MASTER

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# DEVELOPMENT OF HIGH TEMPERATURE TURBINE SUBSYSTEM TECHNOLOGY TO A "TECHNOLOGY READINESS STATUS"

## PHASE II

PROGRESS REPORT FOR JULY, 1978

A. CARUVANA

AUGUST 10, 1978



Work Performed Under Contract No. EX-76-C-01-1806

GENERAL ELECTRIC COMPANY
GAS TURBINE DIVISION
1 RIVER ROAD
SCHENECTADY, NEW YORK 12345

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Prepared for

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OFFICE OF ENERGY TECHNOLOGY

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## ABSTRACT

An exhaust stack diameter of 3.5 ft. has been agreed upon as sufficient to support flow requirements of present TRV and later PRD combustion product and cooling water requirements for the HGPDTS.

The nozzle cooling tube quality control testing equipment has been constructed and is currently being evaluated.

Optional positions for the ignitor in the combustor have been defined. One location is in the mixing cup and the other two positions are both downstream in the pilot liner.

The copper airfoil machining bid package for the HGPDTS nozzle has been released for quotation. Inner and outer endwall machining bid packages will be released shortly.

Final assembly of the turbine simulator modified test stand for combustor checkout is nearly complete. Testing on #2 distillate should begin in mid-August.

A decision has been made that the curved sidewalls in the turbine simulator nozzle will employ the smooth shape. This configuration has been determined to be the best compromise to duplicate the flow conditions at near TRV design conditions.

A number of subcontract inquiries on the Low Btu Gas Chemical Clean Up System have been released for quotes. All major specifications have been completed and approved.

Activity in preparation for the Aerodynamic Tests was initiated this month. A literature search is in progress. Definition, design, and pretest analysis of the cascade models to be tested has begun. Consideration has been given to the required facility modifications and to instrumentation requirements.

All test specimens for the heated vane portion of the Air Turbine Test program have been machined and are in the process of being instrumented. Endwall rework on two vane segments is also complete and ready for instrumentation. The program is proceeding on an accelerated schedule.

An update of the TRV simple cycle performance is presented and the results show an improvement both in output and in efficiency over that previously presented in February 1978.

An exhaust temperature limit of 1300°F has been set to avoid the costly expense of fabricating the exhaust ducting out of Hastelloy X. The resulting degradation in ambient capability is minimal.

Water delivery and distribution through the rotor has been improved by the addition of discrete tubes in the aft core plus lined passages through the rotor to avoid possibilities of stress corrosion cracking.

Combustor development activities are reported. Progress is on schedule. A successful casting of the corrugated pressure shell has been made and a highly satisfactory part appears to have been produced. More details on the design of the combustor liner panels and their attachment are presented.

Detailed progress and status of the design and development of the turbine nozzle and buckets are discussed. Status of the Materials and Process Programs, as well as the Mechanics of Materials Programs are also presented.

# REPORTING CATEGORY I

## Hot Gas Path Development Tests

### Hot Gas Path Development Test Stand, HGPDTS

The status of the final definition drawings for the test stand is as follows:

| | | |
|---|---|---|
| Complete | -- | Mixing Chamber<br>Mixing Chamber Endplate<br>Instrument Dutchman<br>Combustion Chamber<br>Nozzle Mounting Section<br>Combustion Endplate 1st Stage |
| In Review | -- | Flow Shield 1st Stage<br>Air Inlet 1st Stage<br>Test Stand Assembly<br>Hydro Test Assembly<br>Test Stand Installation |
| In Process | -- | Combustion Endplate 2nd Stage<br>Flow Shield 2nd Stage<br>Nozzle Support 1st Stage<br>Nozzle Support 2nd Stage |

Due to a problem in the application of the swirl angle, the combustor endplate 2nd stage and the flow shield 2nd stage will be delayed. Lack of these drawings will not prevent the fabrication vendor from getting started. Completion of these drawings is expected during the next reporting period.

An ANSYS model for HGPDTS combustor endplate is being prepared to solve for displacement and modal characteristics.

Computer models of the hot gas path instrument section are being prepared for thermal and stress analysis.

Bid evaluations on heat exchangers are complete and they have been released to purchasing for order placement.

Redesign of the closed loop cooling water system piping is nearly complete. Specifications for installation material will be released for bid next month.

An exhaust stack diameter of 3.5 ft. has been agreed upon as sufficient to support flow requirements of present TRV, and later PRD combustion product and cooling water requirements. An acoustic silencing and plenum chamber below the stack will utilize standard exhaust system construction materials and techniques. The preliminary design is complete and bid drawings have been submitted to qualified vendors for quotation.

## HGPDTS Instrumentation

The HGPDTS will utilize an optical pyrometer for measurement of nozzle and combustor surface temperature. Specification and requirements are being formulated and will be consistent with commercially available equipment. Vendors are being consulted regarding available equipment capabilities. Similar activity is underway regarding the Laser Velocimeter for measurement of hot gas velocity in the HGPDTS instrumentation section and in the combustor.

