-39	Minor Fork	Right Scatter

** Output side constraints added **

* To outboard edge of upper circle for Runs 111-126, See Fig. 9-34.

Table 9-4 continued

Scale Model Test Results for Initial Torus Chute Configurations

Run #	Chute Config.	Flow Material	Locating Coord* X in	Y in	Z in	Y min in	Attitude Roll o	Pitch o	Yaw o	Dev. From 90° Turn o	Fig. #	Remarks Cohesion	Other
118	S/P II/8	Sand-C	5.4	-4.5	5.4	—	5.5	30.5	10°	25	—	Neg. 1 Fork	
119	↑	↑	5.4	-4.5	5.4	—	5.5	27	10	5	9-40	Same Fork	
120			5.4	-4.5	5.4	—	5.5	30	10	5	9-41	No Fork	1" extra added
121			5.4	-4.5	5.4	—	5.5	27	10	0	9-42, 43	Slight Fork	2" extra added
122			3.6	-6.7	4.4	—	5.5	25.5	12	0	9-44	Fork	
123			7	-6.7	4.1	—	0	26.5	22	0 avg.	9-45	Major Fork	Scatter
124			1	-7.8	4.2	—	25.5	22	23	0	9-46	Definite Fork	Good Reconverg.
125	↓		-0.5	-7.9	5	-6.5	40.5	38	8	10	9-47	No Fork	Poor turn
126	S/P II/8	↓	-0.5	-7.9	5	-7.0	40.5	38	8	0	9-48	No Fork	2" ext. added
131	S/P II/6	Sand-C	4.0*	-7.0*	4.5*	-6.5	20	20	10	0	9-49, 50	No Fork	2" ext. added

* To bottom of circle at lowest section prior to extension (Figure 9-50)

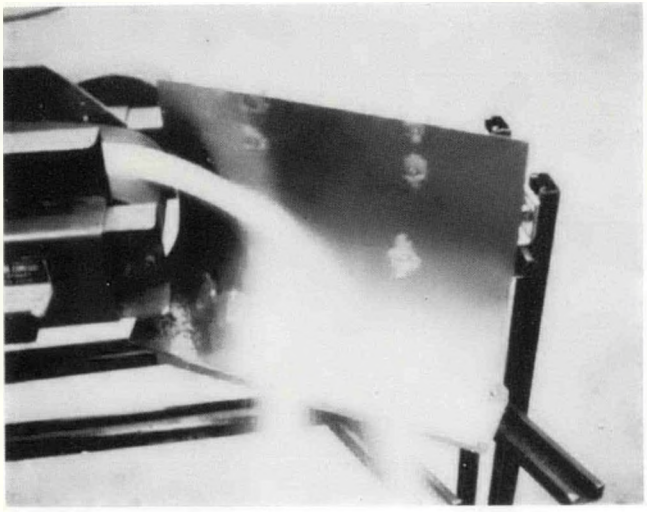


Figure 9-15. Run 5

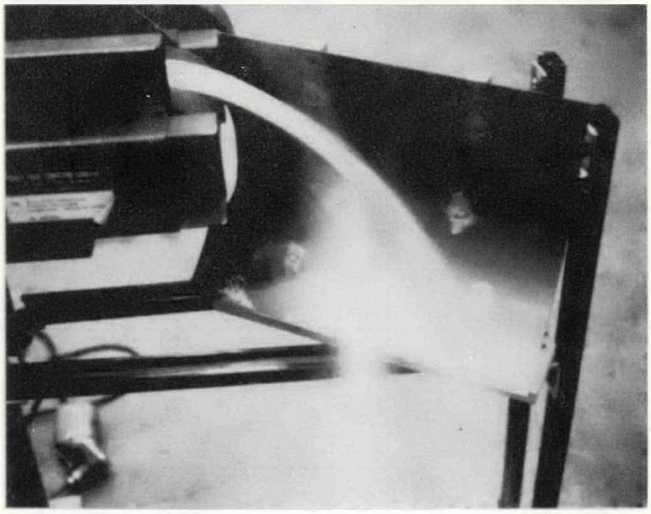


Figure 9-16. Run 6

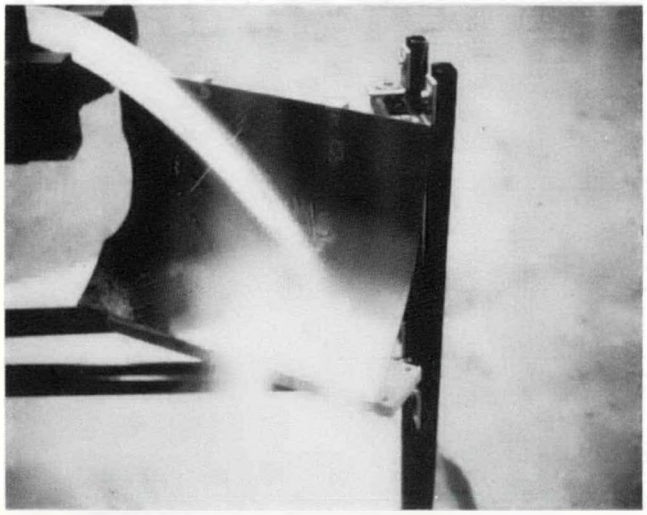


Figure 9-17. Run 7

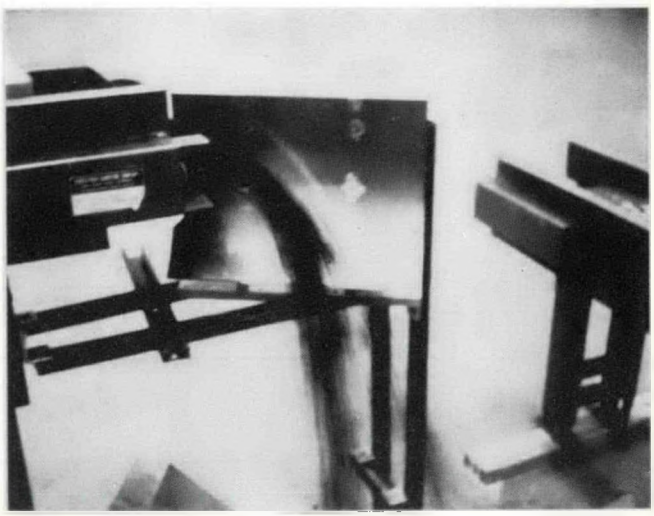


Figure 9-18. Run 8

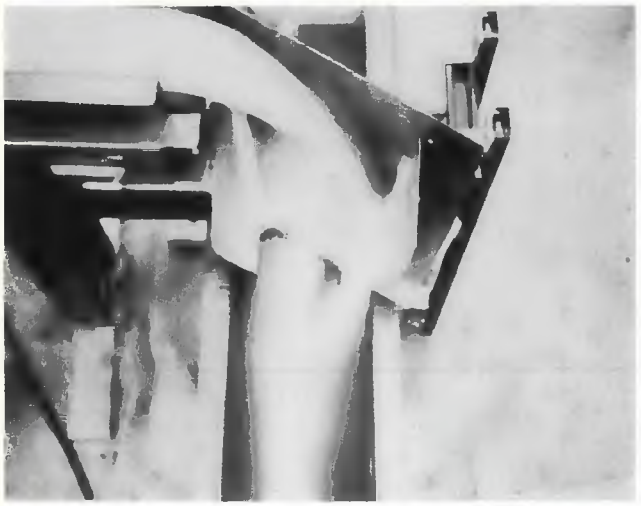


Figure 9-19. Run 9

Figure 9-20. Run 10

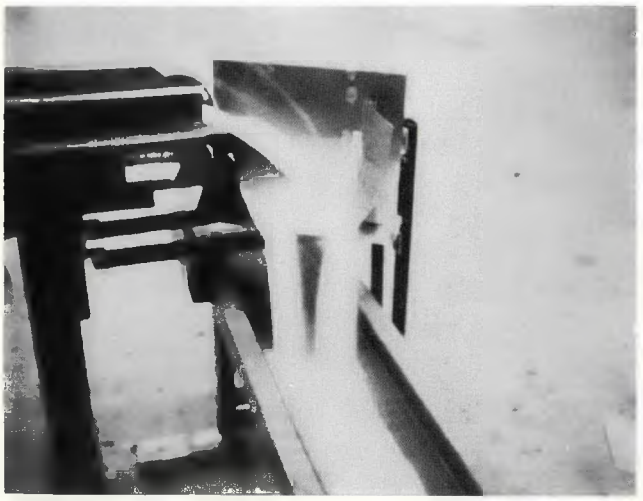


Figure 9-21. Run 11

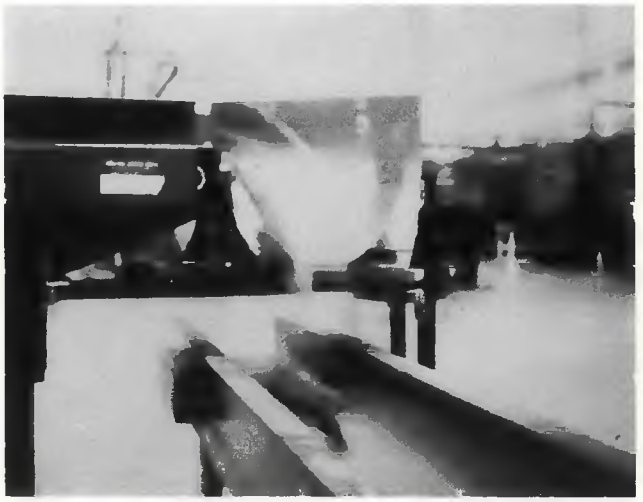


Figure 9-22. Run 12

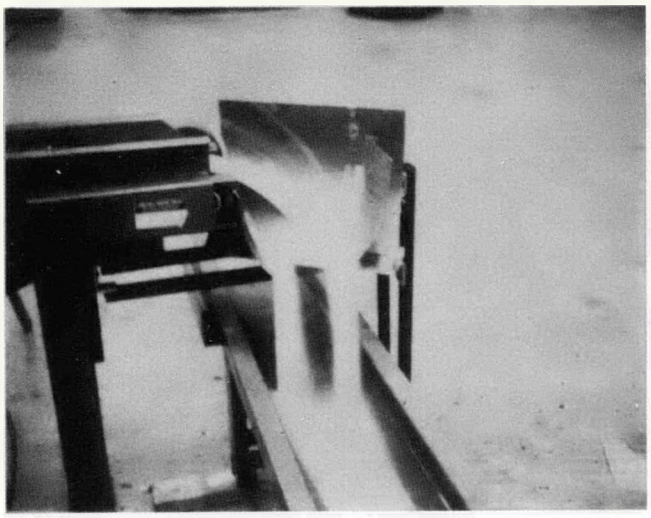


Figure 9-23. Run 13

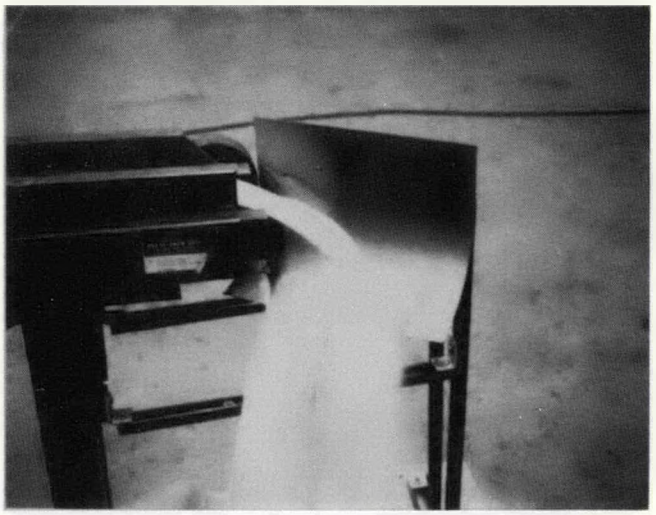


Figure 9-24. Run 22

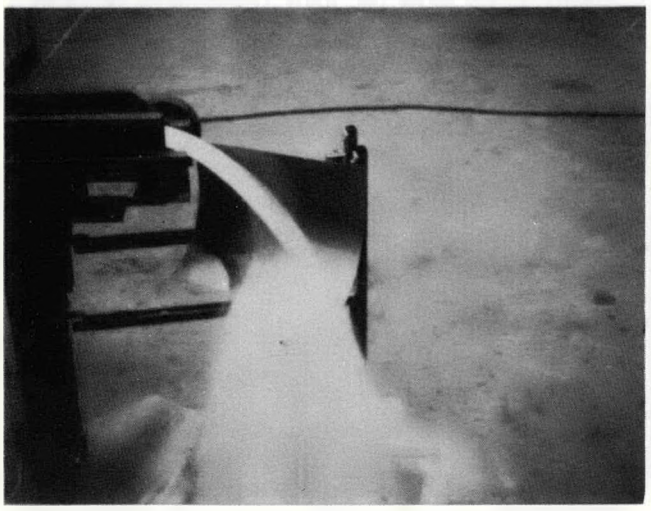


Figure 9-25. Run 23

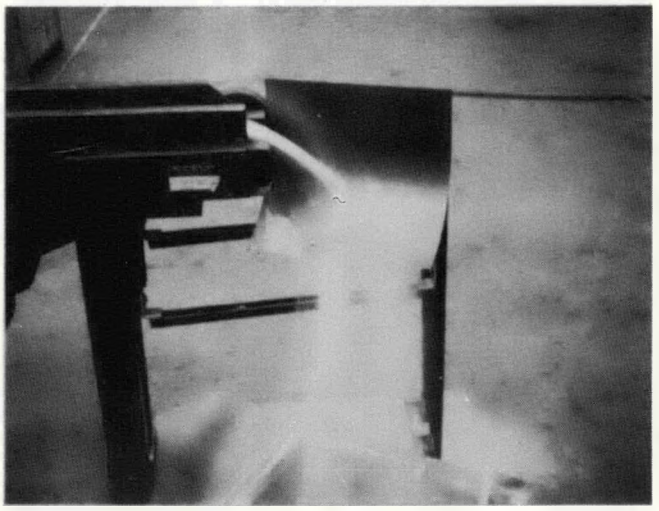


Figure 9-26. Run 25

Figure 9-27. Run 101

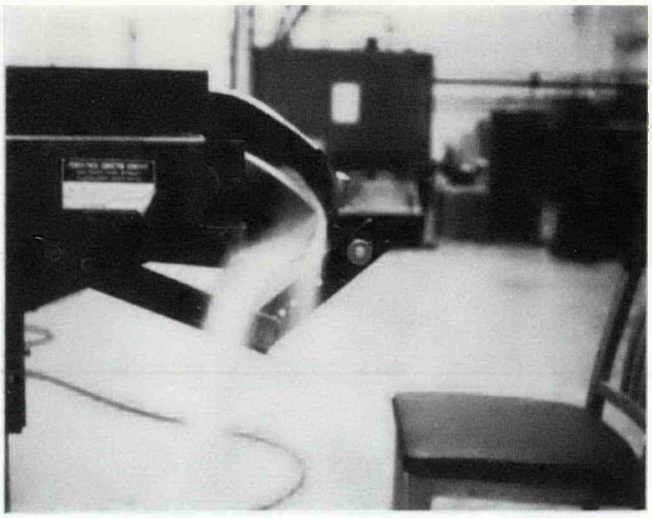


Figure 9-28. Run 102

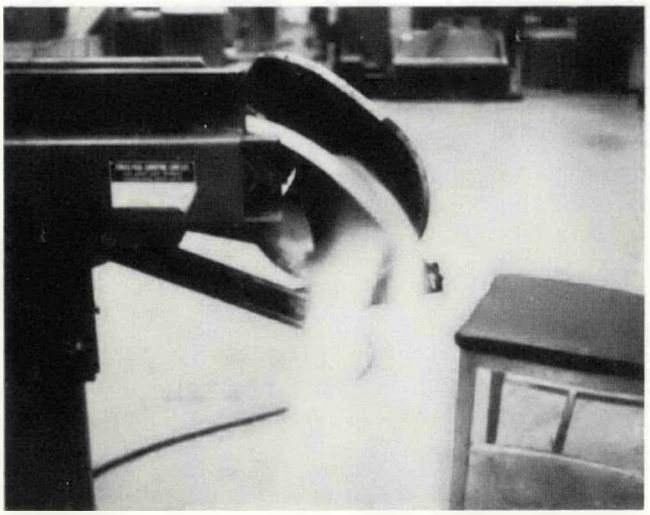


Figure 9-29. Run 103

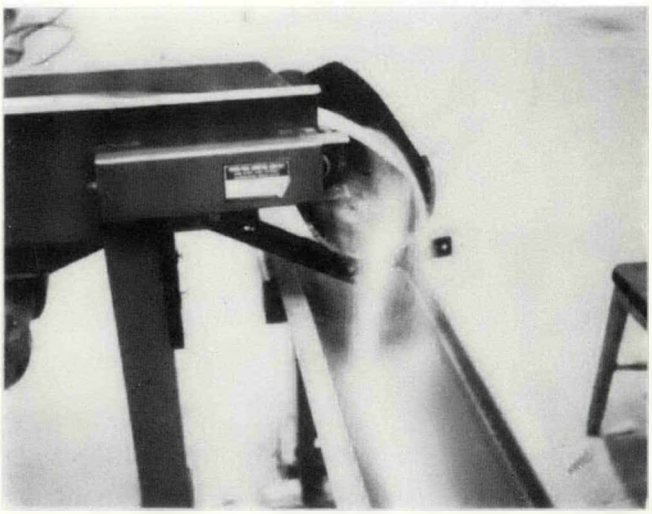


Figure 9-30. Run 104

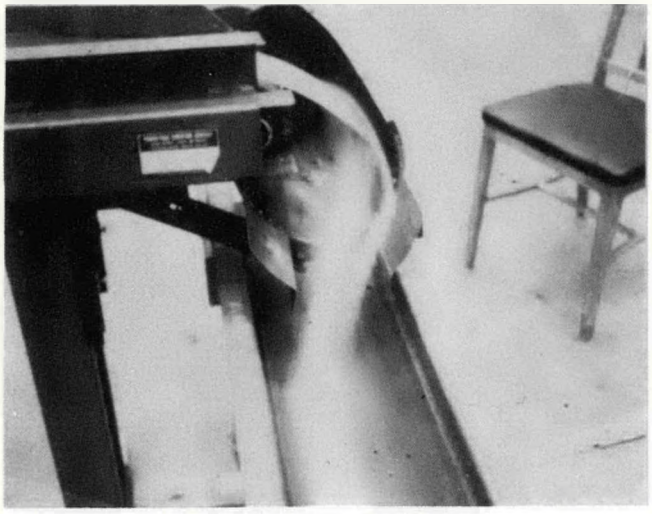


Figure 9-31. Run 105

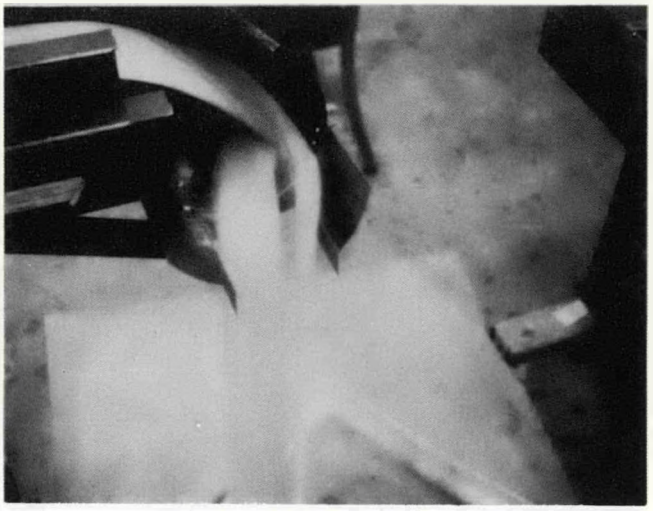


Figure 9-32. Run 106

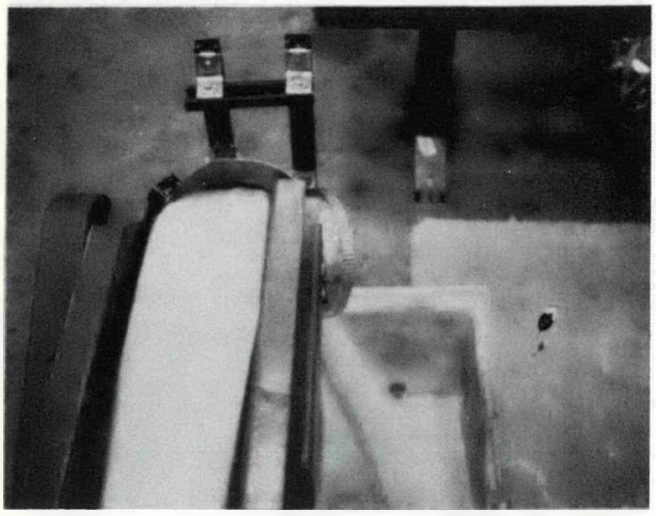


Figure 9-33. Run 107

Figure 9-34. Run 111

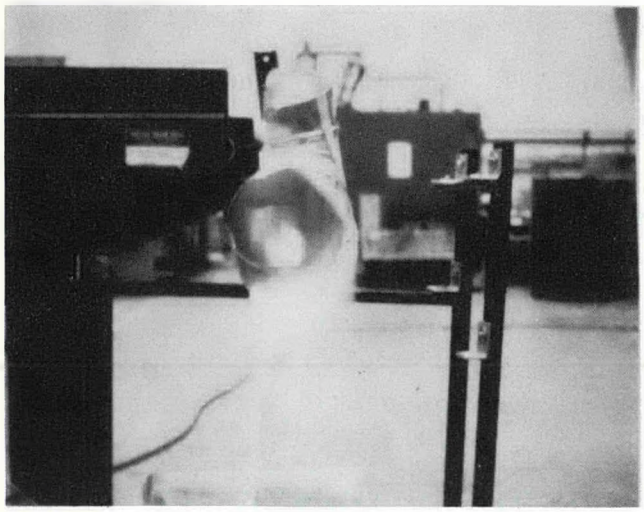


Figure 9-35. Run 112

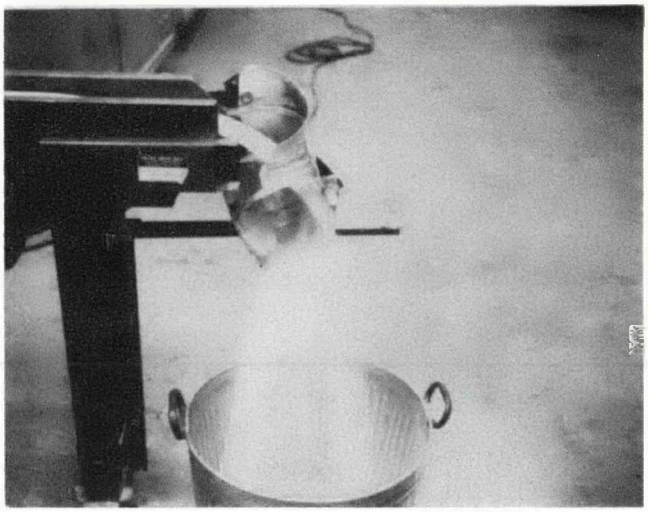


Figure 9-36. Run 114

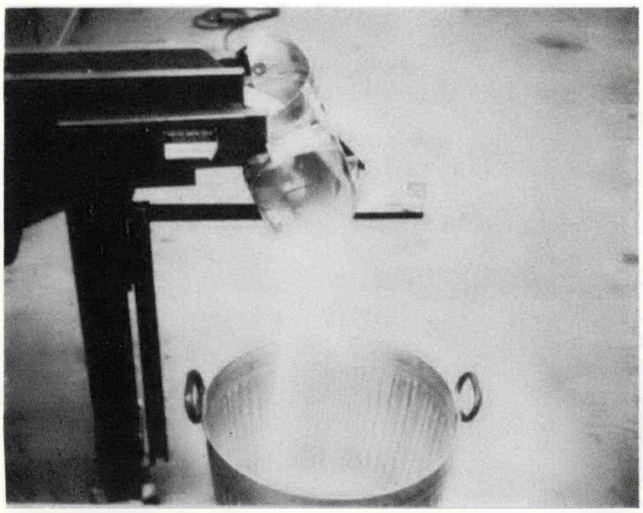


Figure 9-37. Run 115

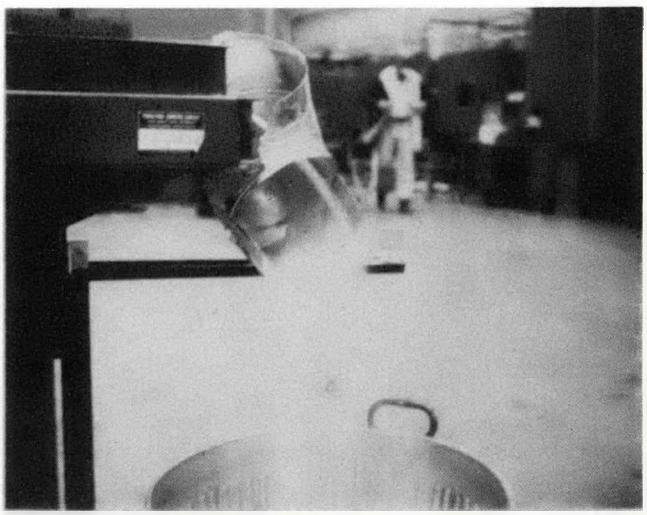


Figure 9-38. Run 116

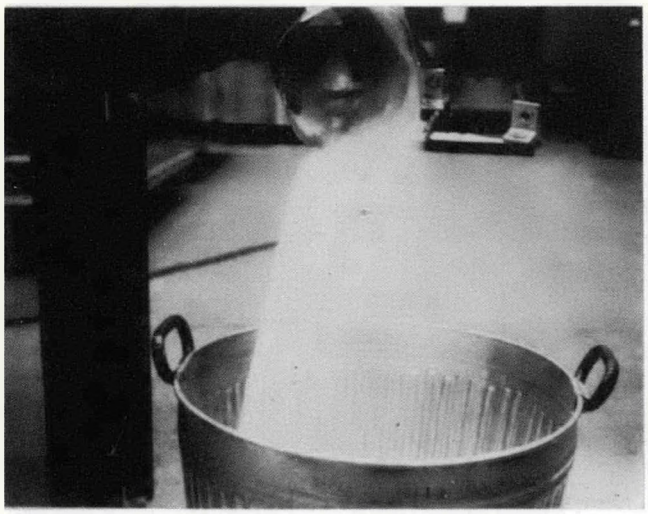


Figure 9-39. Run 117

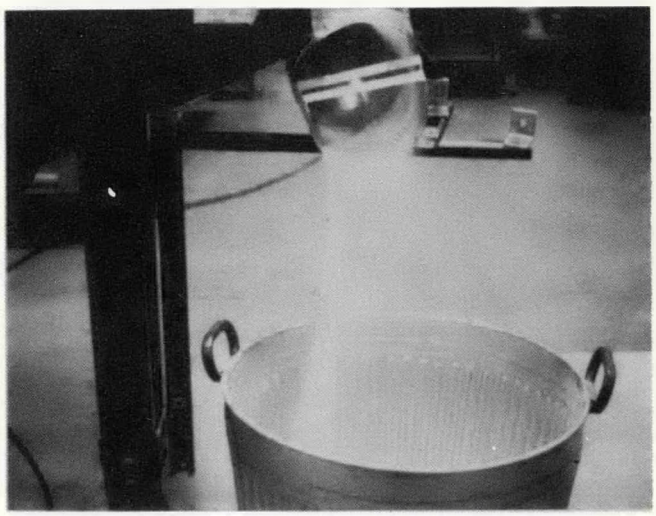


Figure 9-40. Run 119

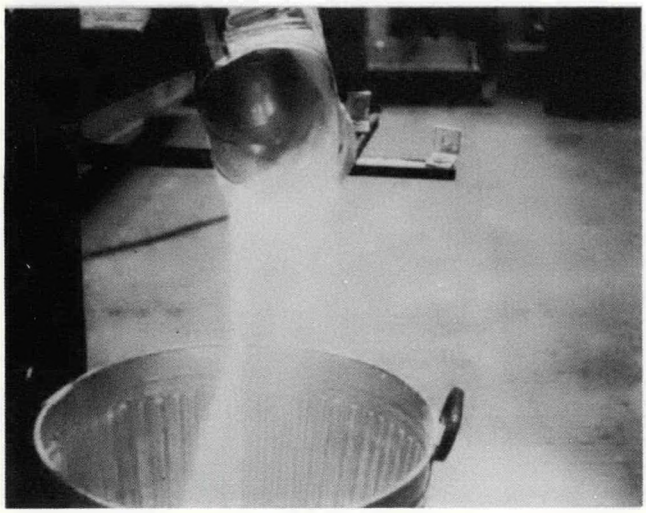


Figure 9-41. Run 120

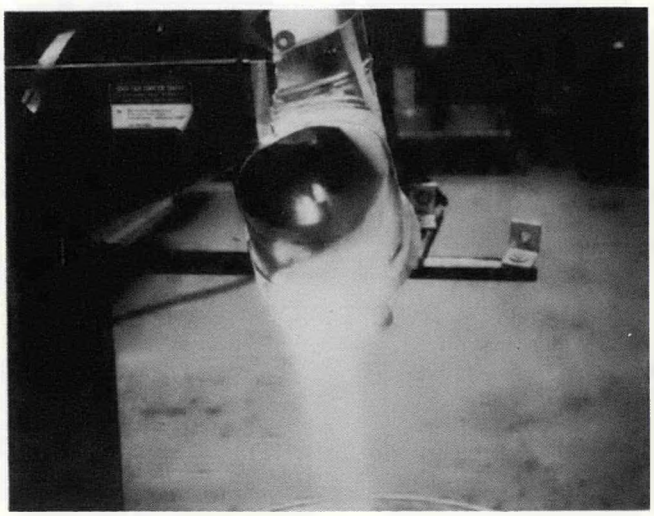


Figure 9-42. Run 121

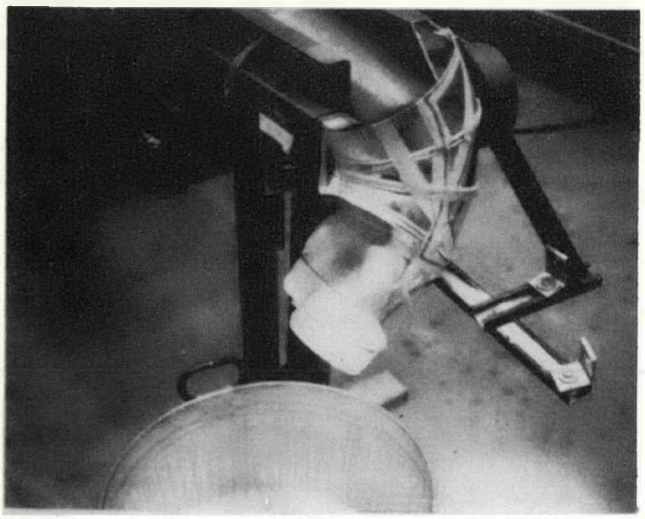


Figure 9-43. Run 121

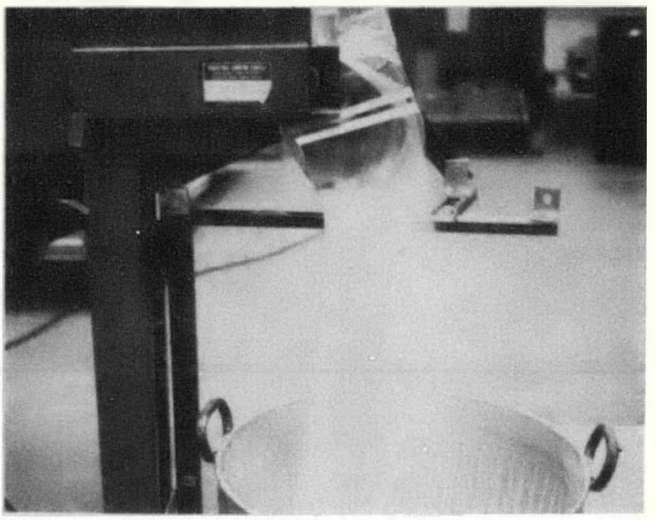


Figure 9-44. Run 122

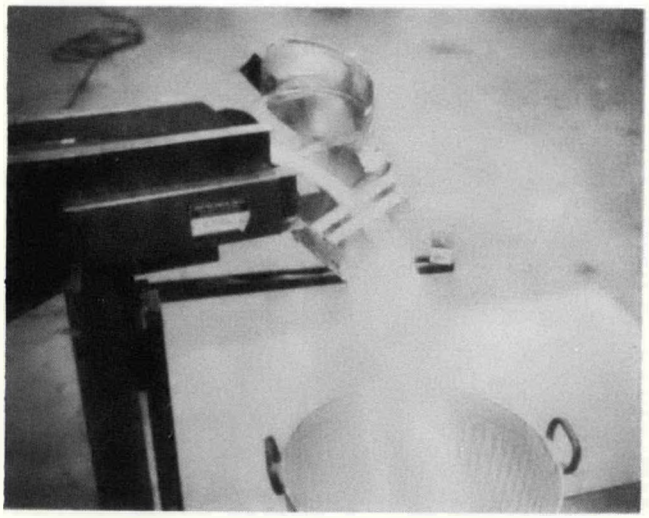


Figure 9-45. Run 123

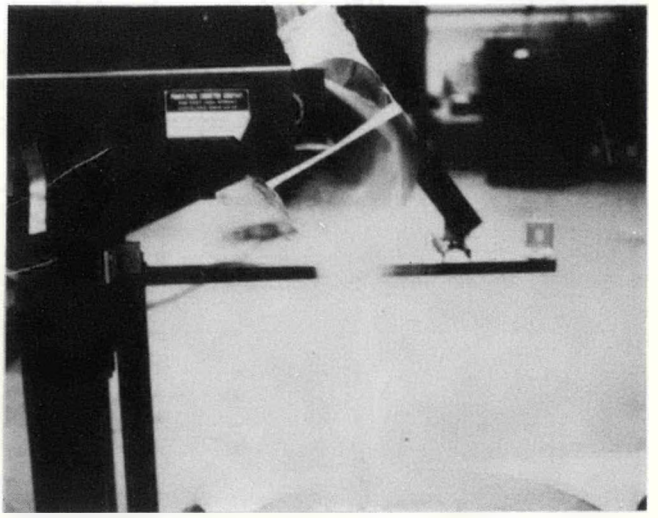


Figure 9-46. Run 124

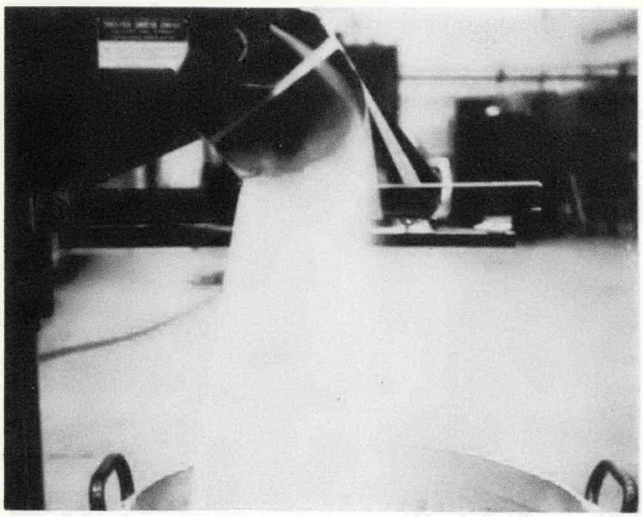


Figure 9-47. Run 125

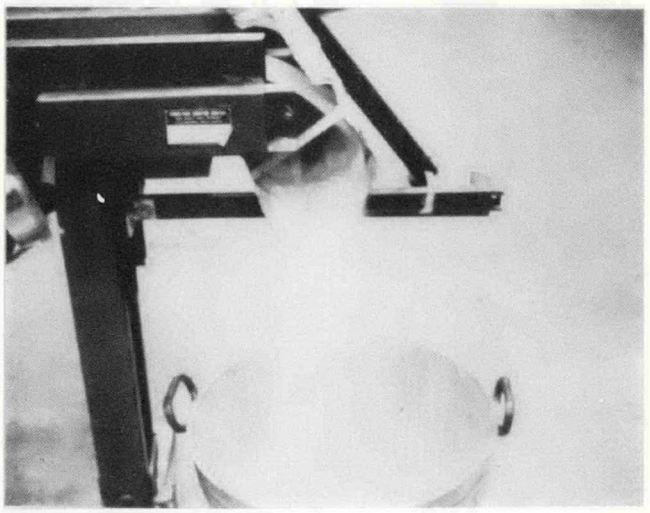


Figure 9-48. Run 126

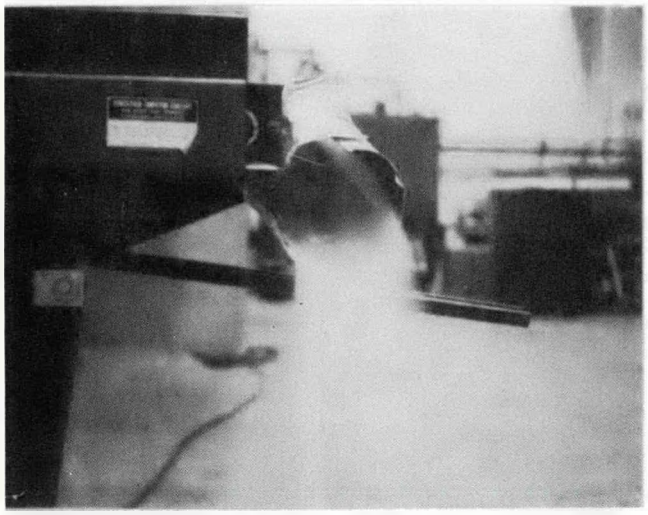


Figure 9-49. Run 131

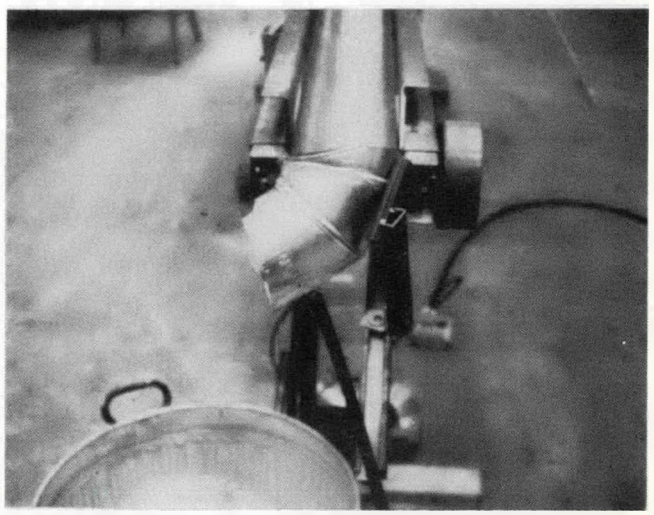


Figure 9-50. Run 131

The first torus configurations (Torus I, 6 and 8 inch sizes) were found to have the outboard side wall cut excessively low, requiring roll angles that caused the impacting stream to interfere with the subsequent frictional flow (Runs 101 to 106).

Simultaneously with the "true", or smooth surface torus models, ones with segmented sections were also tested. As noted in Section 8.0, the most convenient raw material for these scale model chutes were sheet metal, smoke pipes. Dimensional consistency and appearance of the numerous configurations tested here were not of the same quality as for the machined smooth torus chutes; but the primary objectives of these particular tests were satisfied: namely, 1) to confirm general agreement with the corresponding smooth torus configurations, and in particular 2) to verify that the joint intersections between successive cylindrical portions did not result in adverse flow patterns.

The other principal objectives in the many test runs involved with the smoke pipe torus involved achieving a non-splitting impact flow and a 90 degree turn. Of the various positions investigated, that for Run 126 appeared to achieve the best impact conditions and required turn, in the 8 inch minor diameter torus. This involved the addition of a chute extender, which caused the flow to return from an "over"-turn, i.e., one past 90^{o}, back to the center of the chute output area.

In order to enhance the headroom requirements, reflected in the "Y MIN" column of the table, a 6 inch minor diameter chute was also built and tested. Its optimum configuration was achieved in Run 131. (Y MIN is the distance of the lowest point on on the chute from the pulley center axis and corresponds to the identical term used in the analytical chapter.)

Owing to the unsuitable dynamic characteristics encountered with the first smooth torus configurations (I/8" and I/6"), a number II chute was introduced for testing. Only a 6 inch minor diameter case was now investigated, it by now having been verified that this smaller diameter shape was of adequate size to "catch" and turn the

entire flow cross section width for a 6 inch wide (36 inch full size) belt. The results of this second torus cut from a 90 degree pipe elbow are presented in Table 9-5, and in associated Figures 9-51 to 9-64. At this point, the torus chute was the evident stand-out among chute concepts, and the range of possible input belt velocities was investigated, i. e., at 350, 450, and 600 FPM. While the Torus II chute was found, at respectively different attitudes and locations, to be suitable for the higher velocities, the shallowness of the 350 fpm velocity dictated a different solution. It was determined that the Torus I/6" chute, oriented differently from the position attempted in Runs 101, 102, and 105, was optimum for handling this low trajectory (Figures 9-60, 61).

It was found in general that the Torus II chute for the upper velocities was only marginally long enough, measuring length as the arc angle around the major diameter. In the earlier Runs, 61 to 65, the slot area provided in the basic design was covered up by various strip widths to resolve the original internal surface. Subsequent runs (66, 67) achieved reasonably good flow performance with the original slot restored, but optimal flow output, it was judged, would be gained by an additional slide surface extension.

The outboard wall of the Torus II configuration had been raised significantly, to correct the features in the Torus I tests, resulted in the Torus II wall now being too high, and some interference with the upper edge with the free fall stream was now noted. Notching of the wall was performed incrementally (See Figure 9-57) to eliminate the interference.

9.3 REVISED TORUS MODEL TESTS

The need to evolve a third torus configuration arose from five considerations, including some previously identified:

- The outboard side wall shape required optimization
- The chute needed to be longer to optimize the flow output shape
- A more accurate reference surface was needed to measure angular and positional offsets.
- There was need also to raise the chute inboard wall to control and turn flow at the higher roll angles tested (Next text page: 9-29)

Table 9-5

Scale Model Test Results for Second Group of Torus Chute Configurations

Run#	Belt Velocity	Chute Config	Flow Matl	Locating Coord* X in	Locating Coord* Y in	Locating Coord* Z in	Y Min in	Attitude Roll o	Attitude Pitch o	Attitude Yaw o	Dev. from 90^{o}_{o} Turn	Fig#	Remarks Cohes.	Remarks Other
61	246	Torus II/6	Sand-C	2.5	-3.5	3.5	-7.2	37.5	16.9	7	10	9-51,52	Good	Slot Covrd
62	↑ (600 FPM, Full Scale)	↕	↓	2.0	-3.5	3.2	-7.0	40.3	16	2	0-5	9-53,54	Good	2 1/8" Strip
63				2.2	-4.4	3.2	-6.6	32.2	12.	0	0-5	9-55	Good	"
64				2.0	-4	3.2	-7.0	36.0	16	0	0-5	-	Slight Fork	"
65				2.2	-3.6	2.6	-6.4	35.4	4	0	0-5	9-56,57	"	Filler removed
66	↓			2.1	-3.5	3.1	-6.8	39.3	9.8	0	15^{o}	9-58	No Fork	-
67	246	Torus II/6		3.0	-2.9	2.9	-7.0	28.5	10	13	0-5	9-59	No Fork	-
71	143**	Torus I/6		1.0	-2.8	-0.1	-6.2	11	6	0	10-15	9-60	Fork	-
72	143	"		-0.2	-2	-0.5	-6.4	24.4	0	0	0	9-61	Slight	-
73	143	"		-0.2	-2	-0.5	-6.4	24.4	0	0	0	-	"	Extension Added
81	184***	Torus I/6		1.0	-2.8	-0.1	-6.2	"	6	0	15	9-62	"	-
82	184	Torus II/6	↓	3.4	-2.8	2.8	-7.4	25	4.5	0	5-10	9-63	No Fork	-
83	184	Torus II/6	Sand-C	2.0	-3.5	3.0	-6.4	35	6.0	0-5	0-5	9-64	"	-

** 350 FPM, Full Scale

*** 450 FPM, Full Scale

* To Outboard edge of upper circle for runs 61-67, 82, 83
To Aft edge of upper circle for runs 71-73, 81.

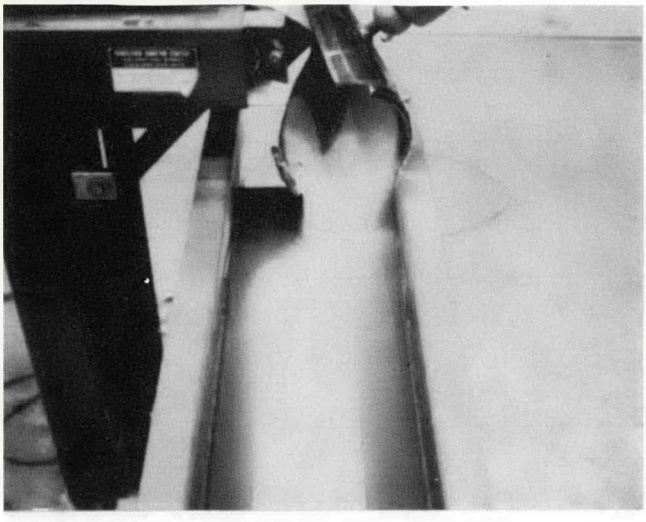


Figure 9-51. Run 61

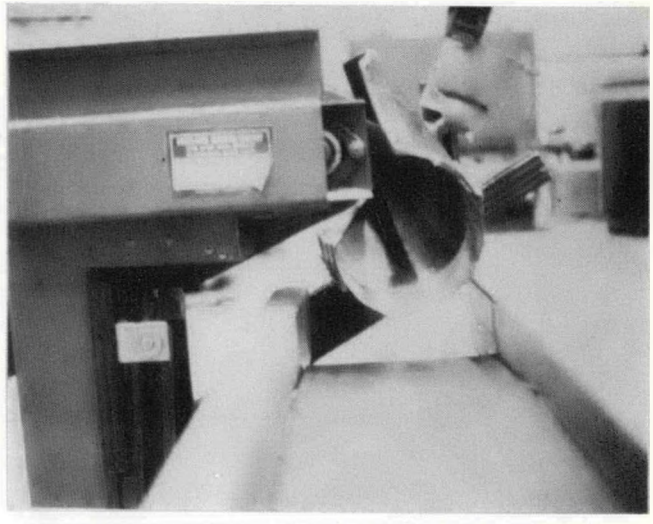
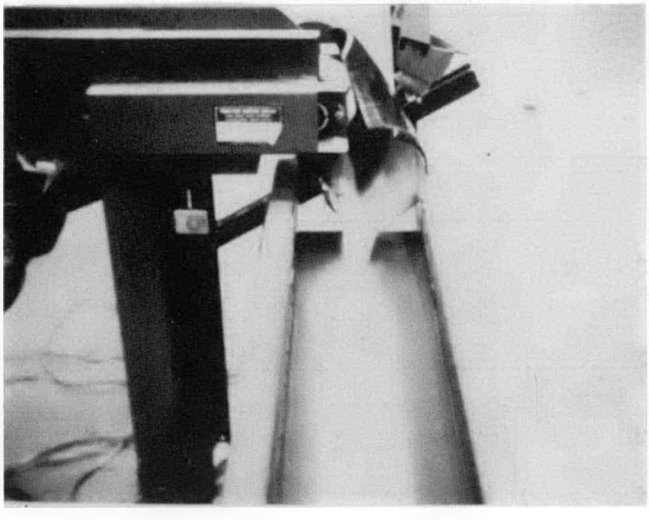


Figure 9-52. Run 61



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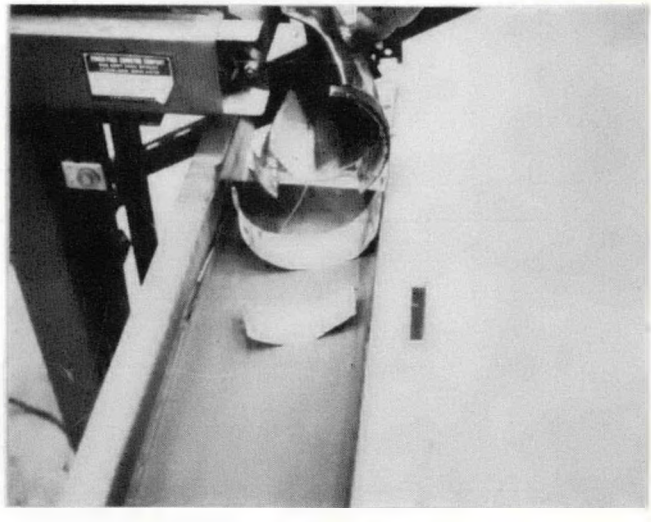

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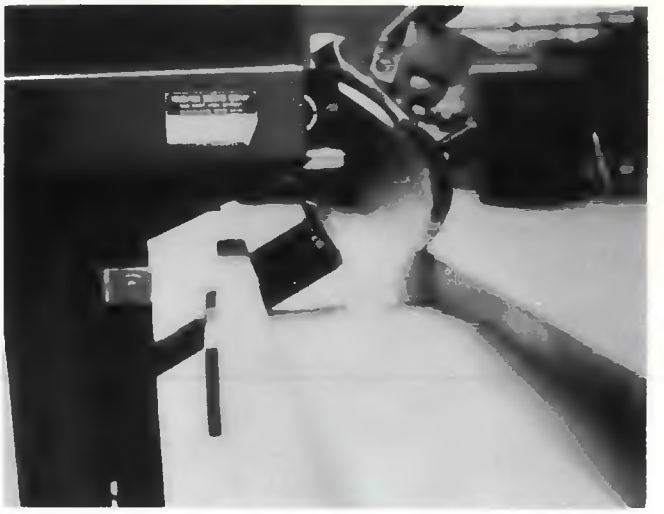
Figure 9-55. Run 63



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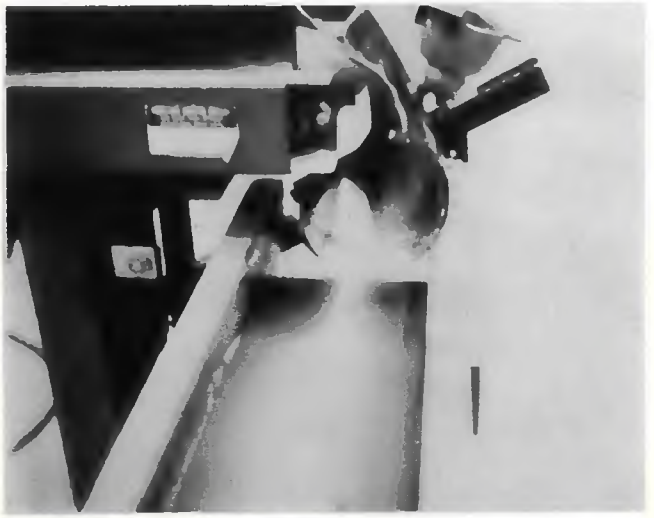

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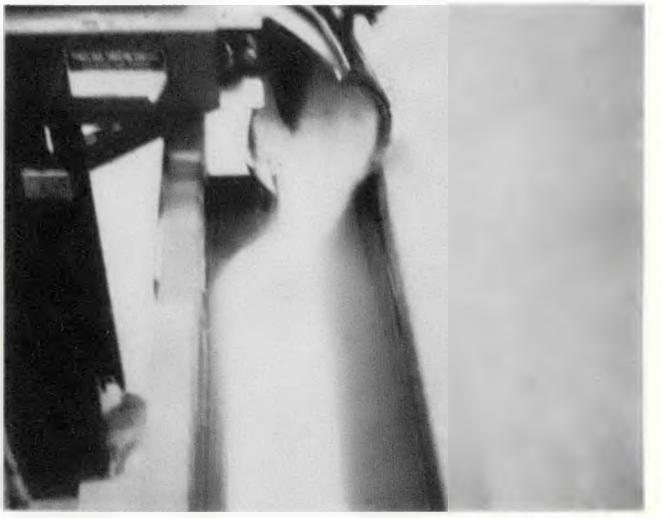

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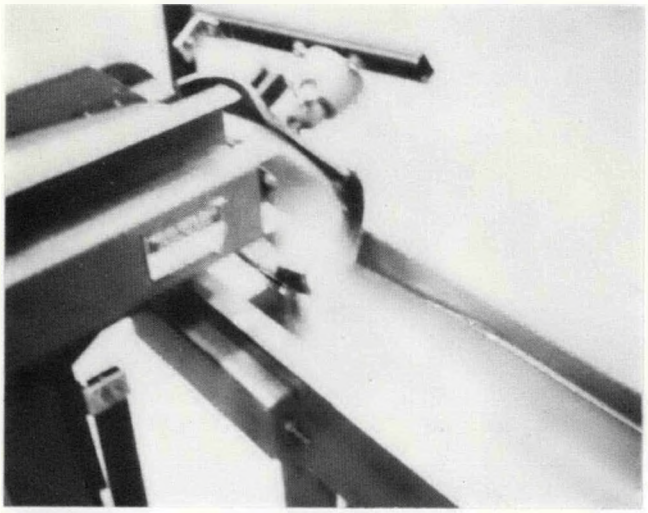

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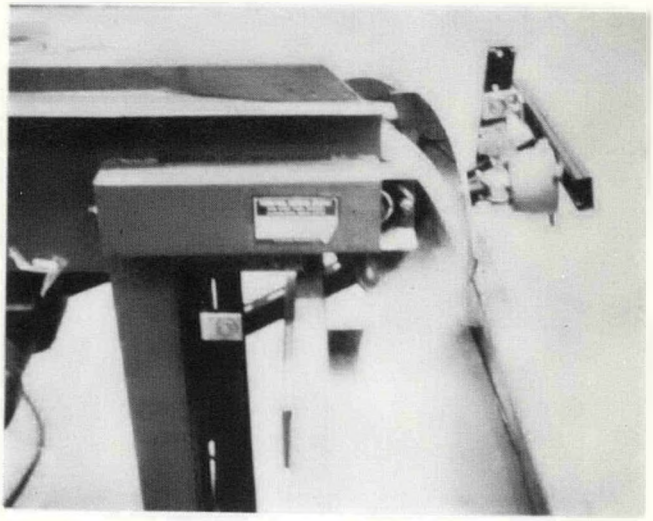

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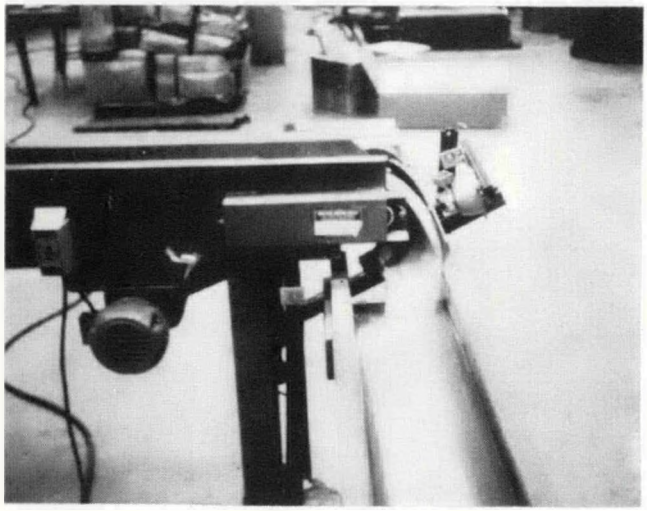

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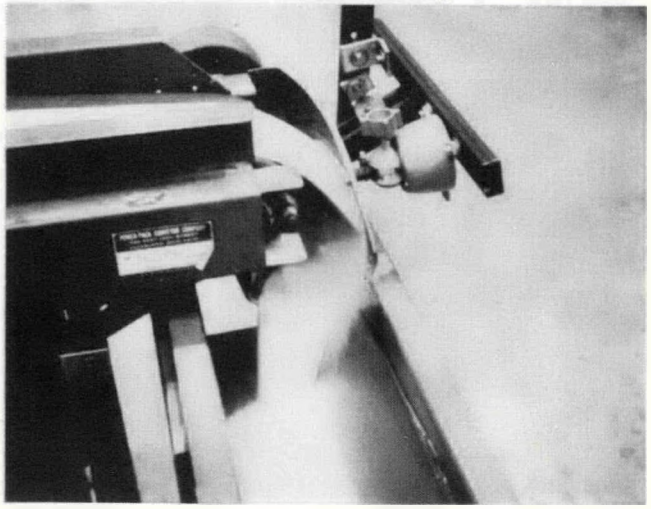

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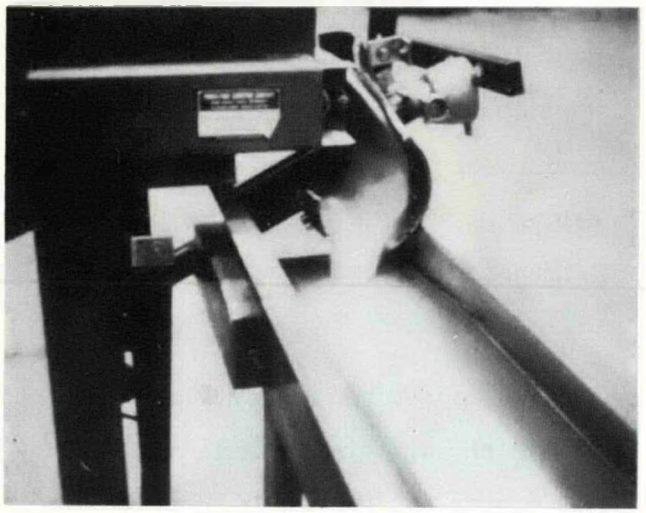

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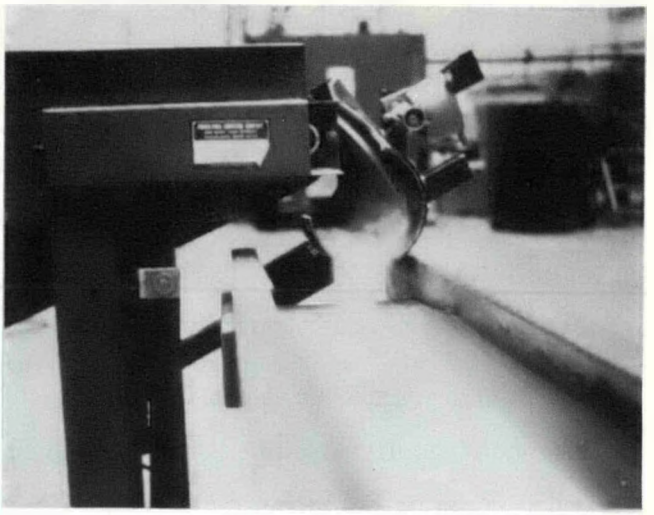

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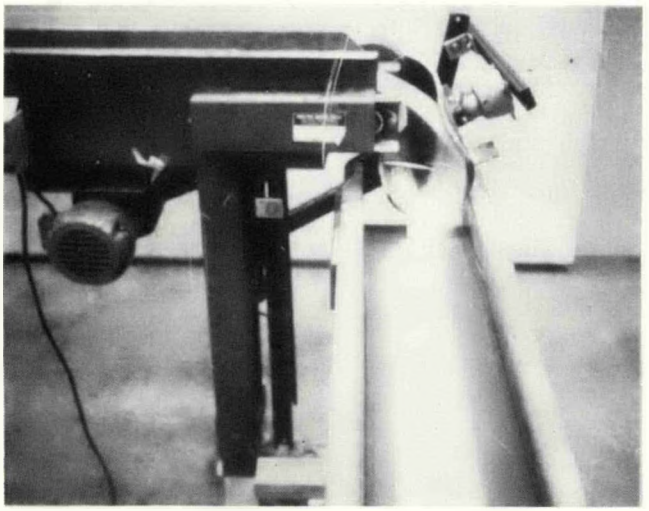

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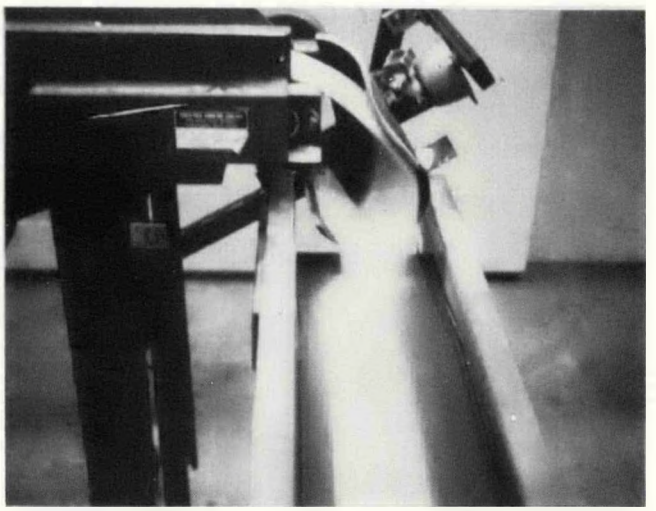

Figure 9-66. Run 462

- To establish baseline configurations for comparison with the analytical results, at the higher speeds of interest.

The Torus III chute was evolved accordingly. Test results involving this configuration are covered in Table 9-6 and Figures 9-65 to 9-69.

One of the test phenomena increasingly recognized through the iterations investigated was the development of a significant flow down the inboard side of the chute, the origin of which was the very fine material falling from the belt after the main flow trajectory had departed. This secondary flow had the effect of turning the main flow to the outboard direction, particularly if this main flow still had a significant velocity vector to the inboard side by the time it arrived at the bottom of the chute. This had a generally beneficial effect from the standpoint of minimizing the length of the chute required to center the flow and achieve a 90 degree turn. However, some disturbance in the flow at the convergence areas is an inherent penalty, although of an apparently second-order magnitude.

Of greater question is whether this phenomenon is matched in an actual transfer point configuration. It was observed during field trips that the effluent from the belt cleaner is sometimes quite significant in volume, although its role in current chute flow situations is not a factor, with the chute being normally clear of the effluent drop area. It is judged that the more conservative approach is to ignore the role of this secondary flow, from the standpoint of making worst case assumptions relating to the length of chute necessary to turn the flow. Thus, chute lengths in some configurations may have to be slightly longer, proportionately, than in these tests, although this is also a function of wall friction. In these tests, the angle of wall friction was measured at about 32^{o} for both the steel pipe elbows and the galvanized steel smoke pipe elbows. For higher frictions, the flows will turn more quickly, and so the length can be shorter, and conversely for lower frictions. Ultimately, the chute design should be sufficiently flexible for varying local situations that the location of the lower chute termination can be varied to suit.

Table 9-6

Scale Model Test Results for Torus III Chute Configuration

Run #	Velocity (FPM)	Flow Material	Locating Coord. * X in	Y in	Z in	Y Min in	Attitude Roll o	Pitch o	Yaw o	Dev. from 90°Turn o	Fig. # **	Remarks Cohesion	Other
461	246(600)	Sand-C	7.6	-2.8	6.8	-7.2	19	16	11.5	10	9-65	Good	Slight Scatter
462	246(600)	"	7.5	-2.5	6.8	-7.2	32	20	11	5-10	9-66	Good	Fines Buildup
481	184(450)	"	6.8	-2.8	7.2	-7.4	28.5	19.5	7	5-10	9-67	"	"
482	184(450)	"	6.2	-2.8	7.2	-7	29	17	3	0-5	_	"	"
483	184(450)	"	6.4	-2.5	7.5	-7	22	15	6	0	9-68	"	"
484	184(450)	Sand-C	6.5	-2.5	7.5	-7	27	14	6.5	0-5	9-69	"	"

* To outboard edge of lower circle

** Original black coating on pipe elbow removed after Run 482.

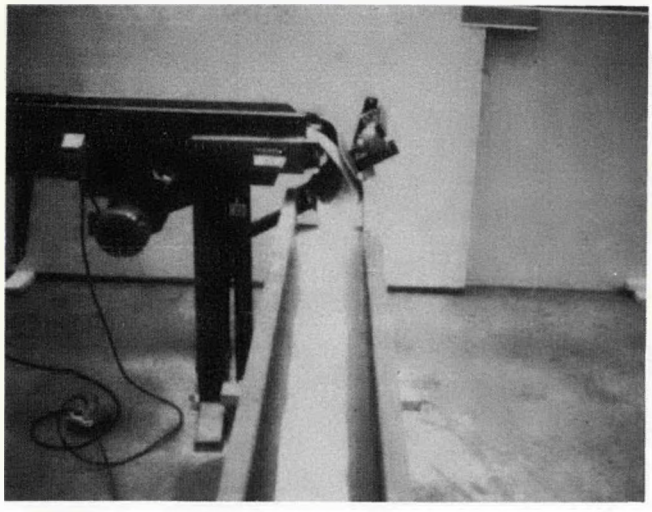

Figure 9-67. Run 481

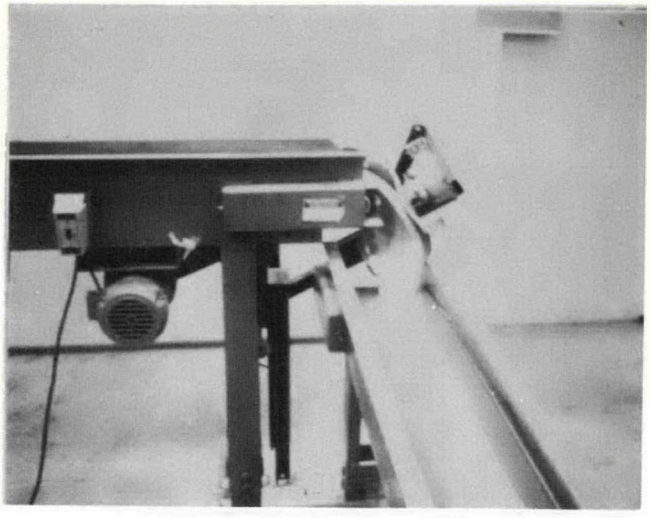

Figure 9-68. Run 483

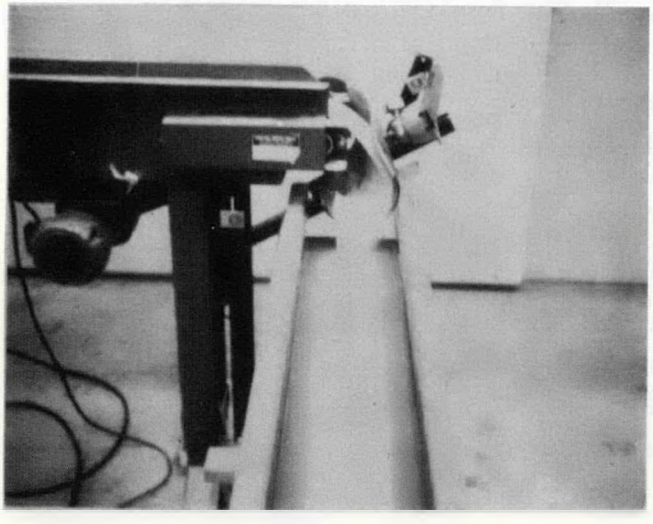

Figure 9-69. Run 484

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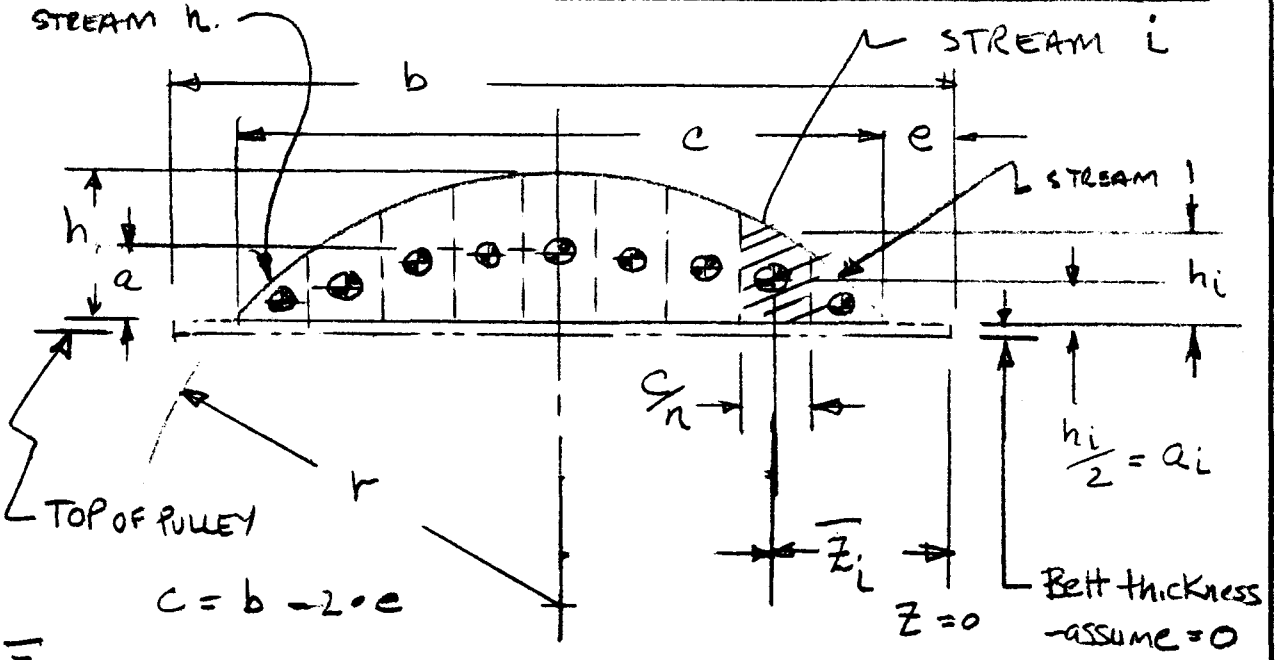
APPENDIX B

MATH MODEL FOR PHASE I DYNAMICS
FREE FALL AND IMPACT DYNAMICS PHASE

1. DIVIDE FLOW CROSS SECTION INTO n (ODD) STREAMS



$\bar{Z}_i$

$$\bar{Z}_i = e + i \times \left(\frac{c}{n}\right) + \frac{c}{2n} = e + \frac{c}{n}\left(i + \tfrac{1}{2}\right)$$

r

$$r - \sqrt{r^2 - \left(\tfrac{c}{2}\right)^2} = h$$

$$r^2 - 2Rh + h^2 = r^2 - c^2/4$$

$$r = \frac{h}{2} + \frac{c^2}{8h} \quad *$$

USING ABOVE VALUES FOR $\bar{X}_i$ and r, THE HEIGHT OF THE STREAM C.G. ABOVE PULLEY IS

$$\frac{h_i}{2} = \frac{\sqrt{r^2 - \left(\frac{b}{2} - Z_i\right)^2} - \sqrt{r^2 - c^2/4}}{2}$$

* see next page for "h"

PREPARED BY	CHECKED BY	DATE	REV.

1 CONTINUED

DERIVATION OF h

REFER TO TABLE A-1 EXTRACT FROM CEMA BULK FLOW TRAJECTORIES, WHERE h IS GIVEN AS FUNCTION OF IDLER TYPE, BELT WIDTH, AND SURCHARGE ANGLE. DATA IS EXTRACTED FROM 20°, 35°, AND 45° IDLER & PLOTTED ON FIGURES A-1 & A-2, TO DETERMINE OTHER MINE IDLER TYPE, 27°, FOR 30 INCH AND 36 INCH BELT WIDTHS. FROM THESE GRAPHS ARE DERIVED THE FOLLOWING DATA TO BE TABULARLY ENTERED INTO THE COMPUTER MODEL.

IDLER ANGLE	SURCHARGE ANGLE	h* - INCHES b = 30"	b = 36"
27°	20°	5.07	6.24
	25°	5.57	6.86
	30°	5.99	7.50
35°	20°	5.71	6.95
	25°	6.04	7.52
	30	6.38	8.09

* ADJUSTED FOR 2-INCH EDGE DISTANCE (e) CASE

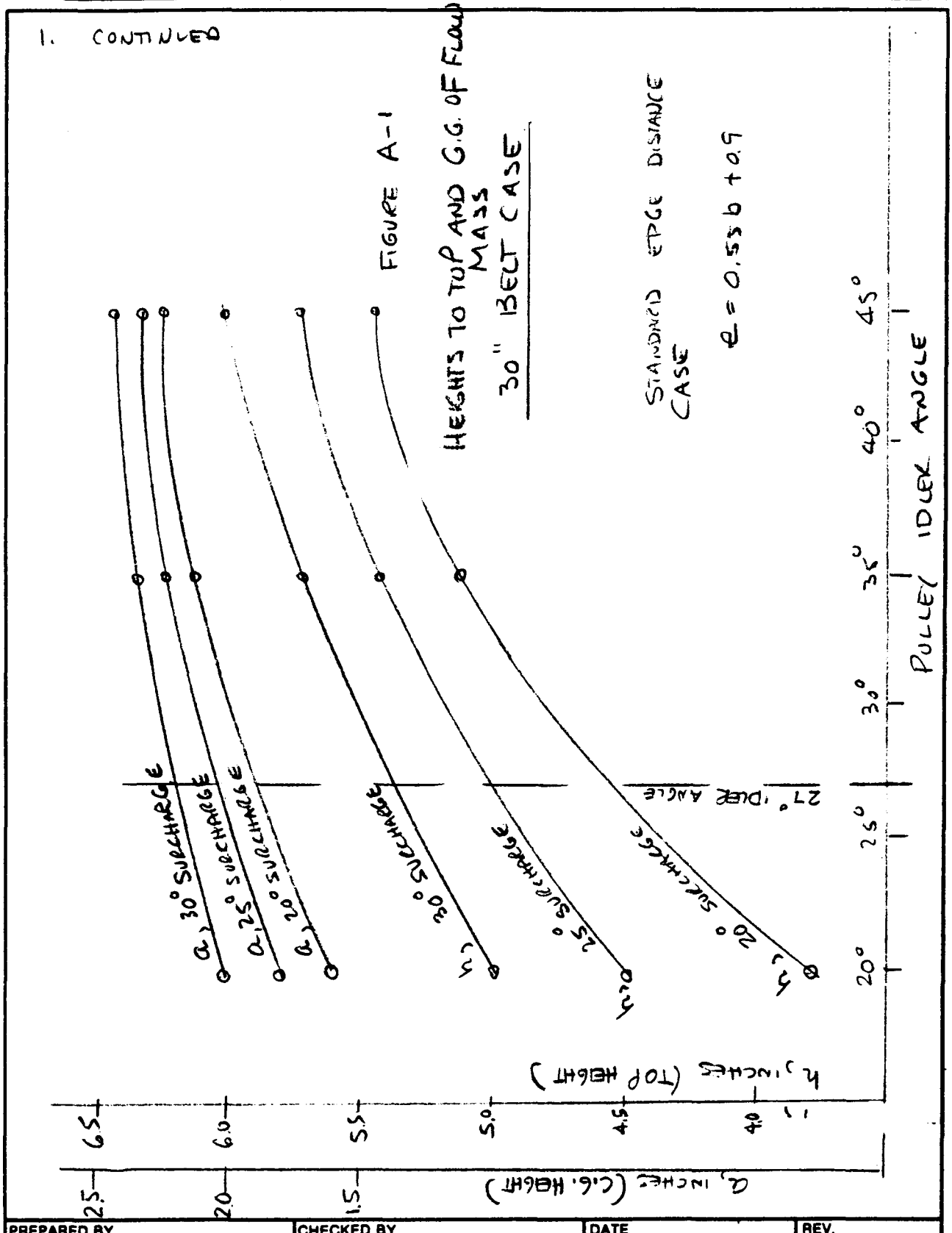
TABLE B-1

Type of idlers	Surcharge angle		"b" and "a_1" values, inches, for Standard Edge Distance of 0.055b + 0.9 inch												
			Belt width, inches												
			14	16	18	20	24	30	36	42	48	54	60	66	72
20° Three-equal-length-roll troughing idlers	0°	h	0.9	1.0	1.1	1.4	1.7	2.1	2.7	3.1	3.7	4.1	4.7	5.3	5.7
		a_1	0.4	0.4	0.4	0.6	0.7	0.8	1.1	1.3	1.5	1.7	1.9	2.1	2.3
	5°	h	1.0	1.2	1.4	1.6	2.0	2.6	3.2	3.9	4.5	5.1	5.6	6.3	6.8
		a_1	0.4	0.5	0.6	0.6	0.8	1.0	1.3	1.6	1.8	2.1	2.3	2.5	2.7
	10°	h	1.2	1.4	1.6	1.9	2.4	3.1	3.7	4.5	5.2	6.0	6.7	7.4	8.1
		a_1	0.5	0.6	0.6	0.8	1.0	1.3	1.5	1.8	2.1	2.4	2.7	3.0	3.3
	20°	h	1.6	1.9	2.2	2.5	3.1	3.8	4.8	5.7	6.8	7.5	8.5	9.5	10.4
		a_1	0.6	0.8	0.9	1.0	1.3	1.6	1.9	2.3	2.7	3.0	3.4	3.8	4.2
	25°	h	1.8	2.1	2.5	2.8	3.5	4.5	5.4	6.4	7.5	8.5	9.6	10.5	11.6
		a_1	0.7	0.8	1.0	1.1	1.4	1.8	2.2	2.6	3.0	3.4	3.8	4.2	4.6
	30°	h	2.0	2.3	2.7	3.1	3.8	5.0	6.0	7.1	8.2	9.4	10.6	11.5	12.7
		a_1	0.8	0.9	1.1	1.3	1.5	2.0	2.4	2.9	3.3	3.8	4.3	4.6	5.1
35° Three-equal-length-roll troughing idlers	0°	h	1.3	1.6	1.9	2.2	2.7	3.5	4.3	5.0	6.0	6.7	7.4	8.4	9.0
		a_1	0.5	0.6	0.8	0.9	1.1	1.4	1.7	2.0	2.4	2.7	3.0	3.4	3.6
	5°	h	1.5	1.8	2.1	2.4	3.0	3.8	4.8	5.5	6.4	7.4	8.1	9.2	10.0
		a_1	0.6	0.7	0.8	1.0	1.2	1.5	1.9	2.2	2.6	3.0	3.3	3.7	4.0
	10°	h	1.7	2.0	2.3	2.6	3.2	4.2	5.2	6.1	7.2	8.2	9.0	10.0	11.0
		a_1	0.7	0.8	0.9	1.0	1.3	1.7	2.1	2.5	2.9	3.3	3.6	4.0	4.4
	20°	h	1.9	2.3	2.7	3.1	3.9	5.1	6.1	7.3	8.4	9.5	10.7	11.7	13.0
		a_1	0.8	0.9	1.1	1.3	1.6	2.1	2.5	2.9	3.4	3.8	4.3	4.7	5.2
	25°	h	2.1	2.5	3.0	3.4	4.2	5.4	6.6	7.8	9.1	10.3	11.6	12.7	13.9
		a_1	0.8	1.0	1.2	1.4	1.7	2.2	2.7	3.1	3.7	4.1	4.6	5.1	5.6
	30°	h	2.3	2.7	3.2	3.6	4.5	5.7	7.1	8.4	9.8	11.1	12.4	13.7	14.9
		a_1	0.9	1.1	1.3	1.5	1.8	2.3	2.9	3.4	4.0	4.5	5.0	5.5	6.0
45° Three-equal-length-roll troughing idlers	0°	h	1.6	1.9	2.2	2.5	3.1	4.0	5.0	6.0	6.8	7.7	8.6	9.5	10.5
		a_1	0.6	0.8	0.9	1.0	1.3	1.6	2.0	2.4	2.7	3.1	3.5	3.8	4.2
	5°	h	1.7	2.1	2.4	2.8	3.4	4.4	5.4	6.4	7.4	8.4	9.5	10.4	11.4
		a_1	0.7	0.8	1.0	1.1	1.4	1.8	2.2	2.6	3.0	3.4	3.8	4.2	4.6
	10°	h	1.9	2.2	2.6	3.0	3.7	4.7	5.8	7.0	7.9	9.0	10.2	11.3	12.2
		a_1	0.8	0.9	1.0	1.2	1.5	1.9	2.3	2.8	3.2	3.6	4.1	4.6	4.9
	20°	h	2.1	2.6	2.9	3.4	4.1	5.4	6.6	7.8	9.1	10.3	11.5	12.8	14.0
		a_1	0.8	1.0	1.2	1.4	1.7	2.2	2.7	3.1	3.7	4.2	4.6	5.2	5.6
	25°	h	2.3	2.7	3.1	3.6	4.4	5.7	7.0	8.3	9.7	10.9	12.3	13.6	14.8
		a_1	0.9	1.1	1.2	1.4	1.8	2.3	2.8	3.3	3.9	4.4	4.9	5.5	5.9
	30°	h	2.4	2.9	3.3	3.8	4.7	6.0	7.4	8.8	10.2	11.5	13.0	14.3	15.6
		a_1	1.0	1.2	1.3	1.5	1.9	2.4	3.0	3.5	4.1	4.6	5.2	5.8	6.3

TABLE EXTRACTED FROM CEMA BULK MATERIALS HANDBOOK, DISCHARGE TRAJECTORIES

PREPARED BY	CHECKED BY	DATE	REV.

1. CONTINUED

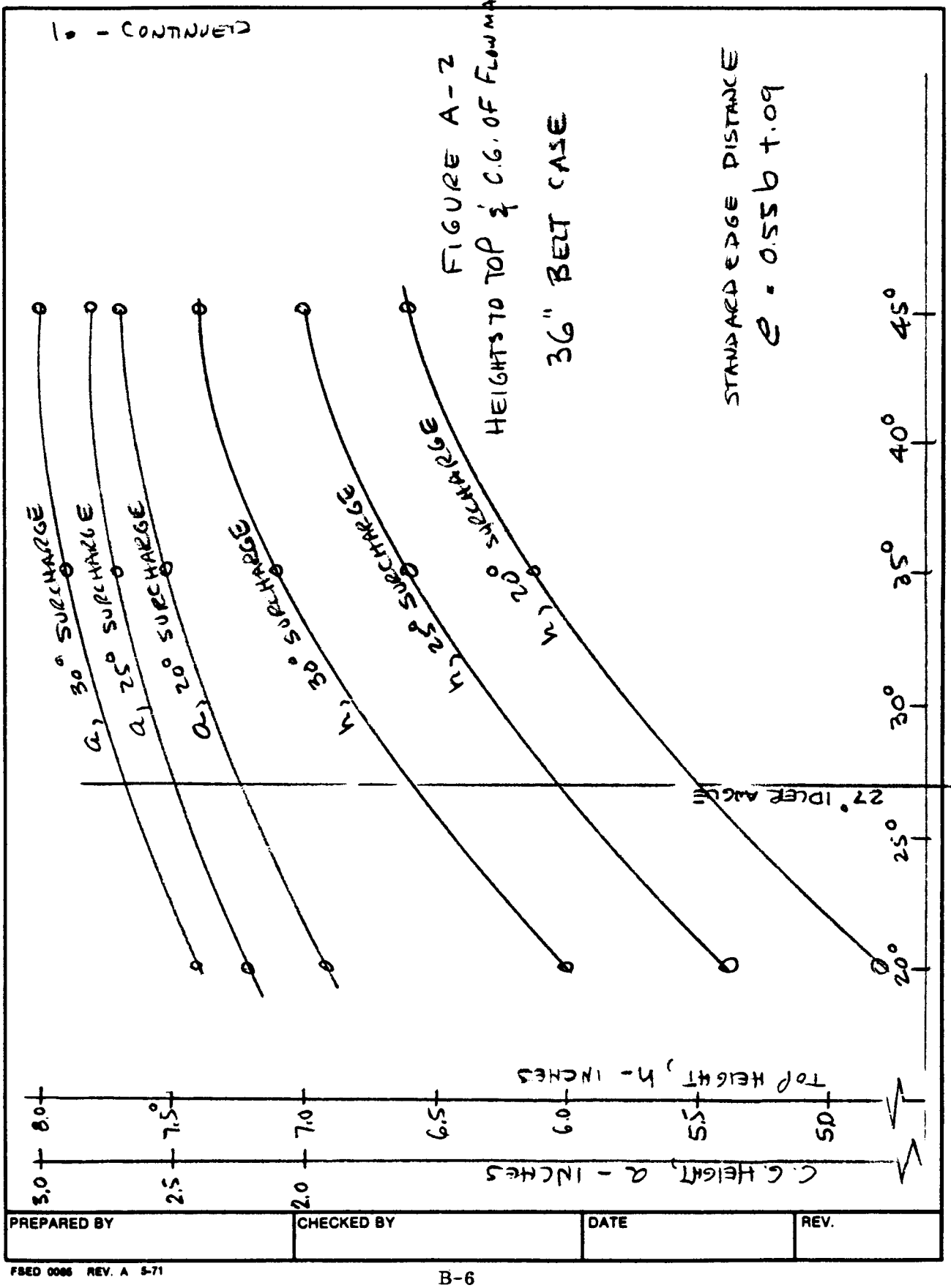


PREPARED BY	CHECKED BY	DATE	REV.

FSED 0086 REV. A 5-71

FAIRCHILD
SPACE & ELECTRONICS COMPANY

1. - CONTINUED



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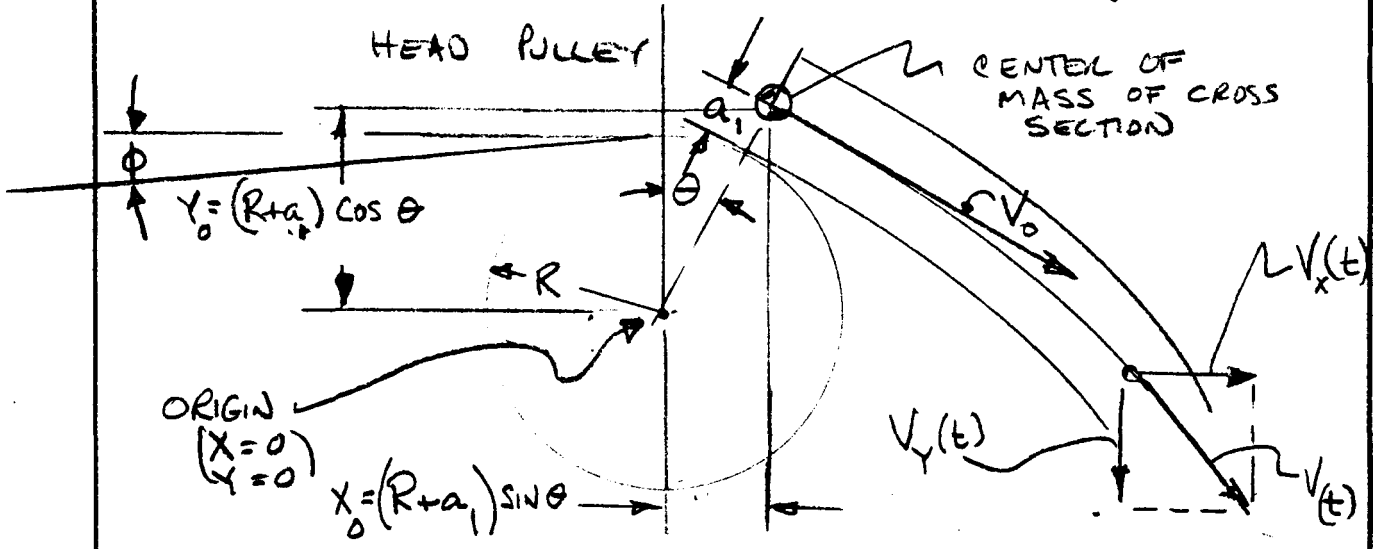
1.

2. DETERMINE POSITION AND DIRECTION OF TRAJECTORY CROSS SECTION LEAVING HEAD PULLEY



V = BELT SPEED

ϕ = BELT INCLINATION (+ = CLIMBING)

θ = ANGLE AT WHICH STREAM LEAVES PULLEY

$$\theta = f(R, \phi, V, a_1, g)$$

CASE 1 : $\phi = 0$

1A. $\dfrac{V^2}{g(R+a_1)} \geq 1 \quad \therefore \theta = 0$

1B $\dfrac{V^2}{g(R+a_1)} \leq 1 \quad \therefore \theta = \cos^{-1}\left(\dfrac{V^2}{g(R+a_1)}\right)$

PREPARED BY	CHECKED BY	DATE	REV.

CASE 2 $\phi > 0$

2A : $\frac{V^2}{g(R+a_1)} > 1$ $\therefore \theta = -\phi$

2B : $\frac{V^2}{g(R+a_1)} = 1$ $\therefore \theta = 0$

2C : $\frac{V^2}{g(R+a_1)} < 0$ $\therefore \theta = \cos^{-1}\left(\frac{V^2}{g(R+a_1)}\right)$

CASE 3 $\phi < 0$ – NOT ADDRESSED AS APPLICABLE

OF THE ABOVE INDEPENDENT PARAMETERS INFLUENCING θ, ALL ARE INDEPENDENTLY SPECIFIED EXCEPT THE HEIGHT TO THE CENTER OF MASS OF THE FLOW CROSS SECTION, a_1. THIS PARAMETER IS ITSELF A FUNCTION OF BELT WIDTH, EDGE DISTANCE, SURCHARGE ANGLE, AND IDLER ANGLE--- -- AS IN THE CASE FOR h. PLOTS FOR a_1 ARE INCLUDED IN FIGURES A1 AND A2, WHEREIN IS DERIVED VALUES FOR A 27° IDLER ANGLE FOR 30 INCH AND 36 INCH BELT WIDTHS THE DATA FOR THE 20°, 35°, AND 45° IDLER ANGLE CASES IS EXTRACTED FROM TABLE A-1

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2., CON'T.

THE FOLLOWING DATA ARE TABULATED HERE FOR ENTRY INTO THE COMPUTER MODEL.

IDLER ANGLE	DISCHARGE ANGLE	a_1 (INCHES) $b = 30"$	$b = 36"$
27°	20°	2.48	2.23
	25°	2.75	2.29
	30°	2.97	2.45
35°	20°	2.35	2.85
	25°	2.46	3.08
	30°	2.58	3.31

THUS, θ IS NOW COMPLETELY SPECIFIED.

USING THE ABOVE DATA, AND ASSUMING THE ORIGIN AT THE CENTER OF THE PULLEY, THE FOLLOWING LOCATIONS ARE THEN APPLICABLE FOR THE TOP, CENTER OF GRAVITY, AND BOTTOM OF A STREAM ℓ, USING THE COORDINATE SYSTEM DEFINED IN FIGUEE A-3, WHEN IT LEAVES THE HEAD PULLEY.

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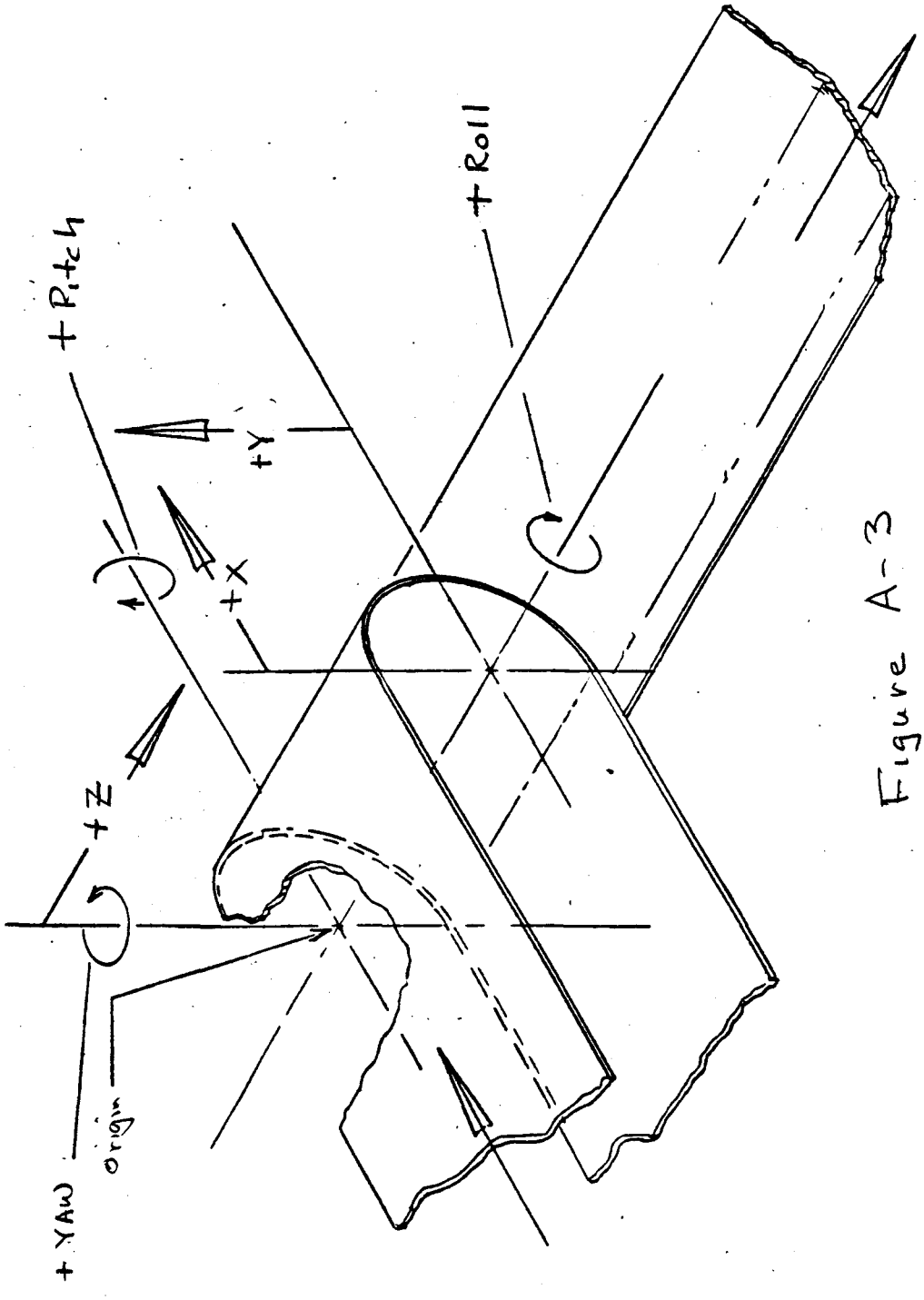

Figure A-3

PREPARED BY	CHECKED BY	DATE	REV.

2. CONT

STREAM i LOCATION AT TIME LEAVING PULLEY ($t = 0$)

COORDINATE	TOP	C.G.	BOTTOM
X_0	$(R + \frac{h_i}{2})\sin\theta$	$(R+a)\sin\theta$	$R\sin\theta$
Y_0	$(R + \frac{h_i}{2})\cos\theta$	$(R+a)\cos\theta$	$R\cos\theta$
Z_0	$e + \frac{s}{n}(i+\frac{1}{2})$	$e + \frac{s}{n}(i+\frac{1}{2})$	$e + \frac{s}{n}(i+\frac{1}{2})$

3. DEFINE THE FREE FALL TRAJECTORY PATH

THE FOLLOWING DYNAMIC PARAMETERS APPLY AT TIME t:

COORDINATE	LOCATION	VELOCITY
X_t	$X_0 + (V\cdot\cos\theta)t$	$V\cos\theta$
Y_t	$Y_0 - V\sin\theta t + \frac{1}{2}gt^2$	$V\sin\theta + gt$
Z_t	$e + \frac{s}{n}(i+\frac{1}{2})$	0

PREPARED BY	CHECKED BY	DATE	REV.

4. LOCATION OF IMPACT POINT OF STREAM i WITH CHUTE

THE IMPACT POINT OF STREAM i (TOP, C.G., AND BOTTOM, RESPECTIVELY) WITH THE CHUTE IS THE INTERCEPT BETWEEN THE FREE FALL TRAJECTORY, A PARABOLIC EQUATION, WITH THE $Z = e + S_n(i+\frac{1}{2})$ LINE EQUATION IN THE PARTICULAR PLATE INTERCEPTED. ASSUME THE RECTANGULAR PLATES TO BE DIVIDED INTO TWO TRIANGLES EACH FOR THIS SOLUTION, WHICH ADDRESSES THE C.G. TRAJECTORY, BUT IS READILY CONVERTED FOR THE INTERCEPTS OF THE TOP AND BOTTOM

4.1 TRAJECTORY EQUATIONS

$$X_t = V_0 \cos\theta + X_0 \quad (1)$$

$$Y_t = Y_0 - V_0 \sin\theta\, t - \tfrac{1}{2} g t^2 \quad (2)$$

WHERE

$$t = \frac{X - X_0}{V \cos\theta} \quad (3)$$

PREPARED BY	CHECKED BY	DATE	REV.

4. CON'T

SUBSTITUTING VALUE FOR t INTO 1ST EQUATION FOR Y ,

$$Y = \left[\frac{-\frac{1}{2}g}{(V\cos\theta)^2}\right]X^2 + \left[\frac{gX_0}{(V\cos\theta)^2} - \tan\theta\right]X + \left[Y_0 + X_0\tan\theta - \frac{0.5gX_0^2}{(V\cos\theta)^2}\right] \quad (4)$$

LET $\alpha = X^2$, OR 1ST TERM FACTOR (4a)

$\beta = X$, OR SECOND TERM FACTOR (4b)

$\gamma =$ CONSTANT, OR THIRD TERM (4c)

4.2 EQUATIONS OF PLANE TRIANGLE j
(GIVEN X, Y, Z COORDINATES FOR THREE CORNERS 1, 2, AND 3)

EVALUATE PLANE EQUATION CONSTANTS FOR GENERAL EQUATION FOR PLANE TRIANGLE :

$$ax + by + cz = 1 \quad (5)$$

PREPARED BY	CHECKED BY	DATE	REV.

4 CON'T

$$a = \frac{\begin{vmatrix} 1 & Y_1 & Z_1 \\ 1 & Y_2 & Z_2 \\ 1 & Y_3 & Z_3 \end{vmatrix}}{\begin{vmatrix} X_1 & Y_1 & Z_1 \\ X_2 & Y_2 & Z_2 \\ X_3 & Y_3 & Z_3 \end{vmatrix}} \qquad (6)$$

$$b = \frac{\begin{vmatrix} X_1 & 1 & Z_1 \\ X_2 & 1 & Z_2 \\ X_3 & 1 & Z_3 \end{vmatrix}}{\begin{vmatrix} X_1 & Y_1 & Z_1 \\ X_2 & Y_2 & Z_2 \\ X_3 & Y_3 & Z_3 \end{vmatrix}} \qquad (7)$$

$$c = \frac{\begin{vmatrix} X_1 & Y_1 & 1 \\ X_2 & Y_2 & 1 \\ X_3 & Y_3 & 1 \end{vmatrix}}{\begin{vmatrix} X_1 & Y_1 & Z_1 \\ X_2 & Y_2 & Z_2 \\ X_3 & Y_3 & Z_3 \end{vmatrix}} \qquad (8)$$

PREPARED BY	CHECKED BY	DATE	REV.

4. CON'T

SOLVING EQUATION 5 FOR X,

$$X = \frac{1 - Cz - by}{a} \tag{9}$$

SINCE THE Z INTERCEPT COORDINATE IS FIXED FOR ANY ONE STREAM, I.E.,

$$z_i = e + \delta_n\left(i + \tfrac{1}{2}\right)$$

THEN LET

$$K = (1 - Cz) \tag{10}$$

HENCE

$$X = \frac{K - by}{a} \tag{11}$$

IS THE EQUATION OF THE LINE INTERSECTION BETWEEN THE $z = z_i$ PLANE AND THE PLANE OF THE PLATE.

THE POSSIBLE INTERCEPT POINTS ARE THEN OBTAINED BY SOLVING EQUATIONS (11) AND (4) SIMULTANEOUSLY.

PREPARED BY	CHECKED BY	DATE	REV.

4.0 CON'T

SUBSTITUTING X IN EQUATION 11 INTO EQUATION 4 ,

$$y = \alpha\left(\frac{K-by}{a}\right)^2 + \beta\left(\frac{K-by}{a}\right) + \gamma \qquad (12)$$

SIMPLIFYING TERMS & SETTING UP IN QUADRATIC FORM

$$0 = \left(\frac{\alpha}{a^2}\cdot b^2\right)y^2 - \left[2Kb\left(\frac{\alpha}{a^2}\right) + \frac{b\beta}{a} - 1\right]y + \left[\frac{\alpha K^2}{a^2} + \frac{\beta}{a}K + \gamma\right]$$

LETTING

Q = CONSTANT FACTOR IN FIRST TERM

R = CONSTANT FACTOR IN 2ND TERM

S = THIRD TERM

$$Y = \frac{-R \pm \sqrt{R^2 - 4QS}}{2Q}$$

THEN SOLVE FOR X

PROPER VALUE FOR Y & X IS DETERMINED BY FOLLOW CRITERIA :

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4 CON'T

CRITERIA

(1) IF $R^2 - 4QS < 0$, THEN NO INTERCEPT OCCURS

(2) IF $R = 4QS$, THEN

$$Y = \frac{-R}{2Q}$$

(3) IF $R - 4QS > 0$, THEN OF TWO ROOTS Y_{MAX} & Y_{MIN},

1) CHOOSE Y_{MAX} IF X FOR $Y_{MAX} > 0$

2) CHOOSE Y_{MIN} IF X FOR $Y_{MAX} < 0$

SINCE ONLY A PORTION OF THE INFINITE PLANE $ax + by + cz = 1$ IS PART OF THE CHUTE, IT IS NECESSARY TO DETERMINE WHETHER THE INTERCEPT POINT P LIES IN THE TRIANGLE WITH CORNERS P_1, P_2, P_3, OR OUTSIDE IT WHILE STILL WITHIN SOME LARGER EXTENSION OF THE PLANE, DEFINED BY P_X, P_Y, P_Z, ON THE NEXT PAGE

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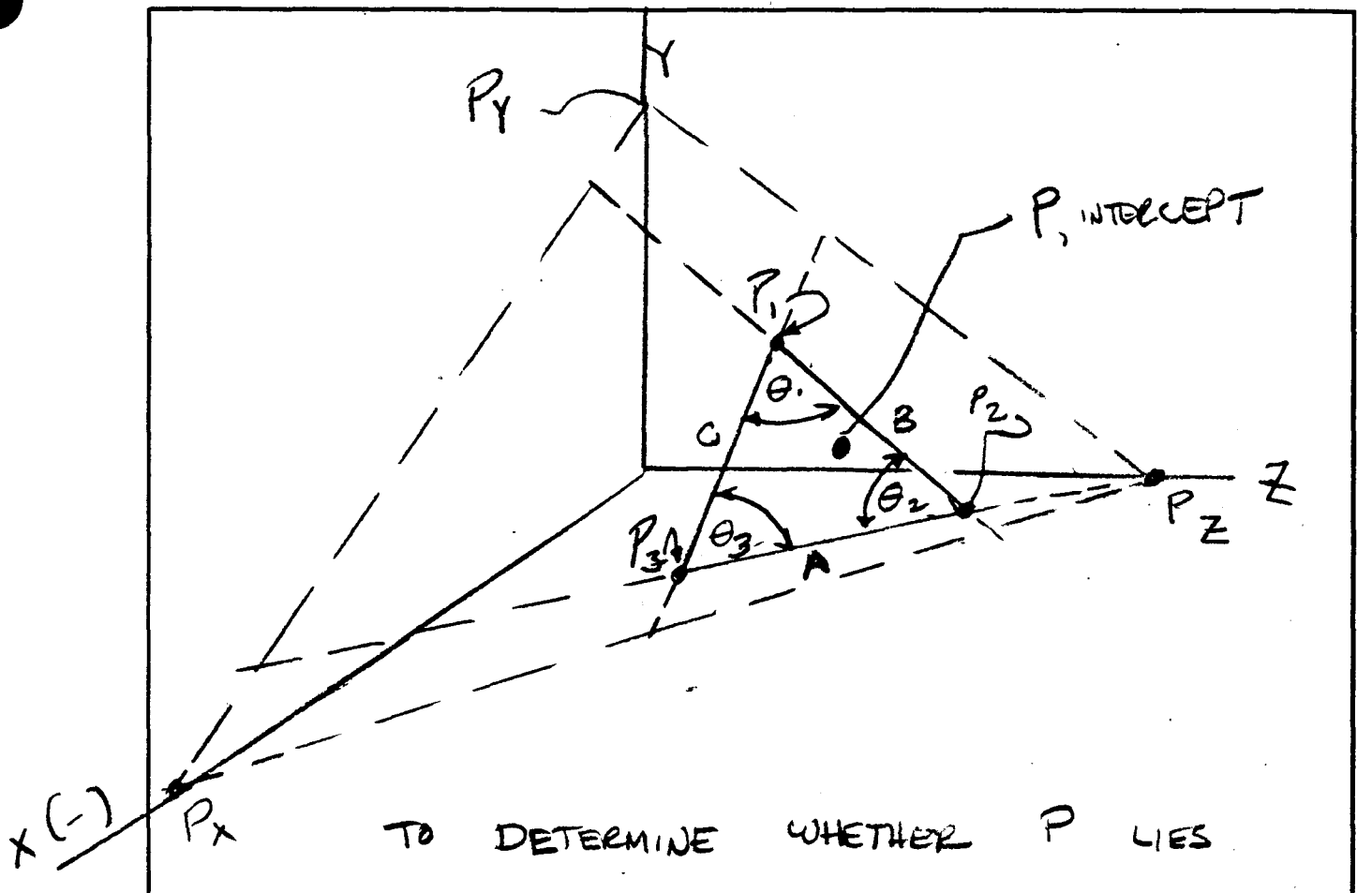

TO DETERMINE WHETHER P LIES WITHIN P_1, P_2, P_3, THE FOLLOWING MUST BE TRUE, INVOLVING ANGLES ($\angle$)

$$\angle P P_1 P_2 \leq \theta_1$$
$$\angle P P_1 P_3 \leq \theta_1$$
$$\angle P P_2 P_1 \leq \theta_2$$
$$\angle P P_2 P_3 \leq \theta_2$$
$$\angle P P_3 P_1 \leq \theta_3$$
$$\angle P P_3 P_2 \leq \theta_3$$

PREPARED BY	CHECKED BY	DATE	REV.

4. CON'T

WHERE

$$\Theta_1 = \cos^{-1}\left(\frac{A^2 - B^2 - C^2}{-2BC}\right)$$

$$\Theta_2 = \cos^{-1}\left(\frac{B^2 - C^2 - A^2}{-2CA}\right)$$

$$\Theta_3 = \cos^{-1}\left(\frac{C^2 - A^2 - B^2}{-2AB}\right)$$

AND A, B, & C ARE THE LENGTHS OF THE SIDES OF THE TRIANGES WITH VERTEX POINTS P_1, P_2 & P_3, GIVEN BY,

$$A^2 = (X_2 - X_3)^2 + (Y_2 - Y_3)^2 + (Z_2 - Z_3)^2$$

$$B^2 = (X_3 - X_1)^2 + (Y_3 - Y_1)^2 + (Z_3 - Z_1)^2$$

$$C^2 = (X_1 - X_2)^2 + (Y_1 - Y_2)^2 + (Z_1 - Z_2)^2$$

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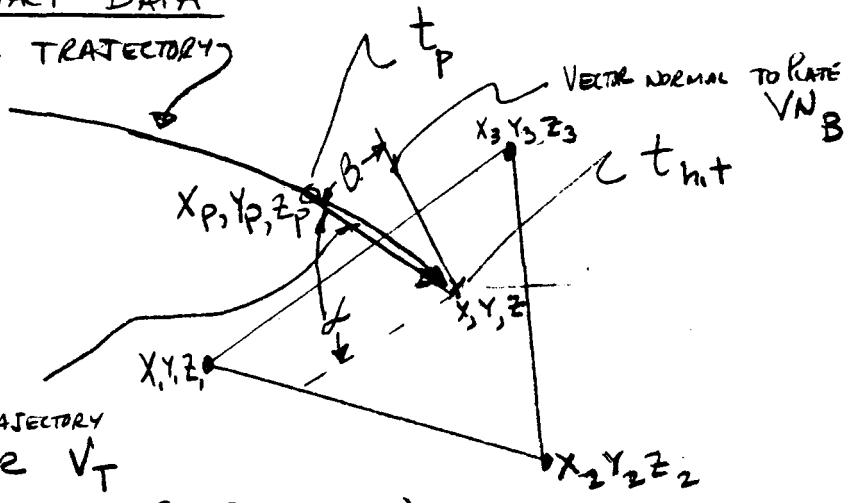
5. OTHER IMPACT DATA

FREE FALL TRAJECTORY



5.1 IMPACT VECTOR DEFINITION

TO DEFINE VELOCITY VECTOR DIRECTION, ASSUME SAME AS RSEGMENT FROM IMPACT POINT UP TO POINT ON TRAJECTORY 0.02 SECOND EARLIER

$$t_p = t_{hit} - .02$$

$$X_p = V\cos\theta \cdot t_p + X_0$$

$$Y_p = Y_0 - V\sin\theta \cdot t_p - 0.5\, g (t_p)^2$$

5.2 VECTOR NORMAL COMPONENTS : DOT CROSS PRODUCTS INVOLVING TRIANGULAR PLATE VERTEX COORDINATES

$$\overline{VN}_X = (Y_3 - Y_1)\cdot(Z_2 - Z_1) - (Y_2 - Y_1)(Z_3 - Z_1)$$

$$\overline{VN}_Y = (Z_3 - Z_1)(X_2 - X_1) - (Z_2 - Z_1)(X_3 - X_1)$$

$$\overline{VN}_Z = (X_3 - X_1)(Y_2 - Y_1) - (X_2 - X_1)(Y_3 - Y_1)$$

PREPARED BY	CHECKED BY	DATE	REV.

5. CON'T

$$\overline{VN}_B = \sqrt{\overline{VN}_x^2 + \overline{VN}_y^2 + \overline{VN}_z^2}$$

5.3 ANGLE BETWEEN IMPACT VECTOR & PLANE NORMAL

$$\overline{V}_{Tx} = X_p - x$$

$$\overline{V}_{Ty} = Y_p - Y$$

$$V_{Tz} = 0$$

$$\therefore \overline{V}_{TB} = \sqrt{\overline{V}_{Tx}^2 + \overline{V}_{Ty}^2}$$

$$\cos\beta = -\frac{\left(V_{Tx} \cdot VN_x + V_{Ty} \cdot V_{N_y}\right)}{VN_B \cdot V_{T_B}}$$

$$\alpha = 90 - \beta$$

5.4 VELOCITY VECTOR AFTER IMPACT

IMPACT VECTOR MAGNITUDES —

$$\overline{VV}_x = \overline{V}\cos\theta$$

$$\overline{VV}_y = \overline{V}\sin\theta - g(t_{h.t})$$

$$\overline{V}_{V_z} = 0$$

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S.0 CON'T

$$\overline{V_{VB}} = \sqrt{\overline{V_{Vx}}^2 + \overline{V_{Vy}}^2}$$

$$\cos(P) = \frac{\overline{V_{Vx}} \cdot \check{n}_x + \overline{V_{Vy}} \cdot \check{n}_y}{\overline{V_{VB}}}$$

WHERE $\check{n}_x$ & $\check{n}_y$ are X & Y COMPONENTS OF UNIT NORMAL TO PLANE

$$\cos(Q) = -\cos(P)$$

$$\sin(P) = \sqrt{1 - \cos^2(P)}$$

$$\tan(P) = \frac{\sin(P)}{\cos(P)}$$

FOR $P > \phi$, THE COMPONENTS OF THE VELOCITY VECTOR AFTER IMPACT ARE *

$$V_{EX} = \left(1 - \frac{\tan\phi}{\tan(P)}\right) \cdot \left(V_{Vx} + \check{n}_x \cdot \cos(P) \cdot V_{VB}\right)$$

$$V_{EY} = \left(1 - \frac{\tan\phi}{\tan(P)}\right) \cdot \left(V_{Vy} + \check{n}_y \cdot \cos(P) \cdot V_{VB}\right)$$

$$V_{EZ} = \left(1 - \frac{\tan\phi}{\tan(P)}\right) \cdot \left(\check{n}_z \cdot \cos(P) \cdot V_{VB}\right)$$

* SEE APPENDIX C, SECTION 3

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APPENDIX C

PHASE I DYNAMICS COMPUTER PROGRAM
FREE FALL AND IMPACT DYNAMICS PHASE

```
      C
      C
      C*************************************************************************
      C
      C                  COAL CHUTE PROGRAM   PHASE 1
      C                  ============================
      C
      C
      C        1.   USE  A GIVEN TRAJECTORY TO CREATE  AND LOCATE
      C             A CHUTE IN THE PATH OF THE COAL STREAM.     (HOPEFULLY)
      C        2.   'SHOOT' AT  THE CHUTE  FROM VARIOUS  PLACES ON THE INCOMING
      C             CONVEYOR BELT.
      C        3.   RECORD THE LOCATIONS OF IMPACT, NORMAL ANGLES ETC.
      C        4.   PASS THIS INFORMATION TO NEXT PROGRAM FOR TRACKING
      C             THE COAL SLIDING DOWN THE CHUTE.
      C
      C
      C
      C*************************************************************************
      C
0001        REAL IDLANG , LAMDA , KAPPA , MU , L11,L12,L13,L14,L15 ,KC
      C
0002        INTEGER IX,SX,BX,SECT,RUNNO
0003        COMMON THET ( 3,200 ) , ABC (3,200) , PT ( 3,3,200) , UN ( 3,200 )
      C
      C     NOTE  COMMON BELONGS IN INTERX
      C     ******************************
      C
0004        DIMENSION PX(6) , PTDAT (3,4,100) , PZ (6) , IPTS (4)
     *           ,H2(15) , HHH(1,3,3,2) , AIII(1,3,3,2)
     *           ,IV(2) , IVP(2) , AI(3,22) , DATE(5) , PPX(3) , VL(3)
     *           , PS(3) , APT(3,2)
     *           ,P4(3) , ISKIP(22)
     *           ,IT(22),ITP(22),AP(3,22)
     *           ,PABC(3,22),ANT(3),VV(3,22)
     *           ,TIME(22,3),AL(22,3),HPT(3,22,3)
      C
      C
0005        DATA HHH/ 5.07,6.24,7.62,  5.57,6.86,8.14,  5.99,7.50,8.76
     *           ,5.71,6.95,8.47,  6.04,7.52,9.05,  6.38,8.09,9.74/
      C
0006        DATA AIII/2.48,2.23,3.03,  2.75,2.29,2.91
     *           ,2.97,2.45,3.19,  2.35,2.85,3.36
     *           ,2.46,3.08,3.60,  2.58,3.31,3.94/
0007        DATA H2/15*0./
0008            DATA G/386.4/
      C
      C
```

```
      C*****************************************************************
0009  C     DIMENSION IPL(22,3)
      C
0010  C     NAMELIST /COLOUT/ LAMDA , XF , YF , ZF , Q , CHLN , NP, APT
     *                ,THETCN, H,A1,H2 , YMIN
      C
0011  C     NAMELIST /COALIN/ V,RADIUS,PHI,SECT,IDLANG,SURANG,BELTWD
     *                  , ND1 , ND2, FLAT , GAMMA,RADUP,DISP
     *                  ,MODET,EPS,RUNNO
     *               , PHIP, GAMD, ELI, KC, DELTF, NP, NT, BMAR, YAW,ZIH
      C
      C*****************************************************************
      C
0012  C     CALL DATCHR ( DATE)
0013  C     V = 120
      C
0014  C        ELI=1.
0015  C      EL=ELI
0016  C     JTP=99
0017  C        PHIP=35.
0018  C        PHIPR=PHIP/57.29578
0019  C     MU=TAN(PHIPR)
0020  C     GAMD = 50
0021  C     ELI = 1
0022  C     KC = 0.5
0023  C      DELTF = 50
0024  C     RADIUS = 12.
0025  C     PHI = 0.
0026  C     SECT = 21
0027  C     IDLANG = 35.
0028  C     SURANG = 25.
0029  C     BELTWD = 36.
0030  C     BMAR = 2
0031  C     ND1 = 6
0032  C     ND2 = 10.
0033  C     FLAT = 12.
0034  C     GAMMA = 0
0035  C     ZIH = 0
0036  C     YAW = 0
0037  C      RADUP=12.
0038  C     MODET = 1
0039  C     EPS = 10.
      C
0040  C     DISP = 6
0041  C     RTI = 36
0042  C     RT2 = 18
0043  C     XT = 12
0044  C     YT = 16
```

```
      C
      C****   GORSENS DEBUGINNG  CONSTANTS
0045        ND1 = 2
0046        ND2 = 2
0047        NT1 = 7
0048        NT2 = 8
      C
      C
      C.....................................................................
0049        READ ( 5,COALIN,END=600)
      C
0050        WRITE ( 6,905)
0051      905 FORMAT('1')
0052        WRITE ( 6,901)
0053      901 FORMAT(//)
0054        WRITE ( 6,916)
0055      916 FORMAT ( /1X,132('*'))
0056        WRITE ( 6,901)
0057        WRITE    ( 6,918) RUNNO ,DATE
0058      918 FORMAT ( 1X,10X,'BEGIN INDEPENDENT RUN OF COAL CHUTE DESIGNER',
     *           30X,'RUN NUMBER',13,5X,'DATE ',5A4)
0059        WRITE ( 6,919)
0060      919 FORMAT ( /1X,31X,10('.'),5X,
     *       'INDEPENDENT VARIABLES FOR THIS RUN ', 5X,10('.')/)
0061        WRITE(6,4000)
0062     4000   FORMAT(5X,' A. INPUT DATA')
0063        WRITE(6,4001)
0064     4001   FORMAT(//20X,' FEED CONVEYOR DATA',50X,' TORUS CHUTE DATA')
0065        WRITE(6,4002) V,RT1
0066     4002  FORMAT(//5X,' BELT SPEED  V , IPS.', F7.2 ,40X,' MAJOR RADIUS RT1,
     * IN',F7.2 )
0067        WRITE(6,4003) RADIUS,RT2
0068     4003  FORMAT(//5X,' PULLEY RADIUS R, IN.', F7.2 ,40X,' MINOR RADIUS RT2,
     * IN.',F7.2)
0069        WRITE(6,4004) BELTWD,GAMMA,YAW    , ZIH
0070     4004  FORMAT(//5X,' BELT WIDTH  BELTWD IN.',F7.2,40X,' ROTATIONS,DEG.',
     */70X,
     *' Z-AXIS-GAMMA',F7.2,/70X,' Y AXIS-YAW   ',F7.2,/70X,' X-AXIS-ZIH'
     *,F7.2)
0071        WRITE (6,4010) BMAR
0072     4010  FORMAT(//5X, 'BELT EDGE DISTANCE  BMAR IN.', F7.2)
0073        WRITE(6,4005) IDLANG,DISP
0074     4005  FORMAT (//5X, ' TROUGH ANGLE IDLANG DEG.',E7.2,40X' EXTRA LENGTH
     * DISP IN.', F7.2)
0075        WRITE(6,4006) SURANG,XT,YT
0076     4006  FORMAT(//5X, 'SURCHARGE ANGLE SURANG DEG.',F7.2,40X, ' COORDINATES
     *PRIOR TO ROTATION',/65X,' XT IN.',F7.2,/65X,' YT IN.', F7.2)
0077        WRITE(6,4007) PHI,NT1,NT2
```

```
0078        4007  FORMAT(//5X,' INCLINATION ANGLE PHI DEG.',F7.2,40X,' FLAT PLATE
                 *DIVISION',/65X,
                 *          ' MAJOR RADIUS-NT1',I7,/65X,' MINOR RADIUS-NT2',I7)
0079              WRITE ( 6,901)
0080              WRITE (6,4111)
0081        4111  FORMAT(//20X, ' RUN OF MINE COAL DATA',50X,' RUN CONVENTION
                 * CONSTANTS')
0082              WRITE (6,4112) GAMD
0083        4112  FORMAT(//5X,' DENSITY, GAMD  LBS./CU. FT. ', F7.2)
0084              WRITE (6,4113) DELTF , ELI
0085        4113  FORMAT(//5X,' EFFECTIVE ANGLE OF FRICTION  DELTF  DEG.',F7.2,
                 *40X,' FRICTION STEP DISTANCE - NOM.,ELI, IN.', F7.2)
0086              WRITE (6,4114) PHIP , SECT
0087        4114  FORMAT(//5X,' DYNAMIC ANGLE OF WALL FRICTION PHIP DEG.',F7.2, 40X,
                 *' NO OF STREAM SUBDIVISIONS SECT ', I7)
0088              WRITE ( 6,901)
0089              WRITE ( 6,COALIN)
0090              WRITE ( 6,916)
                C
                C          WRITE A CARD FOR PLOT PROGRAM IDENTIFIG  THE RUN NUMBER
                C
0091              WRITE ( 11,930) RUNNO , DATE
0092          930 FORMAT ( 40X,'RUN NO',I3,5X,'DATE ',5A4)
                C
                C.....
                C       USE BELTWD , SURANG , IDLANG  TO GET  'A1 , 'HH , AND '2 ARRAY
0093              IX = 1
0094              IF ( IDLANG.EQ. 35.) IX = 2
                C
0095              SX = 1
0096              IF ( SURANG.EQ. 25.) SX= 2
0097              IF ( SURANG.EQ.30.) SX=3
                C
0098              BX = 1
0099              IF ( BELTWD.EQ.36.) BX=2
0100              IF ( BELTWD.EQ.42.) BX=3
                C
0101              H = HHHI( 1,BX,SX,IX)
                CC
0102              A1 = A1I( 1,BX,SX,IX)
                C
0103              C = BELTWD - 2.*BMAR
0104              R= H/2. + C**2/(8.*H)
                C
0105              DLT = C/SECT
0106              MID = SECT/2 + 1
                C
0107              DO 40 K=1,SECT
```

```
0108              B = SQRT(R**2  -C**2/4)
0109              N = IABS(MID-K)
0110              XI = N*DLT
0111              A = SQRT( R**2 - XI**2)
0112              H2(K) = (A-B)/2.
0113           40 CONTINUE
               C      CALL TRAJECTORY TO GET 'THETCN'. ONLY.  THIS IS REQUIRED BY
               C      THE CHUTE DESIGN  SUBROTUINE 'KLUGE'
0114              RSE = RADIUS + A1
               C                 .. INPUT...../ ...  OUTPUT.......
0115              CALL TRAJ (V , RSE , PHI , NC , XO,YG, THETCN )
0116              THETR=RADC(THETCN)
               C.....................................................................
               C        CALL APPROPRIATE SUB-ROUTINE WHICH  GENERATES A COAL CHUTE.
               C.....................................................................
               C        REQUIRED INPUT WILL VARY.
               C        OUTPUT-  PTDAT   ARRAY CONTAING X,Y,Z COORDINATES
               C                 NP    NO OF 4 SIDED PLATES.
               C                YMIN      MINIMUM 'Y' (VERTICAL)  VALUE.
               C     GO TO 50
               C  51 CONTINUE
               C                  ............. INPUT FOR CONE CHUTE ,...........
               C     CALL CONE  ( RADIUS , A1 ,THETCN, V  , GAMMA, RADUP , BELTWD
               C    *           , DISP , H ,MODET , EPS
               C    *                  , YAW, RUNNO
               C    *             , FLAT , ND1 , ND2
               C                  .... OUTPUT OF CONE .....................
               C    *             ,PTDAT , NP , YMIN
               C    *             , LAMDA,CHLN
               C    *             ,BETA ,RHO , L11,L12,L13,L14,L15,XF,YF,ZF,Q )
               C     GOTO 55
0117           50 CONTINUE
0118              CALL TORUS ( RADIUS ,  GAMMA , BELTWD , DISP
                 *   ,RT1,RT2,NT1,NT2
                 *           , XT, YT, ZTH, YAW
               C                 .... OUTPUT OF  TORUS ......
               C
                 *    ,PTDAT,NP,YMIN,ZT,DZT,DETAT,XG,YG)
               C.....................................................................
               C
               C      PUT CHUTE GEOMETRY AND A ROLLER INTO A NASTRAN PLOT FILE
               C
0119           55 CONTINUE
0120              ID = 0
0121              NE = 0
               C     CALL ROLRI( NE,BELTWD,RADIUS,ID,PHI)
0122              NL = 1000
               C
```

```
0123              DO 90 J=1,NP
0124              DO 80 L=1,4
0125              CALL GRIDCD ( ID , PTDAT(1,L,J))
0126              IPTS(L) = ID
0127           80 CONTINUE
0128              CALL CQDCD( NE,IPTS)
0129           90 CONTINUE
                C
                C.....................................................................
                C
                C      CONVERT  PLATES INTO TRIANGULAR ELEMENTS FOR INTERNAL USE.
                C
                C      NP = NO. OF PLATE IN CHUTE   NT = NO. OF SUBDIVIDED TRIANGLES.
                C
0130              NT = 0
0131              DO 130 J=1,NP
                C
0132              NT = NT + 1
0133              DO 110 K=1,3
0134              DO 110 L=1,3
0135          110 PT(L,K,NT) = PTDAT(L,K,J)
                C
0136              NT = NT + 1
0137              M=0
0138               DO 125 K=1,4
0139              IF (K.EQ.2) GO TO 125
0140              M=M + 1
0141              DO 120 L=1,3
0142          120 PT(L,M,NT ) = PTDAT(L,K,J)
0143          125 CONTINUE
0144          130 CONTINUE
                C
0145              WRITE (7,COALIN)
0146               WRITE(7,3001)
0147          3001  FORMAT(' COORDS OF PLATE')
0148               DO 135 J=1,NP
0149               DO 135 K=1,4
0150               WRITE(7,151) (PTDAT(L,K,J),L=1,3)
0151          135  CONTINUE
0152               WRITE(7,3002)
0153          3002  FORMAT(' COORDS OF TRIANGLES')
0154               DO 138 J=1,NT
0155               DO 138 K=1,3
0156               WRITE(7,151) (PT(L,K,J),L=1,3)
0157          138  CONTINUE
                C
                C
                C.....................................................................
```

```
C   CONSTRUCT UNIT NORMALS TO EACH TRIANGLE AND STORE IN UN(3,80) .
C.....
C
0158          WRITE(7,3003)
0159    3003   FORMAT(' UNIT NORMALS ARE')
0160          DO 140 J=1,NT
C
0161          X1= PT(1,1,J)
0162          Y1= PT(2,1,J)
0163          Z1= PT(3,1,J)
C
0164          X2=PT(1,2,J)
0165          Y2=PT(2,2,J)
0166          Z2=PT(3,2,J)
C
0167          X3=PT(1,3,J)
0168          Y3=PT(2,3,J)
0169          Z3=PT(3,3,J)
C
C
0170          VNX= (Y3-Y1)*(Z2-Z1)-(Y2-Y1)*(Z3-Z1)
0171          VNY= (Z3-Z1)*(X2-X1) -(Z2-Z1)*(X3-X1)
0172          VNZ=(X3-X1)*(Y2-Y1)-(X2-X1)*(Y3-Y1)
0173          VNB=SQRT(VNX**2+VNY**2+VNZ**2)
C
0174          UN(1,J)=VNX/VNB
C
0175          UN(2,J)=VNY/VNB
C
0176          UN(3,J)=VNZ/VNB
0177           WRITE(7,151) (UN(L,J),L=1,3)
0178    151   FORMAT (3F20.8)
C
0179    140   CONTINUE
C
C       GET A,B , C  AND THETAS FOR AL  PLATES.
C
0180          DO 150 J=1,NT
0181          CALL PLATE( PT(1,1,J) , PT(1,2,J) , PT(1,3,J) ,
             *                ABC(1,J) , THET(1,J) )
0182      150 CONTINUE
0183           WRITE(7,3004)
0184    3004   FORMAT(' ABC FOR PLATES ARE')
0185          DO 153 J=1,NT
0186    153    WRITE(7,151) (ABC(L,J),L=1,3)
0187          WRITE(7,3006)
0188    3006   FORMAT(' THETAS FOR PLATES ARE')
0189          DO 154 J=1,NT
```

```
0190                WRITE(7,151) (THETA(I,J),I=1,4)
0191          154   CONTINUE
              C
              C.....................................................................
              C     PRINT OUT INPUT CONDITIONS  , CALCULATED PARAMETERS AND FINAL
              C     CHUTE  XYZ GEOMETRY.
              C
0192                WRITE ( 6,905)
0193                WRITE ( 6,901)
0194                WRITE ( 6,920)
0195          920 FORMAT ( 31X,10('='),5X
                 *,'SUMMARY OF KEY CALCULATED PARAMETERS AND FINAL PLATE '
                 *      ,'COORDINATES',5X,10('=')/)
0196                WRITE(6,5000)
0197          5000   FORMAT(5X,' B. OUTPUT DATA ')
0198                WRITE(6,5001) THETCN,H,BETAT,YMIN
0199          5001   FORMAT(//10X,' PULLEY CONTACT DEP. ANGLE,DEG., ',F7.2,
                 */10X,' INITIAL LOAD HEIGHT,IN. ',F7.2,
                 * /10X,' TORUS CUTOFF ANGLE,DEG.',F7.2,
                 */10X,' MINIMUM Y COORDINATE',F7.2)
              C     WRITE ( 6,COLOUT)
0200                DO 160 L=1,NP
0201                WRITE ( 6,901)
0202                WRITE ( 6,907) L
0203          907 FORMAT ( 36X,'PLATE',I3/)
0204                WRITE ( 6,921) ((PTDAT(J,K,L),K=1,4),J=1,3)
0205          921 FORMAT ( 1X,4(5X,F15.3))
0206          160 CONTINUE
              C
              C
              C*********************************************************************
              C                   END  OF CHUTE  DEFINITION PHASE.
              C*********************************************************************
              C
              C        A THIS POINT A 'COAL CHUTE' OF TRIANGUALR FLAT PLATES IS CREATED
              C        IN THE 'PT' ARRAY.  TEST IT BY 'SHOOTING' ATE IT FROM
              C        VARIOUS POINTS AND HEIGHTS ON THE BELT.
              C        RECORD THE LOCATIONS OF INITIAL IMPACT AND OTHER ANGLES ETC.
              C
0207          165 CONTINUE
0208                NHC = 0
0209                NE = 2000
0210                DO 510 II=1,3
0211                NS=)
0212                JF = 0
              C
0213                DO 500 LL=1,SECT
              C
```

```
0214                ZO = BMAR + DLT/2. + ( LL-1)*DLT
                C   GET TRAJECTORY  FROM INITIAL CONDITIONS
0215                IF ( II.EQ. 1) A=0.
0216                IF ( II.EQ.2) A = H2(LL)
0217                IF (II.EQ. 3) A=2.*H2(LL)
0218                RSE = RADIUS + A
0219                VZ = V
0220                XO=RSE*SIN(THETR)
0221                YO=RSE*COS(THETR)
                C   GO THRU ALL PLATES . CHEXK IF TRAJECTORY UNTERSECTS PLAT.
                C    GET TIME OF INTERSECT AND FIN MINUM TIME.
0222                THIT = 1.0F10
0223                JP = 0
                C
0224                NII=0
0225                NTT = NT+1
0226              189  CONTINUE
0227                DO 200 J = 1,NTT
0228                IF(J.EQ.NTT) ZO = ZO + 0.05
0229                IF(NII.EQ.1) GO TO 200
0230                IF(J.EQ.NTT) NII = 1
0231                IF(J.EQ.NTT) GO TO 189
0232                KP = (J-1)/2 + 1
0233                CALL INTERX ( J, XO,YO,ZO,VZ,THETCN, PZ , TS , TAL, TKAP,TDEL,VL
                   * ,PHIP)
0234                IF ( TS.LT.0) GOTO 200
0235                IF ( TS.GT.THIT) GOTO 200
                C
                C    THIS IS THE NEAREST HIT SO FAR.  SAVE   TIME ETC.
                C
0236                DO 190 L=1,6
0237              190 PX(L) = PZ(L)
0238                THIT = TS
0239                ALPHA = TAL
0240                KAPPA = TKAP
0241                DELTA = TDEL
0242                JP = KP
0243                  JT=J
0244                 GO TO 222
0245              200 CONTINUE
0246              222     CONTINUE
                C
0247              908 FORMAT (//1X,I2,'  VEL=',F6.1,'   PHI=',F4.1,
                   *       '   XO,YO,ZO=',3F7.2,'  DELTRAD=',F5.2)
0248                IF  ( JP .NE. 0) GOTO 255
0249              903 FORMAT ( 1X,4X,'MISSED')
0250                GO TO 500
                C
```

```
C       A THIS POINT  THE JP'TH PLATE WAS  INTERSECT BY THE TRAJ.
C       THE  XYZ OF THE INTERSECTION IS IN THE PX ARRAY.
C
  255  CONTINUE
       NHC = NHC + 1
       NS=NS+1
       IT(NS)=JT
       DO 195 KK=1,3
       VV(KK,NS)=VL(KK)
       AI(KK,NS)=PX(KK)
1001     FORMAT(//1X,2F7.2,I3)
195    CONTINUE
       IF(NS.NE.SECT) GO TO 333
       IF(II.NE.2) GO TO 333
       WRITE(7,3010)
3010    FORMAT(' THE VELOCITIES AFTER IMPACT ARE')
       DO 196 I=1,NS
196    WRITE(7,151) (VV(KK,I),KK=1,3)
       WRITE(7,3020)
3020    FORMAT(' THE COORDS OF HIT POINTS ARE')
       DO 197 I=1,NS
197    WRITE(7,151) (AI(KK,I),KK=1,3)
       WRITE(7,3025)
3025    FORMAT(' THE SURFACES ARE')
       DO 199 I=1,NS
       WRITE(7,3026) IT(I)
3026    FORMAT(I8)
199    CONTINUE
333    CONTINUE
C
  909 FORMAT ( 5X,'HIT PLATE',I3,' AT',3F8.3,5X,'TIME=',F6.3
     *         /5X,'ALPHA=',F6.1,'   KAPPA=',F6.1,'   DELTA=',F6.1)
       TIME(LL,II)=THIT
       AL(LL,II)=ALPHA
       HPT(1,LL,II)=PX(1)
       HPT(2,LL,II)=PX(2)
       HPT(3,LL,II)=PX(3)
       IPL(LL,II)=JP
C
C       DRAW LINE CONNECTING HIT POINTS OD  CHUTE .
C
       IF ( JF.EQ. 0) GOTO 280
       CALL GRIDCD ( ID, PX)
       IPTS(1) = ID
       CALL GRIDCD ( ID, PS)
       IPTS(2) = ID
       CALL CHARCD ( NE, IPTS )
  280 CONTINUE
```

```
0291              JF = 1
0292              DO 290 J=1,3
0293            290 PS(J)=PX(J)
0294            500 CONTINUE
0295          999   CONTINUE
0296            510 CONTINUE
0297                WRITE(6,905)
0298                WRITE(6,901)
0299                WRITE(6,916)
0300                WRITE(6,901)
0301                 WRITE(6,6000)
0302          6000   FORMAT(//5X,' B. OUTPUT DATA')
0303                WRITE(6,6001)
0304          6001   FORMAT(//5X,' 1. HIT DATA')
0305                WRITE(6,6002)
0306          6002   FORMAT(//5X,'  STREAM                                  C.G.
                    *                          BOTTOM                       TOP')
0307                WRITE(6,6003)
0308           6003 FORMAT(!              TIME      ANGLE      X       Y       Z
                    *                  ANGLE     X      Y     PLATE          ANGLE     X
                    *   Y    PL')
0309                DO 8000 LL=1,SECT
0310                WRITE(6,6010) LL,TIME(LL,2),AL(LL,2),(HPT(K,LL,2),K=1,3),
                    * IPL (LL,2),AL(LL,1),(HPT(K,LL,1),K=1,2),IPL(LL,1),
                    * AL(LL,3),(HPT(K,LL,3),K=1,2),IPL(LL,3)
0311           6010 FORMAT(//1X,I6,F9.2,4F9.1,I6,5X,3F9.1,I6,5X,3F9.1,I5)
0312          8000   CONTINUE
0313            600 CONTINUE
0314                STOP
0315            910 FORMAT(1X,3F15.5)
0316                END
```

```
0001          SUBROUTINE TORUS (R, GAMA, BL, DOF, RT1, RT2, NT1, NT2
*                             , XTT, YTT, ZTHH, YAWW
*   ,P,NP,YMIN,ZTT,DZTT,BETATT,XGG,YGG)
0002          DIMENSION P(3,4,1)
0003          DIMENSION PA(3) , PB(3)
0004          DATA PI/3.14159/
0005          NAMELIST / TORS / XT, YT, ZT, ALP, BETAT, XG, YG, GAMMA
*                             , ZTH,YAW, DZT
* , ZU, YU, ZYGR, APS, YUR, XUR, ZUR
* ,TYUR,TXUR,TZUR,XLR,YLR,ZLR,TXLR,TYLR,TZLR
C
C       DU CHUTE COORDINATES PRE-PROCESSING
C
0006          GAMMA = GAMA
0007          GMR   = RADC(GAMMA)
0008          SNG = SIN(GMR )
0009          CSG = COS(GMR)
0010          TNG = TAN(GMR)
0011          XT = XTT
0012          YT = YTT
0013          ZTH = ZTHH
0014          ZHR = RADC(ZTH)
0015          SNZ = SIN(ZHR)
0016          CSZ = COS(ZHR)
0017          YAW = YAWW
0018          YWR = RADC(YAW)
0019          REAL LAMDA, LMDA
0020          LAMDA = YAW
0021          ZT = ZTT
0022          DZT = DZTT
C
0023          T = ( YT + XT*TNG) / ( RT1 + RT2 )
0024          ALPR = ARSIN(T)
0025          ALP = DEGC(ALPR)
0026          CSA = COS(ALPR)
C
0027          ZT = ( RT1 + RT2)*(1.-CSA)
0028          F = SNZ * CSG
0029          Q = ARSIN (F)
0030          T = ( RT1 + RT2 - ( BL + DOF)/(COS(YWR)))/ ( RT1 +RT2)
0031          BETR = ARCOS (T) + Q
0032          BETAT = DEGC(BETR)
0033          BETAT = 105.335
0034          BETR = RADC(BETAT)
0035          BETATT=DEGC(BETR)
C
0036          ZT = -ZT + RT1 + RT2
C
```

```
      C
      C*************************************************************************
      C
      C        CREAT A PHYSICAL  'TORUS' SHAPED CHUTE IN PT ARRAY
      C
0037        NP = 0
      C
0038        BETD = BETR/ NT1
0039        SCR = ( PI + PI/3)/ NT2
      C
0040        DO 200 J=1,NT1
0041        A1 = PI + (J-1)*BETD
0042        A2 = PI +  J*BETD
0043        SNB1 = SIN(A1)
0044        CSB1 = COS(A1)
      C
0045        SNB2 = SIN(A2)
0046        CSB2 = COS(A2)
      C
0047        NX = NT2 + 1
0048        DO 150 K=1,NX
0049        PSI = 1.5*PI - (K-1)*SCR+ PI/3
      C
      C
0050        CSY = COS(PSI)
0051        SNY = SIN(PSI)
0052        PA(1) = RT2*SNY
0053        PA(2) = (RT1 - RT2*CSY) * SNB1
0054        PA(3) = (RT1-RT2*CSY)*CSB1
      C
0055        PB(1) = RT2*SNY
0056        PB(2) = (RT1-RT2*CSY)*SNB2
0057        PB(3) = (RT1-RT2*CSY)*CSB2
0058        IF ( K.EQ. 1) GOTO 140
      C
0059        CALL LOADP ( P,2,NP,PA)
0060        CALL LOADP ( P,3,NP,PB)
      C
0061        IF ( K.EQ. NX ) GOTO 150
0062      140 CONTINUE
0063        NP = NP + 1
0064        CALL LOADP ( P,1,NP , PA )
0065        CALL LOADP ( P,4,NP , PB )
0066      150 CONTINUE
0067      200 CONTINUE
      C
0068        J0 = NP
0069        J1 = NP-1
```

```
0070              J2 = NP-2
0071              J3 = NP-3
0072              J4 = NP-4
0073              J5 = NP-5
0074              J6 = NP-6
0075              IF (NT2.EQ.8) J6 = NP
0076              J7 = NP-7
0077              IF (NT2.EQ.7) J7 = NP
0078              IF (NT2.EQ.8) J7 = NP-1
0079              J8 = NP-8
0080              IF (NT2.EQ.7) J8 = NP- 1
0081              IF (NT2.EQ.8) J8 = NP-2
0082              J9 = NP-9
0083              IF (NT2.EQ.7) J9 = NP- 2
0084              IF (NT2.EQ.8) J9 = NP-3
0085              J10= NP-10
0086              IF (NT2.EQ.7) J10= NP- 3
0087              IF (NT2.EQ.8) J10= NP-4
0088              J11= NP-11
0089              IF (NT2.EQ.7) J11= NP- 4
0090              IF (NT2.EQ.8) J11= NP-5
0091              J12= NP-12
0092              IF (NT2.EQ.7) J12= NP- 5
0093              IF (NT2.EQ.8) J12= NP-6
0094              J13= NP-13
0095              IF (NT2.EQ.7) J13= NP- 6
0096              IF (NT2.EQ.8) J13= NP-7
0097              EXT = DDF
0098              UY = P(2,1,J13)
0099               UZ = P(3,1,J13)
0100              LY = P(2,4,J13)
0101              LZ = P(3,4,J13)
0102              SLOPE = (LY - UY)/(LZ - UZ)
0103              SLOPE = ATAN(SLOPE)
0104              SNSL = SIN(SLOPE)
0105              CSSL = COS(SLOPE)
0106              ESNS = EXT*SNSL
0107              ECSS = (EXT) * (CSSL)
0108              NP = NP + 1
0109              P(1,1,NP) = P(1,4,J13)
0110              P(2,1,NP) = P(2,4,J13)
0111              P(3,1,NP) = P(3,4,J13)
0112              P(1,2,NP) = P(1,3,J13)
0113              P(2,2,NP) = P(2,3,J13)
0114              P(3,2,NP) = P(3,3,J13)
0115              P(1,3,NP) = P(1,3,J13)
0116              P(2,3,NP) = P(2,3,J13) + ESNS
0117              P(3,3,NP) = P(3,3,J13) + ECSS
```

```
0115              P(2,3,NP) = P(2,3,J13) + ESNS
0116              P(3,3,NP) = P(3,3,J13) + ECSS
0117              P(1,4,NP) = P(1,4,J13)
0118              P(2,4,NP) = P(2,4,J13) + ESNS
0119              P(3,4,NP) = P(3,4,J13) + ECSS
0120              NP = NP + 1
0121              P(1,1,NP) = P(1,4,J12)
0122              P(2,1,NP) = P(2,4,J12)
0123              P(3,1,NP) = P(3,4,J12)
0124              P(1,2,NP) = P(1,3,J12)
0125              P(2,2,NP) = P(2,3,J12)
0126              P(3,2,NP) = P(3,3,J12)
0127              P(1,3,NP) = P(1,3,J12)
0128              P(2,3,NP) = P(2,3,J12) + ESNS
0129              P(3,3,NP) = P(3,3,J12) + ECSS
0130              P(1,4,NP) = P(1,4,J12)
0131              P(2,4,NP) = P(2,4,J12) + ESNS
0132              P(3,4,NP) = P(3,4,J12) + ECSS
0133              NP = NP + 1
0134              P(1,1,NP) = P(1,4,J11)
0135              P(2,1,NP) = P(2,4,J11)
0136              P(3,1,NP) = P(3,4,J11)
0137              P(1,2,NP) = P(1,3,J11)
0138              P(2,2,NP) = P(2,3,J11)
0139              P(3,2,NP) = P(3,3,J11)
0140              P(1,3,NP) = P(1,3,J11)
0141              P(2,3,NP) = P(2,3,J11) + ESNS
0142              P(3,3,NP) = P(3,3,J11) + ECSS
0143              P(1,4,NP) = P(1,4,J11)
0144              P(2,4,NP) = P(2,4,J11) + ESNS
0145              P(3,4,NP) = P(3,4,J11) + ECSS
0146              NP = NP + 1
0147              P(1,1,NP) = P(1,4,J10)
0148              P(2,1,NP) = P(2,4,J10)
0149              P(3,1,NP) = P(3,4,J10)
0150              P(1,2,NP) = P(1,3,J10)
0151              P(2,2,NP) = P(2,3,J10)
0152              P(3,2,NP) = P(3,3,J10)
0153              P(1,3,NP) = P(1,3,J10)
0154              P(2,3,NP) = P(2,3,J10) + ESNS
0155              P(3,3,NP) = P(3,3,J10) + ECSS
0156              P(1,4,NP) = P(1,4,J10)
0157              P(2,4,NP) = P(2,4,J10) + ESNS
0158              P(3,4,NP) = P(3,4,J10) + ECSS
0159              NP = NP + 1
0160              P(1,1,NP) = P(1,4,J9 )
0161              P(2,1,NP) = P(2,4,J9 )
0162              P(3,1,NP) = P(3,4,J9 )
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0163              P(1,2,NP) = P(1,3,J9 )
0164              P(2,2,NP) = P(2,3,J9 )
0165              P(3,2,NP) = P(3,3,J9 )
0166              P(1,3,NP) = P(1,3,J9 )
0167              P(2,3,NP) = P(2,3,J9 ) + ESNS
0168              P(3,3,NP) = P(3,3,J9 ) + ECSS
0169              P(1,4,NP) = P(1,4,J9 )
0170              P(2,4,NP) = P(2,4,J9 ) + ESNS
0171              P(3,4,NP) = P(3,4,J9 ) + ECSS
0172              NP = NP + 1
0173              P(1,1,NP) = P(1,4,J8 )
0174              P(2,1,NP) = P(2,4,J8 )
0175              P(3,1,NP) = P(3,4,J8 )
0176              P(1,2,NP) = P(1,3,J8 )
0177              P(2,2,NP) = P(2,3,J8 )
0178              P(3,2,NP) = P(3,3,J8 )
0179              P(1,3,NP) = P(1,3,J8 )
0180              P(2,3,NP) = P(2,3,J8 ) + ESNS
0181              P(3,3,NP) = P(3,3,J8 ) + ECSS
0182              P(1,4,NP) = P(1,4,J8 )
0183              P(2,4,NP) = P(2,4,J8 ) + ESNS
0184              P(3,4,NP) = P(3,4,J8 ) + ECSS
0185              NP = NP + 1
0186              P(1,1,NP) = P(1,4,J7 )
0187              P(2,1,NP) = P(2,4,J7 )
0188              P(3,1,NP) = P(3,4,J7 )
0189              P(1,2,NP) = P(1,3,J7 )
0190              P(2,2,NP) = P(2,3,J7 )
0191              P(3,2,NP) = P(3,3,J7 )
0192              P(1,3,NP) = P(1,3,J7 )
0193              P(2,3,NP) = P(2,3,J7 ) + ESNS
0194              P(3,3,NP) = P(3,3,J7 ) + ECSS
0195              P(1,4,NP) = P(1,4,J7 )
0196              P(2,4,NP) = P(2,4,J7 ) + ESNS
0197              P(3,4,NP) = P(3,4,J7 ) + ECSS
0198              IF (NT2.EQ.7) GO TO 220
0199              NP = NP + 1
0200              P(1,1,NP) = P(1,4,J6 )
0201              P(2,1,NP) = P(2,4,J6 )
0202              P(3,1,NP) = P(3,4,J6 )
0203              P(1,2,NP) = P(1,3,J6 )
0204              P(2,2,NP) = P(2,3,J6 )
0205              P(3,2,NP) = P(3,3,J6 )
0206              P(1,3,NP) = P(1,3,J6 )
0207              P(2,3,NP) = P(2,3,J6 ) + ESNS
0208              P(3,3,NP) = P(3,3,J6 ) + ECSS
0209              P(1,4,NP) = P(1,4,J6 )
0210              P(2,4,NP) = P(2,4,J6 ) + ESNS
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0211          P(3,4,NP) = P(3,4,J6 ) + ECSS
0212          IF (NT2.EQ.8) GO TO 220
0213          NP = NP + 1
0214          P(1,1,NP) = P(1,4,J5 )
0215          P(2,1,NP) = P(2,4,J5 )
0216          P(3,1,NP) = P(3,4,J5 )
0217          P(1,2,NP) = P(1,3,J5 )
0218          P(2,2,NP) = P(2,3,J5 )
0219          P(3,2,NP) = P(3,3,J5 )
0220          P(1,3,NP) = P(1,3,J5 )
0221          P(2,3,NP) = P(2,3,J5 ) + ESNS
0222          P(3,3,NP) = P(3,3,J5 ) + ECSS
0223          P(1,4,NP) = P(1,4,J5 )
0224          P(2,4,NP) = P(2,4,J5 ) + ESNS
0225          P(3,4,NP) = P(3,4,J5 ) + ECSS
0226          NP = NP + 1
0227          P(1,1,NP) = P(1,4,J4 )
0228          P(2,1,NP) = P(2,4,J4 )
0229          P(3,1,NP) = P(3,4,J4 )
0230          P(1,2,NP) = P(1,3,J4 )
0231          P(2,2,NP) = P(2,3,J4 )
0232          P(3,2,NP) = P(3,3,J4 )
0233          P(1,3,NP) = P(1,3,J4 )
0234          P(2,3,NP) = P(2,3,J4 ) + ESNS
0235          P(3,3,NP) = P(3,3,J4 ) + ECSS
0236          P(1,4,NP) = P(1,4,J4 )
0237          P(2,4,NP) = P(2,4,J4 ) + ESNS
0238          P(3,4,NP) = P(3,4,J4 ) + ECSS
0239          NP = NP + 1
0240          P(1,1,NP) = P(1,4,J3 )
0241          P(2,1,NP) = P(2,4,J3 )
0242          P(3,1,NP) = P(3,4,J3 )
0243          P(1,2,NP) = P(1,3,J3 )
0244          P(2,2,NP) = P(2,3,J3 )
0245          P(3,2,NP) = P(3,3,J3 )
0246          P(1,3,NP) = P(1,3,J3 )
0247          P(2,3,NP) = P(2,3,J3 ) + ESNS
0248          P(3,3,NP) = P(3,3,J3 ) + ECSS
0249          P(1,4,NP) = P(1,4,J3 )
0250          P(2,4,NP) = P(2,4,J3 ) + ESNS
0251          P(3,4,NP) = P(3,4,J3 ) + ECSS
0252          NP = NP + 1
0253          P(1,1,NP) = P(1,4,J2 )
0254          P(2,1,NP) = P(2,4,J2 )
0255          P(3,1,NP) = P(3,4,J2 )
0256          P(1,2,NP) = P(1,3,J2 )
0257          P(2,2,NP) = P(2,3,J2 )
0258          P(3,2,NP) = P(3,3,J2 )
```

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0259              P(1,3,NP) = P(1,3,J2 )
0260              P(2,3,NP) = P(2,3,J2 ) + ESNS
0261              P(3,3,NP) = P(3,3,J2 ) + ECSS
0262              P(1,4,NP) = P(1,4,J2 )
0263              P(2,4,NP) = P(2,4,J2 ) + ESNS
0264              P(3,4,NP) = P(3,4,J2 ) + ECSS
0265              NP = NP + 1
0266              P(1,1,NP) = P(1,4,J1 )
0267              P(2,1,NP) = P(2,4,J1 )
0268              P(3,1,NP) = P(3,4,J1 )
0269              P(1,2,NP) = P(1,3,J1 )
0270              P(2,2,NP) = P(2,3,J1 )
0271              P(3,2,NP) = P(3,3,J1 )
0272              P(1,3,NP) = P(1,3,J1 )
0273              P(2,3,NP) = P(2,3,J1 ) + ESNS
0274              P(3,3,NP) = P(3,3,J1 ) + ECSS
0275              P(1,4,NP) = P(1,4,J1 )
0276              P(2,4,NP) = P(2,4,J1 ) + ESNS
0277              P(3,4,NP) = P(3,4,J1 ) + ECSS
0278              NP = NP + 1
0279              P(1,1,NP) = P(1,4,J0 )
0280              P(2,1,NP) = P(2,4,J0 )
0281              P(3,1,NP) = P(3,4,J0 )
0282              P(1,2,NP) = P(1,3,J0 )
0283              P(2,2,NP) = P(2,3,J0 )
0284              P(3,2,NP) = P(3,3,J0 )
0285              P(1,3,NP) = P(1,3,J0 )
0286              P(2,3,NP) = P(2,3,J0 ) + ESNS
0287              P(3,3,NP) = P(3,3,J0 ) + ECSS
0288              P(1,4,NP) = P(1,4,J0)
0289              P(2,4,NP) = P(2,4,J0 ) + ESNS
0290              P(3,4,NP) = P(3,4,J0 ) + ECSS
0291          220 CONTINUE
0292              DIMENSION NOPLT(50) , INX(50)
0293              DATA NOPLT/ 1,2,3,4,5,6,7,8,9,10,11,12,17,25,33,41,0/
              C
              C
0294              IF ( NOPLT(1) .EQ. 0) GOTO 290
              C
0295              K=0
0296              J=1
0297              DO 250 M=1,NP
              C
0298              IF ( NOPLT(J).NE. M)  GOTO 240
0299              J=J + 1
0300              GOTO 250
              C
0301          240 CONTINUE
```

```
0302                K=K + 1
0303                INX(K) = M
0304              250 CONTINUE
0305                NP = K
                C
0306                DO 280 J=1,NP
0307                DO 280 K=1,4
0308              280 CALL LOADP ( P , K , J , P(1,K,INX(J) ) )
0309              290 CONTINUE
                C
                C
                C       ROTATE TORUS AN MOVE IT TO REQUIRED PPSITION
                C
0310                CALL THREED ( ZIH, LAMDA, GAMMA, XT, YT, ZT)
                C
0311                YMIN = 1.0E50
0312                DO 300 J=1,NP
0313                DO 300 K=1,4
0314                CALL THRZYX ( X , Y , Z , P(1,K,J) , P(2,K,J) , P(3,K,J) )
0315                P(1,K,J) = X
0316                P(2,K,J) = Y
0317                P(3,K,J) = Z
0318                YMIN = AMIN1( P(2,K,J) , YMIN)
0319              300 CONTINUE
0320                RETURN
0321                END
```

```
0001                  SUBROUTINE CONE ( RADIUS , A1 , THETCN , V , GAMMA,RADUP ,BELTWD
                     *                , DISP , N ,MODET , EPS
                     *                          , YAW, RUNNO
                     *                , FLAT , ND1 , ND2
                     *                , PTDAT , DP , YMIN
                     *                , LAMDA,CHLN
                     *                ,BETA ,RHO , L11,L12,L13,L14,L15,XF,YF,ZF,Q )
                     C
0002                  INTEGER RUNNO
0003                  DIMENSION PTDAT ( 3,4,1) , APT(3,2)
                     C
                     C.....
                     C
                     C       FOR THIS TRAJECTORY GET CRITICAL PARAMETERS FOR CHUTE DESIGN.
                     C
0004                  WRITE ( 6,905)
0005                905 FORMAT ('1')
                     C                        ..........  INPUT TO KLUGE  ..........
0006                  CALL KLUGE ( RADIUS , A1 ,THETCN, V  , GAMMA, RADUP , BELTWD
                     *           , DISP , N ,MODET , EPS
                     *           , YAW, RUNNO
                     C
                     C              ..... OUTPUT FROM KLUGE .....
                     *      ,LAMDA , XF , YF , ZF , Q , CHLN , APT
                     *  ,BETA,RHO,L11,L12,L13,L14,L15 )
                     C
0007                  YFM = -YF
                     C
                     C          HAS KLUGE BLOWN UP AGAIN ..............
                     C
0008                  IF ( ABS(XF) .GT. 1000.) GOTO 55
0009                  IF ( ABS(YF) .GT. 1000.) GOTO 55
0010                  IF ( MODET .EQ. 2) GOTO 60
0011                  DO 50 J=1,3
0012                  DO 50 K=1,2
0013                  IF ( ABS( APT(J,K)).GT. 1000.) GOTO 55
0014                 50 CONTINUE
0015                  GO TO 60
0016                 55 CONTINUE
0017                  WRITE ( 6,921)
0018                921 FORMAT ( ////1X,25('STOP ')//25X,
                     * ' PROGRAM STOPPED BECAUSE OF IMPOSSIBLE NUMBERS CALCULATED BY',
                     * ' THE KLUGE ROUTINE'//1X,25('STOP '))
0019                  STOP
                     C
                     C       CREATE THE CHUTE IN THE PTDAT ARRAY IN XYZ COORDINATES.
                     C
0020                 60 CONTINUE
```

```
0021            IF ( MODIT.EQ. 2) APT(I,I) = 0.
0022            IF (RUNNO.GE.30) FLAT = 0
                C
                C                    .... OUTPUT FROM CHUTE ....
0023            CALL CHUTE ( PTDAT , NP
                C
                C                    ......... INPUT TO CHUTE ...!.........
                *                   ,FLAT , LAMDA , NU1,NU2 , W , RADUP , CHLN , APT )
                C
                C
                C.....................................................................
                C
                C     ROTATE   CHUTE AND MOVE IT TO CALCULATED POSITINE
                C
0024            IF (RUNNO.GE.30) YAW = BETA
                C                    THREE ANGLES      /THREE OFFSETS
0025            CALL THREED ( 0., GAMMA, YAW, 0., 0., 0.)
                C
0026            YMIN = 1.0E10
0027            DO 75 J=1,NP
0028            DO 75 K=1,4
0029            CALL THRZYX (Z, X ,Y, PTDAT(3,K,J),PTDAT(1,K ,J),PTDAT(2,K,J))
0030            PTDAT(1,K,J)=X+XF
0031            PTDAT(2,K,J)=Y+YFM
0032            PTDAT(3,K ,J)= Z + ZF
0033            YMIN = AMIN1( YMIN , PTDAT(2,K,J))
0034         75 CONTINUE
0035            RETURN
0036            END
```

```
0001        SUBROUTINE KEOGC ( R , A1,  THTA, VS, GMA, L, BL, DUF,H
           *      ,MODEL,EPS
           *      , YAW, KONKO
           *      ,LAMDA , XS,YS,ZS, G , CHEN ,APT
           *  ,DELTA,EDO,LL1,LL2,LL3,LL4,LL5 )
          C
0002        IMPLICIT REAL ( A-Z)
0003        INTEGER MODEL
0004        INTEGER KONKO
0005         REAL LL1,LL2,LL3,LL4,LL5
          C
0006        DIMENSION APT(3,2)
          C
0007        RADC(X) = X/57.29578
0008        DEGC(X) = X*57.29578
          C
0009        DATA G/386.42 , PI/3.141592
          C
0010        EPR = RADC(EPS)
0011        TNE = TAN(EPR)
          C
0012        RA1 = R + A1
0013        RH = A + L
          C
0014        THT = RADC(THTA)
0015        SNT = SIN(THT)
0016        CST = COS(THT)
          C
0017        GAMA = RADC(GMA)
0018        SNG = SIN(GAMA)
0019        CSG = COS(GAMA)
0020        TNG = TAN(GAMA)
          C
0021      1 CONTINUE
          C
          C                       PAGE 1
          C
0022        THA = ( 18*24.1 - RH *SNT)/(VS*CST)
0023        THB = (-VS*SNT + SQRT((VS**2)*SNT**2 + 2.*G*(24.*RH *CST)))/G
0024        TH = AMIN1(THA,THB)
0025        YH = .5*G*TH**2 + VS*SNT*TH-RH *CST
          C
0026        ZHR = ATAN((VS*SNT+G*TH)/(VS*CST))
0027        ZHD = DEGC(ZHR)
          C
0028        STYH = PI/2. -ZHR
0029        PSIH = DEGC(STYH)
          C
```

```
0030                STYH = PI/2. - ZHR
0031                PSIH = DTGLE(STYH)
                    C
0032                XH=VS*CST*(TH+TH*SNT
0033                XH = XH-(H-A1)*SIN(ZHR)
0034                YA=YH+(H-A1)*COS(ZHR)
                    C
                    C                          PAGE 1A
                    C
0035                K1 = .5*(G**2)*TN
                    C
                    C  EQ . 46 TO 49
0036                K19 = VS*SNT*TNE
0037                K20 = VS*CST-K19
0038                K21 = RA1*CST + YH
0039                K22 = VS*(SNT+CST*TNE)
0040                K23 = RA1*SNT-XH
                    C
0041                K2 = G*(VS*CST-.5*K20) + K19
0042                K3 = VS*(CST*K22 - SNT*K20) + G*(K23-K21*TNE)
0043                K4 =  (K22*K23 + K20*K21)
                    C
                    C     SELECT PROPER CALCULATION FOR TI DEPENDING ON MODE T PARAMETER
                    C
                    C
0044                IF ( MODET .NE. 1) GOTO 50
0045                RCL = K3**2-4*K2*K4
0046                X  = (-K3+SQRT(RCL)) / (2*K2)
0047                Y  = (-K3-SQRT(RCL)) / (2*K2)
0048                C = AMIN1(X,Y)
0049                IF ( C.LT.TH) C=AMAX1(X,Y)
0050                TI = C
0051                GOTO 200
                    C
0052             50 CONTINUE
0053                IF ( MODET .NE. 2) GOTO 60
0054                TI = TH
0055                RA1=RH
0056                GO TO 200
                    C
                    C
                    C*****************************************************************
                    C
                    C                    CUBIC SOLUTION FOR TI =F(K1,K2,K3,K4)
                    C
                    C                 PAGE 2A
                    C
0057             60 CONTINUE
```

```
0058                K6 = K7/11
0059                K7 = K3/11
0060                K8 = K4/11
0061                K9 = 3.*(E6/3.)**2-K7
0062                K10 = -2.*(E6/3.)**3 + E/(8.0/3. - K8
0063                K11 = K9/3
0064                K12 = K10/2
0065                K13 = K12**2 - K11**3
                C
                C                       PAGE 2B
                C
0066                W3 = 1./3.
0067                IF ( K13.LE. 0.) GOTO 100
0068                RK 13 = SQRT(K13)
0069                T1A = POOT(K12+RK13,W3) + ROOT(K12-RK13,W3) -K6/3.
0070                GOTO 150
                C
0071              100 CONTINUE
0072                IF ( K13.LT. 0.) GOTO 110
0073                T1A = 2.*ROOT(K12,W3) -K6/3.
0074                T1B = -ROOT(K12,W3) -K6/3.
0075                GO TO 150
                C
0076              110 CONTINUE
0077                X = 2*SQRT(K11)
0078                Y = ARCOS( K12/(K11*SQRT(K11)))
0079                Z = PI/3.
0080                T1A = X*COS(Y/3.) -K6/3.
0081                T1B = X*COS(Y/3. + 2.*Z) - K6/3.
0082                T1C = X*COS(Y/3. + 4.*Z) -.K6/3.
                C
0083              150 CONTINUE
                C
0084                X = T1A
0085                IF ( X.LT. T1B ) X=T1B
0086                IF ( X.LT.T1C) X = T1C
0087                T1 = X
0088                GOTO 200
                C
                C
                C                       PAGE 2C
                C
0089              200 CONTINUE
                C
0090                IF ( T1.LT. T1 ) STOP
0091                IF ( T1 .LT. 0. ) STOP
                C
```

```
      X1 = VS*CSI*I1 + BAI*SGI
      Y1 = .5*G*I1**2 + VS*SGI*I1 - BAI*CSI
      ZIR = ATAN((VS*SGI + G*I1)/ (VS*CSI))
      ZI1 = DEGC(ZIR)
C
      SIY = PI/2. - ZIR -EPR
      TN1 = TAN(SIY)
      PSI = DEGC(SIY)
C
      BET = ATAN( TN1*SNG)
      BETA = DEGC(BET)
      IF (RUNNO.GE.30) BET = 0
      IF(RUNNO.GE.30) L = 18
C
      H = L + BL*TAN(BET)/(2.*CSG)
      Q1=SIN(BET)*TAN(GAMA+BET)+COS(BET)
      Q=SIN(BET)*((BL+DUE)/COS(GAMA+BET)+ L*TAN(GAMA)*Q1)+L
C
C
      U = H*(CSG  + SNG*TAN(GAMA+BET))
      W = H*(CSG+SNG*TAN(GAMA-BET))
C
C                          PAGE 3
C
      A = (U+W)/2.
      B = SQRT( (A+ (U-W)*SNG*TAN(BET)/2.)**2 -
     *        (((U-W)/2.)**2)*CSG**2)
      K5 = SQRT( A**2*TN1**2+B**2)
      DY1=A**2*TAN(SIY)/K5
      DX1 = K5-TN1*DY1
      X2 = X1-DX1
      Y2 = Y1 + DY1 -(U-W)/2.
      Y3 = Y2-BL*TNG/2.
      IF(MODET.EQ.2) Y3=Y3-1.
      X3 = X2
      BTR = RADC(BETA)
      CBR = COS (BTR)
      SBR = SIN (BTR)
      X4 = X3 + CBR + (BL/2) * SBR
      X5 = X4 - X3
      IF ( RUNNO.GE.30) X3 = X3 - X5
      Z3 = 0.
C
C                          PAGE 4
C
      M2 = H- ( DY1-(U-W)/2.)*SNG*TAN(BET)
      F = (DY1-(U-W)/2.)*CSG
```

```
0127                LAMDR = ARSIN(1/P1)
0128                LAMDR = DEG(LAMDR)
0129                CHLN = ( G - L ) / TAN(BET)
0130                RHOR=ATAN(TN1*CSG)
0131                RHR = DEG(RHOR)
                    C
                    C
                    C
                    C  CALCULATE COORDINATES OF 'A' PLATE. PUT IN APT ARRAY FOR USE IN CHUTE ROUTINE
                    C
0132                K31 = DY1 - ( D-K)/2. +( Y1 -YH)
0133                K32 = BL*TNG/2.
0134                K33 = K31 - K32
0135                K34 = K33/TNG
                    C
                    C
0136                DY1 = ( BL+K34)*SNG +1.
0137                DY2 = K33*CSG  +1.
0138                APT(2,1) = DY2
0139                APT(2,2) = DY1
                    C
                    C
0140                DK3 = K23*SNG
0141                DW1 = ( BL +K34)*CSG - DK2 - K34*CSG
                    C
0142                APT(3,1) = -DK2
0143                APT(3,2) = DW1
                    C
                    C
0144                R2 = L - DW2*TAN(BET)
0145                R1 = L + DW1*TAN(BET)
0146                CSL=COS(LAMDR)
0147                SNL=SIN(LAMDR)
0148                DU1 = R1*CSL - TAN(RHOR)*(DY1-R1*SNL)
0149                DU2 = R2*CSL - TAN(RHOR) * (DY2-R2*SNL)
                    C
0150                APT(1,2) = DU1
0151                APT(1,1) = DU2
                    C
0152                 L11=SQRT((APT(1,2)-APT(1,1))**2+(APT(2,3)-APT(2,1))**2+
                   1(APT(3,2)-APT(3,1))**2)
0153                 L12=SQRT((Q*CSL-APT(1,2))**2+(Q*SNL-APT(2,2))**2+(CHLN-APT(3,2))
                   1**2)
0154                 L13=SQRT((L*CSL-Q*CSL)**2+(L*SNL-Q*SNL)**2+CHLN**2)
0155                 L14=SQRT((APT(1,1)-L*CSL)**2+(APT(2,1)-L*SNL)**2+APT(3,1)**2)
0156                 L15=SQRT((Q*CSL-APT(1,1))**2+(Q*SNL-APT(2,1))**2+(CHLN-APT(3,1))
                   1**2)
0157                 RETURN
```

```
0158          900 FORMAT ( 1X,4E20.10)
            C.......................................
            C
            C          DEBUGGING LOGIC
            C
            C.......................................
0159              DEBUG INIT(P,A1,    VS,GMA,I,BL,DDF,H
                 *        ,THA,THB,TB,YB,    XB,XA,YA
                 *        ,K1,K2,K3,K4,K5,K6,K7,K8,K9,K11,K12,K13,RK13,K10
                 *        ,K19,K20,K21,K22,K23,K23,K31,K32,K33,K34,DV1,DV2
                 *        ,TTA,TTB,TTC,T1,G1,DW2,DW1,R2,R1,DU1,DU2
                 *        ,X1,Y1,M,Q,D,W
                 *        ,A,B,    DY1,DX1,X2,Y2,Y3,X3,Z3
                 *        ,THTA,LAMDA,RHO,BETA,Z11,Z10,EPS,PS1,PSIH
                 *        ,L11,L12,L13,L14,L15
                 *        ,H2,F ,CHLN,APT )
0160              AT 1
0161              END
```

```
0001              SUBROUTINE INTERX( N,XO,YO,ZO,V,ANG,PX,THIT,ALPHA,KAPPA,DELT,VE
                 *  ,PHIP)
0002                REAL K,KAPPA,MU
                C
0003              COMMON THET ( 3,200 ) , ABC (3,200) , PT ( 3,3,200) , UN ( 3,200 )
                C
0004              DIMENSION PX(6) , DUM(3) , ANT(3)
0005              DIMENSION VE(3)
                C
0006              DATA G/386.4/
                C
0007               PHIPR=PHIP/57.29578
0008              MU=TAN(PHIPR)
0009              A = ABC(1,N)
0010              B= ABC(2,N)
0011              C=ABC(3,N)
                C
0012              IF ( A.EQ. 0. ) A=1.0E-10
                C
0013              THIT= -1.
0014              THR = RADC(ANG)
0015              VC= V*COS(THR)
0016              VCQ = VC**2
                C
                C       GET ALPHA BETA GAMMA
                C
0017              AL = -.5*G/VCQ
0018              BET = G*XO/VCQ-TAN(THR)
0019              GAM = YO + XO*TAN(THR)-.5*G*XO**2/VCQ
                C
0020              K=1.-C*ZO
                C
0021              Q= ( AL*B**2)/A**2
0022              R = (-AL*2.*K*B)/A**2 - BET*B/A  -1.
0023              S = (AL*K**2)/A**2 + BET*K/A  + GAM
                C
0024              Y = -S/R
0025              IF ( Q.EQ. 0. ) GOTO 110
                C
0026              RCL = R**2-4*Q*S
0027              IF ( RCL.GE.0.) GOTO 100
0028            900 FORMAT(///10X,'NEG ROOT INTERX')
0029              RETURN
                C
                C
0030            100 CONTINUE
0031              RCL = SQRT(RCL)
0032              Y1 = (-R+RCL)/(2*Q)
```

```
0033                Y2 = (-R-RCL)/(2*Q)
0034                Y = AMAX1(Y1,Y2)
                C
0035              110 CONTINUE
0036                X= ( K-B*Y) / A
0037                IF(X.LE.0.) Y=AMIN1(Y1,Y2)
0038                X = (K - B*Y)/A
                C
0039                PX(1) = X
0040                PX(2) = Y
0041                PX(3) = Z0
                C
                C       IS THIS INTERSECT POINT ON THE PHYSICAL PLATE
                C
0042                TH1 = DEGC(THET(1,N))
0043                TH2 = DEGC(THET(2,N))
0044                TH3 = DEGC(THET(3,N))
                C
0045                CALL PLATE ( PX, PT(1,1,N) , PT(1,2,N) , DUM,ANT )
                C
                C        ANT(2)=P P1 P2      ANT(3) =P P2 P1
                C
0046                D2 = DEGC(ANT(2))
0047                D3 = DEGC(ANT(3))
0048                NN = 0
0049                IF (D2.GT.TH1) NN = 1
0050                IF (D3.GT.TH2) NN= 1
0051                IF(N.NE.47.AND.N.NE.48.AND.N.NE.61.AND.N.NE.62.AND. NN.EQ.1)RETURN
0052                IF(N.EQ.47.OR.N.EQ.48.OR.N.EQ.61.OR.N.EQ.62)
                   *WRITE(6,111) D2,TH1,D3,TH2,N,NN
0053             111  FORMAT (4(E8.4,1X),2(I3,1X))
                C
0054                CALL PLATE( PX,PT(1,2,N) , PT(1,3,N) , DUM , ANT )
                C
                C       ANT(2) = P P2 P3        ANT(3) = P P3 P2
                C
0055                D2 = DEGC(ANT(2))
0056                D3 = DEGC(ANT(3))
0057                IF (D2.GT.TH2) NN = 1
0058                IF (D3.GT.TH3) NN = 1
0059                IF(N.NE.47.AND.N.NE.48.AND.N.NE.61.AND.N.NE.62.AND. NN.EQ.1)RETURN
0060                IF(N.EQ.47.OR.N.EQ.48.OR.N.EQ.61.OR.N.EQ.62)
                   *WRITE(6,111) D2,TH2,D3,TH3,N,NN
                C
0061                CALL PLATE( PX, PT(1,3,N) , PT(1,1,N) , DUM,ANT)
                C
                C        ANT(2)= P P3 P1       ANT(3) = P P1 P3
                C
```

```
0062              D2 = DEGC(ANT(2))
0063              D3 = DEGC(ANT(3))
0064              IF (D2.GT.TH3) NN = 1
0065              IF (D3.GT.TH1) NN = 1
0066              IF(N.NE.47.AND.N.NE.48.AND.N.NE.61.AND.N.NE.62.AND. NN.EQ.1)RETURN
0067              IF(N.EQ.47.OR.N.EQ.48.OR.N.EQ.61.OR.N.EQ.62)
                 *WRITE(6,111) D2,TH3,D3,TH1,N,NN
0068              IF(NN.EQ.1) RETURN
                  C
                  C       THIS   POINT IS ON THE N TH PLATE IN TH E LIST
                  C     GET TIME OF INTERSECTION
                  C
0069              THIT = (X-X0)/VC
                  C
                  C     THIS SECTUON  CALCULATE ALPHA THE ANGLE OF INTERSECT OF THE YRAJECTORY
                  C     WITH THE PLATE.
                  C
                  C
                  C     GET LOCATION PF POINT  NEAR POINT OF INTERSECTION
                  C
0070              TP = THIT- .02
0071              XP = VC*TP + X0
0072              YP = Y0 - V*SIN(THR)*TP - .5*G*TP**2
                  C
0073              PX(4) = XP
0074              PX(5) = YP
0075              PX(6) = Z0
                  C
0076              X1 = PT(1,1,N)
0077              Y1 = PT(2,1,N)
0078              Z1 = PT(3,1,N)
                  C
0079              X2 = PT(1,2,N)
0080              Y2 = PT(2,2,N)
0081              Z2 = PT(3,2,N)
                  C
0082              X3 = PT(1,3,N)
0083              Y3 = PT(2,3,N)
0084               Z3 = PT(3,3,N)
                  C
                  C     ***** GET ALPHA *****
                  C
0085              VNX = (Y3-Y1)*(Z2-Z1)-(Y2-Y1)*(Z3-Z1)
0086              VNY = (Z3-Z1)*(X2-X1) - (Z2-Z1)*(X3-X1)
0087              VNZ = (X3-X1)*(Y2-Y1) - (X2-X1)*(Y3-Y1)
                  C
0088              VNB = SQRT ( VNX**2 + VNY**2 + VNZ**2)
                  C
```

```
0089                VTX = XP - X
0090                VTY = YP-Y
                C
0091                VTB = SQRT( VTX**2 + VTY**2)
                C
0092                CSB = -(VTX*VNX + VTY*VNY)/ ( VNB*VTB)
                C
                C
0093             1     CONTINUE
0094                VVX=VC
0095                VVY=V*SIN(THR)-G*THIT
0096                VVB=SQRT(VVX**2+VVY**2)
0097                 CSP=-(VVX*UN(1,N)+VVY*UN(2,N))/VVB
0098                 CSQ=-CSP
0099                 IF(CSQ.GT.1) CSP=1
0100                XXX = 1.-CSP**2
0101                SNP = SQRT(XXX)
0102                 TNP=SNP/CSP
                C  CALC. VELOCITIES OF STREAM AFTER IMPACT
                C
                C
                C
0103                IF (TNP.GT.MU) GO TO 50
                C
0104                VE(1)=0.
                C
0105                VE(2)=0.
                C
0106                VE(3)=0.
0107                GO TO 60
0108             50 CONTINUE
                C
0109                  VE(1)=(1.-MU/TNP)*(VVX+UN(1,N)*CSP*VVB)
                C
0110                  VE(2)=(1.-MU/TNP)*(VVY+UN(2,N)*CSP*VVB)
                C
0111                 VE(3)=(1.-MU/TNP)*(UN(3,N)*CSP*VVB)
                C
                C
0112             60 CONTINUE
                C
0113                BETA = ARCOS(CSB)
0114                BETA = DEGC(BETA)
0115                ALPHA = 90. - BETA
                C
                C       *****   GET KAPPA   ******
                C
0116                K = VNX*VTY - VNY*VTX
```

```
      C
0117        VTSX = VNY*K - VNZ*VNZ*VTX
0118        VTSY = - VNZ*VNZ*VTY + VNX*K
0119        VTSZ = VNX*VNZ*VTX + VNY*VNZ*VTY
      C
0120        VTSB = SQRT( VTSX**2 + VTSY**2 + VTSZ**2)
0121        VBBR = SQRT ( (X3-X1)**2 + (Y3-Y1)**2 + (Z3-Z1)**2 )
      C
0122        K = ( (X3-X1)*VTSX+ (Y3-Y1)*VTSY + (Z3-Z1)*VTSZ )/(VTSB*VBBR)
0123        KAPPA = DEGC( ARCOS(K))
      C
      C
      C   *****  GET DELTA ******
      C
0124        VGX = -VNX*VNZ
0125        VGY = -VNZ*VNZ
0126        VGZ = VNZ*VNY + VNX*VNX
      C
0127        VGGB = SQRT ( VGX**2 + VGY**2 + VGZ**2)
0128        K = ( (X3-X1)*VGX + (Y3-Y1)*VGY + (Z3-Z1)*VGZ) / (VBBR*VGGB)
      C
0129        DELT = DEGC(ARCOS(K))
      C
0130        RETURN
0131        END
```

```
0001            SUBROUTINE DIST ( P,NT2)
0002            DIMENSION P(3,4,1)
0003            DIMENSION
               *ADIS(40), BDIS(40),CDIS(40),DDIS(40), EDIS(40), FDIS(40), GDIS(40)
0004            DO 100 J = 1, NT2
0005            R=(P(1,1,J) - P(1,2,J))**2
0006            S=(P(2,1,J)-P(2,2,J))**2
0007             T=(P(3,1,J)- P(3,2,J))**2
0008             ADIS(J) = SQRT( R+S+T)
0009            R=(P(1,2,J)-P(1,3,J))**2
0010            S=(P(2,2,J)-P(2,3,J))**2
0011            T=(P(3,2,J)-P(3,3,J))**2
0012            BDIS(J) = SQRT( R+T+S)
0013             R=(P(1,3,J)-P(1,4,J))**2
0014             S=(P(2,3,J)-P(2,4,J))**2
0015            T=(P(3,3,J)-P(3,4,J))**2
0016            CDIS(J) = SQRT( R+S+T)
0017            R=(P(1,4,J)-P(1,1,J))**2
0018            S=(P(2,4,J)-P(2,1,J))**2
0019            T=(P(3,4,J)-P(3,1,J))**2
0020            DDIS(J) = SQRT(R+S+T)
0021            R=(P(1,1,J)-P(1,3,J))**2
0022            S=(P(2,1,J)-P(2,3,J))**2
0023            T=(P(3,1,J)-P(3,3,J))**2
0024            EDIS(J) = SQRT( R+T+S)
0025            FDIS(J) = (BDIS(J))/2
0026            GDIS(J) = (DDIS(J))/2
0027        100 CONTINUE
0028            WRITE (6,900) ADIS,BDIS,CDIS,DDIS,EDIS,FDIS,GDIS
0029        900 FORMAT(1X,10F13.4)
0030            RETURN
0031            END
```

APPENDIX D

MATH MODEL FOR PHASE II DYNAMICS
FRICTIONAL FLOW PHASE

MATHEMATICAL MODEL OF

COAL TRANSFER CHUTE

Fairchild Space and Electronics Corp.

76 - 37

Jenike & Johanson, Inc.
Storage and Flow of Solids
No. Billerica, Massachusetts

October 1976

MATHEMATICAL MODEL OF COAL TRANSFER CHUTE

Fairchild Space and Electronics Corp.

Scope of the work

A mathematical model of the sliding of coal on a belt-to-belt transfer chute is presented along with a calculation procedure to solve the various equations describing the flow of the coal.

1. Introduction

1.1 Design concepts

The typical approach to transferring material from one belt to another, particularly at a right angle, is simply to drop the material off the end of the initial belt into an enclosure. The material is thereby confined to the belt area during the period that it must be accelerated to the speed of the receiving belt. The depth of material may vary from side-to-side on the belt and bouncing of particles is likely to occur. This type of approach has been used with some degree of success for several years. With low speed belt transfer conditions, the results are reasonable; however, with high speed belt transfer, problems of wear, spillage, and non-uniformity of loading on the belt become significant.

The ideal belt-to-belt transfer chute would transfer the material cross-section from the initial belt essentially intact to the receiving belt - in the same direction and at the same speed as the belt. Such a transfer would eliminate belt wear, dusting and any off-center loading on the receiving belt. In addition, this should be accomplished with a minimum amount of head room for underground coal mining applications. These constraints, combined with the flow properties of coal, constitute a well-posed problem.

The chute must be able to handle reasonable variations in coal properties and incoming belt speed, and also cope with transient starting and stopping conditions. The chute must be fairly easy to fabricate and be equipped with replaceable wear liners. The allowable degree of deviation from an ideal transfer of the coal must be determined by empirical data and field experience.

1.2 Mathematical approach

The mathematical analysis of the behavior of material on transfer chutes consists of a dynamic force analysis with restraints. Forces acting on a stream of material sliding on a chute can be summarized as follows: gravity, normal and frictional forces from the chute surface, lateral forces between streams of material, and the stream-to-stream frictional drag. These forces are created by or restrained by the physical shape of the chute and are limited by the friction coefficient on the chute, the plastic deformation of the coal and the coal slip-line condition between streams. In addition, continuity of the solid provides the means for determining the thickness of the stream as a function of velocity of the material.

1.3 Assumptions for mathematical model

a) The coal sliding on the chute behaves as a Coulomb frictional solid in a steady flow state. This means that the coal is yielding at all times in accordance with the effective yield concepts.* This yield condition is described entirely by the effective angle of internal friction δ.

b) The frictional drag τ on the chute is proportional to the pressure σ_N perpendicular to the chute surface

$$\tau = \mu \sigma_N$$

where $\mu = \tan \phi'$

In general ϕ' (the kinematic angle of surface friction) is not constant but a function of σ_N to be determined empirically.

c) The sliding sheet of coal can be approximated by a series of interacting streams of rectangular cross-section, constantly in lateral contact with each other.

d) Compressive yielding, or shortening of the width between streams, occurs at a stress level on the interactive surface of adjoining streams equal to the yield stress for converging plastic flow across the stream.

---

* A. W. Jenike, Bulletin No. 108, "Gravity Flow of Bulk Solids," and Bulletin 123, "Storage and Flow of Solids," University of Utah, Engineering Experiment Station, Salt Lake, Utah

J. R. Johanson, "Stress and Velocity Fields in the Gravity Flow of Bulk Solids," ASME Journal of Applied Mechanics, Vol 31, Ser E, No. 3 Sept. 1964.

e) Expansive yielding, or increasing of the width between streams, occurs at a stress level on the interactive surface of adjoining streams equal to the yield stress for diverging plastic flow across the stream. Note that the diverging stress level is much lower than the converging stress.

f) Forces on the various stream faces are in balance with the various components of acceleration and gravitational force components (Newton's law applies).

g) The streams are, in general, of different thicknesses and, because of the force balance, the thinner stream has a larger interactive stress level than the thicker adjoining stream. Consequently, if two adjoining streams converge, only the thinner stream yields in compression and becomes thicker. If two adjoining streams diverge, only the thicker stream yields in expansion and becomes thinner.

h) The streams are initially defined by slicing the coal on the incoming conveyer belt into vertical strips of a given area and uniform velocity and hence a given mass flow rate that is maintained constant throughout the calculation for that stream.

i) The chute catches the incoming stream of coal sufficiently close to the direction of the trajectory from the conveyor belt as to negate any effects of bouncing of lumps of coal.

j) The chute consists of a single continuously smooth surface in space. If this is not satisfied (e.g. if the surface is specifie as a series of flat plates joined at the edges), the non-smooth surface must be approximated by a smooth surface by means of a suitable interpolation scheme.

k) The stress acting in the direction of flow is always in a state of yielding and hence is constant on a given element.

1.4 Use of the report

The report is divided into subsections each describing a particular part of the theory with the last section providing the method of calculation relating all of the parts. The theory is not exact nor

does it cover all possible chute configurations. For example, chute edges are not treated by the theory but would have to be taken into account in some approximate manner at a later date. Before any extensive calculation of a variety of surfaces or any parametric study of chute geometry is undertaken, the theory should be verified with small-scale experiments. These experiments should be related to the full scale conditions by the scaling laws discussed in the following section.

2. Velocity and Length Scaling for Subscale Experiments

Two experiments involving belts and chutes will be called "dynamically similar" if

1) The experiments involve the same belt and chute materials, and the same coal.
2) The setups are geometrically similar, with characteristic lengths ℓ_1 and ℓ_2 respectively.
3) The corresponding belt velocities are proportional with characteristic velocities V_1 and V_2 respectively
4) $$\frac{\ell_1 g}{V_1^2} = \frac{\ell_2 g}{V_2^2}, \text{ whence } \frac{\ell_1}{V_1^2} = \frac{\ell_2}{V_2^2} \qquad (2.1)$$

If two experiments are dynamically similar, the coal trajectories in the chutes should be geometrically similar; one experiment can be used to predict the results of the other.*

For example, suppose we wish to model a chute for a 36" wide, 600 fpm belt, with a 1/6 scale chute and a 6" wide belt. The required subscale belt velocity V_2 is given by

$$\frac{V_2}{V_1} = \sqrt{\frac{\ell_2}{\ell_1}} = \sqrt{\frac{1}{6}} = 0.408 \text{ , whence}$$

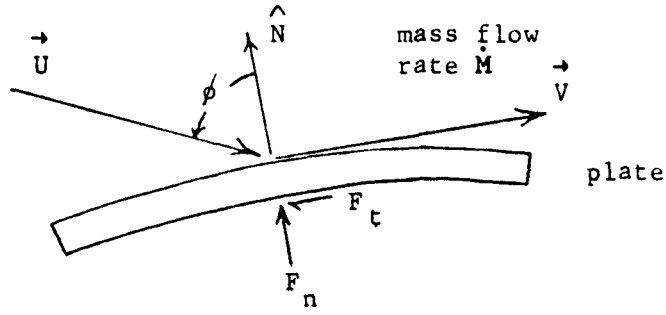
$$V_2 = (0.408)\ (600 \text{ fpm}) = 245 \text{ fpm}$$

$\frac{\ell g}{V^2}$ is the only dimensionless quantity which can be formed from the gravitational acceleration g, the characteristic length ℓ, and the characteristic velocity V. When the equations governing the motion of the coal are written in dimensionless form, the parameter $\frac{\ell g}{V^2}$ appears naturally.

---

* Some reservations: the largest lumps in the coal should be small compared to the characteristic length scales of both experiments. Effects due to air trapped in the coal should be negligible

3. Coal stream - plate impact model



The impacting coal is regarded as being composed of a number of individual streams. Consider one such stream. Let $\vec{U}$ and $\vec{V}$ be the coal velocity vectors just before and just after impact, respectively. Let $\hat{N}$ be the unit vector normal to the curved plate at the impact point. The outgoing stream is assumed to be tangent to the plate at the impact point, and coplanar with $\vec{U}$ and $\hat{N}$.

Let F_n, F_t be the total normal and tangential impact forces exerted on the stream by the plate. A momentum balance in the + N direction gives $F_n = \dot{M}\ U \cos\phi$, with $U = |\vec{U}|$ the speed of the incoming stream, $\dot{M}$ (Slugs/sec.) the mass flow rate associated with this stream, and ϕ the angle between the incoming velocity vector $\vec{U}$ and the normal vector $\hat{N}$. (see diagram)

We have $F_t = \mu F_n$, where μ is the coefficient of sliding friction for this particular plate material and type of coal. Another momentum balance, in the $\vec{V}$ direction, now leads to

$$V = U(\sin\phi - \mu\cos\phi) \qquad (3.1)$$

$$[\tan\phi > \mu] \qquad (3.2)$$

$$V = 0 \qquad (3.3)$$

$$[\tan\phi \leq \mu] \qquad (3.4)$$

with $V = |\vec{V}|$ the speed of the stream after impact.

In vector form, the impact model may be summarized as

$$\left.\begin{aligned} &\vec{V} = \left(1 - \frac{\mu}{\tan \phi}\right) \left(\vec{U} + \hat{N}\, U \cos\phi\right) \\ &\text{with } U \cos \phi = - U \cdot \hat{N} \\ &[\tan \phi > \mu] \end{aligned}\right\} \qquad (3.5)$$

After impacting on the plate, the coal stream is assigned a width as described in section 5 below.

Equation (3.3) predicts that the outgoing velocity will be zero whenever $\tan \phi \leq \mu$. If this should occur, any subsequent calculation of either sliding or free fall should start with zero initial velocity at the point of impact. In practice, this condition should be avoided because of the excessive coal build-up or chute wear that will occur at the impact point.

4. Equations of motion for steady sliding of a layer of coal on a curved plate

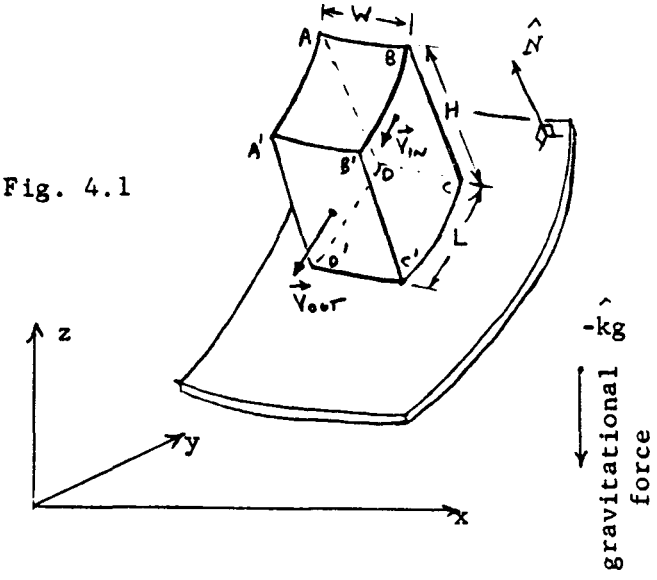


Fig. 4.1

Adopt a rectangular Cartesian coordinate system (x, y, z) in which the + z axis points vertically upward. Let $\hat{i}$, $\hat{j}$, $\hat{k}$ be unit vectors parallel to the x -, y -, and z - axes respectively. Let $\hat{N}$ be the unit vector normal to the plate, directed towards the side of the plate on which the coal is sliding. For force calculations, it is assumed that the coal velocity $\vec{V}$ is independent of distance along the local normal to the curved plate, and that $\vec{V} \cdot \hat{N} = 0$; thus the coal always moves "locally parallel" to the curved plate.

Consider the small volume element of Fig. 4.1, which represents a short section of one stream of coal. Mass enters and leaves the element only through the faces ABCD and A'B'C'D'; the other four faces are stream surfaces. All the lateral faces are composed of lines normal to the plate.

$\vec{V}_{in}$ is normal to ABCD; $\vec{V}_{out}$ is normal to A'B'C'D'

Mass conservation requires

$$\dot{M} = W\,H\,\rho\,|\vec{V}| = \text{const.} \tag{4.1}$$

for any given stream of coal. (ρ = coal density, slugs/ft^3 = γ/g, where γ is the bulk density of the coal in lbs/ft^3). Since this model assumes that the coal density ρ is constant, (4.1) gives the stream depth H in terms of the width W and $|\vec{V}|$.

A momentum balance for this volume element gives

$$\dot{M}(\vec{V}_{out} - \vec{V}_{in}) = \dot{M}\,\Delta\vec{V} = -M g \hat{k} + WL\cdot P\cdot\hat{N} - WL\cdot P\,\mu\,\frac{\vec{V}}{|\vec{V}|} + \vec{F}_I \tag{4.2}$$

where $M = LWH\rho$ is the mass of coal in the volume element.

The force terms on the righthand side of (4.2) are:

1. Body force due to gravity
2. Normal force exerted on the coal by the curved plate. [P (lbs/ft^2) is the associated pressure at the plate surface]
3. Friction force acting opposite the direction of motion. (μ = coefficient of sliding friction).
4. The $\vec{F}_I$ are interaction forces arising from adjacent coal streams. They are assumed to act at right angles to $\hat{N}$, and are discussed in detail below.

The plate pressure P is found as follows:

$$\hat{N}\cdot\vec{V} = 0 \text{ implies that } \Delta(\hat{N}\cdot\vec{V}) \approx \Delta\hat{N}\cdot\vec{V} + \hat{N}\cdot\Delta\vec{V} = 0 \tag{4.3}$$

Take the dot product of (4.2) with $\hat{N}$ and use (4.1), (4.3) to get

$$P = \rho H\left(g\hat{N}\cdot\hat{k} - |\vec{V}|\vec{V}\cdot\frac{\Delta\hat{N}}{L}\right) \tag{4.4}$$

The coal will fall off the plate unless $P > 0$.

(4.5)

The quantity $\vec{V}\cdot\frac{\Delta\hat{N}}{L}$ in (4.4) is just $\frac{|\vec{V}|}{R}$, with "R" the plate radius of curvature along the local coal trajectory, reckoned positive if the plate bends away from $\hat{N}$ when following the coal. The assumptions made here concerning the velocity and stress fields in the sliding coal layer become dubious if the layer is too thick relative to the local plate radius of curvature. It is recommended that the flow field calculations cease if the condition

$$H < \tfrac{1}{2}\,|R| \tag{4.6}$$

is violated.

$\hat{N}\cdot\hat{k}$ in (4.4) is the cosine of the plate tilt angle with respect to the horizontal; this angle is zero for a level plate with coal sliding on the top side.

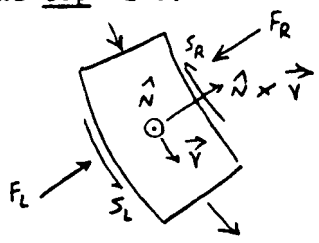


Fig. 4.2 top view of coal stream element

The interaction forces arising from adjacent streams are shown in Fig. 4.2. For the present model, it seems sufficien to write these stream interaction forces as

$$\vec{F}_I = (S_L - S_R)\frac{\vec{V}}{|\vec{V}|} + (F_L - F_R)\hat{N} \times \frac{\vec{V}}{|\vec{V}|} \tag{4.7}$$

The shear S and normal force F acting across the interface between two coal streams are related by

$$S = \pm F \sin\delta \quad (F > 0) \tag{4.8}$$

where δ is the effective angle of internal friction of the coal, and the sign in (4.8) is chosen to accelerate the slower-moving of the two streams.

For the normal force F, let the heights of the adjacent streams be H_A, H_B. Then if the center lines of the streams are inclined towards each other, the stream with the lower height yields plastically and

$$F = k_c \cdot PL \frac{H_A + H_B}{2} \tag{4.9A}$$

On the other hand, if the center lines of the streams are inclined away from each other, the higher stream yields plastically and

$$F = k_e \cdot PL \frac{H_A + H_B}{2} \tag{4.9B}$$

The values of k_c and k_e in general depend on the details of the stress distribution in a given element of material. As a first approximation

$$k_c = 0.5 \text{ and } k_e = 0.5\left(\frac{1 - \sin\delta}{1 + \sin\delta}\right) \tag{4.10}$$

where δ is the effective angle of internal friction.

5. Method of solution of the equations of motion

5A. Extension of a streamline - following net across the curved plate

The streaming coal is divided into a network of small cells of the type considered in section 4. (see Fig. 5.1).

The sidewalls of this network are composed of local normals to the plate surface ξ. These normals spring from the arcs $\overset{\frown}{A_1 A_2}$, $\overset{\frown}{A_1 A_1'}$ etc. drawn on ξ. The arcs $\overset{\frown}{A_1 A_2}$, $\overset{\frown}{A_1 A_1'}$ etc are found as the intersections of ξ with certain planes, defined below.

The net is extended across the curved plate by constructing one new cross-stream row of cells at a time. The construction begins with the row of points $A_1, A_2, A_3 \ldots$ on the plate surface ξ and the corresponding unit normals $\hat{N}_1, \hat{N}_2, \hat{N}_3, \ldots$. Let (A,B) denote the distance between the points "A" and "B" in three dimensional space; then the initial stream widths are $W_1 = (A_1, A_2)$, $W_2 = (A_2, A_3)$ etc. The velocities $\vec{V}_1, \vec{V}_2, \vec{V}_3 \ldots$ associated with the streams on the initial arc $A_1 A_2 A_3 \ldots$ have the following properties:

$$\vec{V}_1 \text{ is perpendicular to the line } \overline{A_1 A_2} \text{ in space, and also perpendicular to } \frac{\hat{N}_1 + \hat{N}_2}{2} \tag{5.1}$$

$$\vec{V}_2 \text{ is perpendicular to the line } \overline{A_2 A_3} \text{ in space, and also perpendicular to } \frac{\hat{N}_2 + \hat{N}_3}{2}$$

. . . . . .

The arc $\overset{\frown}{A_1 A_2}$ is defined as the intersection of ξ with the plane, perpendicular to $\vec{V}_1$, passing through points A_1 and A_2; similarly $\overset{\frown}{A_2 A_3}$ is the intersection of ξ with the plane, perpendicular to $\vec{V}_2$, passing through points A_2 and A_3; and so forth. The mass flow rates $\dot{M}_1, \dot{M}_2, \dot{M}_3, \ldots$ are known for each stream, so equation (4.1) gives the initial stream heights as

$$H_1 = \frac{\dot{M}_1}{W_1 \rho \left| \vec{V}_1 \right|}, \quad H_2 = \frac{\dot{M}_2}{W_2 \rho \left| \vec{V}_2 \right|}, \ldots \tag{5.2}$$

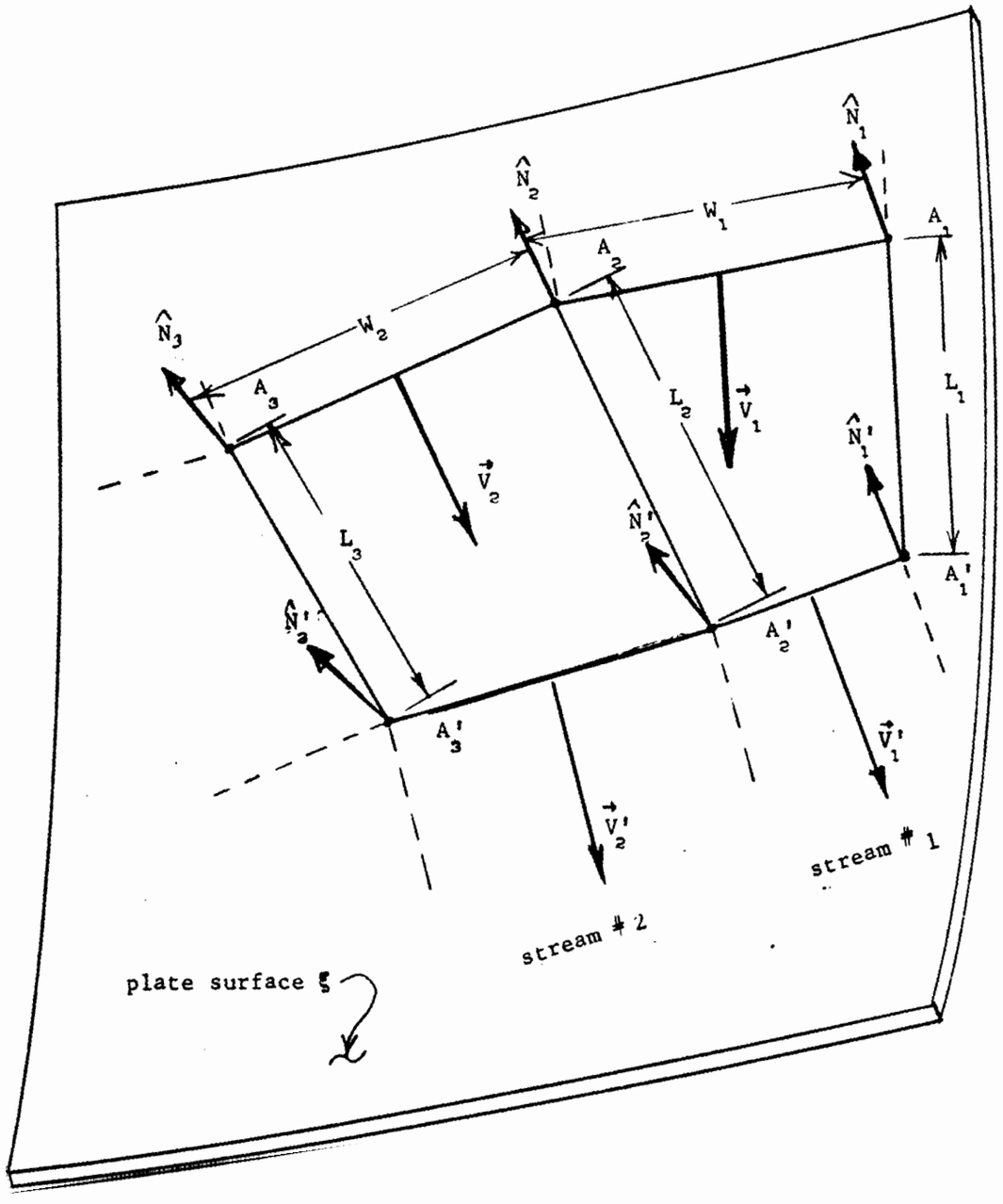


Fig. 5.1

Gridwork of Coal on Chute

To find the initial plate pressures P_i ($i = 1,2,3,4, \ldots$) we proceed as follows:

In equation (4.4) of section 4, take the limit as $L \to 0+$. $\frac{\Delta \hat{N}}{L}$ becomes $\frac{d\hat{N}}{dS}$, where dS is the arc length measured parallel to $\vec{V}$, and the formula for the local plate pressure is

$$P = \rho H \left[g\hat{N}\cdot\hat{k} - \left|\vec{V}\right| \vec{V}\cdot \frac{d\hat{N}}{dS} \right] \tag{5.3}$$

The calculation of the centrifugal force term $\left|\vec{V}\right| \vec{V}\cdot \frac{d\hat{N}}{dS}$ is discussed in detail in section 5c. Let $\left|\vec{V}\right| \vec{V}\cdot \left(\frac{d\hat{N}}{dS}\right)_i$ denote the centrifugal force term associated with the velocity $\vec{V}$ and the point A_i on ξ. Then it is reasonable to approximate the initial plate pressures P_i as

$$P_i = \rho H_i \cdot \left\{ g\left(\frac{\hat{N}_i + \hat{N}_{i+1}}{2}\right)\cdot\hat{k} - \tfrac{1}{2}\left[\left|\vec{V}_i\right| \vec{V}_i \cdot \left(\frac{d\hat{N}}{dS}\right)_i + \left|\vec{V}_i\right| \vec{V}_i \cdot \left(\frac{d\hat{N}}{dS}\right)_{i+1} \right] \right\} \tag{5.4}$$

(see note at the end of this section)

Now let f_i, s_i denote the normal and shearing interaction forces per unit length, exerted on the ith stream by the (i-1)th stream. [The sign conventions used are those of Fig. 4.2] The equations of section 4 give

$$\left.\begin{aligned} \frac{\dot{M}_i \left(\vec{V}_i' - \vec{V}_i\right)}{L_i} &= -W_i H_i \rho g \hat{k} + W_i P_i \left(\frac{\hat{N}_i + \hat{N}_{i+1}}{2} - \mu \frac{\vec{V}_i}{\left|\vec{V}_i\right|}\right) \\ &+ \left(f_{i+1} - f_i\right)\left(\frac{\hat{N}_i + \hat{N}_{i+1}}{2}\right) \times \frac{\vec{V}_i}{\left|\vec{V}_i\right|} + \left(s_{i+1} - s_i\right) \frac{\vec{V}_i}{\left|\vec{V}_i\right|} \\ &(i = 1,2,3,4,\ldots) \end{aligned}\right\} \tag{5.5}$$

The stream surface separating the ith and (i-1)th streams consists of local normals to ξ, springing from the arc $\overset{\frown}{A_iA_i'}$ on ξ. $\overset{\frown}{A_iA_i'}$ is the intersection of ξ with a "dividing plane" $\mathbb{P}_i$ which has the following properties:

1. $\mathbb{P}_i$ passes through the point A_i

2. $\mathbb{P}_i$ is parallel to $\hat{N}_i$

3. $\mathbb{P}_i$ is parallel to either $\vec{V}_i$ or $\vec{V}_{i-1}$,

depending on which of these two adjoining streams is yielding near the dividing plane $\mathbb{P}_i$. (e.g. If the i stream is non-yielding $\mathbb{P}_i$ is parallel to $\vec{V}_i$. If the i+1 stream is non-yielding $\mathbb{P}_i$ is parallel to $\vec{V}_{i+1}$)

Now consider the ith and (i-1)th streams.

Let $$C_i = (\vec{V}_{i-1} \times \vec{V}_i) \cdot \hat{N}_i \tag{5.6}$$

If $C_i > 0$, the streams are converging:

$$\left\{ \begin{array}{ll} \text{If } H_i > H_{i-1}, & \text{the (i-1)th stream yields plastically near the dividing plane } \mathbb{P}_i, \text{ and } \mathbb{P}_i \text{ is parallel to } \vec{V}_i. \\ \text{If } H_i < H_{i-1}, & \text{the ith stream yields near } \mathbb{P}_i, \text{ and } \mathbb{P}_i \text{ is parallel to } \vec{V}_{i-1} \end{array} \right\} \tag{5.7}$$

$$f_i = k_c \left(\frac{P_i + P_{i-1}}{2}\right) \left(\frac{H_i + H_{i-1}}{2}\right) \tag{5.8}$$

$$s_i = \left\{ \begin{array}{l} f_i \sin\delta \quad (|\vec{V}_i| > |\vec{V}_{i-1}|) \\ -f_i \sin\delta \quad (|\vec{V}_i| < |\vec{V}_{i-1}|) \end{array} \right\} \tag{5.9}$$

If $C_i < 0$, the streams are diverging:

$$\left\{ \begin{array}{ll} \text{If } H_i > H_{i-1}, & \text{the ith stream yields near } \mathbb{P}_i, \text{ and } \mathbb{P}_i \text{ is parallel to } \vec{V}_{i-1}. \\ \text{If } H_i < H_{i-1}, & \text{the (i-1)th stream yields near } \mathbb{P}_i, \text{ and } \mathbb{P}_i \text{ is parallel to } \vec{V}_i. \end{array} \right\} \tag{5.10}$$

$$f_i = k_e \left(\frac{P_i + P_{i-1}}{2}\right) \left(\frac{H_i + H_{i-1}}{2}\right) \tag{5.11}$$

$$s_i = \left\{ \begin{array}{l} f_i \sin\delta \quad (|\vec{V}_i| > |\vec{V}_{i-1}|) \\ -f_i \sin\delta \quad (|\vec{V}_i| < |\vec{V}_{i-1}|) \end{array} \right\} \tag{5.12}$$

Suppose that the net currently contains j separate streams of coal. Then (5.5) applies with $i = 1,2,3, \ldots, j$ and the interaction forces

$$(f_1,s_1),\ (f_2,s_2),\ \ldots,\ (f_j,s_j),\ (f_{j+1},s_{j+1})$$

are called for. Since the edges of the coal sheet are regarded as traction-free and non-yielding in this model, we want to ensure that

$$\left\{\begin{array}{l} f_1 = s_1 = f_{j+1} = s_{j+1} = 0 \\ \mathbb{PP}_1 \text{ (the right-hand edge plane) is parallel to } \vec{V}_1 \\ \mathbb{PP}_{j+1} \text{ (the left-hand edge plane) is parallel to } \vec{V}_j \end{array}\right\} \qquad (5.13)$$

(5.13) can be satisfied if we apply the equations (5.6) - (5.12) for $i = 1,2,3, \ldots, j+1$

and choose $\left\{\begin{array}{l} \vec{V}_o = \vec{V}_1,\ H_o = -H_1,\ P_o = -P_1 \\ \vec{V}_{j+1} = \vec{V}_j,\ H_{j+1} = -H_j,\ P_{j+1} = -P_j \end{array}\right\}$ (5.14)

We have now found all the dividing planes $\mathbb{PP}_i$ ($i = 1,2, \ldots, j+1$). Moreover, if the lengths L_i ($i = 1,2, \ldots, j$) were known, we could find the final velocity vectors $\vec{V}_i'$ from (5.5). To complete the construction of the new row of cells, one further piece of information is required; namely, the point A_1' on the right hand edge of the coal sheet. A_1' can be chosen to make the length L_1 a pre-determined fixed value (it is not important to get L_1 <u>exactly</u> right); or A_1' can be determined by a coal stream impact point to the right of the net.(see section 5B below)

Given A_1', the final row of points A_2', A_3', ..., A_j' is found sequentially, working from right to left as follows:

Find $L_1 = (A_1, A_1')$.

Get $\vec{V}_1'$ from (5.5).

Pass a plane ϵ_1 through A_1', perpendicular to $\vec{V}_1'$.

ϵ_1 and $\mathbb{P}_2$ intersect in a straight line ℓ_2, and ℓ_2 intersects ξ at A_2'.

Find $L_2 = (A_2, A_2')$

Get $\vec{V}_2'$ from (5.5).

Pass a plane ϵ_2 through A_2', perpendicular to $\vec{V}_2'$.

ϵ_2 and $\mathbb{P}_3$ intersect in a straight line ℓ_3, and ℓ_3 intersects ξ at A_3'.

etc. (5.15)

Note that the cell lengths L_i are not equal, in general.

We are almost back to the situation we started in, with a row of points A_i' and corresponding velocity vectors $\vec{V}_i'$. But the $\vec{V}_i'$ do not satisfy the criteria (5.1), because $\vec{V}_i'$ is not exactly perpendicular to $\frac{\hat{N}_i' + \hat{N}_{i+1}'}{2}$, in general.

[The use of the plate pressure (5.4) ensures that the velocity vectors $\vec{V}_i'$ are almost parallel to the surface at the end of the cell row construction process; but small errors will arise owing to the finite cell lengths L_i.]

To avoid the possibility of a progressive buildup of errors in the velocities, we produce corrected velocity vectors $\vec{V}_i''$ at the end of each cell row construction, according to

$$\vec{V}_i'' = \left|\vec{V}_i'\right| \frac{\vec{\nu}_i' \times \vec{a}_i'}{\left|\vec{\nu}_i' \times \vec{a}_i'\right|} \qquad (5.16)$$

where $\vec{\nu}_i' = \frac{\hat{N}_i' + \hat{N}_{i+1}'}{2}$ and $\vec{a}_i'$ is a vector pointing from A_i' to A_{i+1}'.

We then have $\vec{V}_i'' \cdot \vec{a}_i' = \vec{V}_i' \cdot \vec{a}_i' = 0$

$$\left|\vec{V}_i''\right| = \left|\vec{V}_i'\right|$$

and also $\vec{V}_i'' \cdot \vec{v}_i' = 0$ (5.17)

The cell row construction process is now complete; the final points are the A_i', and the final associated velocity vectors are the $\vec{V}_i''$.

If we wish to find A_1', given an approximate value of L_1, it suffices to calculate the intersection of ξ with a line in the plane $\mathcal{P}_1$, parallel to $\hat{N}_1$ and a distance L_1 from A_1.

Note: the details of the arcs $\overset{\frown}{A_1 A_2}$, $\overset{\frown}{A_1 A_1'}$, etc. are not important; only the corner points A_i, A_i' require calculation.

The net extension process described in this section requires computer subroutines to perform the following computations about the chosen curved plate surface ξ:

- Intersection of ξ with a given straight line in three-dimensional space.
- Calculation of unit normal $\hat{N}$ at a given point on ξ.
- Calculation of centrifugal force term $\left|\vec{V}\right|\vec{V} \cdot \frac{d\hat{N}}{dS}$ for a given point on ξ and a given tangential velocity vector $\vec{V}$.

Note to follow equation (5.4):

At this point, the two inequality checks mentioned in section 4 should be made for each cell. The computation halts unless $P_i > 0$ and also $H_i < \frac{1}{2}\left|R_i\right|$, where

$$R_i = \frac{\left|\vec{V}_i\right|^2}{\frac{1}{2}\left[\left|\vec{V}_i\right|\vec{V}_i \cdot \left(\frac{d\hat{N}}{dS}\right)_i + \left|\vec{V}_i\right| \vec{V}_i \cdot \left(\frac{d\hat{N}}{dS}\right)_{i+1}\right]}$$

is the local plate radius of curvature in the direction $\vec{V}_i$

5B. Method of starting the net, given a set of coal stream impact points.

5B.1 General procedure for widening a net to incorporate an additional stream on the right hand edge

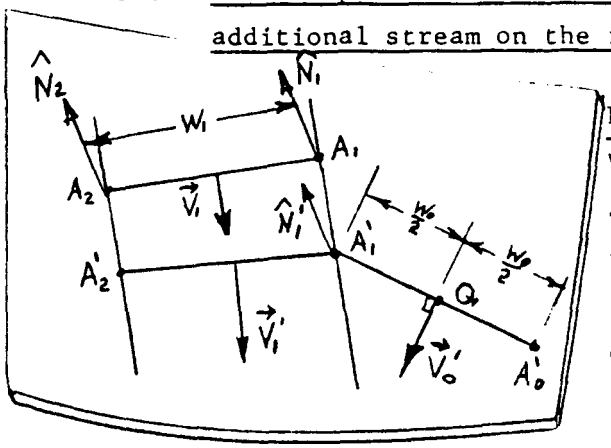


Fig. 5.2

Let the points $A_1, A_2, \ldots$ and velocities $\vec{V}_1, \vec{V}_2, \ldots$ belong to an existing net, and let Q be a new coal stream impact point to the right of the net. (If Q lies inside the net, the coal is falling on itself and the computation should be terminated.) The right hand edge plane FP_1 of the original net passes through A_1 and is parallel to $\hat{N}_1$ and $\vec{V}_1$. The coal stream plate impact model of section 3 will provide the velocity ($\vec{V}_0'$, say) of the impacting stream just after impact. Pass the plane ϵ_0 through Q, perpendicular to $\vec{V}_0'$. ϵ_0 intersects FP_1 in a straight line ℓ, and ℓ intersects the plate surface $\mathcal{S}$ at A_1'. Use A_1' to construct the arc $A_1' A_2'' A_3' \ldots$ terminating this row of cells, as described in section 5A. Let $(A_1', Q) = \frac{W_0}{2}$, the half-width of a new right hand cell through which the impacting stream is sliding. Let ℓ_0 be the line in the plane ϵ_0, parallel to the normal N_1' to $\mathcal{S}$ at A_1', and a distance W_0 from A_1'. Find point A_0', the intersection of the plate surface $\mathcal{S}$ with ℓ_0. $A_0', A_1', A_2', \ldots$ and the associated velocity vectors $\vec{V}_0', \vec{V}_1', \vec{V}_2', \ldots$ constitute the beginning of a wider net, which incorporates the impacting stream; the computation now proceeds as described in section 5A. (The net points A_i and velocities $\vec{V}_i$ can be renumbered if desired.

5B.2 Special cases: one and two streams

The net-widening procedure just described is applicable if the existing net, prior to incorporation of the new stream, already contains at least two streams. An isolated stream, sliding on a plate, need not be assigned a width or height; in the absence of stream interaction forces, the equation of motion reduces to

$$\vec{V}_1 \frac{\vec{V}_1' - \vec{V}_1}{L_1} = -g\,k + \left\{ g\,N_1 \cdot k - \vec{V}_1 \vec{V}_1 \cdot \left(\frac{dN}{dS}\right)_1 \right\} (N_1 - \mu \frac{\vec{V}_1}{\vec{V}_1}), \qquad (5.18)$$

where the normals $\hat{N}_1$ are taken on the stream center line. (5.18) describes the initial motion of the stream of coal originating at the top-most impact point on the chute. The initial value of $\vec{V}_1$ is found from the impact model of section 3.

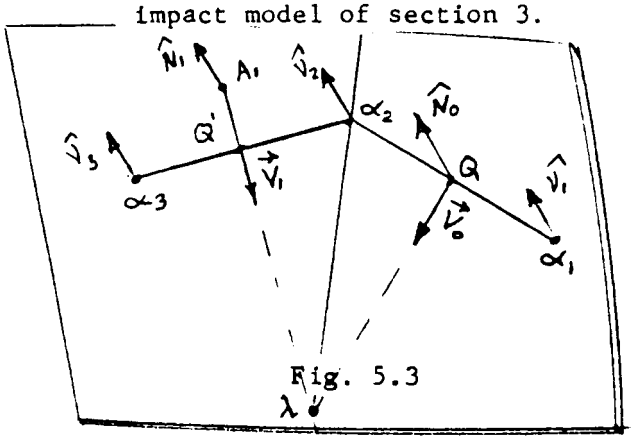


Fig. 5.3

At the Point A_1 of closest approach of the isolated stream, given by (5.18), to the second highest impact point Q on the chute, both streams are assigned widths and heights, and construction of the streamline - following net of section 5A is started.

Let $\hat{N}_0$, $\hat{N}_1$ be the unit normals to ξ at Q and A_1, respectively; and let $\vec{V}_0$, $\vec{V}_1$ be the corresponding velocity vectors. (V_0 is found from the impact model of section 3.) Let the plane PP_0 pass through Q and be parallel to $\hat{N}_0$ and $\vec{V}_0$. Let the plane PP_1 pass through A_1 and be parallel to $\hat{N}_1$ and $\vec{V}_1$. Let PP_0 and PP_1 intersect in a line ℓ which cuts the plate surface ξ at the point λ. Let $\mathrm{PP}_{\frac{1}{2}}$ denote the plane containing ℓ which bisects the angle between PP_0 and PP_1, and passes between Q and A_1.

Now pass the plane ϵ_0 through Q perpendicular to $\vec{V}_0$, and let ϵ_0 intersect $\mathrm{PP}_{\frac{1}{2}}$ in a line ℓ' which cuts ξ at α_2. Let $\hat{\nu}_2$ be the unit normal to ξ at α_2. $(Q,\alpha_2) = \frac{1}{2} W_0$, the half-width of the right hand stream.

Now find point α_1 as the intersection of ξ with a line in ϵ_0, parallel to $\hat{\nu}_2$, a distance W_0 from α_2 in the direction of Q.

Next pass the plane ϵ_1 through α_2 perpendicular to $\vec{V}_1$; let ϵ_1 intersect PP_1 in a line ℓ'' which cuts ξ at Q'. Let $(\alpha_2, Q') = \frac{1}{2} W_1$, the half-width of the left hand stream. Find point α_3 as the intersection of ξ with a line in ϵ_1, parallel to $\hat{\nu}_2$, a distance W_1 from α_2 in the direction of Q'.

The points α_1, α_2, α_3 and the velocity vectors $\vec{V}_0$, $\vec{V}_1$ are now used to start a two-stream net. The first step in this procedure is to adjust $\vec{V}_0$, $\vec{V}_1$ slightly to ensure that $\vec{V}_0 \cdot \left(\frac{\hat{\nu}_1 + \hat{\nu}_2}{2}\right) = \vec{V}_1 \cdot \left(\frac{\hat{\nu}_2 + \hat{\nu}_3}{2}\right) = 0$, as explained toward the end of section 5A.

5c. Calculation of the centrifugal forces produced by the curved plate

The quantity of interest here is the centrifugal force term $\left|\vec{V}\right|\vec{V}\cdot\frac{d\hat{N}}{dS}$ (S = distance parallel to $\vec{V}$ where $\vec{V}\cdot\hat{N} = 0$) which appears in the equations of section 5A.

Let the plate surface ξ be defined by $F(x,y,z) = 0$ for some function F. Let F_x denote $\frac{\partial F}{\partial x}$, F_{xx} denote $\frac{\partial^2 F}{\partial x^2}$, F_{xy} denote $\frac{\partial^2 F}{\partial x \partial y}$ etc.

The vector field $\vec{N}(x,y,z) = F_x(x,y,z)\,\hat{i} + F_y(x,y,z)\,\hat{j} + F_z(x,y,z)\,\hat{k}$ is normal, at any point (x_p,y_p,z_p), to the surface $F(x,y,z) = F(x_p,y_p,z_p)$. Consequently $\vec{N}$ is normal to ξ on ξ.

Now $\hat{N} = \pm\frac{\vec{N}}{\left|\vec{N}\right|}$, with the sign chosen to make $\hat{N}$ point towards the side of the plate on which the coal is sliding.

So
$$\vec{V}\cdot\frac{d\hat{N}}{dS} = \pm\,\vec{V}\cdot\frac{d}{dS}\left(\frac{\vec{N}}{\left|\vec{N}\right|}\right) = \pm\,\vec{V}\cdot\left(\frac{1}{\left|\vec{N}\right|}\frac{d\vec{N}}{dS} - \frac{\vec{N}}{\left|\vec{N}\right|^2}\frac{d}{dS}\left|\vec{N}\right|\right) =$$

$$= \frac{\pm}{\left|\vec{N}\right|}\,\vec{V}\cdot\frac{d\vec{N}}{dS} \qquad \text{since } \vec{V}\cdot\vec{N} = 0$$

But $$\frac{d\vec{N}}{dS} = \frac{\partial\vec{N}}{\partial x}\frac{dx}{dS} + \frac{\partial\vec{N}}{\partial y}\frac{dy}{dS} + \frac{\partial\vec{N}}{\partial z}\frac{dz}{dS}$$

and $$\frac{dx}{dS}\hat{i} + \frac{dy}{dS}\hat{j} + \frac{dz}{dS}\hat{k} = \frac{\vec{V}}{\left|\vec{V}\right|}.$$

Thus $$\frac{d\vec{N}}{dS} = (\text{grad } F_x)\cdot\frac{\vec{V}}{\left|\vec{V}\right|}\hat{i} + (\text{grad } F_y)\cdot\frac{\vec{V}}{\left|\vec{V}\right|}\hat{j} + (\text{grad } F_z)\cdot\frac{\vec{V}}{\left|\vec{V}\right|}\hat{k}$$

and finally, after some algebra,

$$\left|\vec{V}\right|\vec{V}\cdot\frac{d\hat{N}}{dS} = \pm\,\frac{F_{xx}V_x^2 + F_{yy}V_y^2 + F_{zz}V_z^2 + 2F_{xy}V_xV_y + 2F_{yz}V_yV_z + 2F_{xz}V_xV_z}{\sqrt{F_x^2 + F_y^2 + F_z^2}}$$

The local plate radius of curvature along the coal trajectory is

$$R = \frac{\left|\vec{V}\right|^2}{\left|\vec{V}\right| \; \vec{V}\cdot\frac{d\hat{N}}{dS}} \quad ; \text{ with our sign}$$

convention for $\hat{N}$, R is positive if the plate bends away from $\hat{N}$ when following the coal.

Example:

$F(x,y,z) = x^2 + y^2 + z^2 - r^2 = 0$ defines a <u>sphere</u> $\mathcal{S}$ of radius r, centered at the origin. We have $F_x = 2x$; $F_y = 2y$; $F_z = 2z$

$$F_{xx} = F_{yy} = F_{zz} = 2; \; F_{xy} = F_{yz} = F_{xz} = 0$$

and so

$$\left|\vec{V}\right| \; \vec{V}\cdot\frac{d\hat{N}}{dS} = \frac{V_x^2 + V_y^2 + V_z^2}{\sqrt{x^2 + y^2 + z^2}} = \frac{\left|\vec{V}\right|^2}{r} \quad [\text{ for any point on } \mathcal{S} \text{ }].$$

The local radius of curvature is $R = \dfrac{\left|\vec{V}\right|^2}{\left|\vec{V}\right| \; \vec{V}\cdot\frac{d\hat{N}}{dS}} = r.$

APPENDIX E

PHASE II DYNAMICS COMPUTER PROGRAM

FRICTIONAL FLOW DYNAMICS PHASE

```
0001                  REAL MU
0002                   REAL KC,KE
0003                  DIMENSION IPL (22,50)
0004                  DIMENSION VELOC(22,50),WIDTH(22,50),HGT(22,50),RAD(22,50),
                     * FORC(22,50),SHEA(22,50),CORD(3,22,50)
0005                  DIMENSION MT(22)
0006                  DIMENSION IPTS(22),PXSAV(3)
0007                   DIMENSION AX(3)
0008                   DIMENSION VQ(3)
0009                   DIMENSION PI(4)
0010                   DIMENSION PY(3), PXX(3), P5(3)
0011                   DIMENSION P3(3) , AIIQ(3)       , ANL(3)
0012                   DIMENSION R(22)
0013                  DIMENSION KK(50),BAI(3,50),BVI(3,50),BAMDOT(50),ITT(50)
0014                     DIMENSION AI(3,22),AN(3,22),VI(3,22),VN(3,22),PP(4,22),TEM(22),
                     *    IV(2),IVP(2),P4(3),
                     * VB(22),F(22),S(22),HE(22),PTDAT(3,4,100) ,
                     *              IT(22),C(22),PX(3),VP(3),P12(4),E(4),
                     *       W(22),PR(22),AMDOT(22)
0015                   DIMENSION H2(22),  HHH(1,3,3,2),AIII(1,3,3,2)
0016                  INTEGER X
0017                  INTEGER X1
0018                  LOGICAL TOOBIG
0019                  LOGICAL FULL
0020                  FULL =.FALSE.
0021                  TOOBIG = .FALSE.
0022                  DATA HHH/ 5.07,6.24,7.62,  5.57,6.86,8.14,  5.99,7.50,8.76
                     *         ,5.71,6.95,8.47,  6.04,7.52,9.05,  6.38,8.09,9.74/
0023                  DATA AIII/2.48,2.23,3.03,  2.75,2.29,2.91
                     *          ,2.97,2.45,3.19,  2.35,2.85,3.36
                     *          ,2.46,3.08,3.60,  2.58,3.31,3.94/
0024                  DATA H2/15*0./
0025                  NAMELIST /COLOUT/ LAMDA , XF , YF , ZF , Q , CHLN , NP, APT
                     *                 ,THETCN, H,A1,H2 , YMIN
0026                  NAMELIST /CUALIN/ V,RADIUS,PHI,SECT,IDLANG,SURANG,BELTWD
                     *                 , ND1 , ND2, FLAT , GAMMA,RADUP,DISP
                     *              ,MODET,EPS,RUNNO,PHIP,GAMD,EL1,KC,DELTE,NP,NI,BMAR
                     *                                 ,YAW,ZIH
0027                  REAL IDLANG , LAMDA,KAPPA
0028                  INTEGER IX,SX,BX,SECT,RUNNO
0029                      DATA G/386.4/
0030                  COMMON THET(3,200),ABC(3,200),PT(3,3,200),UN(3,200)
0031                  COMMON /DENS/GAMD
0032                   DO=1.0E-10
0033                   NF=3000
0034                   ID=3000
0035                    DO 5555 I=1,3
0036                   DO  5555 J=1,3
```

```
0037                DO 5555 L=1,20
0038                ABC(I,L)=0.
0039                PT(I,J,L)=0.
0040                UN(I,L)=0.
0041                R(L)=100.
0042          5555   CONTINUE
0043                READ(5,COALIN,END=9999)
0044              DELTA = DELTF
0045              NS = SECT
0046                 PHIPR=PHIP/57.29578
0047              MU=TAN(PHIPR)
0048              WRITE ( 6,905)
0049            905 FORMAT('1')
0050              WRITE ( 6,901)
0051            901 FORMAT(//)
0052              WRITE ( 6,916)
0053            916 FORMAT ( /1X,132('*'))
0054              WRITE ( 6,901)
0055              WRITE    ( 6,918) RUNNO  ,DATE
0056            918 FORMAT ( 1X,10X,'BEGIN INDEPENDENT RUN OF COAL CHUTE DESIGNER',
                *           30X,'RUN NUMBER',I3,5X,'DATE ',5A4)
0057            919 FORMAT ( /1X,31X,10('.'),5X,
                *       'INDEPENDENT VARIABLES FOR THIS RUN ', 5X,10('.')//)
0058              WRITE ( 6,901)
0059              WRITE ( 6,916)
0060            930 FORMAT ( 40X,'RUN NO',I3,5X,'DATE ',5A4)
0061              IX = 1
0062              IF ( IDLANG.EQ. 35.) IX = 2
0063              SX = 1
0064              IF ( SURANG.EQ. 25.) SX= 2
0065              IF ( SURANG.EQ.30.) SX=3
0066              BX = 1
0067              IF ( BELTWD.EQ.36.) BX=2
0068              IF ( BELTWD.EQ.42.) BX=3
0069              H = HHH( 1,BX,SX,IX)
0070              AL = AIII( 1,BX,SX,IX)
0071               CC=BELTWD-2.*BMAR
0072                RR=H/2.+CC**2/(8.*H)
0073               DLT=CC/SECT
0074              MID = SECT/2 + 1
0075               DO 10 K=1,SECT
0076                B=SQRT(RR**2-CC**2/4)
0077              N = IABS(MID-K)
0078              X1 = N*DLT
0079                A=SQRT(RR**2-X1**2)
0080              H2(K) = (A-B)/2.
0081               RHO=GAMD/(32.2*12**3)
0082               AMDOT(K)=DLT*H2(K)*RHO*V
```

```
0083        10      CONTINUE
0084                R12=100.
0085               DELTA =DELTA/57.29
0086              KF=KC*(1.-SIN(DELTA))/(1.+SIN(DELTA))
0087               READ(5,15)
0088        15     FORMAT(20A4)
0089        18    CONTINUE
0090               DO 20 J=1,NP
0091               DO 20 K=1,4
0092               READ(5,25) (PTDAT(L,K,J),L=1,3)
0093         25   FORMAT(3F20.8)
0094        20    CONTINUE
0095               READ(5,15)
0096               DO 30 J=1,NT
0097               DO 30 K=1,3
0098               READ(5,25) (PT(L,K,J),L=1,3)
0099        30    CONTINUE
0100               READ(5,15)
0101               DO 40 J=1,NT
0102               READ(5,25) (UN(L,J),L=1,3)
0103        40    CONTINUE
0104               READ(5,15)
0105               DO 50 J=1,NT
0106               READ(5,25) (ABC(L,J),L=1,3)
0107        50     CONTINUE
0108               READ(5,15)
0109               DO 60 J=1,NT
0110               READ(5,25) (THET(L,J),L=1,3)
0111        60    CONTINUE
0112               READ(5,15)
0113        1     CONTINUE
0114              DO 70 J=1,NS
0115               READ(5,25) (VI(L,J),L=1,3)
0116        70    CONTINUE
0117               READ(5,15)
0118               DO 80 J=1,NS
0119               READ(5,25) (AI(L,J),L=1,3)
0120        80    CONTINUE
0121               READ(5,15)
0122               DO 90 J=1,NS
0123               READ(5,35) IT(J)
0124        35       FORMAT(I8)
0125        90         CONTINUE
0126        2          CONTINUE
0127              WRITE(6,92)
0128        92    FORMAT(1X,'LISTING OF INPUTS BEFORE ARRANGEMENT')
0129              WRITE (6,127)
0130              DO 91  J=1,NS
```

```
0131              WRITE(6,126)J,II(J),AI(1,J),AI(2,J),AI(3,J),VI(1,J),VI(2,J)
                 *,VI(3,J) ,AMDOT(J)
0132         91   CONTINUE
             C
             C  ARRANGE STREAMS IN ORDER OF ACCUMULATION TO MAIN FLOW
             C
             C     FIND HIGHEST HITTING STREAM
             C
0133              A=AI(2,1)
0134              KK(1)=1
0135              DO 21 J=1,NS
0136              IF(A.GT.AI(2,J))GO TO 21
0137              A=AI(2,J)
0138              KK(1)=J
0139         21   CONTINUE
             C
             C   FIND WHICH OF TWO STREAMS ADJACENT TO ALREADY ACCUMULATED STREAMS
             C HITS HIGHER
             C
0140              JP=KK(1)+1
0141              JM=KK(1)-1
0142              IF(JP.GT.NS)GO TO 27
0143              IF(JM.EQ.0) GO TO 24
0144              DO 23 L=2,NS
0145              KK(L)= JP
0146              IF(AI(2,JP).GT.AI(2,JM)) GO TO 22
0147              KK(L)=JM
0148              JM=JM-1
0149              IF ( JM.EQ.0)GO TO 24
0150              GO TO 23
0151         22    JP=JP+1
0152              IF(JP.GT.NS) GO TO 27
0153         23   CONTINUE
0154              GO TO 29
             C
             C  NUMBER ALL REMAINING STREAMS
             C
0155         24   DO 26 J=JP,NS
0156              KK(J)=J
0157         26   CONTINUE
0158              GO TO 29
0159         27   JMM=NS+1-JM
0160              DO 28 J=JMM,NS
0161              KK(J)=NS-J+1
0162         28    CONTINUE
0163         29   CONTINUE
             C
             C TRANSFER DATA REQUIRED BY RENUMBERING OF STREAMS DUE TO REARRANGEMENT
```

```
      C
0164        DO 31 J=1,NS
0165        DO 31 L=1,3
0166        BAI(L,J)= AI(L,KK(J))
0167        BVI(L,J)= VI(L,KK(J))
0168        BAMDOT(J)= AMDOT(KK(J))
0169        ITT(J) = IT(KK(J))
0170     31 CONTINUE
0171        DO 32 J=1,NS
0172        DO 32 L=1,3
0173        AI(L,J)=BAI(L,J)
0174        VI(L,J)=BVI(L,J)
0175        AMDOT(J)=BAMDOT(J)
0176        IT(J)=ITT(J)
0177        MT(J)=IT(J)
0178     32 CONTINUE
0179   1003   FORMAT(//1X,3I8)
0180   1002   FORMAT(//3X,8F7.2)
0181    121  CONTINUE
      C
0182        WRITE(6,129)
0183    129 FORMAT(1X,'LISTING OF INPUTS AFTER ARRANGEMENT')
0184        WRITE (6,127)
0185        DO 128 J=1,NS
0186        WRITE(6,126)J,IT(J),AI(1,J),AI(2,J),AI(3,J),VI(1,J),VI(2,J)
           * ,VI(3,J) ,AMDOT(J)
0187    128 CONTINUE
0188    126 FORMAT(1X,2(I3,3X),6(F8.2,3X),F8.4)
0189    127 FORMAT (1X,'STREAM,TRIANGLES, HIT POINTS ,VELOCITIES ,FLOW RATES')
      C
0190         ISTEP=1
0191         JT=IT(1)
0192        EX=(AI(2,1)-AI(2,2))/5.
0193    125  CONTINUE
      C
0194        R12=9999
      C
      C  FORMATION OF TWO STREAM NET
      C  DETERMINE PATH OF STREAM 1 IN INCREMENTS EX AND POINT OF CLOSEST
      C  APPROACH TO STREAM 2
      C
0195         PX(1)=AI(1,1)
0196         PX(2)=AI(2,1)
0197         PX(3)=AI(3,1)
0198         PY(1) =PX(1)
0199         PY(2) =PX(2)
0200         PY(3) =PX(3)
0201        VP(1)=VI(1,1)
```

```
0202                VP(2)=VI(2,1)
0203                VP(3)=VI(3,1)
0204                 CALL PLANE(JT,PX,VP,E)
0205                 PP(1,1)=E(1)
0206                 PP(2,1)=E(2)
0207                 PP(3,1)=E(3)
0208                 PP(4,1)=E(4)
              C
              C   DRAW A LINE IN P1 WHICH INTER. JT IN A1*
0209                 P4(1)=AI(1,1)
0210                 P4(2)=AI(2,1)
0211                 P4(3)=AI(3,1)
0212                P5(1)= P4(1)-VI  (1,1)
0213                P5(2)= P4(2)-VI  (2,1)
0214                P5(3)= P4(3)-VI  (3,1)
0215                CALL LOCAT3 (JT,EX,E,P4,P5,PXX )
0216                 CALL FIND (JT,NT,PY,PXX,E,PX,JTP )
0217                 JT = JTP
0218                 PY(1) = PX(1)
0219                 PY(2) = PX(2)
0220                 PY(3) = PX(3)
0221                 PE=G*UN(2,JT)
0222                 DO 130 I=1,NS
0223                 VB(I)=SQRT(VI(1,I)**2+VI(2,I)**2+VI(3,I)**2)
0224          130    CONTINUE
              C
              C   CALCULATE VELOCITY OF STREAM 1
              C
0225                 VE=VB(1)
0226                 VP(1)=VI(1,1)+(EX/VE)*PE*(UN(1,JT)-MU*VI(1,1)/VE)
              C
0227                 VP(2)  = VI(2,1) + (EX/VE)* (-G + PE*(UN(2,JT)-MU* VI (2,1) /VE))
              C
0228                VP(3)    =VI(3,1) +(EX/VE) * PE* (UN(3,JT)-MU*VI(3,1)/VE)
0229                 D=0.
              C
0230                 DO 140 L=1,3
0231                 D=D+(PX(L)-AI(L,2))**2
0232          140    CONTINUE
0233                 D=SQRT(D)
0234                 IF(ISTEP.EQ.1) GO TO 160
0235                 IF(D.GT.DOLD) GO TO 200
0236          160    CONTINUE
0237                 DO 170 L=1,3
0238                 AI(L,1)=PX(L)
0239                 VI(L,1)=VP(L)
0240          170    CONTINUE
0241                 DOLD=D
```

```
0242                ISTEP=ISTEP+1
0243                GO TO 125
                C
                C
0244          200   CONTINUE
0245                WRITE(6,3001) DOLD
0246          3001    FORMAT(' THE CLOSEST DIST. OF APPR.  OF ISOLATED STREAM TO
                     1   SECOND HIGHEST IMPACT POINT IS =',F8.2)
                C
0247              JTT = IT(2)
0248                JT=IT(2)
0249              DO 203 L= 1,4
0250              F(L) = PP(L,1)
0251          203 CONTINUE
0252              DO 205 L= 1,3
0253              P3(L) = AI(L,1)
0254              P4(L) = AI(L,2)
0255              P5(L) = AI(L,2)
0256          205 CONTINUE
                C
                C   FIND LOCATION OF NET POINT 2 HALFWAY BETWEEN HIT POINT 2
                C   AND STREAM 1'S PATH
                C
0257                E(4)=0.
0258                DO 210 L=1,3
0259                E(L)=VI(L,2)
0260                E(4)=E(4)+VI(L,2)*AI(L,2)
0261              PXX(L)= 2.*P4(L)-P3(L)
0262          210   CONTINUE
0263                E(4)=-E(4)
                C
0264              CALL LOCATE(JT,E,F,PY)
0265              DOLD= SQRT( (PY(1)-AI(1,2))**2
                *                 +(PY(2)-AI(2,2))**2
                *                 +(PY(3)-AI(3,2))**2          )
0266                DOLD=DOLD/2.
0267              CALL LOCAT3(IT(2),DOLD,E,P4,PXX,PX )
                C
0268                JTP=100
0269                CALL FIND (JT,NT,P4,PX,E,PY,JTP )
0270                IF (JTP.EQ.100) WRITE( 6,5000 )
0271                AN(1,2)= PY(1)
0272                AN(2,2)= PY(2)
0273                AN(3,2)= PY(3)
0274          5000   FORMAT(' POINT NOT LOCATABLE')
                C
0275                  IT(2)=JTP
0276                WW=0.
```

```
0277                DO 230 L=1,3
0278                  WW=WW*(AN(L,2)-AI(L,2))**2
0279          230   CONTINUE
0280                WW=2.0*SQRT(WW)
              C
              C     FIND OTHER NET POINT FOR 2ND HIGHEST HITTING STREAM  ***************
              C
              C IGROUP = 1 MEANS Z COORDINATE LESS THAN Z COORDINATE OF PRECEEDING STREAMS
              C IGROUP OTHERWISE
              C
0281                  IGROUP=1
0282                IF ( AI(3,2) .LT. AN(3,2)) IGROUP = 2
0283                  IF(IGROUP.EQ.1) W(1)=WW
0284                 IF(IGROUP.EQ.2) W(2)=WW
0285                 DO 220 L=1,3
0286                 PXX(L)=AI(L,2) + (AI(L,2) -AN(L,2))
0287            220  CONTINUE
0288                JTP = 100
0289                CALL FIND ( JTT,NT,P5,PXX,E,PX,JTP)
0290                 IF (JTP.EQ.100) WRITE( 6,5000 )
0291                 DO 240 L=1,3
0292                 IF(IGROUP.EQ.2) AN(L,3)=PX(L)
0293                  IF(IGROUP.EQ.1) AN(L,1)=PX(L)
0294          240   CONTINUE
              C
0295                  IF(IGROUP.EQ.1) IT(1)=JTP
0296                 IF(IGROUP.EQ.2) IT(3)=JTP
              C
              C     FIND LOCATION OF CENTER OF 1 ST HITTING STREAM  ****************
              C
0297                 E(4)=0.
0298                 DO 250 L=1,3
0299                PXX(L) = PY(L)
0300                 E(L)=VI(L,1)
0301                 E(4)=E(4)+VI(L,1)*AN(L,2)
0302          250   CONTINUE
0303                 E(4)=-E(4)
              C
0304                 F(1)=PP(1,1)
0305                 F(2)=PP(2,1)
0306                 F(3)=PP(3,1)
0307                 F(4)=PP(4,1)
0308                 KT=IT(2)
0309                 CALL LOCATE(KT,E,F,PX)
0310                CALL FIND ( KT,NT,PXX,PX,E,PY,JTTP )
              C
0311                 WW=0.
0312                 DO 260 L=1,3
```

```
0313                WW=WW + (AN(L,2)-PY(L)) **2
0314          260     CONTINUE
0315                WW=2.0*SQRT(WW)
0316                IF(IGROUP.EQ.1) W(2)=WW
0317                  IF(IGROUP.EQ.2) W(1)=WW
              C
              C
              C     FIND LOCATION OF OTHER NET POINT OF FIRST HITTING STREAM    ********
              C
0318                  P4(1)=AN(1,2)
0319                  P4(2)=AN(2,2)
0320                  P4(3)=AN(3,2)
0321                DO 265 L=1,3
0322                PXX(L) = PY(L) + (PY(L) - AN(L,2))
0323            265  CONTINUE
0324                JTP = 100
0325                 CALL FIND(JTTP,NT,PY,PXX,E,PX,JTP )
0326                 IF ( JTP.EQ.100) WRITE (6,5000) )
0327                 DO 270 L=1,3
0328                  IF(IGROUP.EQ.2) AN(L,1)=PX(L)
0329                  IF(IGROUP.EQ.1) AN(L,3)=PX(L)
0330          270      CONTINUE
0331                IF(IGROUP.EQ.2) IT(1)=JTP
0332                  IF(IGROUP.EQ.1) IT(3)=JTP
              C
              C  TRANSFER STREAM 1 AND STREAM 2 DATA IF IGROUP = 1
              C
0333                  IF(IGROUP.EQ.2) GO TO 275
0334                DO 273 L= 1,3
0335                VN(L,2) = VI(L,1)
0336                VN(L,1) = VI(L,2)
0337                VN(L,3) = VN(L,2)
0338            273 CONTINUE
0339                D=AMDOT(2)
0340                AMDOT(2)=AMDOT(1)
0341                AMDOT(1)=D
0342                 GO TO 285
0343          275       CONTINUE
0344                 DO 280 I=1,2
0345                 DO 280 L=1,3
0346                 VN(L,I)=VI(L,I)
0347                   VN(L,3)=VN(L,2)
0348          280    CONTINUE
0349          285      CONTINUE
              C
              C  INITIAL VELOCITIES AND HEIGHTS FOR  2 STREAM NET ****************
              C
0350                 DO 290 I=1,2
```

```
0351                VB(I)=SQRT(VN(1,I)**2+VN(2,I)**2+VN(3,I)**2)
0352          290    CONTINUE
0353                DO 300 I=1,2
0354                HE(I)=AMDOT(I)/(W(I)*RHO*VB(I))
0355                JT=IT(I)
0356                K=I+1
0357                KT=IT(K)
0358                UNN=(UN(2,JT)+UN(2,KT))/2.
0359                PR(I)=RHO*HE(I)*UNN*G
0360          300     CONTINUE
0361                HE(3)=-HE(2)
0362                PR(3)=-PR(2)
0363                 IF(IGROUP.EQ.2) PR(3)=PR(2)
0364                 IF(IGROUP.EQ.2) PR(2)=PR(1)
0365                 IF(IGROUP.EQ.2) PR(1)=-PR(2)
                C
                C  FIND DIVIDING PLAND FOR TWO STREAM NET BASED ON STREAM HEIGHT(HE)
                C    AND DIVERGENCE OR CONVERGENCE
                C
0366                 JT=IT(1)
0367               DO 325 L= 1,3
0368               VP(L)= VN(L,2)
0369               VQ(L) = VN(L,1)
0370               PX(L) = AN(L,1)
0371            325 CONTINUE
0372                    CALL PLANE(JT,PX,VQ,E)
0373                 PP(1,1)=E(1)
0374                 PP(2,1)=E(2)
0375                 PP(3,1)=E(3)
0376                 PP(4,1)=E(4)
0377                 JT=IT(2)
0378               CALL DETR(VQ,VP,UN(1,JT),C(2))
                C
                C  C(2) LESS THAN ZERO MEANS DIVERGENCE
                C
0379                IF(C(2).LT.0.) GO TO 350
0380                PX(1)=AN(1,2)
0381                PX(2)=AN(2,2)
0382                PX(3)=AN(3,2)
0383                IF(HE(2).GT.HE(1)) CALL PLANE(JT,PX,VP,E)
0384                IF(HE(2).LT.HE(1)) CALL PLANE(JT,PX,VQ,E)
0385                GO TO 360
0386          350   CONTINUE
0387                IF(HE(2).GT.HE(1)) CALL PLANE(JT,PX,VQ,E)
0388                IF(HE(2).LT.HE(1)) CALL PLANE(JT,PX,VP,E)
0389          360   CONTINUE
0390                PP(1,2)=E(1)
0391                PP(2,2)=E(2)
```

```
0392                PP(3,2)=E(3)
0393                PP(4,2)=E(4)
                C
0394                JT=IT(3)
0395                PX(1)=AN(1,3)
0396                PX(2)=AN(2,3)
0397                PX(3)=AN(3,3)
0398                CALL PLANE(JT,PX,VP,E)
0399                PP(1,3)=E(1)
0400                PP(2,3)=E(2)
0401                PP(3,3)=E(3)
0402                PP(4,3)=E(4)
                C
0403                DO 365 J=1,3
0404                  VB(J)=SQRT(VN(1,J)**2+VN(2,J)**2+VN(3,J)**2)
0405              365 CONTINUE
0406                ISTEP=0
0407                 IQ=3
                C ***************************************************************
                C   REPETITIVE LOOP ADDING STREAMS ****************************
                C ***************************************************************
0408              370    CONTINUE
                C
0409                    IGROUP=9999
0410                     IF(AI(3,IQ).GT.AN(3,1)) IGROUP=1
0411                    IF(AI(3,IQ).LT.AN(3,IQ)) IGROUP=2
0412                    IF(IGROUP.EQ.9999) GO TO 375
0413                    GO TO 380
0414              375    WRITE(6,3003) IQ
0415              3003    FORMAT(' HIT POINT',I4,' LIES WITHIN NET')
0416                   GO TO 1400
0417              380    CONTINUE
0418                   WRITE(6,379) IGROUP
0419              379    FORMAT ( ' IGROUP=',I2)
                C
                C  CHECK IF NEW STREAM ADDS NORMALLY ( I.E. WAVE FRONT THRU HIT  POINT
                C  INTERSECTS EXISTING TOTAL FLOW BELOW LAST CALCULATED WAVE FRONT)
                C
0420                   K= IQ
0421                   IF ( IGROUP .EQ.1) K=1
0422                   BELOW =0.
0423                   DO 381 L=1,3
0424                   BELOW = BELOW +VI(L,IQ)*(AN(L,K)-AI(L,IQ))
0425              381 CONTINUE
0426                   EX = BELOW/SQRT(VI(1,IQ)**2+VI(2,IQ)**2+VI(3,IQ)**2)
0427                   EXLIM = 1.
0428                   IF(BELOW.LT.0..AND. ABS(EX).GT.EXLIM) GO TO 388
0429                   IF ( BELOW .LT.0.) GO TO 390
```

```
C
C  ESTABLISH NON-NORMAL NET POINT **********************
C
C  FLOW ALONG HIT VELOCITY VECTOR IS ASSUMED UNTIL NEW WAVE FRONT
C   JOINS EXISTING WAVE FRONT
C
0430          WRITE(6,385)IQ
0431      385 FORMAT(' NON-NORMAL NET POINT',I3)
0432          DO 382 L=1,3
0433          AIIQ(L)= AI(L,IQ)
0434          VP(L)= VI(L,IQ)
0435          P4(L) = AIIQ(L)-VI(L,IQ)
0436          PY(L) = AN(L,K)
0437      382 CONTINUE
0438          CALL PLANE ( MT(IQ),AIIQ,VP,E)
0439          CALL LOCAT3(MT(IQ),EX,E,AIIQ,P4,PX)
0440          VP(1)= PX(1)-PY(1)
0441          VP(2)= PX(2)-PY(2)
0442          VP(3)= PX(3)-PY(3)
0443          VQ(1)=PY(1)-VP(1)
0444          VQ(2)=PY(2)-VP(2)
0445          VQ(3)=PY(3)-VP(3)
0446          CALL PLANE (IT(K),PY,VP,E)
0447          WW= 2.*SQRT(VP(1)**2+VP(2)**2+VP(3)**2)
0448          CALL LOCAT3 ( IT(K) , WW, E, PY,VQ,PX)
0449          CALL FIND ( IT(K),NT,PY,PX,E,PXX,JTP)
0450          IF( IGROUP .EQ.1) GO TO 600
0451          DO 383 L=1,3
0452          AN(L,IQ+1) = PXX(L)
0453      383 CONTINUE
0454          GO TO 795
0455      388 CONTINUE
C
C  IF WAVE FRONT DISPLACEMENT TO JOINING BY NEXT STREAM GREATER THAN
C  EXLIM (I.E.  TOOBIG = TRUE) THEN STREAM 1 MOVED EXLIM AND TOTAL
C  WAVE FRONT ADVANCES
C
0456          TOOBIG=.TRUE.
0457          IGROUP = 1
0458          WRITE(6,387)
0459      387 FORMAT(1X,'STEP SIZE TOO BIG, FIXED STEP TAKEN,NO STREAM ADDED')
0460          DO 399 L=1,3
0461          P3(L)= AN(L,1)-VN(L,1)
0462      399 CONTINUE
0463          CALL LOCAT3(IT(1),EXLIM,PP(1,1),AN(1,1),P3,PY)
0464          CALL FIND (IT(1),NT,AN(1,1),PY,PP(1,1),PX,JTP)
0465          DO 491 L=1,3
0466          AN(L,1)=PX(L)
```

```
0467          391   CONTINUE
0468                EL=EXLIM
0469                IT(1)= JTP
0470                GO TO 444
0471          390   CONTINUE
              C
              C FIND JUNCTION TO NET OF ADDING STREAM ******************
              C
0472                E(4)=0.
0473                 DO 400 L=1,3
0474                 E(L)=VI(L,IQ)
0475                E(4)=E(4)+VI(L,IQ)*AI(L,IQ)
0476          400   CONTINUE
0477                E(4)=-E(4)
0478               AIIQ(1) = AI(1,IQ)
0479               AIIQ(2) = AI(2,IQ)
0480               AIIQ(3) = AI(3,IQ)
              C
0481                 JT=IT(1)
0482                JP=(JT-1)/2+1
0483                F(1)=PP(1,1)
0484                F(2)=PP(2,1)
0485                F(3)=PP(3,1)
0486                F(4)=PP(4,1)
0487                DO 405 L=1,4
0488          405     IF(IGROUP.EQ.2) F(L)=PP(L,IQ)
0489               CALL LOCATE ( MT(IQ) ,E,F,PY)
0490              CALL FIND ( MT(IQ),NT,AIIQ,PY,E,PX,JTP)
              C  FIND RADIUS AT START OF STEP FOR OLD BOUNDARY
0491               IF(IGROUP.EQ.1) CALL LOCAT3(IT(1),1.,F,AN(1,1),PY,P3)
0492               IF(IGROUP.EQ.2) CALL LOCAT3(IT(IQ),1.,F,AN(1,IQ),PY,P3)
0493               IF(IGROUP.EQ.1) CALL RA(IT(1),NT,AN(1,1),P3,F,R12)
0494               IF(IGROUP.EQ.2) CALL RA (IT(IQ),NT,AN(1,IQ),P3,F,R12)
0495               IF(R12.LT.18.) R12=18.
              C FIND NEW STREAM BOUNDARY POINT *********************************
0496              PY(1)= AI(1,IQ)+(AI(1,IQ)-PY(1))
0497              PY(2)= AI(2,IQ)+(AI(2,IQ)-PY(2))
0498              PY(3)= AI(3,IQ)+(AI(3,IQ)-PY(3))
0499              CALL FIND (MT(IQ),NT,AIIQ,PY,F,PXX,JTP)
0500               EL=0.
0501               DO 410 L=1,3
0502                 IF(IGROUP.EQ.2) EL=EL+(PX(L)-AN(L,IQ))**2
0503                 IF(IGROUP.EQ.1) EL=EL+(PX(L)-AN(L,1))**2
0504                 IF(IGROUP.EQ.2) AN(L,IQ)=PX(L)
0505                   IF(IGROUP.EQ.1) AN(L,1)=PX(L)
0506          410   CONTINUE
0507                EL=SQRT(EL)
0508                JPP=(JTP-1)/2+1
```

```
0509          450    CONTINUE
0510          444    CONTINUE
0511          1001    FORMAT(//1X,F7.2)
              C
              C
0512                 F(1)=0.
0513                 S(1)=0.
0514                 F(IQ)=0.
0515                 S(IQ)=0.
              C
              C  FIND INNER DIVIDING PLANES BASED ON STREAM HEIGHT (HE) AND
              C   CONVERGENCE OR DIVERGENCE
              C
0516                 IQ1=IQ-1
0517                 DO 490 L=2,IQ1
0518                 JT=IT(L)
0519                 K=L-1
0520                 PX(1)=AN(1,L)
0521                 PX(2)=AN(2,L)
0522                 PX(3)=AN(3,L)
0523                 VP(1)=VN(1,L)
0524                 VP(2)=VN(2,L)
0525                 VP(3)=VN(3,L)
0526                  VQ(1)=VN(1,K)
0527                  VQ(2)=VN(2,K)
0528                  VQ(3)=VN(3,K)
              C
              C  C(L) LESS THAN ZERO MEANS STREAMS DIVERGING
              C
0529                 IF(C(L).LT.0.) GO TO 470
0530                 F(L)=KE*(PR(L)+PR(K))*(HE(L)+HE(K))/4.
0531                 S(L)=F(L)*SIN(DELTA)
0532                 IF(VB(L).LT.VB(K)) S(L)=-S(L)
0533                 IF(HE(L).GT.HE(K)) CALL PLANE(JT,PX,VP,E)
0534                 IF(HE(L).LE.HE(K)) CALL PLANE(JT,PX,VQ,E)
0535                  GO TO 480
0536          470      CONTINUE
0537                F(L)=KE*(PR(L)+PR(K))*(HE(L)+HE(K))/4.
0538                 S(L)=F(L)*SIN(DELTA)
0539                 IF(VB(L).LT.VB(K)) S(L)=-S(L)
0540                IF(HE(L).GT.HE(K)) CALL PLANE(JT,PX,VQ,E)
0541                IF(HE(L).LE.HE(K)) CALL PLANE(JT,PX,VP,E)
0542          480     CONTINUE
0543                PP(1,L)=E(1)
0544                PP(2,L)=E(2)
0545                PP(3,L)=E(3)
0546                 PP(4,L)=E(4)
0547          490      CONTINUE
```

```
      C
0548            IF(IGROUP.EQ.2) GO TO 699
      C
      C  NEW VELOCITY FOR STREAM 1 ****************************************
      C
0549            JT=IT(1)
0550           IT(1)=JTP
0551            LT=IT(2)
0552            WW=W(1)
0553            VQ(1)=VN(1,1)
0554            VQ(2)=VN(2,1)
0555            VQ(3)=VN(3,1)
0556           R(1) = R12
0557           PR(1) =         RHO*HE(1)*(VB(1)**2/R(1)+G*UN(2,JT))
0558            CALL VEL(EL,AMOOT(1),JT,LT,HE(1),WW,F(1),F(2),S(1),S(2),PR(1),
     *  VQ,VP,
     *  MU)
0559            DO 500 L=1,3
0560            VN(L,1)=VP(L)
0561      500   CONTINUE
      C
      C       MAIN IGROUP.EQ.1  ROUTINE      ********************************************
      C
0562            DO 600 I=2,IQ
0563            K=I-1
0564            VB(K)=SQRT(VN(1,K)**2+VN(2,K)**2+VN(3,K)**2)
      C
      C  LOCATE NEW NET POINT I AT INTERSECTION OF DIVIDING PLANE THRU OLD NET POINT,
      C  CHUTE SURFACE AT OLD NET POINT AND PLANE NORMAL TO VELOCITY VECTOR THRU
      C   NEW NET POINT WITH INDEX I-1
      C
0565            JT=IT(I)
0566            JP=(JT-1)/2+1
0567            E(4)=0.
0568            DO 510 L=1,3
0569            E(L)=VN(L,K)
0570      510   E(4)=E(4)+VN(L,K)*AN(L,K)
0571            E(4)=-E(4)
0572            JT=IT(I)
0573            JP=(JT-1)/2+1
0574            PI(1)=PP(1,I)
0575            PI(2)=PP(2,I)
0576            PI(3)=PP(3,I)
0577            PI(4)=PP(4,I)
      C
0578           CALL LOCATE (JT,E,PI,PY)
0579           ANL(1)= AN(1,I)
0580           ANL(2)= AN(2,I)
```

```
0581              ANL(3)= AN(3,I)
0582              CALL FIND (JT,NT,ANL,PY,PI,PX,JTP )
0583              EL=0.
0584              DO 520 L=1,3
0585         520   EL=EL+(AN(L,I)-PX(L))**2
0586              EL=SQRT(EL)
0587              W(K) = 0.
0588               DO 560 L=1,3
0589              W(K) = W(K)+(PX(L)-AN(L,K))**2
0590         560     CONTINUE
0591              W(K) = SQRT(W(K))
0592              HE(K) = AMDOT(K)/(W(K)*RHO * VB(K) )
0593              CALL RA(IT(I),NT,AN(1,I),PX,PI,R12)
0594              IF(R12.LT.16.) R12=18.
0595              R(I)=R12
0596              PR(I) =          RHO*HE(I)*(VB(I)**2/R(I)+G*UN(2,IT(I)))
          C
0597               IT(I)=JTP
0598               JPP=(JTP-1)/2+1
0599         550   CONTINUE
0600         544   CONTINUE
          C
0601         2002   FORMAT(//2X,I8,10F7.2)
0602               IF(I.EQ.IQ) GO TO 565
          C
0603               LT=IT(I)
0604               JT=IT(K)
0605               VQ(1)=VN(1,I)
0606               VQ(2)=VN(2,I)
0607               VQ(3)=VN(3,I)
0608               CALL VEL(EL,AMDOT(I),JT,LT,HE(I),W(I),F(I),F(I+1),
                  * S(I),S(I+1),PR(I),VQ,VP ,
                  *  MU)
0609               VB(I) = SQRT(VP(1)**2+VP(2)**2+VP(3)**2)
0610         565     CONTINUE
0611               DO 570 L=1,3
0612               VN(L,I)=VP(L)
0613               AN(L,I)=PX(L)
0614         570     CONTINUE
0615         600     CONTINUE
0616               IF ( TOOBIG) GO TO 799
          C
          C  TRANSFER ALL WAVE FRONT PARAMETERS TO ACCORD WITH RENUMBERING REQUIRED
          C  BY ADDED STREAM
          C
0617                DO 601 J=1,IQ
0618               I=IQ-J+1
0619                K=I+1
```

```
0620              DO 601 L=1,3
0621             AN(L,K)=AN(L,I)
0622              IT(K)=IT(I)
0623              VN(L,K)=VN(L,I)
0624             VB(K)=VB(I)
0625             W(K) = W(I)
0626             HE(K) = HE(I)
0627             AMDOT(K) = AMDOT(I)
0628         601  CONTINUE
0629              IT(I)=JTP
0630             WW=0.
0631             DO 698 L=1,3
0632              VN(L,I)=VI(L,IQ)
0633              AN(L,I)=PXX(L)
0634             WW=WW+(AN(L,1)-AN(L,2))**2
0635          698 CONTINUE
0636             W(I)= SQRT (WW)
0637              VB(I)=SQRT(VN(1,I)**2+VN(2,I)**2+VN(3,I)**2)
0638             AMDOT(I) =BAMDOT (IQ)
0639              HE(I)=AMDOT(I)/(W(I)*RHO*VB(I))
0640               GO TO 799
          C ***************************************************************
0641         699  CONTINUE
          C
          C  NEW VELOCITY FOR STREAM IQ-1 ***************************************
          C
0642              JT=IT(IQ)
0643             IT(IQ)= JTP
0644              LT=IT(IQ-1)
0645              WW=W(IQ-1)
0646              VQ(1)=VN(1,IQ-1)
0647              VQ(2)=VN(2,IQ-1)
0648              VQ(3)=VN(3,IQ-1)
0649              R(IQ-1)=R12
0650              PR(IQ-1)=          RHO*HE(IQ-1)*(VB(IQ-1)**2/R(IQ-1)+G*UN(2,LT))
0651              CALL VEL(EL,AMDOT(IQ),JT,LT,HE(IQ-1),WW,F(IQ-1),F(IQ),S(IQ-1),S(I
                 *Q),PR(IQ-1),VQ,VP,
                 * MU)
0652              DO 501 L=1,3
0653             VN(L,IQ-1)=VP(L)
0654         501  CONTINUE
0655         700  CONTINUE
          C
          C       MAIN IGROUP.EQ.2  ROUTINE   ***********************************************
          C
0656         701  CONTINUE
0657              DO 795 I=2,IQ
0658                J=IQ-I+1
```

```
0659                K=J+1
0660                VB(J)=SQRT(VN(1,J)**2+VN(2,J)**2+VN(3,J)**2)
0661                 E(4)=0.
0662                DO 710 L=1,3
0663                E(L)=VN(L,K)
0664          710   E(4)=E(4)+VN(L,J)*AN(L,K)
0665                E(4)=-E(4)
0666                JT=IT(J)
0667                JP=(JT-1)/2+1
0668                PI(1)=PP(1,J)
0669                PI(2)=PP(2,J)
0670                PI(3)=PP(3,J)
0671                PI(4)=PP(4,J)
              C
              C  LOCATE NEW NET POINT J BASED  ON INTERSECTION OF DIVIDING
              C  PLANE THRU OLD NET POINT, CHUTE SURFACE AT OLD NET POINT AND PLANE
              C  NORMAL TO VELOCITY VECTOR THRU NEW NET POINT WITH INDEX J+1
              C
0672                CALL LOCATE (JT,E,PI,PY)
0673                ANL(1)= AN(1,J)
0674                ANL(2)= AN(2,J)
0675                ANL(3)=AN(3,J)
0676                CALL FIND (IT(J),NT,ANL,PY,PI,PX,JTP)
0677                IF(JTP.EQ.100) WRITE ( 6,1402) J
0678                IF(JTP.EQ.100) GO TO 1401
0679                EL=0.
0680                DO 720 L=1,3
0681          720    EL=EL+(AN(L,J)-PX(L))**2
0682                EL=SQRT(EL)
0683                  W(J)=0.
0684                  DO 760 L=1,3
0685                 W(J)=W(J)+(PX(L)-AN(L,K))**2
0686          760    CONTINUE
0687                 W(J)=SQRT(W(J))
0688                CALL RA(IT(J),NT,AN(1,J),PX,PI,R12)
0689                IF(R12.LT.18.) R12=18.
0690                 R(J)=R12
0691                PR(J) =          RHO*HE(J)*(VB(J)**2/R(J)+G*UN(2,IT(J)))
0692                 IT(J)=JTP
0693                  JPP=(JTP-1)/2+1
0694                 IF(J.EQ.1) GO TO 765
0695                  LT=IT(J)
0696                N=J-1
0697                 JT=IT(N)
0698                 VQ(1)=VN(1,N)
0699                 VQ(2)=VN(2,N)
0700                 VQ(3)=VN(3,N)
0701                 CALL VEL(EL,AMDOT(N),JT,LT,HE(N),W(N),F(N),F(J),S(N),S(J),PR(J),
```

```
     1   VQ,VP,
     *  MU)
0702  765   CONTINUE
      C PARAMETERS FOR NEW WAVE FRONT ************************
0703        DO 770 L=1,3
0704        VN(L,N)=VP(L)
0705        AN(L,J)=PX(L)
0706        AN(L,IQ+1)=PXX(L)
0707  770   CONTINUE
0708        VB(J) = SQRT(VN(1,J)**2+VN(2,J)**2+VN(3,J)**2)
0709        HE(J)=AMDOT(J)/(W(J)*RHO*VB(J) )
0710  795   CONTINUE
0711        WW=0.
0712        DO 798 L=1,3
0713        VN(L,IQ)= VI(L,IQ)
0714        VN(L,IQ+1)= VI(L,IQ)
0715        WW=WW+(AN(L,IQ)-AN(L,IQ+1))**2
0716  798   CONTINUE
0717        W(IQ)= SQRT(WW)
0718        VB(IQ)= SQRT(VN(1,IQ)**2+VN(2,IQ)**2+VN(3,IQ)**2 )
0719        HE(IQ)=AMDOT(IQ)/(W(IQ)*RHO*VB(IQ) )
0720        IT(IQ+1)=JTTP
0721  799   CONTINUE
      C
0722        IF ( TOOBIG) IQ=IQ-1
0723        TOOBIG = .FALSE.
      C
0724        DO 815 I=1,IQ
0725        JT=IT(I)
0726        K=I+1
0727        LT=IT(K)
0728        UNN=(UN(2,LT)+UN(2,JT))/2.
0729        PR(I) =        RHO*HE(I)*(VB(I)**2/R(I)+G*UNN)
0730  815   CONTINUE
0731        IQ1= IQ+1
0732        HE(IQ1)=-HE(IQ)
0733        PR(IQ1)=-PR(IQ)
      C
      C FORCE VELOCITY VECTOR TO BE NORMAL TO WAVE FRONT
      C
0734        DO 822 K=2,IQ1
0735        DO 820 L=1,3
0736        P3(L)= (AN(L,K)-AN(L,K-1))
0737        P4(L)= UN(L,IT(K))+UN(L,IT(K-1))
0738  820   CONTINUE
0739        P5(1)= P4(2)*P3(3)-P4(3)*P3(2)
0740        P5(2)=P4(3)*P3(1)-P4(1)*P3(3)
0741        P5(3)=P4(1)*P3(2)-P4(2)*P3(1)
```

```
0742                WW=0.
0743                DO 821 L=1,3
0744                WW=WW+P5(L)**2
0745          821   CONTINUE
0746                WW= SQRT(WW)
0747                VN(1,K-1)= P5(1)*VB(K-1)/WW
0748                VN(2,K-1)= P5(2)*VB(K-1)/WW
0749                VN(3,K-1)= P5(3)*VB(K-1)/WW
0750          822    CONTINUE
              C
0751                C(1)= 1.E10
0752                DO 830 L=2,IQ1
0753                 K=L-1
0754                JT=IT(L)
0755                 CALL DETR(VN(1,K),VN(1,L),UN(1,JT),C(L))
0756          830     CONTINUE
              C    STREAM BOUNDARY DIVIDING PLANES **********************
0757                PX(1)=AN(1,1)
0758                PX(2)=AN(2,1)
0759                PX(3)=AN(3,1)
0760                VP(1)=VN(1,1)
0761                VP(2)=VN(2,1)
0762                VP(3)=VN(3,1)
0763                JT=IT(1)
0764                CALL PLANE(JT,PX,VP,E)
0765                PP(1,1)=E(1)
0766                PP(2,1)=E(2)
0767                PP(3,1)=E(3)
0768                PP(4,1)=E(4)
0769                PX(1)=AN(1,IQ1)
0770                PX(2)=AN(2,IQ1)
0771                PX(3)=AN(3,IQ1)
0772                VP(1)=VN(1,IQ)
0773                VP(2)=VN(2,IQ)
0774                VP(3)=VN(3,IQ)
0775                JT= IT(IQ+1)
0776                 CALL PLANE(JT,PX,VP,E)
0777                  PP(1,IQ1)=E(1)
0778                  PP(2,IQ1)=E(2)
0779                  PP(3,IQ1)=E(3)
0780                  PP(4,IQ1)=E(4)
0781          891   FORMAT( ' COORD. OF AN',I3,3X,3(F6.2,1X),3X,'TRI',I4
                    * ,3X,'STEP',I3,3X,'RAD',1X,F5.1,3X,'VEL',F6.1
                    * ,3X,'HGT',F7.3,3X,'WIDTH',F5.2,3X,'C',1X,E13.3)
0782                 DO 892 I=1,IQ1
0783                 WRITE(6,891) I,AN(1,I),AN(2,I),AN(3,I),IT(I),ISTEP,R(I),VB(I)
                    * ,HE(I),W(I),C(I)
0784          892   CONTINUE
```

```
0785                IQ=IQ+1
0786               IF ( IQ.GT. NS) GO TO 900
0787               ISTEP=ISTEP-1
0788                GO TO 370
                C   ************************************************************
0789            900 CONTINUE
0790                IQ=IQ-1
0791                IQ1=IQ+1
0792           1401      CONTINUE
               C
               C  WAVE FRONT PROGRESSION AS BEFORE BUT NO NEW STREAMS ADDED
               C  FIXED STEP ELI TAKEN BY STREAM 1 ( OR LOWEST NUMBERED STREAM STILL ON
               C  CHUTE). IF A STREAM LEAVES CHUTE ALL HIGHER NUMBERED STREAMS ARE
               C  ASSUMED OFF CHUTE ALSO. X= LOWEST NUMBERED STREAM ON CHUTE,NS1= HIGHEST
               C  NUMBERDD STREAM STILL ON CHUTE.
               C
0793           6999   CONTINUE
0794                  NS=IQ1
0795                  ISTEP=1
0796                 X = 1
0797                 NSS = NS
0798                 NSM = NS - 1
0799           1000      CONTINUE
0800                 DO 1010 I=X,NSS
0801           1010   VB(I)=SQRT(VN(1,I)**2+VN(2,I)**2+VN(3,I)**2)
0802           1011  CONTINUE
0803                 NS1 = NSS - 1
0804                 FORC(X,ISTEP) = 0.
0805                 SHEA (X,ISTEP) = 0.
0806                  FORC (NSS,ISTEP) = 0.
0807                 SHEA(NSS,ISTEP) = 0.
0808                 F(X) = 0.
0809                 S(X) = 0.
0810                 F(NSS) = 0.
0811                 S(NSS) = 0.
0812                  JT = IT(X)
0813                  DO 6001 L=1,3
0814                 PX(L) = AN(L,X)
0815            6001 VP(L) = VN(L,X)
0816                  CALL PLANE(JT,PX,VP,E)
0817                  DO 6002 L=1,4
0818            6002 PP(L,X) = E(L)
0819                  DO 6003 L=1,3
0820                 PX(L) = AN(L,NSS)
0821           6003    VP(L)=VN(L,NS1)
0822                 JT = IT(NSS)
0823                  CALL PLANE(JT,PX,VP,E)
0824                  DO 6004 L=1,4
```

```
0825          6004 PP(L,NSS) = E(L)
0826               PR(X) = RHO*HE(X)*(G*UN(2,IT(X))+VB(X)**2/R(X))
0827               X1=X+1
0828               DO 1200 L=X1,NS1
0829                JT=IT(L)
0830                 PR(L)=RHO*HE(L)*(G*UN(2,JT)+VB(L)**2/R(L))
0831                K=L-1
0832                CALL DETR(VN(1,K),VN(1,L),UN(1,JT),C(L))
                 C
                 C  C(L) LESS THAN ZERO MEANS STREAMS DIVERGING
                 C
0833                IF(C(L).LT.0.) GO TO 1020
0834               F(L)=KC*(PR(L)+PR(K))*(HE(L)+HE(K))/4.
0835               S(L)=F(L)*SIN(DELTA)
0836               IF(VB(L).LT.VB(K)) S(L)=-S(L)
0837              P5(1)=VN(1,L)/VB(L)+HE(K)/(HE(K)+HE(L))*
                 * (VN(1,K)/VB(K)-VN(1,L)/VB(L))
0838               P5(2)=VN(2,L)/VB(L)+HE(K)/(HE(K)+HE(L))*
                 * (VN(2,K)/VB(K)-VN(2,L)/VB(L))
0839               P5(3)=VN(3,L)/VB(L)+HE(K)/(HE(K)+HE(L))*
                 * (VN(3,K)/VB(K)-VN(3,L)/VB(L))
0840               CALL PLANE(JT,AN(1,L),P5,PP(1,L))
0841                GO TO 1030
0842          1020    CONTINUE
0843               F(L)=KE*(PR(L)+PR(K))*(HE(L)+HE(K))/4.
0844               S(L)=F(L)*SIN(DELTA)
0845                IF(VB(L).LT.VB(K)) S(L)=-S(L)
0846              P5(1)=VN(1,L)/VB(L)+HE(L)/(HE(K)+HE(L))*
                 * (VN(1,K)/VB(K)-VN(1,L)/VB(L))
0847               P5(2)=VN(2,L)/VB(L)+HE(L)/(HE(K)+HE(L))*
                 * (VN(2,K)/VB(K)-VN(2,L)/VB(L))
0848               P5(3)=VN(3,L)/VB(L)+HE(L)/(HE(K)+HE(L))*
                 * (VN(3,K)/VB(K)-VN(3,L)/VB(L))
0849               CALL PLANE(JT,AN(1,L),P5,PP(1,L))
0850          1030    CONTINUE
0851               FORC(L,ISTEP)=F(L)
0852               SHEA(L,ISTEP)=S(L)
0853          1200    CONTINUE
0854               PR(NSS)=-PR(NS1)
0855                 NSKIP=0
0856               EL1 = 1.2
0857               NSS1 = NS1-1
0858               DO 1202 I = X,NSS1
0859               IF (ABS(VB(I) - VB(I+1)).LT.12.) GO TO 1202
0860               EL1 = EL1/2.
0861               GO TO 1203
0862          1202  CONTINUE
0863          1203  CONTINUE
```

```
0864                DO 2000 I = X,NSS
0865                  JTP=100
0866                JT=IT(I)
0867                LT=JT
0868               IF(I.NE.X) GO TO 1230
0869                EL=EL1
0870          1201    CONTINUE
                    C
                    C  LOCATE NEW SMALLEST NUMBERED NETPOINT
                    C
0871               P5(1)= AN(1,I)-VN(1,X)
0872               P5(2)= AN(2,I)-VN(2,X)
0873               P5(3)= AN(3,I)-VN(3,X)
0874               CALL LOCAT3(LT,EL,PP(1,I),AN(1,I),P5,PX )
0875                CALL FIND(JT,NT,AN(1,I),PX,PP(1,I),AX,JTP)
0876               IF(JTP.EQ.100) GO TO 1228
0877                CALL RA  (JT,NT,AN(1,I),PX,PP(1,I),R12)
0878               IF(R12.LE.18.) R12=18.
0879                DO 1122 L=1,3
0880          1122    PX(L)=AX(L)
0881          1205    CONTINUE
0882               LLP=(JTP-1)/2+1
0883               IPL(I,ISTEP)=LLP
0884                GO TO 1240
0885          1228  CONTINUE
0886               WRITE (6,1121) I,ISTEP
0887          1121   FORMAT(1X,'STREAM',1X,I3,3X,'OFF CHUTE DURING STEP',I3)
0888                X=X+1
0889               IF(X.EQ.NSS-1) GO TO 2500
0890               GO TO 1000
0891          1229  CONTINUE
0892               WRITE (6,1121) I,ISTEP
0893               NSS=I-1
0894               IF(X.GE.NSS-1) GO TO 2500
0895                 GO TO 1998
0896          1230    CONTINUE
                    C
                    C  LOCATE REMAINDER OF NET POINTS STILL ON CHUTE
                    C
0897                K=I-1
0898                E(4)=0.
0899                DO 1235 L=1,3
0900                E(L)=VN(L,K)
0901          1235    E(4)=E(4)+VN(L,K)*AN(L,K)
0902                E(4)=-E(4)
0903                CALL LOCATE(LT,E,PP(1,I),PX)
0904                CALL FIND(JT,NT,AN(1,I),PX,PP(1,I),AX,JTP)
0905               IF(JTP.EQ.100) GO TO 1229
```

```
0906                CALL RA  (JT,NT,AN(L,I),PX,PP(L,I),R12)
0907               IF(R12.LT.18.) R12=18.
0908                DO 1247 L=1,3
0909         1247    PX(L)=AX(L)
0910         1249    CONTINUE
0911               LLP=(JTP-1)/2+1
0912               IPL(I,ISTEP)=LLP
0913                EL=0.
0914                DO 1245 L=1,3
0915                EL=EL+(AN(L,I)-PX(L))**2
0916         1245    CONTINUE
0917                EL=SQRT(EL)
0918                W(K)=0.
0919                 DO 1250 L=1,3
0920                W(K)=W(K)+(PX(L)-AN(L,K))**2
0921         1250    CONTINUE
0922                 W(K)=SQRT(W(K))
0923               WIDTH(K,ISTEP)=W(K)
0924                HE(K)=AMDOT(K)/(W(K)*RHO*VB(K))
0925               HGT(K,ISTEP)=HE(K)
0926         1240    CONTINUE
0927         1241    CONTINUE
0928               CORD(1,I,ISTEP)=PX(1)
0929               CORD(2,I,ISTEP)=PX(2)
0930               CORD(3,I,ISTEP)=PX(3)
0931              IF (I.EQ.X) GO TO 9245
0932              XISTEP = ISTEP
0933              IF(ABS(XISTEP/7.-AINT(XISTEP/7.)).GT.0.1) GO TO 9245
0934               CALL GRIDCD(ID,PXSAV)
0935               IPTS(1)=ID
0936               CALL GRIDCD(ID,PX)
0937               IPTS(2)=ID
0938               CALL CBARCD(NE,IPTS)
0939         9245    CONTINUE
0940                 DO 9246    J=1,3
0941         9246    PXSAV(J)=PX(J)
0942               JP=(JT-1)/2+1
0943               JPP=(JTP-1)/2+1
0944               NCH=1
0945               IF(JPP.EQ.JP) NCH=0
0946               IF(JPP.EQ.JP) JPP=JP+1
0947              IF (JPP.LE.NP) GO TO 5001
0948              GO TO 5005
0949         1310    CONTINUE
0950          5001 CONTINUE
0951               P4(1)=PTDAT(1,4,JPP)
0952               P4(2)=PTDAT(2,4,JPP)
0953               P4(3)=PTDAT(3,4,JPP)
```

```
0954                AX(1)=PTDAT(1,3,JPP)
0955                AX(2)=PTDAT(2,3,JPP)
0956                AX(3)=PTDAT(3,3,JPP)
0957                VP(1)=PTDAT(1,2,JPP)
0958                VP(2)=PTDAT(2,2,JPP)
0959                VP(3)=PTDAT(3,2,JPP)
0960                VQ(1)=PTDAT(1,1,JPP)
0961                VQ(2)=PTDAT(2,1,JPP)
0962                VQ(3)=PTDAT(3,1,JPP)
0963               IF (I.EQ.X) EL = EL1
0964             5005 CONTINUE
0965               R(I) = R12
0966                RAD(I,ISTEP)=R(I)
0967               IF(I.EQ.NSS) GO TO 1275
0968                LT=IT(I)
0969                M=I+1
0970                KT=IT(M)
0971                  UNN=(UN(2,LT)+UN(2,KT))/2.
0972                PR(I)=RHO*HE(I)*(G*UNN+VB(I)**2/R12)
0973               IF (I.EQ.X) EL = EL1
0974                VQ(1)=VN(1,I)
0975                VQ(2)=VN(2,I)
0976                VQ(3)=VN(3,I)
0977                 CALL VEL(EL,AMDOT(I),JT,LT,HE(I),W(I),F(I),F(M),S(I),S(M),PR(I),
                  *   VQ,VP,
                  *  MU)
0978                IF (ISTEP.EQ.14.OR.ISTEP.EQ.15.OR.ISTEP.EQ.16)
                  *WRITE(6,1274) HE(I),W(I),F(I),F(M),S(I),S(M),PR(I),VQ(1),
                  * VQ(2),VQ(3),VP(1),VP(2), VP(3),MU
0979           1274  FORMAT(14(F8.2,1X))
0980           1275    CONTINUE
0981                 VB(I)=SQRT(VP(1)**2+VP(2)**2+VP(3)**2)
0982                VELOC(I,ISTEP)=VB(I)
0983                DO 1280 L=1,3
0984                VN(L,I)=VP(L)
0985                AN(L,I)=PX(L)
0986           1280    CONTINUE
0987                IT(I)=JTP
0988           1290    CONTINUE
0989           3333    FORMAT(' THE POINT',I4,' DIST=',F7.2,' AFTER STEP',I4)
0990           1999    CONTINUE
0991           2000    CONTINUE
0992           1998  CONTINUE
0993                DO 2004 I=1,NS
0994                IF(I.GE.X.AND. I.LE.NSS) GO TO 2004
0995                RAD(I,ISTEP)=0.
0996                FORC(I,ISTEP)=0.
0997                SHEA(I,ISTEP)=0.
```

```
0998                IPL(I,ISTEP)=0
0999                WIDTH(I,ISTEP)=0.
1000                HGT(I,ISTEP)=0.
1001                VELOC(I,ISTEP)=0.
1002                CORD(1,I,ISTEP)= CORD(1,I,ISTEP-1)
1003                CORD(2,I,ISTEP)= CORD(2,I,ISTEP-1)
1004                CORD(3,I,ISTEP)= CORD(3,I,ISTEP-1)
1005          2004  CONTINUE
                    C  FORCE VELOCITY VECTOR TO BE NORMAL TO WAVE FRONT
1006                X1=X+1
1007                DO 802 K=X1,NSS
1008                DO 800 L=1,3
1009                P3(L)= (AN(L,K)-AN(L,K-1))
1010                P4(L)= UN(L,IT(K))+UN(L,IT(K-1))
1011          800    CONTINUE
1012                P5(1)= P4(2)*P3(3)-P4(3)*P3(2)
1013                P5(2)=P4(3)*P3(1)-P4(1)*P3(3)
1014                P5(3)=P4(1)*P3(2)-P4(2)*P3(1)
1015                WW=0.
1016                DO 801 L=1,3
1017                WW=WW+P5(L)**2
1018          801   CONTINUE
1019                WW= SQRT(WW)
1020                VN(1,K-1)= P5(1)*VB(K-1)/WW
1021                VN(2,K-1)= P5(2)*VB(K-1)/WW
1022                VN(3,K-1)= P5(3)*VB(K-1)/WW
1023          802    CONTINUE
1024                DO 2005 I = X,NSS
1025                WRITE(6,891) I,AN(1,I),AN(2,I),AN(3,I),IT(I),ISTEP,R(I),VB(I)
                   *  ,HE(I),W(I), C(I)
1026          2005    CONTINUE
1027                WRITE (6,901)
1028                 ISTEP=ISTEP+1
1029                IF (ISTEP.GT.50) GO TO 3446
1030                 GO TO 1000
1031          2500    CONTINUE
1032                WRITE(6,916)
1033                WRITE(6,901)
1034                WRITE(6,2501)
1035          2501  FORMAT(1X,' PARAMETERS WHEN EACH STREAM LEAVES CHUTE')
1036                WRITE(6,901)
1037                WRITE(6,916)
1038                DO 2345 I=1,NSM
1039                 WRITE(6,2346) I,VN(1,I),VN(2,I),VN(3,I)
1040          2346    FORMAT('0',' THE VELOC. COMP. OF STREAM',I4,' ARE',3F10.2)
1041          2345    CONTINUE
1042                 DO 2347 I=1,NS
1043                ZPLAN=ATAN(VN(2,I)/VN(1,I))
```

```
1044                ZPLAN = 57.2 * ZPLAN
1045                 YPLAN=ATAN(VN(1,I)/VN(3,I))
1046                YPLAN = 57.2 * YPLAN
1047                 XPLAN=ATAN(VN(2,I)/VN(3,I))
1048                XPLAN = 57.2 * XPLAN
1049                 WRITE(6,5678) I,ZPLAN,YPLAN,XPLAN
1050          5678    FORMAT('0',' THE DIRECT. ANGLES FOR STR.',I4,' ARE',3E10.2)
1051          2347    CONTINUE
1052                   WRITE(6,3000) ISTEP
1053          3446  IF (JTP.NE.100.OR.ISTEP.NE.51) WRITE(6,7890)
1054          7890  FORMAT( ' SHORT RUN')
1055                 NSTEP=ISTEP-1
1056                DO 4000 I=1,NSM
1057                 WRITE(6,905)
1058                 WRITE(6,916)
1059                 WRITE(6,901)
1060                 WRITE(6,3004)
1061                 WRITE(6,3005)
1062                  DO 3500 J=1,NSTEP
1063                IF (HGT(I,J).EQ.0.) RAT = 0.
1064                IF (HGT(I,J).EQ.0.) GO TO 3498
1065                 RAT=RAD(I,J)/HGT(I,J)
1066           3498 CONTINUE
1067                 WRITE(6,3010) I,J,VELOC(I,J),WIDTH(I,J),HGT(I,J),RAD(I,J) ,RAT,
                    *   FORC(I,J),SHEA(I,J),(CORD(L,I,J),L=1,3),IPL(I,J)
1068          3500    CONTINUE
1069          3010    FORMAT(3X,I4,3X,I4,5X,10(F6.1,3X),2X,I2)
1070          3004  FORMAT('  STREAM   STEP   VELOCITY    WIDTH    HEIGHT    RADIUS
                   1 RAD/HGT     NORMAL     SHEAR     LOCATION')
1071          3005    FORMAT('
                   1              FORCE      FORCE    RIGHT EDGE')
1072          4000    CONTINUE
1073          1402  FORMAT( ' NET POINT',I3,'OFF CHUTE')
1074          3000      FORMAT(' THE STREAMS HAVE LEFT THE CHUTE AFTER STEP',I5)
1075          1400    CONTINUE
1076          9999    CONTINUE
1077          1500    STOP
1078                  END
```

```
0001              SUBROUTINE RA  ( JJT,NT,O1,PZ,PP,KK)
0002              DIMENSION R(2),  U(2,3), PPNN(3,3),UNIT(3) ,T(4)
0003              DIMENSION O1(3),PZ(3)
0004               DIMENSION O(3),P(3),PP(4),PX(3),MTR(2),OP(3),OY(3),PP1(3),PP2(3),
                 *  PP3(3),P1(3),P2(3),P3(3),PPN(3),PQ(3)
0005              DIMENSION PP4(3)
0006              COMMON THET(3,200),ABC(3,200),PT(3,3,200),UN(3,200)
0007               REAL NP,NQ
0008              K1=1
0009              K2=0
0010              K3=0
0011              K4=0
0012              K5=0
0013              R(1)=100.
0014              R(2)=100.
0015         1000  CONTINUE
0016              K5=K2
0017              LET1=0
0018              LET2=0
0019              JT=JJT
0020              DO 1 L=1,3
0021              O(L)=O1(L)
0022              P(L)=PZ(L)
0023         1    CONTINUE
0024         5    CONTINUE
             C  FIND UNIT VECTOR OP
0025               DO 10 L=1,3
0026              O(L) = O(L)
0027               OP(L)=P(L)-O(L)
0028         10   CONTINUE
0029               OPB=SQRT(OP(1)**2+OP(2)**2+OP(3)**2)
0030               DO 20 L=1,3
0031          20   OP(L)=OP(L)/OPB
0032               OY(1) = UN(2,JT)* OP(3) -UN(3,JT)*OP(2)
0033              OY(2) = UN(3,JT)* OP(1) -UN(1,JT)*OP(3)
0034              OY(3) = UN(1,JT)* OP(2) -UN(2,JT)*OP(1)
0035               DO 30 L=1,3
0036              PP1(L) = PT(L,1,JT)
0037              PP2(L) = PT(L,2,JT)
0038              PP3(L) = PT(L,3,JT)
0039         30   CONTINUE
             C FIND COORDS OF P1,P2,P3 WRT NEW ORIGIN AT O
0040              DO 35 L=1,2
0041              P1(L)=0.
0042              P2(L)=0.
0043         35   P3(L)=0.
0044              DO 40 L=1,3
0045              P1(1) = P1(1) +(PP1(L)-O(L))* OP(L)
```

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0046              P2(1) = P2(1) +(PP2(L)-O(L))* OP(L)
0047              P3(1) = P3(1) +(PP3(L)-O(L))* OP(L)
0048              P1(2) = P1(2) +(PP1(L)-O(L))* OY(L)
0049              P2(2) = P2(2) +(PP2(L)-O(L))* OY(L)
0050         40   P3(2) = P3(2) +(PP3(L)-O(L))* OY(L)
0051              KK=1
0052              IF(K5.EQ.1) GO TO 48
0053              IF(LET1.EQ.1.AND.LET2.EQ.2) GO TO 48
0054              IF(LET2.EQ.1.AND.LET1.EQ.2) GO TO 48
0055              ON =((P2(1)-P1(1)) /(P2(2)-P1(2)))*(-P1(2)) +P1(1)
0056         45   IF(ON.LE.P1(1).AND.ON.GE.P2(1).OR.ON.LE.P2(1).AND.ON.GE.P1(1)) GO
                 * TO 100
0057         48   CONTINUE
0058              IF(LET1.EQ.2.AND.LET2.EQ.3) GO TO 58
0059              IF(LET2.EQ.2.AND.LET1.EQ.3) GO TO 58
0060              KK=2
0061              IF(K5.EQ.2) GO TO 58
0062              ON =((P3(1)-P2(1)) /(P3(2)-P2(2)))*(-P2(2)) +P2(1)
0063         55   IF(ON.LE.P2(1).AND.ON.GE.P3(1).OR.ON.LE.P3(1).AND.ON.GE.P2(1)) GO
                 * TO 110
0064         58   CONTINUE
0065              KK=3
0066              IF(K5.EQ.3) GO TO 97
0067              ON =((P1(1)-P3(1)) /(P1(2)-P3(2)))*(-P3(2)) +P3(1)
0068         65   IF(ON.LE.P3(1).AND.ON.GE.P1(1).OR.ON.LE.P1(1).AND.ON.GE.P3(1)) GO
                 * TO 120
0069         97   WRITE(6,98)
0070         98   FORMAT ( 1X, ' ERROR IN RADIUS ROUTINE')
0071              RR = 54.
0072         99   RETURN
0073         100  CONTINUE
0074              DO 70 L=1,3
0075              PP1(L)=PT(L,1,JT)
0076         70   PP2(L)=PT(L,2,JT)
0077               GO TO 200
0078         110   DO 80 L=1,3
0079               PP1(L) =  PT(L,2,JT)
0080         80   PP2(L)=PT(L,3,JT)
0081               GO TO 200
0082         120   DO 90 L=1,3
0083               PP1(L)=  PT(L,3,JT)
0084              PP2(L)=  PT(L,1,JT)
0085         90   CONTINUE
0086         200   CONTINUE
0087              K5=0
0088              IF(K2.EQ.0) K2=KK
0089              IF(K4.EQ.1) K2=10
              C FIND TRIANGLE HAVING SIDE DEFINED BY PP1,PP2
```

```
0090                DO 300 M=1,NT
0091                IF(M.EQ.JT) GO TO 300
0092               LET1=0
0093               LET2=0
0094                NV=0
0095                DO 310 J=1,3
0096                DO 320 K=1,3
0097                IF(PP1(K).NE.PT(K,J,M)) GO TO 324
0098         320    CONTINUE
0099               LET1=J
0100                NV=NV+1
0101         324    CONTINUE
0102                DO 325 K=1,3
0103                IF(PP2(K).NE.PT(K,J,M)) GO TO 308
0104         325    CONTINUE
0105               LET2=J
0106                NV=NV+1
0107         308    IF(NV.EQ.2) GO TO 350
0108         310   CONTINUE
0109         300    CONTINUE
0110         350    CONTINUE
0111                JTP=M
0112               IF(NV.NE.2) GO TO 204
0113                JT=JTP
0114         204   CONTINUE
0115                DO 205 L=1,3
0116           205 PP4(L) = PP1(L) + 100.*UN(L,JT)
0117                T(1) = PP1(2)*(PP2(3)-PP4(3))
                *       -PP1(3)*(PP2(2)-PP4(2))
                *        +(PP2(2)*PP4(3)-PP4(2)*PP2(3))
0118                T(2)=-(PP1(1)*(PP2(3)-PP4(3))
                *       -PP1(3)*(PP2(1)-PP4(1))
                *      +(PP2(1)*PP4(3)-PP2(3)*PP4(1)))
0119                T(3)=PP1(1)*(PP2(2)-PP4(2))
                *  - PP1(2)*(PP2(1)-PP4(1))
                *      +(PP2(1)*PP4(2)-PP4(1)*PP2(2))
0120                T(4)=-(PP1(1)*(PP2(2)*PP4(3)-PP4(2)*PP2(3))
                *    -PP1(2)*(PP2(1)*PP4(3)-PP4(1)*PP2(3))
                *  + PP1(3)*(PP2(1)*PP4(2)-PP4(1)*PP2(2)))
0121                CALL LOCATE(JT,T,PP,PPN)
0122                IF(NV.NE.2) GO TO 390
0123                N=0
0124                V=0
0125                DO 360  L=1,3
0126                IF(UN(L,JTP).LE.UN(L,JJT)+1.E-5.AND.UN(L,JTP).GT.UN(L,JJT)-1.E-5)
                * N=N+1
0127                U(K1,L)=(UN(L,JTP)+UN(L,JJT))
0128                PPNN(K1,L)=PPN(L)
```

```
0129              V=V+U(K1,L)**2
0130            360 CONTINUE
0131              DO 361 L=1,3
0132              U(K1,L) = U(K1,L)/SQRT(V)
0133            361   CONTINUE
0134              IF(N.EQ.3) GO TO 368
0135              K1=K1+1
0136              K3=K3+1
0137              IF(K1.EQ.4) GO TO 400
0138              IF(K3.EQ.2) GO TO 362
0139              GO TO 368
0140            362   CONTINUE
0141              IF (K1.EQ.4) GO TO 400
0142              K3=0
0143              K4=1
0144              GO TO 1000
0145            390   DO 395 L=1,3
0146              PPNN(K1,L) = PPN (L)
0147             395  CONTINUE
0148              R(K1) = 1.E10
0149              K1=K1+1
0150              IF(R(1).EQ.1.E10 .AND.R(2).EQ.1.E10) WRITE (6,367)
0151            367   FORMAT(1X,' COMPUTATION  FOR RADIUS INVALID')
0152              IF(R(1).EQ.1.E10 .AND.R(2).EQ.1.E10) RR=54
0153              IF(R(1).EQ.1.E10 .AND.R(2).EQ.1.E10) RETURN
0154              GO TO 362
0155            368   NP=100.
0156            369   CONTINUE
0157              CALL LOCAT3 (JTP,NP,PP,PPN,O1,PX)
0158            370    CONTINUE
0159              DO 380 L=1,3
0160              P(L)=PX(L)
0161            380    O(L)=PPN(L)
0162              GO TO 5
0163            400   CONTINUE
0164              DO 450 L=1,3
0165              OP(L)=PZ(L)-O1(L)
0166            450   CONTINUE
0167              OPB=SQRT(OP(1)**2+OP(2)**2+OP(3)**2)
0168              DO 460 L=1,3
0169              OP(L)=OP(L)/OPB
0170            460   CONTINUE
0171              X1= (PPNN( 1,1)-O1(1))*OP(1)+(PPNN( 1,2)-O1(2))*OP(2)
                 *    +(PPNN( 1,3)-O1(3))*OP(3)
0172              X2= (PPNN( 2,1)-O1(1))*OP(1)+(PPNN( 2,2)-O1(2))*OP(2)
                 *    +(PPNN( 2,3)-O1(3))*OP(3)
0173              X3= (PPNN( 3,1)-O1(1))*OP(1)+(PPNN( 3,2)-O1(2))*OP(2)
                 *    +(PPNN( 3,3)-O1(3))*OP(3)
```

```
0174              Y1= (PPNN( 1,1)-O1(1))*UN(1,JJT)+(PPNN(1,2)-O1(2)) *UN(2,JJT)
                 *    +(PPNN( 1,3)-O1(3))*UN(3,JJT)
0175              Y2= (PPNN( 2,1)-O1(1))*UN(1,JJT)+(PPNN(2,2)-O1(2)) *UN(2,JJT)
                 *    +(PPNN( 2,3)-O1(3))*UN(3,JJT)
0176              Y3= (PPNN( 3,1)-O1(1))*UN(1,JJT)+(PPNN(3,2)-O1(2)) *UN(2,JJT)
                 *    +(PPNN( 3,3)-O1(3))*UN(3,JJT)
0177              Z1=-(X1**2+Y1**2)
0178              Z2=-(X2**2+Y2**2)
0179              Z3=-(X3**2+Y3**2)
0180              DENOM=X1*Y2+X2*Y3+X3*Y1-X3*Y2-X2*Y1-X1*Y3
0181              ANUM=Z1*Y2+Z2*Y3+Z3*Y1-Z3*Y2-Z2*Y3-Z1*Y3
0182              BNUM=X1*Z1+X2*Z3+X3*Z1-X3*Z2-X2*Z1-X1*Z3
0183              CNUM=X1*Y2*Z3+X2*Y3*Z1+X3*Y1*Z2-X3*Y2*Z1-X2*Y1*Z3-X1*Y3*Z2
0184              A=ANUM/DENOM
0185              B=BNUM/DENOM
0186              C=CNUM/DENOM
0187              RR=      -C+(-A/2.)**2+( -B/2.)**2
0188              IF(RR.LT.0) WRITE(6,98)
0189              IF (RR.LT.0) RR = 324.
0190              RR = SQRT(RR)
0191              IF(RR.GT.54.) RR=54.
0192               RETURN
0193              END
```

```
FORTRAN IV G LEVEL  21                GRIDCD          DATE = 77169      23/44/04          PAGE 0001

0001                  SUBROUTINE GRIDCD ( ID,XYZ)
                     ,C
0002                    910 FORMAT ( 'GRID',4X,I8,8X,3F8.3)
0003                    911 FORMAT ( 'CBAR',4X,I8,8X,2I8)
0004                    915 FORMAT ('CQDMEM' ,2X,I8,8X,4I8)
                     C
                     C
0005                  DIMENSION XYZ(1)
0006                  ID = ID + 1
0007                  WRITE ( 10,910) ID,XYZ(3) , XYZ(1) , XYZ(2)
0008                  RETURN
                     C
                     C
                     C-------------------------------------------------------------------------
0009                  ENTRY CQDCD ( NE, PTS)
                     C-------------------------------------------------------------------------
0010                  INTEGER PTS(4)
                     C
0011                  NE = NE + 1
0012                  WRITE ( 10,915) NE ,  PTS
0013                  RETURN
                     C
                     C
                     C-------------------------------------------------------------------------
0014                  ENTRY CBARCD ( NE, PTS)
                     C-------------------------------------------------------------------------
                     C
0015                  NE = NE + 1
0016                  WRITE ( 10,911) NE,PTS(1) , PTS(2)
0017                  RETURN
0018                  END
```

```
FORTRAN IV G LEVEL  21                  DETR          DATE = 77109      23/44/04          PAGE 0001

0001                  SUBROUTINE DETR(A,B,C,DT)
                C
0002                  DIMENSION A(1) , B(1) , C(1)
                C
0003                  D=A(1)*B(2)*C(3)
0004                  D = D + A(2)*B(3)*C(1)
0005                  D=D+ A(3)*B(1)*C(2)
                C
0006                  D = D -A(3)*B(2)*C(1)
0007                  D=D-A(2)*B(1)*C(3)
0008                  DT= D-A(1)*B(3)*C(2)
                C
0009                  RETURN
0010                  END
```

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```
0001                SUBROUTINE FIND( JJT,NT,O1,PZ,PP,PX,JIP)
0002                DIMENSION O1(3),PZ(3)
0003                 DIMENSION O(3),P(3),PP(4),PX(3),MTR(2),OP(3),OY(3),PP1(3),PP2(3),
                   *  PP3(3),P1(3),P2(3),P3(3),PPN(3),PQ(3)
0004                 DIMENSION R(4)
0005                DIMENSION PP4(3)
0006                COMMON THET(3,200),ABC(3,200),PT(3,3,200),UN(3,200)
0007                 REAL NP,NQ
0008                JT=JJT
0009                LET1=0
0010                LET2=0
0011                DO 1 L=1,3
0012                O(L)=O1(L)
0013                P(L)=PZ(L)
0014          1     CONTINUE
0015          5     CONTINUE
              C   FIND UNIT VECTOR OP
0016                 DO 10 L=1,3
0017                O(L) = O(L)
0018                 OP(L)=P(L)-O(L)
0019          10    CONTINUE
0020                 OPB=SQRT(OP(1)**2+OP(2)**2+OP(3)**2)
0021                 DO 20 L=1,3
0022           20    OP(L)=OP(L)/OPB
0023                OY(1) = UN(2,JT)* OP(3) -UN(3,JT)*OP(2)
0024                OY(2) = UN(3,JT)* OP(1) -UN(1,JT)*OP(3)
0025                OY(3) = UN(1,JT)* OP(2) -UN(2,JT)*OP(1)
0026                 DO 30 L=1,3
0027                PP1(L) = PT(L,1,JT)
0028                PP2(L) = PT(L,2,JT)
0029                PP3(L) = PT(L,3,JT)
0030          30    CONTINUE
              C FIND COORDS OF P1,P2,P3 WRT NEW ORIGIN AT O
0031                DO 35 L=1,2
0032                P1(L)=0.
0033                P2(L)=0.
0034          35    P3(L)=0.
0035                DO 40 L=1,3
0036                P1(1) = P1(1) +(PP1(L)-O(L))* OP(L)
0037                P2(1) = P2(1) +(PP2(L)-O(L))* OP(L)
0038                P3(1) = P3(1) +(PP3(L)-O(L))* OP(L)
0039                P1(2) = P1(2) +(PP1(L)-O(L))* OY(L)
0040                P2(2) = P2(2) +(PP2(L)-O(L))* OY(L)
0041          40    P3(2) = P3(2) +(PP3(L)-O(L))* OY(L)
0042                K=1
0043                IF(LET1.EQ.1.AND.LET2.EQ.2) GO TO 48
0044                IF(LET2.EQ.1.AND.LET1.EQ.2) GO TO 48
0045                ON =((P2(1)-P1(1)) /(P2(2)-P1(2)))*(-P1(2)) +P1(1)
```

```
0046                IF ( ON .GT.1.E-4 .AND.ON .LT.OPB ) GO TO 45
0047                 GO TO 48
0048          45    IF(ON.LE.P1(1).AND.ON.GE.P2(1).OR.ON.LE.P2(1).AND.ON.GE.P1(1)) GO
                   *  TO 60
0049          48    CONTINUE
0050                 K=2
0051                IF(LET1.EQ.2.AND.LET2.EQ.3) GO TO 58
0052                IF(LET2.EQ.2.AND.LET1.EQ.3) GO TO 58
0053                ON =((P3(1)-P2(1)) /(P3(2)-P2(2)))*(-P2(2)) +P2(1)
0054                IF ( ON .GT.1.E-4 .AND.ON .LT.OPB ) GO TO 55
0055                 GO TO 58
0056          55    IF(ON.LE.P2(1).AND.ON.GE.P3(1).OR.ON.LE.P3(1).AND.ON.GE.P2(1)) GO
                   *  TO 60
0057          58    CONTINUE
0058                 K=3
0059                ON =((P1(1)-P3(1)) /(P1(2)-P3(2)))*(-P3(2)) +P3(1)
0060                IF ( ON .GT.1.E-4 .AND.ON .LT.OPB ) GO TO 65
0061                 GO TO 68
0062          65    IF(ON.LE.P3(1).AND.ON.GE.P1(1).OR.ON.LE.P1(1).AND.ON.GE.P3(1)) GO
                   *  TO 60
0063          68    CONTINUE
0064                JTP=JT
0065                 PX(1)=P(1)
0066                 PX(2)=P(2)
0067                 PX(3)=P(3)
0068                 RETURN
0069          60    CONTINUE
0070                GO TO (100,110,120),K
0071          100   DO 70 L=1,3
0072                PP1(L)=PT(L,1,JT)
0073          70    PP2(L)=PT(L,2,JT)
0074                 GO TO 200
0075          110   DO 80 L=1,3
0076                 PP1(L) =  PT(L,2,JT)
0077          80    PP2(L)=PT(L,3,JT)
0078                 GO TO 200
0079          120   DO 90 L=1,3
0080                 PP1(L)=  PT(L,3,JT)
0081                PP2(L)=  PT(L,1,JT)
0082          90    CONTINUE
0083          200    CONTINUE
              C FIND TRIANGLE HAVING SIDE DEFINED BY PP1,PP2
0084                 DO 300 M=1,NT
0085                 IF(M.EQ.JT) GO TO 300
0086                LET1=0
0087                LET2=0
0088                 NV=0
0089                 DO 310 J=1,3
```

```
0090                DO 320 K=1,3
0091                IF(PP1(K).NE.PT(K,J,M)) GO TO 324
0092          320   CONTINUE
0093               LET1=J
0094                NV=NV+1
0095          324   CONTINUE
0096                DO 325 K=1,3
0097                IF(PP2(K).NE.PT(K,J,M)) GO TO 308
0098          325   CONTINUE
0099               LET2=J
0100                NV=NV+1
0101          308   IF(NV.EQ.2) GO TO 350
0102          310  CONTINUE
0103          300   CONTINUE
0104          350   CONTINUE
0105                JTP=M
0106                IF(NV.NE.2) JTP=100
0107                IF(JTP.EQ.100) RETURN
0108                JT=JTP
0109                DO 205 L=1,3
0110            205 PP4(L) = PP1(L) + 100.*UN(L,JT)
0111               R(1) = PP1(2)*(PP2(3)-PP4(3))
                  *      -PP1(3)*(PP2(2)-PP4(2))
                  *       +(PP2(2)*PP4(3)-PP4(2)*PP2(3))
0112               R(2)=-(PP1(1)*(PP2(3)-PP4(3))
                  *       -PP1(3)*(PP2(1)-PP4(1))
                  *      +(PP2(1)*PP4(3)-PP2(3)*PP4(1)))
0113               R(3)=PP1(1)*(PP2(2)-PP4(2))
                  *  - PP1(2)*(PP2(1)-PP4(1))
                  *      +(PP2(1)*PP4(2)-PP4(1)*PP2(2))
0114               R(4)=-(PP1(1)*(PP2(2)*PP4(3)-PP4(2)*PP2(3))
                  *     -PP1(2)*(PP2(1)*PP4(3)-PP4(1)*PP2(3))
                  *   + PP1(3)*(PP2(1)*PP4(2)-PP4(1)*PP2(2)))
0115               CALL LOCATE(JT,R,PP,PPN)
          C  FIND COORDS OF P'
0116                NP=OPB-ON
0117               CALL LOCAT3 (JTP,NP,PP,PPN,O1,PX)
0118          370   CONTINUE
0119                DO 380 L=1,3
0120                P(L)=PX(L)
0121          380   O(L)=PPN(L)
0122               GO TO 5
0123               END
```

```
0001              SUBROUTINE LOCAT3(IT,EL,P1,A1,AX,A2)
0002                DIMENSION P1(4),A1(3),A2(3),AX(3),X(3,3) ,PX(3)
0003             DIMENSION E(4)    ,D(2)
0004             COMMON THET(3,200),ABC(3,200),PT(3,3,200),UN(3,200)
0005          1    CONTINUE
0006             P1MAG = ABS(P1(4)/SQRT(P1(1)**2 + P1(2)**2 +P1(3)**2))
                C UNIT VECTOR NORMAL TO P1
0007             U1=-P1MAG*P1(1)/P1(4)
0008             U2=-P1MAG*P1(2)/P1(4)
0009             U3=-P1MAG*P1(3)/P1(4)
                C    E IS VECTOR NORMAL TO BOTH IT AND P1 PLANES NORMAL VECTORS
0010             E1= UN(2,IT)*U3-UN(3,IT)*U2
0011             E2= UN(3,IT)*U1-UN(1,IT)*U3
0012             E3= UN(1,IT)*U2-UN (2,IT)*U1
0013             ER= SQRT(E1**2 +E2**2 +E3**2 )
0014             E1=+E1/ER
0015              E2=+E2/ER
0016             E3  =+E3/ER
0017             E(4)=-1.
0018              PE=A1(1)*E1+A1(2)*E2+A1(3)*E3
0019             Y= 1.
0020              IF ( PE.LT.0.) Y=-1.
0021             IF (PE .LT.0. ) PE =-PE
0022             D(1) = PE-EL
0023             D(2)=PE+EL
0024             DO 10 L=1,2
0025             E(1) =(E1/D(L)) *Y
0026             E(2) =(E2/D(L))*Y
0027             E(3) =(E3/D(L))*Y
0028             CALL LOCATE ( IT,P1,E,PX)
0029             X(1,L) = PX(1)
0030             X(2,L) = PX(2)
0031             X(3,L) = PX(3)
0032           10  CONTINUE
0033             DIST1=0.
0034             DIST2=0.
0035             DO 30 L=1,3
0036             DIST1= DIST1+(AX(L)-X(L,1))**2
0037             DIST2= DIST2+(AX(L)-X(L,2))**2
0038           30 CONTINUE
0039             K=2
0040             IF ( DIST1.GT.DIST2) K=1
0041             A2(1)=X(1,K)
0042             A2(2)=X(2,K)
0043             A2(3)=X(3,K)
0044             RETURN
0045             END
```

```
0001                SUBROUTINE LOCATE(JT,P,Q,PX)
0002               COMMON THET(3,200),ABC(3,200),PT(3,3,200),UN(3,200)
0003                DIMENSION P(4),Q(4),R(4),PX(3)
0004          1      CONTINUE
0005                R(1)=ABC(1,JT)
0006                R(2)=ABC(2,JT)
0007                R(3)=ABC(3,JT)
0008                R(4)=1
0009               P(4)=-P(4)
0010                Q(4)=-Q(4)
0011                A=P(4)*(Q(2)*R(3)-R(2)*Q(3))
                   *     -P(2)*(Q(4)*R(3)-R(4)*Q(3))
                   *     +P(3)*(Q(4)*R(2)-R(4)*Q(2))
0012                B=P(1)*(Q(4)*R(3)-R(4)*Q(3))
                   *     -P(4)*(Q(1)*R(3)-R(1)*Q(3))
                   *     +P(3)*(Q(1) *R(4)-R(1)*Q(4))
0013                C=P(1)*(Q(2)*R(4)-R(2)*Q(4))
                   *     -P(2)*(Q(1)*R(4)-R(1)*Q(4))
                   *     +P(4)*(Q(1)*R(2)-R(1)*Q(2))
0014                DR=P(1)*(Q(2)*R(3)-R(2)*Q(3))
                   *     -P(2)*(Q(1)*R(3)-R(1)*Q(3))
                   *    +P(3)*(Q(1)*R(2)-R(1)*Q(2))
0015                PX(1) = A/DR
0016                PX(2) = B/DR
0017                PX(3) = C/DR
0018                P(4) = - P(4)
0019                Q(4) = -Q(4)
0020                RETURN
0021                END
```

```
0001                SUBROUTINE VEL(EL,AMDOT,JT,LT,HE,W,F1,F2,S1,S2,PR,VI,VP,MU)
0002               COMMON THET(3,200),ABC(3,200),PT(3,3,200),UN(3,200)
0003                DIMENSION UNN(3),VI(3),ALPH(3),BET(3),GAM(3),LAM(3)
0004                 DIMENSION VP(3)
0005                   REAL LAM
0006               REAL MU
0007               COMMON /DENS/GAMD
0008          1      CONTINUE
0009                RHO=GAMD/(32.2*12**3)
0010                DO 495 L=1,3
0011                UNN(L)=(UN(L,JT)+UN(L,LT))/2.
0012                G=386
0013          495   CONTINUE
0014                ALPH(1)=0.
0015                ALPH(2)=-W*HE*RHO*G
              C
0016               ALPH(3)=0.
              C
0017                VB=SQRT(VI(1)**2+VI(2)**2+VI(3)**2)
0018                 DO 10 L=1,3
0019                BET(L)=W*PR*(UNN(L)-MU*VI(L)/VB)
              C
0020                LAM(L)= (S2-S1)*VI(L)/VB
0021          10    CONTINUE
0022                GAM(1)= (F2-F1)*(VI(3)*UNN(2)-VI(2)*UNN(3))/VB
              C
0023                GAM(2)=(F2-F1)*(VI(1)*UNN(3)-VI(3)*UNN(1))/VB
0024                GAM(3)=(F2-F1)*(VI(2)*UNN(1)-VI(1)*UNN(2))/VB
0025                  DO 20 L=1,3
0026                VI(L)=VI(L)+EL*(ALPH(L)+BET(L)+GAM(L)+LAM(L))/AMDOT
0027                VP(L)=VI(L)
0028          20    CONTINUE
0029                RETURN
0030                 END
```

```
0001                SUBROUTINE PLANE ( JT , A , V, P )
0002                COMMON THET(3,200),ABC(3,200),PT(3,3,200),UN(3,200)
                C   THIS  SUB  CAL  FUN OF A PLANE DRAWN THROUGH A  AND PAR TO V AND
                C
                C   PAR. TO NORMAL AT A
                C
0003                DIMENSION  A(3), V(3) , P(4)
                C
0004                 DD=1.0E-10
0005            1    CONTINUE
0006                 A1=UN(1,JT)
0007                 B1=UN(2,JT)
0008                 C1=UN(3,JT)
0009                 V1=V(1)
0010                 V2=V(2)
0011                 V3=V(3)
0012                 DR= V(1)*UN(2,JT)-V(2)*UN(1,JT)
0013                    IF(DR.EQ.0.) DR=DD
0014                 P(1)=(V(2)*UN(3,JT)-UN(2,JT)*V(3))/DR
0015                  P(2)=(V(3)*UN(1,JT)-V(1)*UN(3,JT))/DR
0016                 P(3)=1.
                C
                C
                C
0017                P(4) =  - (P(1) * A(1) + P(2) * A(2) + P(3) * A(3))
                C
0018                RETURN
0019                END
```

APPENDIX F

TRADEOFF STUDY OF CANDIDATE TRANSFER CHUTE CONCEPTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

During the initial portion of the Low Headroom Transfer Point Chute Program numerous geometries have been conceived as possible chute configuration candidates. These have been given various degrees of evaluation, usually starting with layout drawings and cardboard models. The more promising ones were also defined mathematically for possible subsequent computer analysis and were constructed as a scale model for testing in a 1/6 scale belt conveyor transfer point set up.

The scope of this interim study is to provide a screening of the more serious candidates evolved, for which various evaluation data, including primarily scale model testing, have been compiled. Essentially seven different configurations are addressed, comprising one- and two-degree curvature surfaces: cones and cylinders in the former case and toroidal shapes in the latter. These different configurations have been evaluated and compared against ten criteria, which themselves have been weighted in relative order of importance.

2.0 CONCLUSIONS

It is the conclusion from the tradeoff analysis herein that a two degree of curvature shape --- the torus--offers the best means of achieving the optimum stream dynamics relative to dust suppression, spillage and belt wear; while 1) simultaneously obtaining the minimum possible headroom and 2) fulfilling operational and economic constraints related to underground coal mining. Potential risk areas, which will require close attention during remaining scale model testing and preliminary design, involve the following areas:

- Clearance with the head pulley: 15 inches is currently provided and must be increased
- Producibility of a two degree of curvature surface

Various means for increasing chute clearance will be investigated during more detailed scale model testing, now that the interim phase of scale modelling of a variety of chute candidates is complete. An additional degree of chute rotation, about a vertical axis, will be evaluated as a means of increasing chute clearance without comprising stream dynamics.

It is the plan to approximate a true toroidal surface by a series of intersecting cylinders, as in the case of a HVAC jointed duct elbow. Thus the problem of producibility will be essentially eliminated.

3.0 CANDIDATE CONFIGURATIONS

3.1 GEOMETRICAL SURFACES CONSIDERED

Geometrical surfaces investigated during conceptual chute design were selected with an eye to three initial dynamic considerations:

- Low angle of incidence at impact between the free fall trajectory and the chute, to avoid ricochet and scatter.
- Cohesiveness and low turbulence of mass flow during the frictional phase
- Convergency of chute flow output, sufficient to achieve clean transfer to the receiving belt.

These guidelines lead to the study of three different geometries:

1. Cone
2. Cylinder
3. Torus

Layout studies and preliminary analysis of these geometries, resulted in turn in the evolution of seven distinct configurations, which are described briefly in the following section.

3.2 SPECIFIC CONFIGURATIONS

3.2.1 CONICAL SHAPES

3.2.1.1 Opening Half Angle Concept

Early computer math modeling work in the study program resulted in evolution of a conical model whose shape and orientation were defined in part by the free fall trajectory of the coal leaving the head pulley. Given independent parameters of 1) conical axis inclination with the horizontal; 2) the minimum cone radius at the upstream end of the cone; and 3) the minimum clearance with the pulley, the computer program determined the cone half angle and its location relative to the pulley (Figure 1A (1)). Another independent parameter that controlled the cone configuration and location was an allowable angle of incidence at impact with the chute defined at the centroid of the flow mass. The test configuration is shown in Figure 1A (2) and a computer plot approximation in 1B.

3.2.1.2 Flat Impact Plate Cone Concept

Owing to a desire to control the impact incidence angle to be as nearly uniform as possible throughout the thickness of the flow mass, an alternative configuration was developed whereby the free fall trajectory would impact a flat surface located above, and tangent to, the conical surface described earlier (Figures 2A & 2B). In this way impact of the flow mass with a constantly curving surface, resulting in a variable incidence angle across the flow thickness, would be avoided. This method of optimizing smoothness of flow at impact has, however, the associated potential penalty of additional headroom requirement.

3.2.1.3 Zero Degree Half Angle Cone Concept

Subsequent testing of the two conical configurations defined above revealed a tendency toward divergency of flow at the output, with attendant failure to achieve a clean deposition of material on the second belt. This problem led to definition of a third version whereby the opening half angle defined by the math model was suppressed to be zero degrees (Figures 3A and 3B). This yields, in fact, a cylindrical configuration. Its

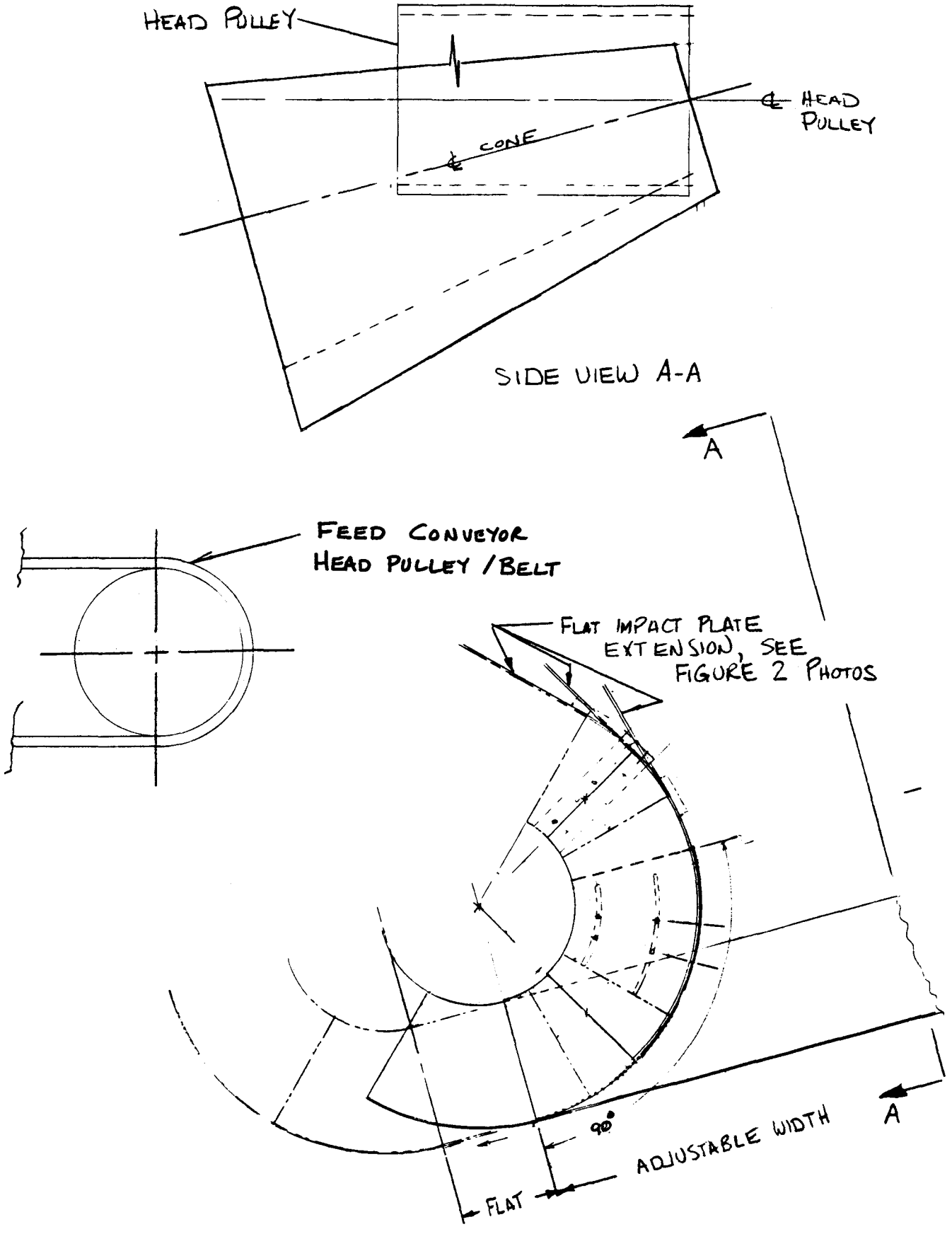
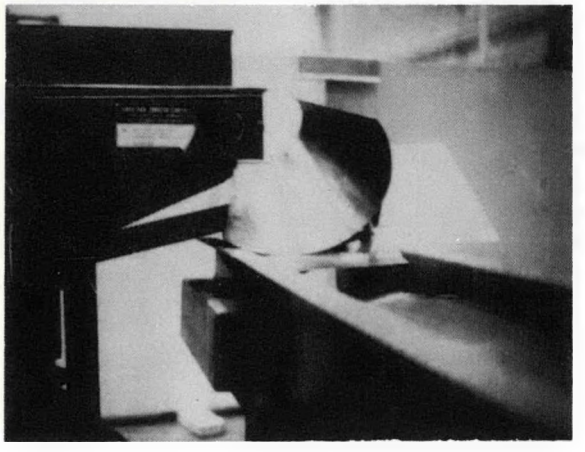
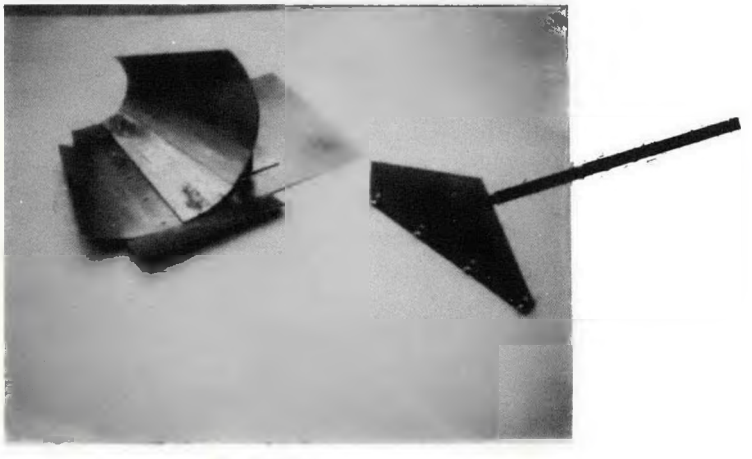


Figure 1A(1) Concept 1: Detail Layout



Installation



Flat Impact Plate - Not Used in Concept 2 (Figure 2)

Details

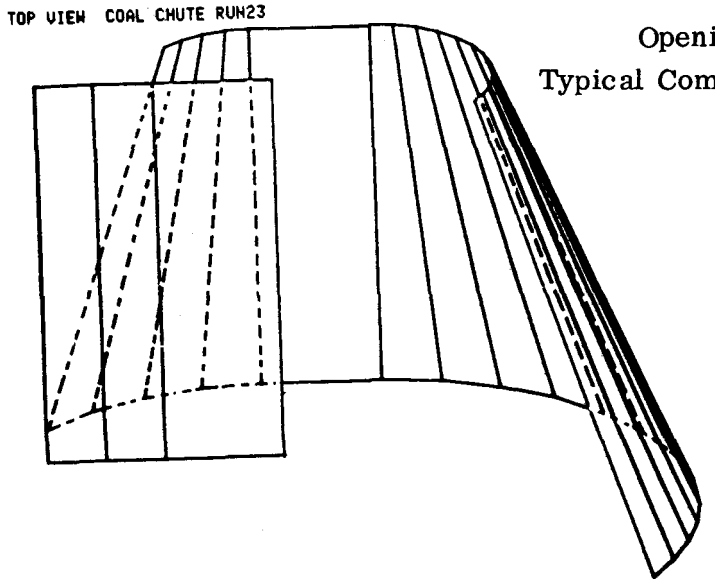
Figure 1A(2) Opening Half Angle Cone
1/6 Scale Test Configuration
Installation Set Up

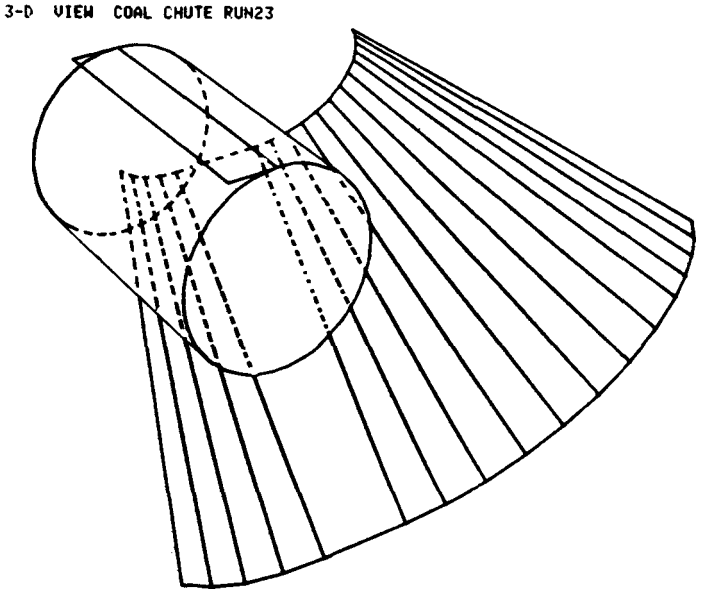
Concept 1

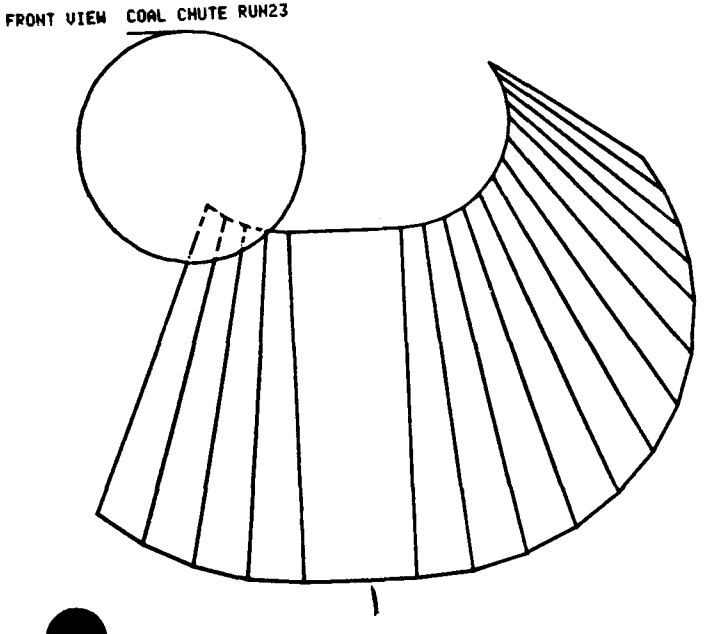
Opening Angle Cone

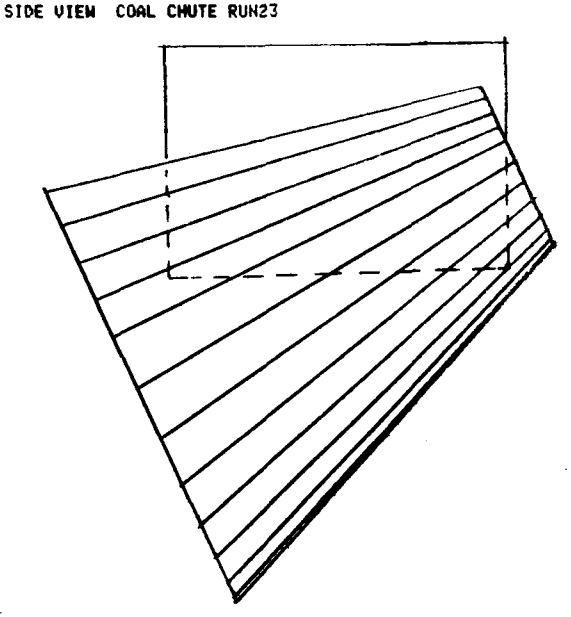
Typical Computer Plot Approximation

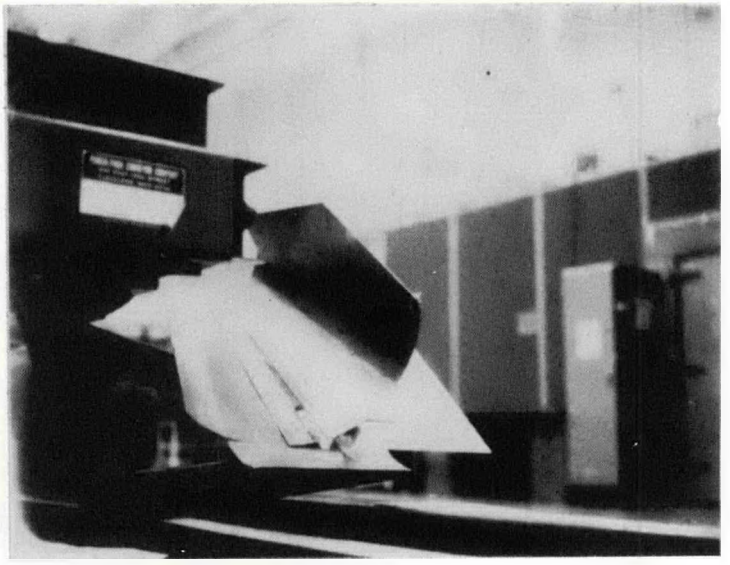
Figure 1B

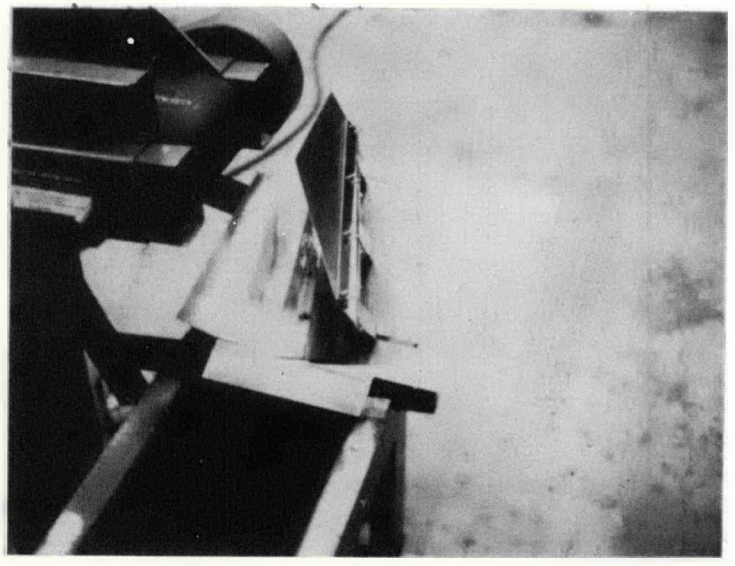












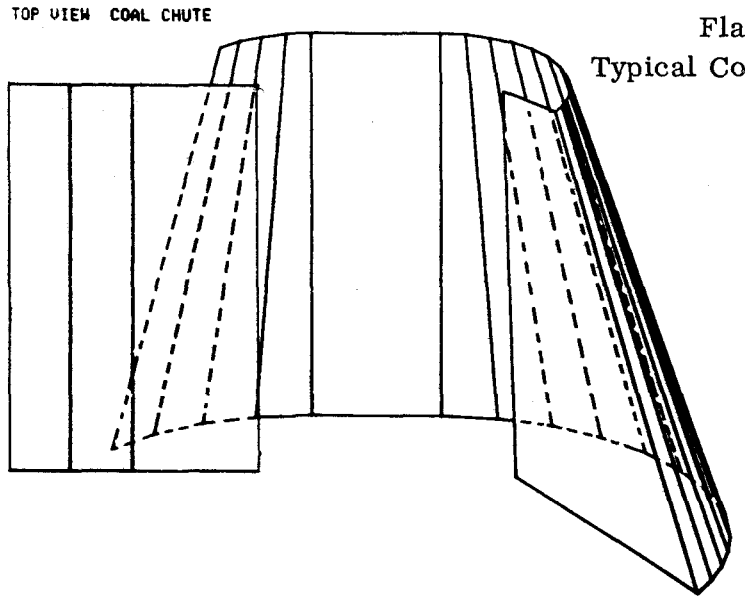
Flat Impact Plate Cone Concept
1/6 Scale Test Configuration

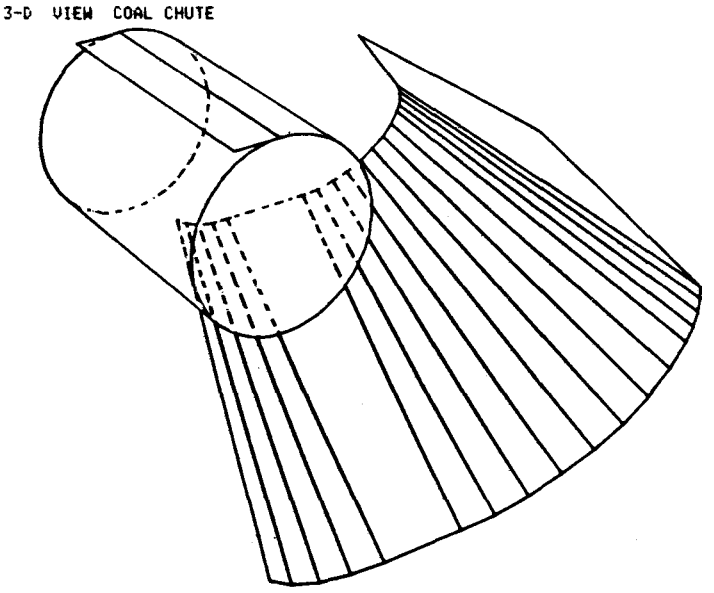
Figure 2A

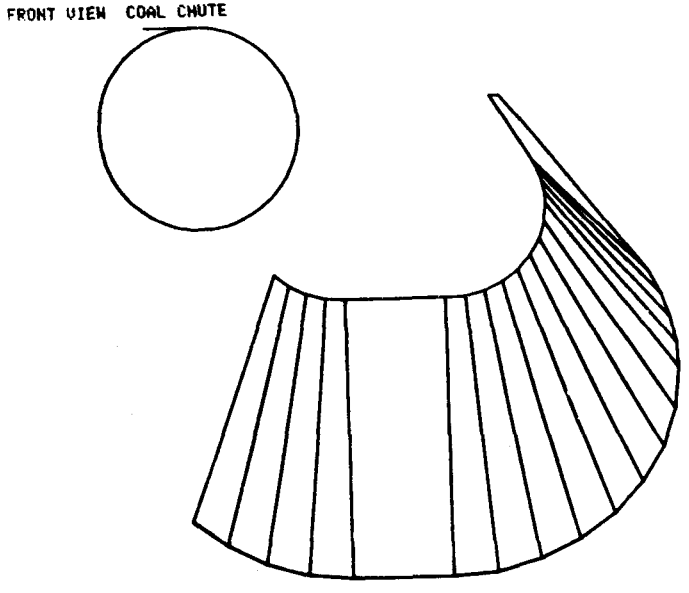
Concept 2

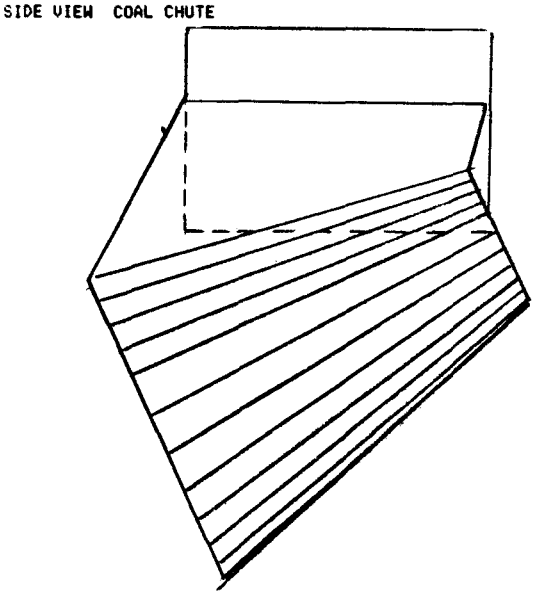
Flat Impact Plate Cone
Typical Computer Plot Approximation

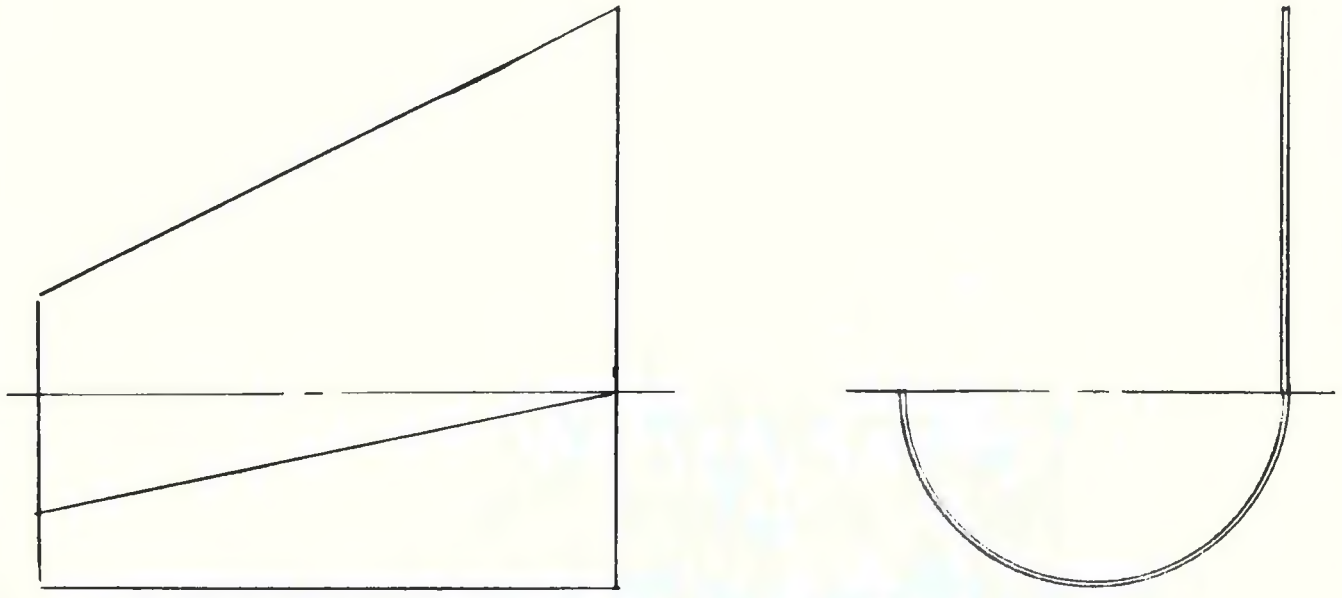
Figure 2B











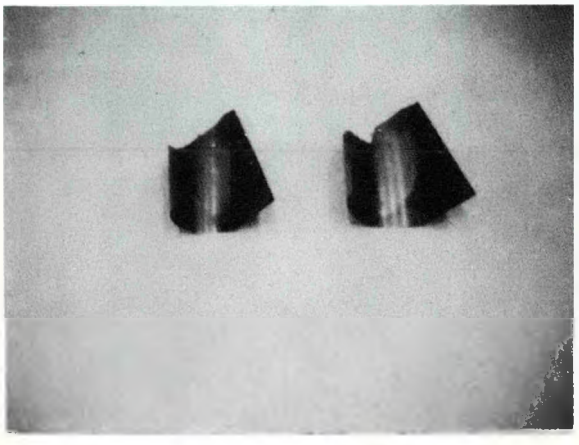
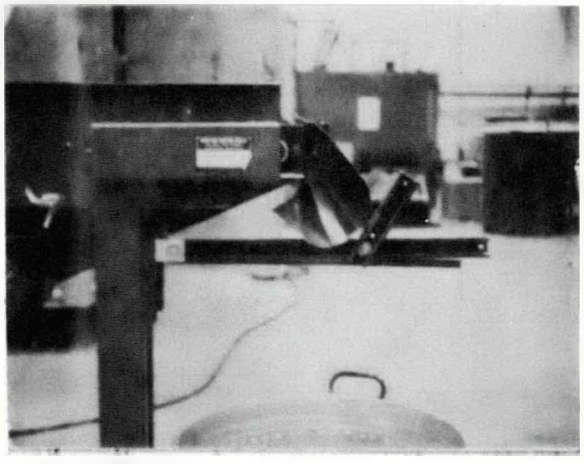


Figure 3A(1) Concept 3: Zero Half Angle Cone
1/6 Scale Test Configuration Details



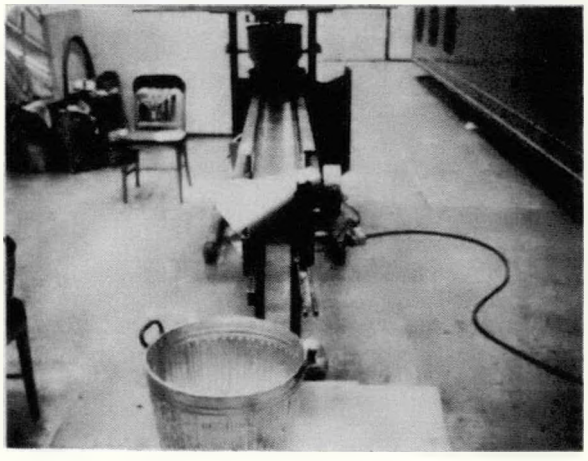
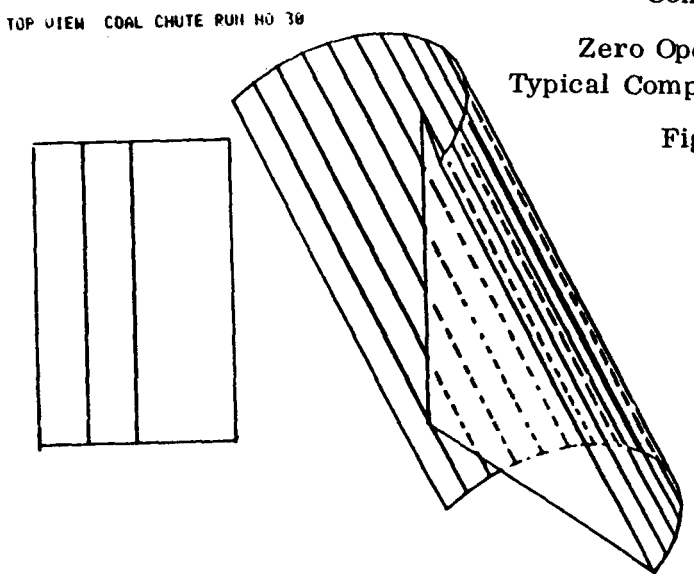


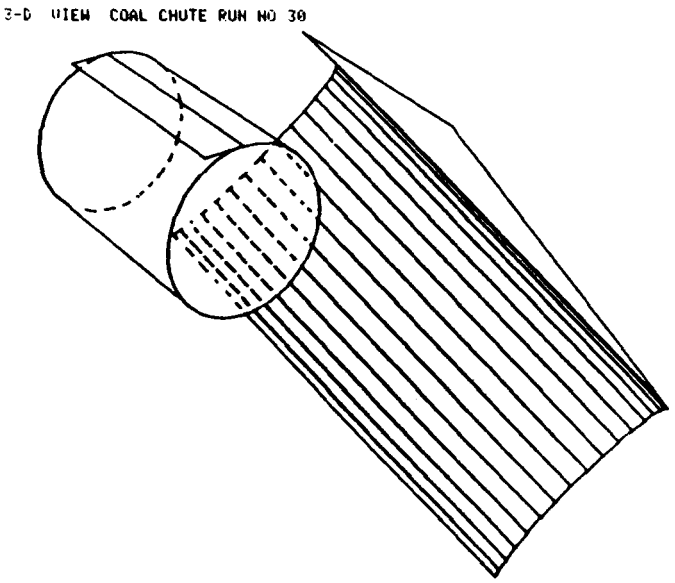
Figure 3A (2) Concept 3: Zero Half Angle Cor
1/6 Scale Test Configuration
Installation Set Up

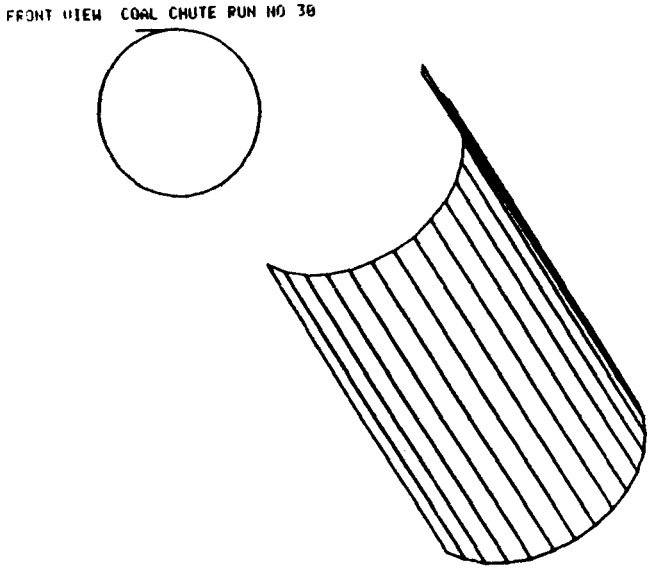
Concept 3

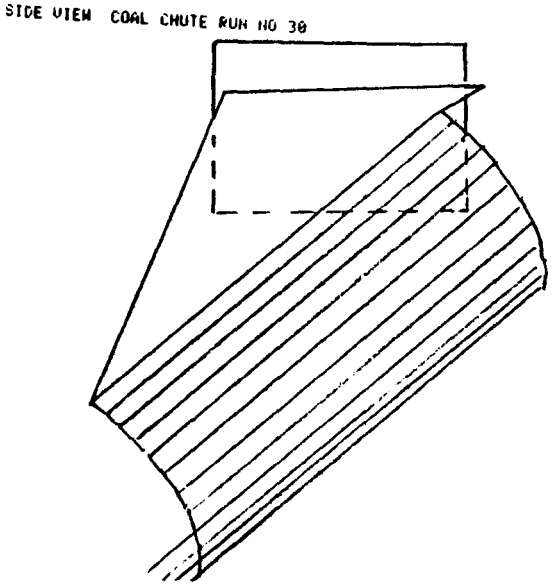
Zero Opening Angle Cone
Typical Computer Plot Approximation

Figure 3B









shape and orientation are quite different from the cylindrical concepts in the following paragraphs, however, in its philosophy of handling flow convergence.

3.2.2 QUARTER CYLINDER SHAPES

3.2.2.1 Single Cylindrical Surface Concept

Figures 4A and 4B show a chute configuration consisting of approximately a one-quarter cylinder shape, whose top edge is tangent to a vertical wall surface that intersects the direction of flow, of the feed conveyor at about a 30 degree angle. Depending upon the height of the tangency line, material at different locations crosswise to the flow mass will impact either against the flat vertical surface or else against the cylindrical portion. The portions of initial flow progressively to the right, i.e., toward the final direction of flow, will impact at points progressively greater in horizontal and vertical distance from the feed pulley.

3.2.2.2 Compound Cylindrical Surface Concept

Although early evidence suggested that the above cylindrical configuration could be oriented and sized to turn all portions of the mass cross section through a common 90-degree angle, this did not guarantee adequate convergency of flow to ensure its proper deposition on the receiving belt. Concepts were, therefore, evolved to define side constraints to the flow once it had been turned. Simple flat side plates, arranged in a troughing fashion (Figure 5B), were considered for this purpose, but their intersection with the cylindrical surface formed Vee channels whose inclination with the horizontal was too shallow to insure flow. It was found that the use of cylindrical surfaces to provide the side wall constraints resulted in Vee channels adequately steep to insure flow at these intersections (Figure 5A).

3.3.3 TOROIDAL SHAPES

3.3.3.1 True Toroidal (Smooth) Concept

The toroidal configuration was evolved with the intent to evaluate the effectiveness of a double curvature surface. The minor radius of curvature would converge the flow cross section, as does the zero degree half angle conical configurations (3.2.1.3), with the other, major radius of curvature providing a vertical curve type chute profile, as afforded by the cylindrical configuration (3.2.2). In the case of a

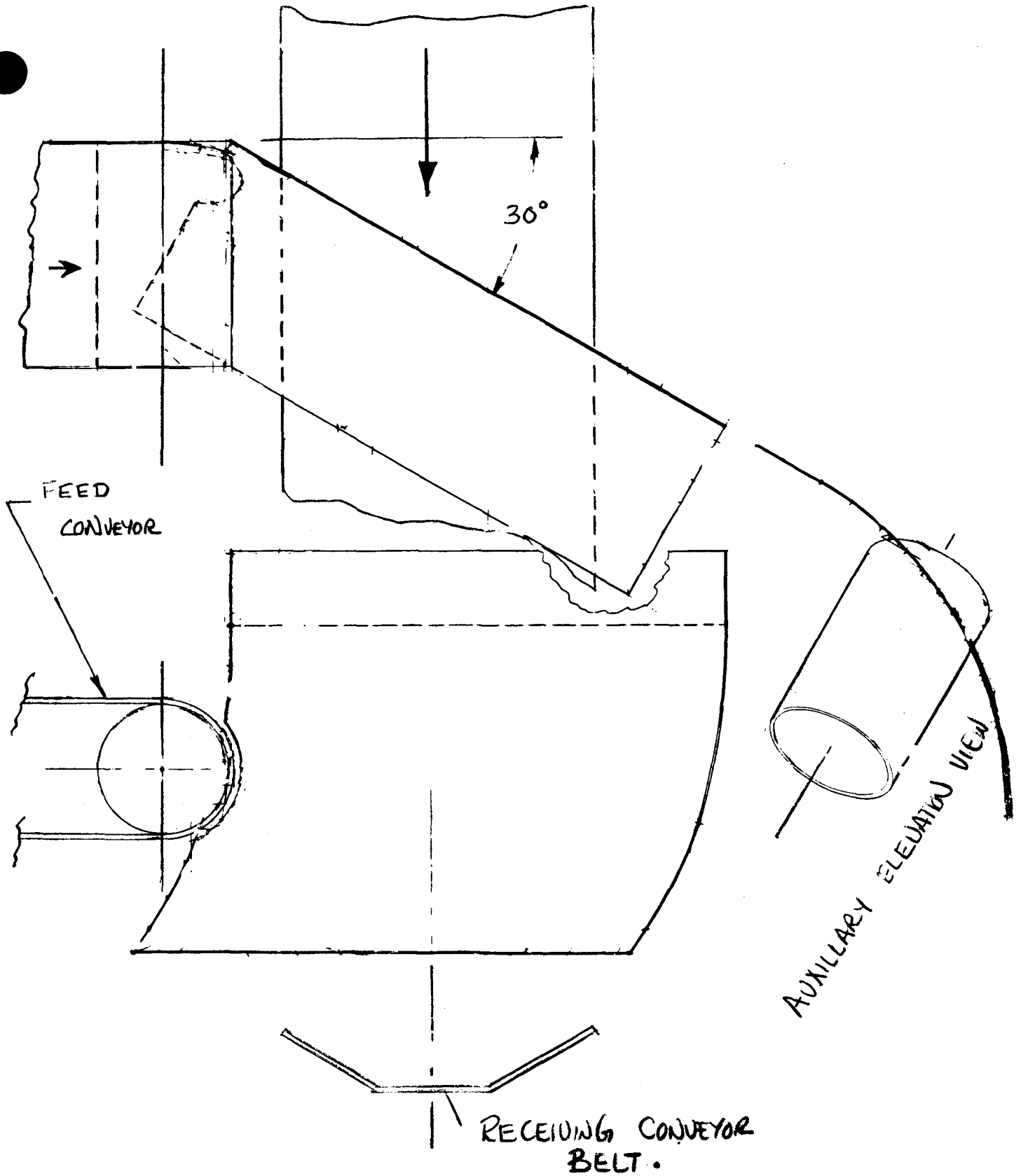
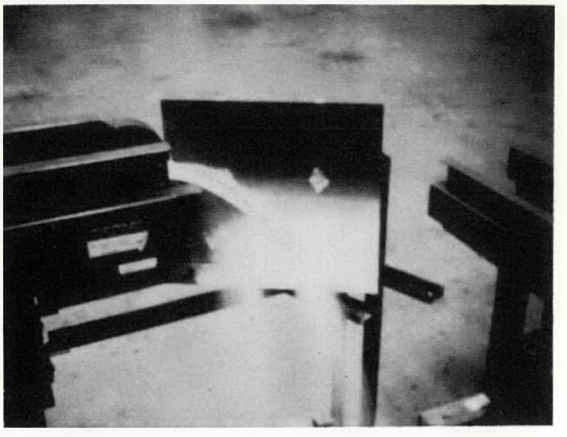


Figure 4A Concept 4 Single Quarter Cylinder
1/6 Scale Configuration Detail Layout



Concept 4

Single Quarter Cylinder
1/6 Scale Test Configuration

Figure 4B

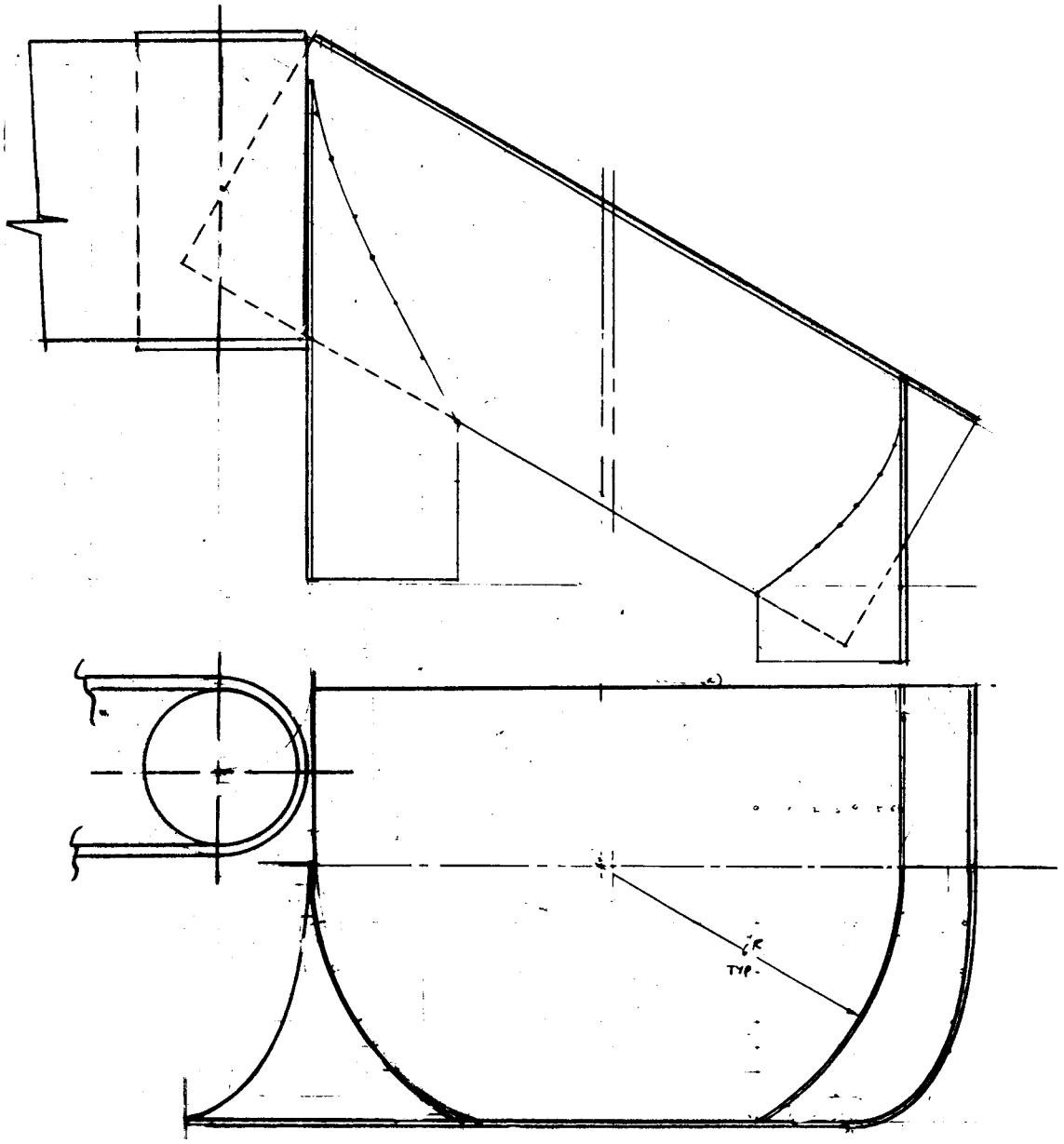
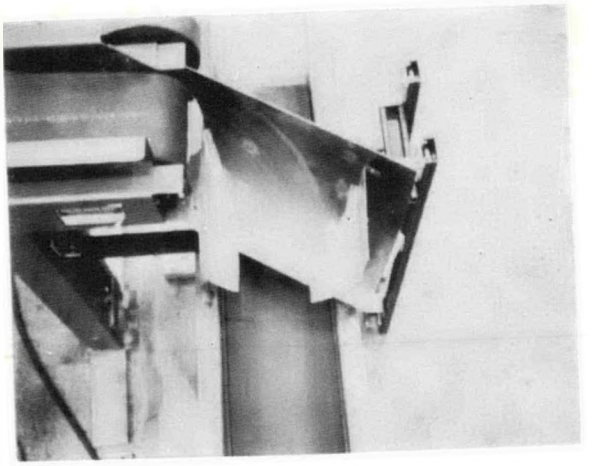
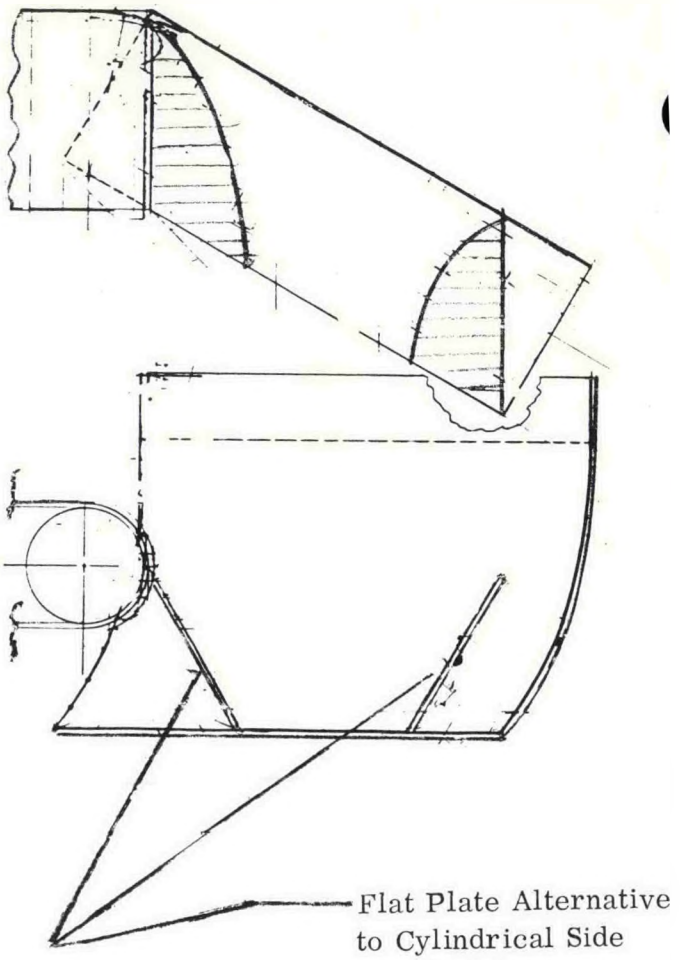


Figure 5A Concept 5: Compound Quarter Cylinder
1/6 Scale Test Configuration
Detail Layout





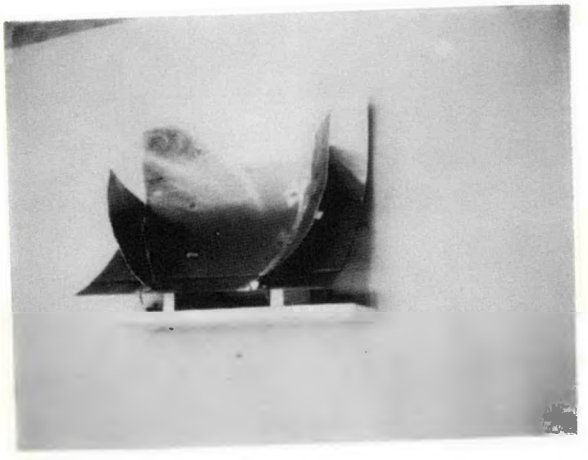


Figure 5 b. Concept 5: Compound Quarter Cylinder
1/6 Scale Test Configuration

single degree of curvature surface such as the cone, the coefficient of wall friction dictates a minimum slope angle upon the attitude of the central axis. This defines directly a minimum headroom clearance between belt surfaces, depending upon the width of the feeder belt. The objective with the vertical curve is to determine whether headroom reduction can be achieved by causing the material to the left* of the flow cross section, which lands upon the steep portion of the vertical profile slope and experiences great vertical acceleration, to drive out that portion on the right* of the flow mass, which falls on the shallow profile slope, where it experiences much lower vertical acceleration.

Figures 6A and 6B chute surfaces which correspond to a true, smoothly defined, toroidal shape, with cutouts as required to clear the feed belt pulley.

3.3.3.2 "Smoke-Pipe" Toroidal Concept

Owing to the inevitable question of producibility of a large double curvature surface, a second investigation was initiated of a modified torus, developed from a series of intersecting cylindrical shapes and corresponding to a portion of a "smoke pipe", or sheet metal, 90 degree elbow, as used in HVAC ductwork. This configuration is depicted in various sizes in Figures 7A (1), 7A (2), and 7A (3).

4.0 EVALUATION

4.1 METHODOLOGY

4.1.1 EVALUATION CRITERIA

The concepts identified in the previous section (3.0) have been evaluated against ten criteria, relating to 1) performance, 2) compatibility with mining operations and 3) economics. The essential considerations involved in defining these criteria are discussed here. The following section describes the weighting system for establishing comparative importance of these criteria.

* Viewed by a person travelling with the flow toward a right hand turn transfer point.

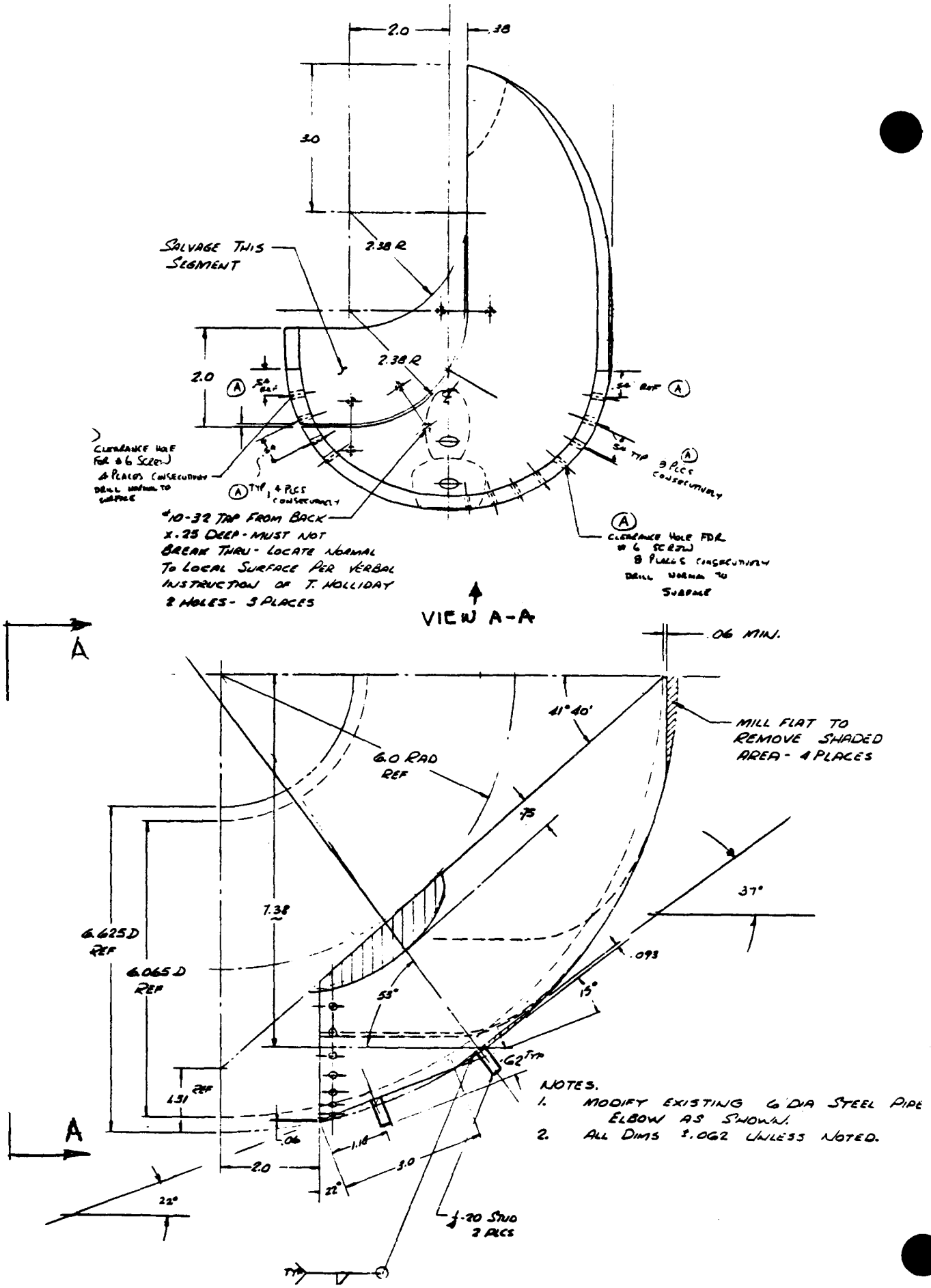
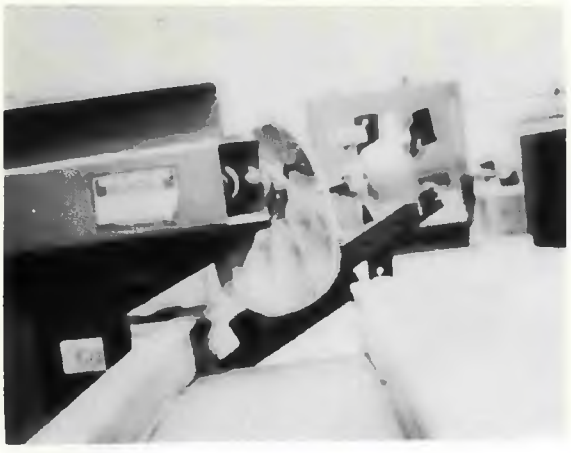
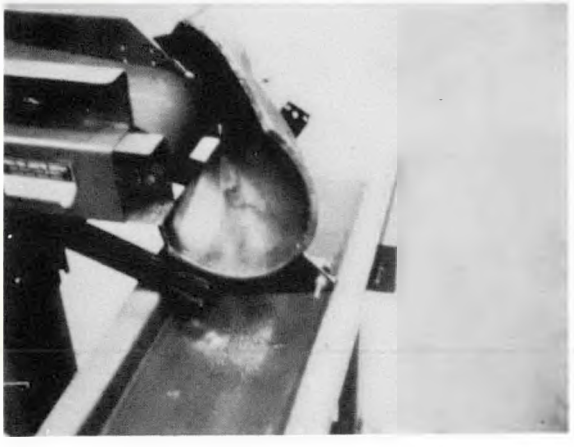


Figure 6A(1) True (Smooth) Torus - 1/6 Scale Test Configuration Detail Layout



Installation, 6" Minor Dia. Case

6" and 8" Minor Dia Cases



Installation, 8" Minor Dia Case

Figure 6A(2) Concept 6: True (Smooth) Torus
1/6 Scale Test Configuration 2
Installation Set Up Detail

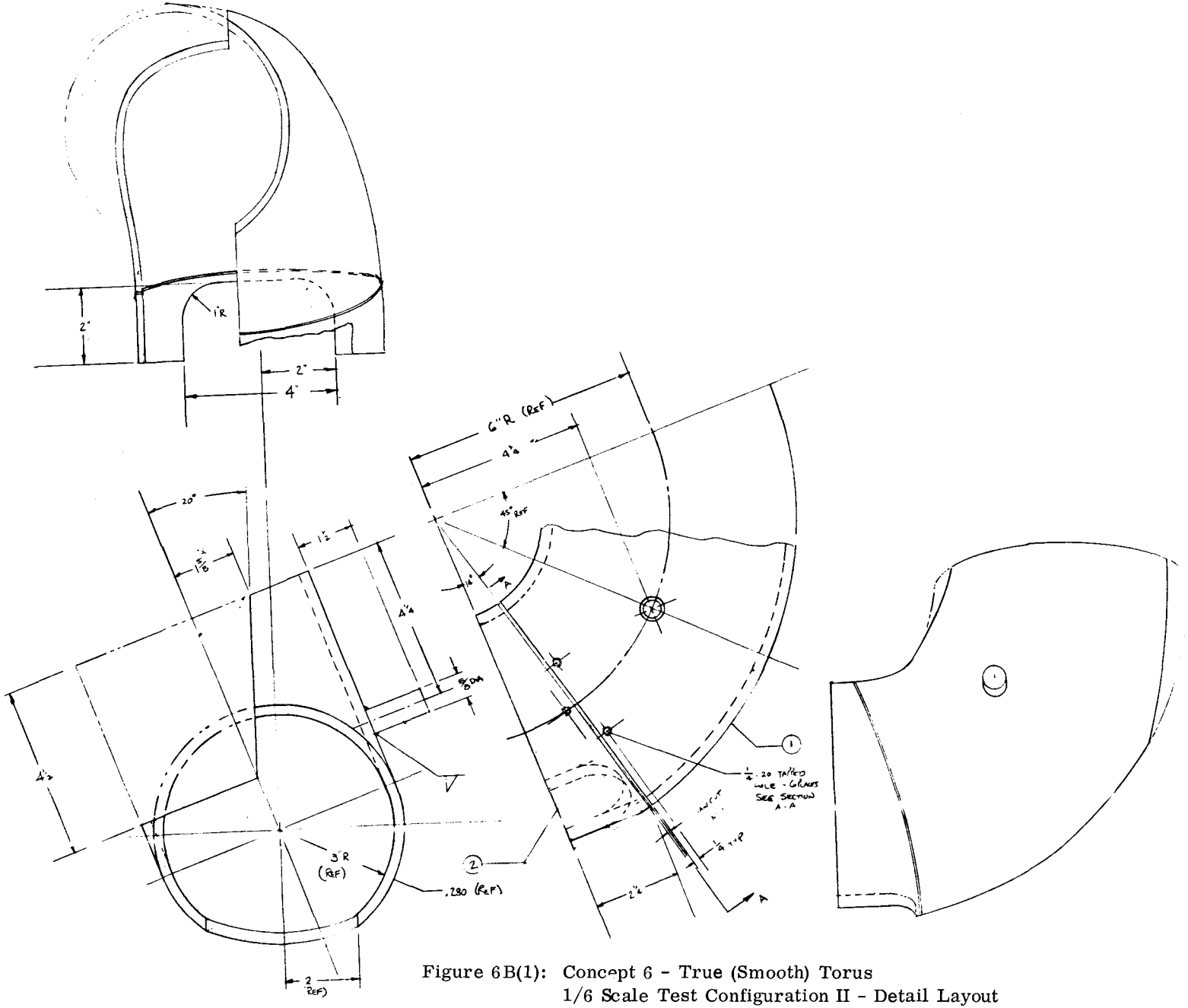


Figure 6B(1): Concept 6 - True (Smooth) Torus
1/6 Scale Test Configuration II - Detail Layout

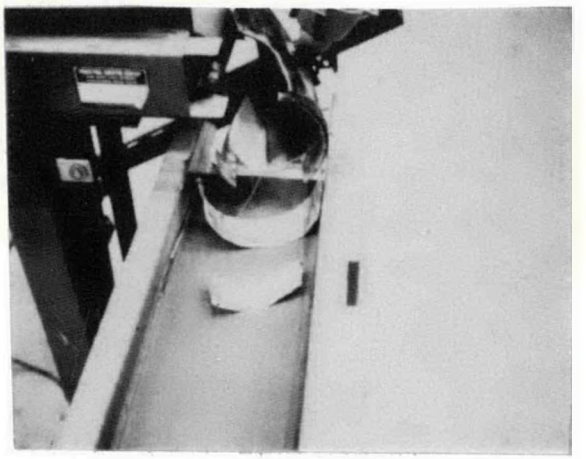


Figure 6B(2) Concept 6 True (Smooth) Torus

1/6 Scale Test Configuration II

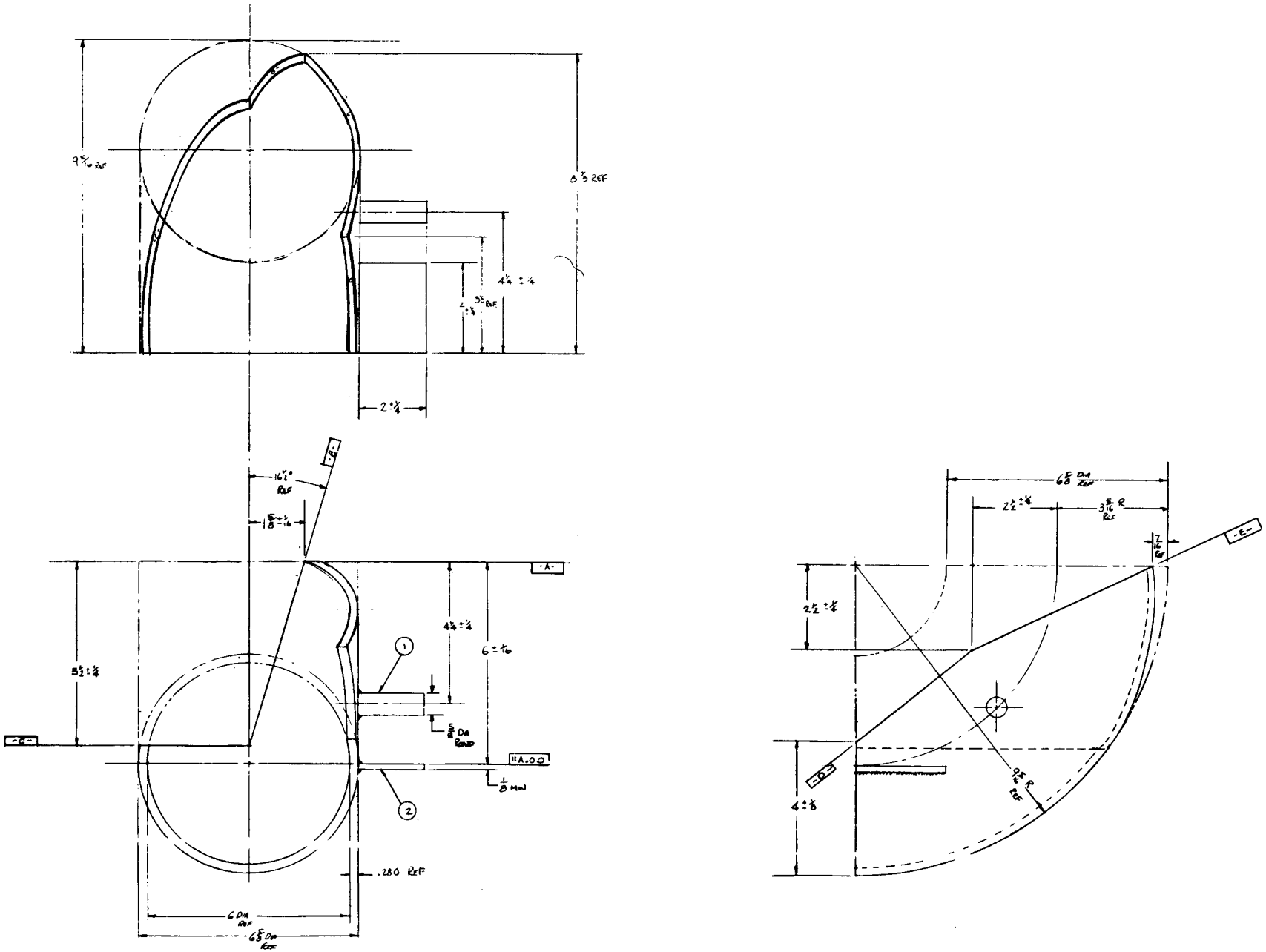
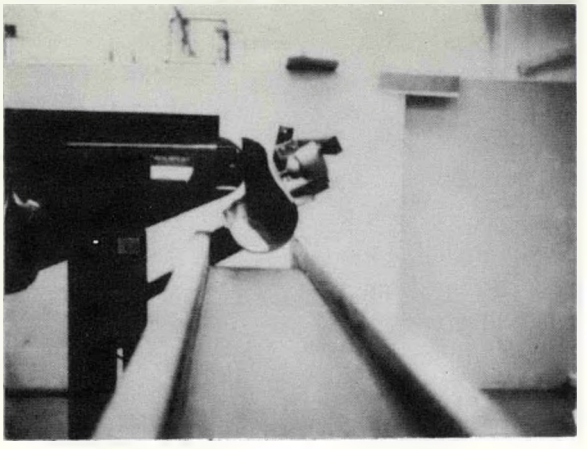
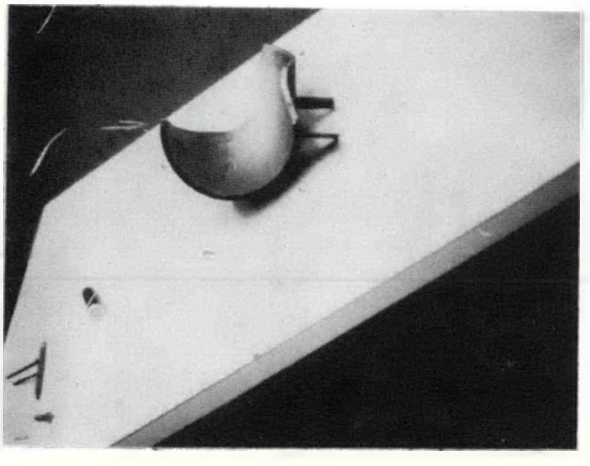


Figure 6C (1) Concept 6. True (Smooth) Torus
1/6 Scale Test Configuration III
Detail Layout



Installation, 6" Minor Dia.



6" Minor Diameter Case

Figure 6C(2) Concept 6: True (Smooth) Torus
1/6 Scale Test Configuration
Installation Detail/Set Up

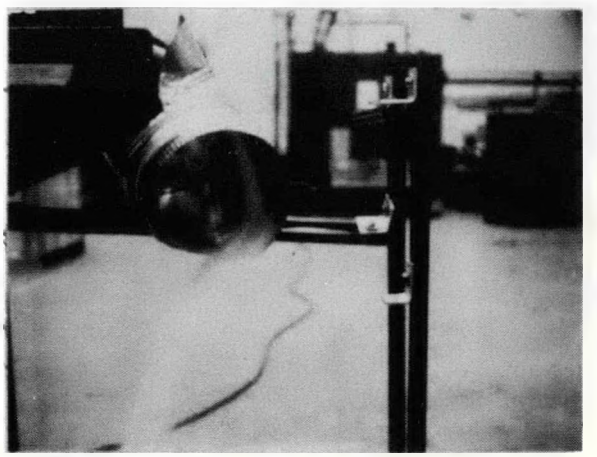


Figure 7A(1) Concept 7: Smoke Pipe Torus
1/6 Scale Model Test Configuration
8" Diameter Case Low Installation

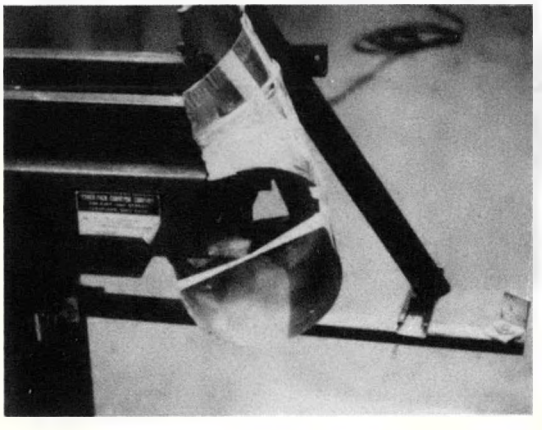


Figure 7A(2) Concept 7: Smoke Pipe Torus
1/6 Scale Test Configuration
8" Diameter Case, High Installation

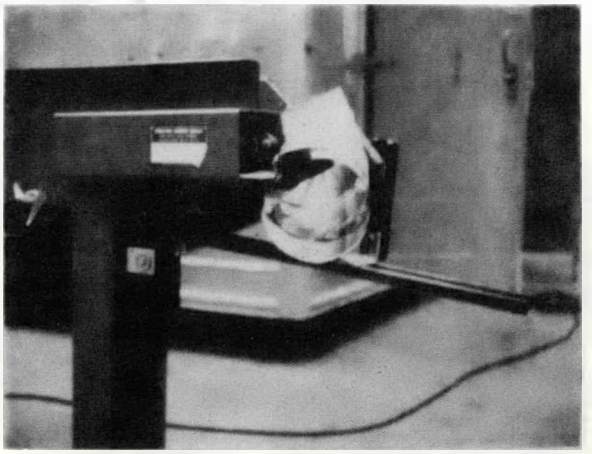
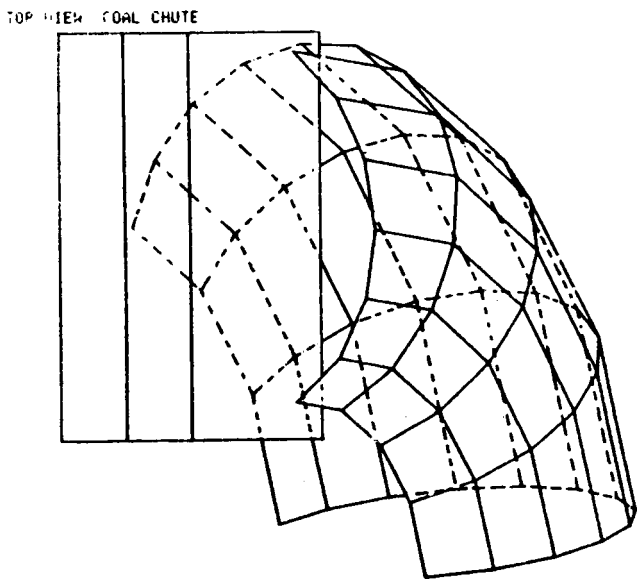
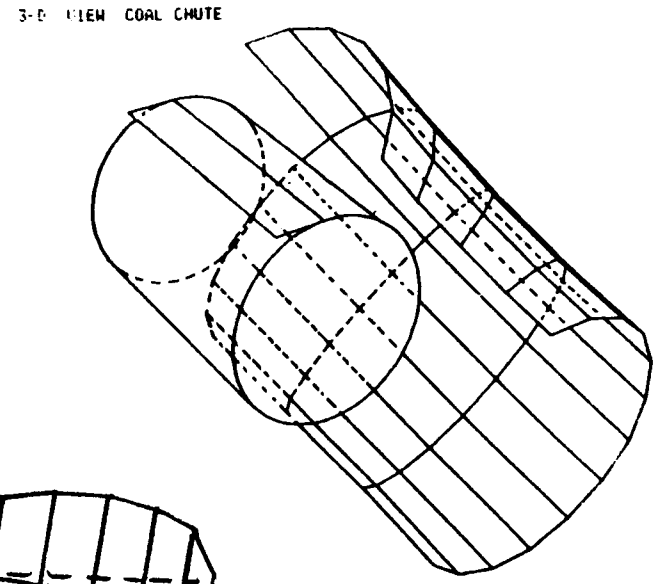
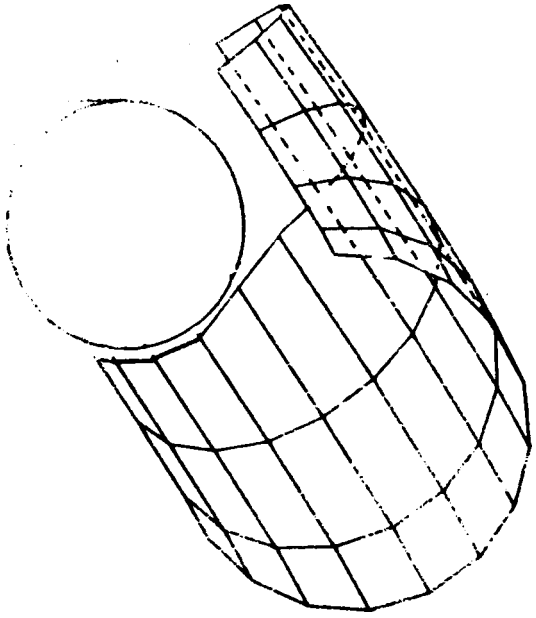
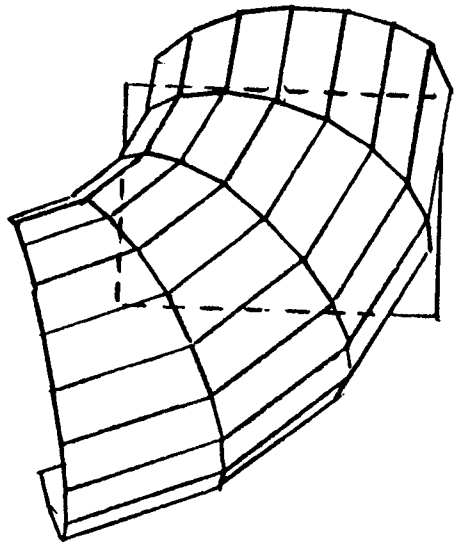


Figure 7A(3) Concept 7 Smoke Pipe Torus
1/6 Scale Test Configuration
6" Diameter Case, Installation









Concept 7

Smoke Pipe Torus

Typical Computer Plot Approximation

Figure 7B

4.1.1.1 Performance Criteria

4.1.1.1.1 Stream Cohesion

The essential characteristic involved here is freedom from flow disintegration and turbulence, both within the coal mass and at the chute wall surface. This characteristic is one of two major measures of low dust evolution. Specific conditions whereby stream cohesion is considered to be degraded are 1) particle bounce upon impact; 2) interference between the impacting stream and flow moving on the surface; 3) material scatter during frictional flow down the chute. (One other source of dust evolution is addressed in the following paragraph.)

4.1.1.1.2 Belt Impact Vector

A design goal from the dynamic standpoint is to match the terminal flow vector leaving the chute with that of the receiving belt velocity. In particular, low belt wear as well as minimum dust evolution will be related to 1) minimizing the vertical component of this terminal vector, as well as 2) matching its horizontal magnitude with the belt speed. By total elimination of the vertical component of chute discharge velocity, it is seen the impact velocity will be confined only to that due to the height of the bottom of the chute above the belt.

4.1.1.1.3 Free-Flow

Freedom of flow along the frictional surface is a function of surface shape as well as material friction and is characterized by absence of a tendency to clog, due to heavy flow, sticky flow material, and related conditions. The primary objective here is prevention of spillage and associated lost personnel time.

4.1.1.1.4 Convergence

A second dynamic criterion essential to avoid spillage is that the flow be converged sufficiently by the chute to confine the impact area in the receiving belt to its central, primarily flat area. Exact definition of the width of this impact zone is somewhat arbitrary, but it is judged that a 12 to 18 inch figure should be a goal* A secondary factor associated with this requirement is that the net flow vector leaving the chute be parallel to the receiving conveyor, in order to avoid disturbing belt tracking on this conveyor.

*for a 36 inch wide belt

4.1.1.2 Mine Operation - Related Criteria

4.1.1.2.1 Jam Clearance

In view of the fact that run of mine coal contains not only large pieces of rock, but also such unplanned items as roof bolts, it is necessary that there be adequate distance between the feed conveyor head pulley and the chute. A sampling of observations by mine personnel during FSEC's site survey indicates that the probable upper dimensional limit of such pieces will be adequately provided for by an 18 to 20 inch clearance.

4.1.1.2.2 Minimum Headroom

Defined narrowly here as the elevation distance between transfer point belt surfaces, a minimum headroom chute is, by original definition, an objective of this program. Associated with this is reduction in the amount of required roof cover removal at transfer points.

The background in this area is that, from observations of eight underground mines around the country, FSEC has seen only one where chutes were used at transfer points with less than a five foot elevation difference between belt surfaces. In three of the mines, where a 2 1/2 to 3 foot headroom clearance was involved, only simple deflector backboard provisions existed, resulting in no right angle acceleration of the flow prior to belt impact.

4.1.1.2.3 Installation

Ease of installation is measured not only by how little time is required for final field assembly and mounting of the chute at the transfer point but also by the simplicity of final alignment procedures. This latter includes absence of the following: 1) tight alignment tolerances; 2) marked sensitivity of the flow dynamics to small variations in chute attitude and location; and 3) requirements for special tools, etc.

4.1.1.3 Economic Criteria

4.1.1.3.1 Maintainability

At the mine sites visited, provision for repairing worn portions of a chute surface generally involved replacement on site of a localized plate section of the chute wall. Generally, torch cutting and welding procedures were utilized, although in one more ambitious maintenance program observed, the slide surface consisted of elements individually attached by flat head cap screws. This approach appears very desirable, as compared with replacement of an entire chute. The ease of maintenance then involves either 1) capability of local fabrication of an individual piece from a drawing or else 2) maintaining an inventory of such pieces, which have been produced in quantity using a more elaborate fabrication process by a regional or national manufacturer.

4.1.1.3.1 Producibility

Herein the essential characteristic is whether the chute dictates manufacturing processes that are normally not available in a local area or, more serious, not feasible in other than high quantity production. This does not necessarily invalidate use of special tooling, providing 1) its design is well documented and it is readily and cheaply reproducible, or else 2) it is perhaps available on loan through a regional or national association of mine owners. Another factor in this connection is the applicability of the same tooling to all possible dimensional configurations of a given basic design, which may vary, for example, for different belt speeds.

An intangible consideration in connection with producibility is saleability, or ease of acceptance among industry users. It is evident that exotic designs or complex geometrical surfaces, completely apart from questions of fabrication, are not going to be indulged by mine owners if they appear to involve production risks in terms of lead time or an inherent limitation on the number of sources where the chute can be obtained.

4.1.1.3.3 Initial Cost

The other consideration involved in industry wide acceptance is, of course, cost. Here a number of interrelated factors apply, however. Depending upon an individual mine owner's sensitivity to such problems as dust evolution, belt wear, and spillage, a given chute design may warrant a considerably higher cost than ones in typical use now.

4.1.2 WEIGHTING OF EVALUATION CRITERIA

Table 1 shows the relative weighting importance considered to apply among the criteria previously described. The criteria are ranked on a scale of from 1 to 5.

Table 1
Evaluation Criteria Weighting

Evaluation Area	Criterion	Weight Value
Performance	1. Stream Cohesion	4
	2. Belt Impact Vector	4
	3. Free Flow (Non Clogging)	5
	4. Convergence	5
Mine Operation	5. Jam Clearance	5
	6. Minimum Headroom	2
	7. Installation Complexity	2
Economics	8. Maintainability	3
	9. Producibility	3
	10. Initial Cost	3

Assignment of the above weighing inevitably involves subjective rationale. It will be seen that three of the four criteria given the highest weight -- namely items 3, 4, and 5 --- relate to the most basic consideration: it has to handle the flow without 1) clogging (free flow); 2) missing or falling off the receiving belt (convergence); and 3) getting a large piece caught between the pulley and the chute (jam clearance). Of the three original considerations identified at the outset of this program --- spillage, dust, and belt wear --- the first is most directly related to the essential questions: Does the chute work? and, Are there any operational risks?

The next highest weight, 4, is given to the dust-related criteria of stream cohesion and belt impact vector. This reflects the outlook that dust suppression is, as of today, nearly as fundamental as the mechanics of the rightangle transfer itself.

While belt wear is, coincidentally, a factor in the belt impact vector criterion, it is not judged to be as overriding a concern as is dust suppression; and had it been possible to separate them in this area, belt wear would have been weighted 3 rather than 4. There appears to be some question among experts as to the sensitivity of belt life to the impact wear induced at transfer points, it being argued by at least one FSEC consultant that there is little correlation between the two and that catastrophic failures and edge wear are by far the pacing factors in belt life. Whether or not this viewpoint is common within the underground coal industry, or whether the subject is too subtle for the average mine maintenance operator, it is clear that current transfer point design practices observed by FSEC reflect little detailed concern over the wear impact mechanism. Apart from spillage, the provision of a chute to turn the flow appeared to arise primarily from the need to ensure against jams occurring in high volume situations or where more than one transfer point lies along a conveyor.

Three criteria have been weighted with a factor of three. Primarily economic in nature, maintainability, producibility, and initial cost are in reality overriding considerations in the probability of acceptance by the industry of a chute design, irrespective of its functional merits. The medium weighting assigned here reflects not so much a downgrading of these essential aspects as much as a recognition that even difficult design solutions in these areas cannot be ruled out at this R/D stage, and that performance - and operational-related criteria must dictate the cutting edge of this screening of conceptual candidates.

Two remaining criteria --- low headroom and installation --- are weighted at a factor of two. While this treatment of headroom may appear contradictory in view of its place in the title of this program, it appears consistent with the guidance provided for design of the full size chute; namely: "It shall be designed to minimize coal spillage, dust generation, and conveyor belt wear," and "The chute ----- shall have as low a profile as possible."

Of greater issue here, however, is the implicit relative weighting given these four characteristics in mine operations witnessed by FSEC. Concern over spillage and dust generation was clearly evident where these problems existed; and various types of corrective measures were uniformly in evidence. On the other hand, even though cost and roof stability considerations associated with removing significant amounts of rock cover --- up to nine-feet or more --- were found to be well-understood and acknowledged by mine personnel when specifically questioned on this subject, there simply appeared to be little sensitivity on this matter. The mood appeared to be that removing this additional material was a one-time problem, was not a overriding cost factor, and was, moreover, frequently dictated by considerations other than the headroom buildup required by the chute installation.

Apparent evidence of the desirability of low headroom was the stark absence of chutes at some 36 inch to 42 inch belt transfer points, where the elevation distance between belts was held to 30 to 36 inches. The conclusion here is, however, that this practice derived less from an intent to minimize headroom and more from a motivation to dispense with the inconvenience of installing a chute, where a low flow volume made it possible. The headroom utilized at these locations appeared to derive directly from the requirements of the deflector plate geometry, rather than from a conscious effort to minimize ceiling height.

The lower-than-average weighting given to chute installation is explained against the background of relocation and alignment tasks for other types of equipment in underground mines, involving far greater complexity than the relocation and/or installation of a chute. While complex alignment and mounting procedures for the chute are plainly undesirable, it is not anticipated that any serious chute candidate design will dictate unusual requirements in this area.

4.1.3 RATING PROVISION

Using the ten design criteria, each candidate configuration has been rated on a scale of from zero to ten, approximately as noted here:

10	Ideal
7.5	Good
5.0	Fair
2.5	Marginal
0	Totally Unsuitable

It will be seen that with this rating system and the criteria weighting previously established, the maximum possible score is 360.

4.2 TRADEOFF EVALUATION

4.2.1 SUMMARY ANALYSIS

Table 2 summarizes a comparative evaluation of the seven candidate configurations described in 3.0. The following discussion summarizes the principal conclusions from this tradeoff analysis while section 4.2.2 reviews details of the analysis.

It will be seen that for the concepts evaluated, scores compared to the maximum possible ranged from about 60 to 70 percent, with the compound quarter cylinder and the smoke pipe torus leading, with about 70 percent. Because of lack of consistently good performance against all ten evaluation criteria, the scores tended to average out, and no one concept is a runaway. However, the two above mentioned concepts rank markedly above the rest.

It will be seen that the major flaw in the compound cylinder configuration is the serious absence of stream cohesion. This is characterized by a two-pronged split in the flow at impact and was found to persist for various cylindrical radii configurations as well as for various chute location and orientations tried. No solution to this problem has thus far been developed.

In general, the torus concepts ranked the best from the standpoint of performance criteria, but were less impressive when judged against operational and

Table 2. Tradeoff Evaluation Analysis

Evaluation Criterion				Cone						Quarter Cylinder				Torus			
				Opening 1/2Angle		Flat Plate		Zero 1/2Angl		Single		Comp		True, Smooth		Smoke Pipe	
Area		Description	Weight W	R	RW	R	RW	R	RW	R	RW	R	RW	R	RW	R	RW
Performance	1	Stream Cohesion	4	5.0	20	5.0	20	7.5	30	0	0	0	0	9	36	9	36
	2	Belt Impact Vector	4	4	16	4	16	4	16	9	36	9	36	9	36	9	36
	3	Free Flow	5	10	50	10	50	9	45	10	50	9	45	8	40	8	40
	4	Convergence	5	2	10	2	10	7.5	37.5	0	0	9	45	9	45	9	45
Mine Operation	5	Jam Clearance	5	7.5	37.5	7.5	37.5	0	0	10	50	10	50	6	30	6	30
	6	Minimum Headroom	2	6	10	6	10	5	10	9	18	9	18	5	10	5	10
	7	Installation Complexity	2	5	10	7.5	15	5	10	10	20	7.5	15	4	8	5	10
Economics	8	Maintainability	3	7.5	22.5	7.5	22.5	7.5	22.5	8	24	5	15	1	3	5	15
	9	Producibility	3	7.5	22.5	7.5	22.5	7.5	22.5	7.5	22.5	5	15	1	5	5	25
	10	Initial Cost	3	6	18	6	18	7.5	22.5	7.5	22.5	4	12	0	0	3	9
		TOTAL RW	36		226		234.		216		243		251		213		256
		RATING AGAINST MAX POSSIBLE SCORE PERCENT			62.9		64.3		60		67.5		69.7		59.2		71.1

Code:
W - Numerical weight assigned to criterion, 1 to 5
R - Numerical rating given to configuration for indicated criterion, 1 to 10 (See Table 1)
RW - R x W

economic criteria. In the areas of producibility and cost, the smoke pipe torus appears to be a prohibitive choice over the true torus, although in an absolute sense it is still not optimum. A principal area of sensitivity exists in jam clearance, where the chute impact area is estimated to be about 15 inches from the feeder pulley, at the centerline of the belt. This is a design risk area which must be evaluated further by testing and analysis during the balance of the study program.

In general, several of the ratings of the two leading candidates against specific criteria involved very imprecise and preliminary judgement factors, especially in the economic areas. There is not much doubt that the compound quarter cylinder configuration can be produced cheaply, but somewhat more design study is required to gain definition relative to the smoke pipe torus.

In order to select which candidate chute concept, or concepts, should be investigated during final analysis and testing, an initial decision involves the compound cylinder concept, in a tradeoff between the good headroom and the very poor stream cohesion characteristics. The judgment is that the cohesion problem appears irredeemable and that acceptance of this penalty to gain a headroom advantage would not contribute usefully to the state of the art. Too many other chute configurations, as well as deflection boards, now in use already achieve this tradeoff. On this basis, the tradeoffs summarized in Table 2 indicate the torus to be the sole candidate design concept to be further considered.

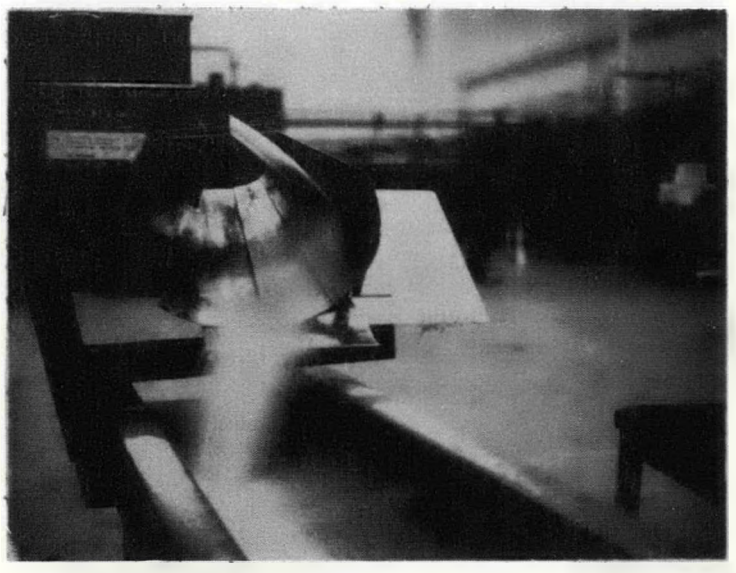
4.2.2 ANALYSIS DETAILS

This section reviews some of the details and rationale behind the trade-off analysis presented in Table 2, covered on a criterion-by-criterion basis.

4.2.2.1 Stream Cohesion

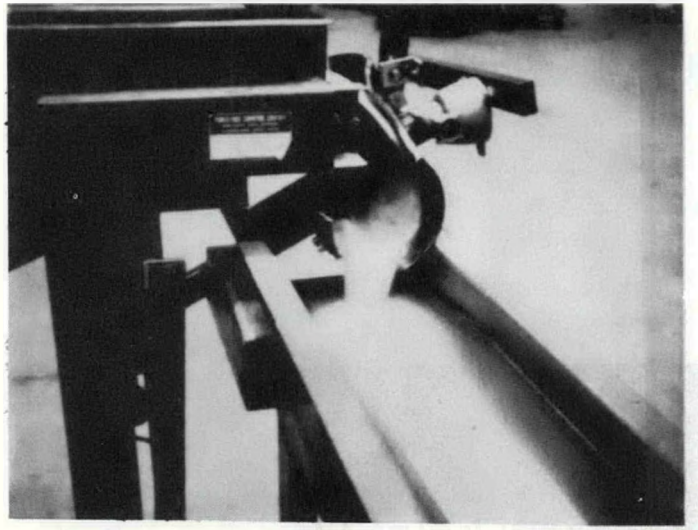
When properly aligned and located relative to the free fall trajectory from the head pulley, both the torus and the cone configurations possess good stream cohesion immediately after impact. The opening half angle cone concepts (1 and 2) tend to lose cohesiveness shortly after impact, however, due to the divergence of this opening angle (Figure 8). The torus and zero half angle cone maintain cohesion for specific positions and orientations (Figure 9).

In the case of the quarter cylinder configurations, impact of the free fall trajectory results in a stream pattern ranging from a diffuse fan to two broadly divergent forks (Figure 10). Movement of the chute in a vertical direction tended to vary the

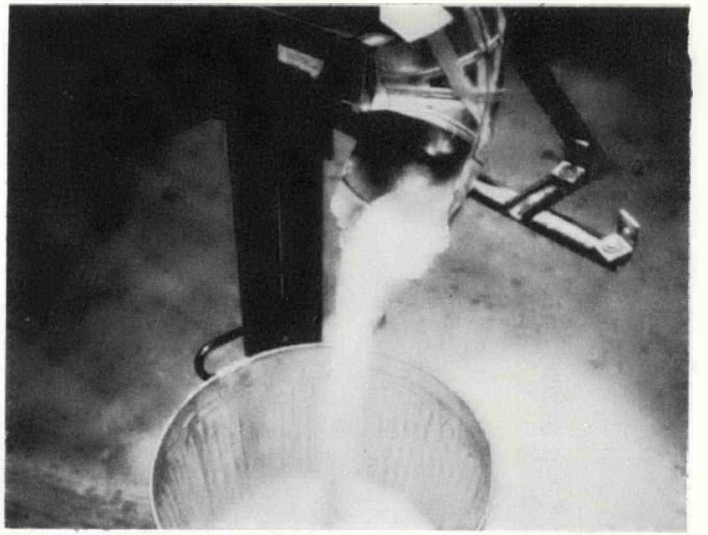


Flow Divergence
Cone Concepts (1, 2)

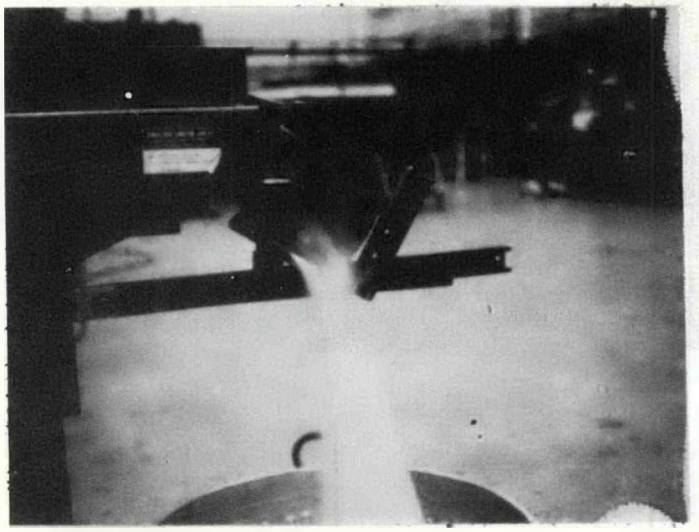
Figure 8



True (Smooth) Torus



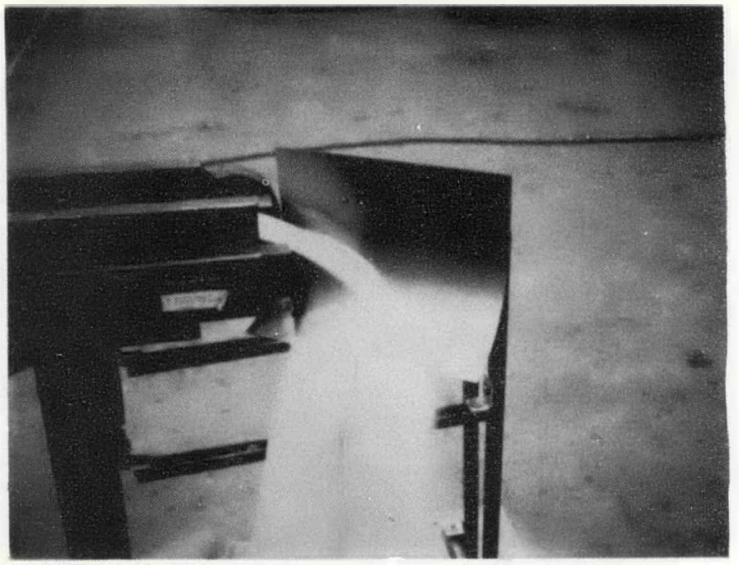
Smokepipe Torus

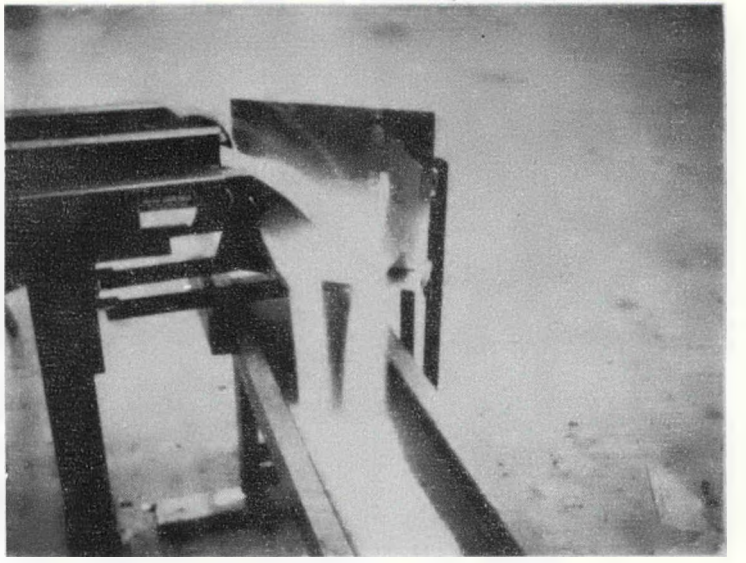


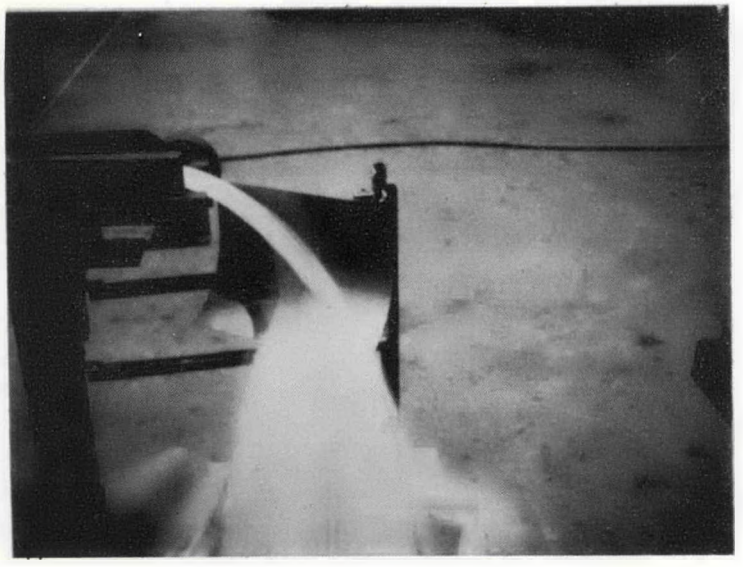
Zero Half Angle Cone

Stream Cohesion Cases

Figure 9







Stream Diffusion/Splitting Characteristics

Quarter Cylinder Concepts (4, 5)

Figure 10

pattern somewhat, with the least divergent corresponding to an extremely large headroom figure in excess of 78 inches (full scale) from the top of the feeder belt to the lower edge of the chute.

4.2.2.2 Belt Impact Vector

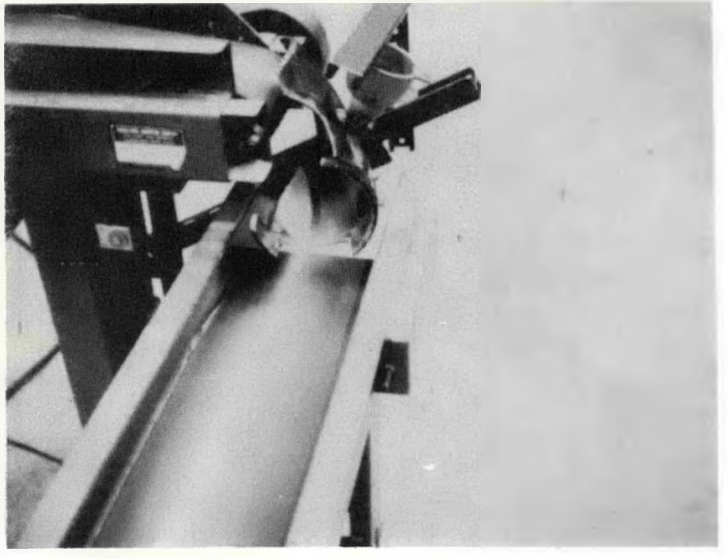
The quarter cylinder and toroidal configurations rank well in this area because of the common characteristic of a vertical curve in the direction of forced flow. Thus, the flow can be caused to leave the chute at a direction not more than 10 to 15 degrees down from the horizontal.

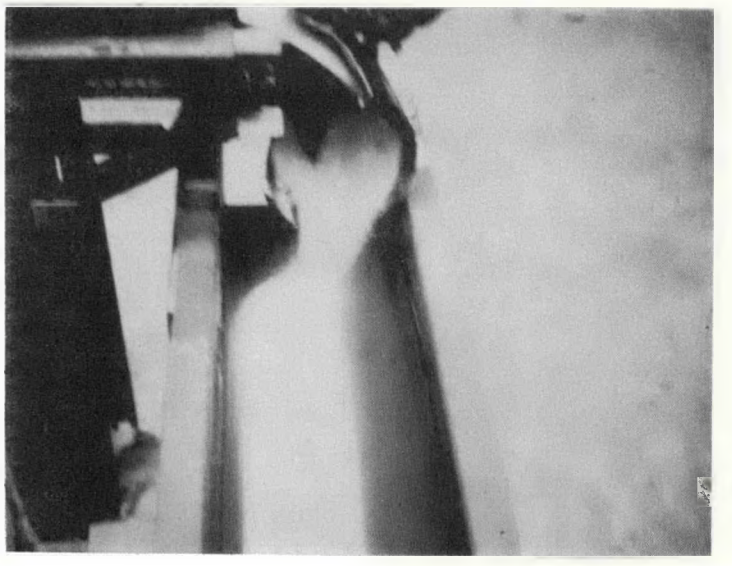
Lacking this vertical curve, the cone configurations will necessarily have a 35 to 45 degree output inclination angle. In an attempt to reduce the downward velocity component, a short curved lip was provided at the lower edge of the cone tested (Figure 2A), but it appeared that this substantial change of direction over a short distance tended to scatter the flow.

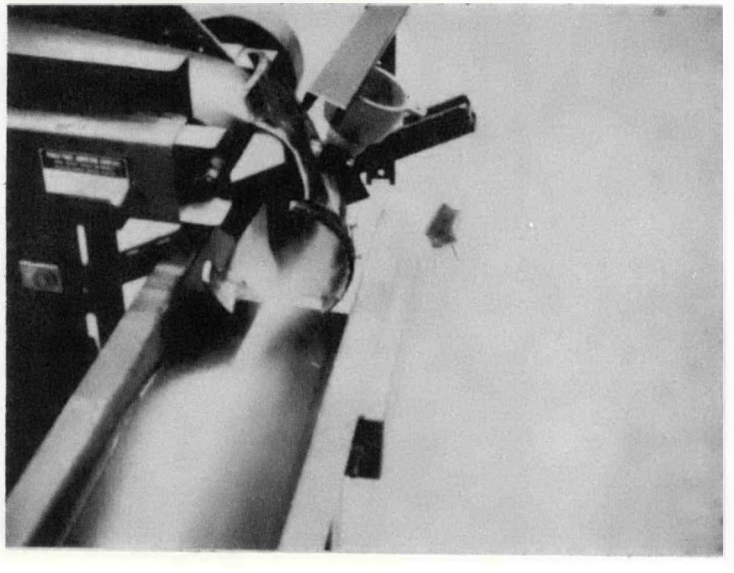
Tests revealed no significant clogging sensitivity among any of the candidate configurations, although the vertical curve shape, identified previously, did sometimes demonstrate a slight tendency to build up flow depth in the case of the torus. In another area it was found that fine particles tended to travel a considerable distance around the pulley radius before falling and sometimes then tended to build up in the chute immediately below the pulley, for some chute altitudes (Figure 11). This build-up was frequently instrumental in turning the main flow coming down and across the chute from the opposite, or outboard, side relative to the head pulley.

4.2.2.4 Convergence

Convergency of the different candidate shapes, in retrospect, should have been relatively predictable. The opening angle cones were divergent, as was the single quarter cylinder configuration. It was found that the addition of the side walls in the case of the compound cylinder configuration achieved an artificial convergency, howbeit a rather turbulent one.







Buildup and Dynamic Effects of Fines
for Some Torus Configurations

Figure 11

4.2.2.5 Jam Clearance

Jam clearance is defined here as the distance between the feed pulley surface and the free full impact point on the chute at the center of flow. It is an arbitrary measure of the likelihood of large pieces of rock to clear between the pulley and the chute and to execute the turn to the lower without jamming. The reason it is a factor at all in chute configurations evaluated here relates to the stream cohesion requirement, whereby impacting flow must meet the chute surface at a relatively low angle of incidence. To achieve this, the tangent to the local wall surface in this impact area needs to be at an altitude ranging between vertical to one leaning slightly toward the pulley. Moreover, the location of this impact point must be as close as possible to the pulley surface to minimize headroom. Based on these criteria, the resulting jam clearances achieved during scale model testing of the different configurations are summarized below, as adjusted to full scale:

	Configuration	Jam Clearance (inches)
1.	Cone, Opening Angle	24
2.	Cone , Flat Inpact Plate	24
3.	Cone, Zero Half Angle	9
4.	Quarter cylinder, Angle	N/A
5.	Quarter cylinder, Compound	N/A
6.	Torus, True	17
7.	Torus, Smoke Pipe	15

It can be concluded that the clearance for all but the zero half angle core are generally viable, although, as noted earlier, the clearances for the torus configurations as presently defined are slightly too small for good design and must be increased.

4.2.2.6 Minimum Headroom

Allowing an additional 8 inches clearance between the bottom of the chute and the receiving belt, the preliminary headroom requirements for the various candidate configurations are summarized below, these figures reflecting test data:

Configuration	Elevation Difference Belt-to-Belt, Inches
Cone, Opening Angle	58

(Cont)

	Configuration	Elevation Difference
2.	Cone, Flat Impact Plate	58
3.	Cone, Zero Half Angle	62
4.	Quarter cylinder, Single	40
5.	Quarter cylinder, Compound	40
6.	Torus, True	62
7.	Torus, Smoke Pipe	62

With the exception of configurations 4 and 5, these figures correspond to the minimum headroom positions for which stream cohesion is maintained. The effect of further decreasing the elevation difference in each case resulted in a part of the frictional stream being diverted above, rather than below the top of the impact zone. (Fig. 12)

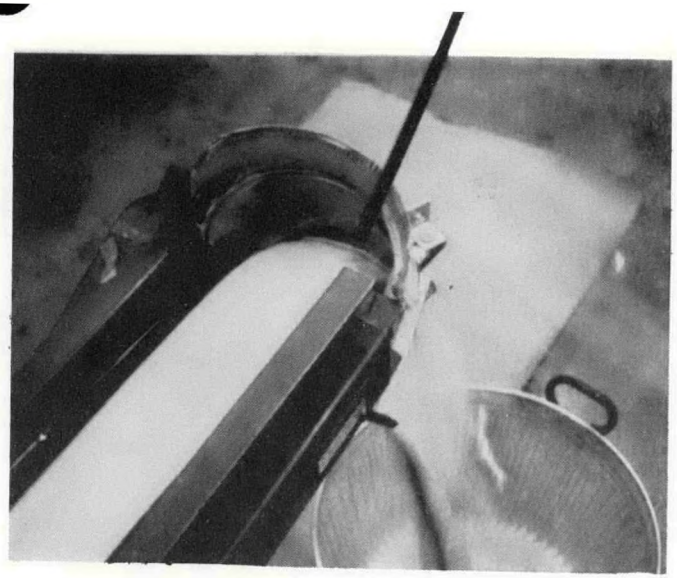
4.2.2.7 Installation Complexity

This area of evaluation, as well as the remaining three criteria, reflect very preliminary judgements. The ratings given to ease of installation are deliberately conservative and indicative of the need for more care in chute alignment to optimize stream cohesion, than is presently observed. Current alignment procedures, which emphasize centering the chute output flow on the receiving conveyor, will have to be broadened to obtain a smooth chute stream flow as well. However, it is not expected that this will introduce any special hardship or significant expenditure of time.

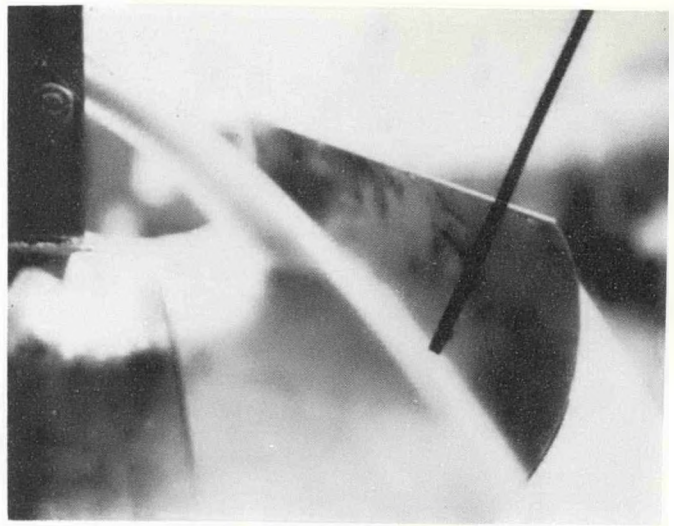
The relatively high scores given to the cylindrical configurations in ease of installation are somewhat misleading, in the sense that alignment efforts will not significantly improve stream cohesion.

4.2.2.8 Maintainability

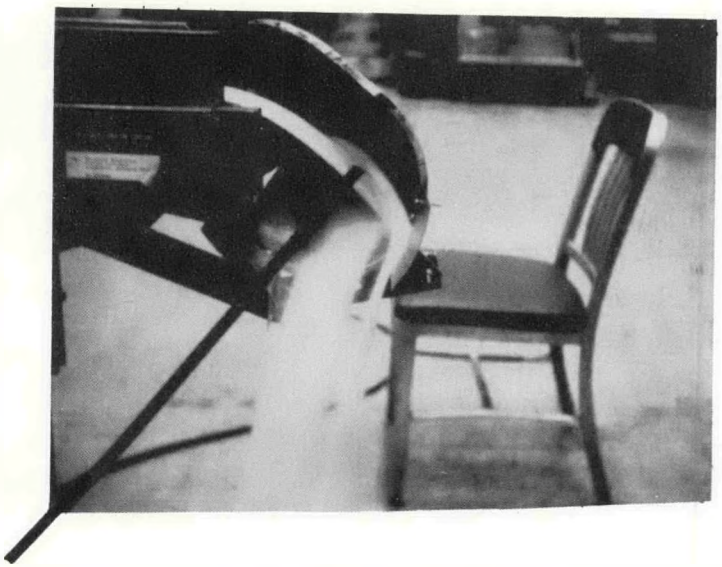
It is envisioned that, with the exception of the "true" torus, the slide surfaces of any of the candidate chute configurations would consist of piece-wise replaceable liner elements. These elements would be flat or single-degree-of-curvature plates and would be bolted to a support structure with flat head screws. The true torus slide surface, it is envisioned, would be made in a similar piece-wise



Smoke Pipe Torus



Cone



True (Smooth) Torus

Figure 12.
Typical Cases of Interference
between impacting and frictional flow
portions of stream

fashion of die-formed, two-degree-of-curvature elements. In this context, replacement time for worn portions of any of the candidate configurations should be essentially the same, although matching pieces with curvature is apt to require more care to achieve surface continuity. In general, maintainability here is a measure of the difficulty of procuring and maintaining an inventory of replacement elements. Flat patterns plainly can be fabricated locally, ensuring no inventory problem for linear configurations constructed of flat plates elements. This includes all cone and cylinder concepts. A single degree of curvature element, as might be required for the smoke pipe torus, should generally entail very little more fabrication capability. On the other hand, a die-formed piece, required for a true torus surface, most likely will involve some lead time,

4.2.2.9 Producibility

This subject has already been largely covered in the previous section. Only the true torus involves a potential problem from the standpoint of construction. The support structure design for the liner wall mosaid will necessarily involve moderate tolerances to ensure surface smoothness, and this may dictate some jigging, especially where single or double curvature is involved.

4.2.2.10 Initial Cost

Here the highest ratings are arbitrarily given on the basis of surface shape simplicity, with the simplest shapes being the zero half angle cone---in reality a 180 degree cylinder --- and the single quarter cylinder. The other cone configurations involve a little more structural jigging cost, and the compound cylinder still more due to the cylindrical intersections involved. The torodial configuration ratings on cost are quite conservative, and probably more nearly reflect prototype development rather than production.

APPENDIX G

TORUS CHUTE MATH MODEL

1. BASIC OFFSETS PRIOR TO ROTATION

a. LINEAR OFFSETS, FROM ORIGIN

INDEPENDENT:

- X_T – X OFFSET TO ℄ OF BASIC TORUS PRIOR TO ROTATIONS
- Y_T – Y OFFSET TO TOP OF BASIC TORUS PRIOR TO ROTATIONS
- Z_T – Z OFFSET OF ℄ OF BASIC TORUS AT TOP PRIOR TO ROTATIONS

b. ROTATIONS ABOUT ORIGIN

INDEPENDENT:

- GAMMA (γ) = ROLL, ABOUT Z AXIS
- ZIH (ξ) = PITCH, ABOUT X AXIS
- LAMDA (λ) = YAW, ABOUT Y AXIS (NOT SHOWN BELOW)

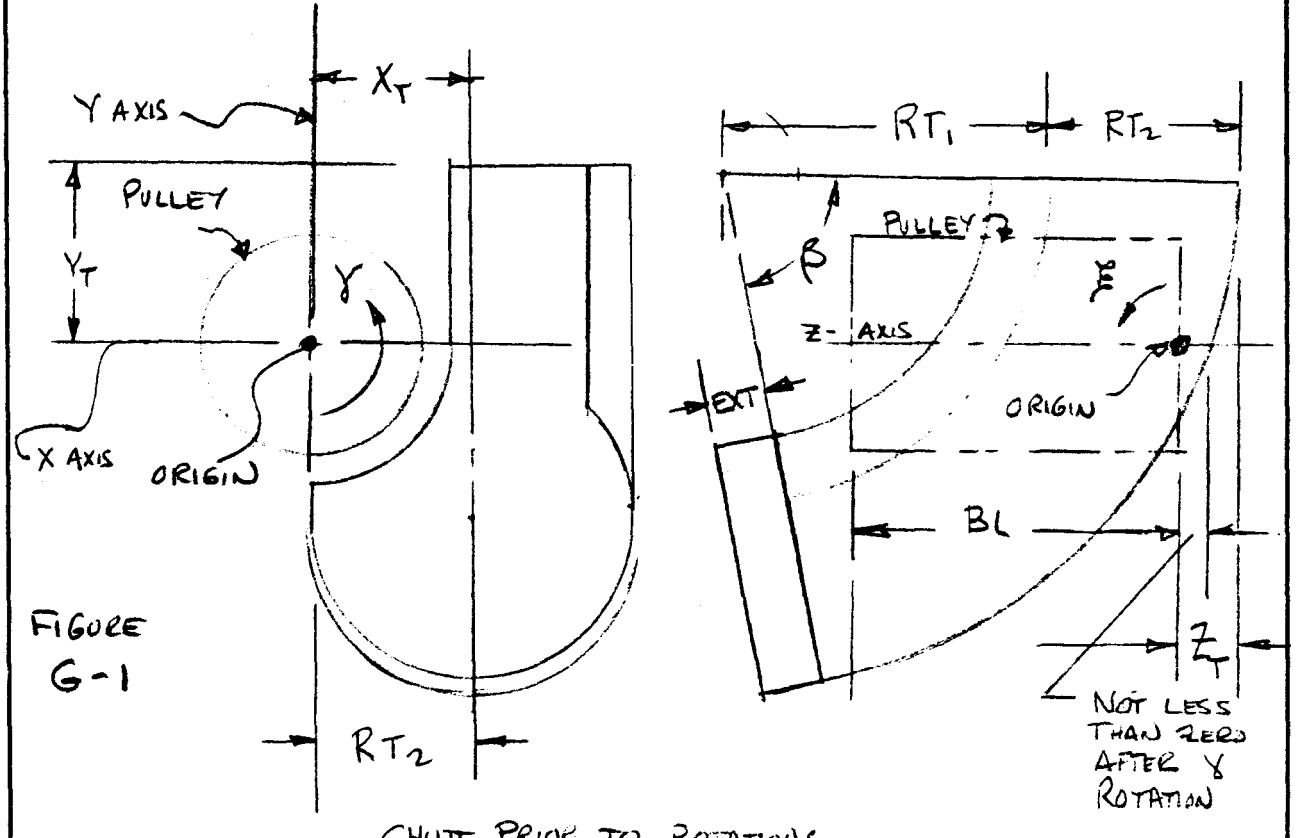


FIGURE G-1

CHUTE PRIOR TO ROTATIONS

PREPARED BY	CHECKED BY	DATE	REV.

2. DERIVATION OF BASIC PARAMETERS

a. ZT OFF SET, REQ'D PRIOR TO ROTATION

SET BACK SURFACE OF CHUTE AT PULLEY ℄ LEVEL EVEN WITH RGHT HAND END OF PULLEY ($Z=0$) AFTER ROLL ROTATION (γ)

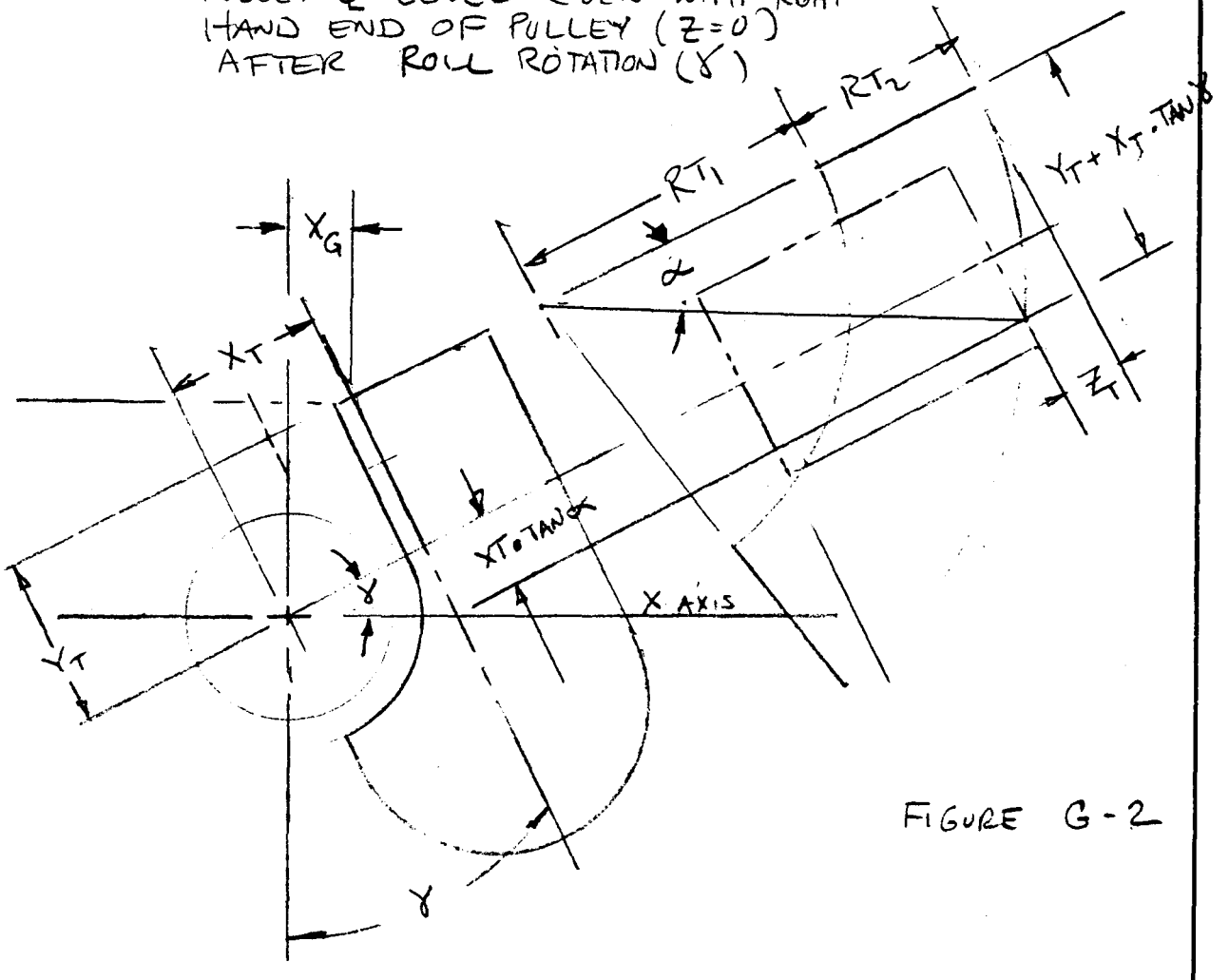


FIGURE G-2

$$\alpha = \text{SIN}\ T$$

$$\text{WHERE}\ T = \frac{Y_T + X_T \cdot \text{TAN}(\gamma)}{RT1 + RT2}$$

PREPARED BY	CHECKED BY	DATE	REV.

2. CON'T.

$$Z_T = (RT1 + RT2)(1 - \cos \alpha)$$

$$X_G = (Y_T + X_T \cdot \tan \gamma) \cos \gamma$$

$$Y_G = X_T \cos \gamma - Y_T \sin \gamma$$

b. AFTER ROTATION - β

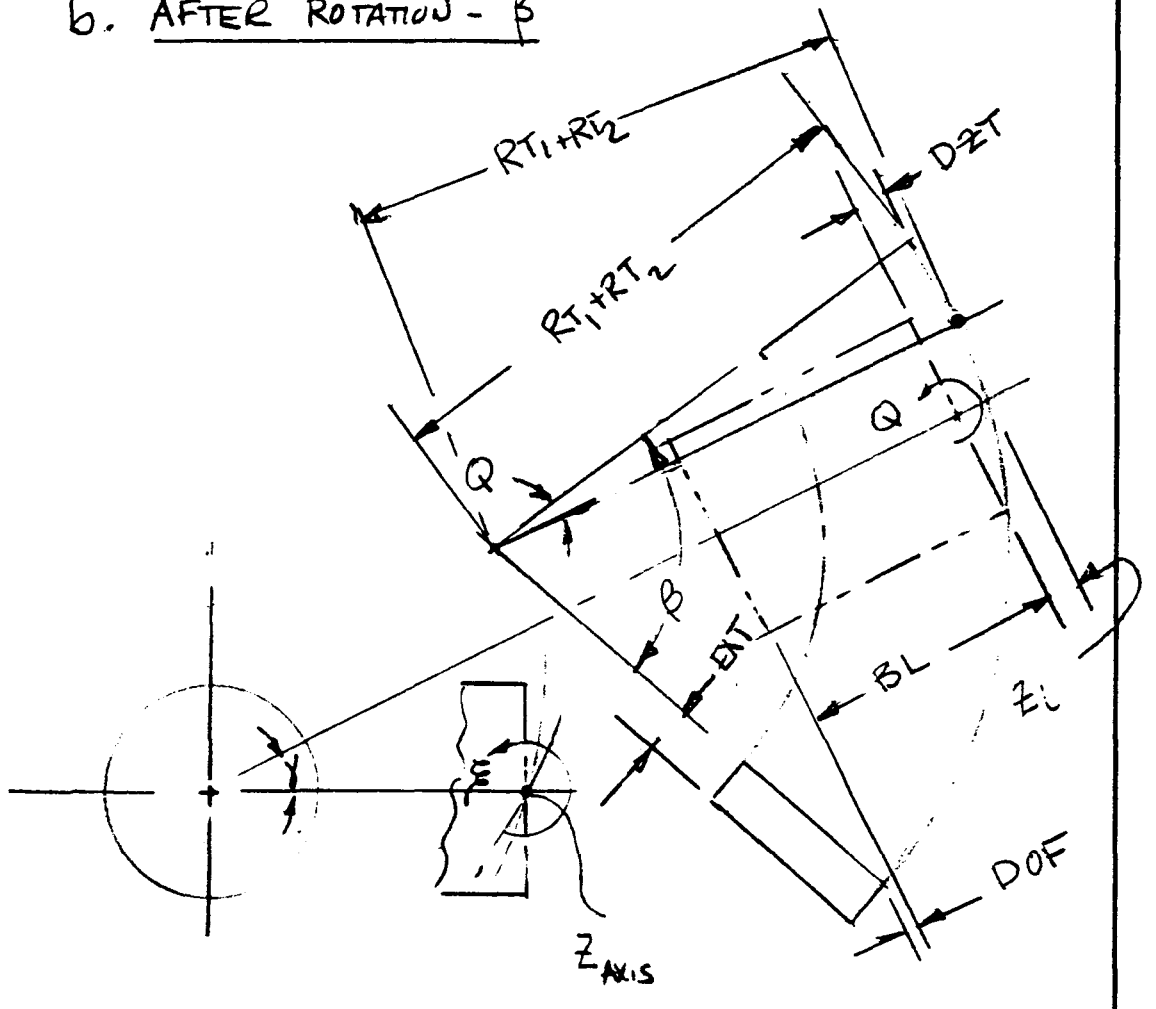


FIGURE G-3

PREPARED BY	CHECKED BY	DATE	REV.

2 CONT

$$Q = \sin^{-1}\left[\frac{2\,RT2 \cdot \sin\xi \cdot \cos\gamma}{2RT2}\right]$$

$$= \sin^{-1}\left(\sin\xi \cdot \cos\gamma\right)$$

$$\cos(\beta - Q) = \frac{RT_1 + RT_2 - (BL + DOF + Z_L)}{RT_1 + RT_2}$$

$$\beta = \cos^{-1}\left[\frac{(RT_1 + RT_2) - (DOF + BL + Z_L)}{RT_1 + RT_2}\right] - Q$$

CORRECTING FORESHORTENING DUE TO YAW AND NEGLETING Z_L,

$$\beta_{APPROX} = \cos^{-1}\left[\frac{(RT_1 + RT_2) - (DOF + BL)}{\cos(YAW)(RT_1 + RT_2)}\right] - Q$$

3. SUBDIVISION INTO RECTANGULAR PLATES

A FLAT PATTERN OF A TOROIDAL SECTION WITH NT1 x NT2 SUBDIVIDED PLATES IS SHOWN IN FIGURE G-4, WITH A TYPICAL PLATE NP HAVING CORNERS 1, 2, 3 & 4 DEFINITION OF WRAP-AROUND ANGLES A AND ψ IN RT1 AND RT2 PLANES IS SHOWN IN FIGURES G-5 & G-6, RESPECTIVELY

PREPARED BY	CHECKED BY	DATE	REV.

3, CONT

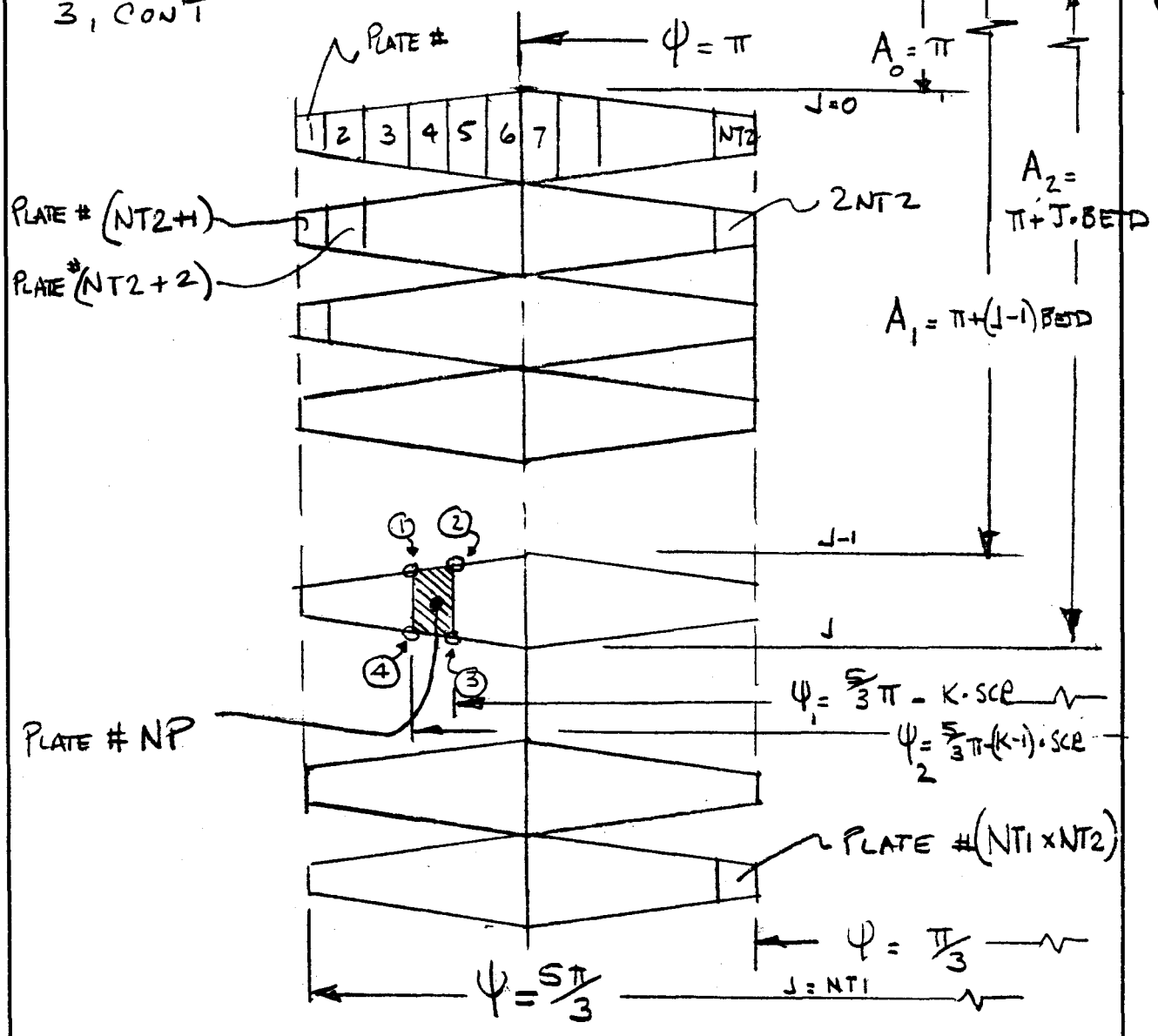


FIGURE G-4

FLAT PATTERN REPRESENTATION OF

RECTANGULAR PLATE SUBDIVISION OF TORUS

INTO NT1 SECTIONS AROUND MAJOR RADIUS RT1 & NT2 SECTIONS AROUND MINOR RADIUS RT2

PREPARED BY	CHECKED BY	DATE	REV.

3. CON'T

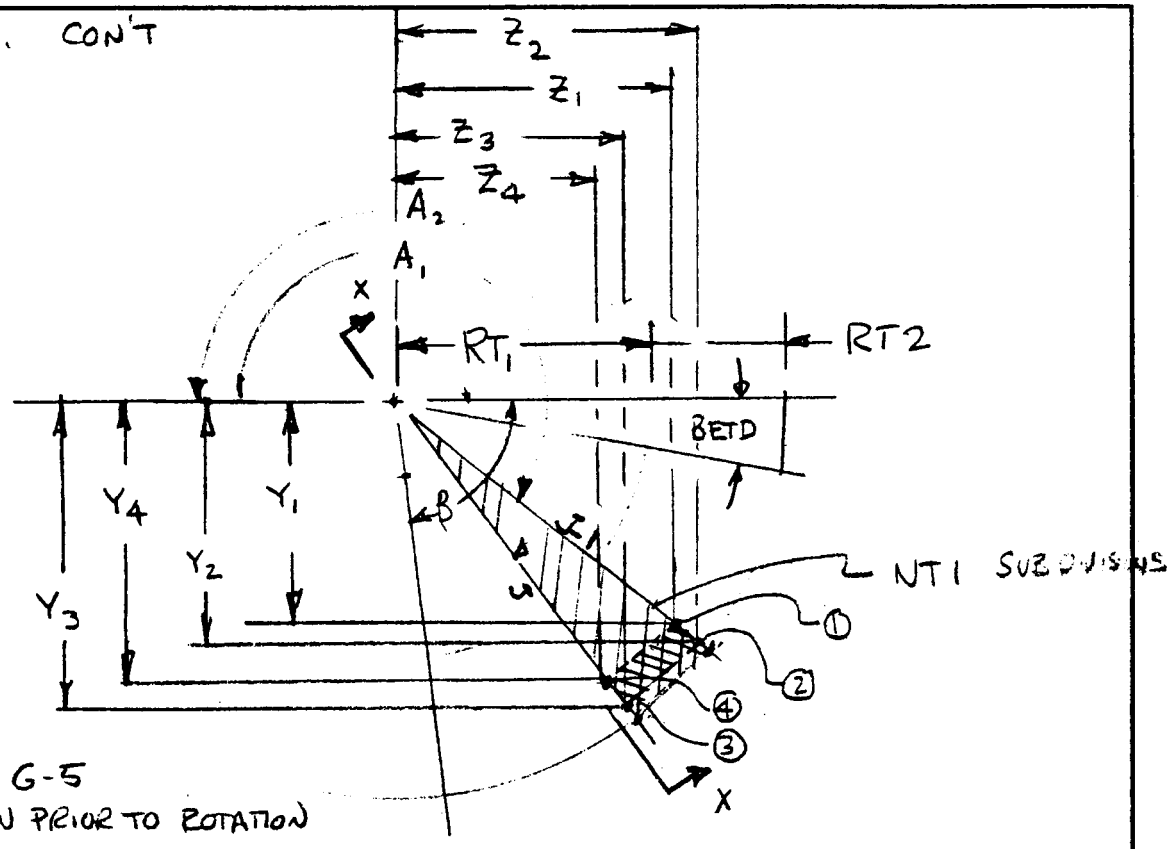


FIGURE G-5
VIEW PRIOR TO ROTATION

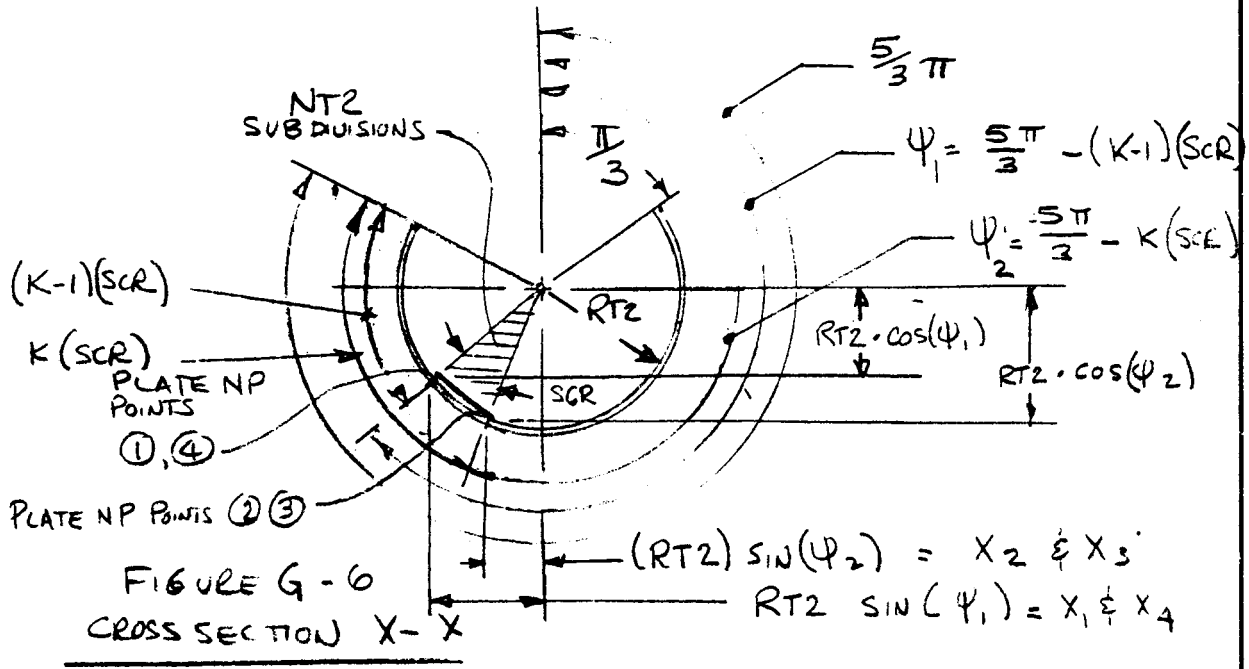


FIGURE G-6
CROSS SECTION X-X

PREPARED BY	CHECKED BY	DATE	REV.

3. CON'T

THE COORDINATES FOR THE 4 CORNERS OF TYPICAL PLATE NP ARE THE FOLLOWING, REFERRING TO FIGURES G-5 & G-6

CORNER #	CORNER X	CORNER Y	CORNER Z
1	$RT2 \cdot \sin \psi_1$	$(RT1 - RT2 \cdot \cos \psi_2) \sin A_1$	$(RT1 - RT2 \cdot \cos \psi_2) \cos A_1$
2	$RT2 \cdot \sin \psi_2$	$(RT1 - RT2 \cdot \cos \psi_1) \sin A_1$	$(RT1 - RT2 \cdot \cos \psi_1) \cos A_1$
3	$RT2 \cdot \sin \psi_2$	$(RT1 - RT2 \cdot \cos \psi_1) \cdot \sin A_2$	$(RT1 - RT2 \cdot \cos \psi_1) \cos A_2$
4	$RT2 \cdot \sin \psi$	$(RT1 - RT2 \cdot \cos \psi_2) \cdot \sin A_2$	$(RT1 - RT2 \cdot \cos \psi_2) \cos A_2$

APPENDIX H

COMPUTER ANALYTICAL RESULTS

Appendix H Contents

SECTION H-1

FREE FALL/IMPACT ANALYSIS RESULTS

350 FPM TRAJECTORY IMPACT CASE

RUNS 626, 627

****

BEGIN INDEPENDENT RUN OF COAL CHUTE DESIGNER RUN NUMBER626 DATE 27 APR 77 20 16 27

..... INDEPENDENT VARIABLES FOR THIS RUN .....

A. INPUT DATA

FEED CONVEYOR DATA

BELT SPEED V , IPS. 70.00

PULLEY RADIUS R, IN. 12.00

BELT WIDTH BELTWD IN. 36.00

BELT EDGE DISTANCE BMAR IN. 2.00

TROUGH ANGLE IDLANG DEG. 35.00

SURCHARGE ANGLE SURANG DEG. 25.00

INCLINATION ANGLE PHI DEG. 0.0

TORUS CHUTE DATA

MAJOR RADIUS RT1, IN 36.00

MINOR RADIUS RT2, IN. 18.00

ROTATIONS,DEG.
Z-AXIS-GAMMA 25.00
Y AXIS-YAW 0.0
X-AXIS-ZIH 0.0

EXTRA LENGTH DISP IN. 0.0

COORDINATESPRIOR TO ROTATION
XT IN. 5.00
YT IN. 10.00

FLAT PLATE DIVISION
MAJOR RADIUS-NT1 7
MINOR RADIUS-NT2 7

RUN OF MINE COAL DATA

DENSITY, GAMD LBS./CU. FT. 50.00

EFFECTIVE ANGLE OF FRICTION DELTF DEG. 50.00

DYNAMIC ANGLE OF WALL FRICTION PHIP DEG. 30.00

RUN CONVENTION CONSTANTS

FRICTION STEP DISTANCE - NOM.,EL1, IN. 1.00

NO OF STREAM SUBDIVISIONS SECT 21

========== SUMMARY OF KEY CALCULATED PARAMETERS AND FINAL PLATE COORDINATES ==========

8. OUTPUT DATA

PULLEY CONTACT DEP. ANGLE,DEG., 32.76
INITIAL LOAD HEIGHT,IN. 7.52
TORUS CUTOFF ANGLE,DEG. 105.33
MINIMUM Y COORDINATE -39.38

PLATE 1

0.305	8.462	14.122	6.230
11.176	14.980	2.841	-1.530
-1.427	0.985	2.754	0.425

PLATE 2

8.462	14.433	19.371	14.122
14.980	17.764	7.176	2.841
0.985	7.573	9.116	2.754

PLATE 3

14.433	16.619	20.569	19.371
17.764	18.783	10.313	7.176
7.573	16.573	17.808	9.116

PLATE 4

16.619	14.433	17.396	20.569
18.783	17.764	11.411	10.313
16.573	25.573	26.499	17.808

PLATE 5

6.230	14.122	19.395	11.749
-1.530	2.841	-8.465	-13.365
0.425	2.754	7.939	5.853

PLATE 6

14.122	19.371	23.970	19.395
2.841	7.176	-2.687	-8.465
2.754	9.116	13.640	7.939

19.371	20.569	24.248	23.970
7.176	10.313	2.423	-2.687
9.116	17.808	21.426	13.640

PLATE 8

20.569	17.396	20.155	24.248
10.313	11.411	5.494	2.423
17.808	26.499	29.213	21.426

PLATE 9

-8.379	-4.286	-0.341	-5.223
-12.792	-15.863	-24.322	-19.559
21.426	13.639	20.833	27.181

PLATE 10

-4.286	3.081	7.604	-0.341
-15.863	-16.072	-25.771	-24.322
13.639	7.939	16.186	20.833

PLATE 11

3.081	11.749	16.483	7.604
-16.072	-13.365	-23.516	-25.771
7.939	5.853	14.485	16.186

PLATE 12

11.749	19.395	23.917	16.483
-13.365	-8.465	-18.164	-23.516
5.853	7.939	16.186	14.485

PLATE 13

19.395	23.970	27.914	23.917
-8.465	-2.687	-11.146	-18.164
7.939	13.640	20.833	16.186

PLATE 14

23.970	24.248	27.404	27.914
-2.687	2.423	-4.345	-11.146
13.640	21.426	27.181	20.833

PLATE 15

24.248	20.155	22.522	21.404
2.423	5.494	0.418	-4.345
21.426	29.213	33.529	27.181

PLATE 16

-5.223	-0.341	2.679	-2.807
-19.559	-24.322	-30.800	-24.741
27.181	20.833	30.203	34.677

PLATE 17

-0.341	7.604	11.066	2.679
-24.322	-25.771	-33.196	-30.800
20.833	16.186	26.928	30.203

PLATE 18

7.604	16.483	20.107	11.066
-25.771	-23.516	-31.289	-33.196
16.186	14.485	25.729	26.928

PLATE 19

16.483	23.917	27.380	20.107
-23.516	-18.164	-25.589	-31.289
14.485	16.186	26.928	25.729

PLATE 20

23.917	27.914	30.935	27.380
-18.164	-11.146	-17.624	-25.589
16.186	20.833	30.203	26.928

PLATE 21

27.914	27.404	29.820	30.935
-11.146	-4.345	-9.527	-17.624
20.833	27.181	34.677	30.203

PLATE 22

27.404	22.522	24.334	29.820
-4.345	0.418	-3.468	-9.527
27.181	33.529	39.151	34.677

PLATE 23

-2.807	2.679	4.568	-1.296

34.677	30.203	41.108	43.401

PLATE 24

2.679	11.066	13.231	4.568
-30.800	-33.196	-37.839	-34.850
30.203	26.928	39.429	41.108

PLATE 25

11.066	20.107	22.374	13.231
-33.196	-31.289	-36.149	-37.839
26.928	25.729	38.815	39.429

PLATE 26

20.107	27.380	29.545	22.374
-31.289	-25.589	-30.232	-36.149
25.729	26.928	39.429	38.815

PLATE 27

27.380	30.935	32.823	29.545
-25.589	-17.624	-21.674	-30.232
26.928	30.203	41.108	39.429

PLATE 28

30.935	29.820	31.331	32.823
-17.624	-9.527	-12.767	-21.674
30.203	34.677	43.401	41.108

PLATE 29

29.820	24.334	25.467	31.331
-9.527	-3.468	-5.899	-12.767
34.677	39.151	45.694	43.401

PLATE 30

-1.296	4.568	5.195	-0.794
-27.981	-34.850	-36.195	-29.058
43.401	41.108	52.798	52.753

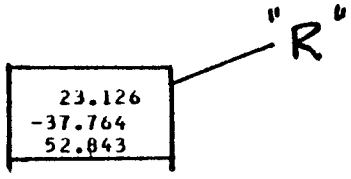
PLATE 31

4.568	13.231	13.951	5.195
-34.850	-37.839	-39.382	-36.195
41.108	39.429	52.831	52.798

PLATE 32

13.231	22.374	23.126	13.951
-37.839	-36.149	-37.764	-39.382
39.429	38.815	52.843	52.831

PLATE 33



22.374	29.545	30.264	23.126
-36.149	-30.232	-31.775	-37.764
38.815	39.429	52.831	52.843

PLATE 34

29.545	32.823	33.451	30.264
-30.232	-21.674	-23.019	-31.775
39.429	41.108	52.798	52.831

PLATE 35

32.823	31.331	31.833	33.451
-21.674	-12.767	-13.843	-23.019
41.108	43.401	52.753	52.798

PLATE 36

31.331	25.467	25.844	31.833
-12.767	-5.899	-6.706	-13.843
43.401	45.694	52.708	52.753

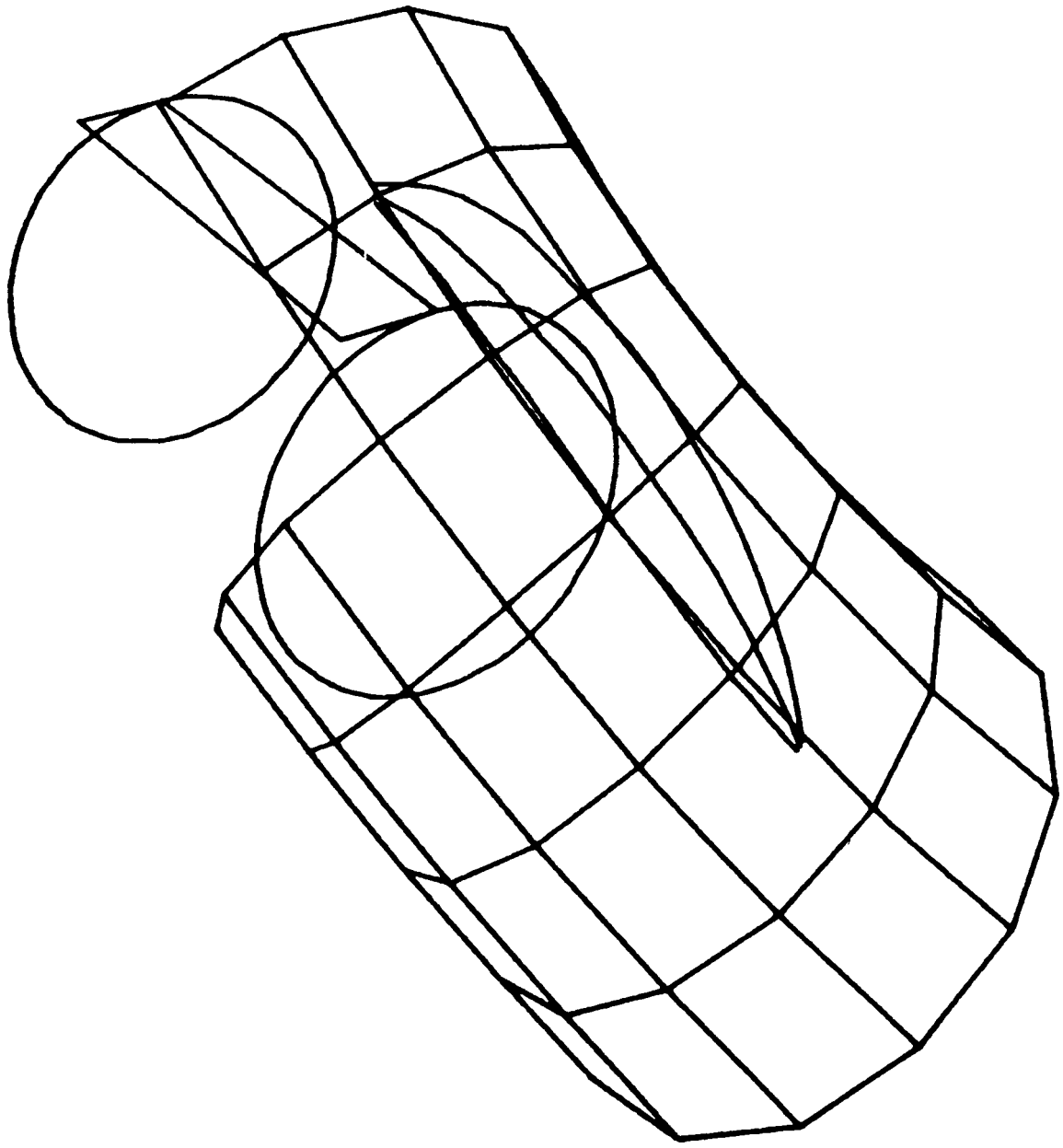
B. OUTPUT DATA

1. HIT DATA

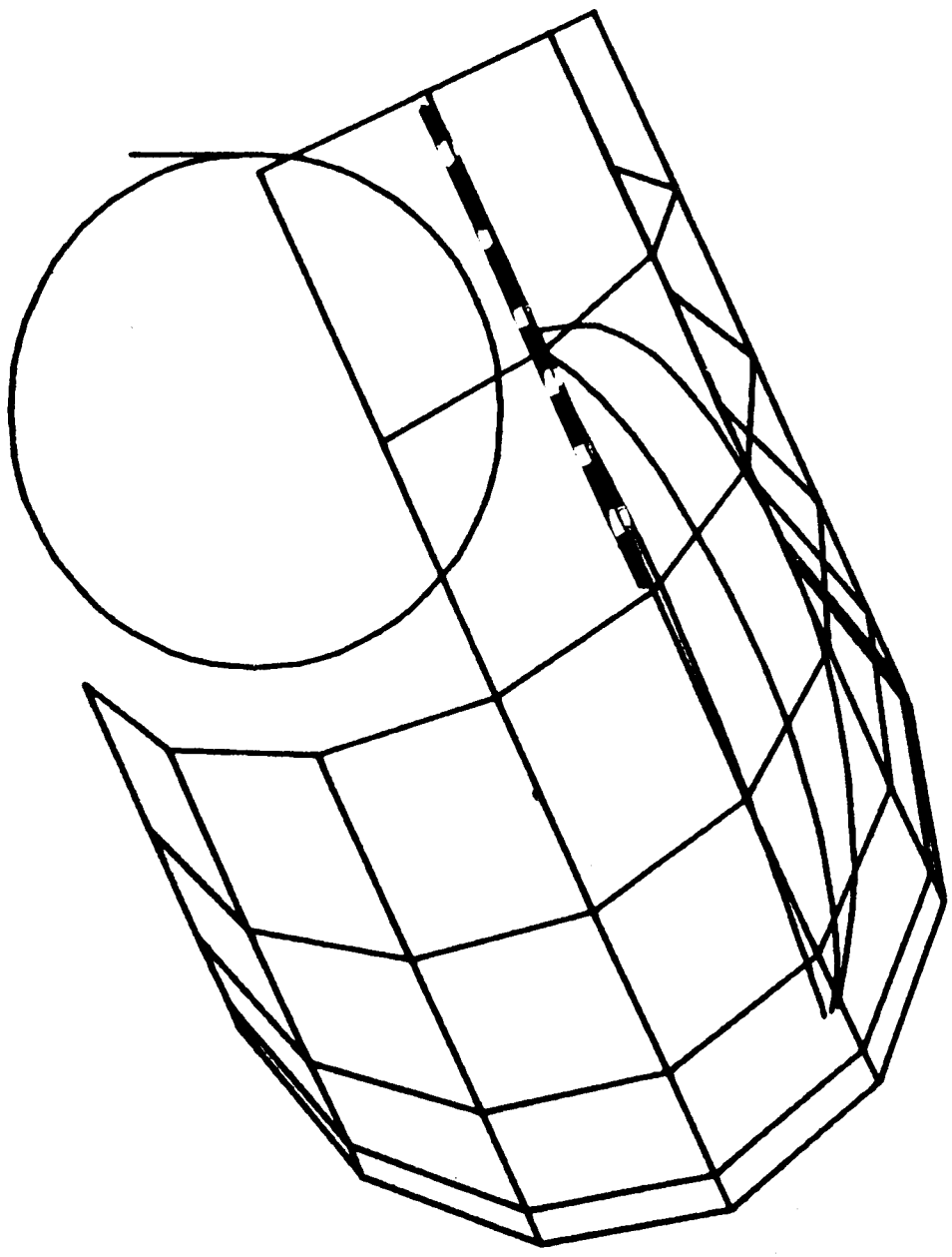
STREAM	TIME	C.G. ANGLE	C.G. X	C.G. Y	C.G. Z		BOTTOM ANGLE	BOTTOM X	BOTTOM Y	BOTTOM PLATE	TOP ANGLE	TOP X	TOP Y	TOP PL
1	0.12	-24.3	14.1	2.7	2.8	5	-24.3	13.8	2.3	5	-13.5	13.8	3.8	2
2	0.14	-21.9	15.5	1.7	4.3	6	-23.5	15.7	-0.5	5	-12.4	15.4	4.0	2
3	0.16	-20.5	16.9	0.5	5.8	6	-19.1	17.2	-3.2	6	-22.1	16.7	3.9	6
4	0.18	-19.1	18.4	-1.2	7.3	6	-17.5	18.7	-6.1	6	-21.0	18.1	3.5	6
5	0.20	-17.8	19.8	-3.2	8.9	6	-26.2	20.0	-8.8	13	-19.8	19.5	2.6	6
6	0.22	-16.6	21.3	-5.5	10.4	6	-25.4	20.8	-10.6	13	-18.6	20.9	1.2	6
7	0.24	-25.7	22.3	-7.1	11.9	13	-24.7	21.6	-12.5	13	-17.4	22.3	-0.6	6
8	0.25	-25.1	23.1	-8.6	13.4	13	-24.1	22.5	-14.4	13	-16.3	23.8	-2.9	6
9	0.26	-24.4	24.0	-10.3	15.0	13	-23.5	23.3	-16.4	13	-25.5	24.7	-4.3	13
10	0.28	-23.8	24.8	-12.1	16.5	13	-31.4	24.0	-18.3	20	-8.3	25.4	-5.4	14
11	0.29	-23.3	25.6	-14.1	18.0	13	-48.6	24.5	-19.5	19	-7.5	26.2	-7.4	14
12	0.30	-31.3	26.2	-15.6	19.5	20	-48.4	24.9	-20.6	19	-23.6	27.2	-9.8	13
13	0.31	-31.0	26.6	-16.9	21.0	20	-48.2	25.3	-21.7	19	-31.5	27.8	-11.9	20
14	0.32	-30.6	27.0	-18.3	22.6	20	-48.1	25.7	-22.8	19	-31.1	28.2	-13.4	20

15	0.32	-30.3	27.4	-19.8	24.1	20	-47.9	26.1	-24.3	19	-30.1	28.9	-19.2	20
16	0.33	-30.0	27.8	-21.4	25.6	20	-47.8	26.5	-25.1	19	-30.4	28.8	-17.2	20
17	0.34	-29.7	28.1	-23.2	27.1	20	-59.8	26.9	-26.2	26	-30.0	29.0	-19.4	20
18	0.35	-35.7	28.2	-24.6	28.7	27	-59.7	27.1	-26.8	26	-35.9	29.1	-21.7	27
19	0.35	-35.5	28.2	-25.9	30.2	27	-59.6	27.3	-27.4	26	-35.7	29.0	-23.7	27
20	0.36	-35.3	28.2	-27.3	31.7	27	-59.5	27.5	-28.0	26	-35.4	28.7	-25.8	27
21	0.36	-59.4	28.0	-28.4	33.2	26	-59.4	27.7	-28.6	26	-59.4	28.2	-28.1	26

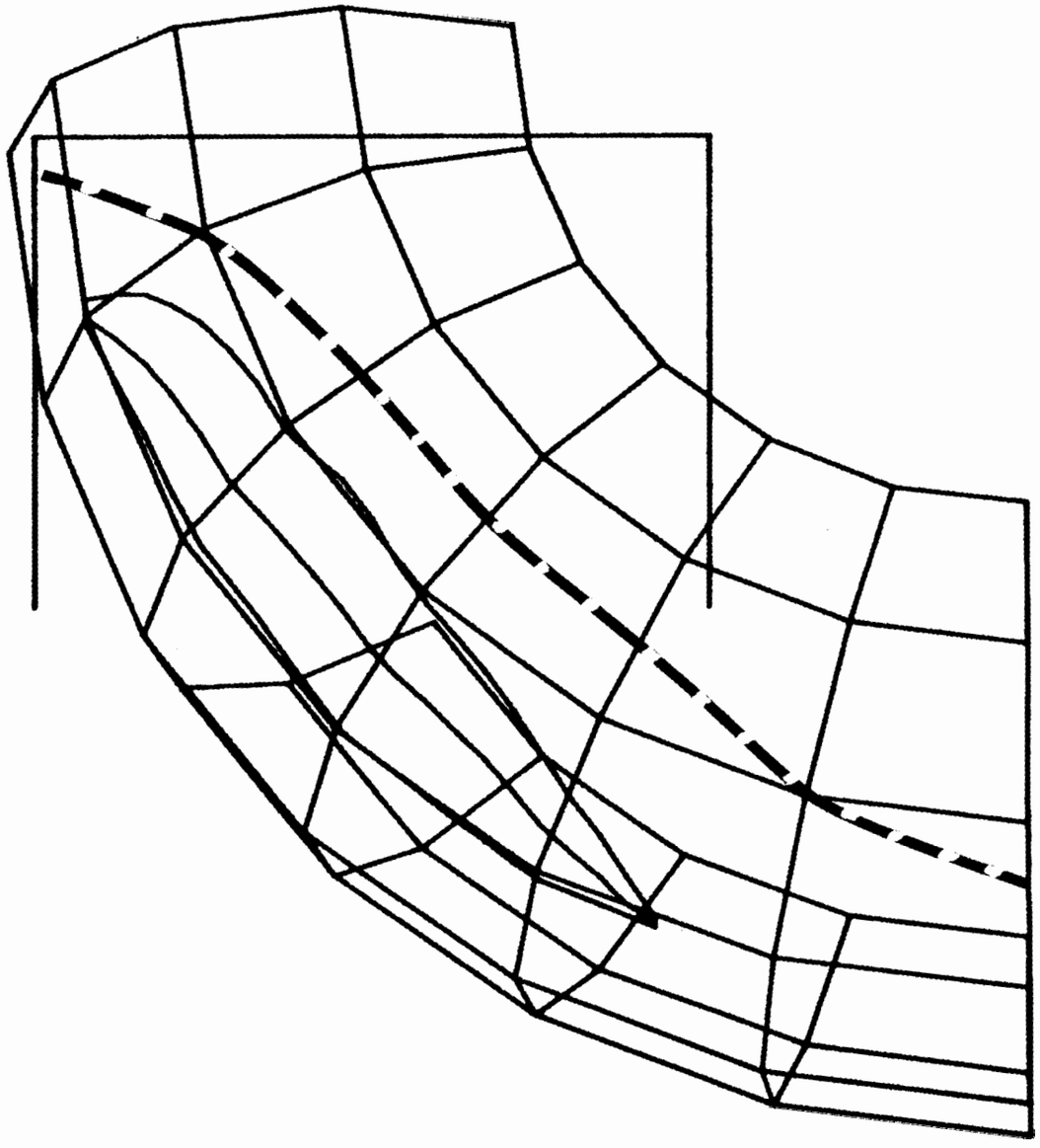
3-D VIEW RUN 626 ELEMENTS 1,99999



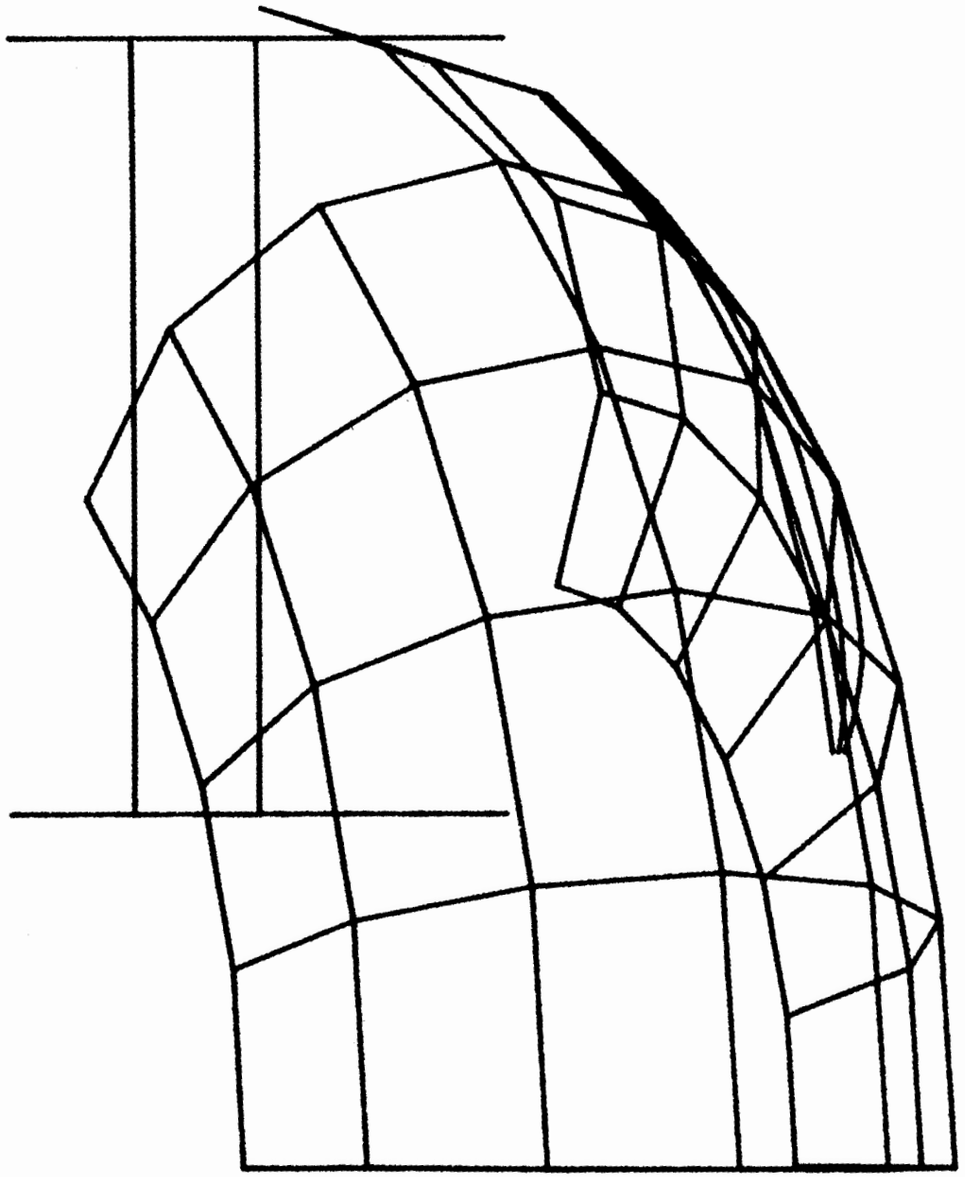
FRONT VIEW RUN 626 ELEMENTS 1,99999



SIDE VIEW RUN 626 ELEMENTS 1,99999



TOP VIEW RUN 626 ELEMENTS 1,99999



BEGIN INDEPENDENT RUN OF COAL CHUTE DESIGNER RUN NUMBER627 DATE 27 APR 77 20 18 30

..... INDEPENDENT VARIABLES FOR THIS RUN .....

A. INPUT DATA

FEED CONVEYOR DATA

BELT SPEED V , IPS. 70.00

PULLEY RADIUS R, IN. 12.00

BELT WIDTH BELTWD IN. 36.00

BELT EDGE DISTANCE BMAR IN. 2.00

TROUGH ANGLE ICLANG DEG. 35.00

SURCHARGE ANGLE SURANG DEG. 25.00

INCLINATION ANGLE PHI DEG. 0.0

TORUS CHUTE DATA

MAJOR RADIUS RT1, IN 36.00

MINOR RADIUS RT2, IN. 18.00

ROTATIONS,DEG.
Z-AXIS-GAMMA 25.00
Y AXIS-YAW 0.0
X-AXIS-ZIH 0.0

EXTRA LENGTH DISP IN. 0.0

COORDINATESPRIOR TO ROTATION
XT IN. 4.00
YT IN. 10.00

FLAT PLATE DIVISION
MAJOR RADIUS-NT1 7
MINOR RADIUS-NT2 7

RUN OF MINE COAL DATA

DENSITY, GAMD LBS./CU. FT. 50.00

EFFECTIVE ANGLE OF FRICTION DELTF DEG. 50.00

DYNAMIC ANGLE OF WALL FRICTION PHIP DEG. 30.00

RUN CONVENTION CONSTANTS

FRICTION STEP DISTANCE - NOM.,EL1, IN. 1.00

NO OF STREAM SUBDIVISIONS SECT 21

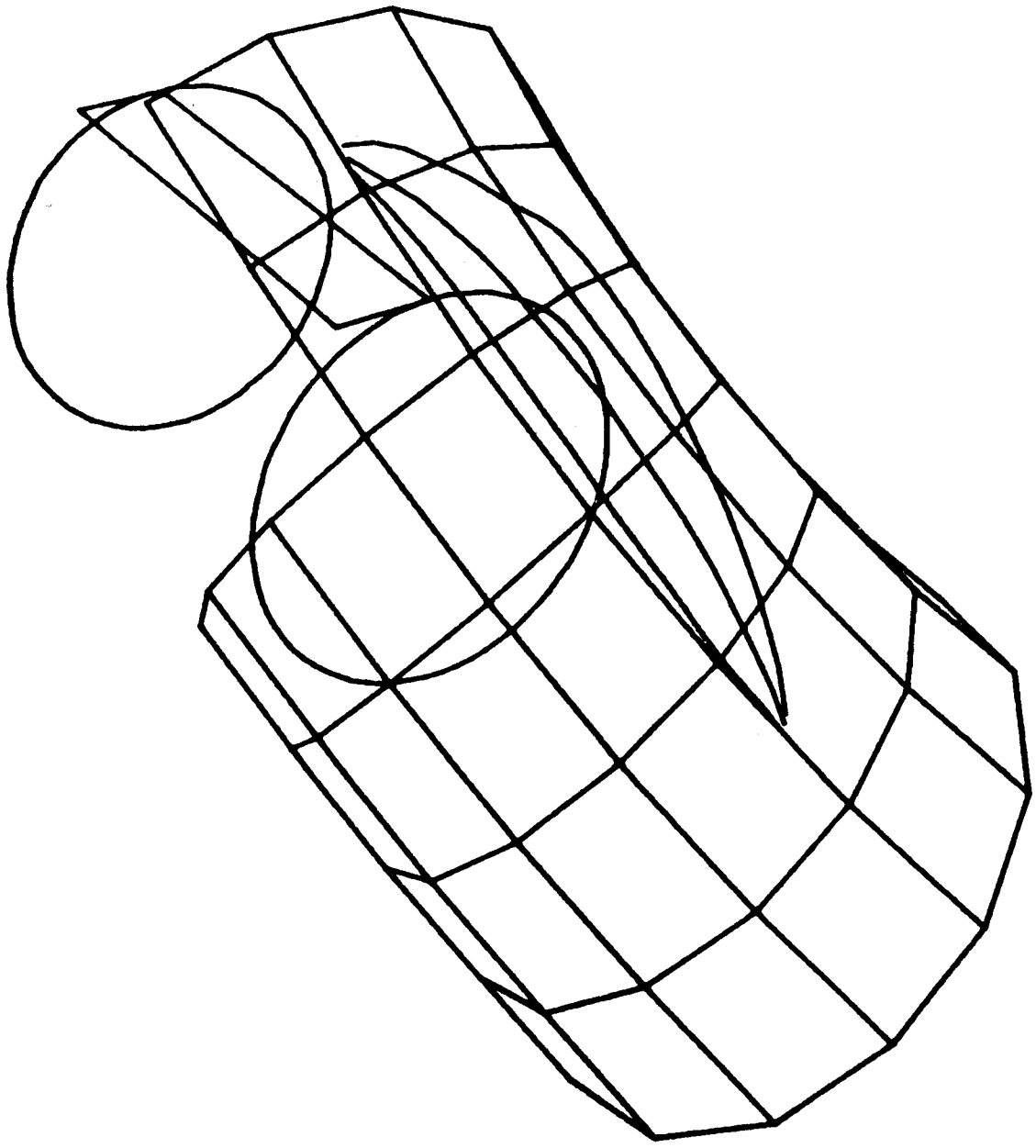
B. OUTPUT DATA

1. HIT DATA

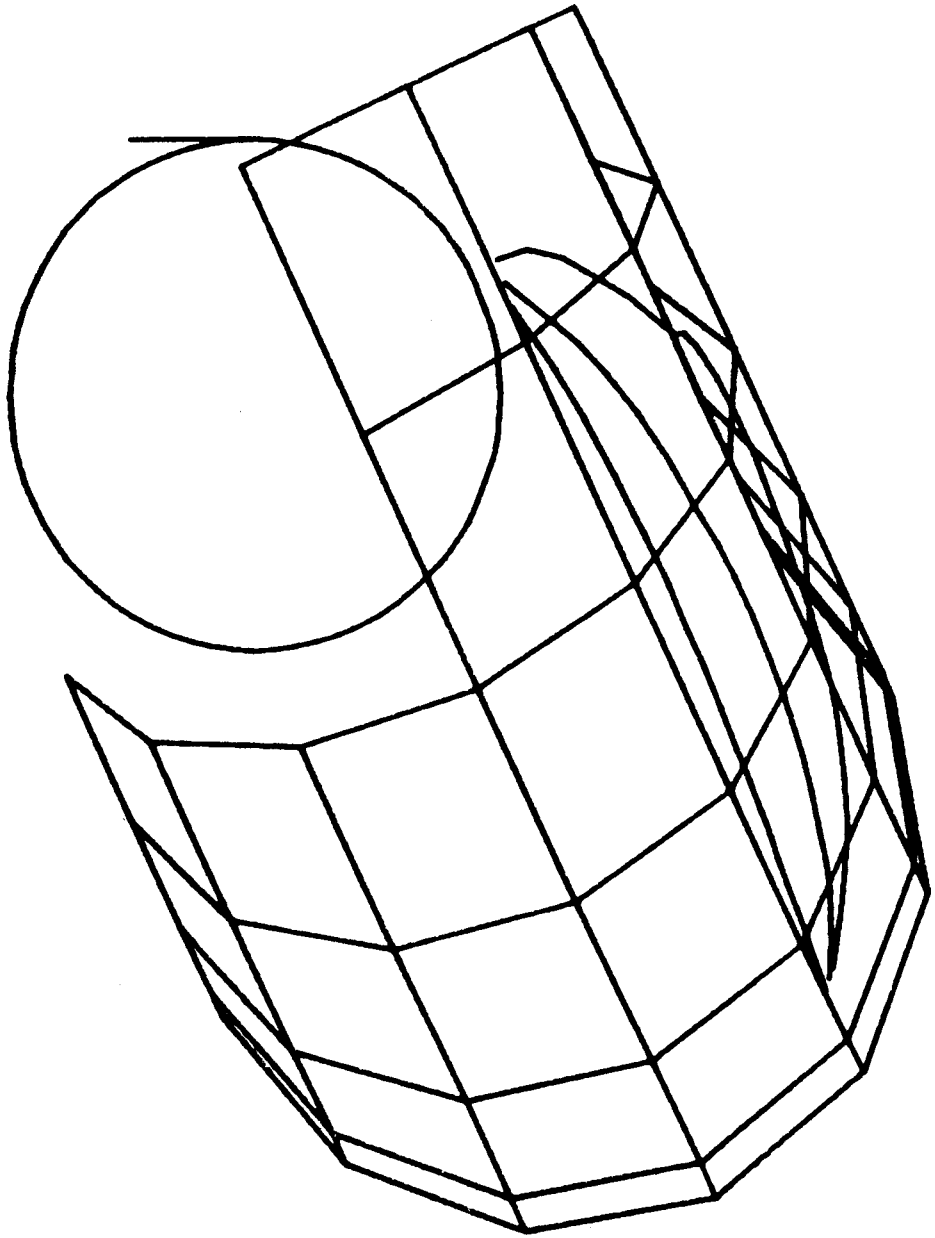
STREAM	TIME	C.G. ANGLE	C.G. X	C.G. Y	C.G. Z	C.G. PLATE	BOTTOM ANGLE	BOTTOM X	BOTTOM Y	BOTTOM PLATE	TOP ANGLE	TOP X	TOP Y	TOP PL
1	0.09	-15.8	12.2	5.2	2.8	2	-14.8	12.6	4.1	2	-16.9	11.9	6.3	2
2	0.12	-13.0	14.3	3.5	4.3	2	-22.4	14.5	1.3	6	-15.7	13.3	6.8	2
3	0.14	-22.0	15.8	2.4	5.8	6	-20.4	16.0	-1.1	6	-13.9	15.0	6.4	2
4	0.16	-20.5	17.2	0.9	7.3	6	-18.7	17.5	-3.8	6	-22.5	16.9	5.3	6
5	0.18	-19.0	18.7	-0.9	8.9	6	-17.1	19.1	-6.8	6	-21.3	18.3	4.5	6
6	0.20	-17.7	20.1	-3.1	10.4	6	-26.1	20.1	-8.9	13	-19.9	19.7	3.3	6
7	0.23	-26.4	21.5	-5.4	11.9	13	-25.4	20.9	-10.8	13	-10.4	20.5	2.8	7
8	0.24	-25.7	22.4	-6.9	13.4	13	-24.7	21.7	-12.7	13	-10.2	20.9	2.8	7
9	0.25	-25.0	23.3	-8.6	15.0	13	-24.0	22.6	-14.6	13	-9.5	21.5	2.2	7
10	0.26	-24.4	24.1	-10.3	16.5	13	-23.4	23.4	-16.6	13	-8.4	22.4	0.9	7
11	0.28	-23.8	24.9	-12.3	18.0	13	-31.5	24.0	-18.1	20	-10.5	23.4	-1.1	14
12	0.29	-31.7	25.7	-14.2	19.5	20	-31.1	24.4	-19.3	20	-9.4	24.3	-3.2	14
13	0.30	-31.3	26.1	-15.5	21.0	20	-30.8	24.9	-20.6	20	-8.1	25.5	-6.1	14
14	0.31	-31.0	26.5	-16.9	22.6	20	-33.5	25.3	-21.8	20	-9.3	27.0	-10.3	21

16	0.32	-30.3	27.2	-20.0	25.6	20	-29.9	26.2	-24.3	20	-30.7	28.3	-15.8	20
17	0.33	-30.0	27.6	-21.7	27.1	20	-29.6	26.6	-25.5	20	-30.3	28.5	-17.9	20
18	0.34	-36.0	27.8	-23.4	28.7	27	-35.7	26.9	-26.2	27	-29.9	28.7	-20.3	20
19	0.35	-35.8	27.8	-24.7	30.2	27	-35.6	27.1	-26.9	27	-35.9	28.6	-22.5	27
20	0.35	-35.6	27.8	-26.1	31.7	27	-35.5	27.3	-27.6	27	-35.7	28.3	-24.6	27
21	0.36	-35.3	27.7	-27.7	33.2	27	-35.3	27.6	-28.2	27	-35.4	27.9	-27.2	27

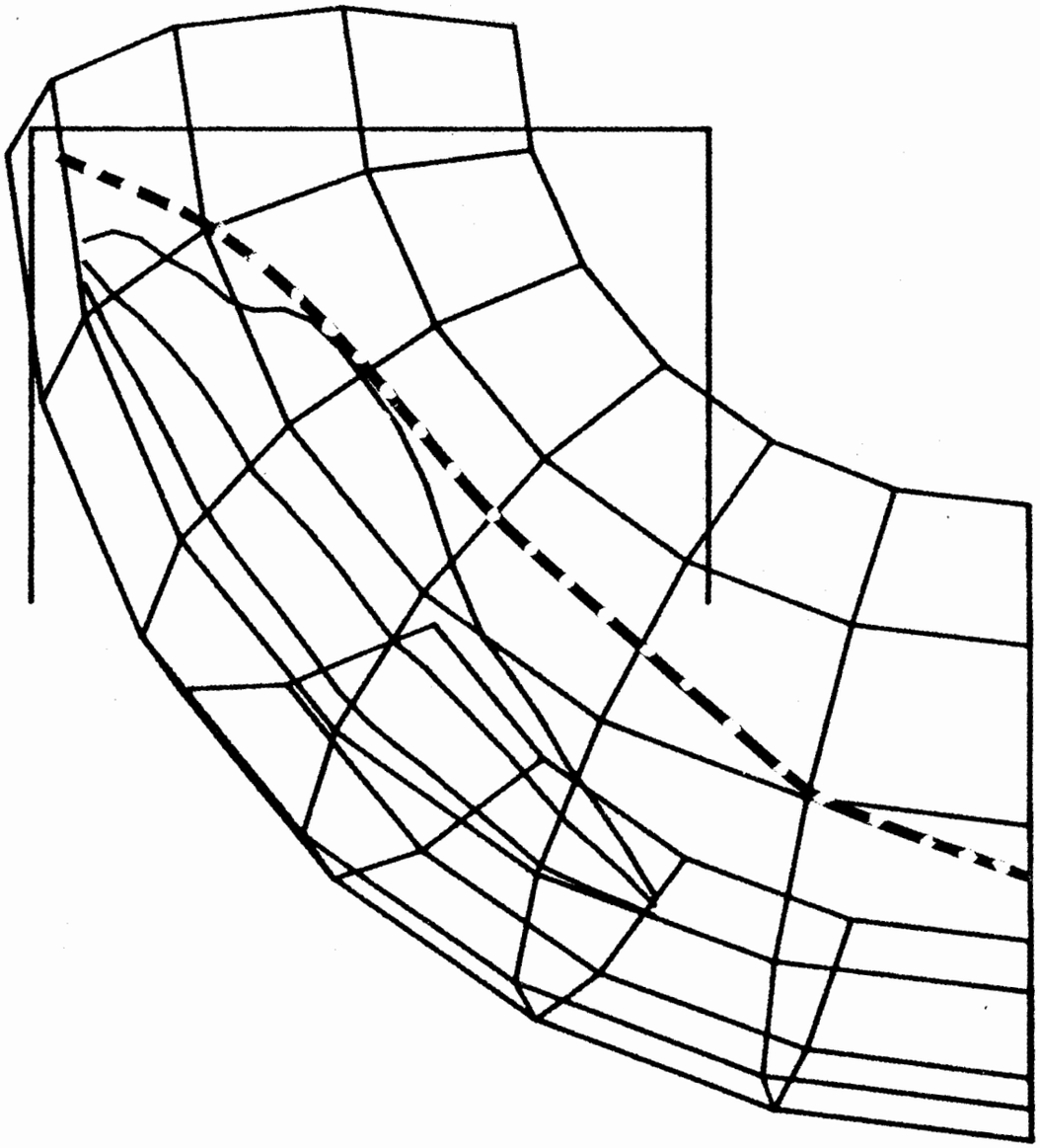
3-D VIEW RUN 627 ELEMENTS 1,99999



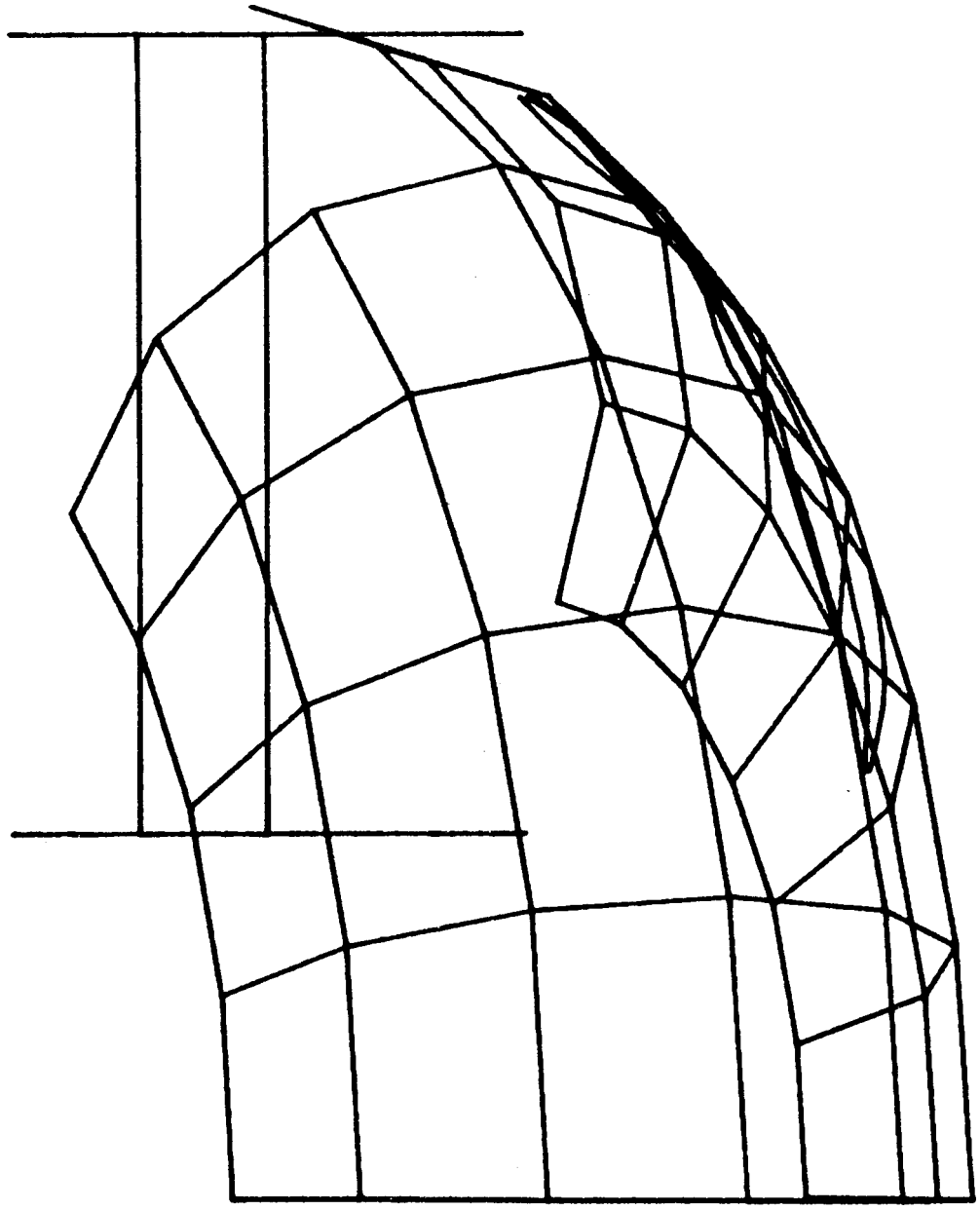
FRONT VIEW RUN 627 ELEMENTS 1,99999



SIDE VIEW RUN 627 ELEMENTS 1,99999



TOP VIEW RUN 627 ELEMENTS 1,99999



450 FPM TRAJECTORY CASE

RUNS 746, 706

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BEGIN INDEPENDENT RUN OF COAL CHUTE DESIGNER RUN NUMBER746 DATE 27 APR 77 18 55 12

..... INDEPENDENT VARIABLES FOR THIS RUN .....

A. INPUT DATA

FEED CONVEYOR DATA

BELT SPEED V , IPS. 90.00

PULLEY RADIUS R, IN. 12.00

BELT WIDTH BELTWD IN. 36.00

BELT EDGE DISTANCE BMAR IN. 2.00

TROUGH ANGLE IDLANG DEG. 35.00

SURCHARGE ANGLE SURANG DEG. 25.00

INCLINATION ANGLE PHI DEG. 0.0

TORUS CHUTE DATA

MAJOR RADIUS RT1, IN 36.00

MINOR RADIUS RT2, IN. 18.00

ROTATIONS,DEG.
Z-AXIS-GAMMA 30.00
Y AXIS-YAW 5.00
X-AXIS-ZIH 15.00

EXTRA LENGTH DISP IN. 6.00

COORDINATESPRIOR TO ROTATION
XT IN. 12.00
YT IN. 16.00

FLAT PLATE DIVISION
MAJOR RADIUS-NT1 7
MINOR RADIUS-NT2 7

RUN OF MINE COAL DATA

DENSITY, GAMD LBS./CU. FT. 50.00

EFFECTIVE ANGLE OF FRICTION DELTF DEG. 50.00

DYNAMIC ANGLE OF WALL FRICTION PHIP DEG. 30.00

RUN CONVENTION CONSTANTS

FRICTION STEP DISTANCE - NOM,,EL1, IN. 1.00

NO OF STREAM SUBDIVISIONS SECT 21

========== SUMMARY OF KEY CALCULATED PARAMETERS AND FINAL PLATE COORDINATES ==========

B. OUTPUT DATA

PULLEY CONTACT DEP. ANGLE,DEG., 0.0
INITIAL LOAD HEIGHT,IN. 7.52
TORUS CUTOFF ANGLE,DEG. 105.33
MINIMUM Y COORDINATE -42.88

PLATE 1

9.082	16.738	23.404	16.060
8.504	12.943	1.311	-3.671
-1.929	0.987	2.655	-0.183

PLATE 2

16.738	22.125	27.939	23.404
12.943	16.025	5.878	1.311
0.987	7.937	9.392	2.655

PLATE 3

22.125	23.799	28.450	27.939
16.025	16.924	8.807	5.878
7.937	17.058	18.223	9.392

PLATE 4

23.799	21.312	24.801	28.450
16.924	15.399	9.311	8.807
17.058	25.907	26.781	18.223

PLATE 5

-2.608	1.042	6.318	1.613
-9.283	-9.788	-19.346	-16.930
16.189	7.631	12.067	19.738

PLATE 6

1.042	7.875	13.924	6.318
-9.788	-7.734	-18.691	-19.346
7.631	1.638	6.725	12.067

PLATE 7

7.875	16.060	22.391	13.924
-7.734	-3.671	-15.141	-18.691
1.638	-0.183	5.141	6.725

PLATE 8

16.060	23.404	29.453	22.391
-3.671	1.311	-9.646	-15.141
-0.183	2.655	7.742	5.141

PLATE 9

23.404	27.939	33.215	29.453
1.311	5.878	-3.680	-9.646
2.655	9.392	13.829	7.742

PLATE 10

27.939	28.450	32.671	33.215
5.878	8.807	1.160	-3.680
9.392	18.223	21.772	13.829

PLATE 11

28.450	24.801	27.966	32.671
8.807	9.311	3.577	1.160
18.223	26.781	29.443	21.772

PLATE 12

1.613	6.318	10.695	5.114
-16.930	-19.346	-27.660	-23.581
19.738	12.067	19.181	25.429

PLATE 13

6.318	13.924	18.941	10.695
-19.346	-18.691	-28.222	-27.660
12.067	6.725	14.880	19.181

PLATE 14

13.924	22.391	27.643	18.941
-18.691	-15.141	-25.117	-28.222
6.725	5.141	13.678	14.880

22.391	29.453	34.470	27.643
-15.141	-9.646	-19.177	-25.117
5.141	7.742	15.897	13.678

PLATE 16

29.453	33.215	37.592	34.470
-9.646	-3.680	-11.993	-19.177
7.742	13.829	20.943	15.897

PLATE 17

33.215	32.671	36.173	37.592
-3.680	1.160	-5.491	-11.993
13.829	21.772	27.463	20.943

PLATE 18

32.671	27.966	30.592	36.173
1.160	3.577	-1.411	-5.491
21.772	29.443	33.711	27.463

PLATE 19

5.114	10.695	13.871	7.655
-23.581	-27.660	-34.159	-28.780
25.429	19.181	28.484	32.871

PLATE 20

10.695	18.941	22.582	13.871
-27.660	-28.222	-35.673	-34.159
19.181	14.880	25.545	28.484

PLATE 21

18.941	27.643	31.455	22.582
-28.222	-25.117	-32.917	-35.673
14.880	13.678	24.841	25.545

PLATE 22

27.643	34.470	38.111	31.455
-25.117	-19.177	-26.628	-32.917
13.678	15.897	26.562	24.841

PLATE 23

-19.177 15.897	-11.993 20.943	-18.493 30.246	-26.628 26.562

PLATE 24

37.592 -11.993 20.943	36.173 -5.491 27.463	38.714 -10.690 34.906	40.768 -18.493 30.246

PLATE 25

36.173 -5.491 27.463	30.592 -1.411 33.711	32.498 -5.311 39.293	38.714 -10.690 34.906

PLATE 26

7.655 -28.780 32.871	13.871 -34.159 28.484	15.629 -38.398 39.338	9.062 -32.172 41.555

PLATE 27

13.871 -34.159 28.484	22.582 -35.673 25.545	24.598 -40.533 37.988	15.629 -38.398 39.338

PLATE 28

22.582 -35.673 25.545	31.455 -32.917 24.841	33.565 -38.004 37.866	24.598 -40.533 37.988

PLATE 29

31.455 -32.917 24.841	38.111 -26.628 26.562	40.127 -31.488 39.005	33.565 -38.004 37.866

"R"

PLATE 30

38.111 -26.628 26.562	40.768 -18.493 30.246	42.527 -22.732 41.100	40.127 -31.488 39.005

PLATE 31

40.768 -18.493	38.714 -10.690	40.120 -14.082	42.527 -22.732

PLATE 32

38.714	32.498	33.553	40.120
-10.690	-5.311	-7.855	-14.082
34.906	39.293	45.805	43.589

PLATE 33

9.062	15.629	15.849	9.238
-32.172	-38.398	-40.087	-33.522
41.555	39.338	50.999	50.884

PLATE 34

15.629	24.598	24.850	15.849
-38.398	-40.533	-42.469	-40.087
39.338	37.988	51.357	50.999

PLATE 35

24.598	33.565	33.829	24.850
-40.533	-38.004	-40.030	-42.469
37.988	37.866	51.860	51.357

PLATE 36

33.565	40.127	40.379	33.829
-38.004	-31.488	-33.424	-40.030
37.866	39.005	52.374	51.860

PLATE 37

40.127	42.527	42.746	40.379
-31.488	-22.732	-24.421	-33.424
39.005	41.100	52.761	52.374

PLATE 38

42.527	40.120	40.296	42.746
-22.732	-14.082	-15.432	-24.421
41.100	43.589	52.918	52.761

PLATE 39

40.120	33.553	33.685	40.296
-14.082	-7.855	-8.868	-15.432
43.589	45.805	52.802	52.918

PLATE 40

9.238	15.849	15.698	9.087
-33.522	-40.087	-40.501	-33.936
50.884	50.999	56.983	56.867

PLATE 41

15.849	24.850	24.699	15.698
-40.087	-42.469	-42.883	-40.501
50.999	51.357	57.340	56.983

PLATE 42

24.850	33.829	33.678	24.699
-42.469	-40.030	-40.444	-42.883
51.357	51.860	57.843	57.340

PLATE 43

33.829	40.379	40.228	33.678
-40.030	-33.424	-33.838	-40.444
51.860	52.374	58.357	57.843

PLATE 44

40.379	42.746	42.596	40.228
-33.424	-24.421	-24.834	-33.838
52.374	52.761	58.745	58.357

PLATE 45

42.746	40.296	40.145	42.596
-24.421	-15.432	-15.846	-24.834
52.761	52.918	58.901	58.745

PLATE 46

40.296	33.685	33.534	40.145
-15.432	-8.868	-9.282	-15.846
52.918	52.802	58.786	58.901

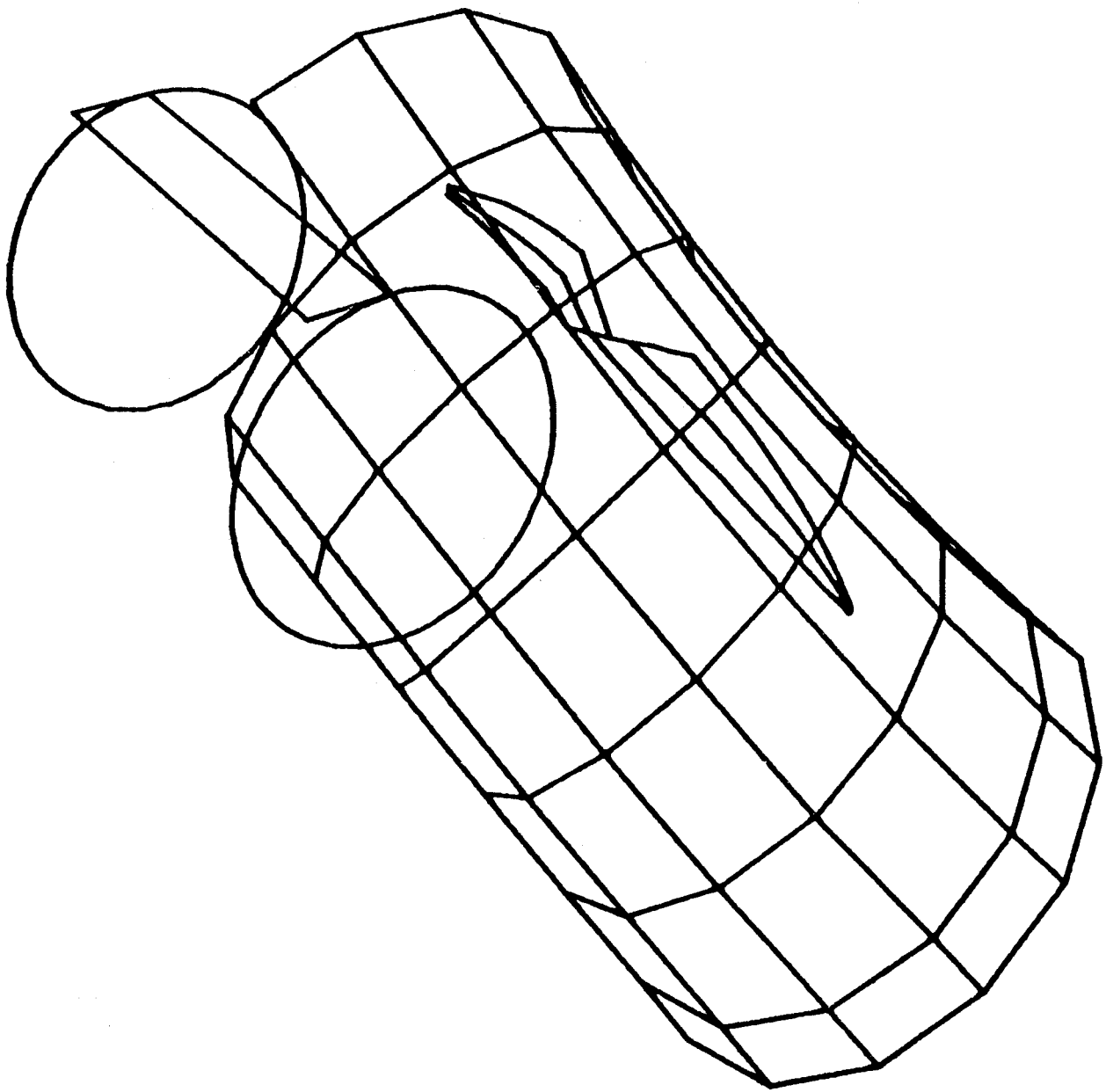
B. OUTPUT DATA

1. HIT DATA

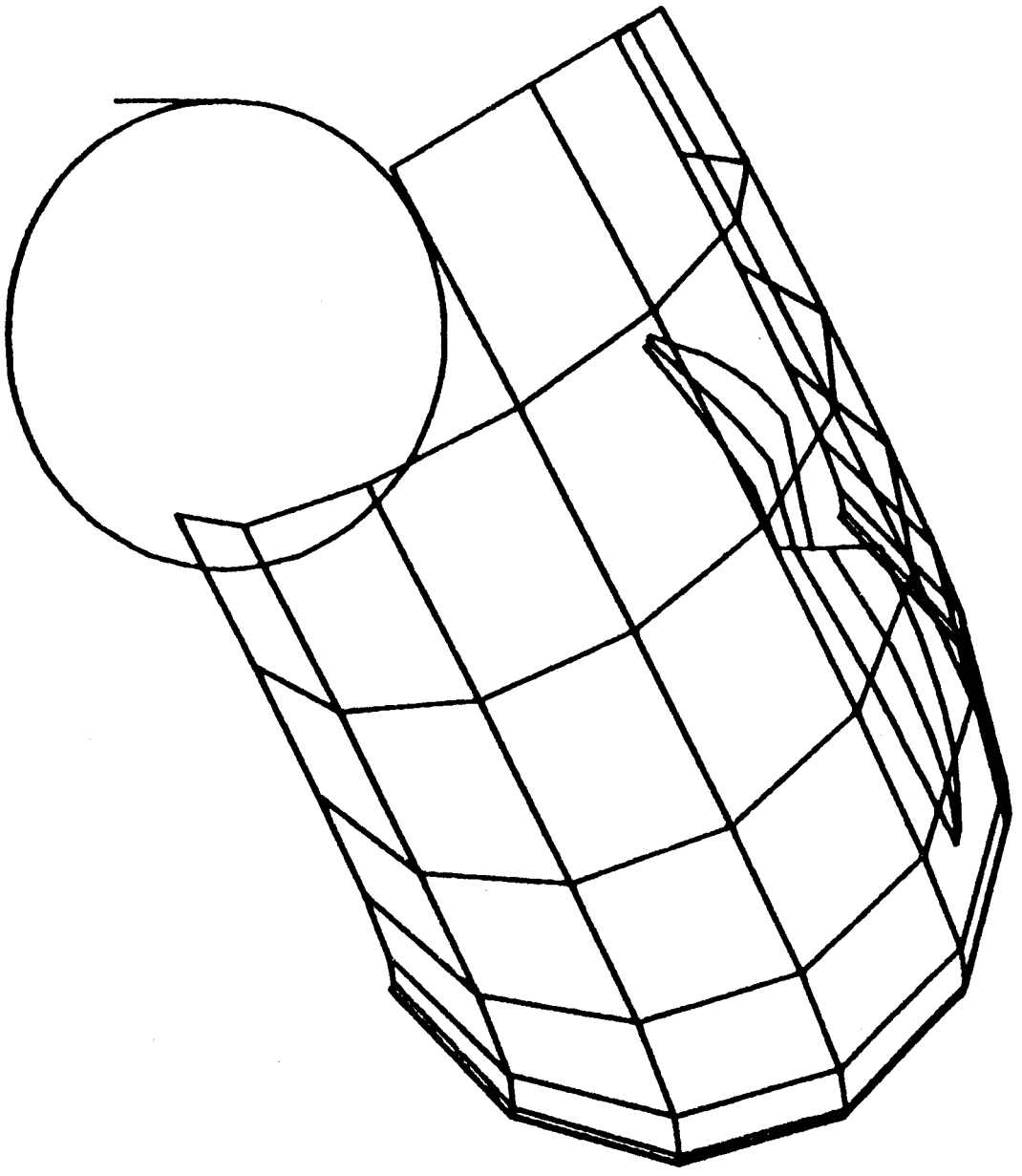
STREAM	TIME	C.G. ANGLE	C.G. X	C.G. Y	C.G. Z		BOTTOM ANGLE	BOTTOM X	BOTTOM Y	BOTTOM PLATE	TOP ANGLE	TOP X	TOP Y	TOP PL
1	0.26	-25.1	23.1	-0.2	2.8	8	-25.2	22.9	-0.6	8	-25.1	23.2	0.1	8
2	0.28	-23.4	25.3	-2.1	4.3	9	-24.5	25.1	-3.0	8	-23.6	25.1	-0.6	9
3	0.30	-22.2	26.8	-3.3	5.8	9	-23.9	27.1	-5.6	8	-22.6	26.3	-1.0	9
4	0.31	-21.1	28.2	-4.7	7.3	9	-20.6	28.8	-7.8	9	-21.5	27.7	-1.7	9
5	0.33	-19.9	29.8	-6.4	8.9	9	-22.1	30.1	-10.8	16	-20.4	29.1	-2.8	9
6	0.35	-15.7	31.1	-10.8	10.4	16	-31.0	31.1	-10.8	16	-19.4	30.6	-4.2	9
7	0.36	-19.1	32.0	-10.8	11.9	16	0.0**********				-11.3	32.0	-10.8	16
8	0.37	-24.9	33.0	-10.8	13.4	16	-0.0*********		0.0******		-12.9	33.0	-10.8	16
9	0.00**********		0.0**********				*********	1.1	0.0******		-15.5	33.9	-10.7	16
10	-0.00**********						**********		0.0	1	-19.8	34.8	-10.7	16
11**********		-0.0*********		4.0******			-35.0	35.5	-18.1	23	-28.1	35.8	-10.7	16
12	0.41	-34.4	36.5	-16.0	19.5	23	-34.7	36.1	-19.0	23	*********	0.0	0.0******	
13	0.41	-34.1	37.0	-17.0	21.0	23	-34.3	36.6	-19.9	23	-33.9	37.4	-14.0	23
14	0.42	-33.8	37.5	-18.0	22.6	23	-34.0	37.1	-20.9	23	-33.6	37.9	-15.2	23

15	0.42	-33.5	38.0	-19.2	24.1	23	-33.7	37.7	-21.8	23	-33.3	38.4	-16.5	23
16	0.43	-33.2	38.5	-20.4	25.6	23	-33.4	38.2	-22.8	23	-33.0	38.8	-17.9	23
17	0.43	-32.9	39.0	-21.6	27.1	23	-33.1	38.7	-23.8	23	-32.8	39.3	-19.4	23
18	0.44	-39.3	39.4	-22.8	28.7	30	-39.5	39.1	-24.5	30	-32.5	39.7	-21.1	23
19	0.44	-39.2	39.6	-23.7	30.2	30	-39.4	39.4	-25.0	30	-39.1	39.9	-22.4	30
20	0.44	-39.1	39.8	-24.6	31.7	30	-39.2	39.6	-25.5	30	-39.0	40.0	-23.8	30
21	0.44	-39.0	40.0	-25.7	33.2	30	-39.1	39.9	-26.0	30	-39.0	40.0	-25.4	30

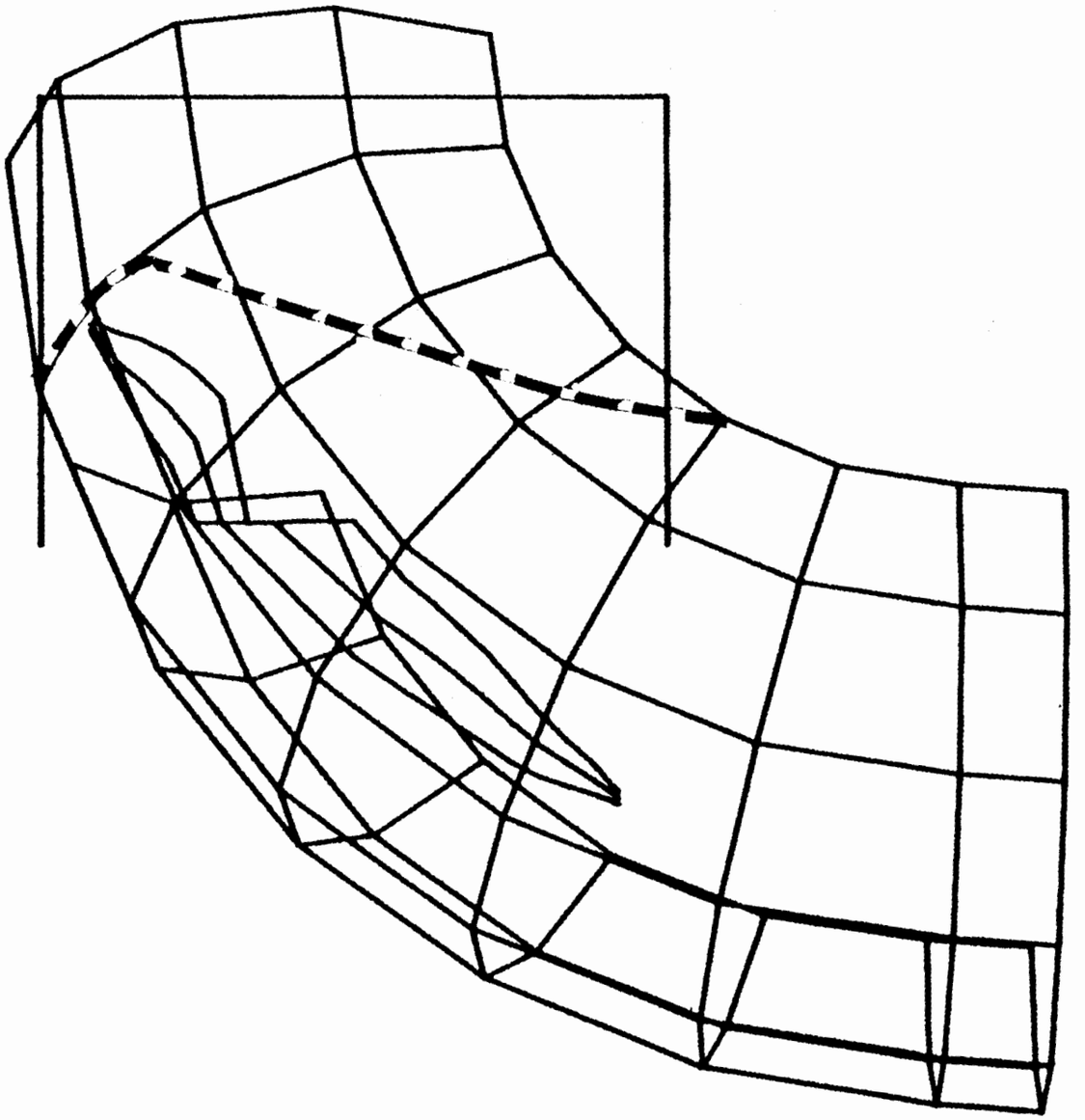
3-D VIEW RUN 746 ELEMENTS 1,99999



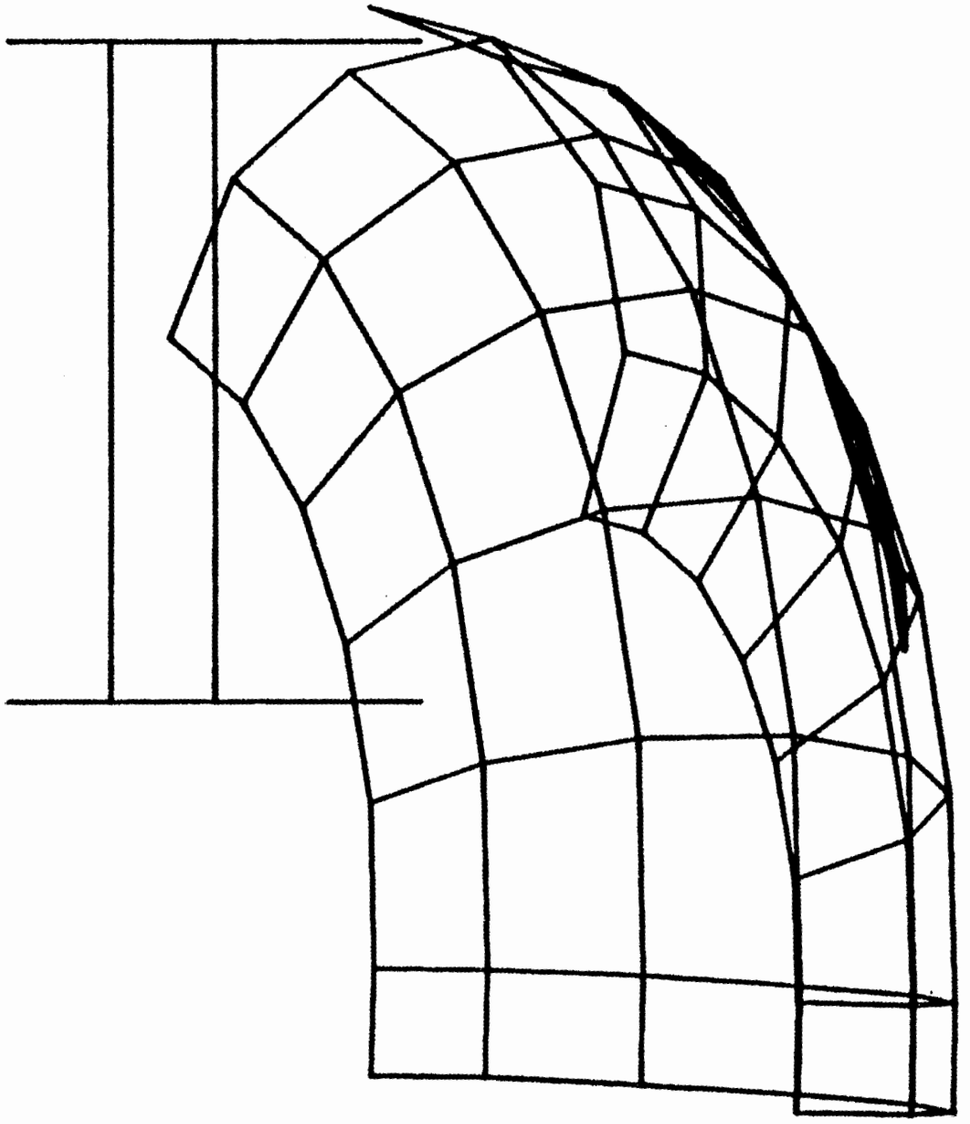
FRONT VIEW RUN 746 ELEMENTS 1,99999



SIDE VIEW RUN 746 ELEMENTS 1,99999



TOP VIEW RUN 746 ELEMENTS 1,99999



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BEGIN INDEPENDENT RUN OF COAL CHUTE DESIGNER RUN NUMBER706 DATE 27 APR 77 18 56 18

..... INDEPENDENT VARIABLES FOR THIS RUN .....

A. INPUT DATA

FEED CONVEYOR DATA

BELT SPEED V , IPS. 90.00

PULLEY RADIUS R, IN. 12.00

BELT WIDTH BELTWD IN. 36.00

BELT EDGE DISTANCE BMAR IN. 2.00

TROUGH ANGLE IDLANG DEG. 35.00

SURCHARGE ANGLE SURANG DEG. 25.00

INCLINATION ANGLE PHI DEG. 0.0

TORUS CHUTE DATA

MAJOR RADIUS RT1, IN 36.00

MINOR RADIUS RT2, IN. 18.00

ROTATIONS,DEG.
Z-AXIS-GAMMA 20.00
Y AXIS-YAW 5.00
X-AXIS-ZIH 20.00

EXTRA LENGTH DISP IN. 6.00

COORDINATESPRIOR TO ROTATION
XT IN. 12.00
YT IN. 16.00

FLAT PLATE DIVISION
MAJOR RADIUS-NT1 7
MINOR RADIUS-NT2 7

RUN OF MINE COAL DATA

DENSITY, GAMD LBS./CU. FT. 50.00

EFFECTIVE ANGLE OF FRICTION DELTF DEG. 50.00

DYNAMIC ANGLE OF WALL FRICTION PHIP DEG. 30.00

RUN CONVENTION CONSTANTS

FRICTION STEP DISTANCE - NOM.,EL1, IN. 1.00

NO OF STREAM SUBDIVISIONS SECT 21

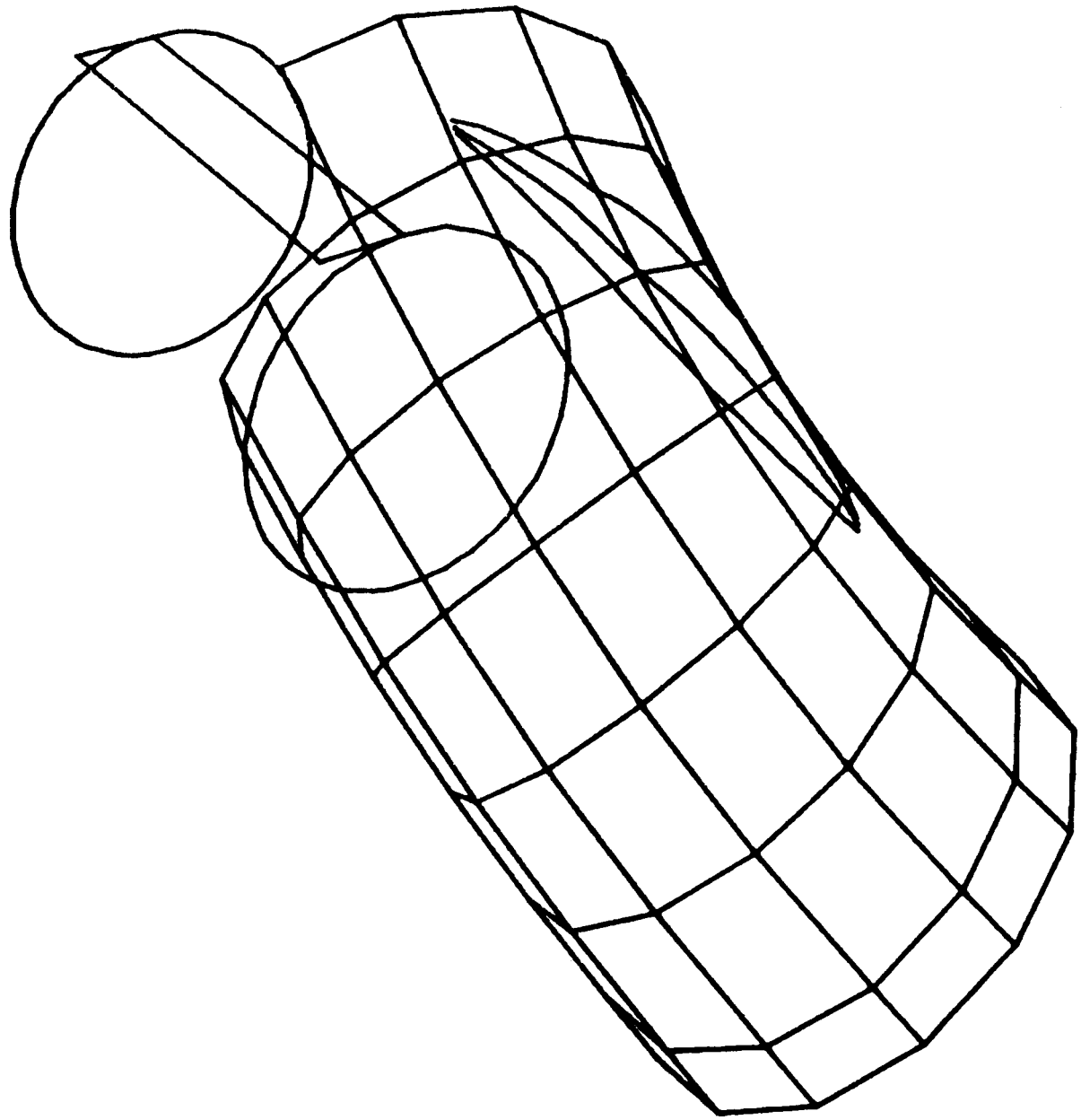
B. OUTPUT DATA

1. HIT DATA

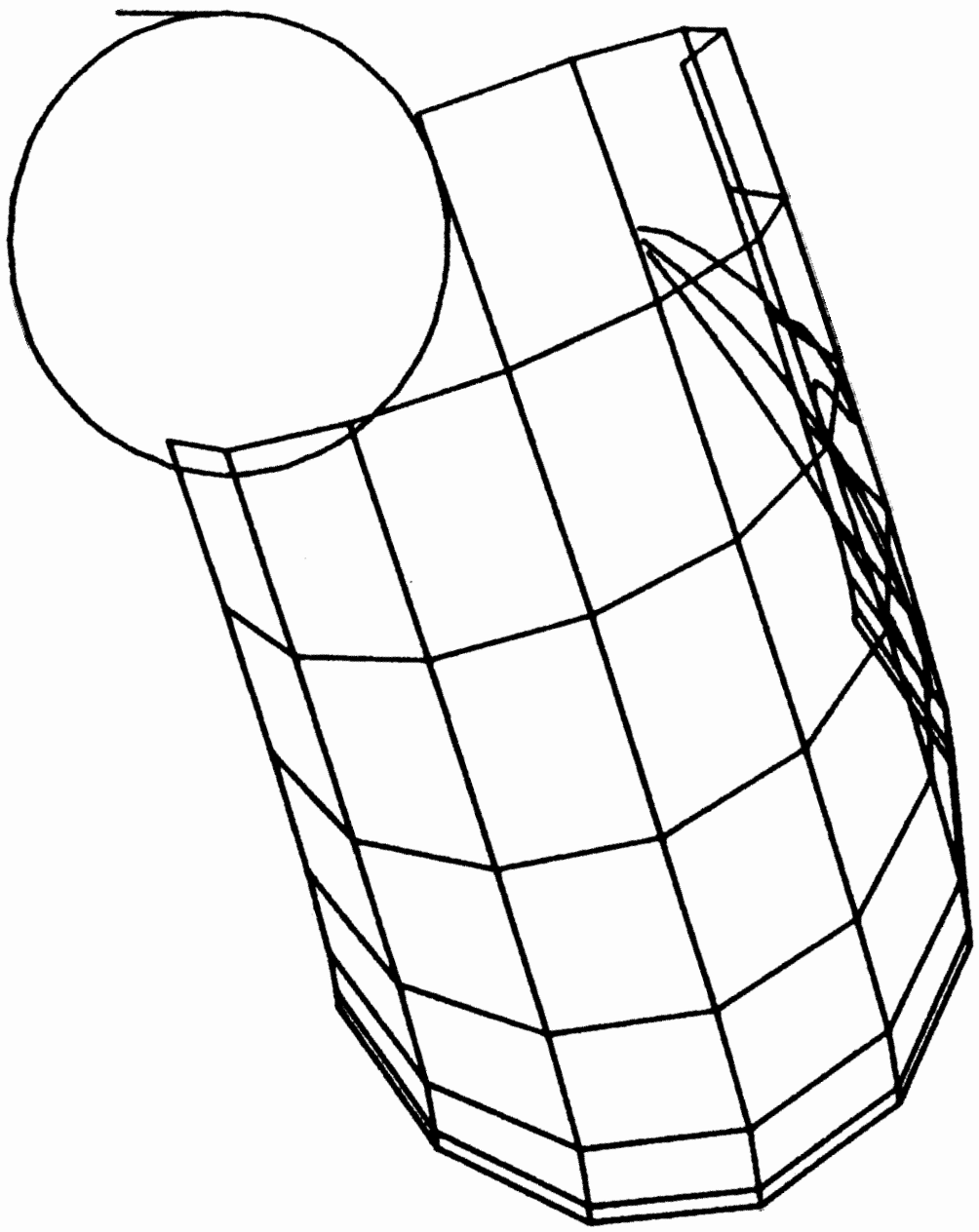
STREAM	TIME	C.G. ANGLE	C.G. X	C.G. Y	C.G. Z		BOTTOM ANGLE	BOTTOM X	BOTTOM Y	BOTTOM PLATE	TOP ANGLE	TOP X	TOP Y	TOP PL
1	0.25	-18.3	22.8	0.1	2.8	2	-18.1	23.0	-0.6	2	-18.5	22.5	0.8	2
2	0.28	-16.5	24.8	-1.4	4.3	2	-26.8	25.1	-3.0	9	-17.1	24.1	0.5	2
3	0.29	-25.8	26.4	-2.8	5.8	9	-25.7	26.5	-4.8	9	-15.6	25.9	-0.5	2
4	0.31	-24.8	27.8	-4.1	7.3	9	-24.6	28.0	-6.7	9	-24.9	27.6	-1.6	9
5	0.32	-23.8	29.2	-5.6	8.9	9	-23.6	29.4	-8.7	9	-23.9	29.0	-2.6	9
6	0.34	-22.8	30.6	-7.4	10.4	9	-22.7	30.9	-10.8	9	-23.0	30.4	-3.9	9
7	0.36	-21.9	32.1	-9.3	11.9	9	-32.5	32.1	-12.5	16	-18.6	30.8	-4.1	10
8	0.37	-20.5	33.0	-10.4	13.4	17	-31.9	33.0	-13.9	16	-18.3	31.2	-4.3	10
9	0.37	-20.2	33.4	-10.9	15.0	17	-31.4	33.9	-15.3	16	-17.9	31.7	-4.7	10
10	0.38	-19.8	33.8	-11.5	16.5	17	-30.9	34.7	-16.8	16	-17.4	32.2	-5.3	10
11	0.38	-19.5	34.2	-12.2	18.0	17	-18.5	35.5	-18.1	17	-17.0	32.8	-6.1	10
12	0.39	-19.1	34.7	-13.0	19.5	17	-18.2	36.0	-18.9	17	-20.1	33.4	-7.2	17
13	0.39	-18.8	35.2	-13.8	21.0	17	-21.1	36.3	-19.5	24	-19.7	33.9	-8.1	17
14	0.40	-18.4	35.7	-14.8	22.6	17	-20.9	36.6	-20.0	24	-19.3	34.5	-9.3	17

15	0.40	-21.2	36.2	-15.9	24.1	24	-20.7	36.9	-20.5	24	-3.4	34.1	-9.1	18
16	0.41	-20.9	36.5	-16.8	25.6	24	-20.5	37.2	-21.0	24	-4.5	32.7	-7.4	18
17	0.41	-20.7	36.9	-17.8	27.1	24	-20.3	37.5	-21.6	24	-5.0	32.1	-7.1	18
18	0.41	-20.4	37.3	-18.9	28.7	24	-20.1	37.8	-22.1	24	-5.1	32.0	-7.8	18
19	0.42	-20.1	37.7	-20.2	30.2	24	-19.9	38.1	-22.7	24	-4.6	32.5	-9.7	18
20	0.42	-22.2	38.2	-21.6	31.7	31	-22.1	38.4	-23.1	31	-20.0	37.9	-19.9	24
21	0.43	-22.0	38.5	-22.8	33.2	31	-22.0	38.5	-23.4	31	-22.1	38.4	-22.3	31

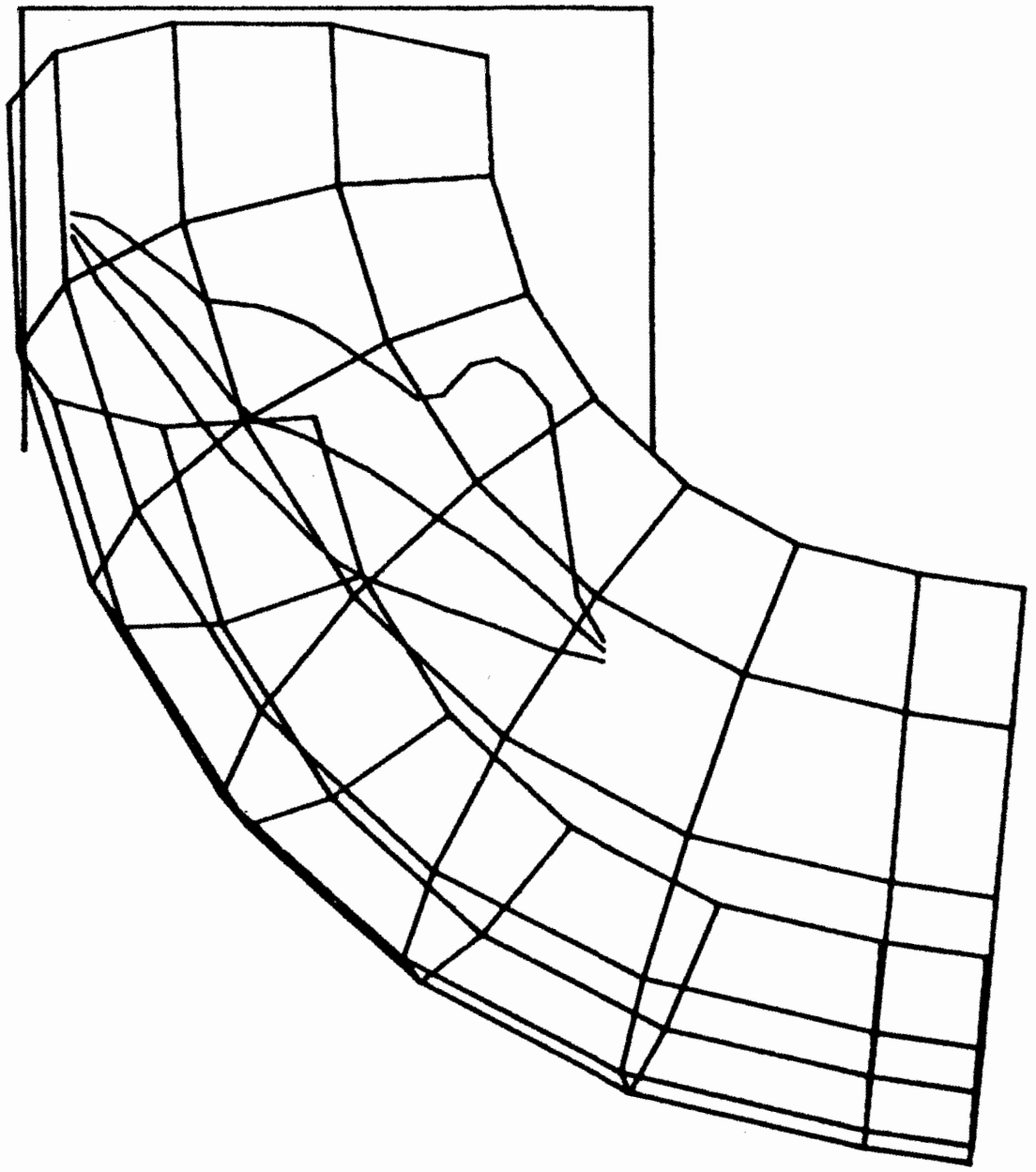
3-D VIEW RUN 706 ELEMENTS 1,99999



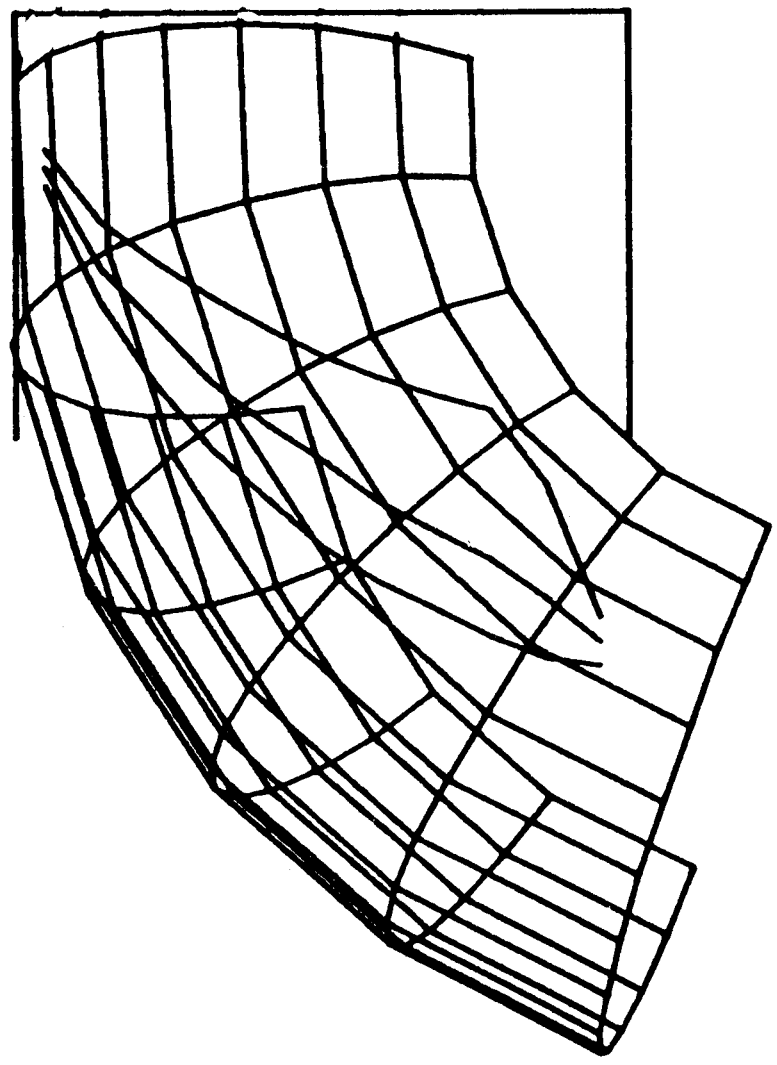
FRONT VIEW RUN 706 ELEMENTS 1,99999



SIDE VIEW RUN 706 ELEMENTS 1,99999

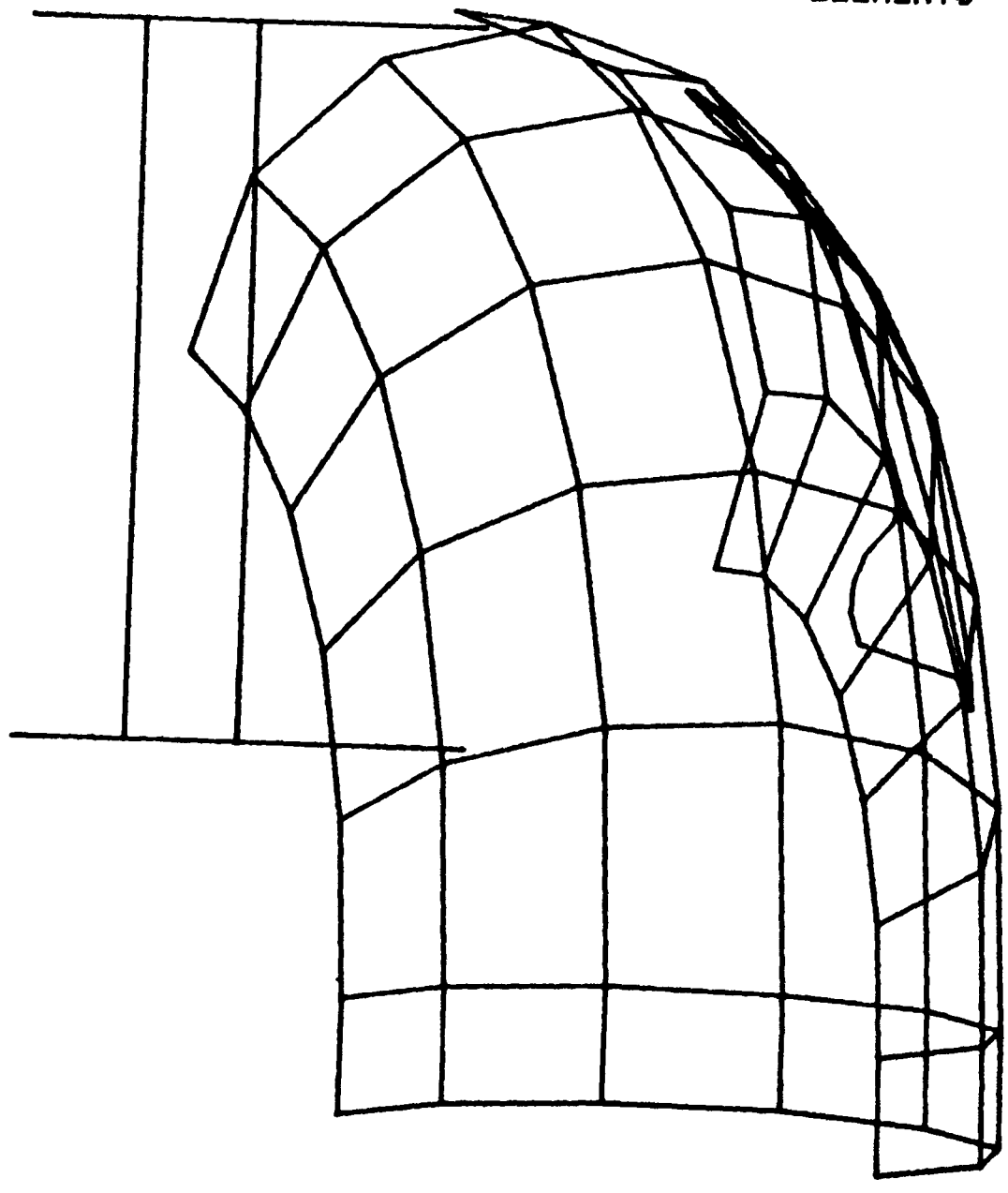


SIDE VIEW TEKPLOT NASDEK1 348,12,16 ELEMENTS 1,99999



TOP VIEW

RUN 706 ELEMENTS 1,99999



600 FPM TRAJECTORY CASE

RUNS 846, 806

BEGIN INDEPENDENT RUN OF COAL CHUTE DESIGNER RUN NUMBER846 DATE 27 APR 77 18 57 23

..... INDEPENDENT VARIABLES FOR THIS RUN .....

A. INPUT DATA

FEED CONVEYOR DATA

BELT SPEED V , IPS. 120.00

PULLEY RADIUS R, IN. 12.00

BELT WIDTH BELTWD IN. 36.00

BELT EDGE DISTANCE BMAR IN. 2.00

TROUGH ANGLE IDLANG DEG. 35.00

SURCHARGE ANGLE SURANG DEG. 25.00

INCLINATION ANGLE PHI DEG. 0.0

TORUS CHUTE DATA

MAJOR RADIUS RT1, IN 36.00

MINOR RADIUS RT2, IN. 18.00

ROTATIONS,DEG.
Z-AXIS-GAMMA 30.00
Y AXIS-YAW 10.00
X-AXIS-ZIH 20.00

EXTRA LENGTH DISP IN. 6.00

COORDINATESPRIOR TO ROTATION
XT IN. 15.00
YT IN. 17.00

FLAT PLATE DIVISION
MAJOR RADIUS-NT1 7
MINOR RADIUS-NT2 7

RUN OF MINE COAL DATA

DENSITY, GAMD LBS./CU. FT. 50.00

EFFECTIVE ANGLE OF FRICTION DELTF DEG. 50.00

DYNAMIC ANGLE OF WALL FRICTION PHIP DEG. 30.00

RUN CONVENTION CONSTANTS

FRICTION STEP DISTANCE - NOM.,EL1, IN. 1.00

NO OF STREAM SUBDIVISIONS SECT 21

========== SUMMARY OF KEY CALCULATED PARAMETERS AND FINAL PLATE COORDINATES ==========

B. OUTPUT DATA

PULLEY CONTACT DEP. ANGLE,DEG., 0.0
INITIAL LOAD HEIGHT,IN. 7.52
TORUS CUTOFF ANGLE,DEG. 105.33
MINIMUM Y COORDINATE -44.08

PLATE 1

10.521	18.293	25.336	17.893
11.717	16.115	4.587	-0.350
-2.718	-0.059	0.027	-2.628

PLATE 2

18.293	24.174	30.318	25.336
16.115	18.748	8.692	4.587
-0.059	6.671	6.746	0.027

PLATE 3

24.174	26.590	31.505	30.318
18.748	18.910	10.865	8.692
6.671	15.669	15.729	6.746

PLATE 4

26.590	24.892	28.578	31.505
18.910	16.557	10.523	10.865
15.669	24.523	24.568	15.729

PLATE 5

0.801	3.728	9.574	5.478
-7.901	-7.560	-17.302	-15.695
14.660	5.820	8.951	17.164

PLATE 6

3.728	9.984	16.686	9.574
-7.560	-4.796	-15.965	-17.302
5.820	-0.507	3.082	8.951

PLATE 7

9.984	17.893	24.908	16.686
-4.796	-0.350	-12.041	-15.965
-0.507	-2.628	1.129	3.082

PLATE 8

17.893	25.336	32.037	24.908
-0.350	4.587	-6.582	-12.041
-2.628	0.027	3.616	1.129

PLATE 9

25.336	30.318	36.163	32.037
4.587	8.692	-1.050	-6.582
0.027	6.746	9.877	3.616

PLATE 10

30.318	31.505	36.181	36.163
8.692	10.865	3.071	-1.050
6.746	15.729	18.233	9.877

PLATE 11

31.505	28.578	32.085	36.181
10.865	10.523	4.678	3.071
15.729	24.568	26.446	18.233

PLATE 12

5.478	9.574	14.720	9.595
-15.695	-17.302	-26.062	-22.703
17.164	8.951	14.922	21.941

PLATE 13

9.574	16.686	22.585	14.720
-17.302	-15.965	-26.007	-26.062
8.951	3.082	9.927	14.922

PLATE 14

16.686	24.908	31.083	22.585
-15.965	-12.041	-22.552	-26.007
3.082	1.129	8.295	9.927

24.908	32.037	37.937	31.083
-12.041	-6.582	-16.624	-22.552
1.129	3.616	10.462	8.295

PLATE 16

32.037	36.163	41.310	37.937
-6.582	-1.050	-9.810	-16.624
3.616	9.877	15.848	10.462

PLATE 17

36.163	36.181	40.298	41.310
-1.050	3.071	-3.937	-9.810
9.877	18.233	23.010	15.848

PLATE 18

36.181	32.085	35.173	40.298
3.071	4.678	-0.578	-3.937
18.233	26.446	30.029	23.010

PLATE 19

9.595	14.720	18.814	12.870
-22.703	-26.062	-33.239	-28.445
21.941	14.922	23.325	28.663

PLATE 20

14.720	22.585	27.279	18.814
-26.062	-26.007	-34.235	-33.239
14.922	9.927	19.561	23.325

PLATE 21

22.585	31.083	35.996	27.279
-26.007	-22.552	-31.165	-34.235
9.927	8.295	18.378	19.561

PLATE 22

31.083	37.937	42.630	35.996
-22.552	-16.624	-24.852	-31.165
8.295	10.462	20.095	18.378

PLATE 23

[illegible]	41.310	[illegible]	[illegible]

10.462	15.848	24.251	20.095

PLATE 24

41.310	40.298	43.573	45.404
-9.810	-3.937	-9.678	-16.987
15.848	23.010	29.733	24.251

PLATE 25

40.298	35.173	37.629	43.573
-3.937	-0.578	-4.884	-9.678
23.010	30.029	35.071	29.733

PLATE 26

12.870	18.814	21.575	15.079
-28.445	-33.239	-38.341	-32.526
28.663	23.325	33.583	36.870

PLATE 27

18.814	27.279	30.444	21.575
-33.239	-34.235	-40.083	-38.341
23.325	19.561	31.320	33.583

PLATE 28

27.279	35.996	39.309	30.444
-34.235	-31.165	-37.287	-40.083
19.561	18.378	30.688	31.320

PLATE 29

35.996	42.630	45.795	39.309
-31.165	-24.852	-30.700	-37.287
18.378	20.095	31.855	30.688

PLATE 30

42.630	45.404	48.165	45.795
-24.852	-16.987	-22.089	-30.700
20.095	24.251	34.509	31.855

PLATE 31

45.404	43.573	49.782	48.165
-16.987	-9.678	-13.760	-22.089

PLATE 32

43.573	37.629	39.286	45.782
-9.678	-4.884	-7.945	-13.760
29.733	35.071	41.226	37.939

PLATE 33

15.079	21.575	22.814	16.070
-32.526	-38.341	-41.018	-34.667
36.870	33.583	44.993	45.997

PLATE 34

21.575	30.444	31.864	22.814
-38.341	-40.083	-43.152	-41.018
33.583	31.320	44.400	44.993

PLATE 35

30.444	39.309	40.796	31.864
-40.083	-37.287	-40.499	-43.152
31.320	30.688	44.379	44.400

PLATE 36

39.309	45.795	47.216	40.796
-37.287	-30.700	-33.769	-40.499
30.688	31.855	44.935	44.379

PLATE 37

45.795	48.165	49.403	47.216
-30.700	-22.089	-24.766	-33.769
31.855	34.509	45.919	44.935

PLATE 38

48.165	45.782	46.773	49.403
-22.089	-13.760	-15.901	-24.766
34.509	37.939	47.067	45.919

PLATE 39

45.782	39.286	40.029	46.773
-13.760	-7.945	-9.551	-15.901
37.939	41.226	48.071	47.067

PLATE 40

16.070	22.814	23.177	16.433
-34.667	-41.018	-41.948	-35.598
45.997	44.993	50.909	51.914

PLATE 41

22.814	31.864	32.227	23.177
-41.018	-43.152	-44.083	-41.948
44.993	44.400	50.317	50.909

PLATE 42

31.864	40.796	41.159	32.227
-43.152	-40.499	-41.430	-44.083
44.400	44.379	50.295	50.317

PLATE 43

40.796	47.216	47.578	41.159
-40.499	-33.769	-34.700	-41.430
44.379	44.935	50.851	50.295

PLATE 44

47.216	49.403	49.766	47.578
-33.769	-24.766	-25.696	-34.700
44.935	45.919	51.835	50.851

PLATE 45

49.403	46.773	47.136	49.766
-24.766	-15.901	-16.832	-25.696
45.919	47.067	52.983	51.835

PLATE 46

46.773	40.029	40.392	47.136
-15.901	-9.551	-10.482	-16.832
47.067	48.071	53.988	52.983

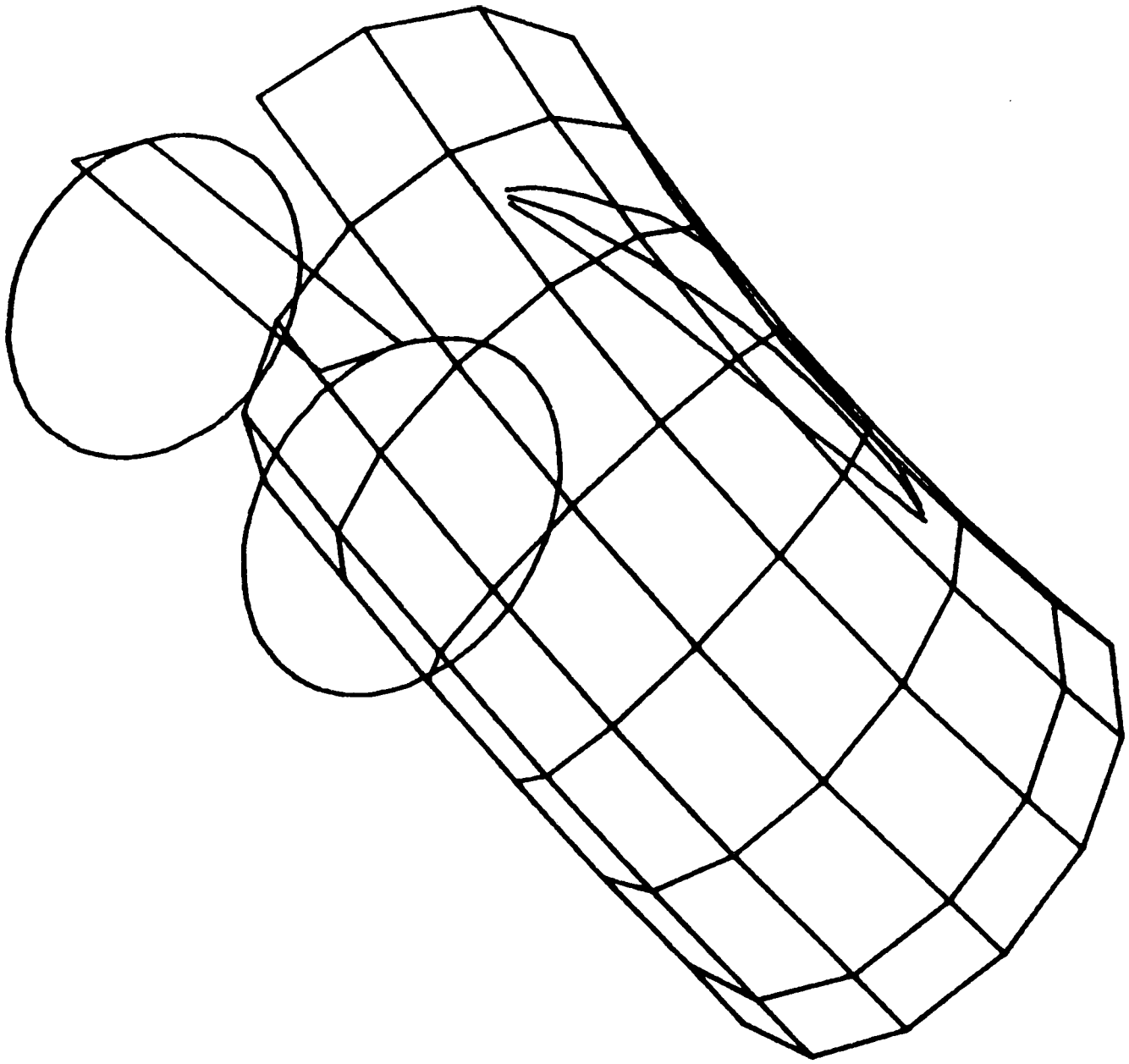
B. OUTPUT DATA

1. HIT DATA

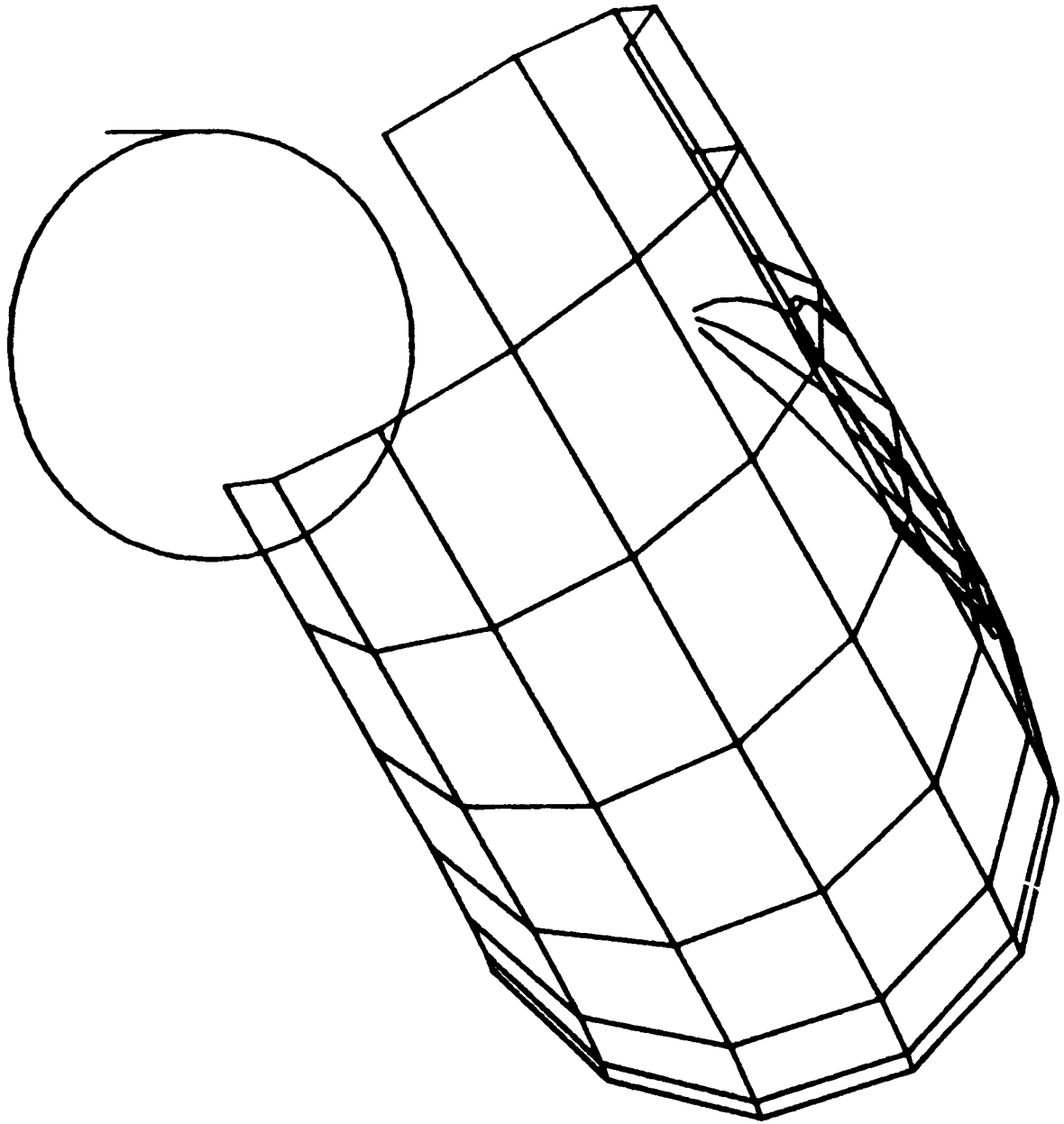
STREAM	TIME	C.G. ANGLE	C.G. X	C.G. Y	C.G. Z		BOTTOM ANGLE	BOTTOM X	BOTTOM Y	BOTTOM PLATE	TOP ANGLE	TOP X	TOP Y	TOP PL
1	0.24	-26.5	28.9	1.2	2.8	9	-26.4	29.1	0.7	9	-26.6	28.7	1.8	9
2	0.25	-25.5	30.4	0.7	4.3	9	-25.1	30.9	-0.8	9	-25.8	30.0	2.3	9
3	0.27	-24.4	32.1	-0.0	5.8	9	-24.0	32.8	-2.5	9	-24.9	31.4	2.4	9
4	0.28	-23.4	33.8	-1.0	7.3	9	-33.6	34.5	-4.0	16	-23.9	32.9	2.1	9
5	0.30	-33.0	35.5	-2.2	8.9	16	-32.8	35.8	-5.2	16	-23.0	34.5	1.5	9
6	0.31	-32.3	36.7	-3.0	10.4	16	-32.1	37.0	-6.4	16	-20.1	34.8	1.8	10
7	0.32	-21.3	37.9	-3.9	11.9	17	-31.4	38.2	-7.6	16	-19.9	35.0	2.1	10
8	0.32	-21.0	38.3	-4.2	13.4	17	-30.7	39.5	-8.9	16	-19.6	35.4	2.2	10
9	0.32	-20.6	38.8	-4.6	15.0	17	-30.1	40.7	-10.2	16	-19.2	35.9	2.0	10
10	0.33	-20.2	39.4	-5.1	16.5	17	-39.6	41.6	-11.2	23	-22.5	36.4	1.7	17
11	0.33	-19.8	40.0	-5.7	18.0	17	-39.1	42.3	-12.0	23	-22.0	36.9	1.2	17
12	0.34	-19.3	40.6	-6.4	19.5	17	-38.7	43.1	-12.9	23	-21.6	37.6	0.5	17
13	0.34	-22.2	41.1	-7.1	21.0	24	-20.5	43.5	-13.4	24	-6.7	36.9	1.0	18
14	0.35	-21.8	41.7	-7.8	22.6	24	-20.2	44.0	-14.0	24	-7.8	35.5	2.1	18

15	0.35	-21.4	42.2	-8.6	24.1	24	-19.9	44.4	-14.5	24	-8.5	34.7	2.4	18
16	0.36	-21.0	42.9	-9.6	25.6	24	-19.6	44.9	-15.1	24	-8.7	34.4	2.2	18
17	0.36	-20.5	43.5	-10.7	27.1	24	-21.9	45.2	-15.4	31	-8.6	34.5	1.4	18
18	0.37	-22.6	44.2	-11.9	28.7	31	-21.8	45.4	-15.7	31	-8.0	35.2	-0.1	18
19	0.37	-22.2	44.7	-13.1	30.2	31	-21.6	45.7	-16.0	31	-1.8	39.4	-5.3	25
20	0.38	-21.8	45.3	-14.4	31.7	31	-21.4	46.0	-16.4	31	-22.2	44.7	-12.4	31
21	0.38	-21.4	46.0	-16.0	33.2	31	-21.2	46.3	-16.7	31	-21.5	45.8	-15.2	31

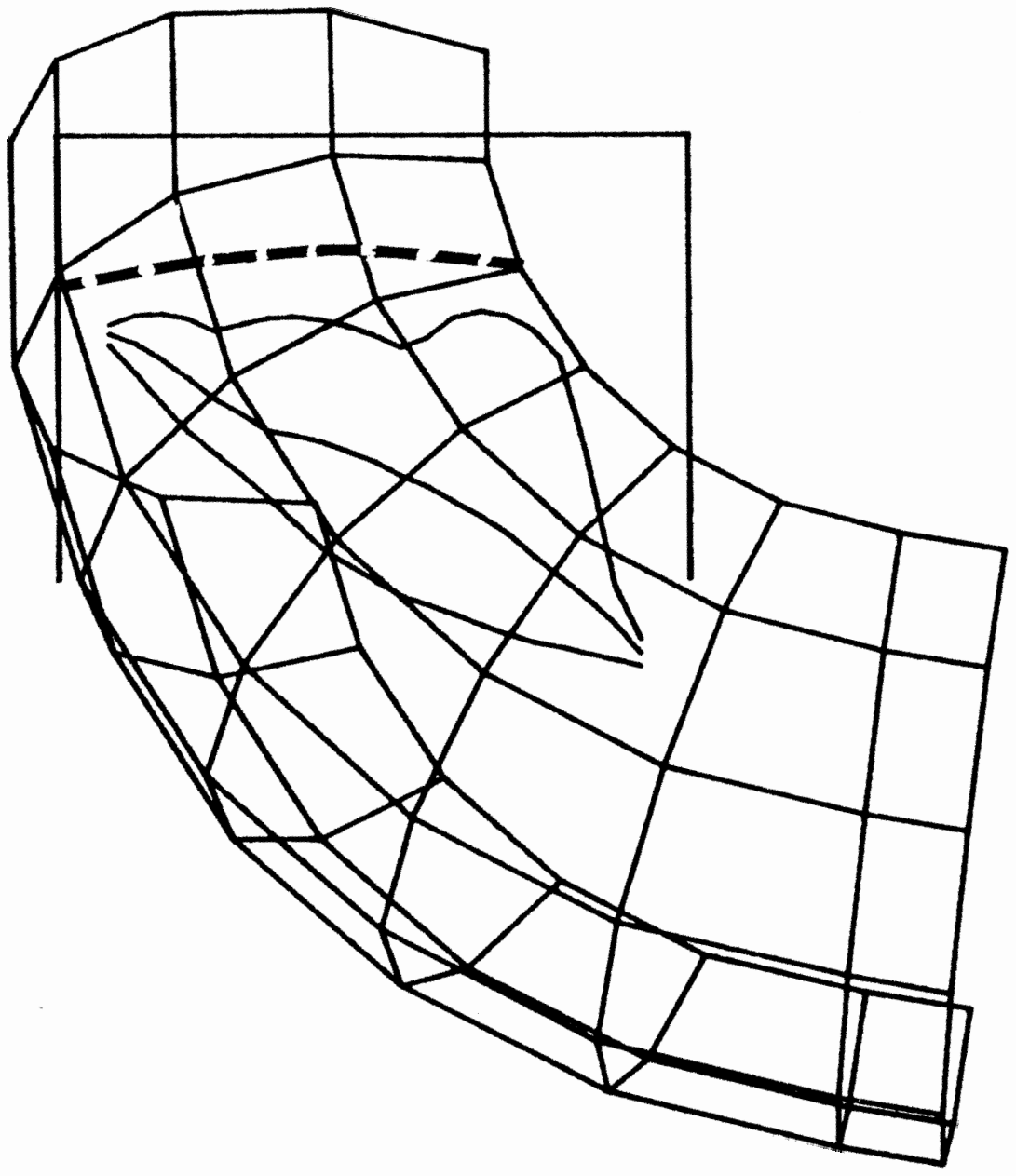
3-D VIEW RUN 846 ELEMENTS 1,99999

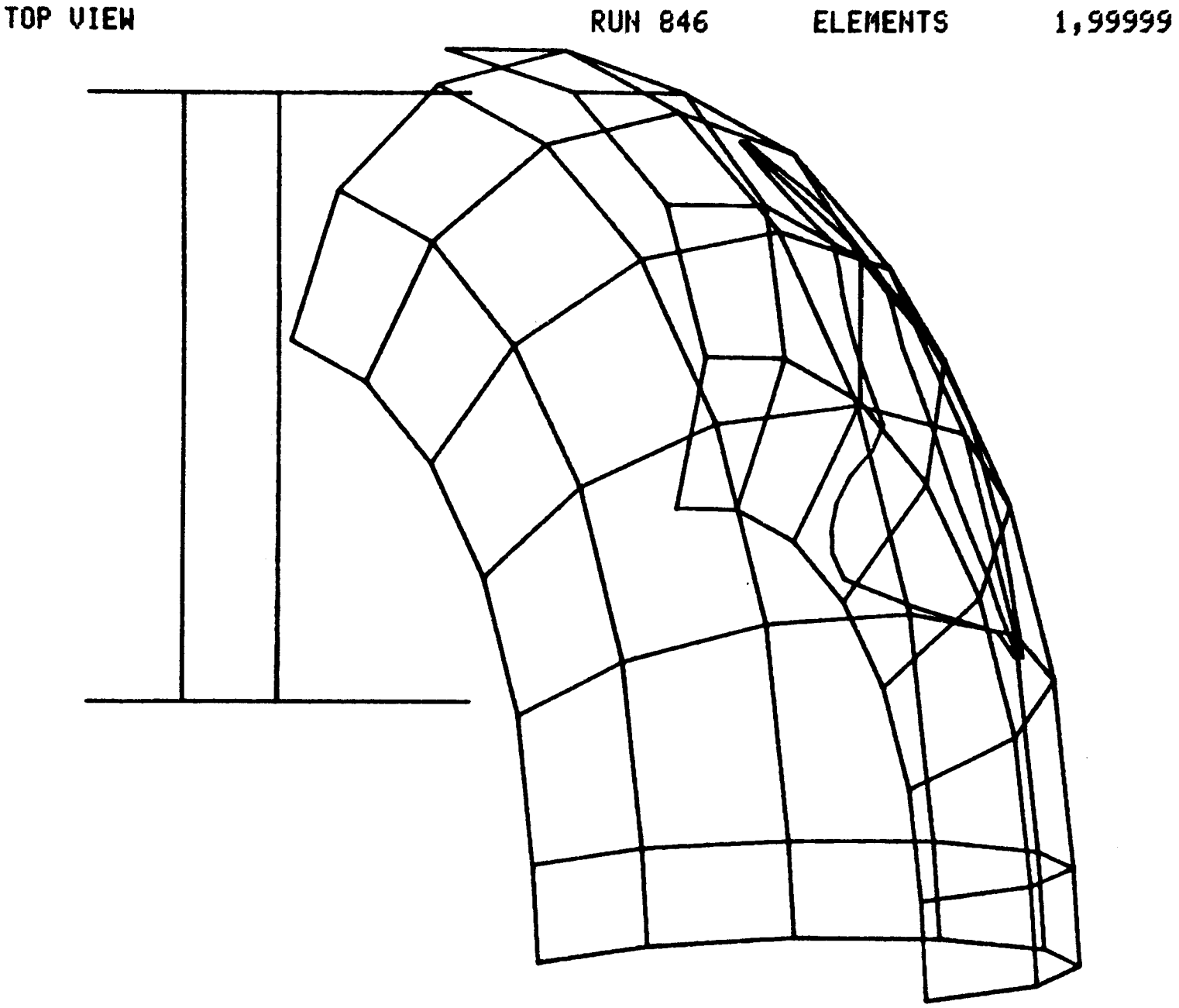


FRONT VIEW RUN 846 ELEMENTS 1,99999



SIDE VIEW RUN 846 ELEMENTS 1,99999




TOP VIEW
RUN 846
ELEMENTS
1,99999

****

BEGIN INDEPENDENT RUN OF COAL CHUTE DESIGNER RUN NUMBER806 DATE 27 APR 77 18 58 38

..... INDEPENDENT VARIABLES FOR THIS RUN .....

A. INPUT DATA

FEED CONVEYOR DATA

BELT SPEED V , IPS. 120.00

PULLEY RADIUS R, IN. 12.00

BELT WIDTH BELTWD IN. 36.00

BELT EDGE DISTANCE BNAR IN. 2.00

TROUGH ANGLE IDLANG DEG. 35.00

SURCHARGE ANGLE SURANG DEG. 25.00

INCLINATION ANGLE PHI DEG. 0.0

TORUS CHUTE DATA

MAJOR RADIUS RT1, IN 36.00

MINOR RADIUS RT2, IN. 18.00

ROTATIONS,DEG.
Z-AXIS-GAMMA 20.00
Y-AXIS-YAW 10.00
X-AXIS-ZIH 15.00

EXTRA LENGTH DISP IN. 6.00

COORDINATESPRIOR TO ROTATION
XT IN. 15.00
YT IN. 17.00

FLAT PLATE DIVISION
MAJOR RADIUS-NT1 7
MINOR RADIUS-NT2 7

RUN OF MINE COAL DATA

DENSITY, GAMD LBS./CU. FT. 50.00

EFFECTIVE ANGLE OF FRICTION DELTF DEG. 50.00

DYNAMIC ANGLE OF WALL FRICTION PHIP DEG. 30.00

RUN CONVENTION CONSTANTS

FRICTION STEP DISTANCE - NOM.,EL1, IN. 1.00

NO OF STREAM SUBDIVISIONS SECT 21

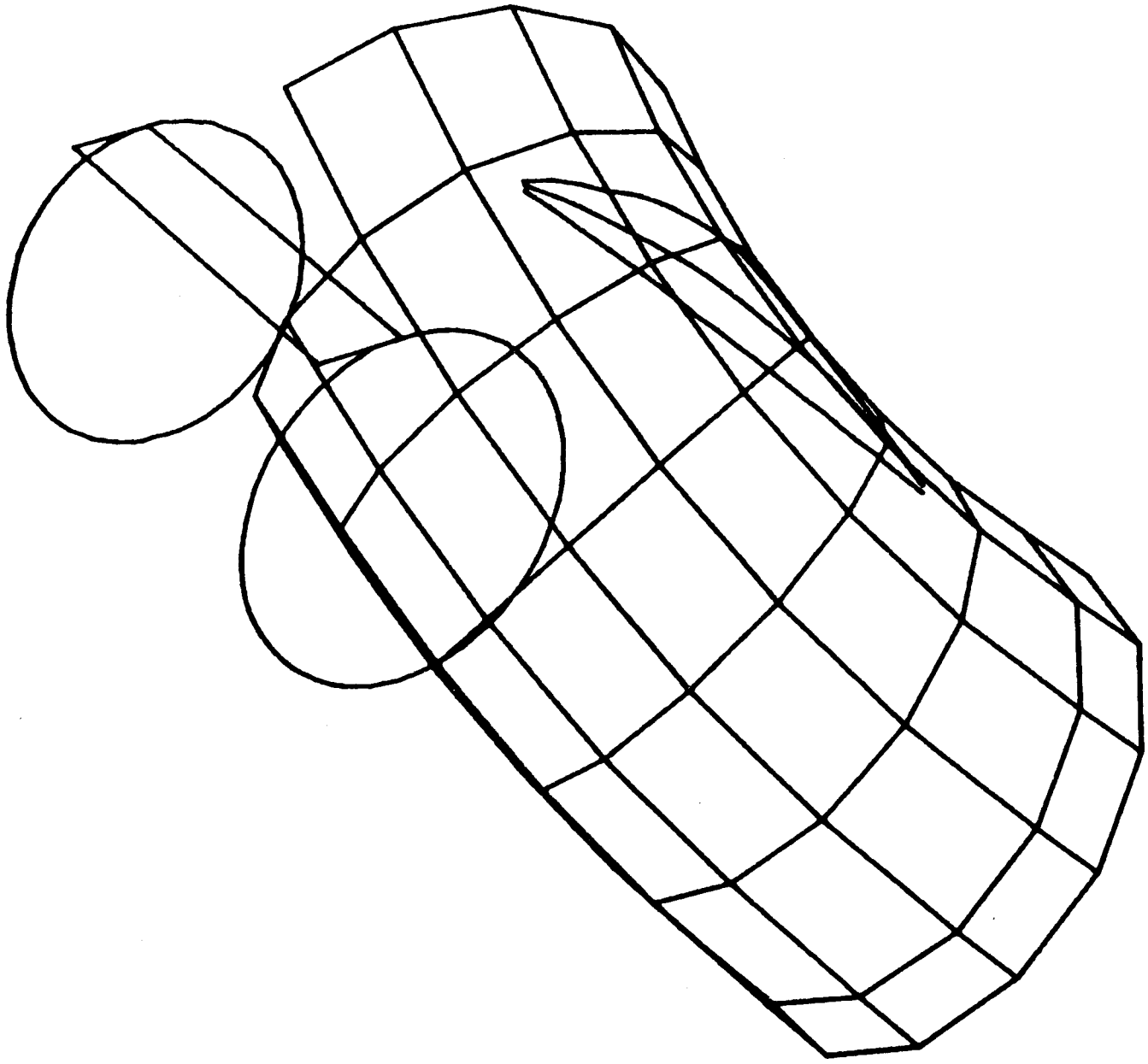
8. OUTPUT DATA

1. HIT DATA

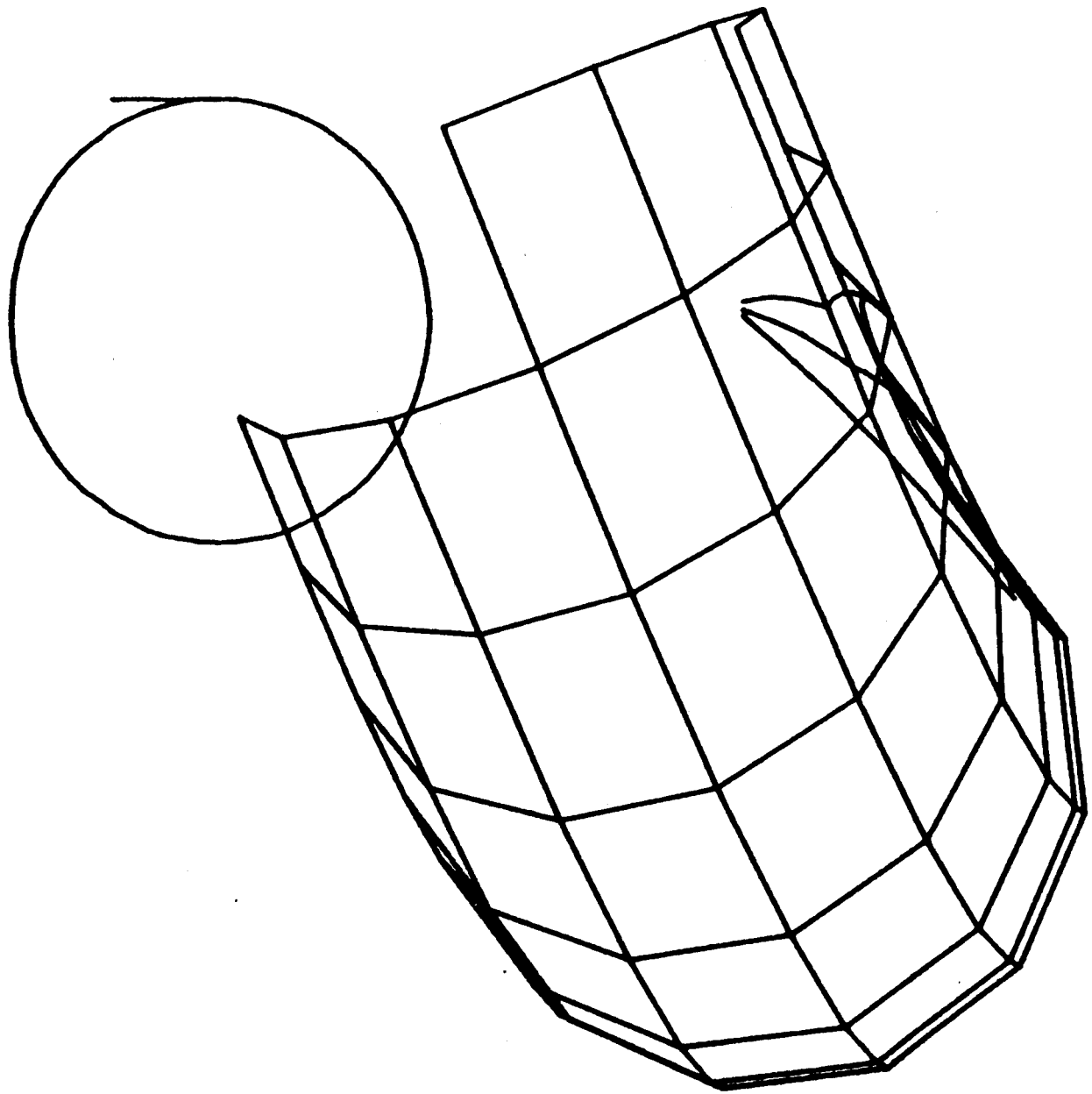
STREAM		C.G.				BOTTOM				TOP			
	TIME	ANGLE	X	Y	Z	PLATE	ANGLE	X	Y	PLATE	ANGLE	X	Y	PL
1	0.24	-33.4	28.8	1.3	2.8	9	-33.4	28.8	0.8	9	-33.4	28.8	1.7	9
2	0.25	-32.6	30.4	0.8	4.3	9	-32.6	30.4	-0.4	9	-32.7	30.4	2.0	9
3	0.27	-31.8	32.0	0.1	5.8	9	-31.8	32.0	-1.8	9	-31.9	31.9	1.9	9
4	0.28	-31.1	33.5	-0.8	7.3	9	-31.0	33.6	-3.2	9	-31.2	33.0	2.0	10
5	0.29	-30.0	34.5	-1.2	8.9	10	-30.3	35.2	-4.6	9	-30.9	33.4	2.5	10
6	0.29	-29.5	35.0	-1.4	10.4	10	-28.5	36.3	-5.7	10	-30.5	33.8	2.7	10
7	0.30	-29.0	35.7	-1.8	11.9	10	-31.8	36.9	-6.3	17	-30.1	34.3	2.8	10
8	0.30	-28.5	36.3	-2.2	13.4	10	-31.3	37.5	-6.9	17	-29.7	34.9	2.7	10
9	0.31	-28.0	37.0	-2.7	15.0	10	-30.9	38.1	-7.5	17	-29.2	35.5	2.4	10
10	0.31	-31.3	37.6	-3.2	16.5	17	-30.5	38.7	-8.1	17	-19.4	36.0	2.0	11
11	0.32	-30.9	38.2	-3.8	18.0	17	-30.0	39.3	-8.7	17	-20.0	35.4	2.7	11
12	0.32	-30.4	38.8	-4.4	19.5	17	-29.6	39.9	-9.4	17	-20.4	34.8	3.2	11
13	0.32	-13.8	38.9	-4.7	21.0	18	-29.2	40.5	-10.0	17	-20.8	34.4	3.4	11
14	0.32	-14.2	38.5	-4.4	22.6	18	-32.1	41.0	-10.6	24	-21.1	34.1	3.4	11

16	0.32	-14.7	37.8	-4.2	25.6	18	-31.4	41.9	-11.6	24	*********	0.0	**********	
17	0.31	-14.8	37.7	-4.4	27.1	18	-31.1	42.4	-12.1	24	*********	-0.0	0.0	******
18	0.31	-12.0	37.7	-4.8	28.7	25	-30.8	42.9	-12.6	24	*********	0.0	0.0	******
19	0.32	-11.6	38.2	-5.8	30.2	25	-8.6	42.4	-12.1	25	*********	0.0	**********	
20	0.32	-11.1	38.9	-7.1	31.7	25	-9.1	41.6	-11.3	25	**********		0.0	******
21	0.33	-10.3	39.9	-9.0	33.2	25	-7.4	41.0	-10.6	32	-11.0	39.0	-7.5	25

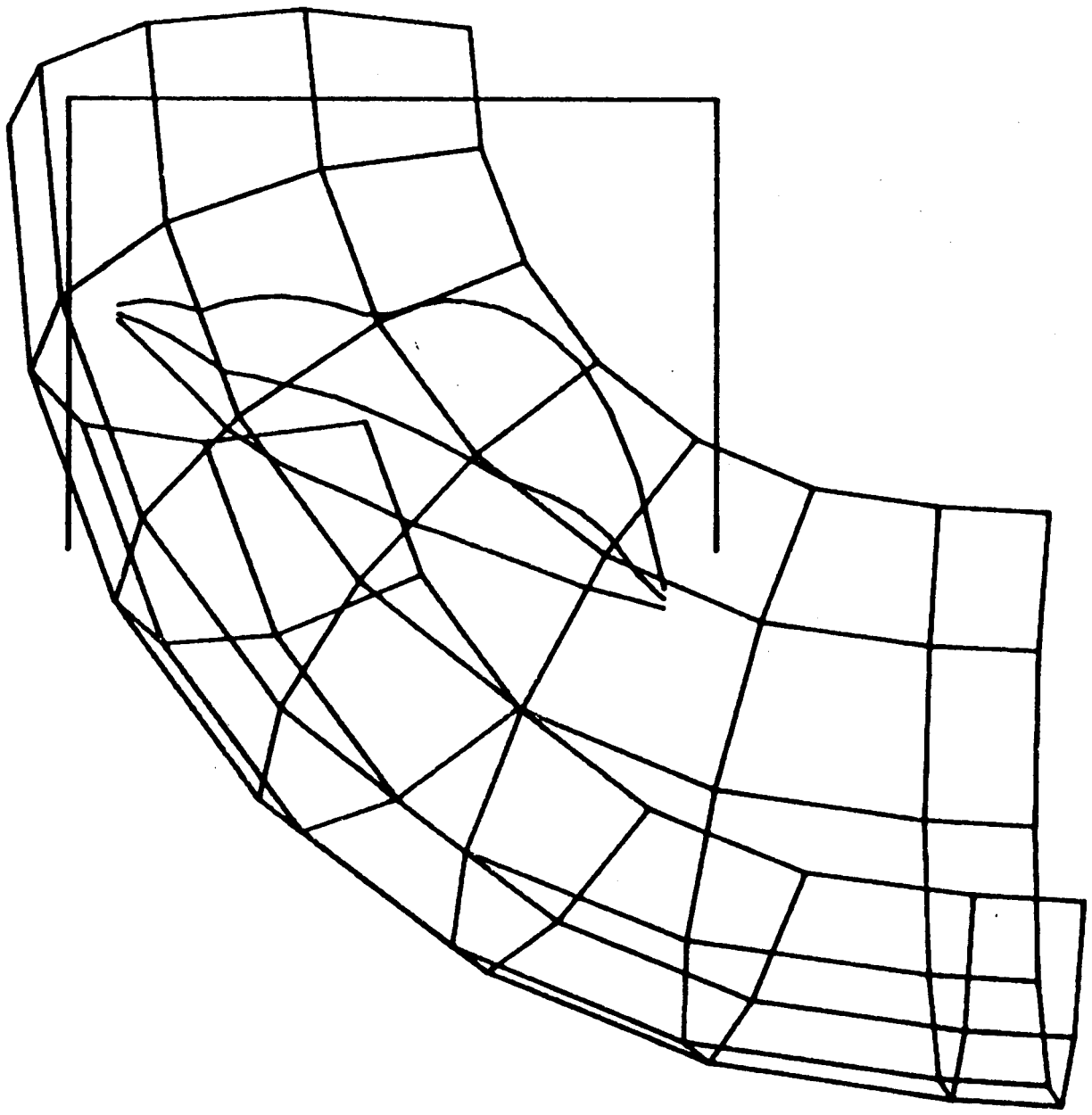
3-D VIEW RUN 807 ELEMENTS 1,99999



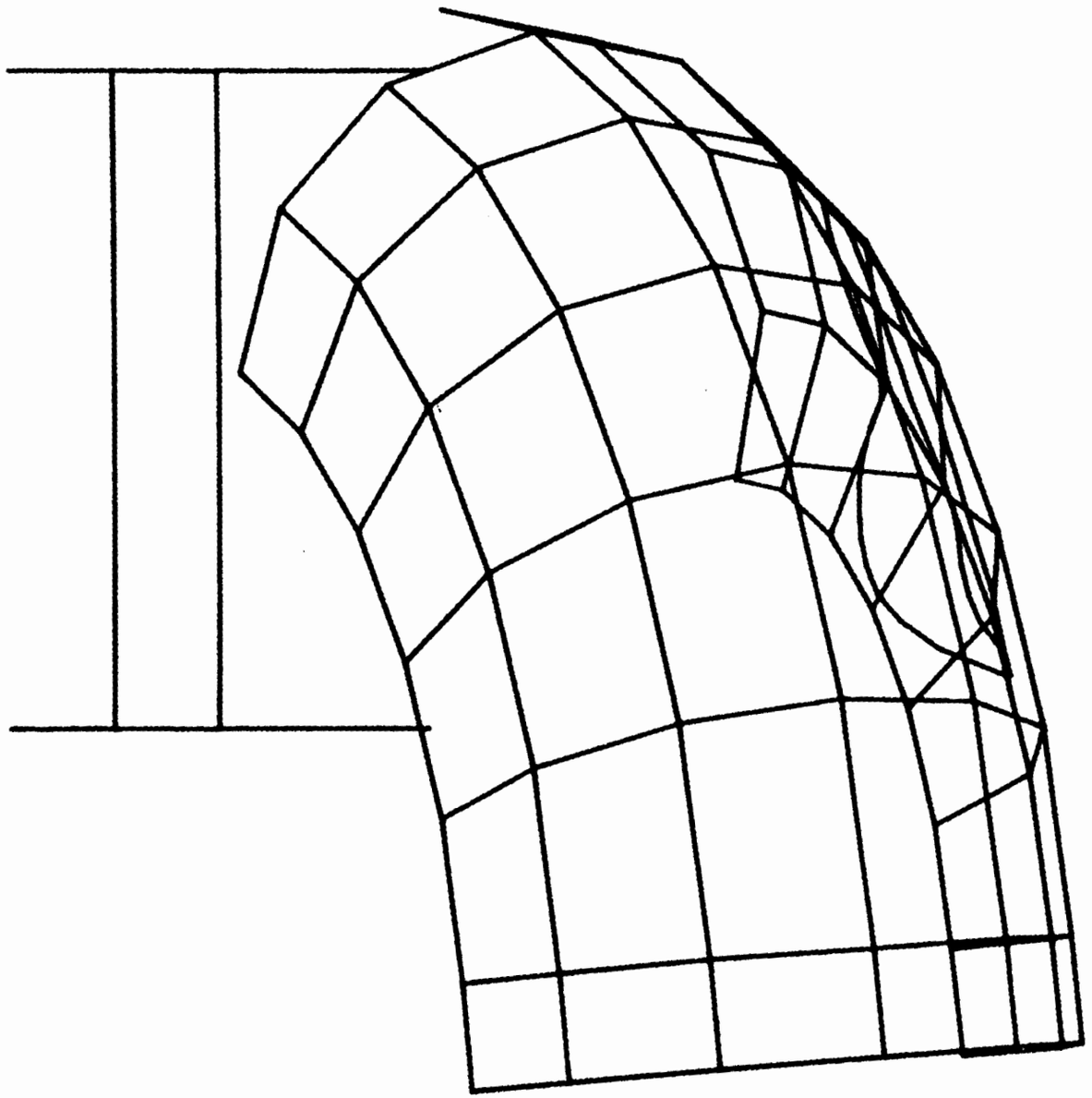
FRONT VIEW RUN 807 ELEMENTS 1,99999



SIDE VIEW RUN 807 ELEMENTS 1,99999



TOP VIEW RUN 807 ELEMENTS 1,99999



H-2

FRICTIONAL FLOW ANALYSIS RESULTS

TYPICAL STREAM DATA LOG

STREAM	STEP	VELOCITY (IN./SEC)	WIDTH (IN)	HEIGHT (IN)	RADIUS (IN)	RAD/HGT	NORMAL FORCE *	SHEAR FORCE *	LOCATION X	Y	RIGHT EDGE Z	PLATE LOCATION
3	1	153.3	1.4	1.5	31.1	21.2	0.4	0.3	46.1	-16.7	31.2	31
3	2	155.2	1.4	1.5	33.7	23.2	0.1	-0.1	46.4	-17.9	31.3	31
3	3	156.3	1.4	1.4	38.7	26.7	0.5	0.4	46.6	-18.5	31.3	31
3	4	157.4	1.4	1.4	41.4	28.7	0.4	0.3	46.8	-19.1	31.4	31
3	5	159.0	1.4	1.4	44.2	30.9	0.0	0.0	47.0	-19.6	31.4	31
3	6	159.4	1.5	1.4	46.9	33.4	0.3	0.3	47.2	-20.2	31.5	31
3	7	161.4	1.5	1.4	49.6	35.8	0.0	0.0	47.3	-20.8	31.5	30
3	8	160.3	1.5	1.4	48.6	34.7	0.4	0.3	47.3	-21.4	31.6	30
3	9	162.7	1.5	1.4	46.8	33.9	0.4	-0.3	47.2	-22.0	31.7	30
3	10	161.3	1.4	1.4	44.9	32.2	0.4	0.3	47.2	-22.5	31.9	30
3	11	163.8	1.4	1.4	43.0	31.2	0.4	-0.3	47.1	-23.1	32.0	30
3	12	162.2	1.4	1.4	41.1	29.5	0.4	0.3	47.0	-23.7	32.1	30
3	13	163.6	1.4	1.4	39.2	28.3	0.4	-0.3	47.0	-24.3	32.2	30
3	14	165.3	1.4	1.4	37.5	27.4	0.1	0.0	46.9	-24.9	32.3	30
3	15	163.3	1.4	1.4	35.6	25.6	0.5	0.4	46.9	-25.5	32.4	30
3	16	166.0	1.4	1.4	33.7	24.5	0.5	-0.4	46.8	-26.1	32.6	30
3	17	163.7	1.4	1.4	31.7	22.7	0.5	0.4	46.8	-26.7	32.7	30
3	18	164.8	1.4	1.4	29.6	21.4	0.5	-0.4	46.7	-27.3	32.8	30
3	19	163.1	1.4	1.4	28.0	20.0	0.1	-0.1	46.6	-27.9	33.0	37
3	20	164.8	1.4	1.4	54.0	38.8	0.5	-0.4	46.5	-28.5	33.1	37
3	21	163.6	1.4	1.4	54.0	38.5	0.0	-0.0	46.4	-29.1	33.3	37
3	22	164.5	1.4	1.4	54.0	38.7	0.4	-0.3	46.3	-29.6	33.4	37
3	23	163.6	1.4	1.4	54.0	38.2	0.4	-0.3	46.2	-30.2	33.6	37
3	24	162.7	1.4	1.4	54.0	37.8	0.4	-0.3	46.1	-30.8	33.7	37
3	25	165.6	1.4	1.4	54.0	37.9	0.4	-0.3	45.9	-31.3	33.9	36
3	26	163.3	1.4	1.5	54.0	36.7	0.5	0.4	45.5	-31.8	34.1	36
3	27	162.6	1.3	1.5	54.0	36.0	0.6	-0.4	45.2	-32.2	34.3	36
3	28	165.2	1.3	1.5	54.0	36.0	0.5	-0.4	44.8	-32.7	34.5	36
3	29	162.6	1.3	1.5	54.0	34.9	0.5	0.4	44.5	-33.1	34.8	36
3	30	165.4	1.3	1.5	54.0	34.9	0.6	-0.4	44.1	-33.6	35.0	36
3	31	162.6	1.3	1.6	54.0	33.8	0.6	0.4	43.8	-34.1	35.2	36
3	32	165.6	1.2	1.6	54.0	34.1	0.6	-0.4	43.4	-34.5	35.5	36
3	33	162.7	1.2	1.6	54.0	33.2	0.6	0.5	43.1	-35.0	35.7	36
3	34	165.7	1.2	1.6	54.0	33.5	0.6	-0.5	42.8	-35.4	35.9	36
3	35	162.7	1.2	1.7	54.0	32.7	0.6	0.5	42.4	-35.9	36.2	36
3	36	163.5	1.2	1.6	54.0	32.8	0.6	-0.5	42.1	-36.3	36.4	36
3	37	161.6	1.2	1.7	54.0	32.3	0.1	-0.1	41.7	-36.8	36.7	36
3	38	163.0	1.2	1.7	54.0	32.5	0.6	-0.5	41.4	-37.2	36.9	36
3	39	161.1	1.2	1.7	54.0	32.0	0.1	-0.1	41.1	-37.7	37.2	36
3	40	162.5	1.2	1.7	54.0	32.2	0.6	-0.5	40.8	-38.1	37.4	36
3	41	160.6	1.2	1.7	54.0	31.8	0.1	-0.1	40.4	-38.6	37.7	36
3	42	162.3	1.2	1.7	54.0	32.4	0.6	-0.5	40.1	-39.0	38.0	35
3	43	159.2	1.2	1.7	54.0	31.7	0.1	0.1	39.6	-39.2	38.3	35
3	44	160.1	1.2	1.7	54.0	31.7	0.7	-0.5	39.2	-39.4	38.6	35
3	45	158.2	1.2	1.7	54.0	31.1	0.7	-0.6	38.7	-39.7	38.9	35
3	46	161.4	1.2	1.7	54.0	31.7	0.8	-0.6	38.2	-39.9	39.3	35
3	47	156.9	1.2	1.8	54.0	30.8	0.8	0.6	37.8	-40.1	39.6	35
3	48	157.9	1.2	1.7	54.0	31.0	0.8	-0.6	37.3	-40.4	40.0	35
3	49	154.6	1.2	1.8	54.0	30.2	0.1	0.1	36.9	-40.6	40.3	35
3	50	156.1	1.2	1.8	54.0	30.7	0.8	-0.6	36.4	-40.8	40.7	35
3	51	155.8	1.2	1.8	54.0	30.3	0.8	0.6	35.9	-41.1	41.1	35
3	52	152.4	1.2	1.8	54.0	29.6	0.1	0.1	35.5	-41.3	41.4	35
3	53	153.5	1.2	1.8	54.0	29.9	0.8	-0.6	35.1	-41.5	41.8	35
3	54	150.0	1.2	1.9	54.0	29.2	0.1	0.1	34.6	-41.7	42.2	35
3	55	151.1	1.2	1.8	54.0	29.4	0.8	-0.6	34.2	-42.0	42.6	35
3	56	147.7	1.2	1.9	54.0	28.3	0.1	0.1	33.7			

* LBS/IN^2

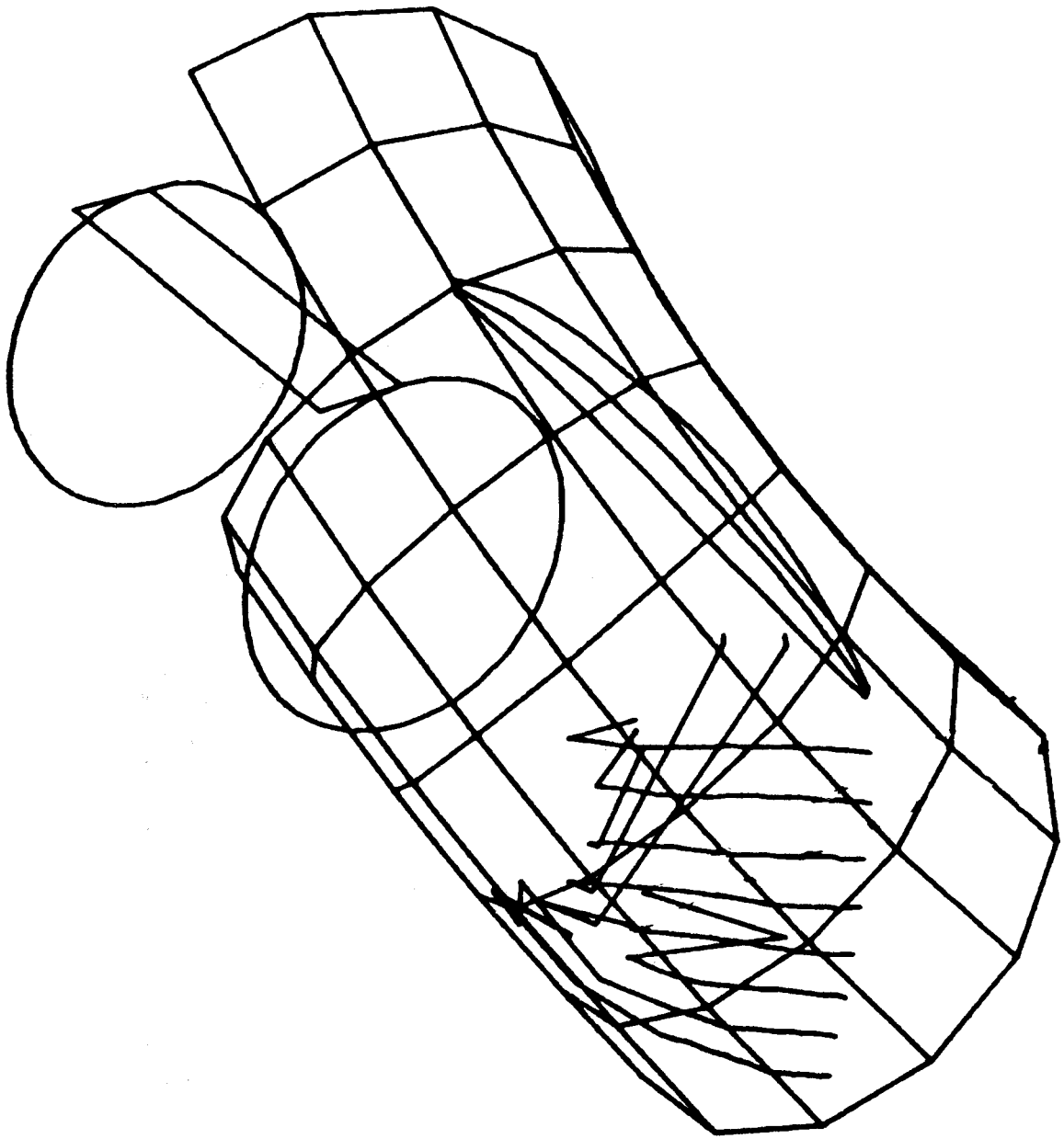
3	57	148.8	1.2	1.9	54.0	25.1	0.8	-0.6	33.3	-42.4	43.3	35
3	58	149.4	1.2	1.9	54.0	28.5	0.1	0.1	32.9	-42.7	43.7	35
3	59	148.5	1.2	1.9	54.0	28.8	0.6	-0.6	32.5	-42.9	44.1	35
3	60	146.5	1.2	1.9	53.9	26.2	0.1	0.1	31.6	-43.2	44.9	41
3	61	146.9	1.2	2.0	54.0	27.0	0.9	0.7	31.2	-43.1	45.3	41
3	62	141.4	1.2	2.0	54.0	27.0	0.9	-0.7	30.8	-43.1	45.8	41
3	63	144.6	1.1	2.0	54.0	27.3	0.9	-0.7	30.3	-43.0	46.2	41
3	64	138.2	1.1	2.1	54.0	26.2	0.9	0.7	29.5	-43.0	47.1	41
3	65	134.0	1.1	2.1	54.0	25.1	0.1	-0.1	29.1	-42.9	47.6	41
3	66	138.6	1.1	2.1	54.0	25.9	0.1	-0.1	28.2	-42.8	48.6	41
3	67	134.4	1.1	2.1	20.1	9.4	1.0	0.7	27.8	-42.8	49.0	41
3	68	129.0	1.2	2.2	18.0	8.2	0.0	0.0	27.1	-42.8	50.0	41
3	69	132.4	1.1	2.1	54.0	25.2	0.0	0.0	26.7	-42.8	50.5	41
3	70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.7	-42.8	50.5	0
3	71	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.7	-42.8	50.5	0
3	72	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.7	-42.8	50.5	0
3	73	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.7	-42.8	50.5	0
3	74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.7	-42.8	50.5	0
3	75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.7	-42.8	50.5	0

TYPICAL STREAM DATA LOG

450 FPM TRAJECTORY CASE

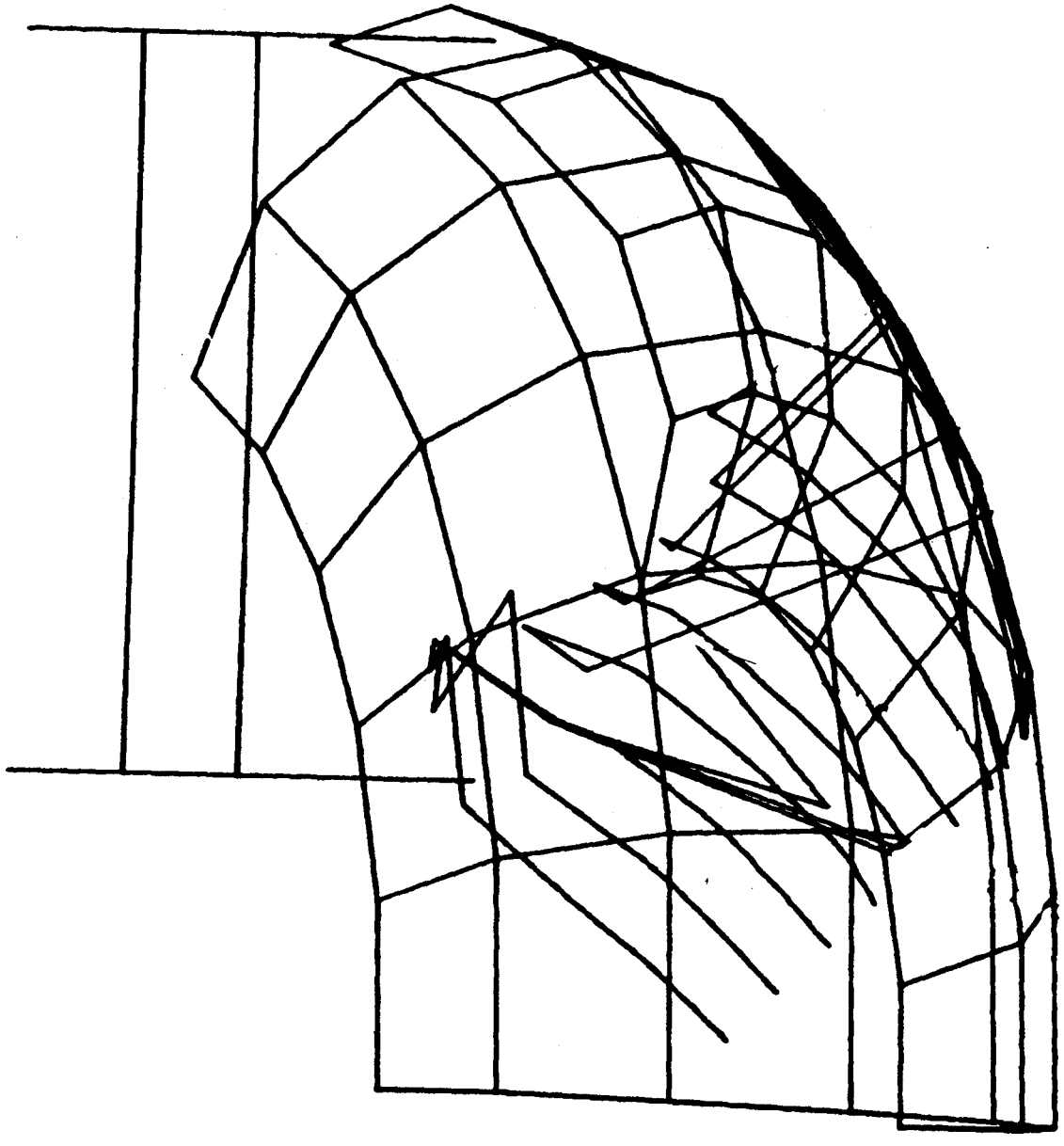
RUN	ANGLE OF WALL FRICTION
746	0^{o}
747	20^{o}

3-D VIEW RUN 746 1 ELEMENTS 1,99999

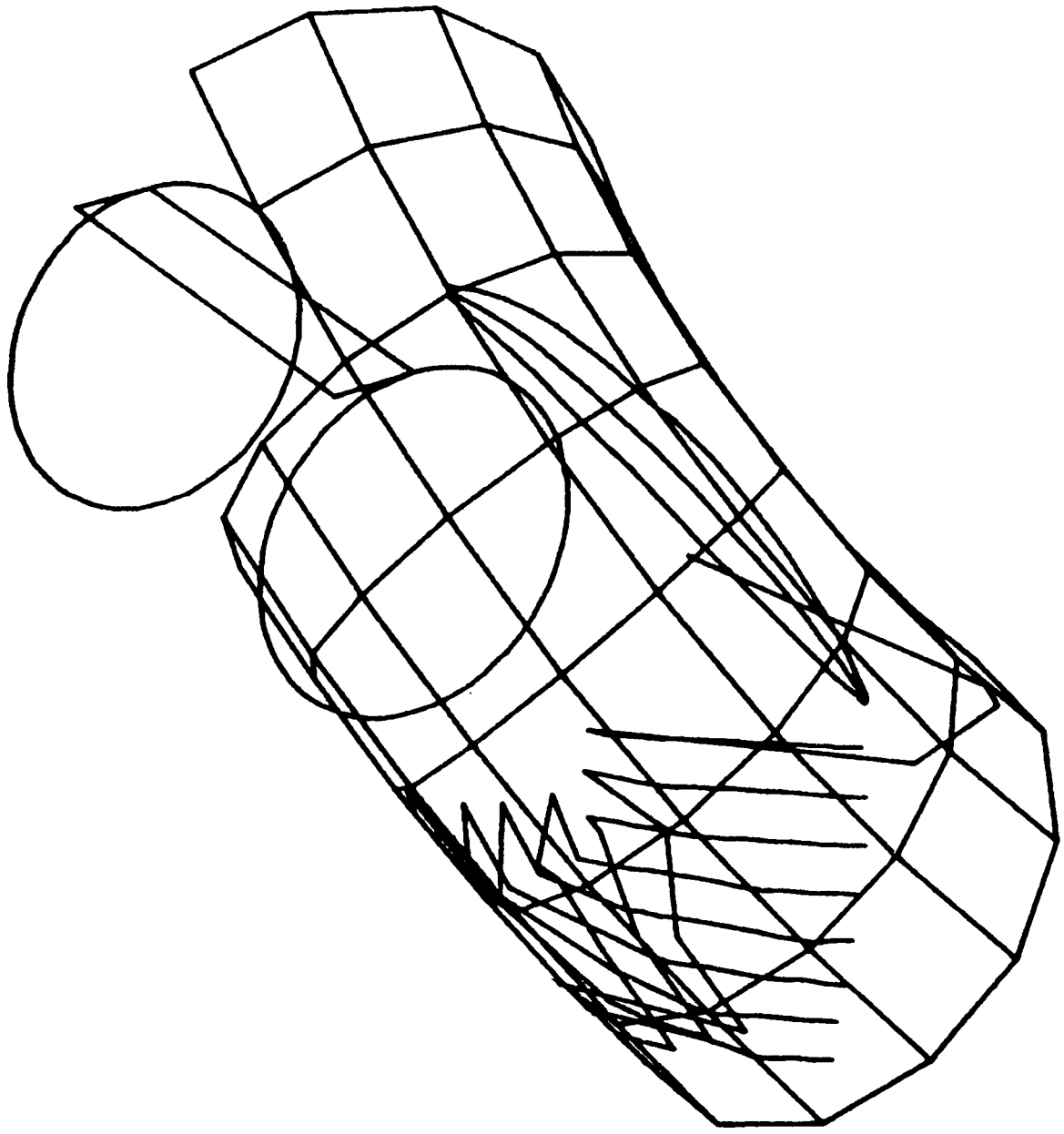


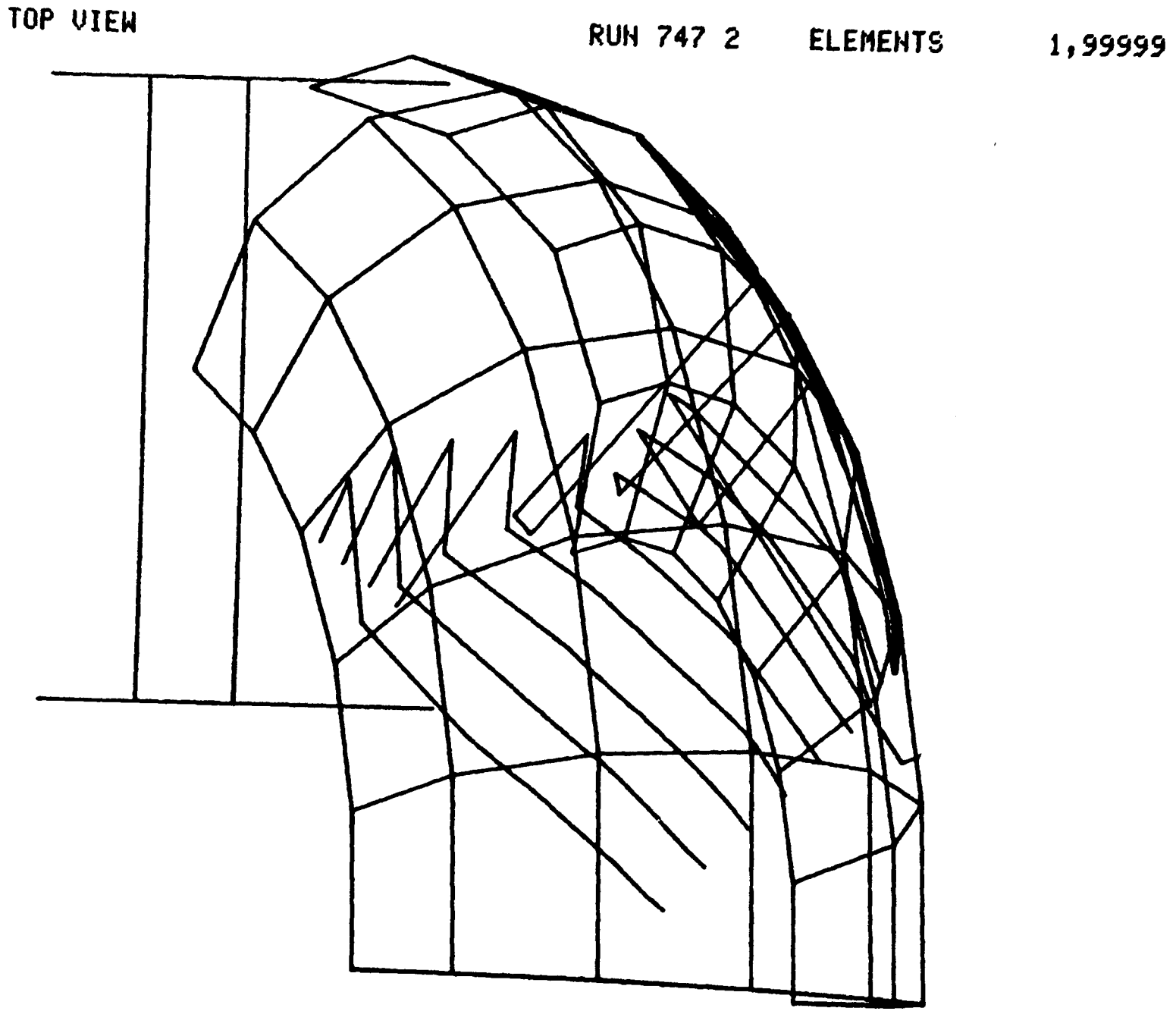
TOP VIEW

RUN 746 1 ELEMENTS 1,99999



3-D VIEW RUN 747 2 ELEMENTS 1,99999

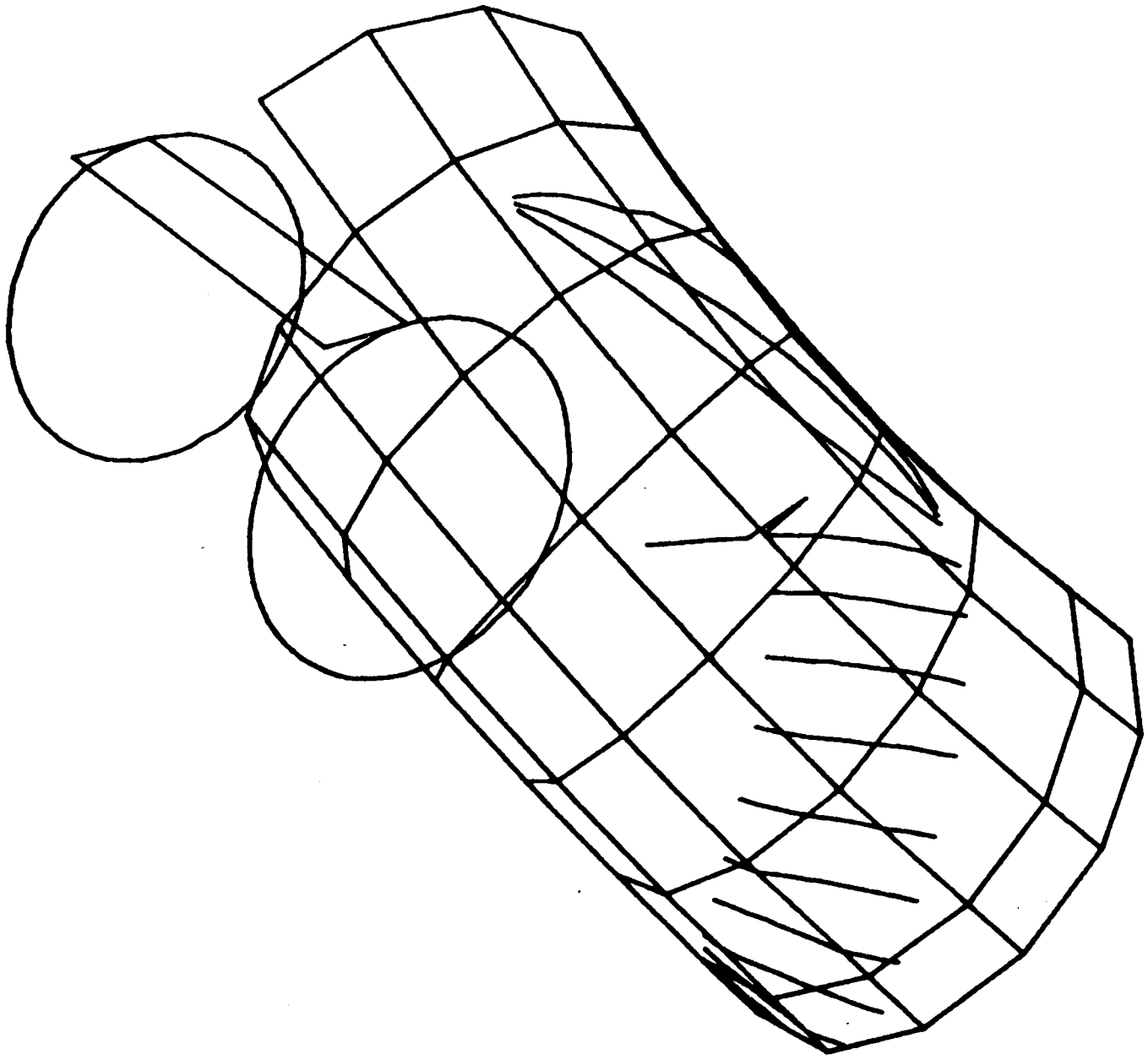



TOP VIEW
RUN 747 2
ELEMENTS
1,99999

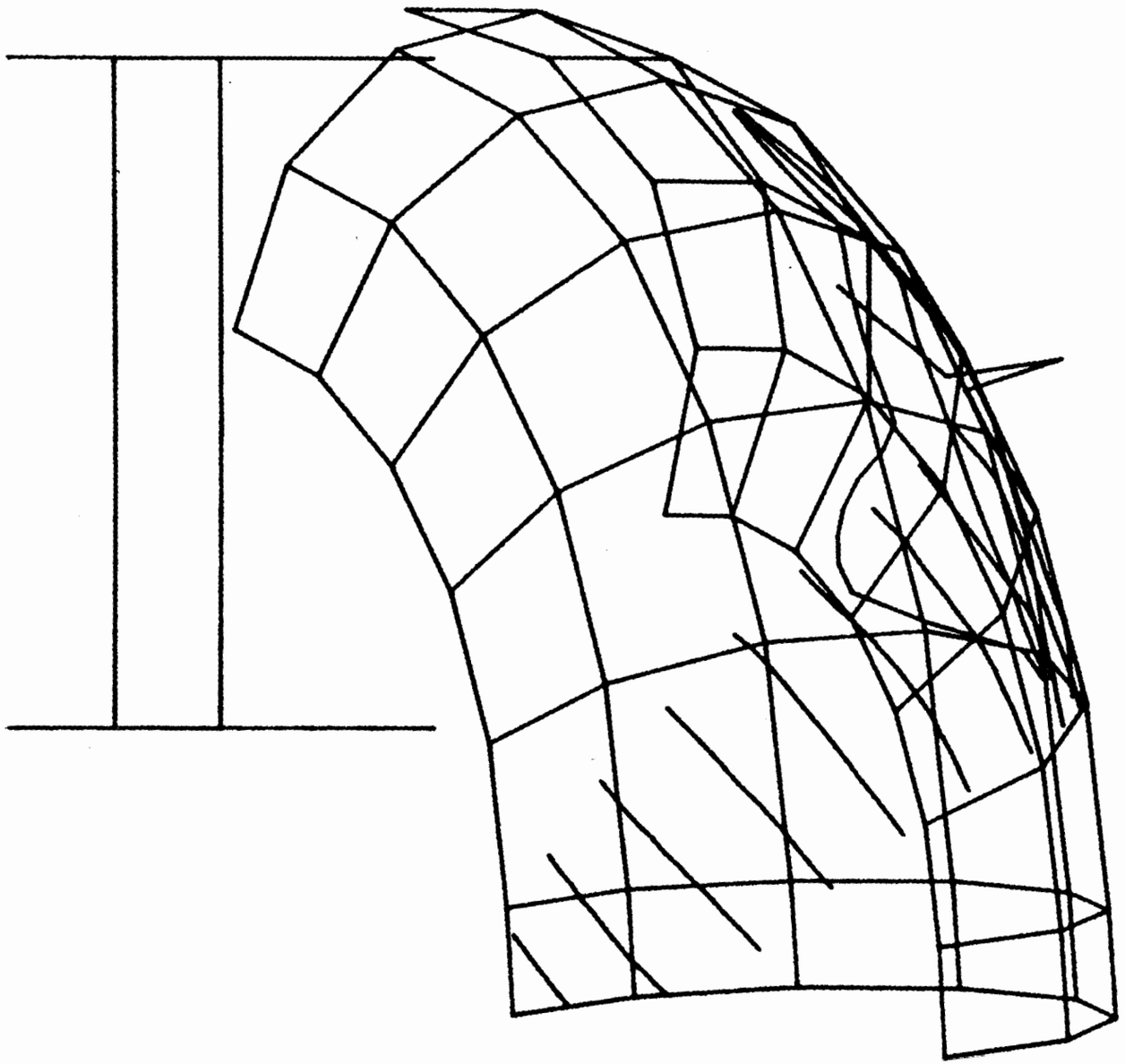
600 FPM TRAJECTORY CASE

RUN	ANGLE OF WALL FRICTION
846	0
847	20

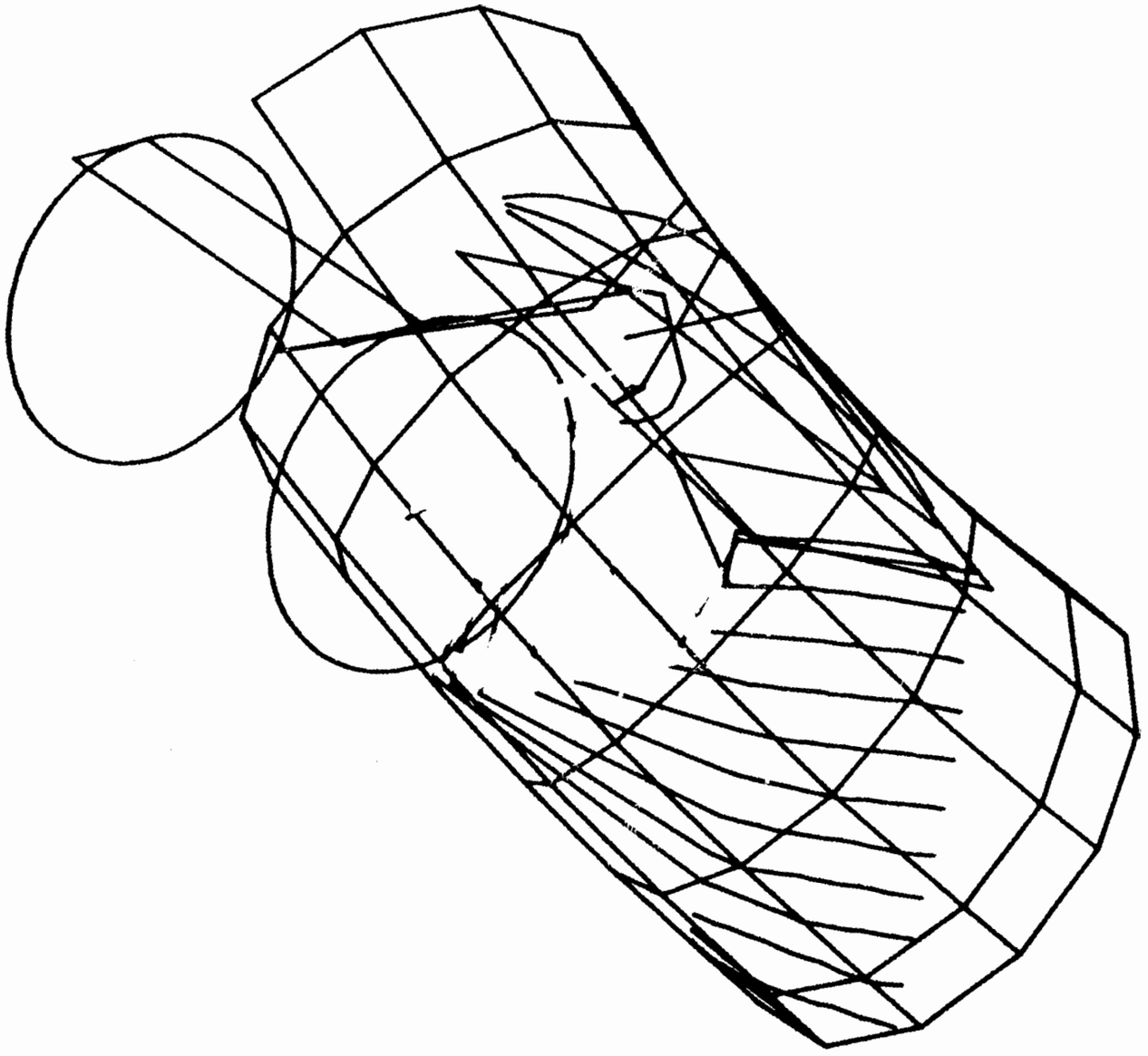
3-D VIEW RUN 846 6 ELEMENTS 1,99999



TOP VIEW RUN 846 6 ELEMENTS 1,99999



3-D VIEW RUN 847 7 ELEMENTS 1,99999



TOP VIEW RUN 847 7 ELEMENTS 1,99999