## Nozzle Cooling Tube Quality Control Testing

The equipment for quality control testing of the nozzle cooling tubes was described in the April Monthly Technical report. This equipment has been constructed and is currently being evaluated. Reasonable agreement has been obtained between theoretical and measured pressure versus flow in a nozzle tube.

## Hot Gas Path Test Specimen Design

Design details of the first and second stage nozzles are described under Category XI.

Design work on integrating the second stage nozzle into the test stand has begun. Difficulty is being encountered in the attempt to simulate the structural loads of the turbine. Presently, it appears that provision for inner end deflection and application of correct diaphragm loading would require extreme complication and probably would jeopardize the thermal tests by allowing too much leakage. Therefore, it appears prudent to support the vane at both ends and seek only simulation of thermal conditions.

## Combustor Ignitor

The ignitor for the sectoral combustor has been located in the HGPDTS with three optional positions. One is in the mixing cup and the other two are downstream in the pilot liner. These positions were selected based on a retractable ignitor. A fixed position ignitor will also be tested for full pressure relight.

## Manufacture of First Stage HGPDTS Nozzles

Metallurgical evaluations of transverse and longitudinally mounted samples of Monel 400 tubes received revealed cracks and evidence of intergranular attack in both the ID and OD surfaces. The presence of these degraded surfaces indicate a need for the development of applicable QC tests and analysis of incoming tube materials prior to use. In this regard, a 347 stainless steel block capable of testing the radial ductility of sample specimens as a function of temperature through internal tube pneumatic pressurizing is being considered. This device should provide a "go; no-go" assessment of the mechanical properties of tube lots prior to their use.

It should be noted that the prime tube material is now Nitronic-50, however, the Q.C. tests defined above will be useful also for almost any tube material selected for the program.

Technical recommendations have been received for inclusion in the copper airfoil, inner endwall, and outer endwall machining bid packages. This includes information in the following subject areas: manufacturing drawing modifications, quality control requirements, final inspection requirements, manufacturing operation planning requirements, packaging requirements, and tooling requirements.

The copper airfoil machining bid package has been sent to nine (9) vendors for quotation. Responses to this fixed price procurement should be received by August 18, 1978.

Both the inner endwall and outer endwall machining bid packages should be completed and sent to the potential machining vendors by August 11, 1978.

A decision point over whether copper alloy powder can be used for nozzle endwall fabrication is very near. This will eliminate the need to machine four wrought copper alloy parts and thus should aid in our efforts to secure machining vendors by removing some complexity from the job.

A detailed manufacturing plan has been prepared in PERT format and is being circulated for comments. Current activities in this area include updating the time estimates for completion of each task in the plan.

## REPORTING CATEGORY II

## Turbine Simulator Tests

Final assembly of the modified test stand for combustor checkouts is nearly completed. The test stand will be fired with #2 distillate for checkout tests in mid-August.

The redesigned test stand components for the nozzle tests (pressure box, transition piece, etc.) are being fabricated as scheduled.

Material has been ordered for the monolithic airfoil in the heat transfer test. The airfoil pressure and temperature locations have been defined. Instrumentation assembly techniques and schedule have been reviewed. Thermocouple installation techniques in the outer airfoil surfaces are currently being investigated as to the actual temperature which is being measured.

The test section curved sidewalls will employ the smooth shape. Several tests were conducted in the transonic wind tunnel to explore the differences, at various nozzle pressure ratios, of both the smooth and stepped sidewall configurations. The above decision was reached as a result of the evaluation of the data, which showed that neither sidewall configuration precisely matched the full cascade nozzle surface velocity distribution. The smooth sidewall was chosen as the best compromise to duplicate the flow conditions for the heat transfer test at near TRV design conditions.

Drawings have now been released defining the composite test specimen.

## REPORTING CATEGORY III

## Shock Tunnel Tests

### Flat Plate Tests

It was reported last month, that the heat transfer gauges to be used on the flat plate model had been damaged as a result of a cleaning solvent reacting with the gauges. These gauges have since been refabricated, checked out, installed on the flat plate model, and most recently have been undergoing calibration testing.

Calibration of the pressure gauges to be used on the flat plate model has been completed.

### Nozzle Cascade Tests

Fabrication of the test section for the TRV nozzle cascade to be used in the shock tunnel was completed. Design and layout of the TRV bucket test sections for both the shock tunnel and the transonic tunnel were begun. It is expected that this work will be completed by next month and thus allows fabrication of the test sections to begin in mid-August. Work on laying out the coordinates for the TRV buckets has also begun.

## REPORTING CATEGORY IV

## Low Temperature, Low Btu Gas Chemical Clean Up System Tests

The Pilot Gas Cleanup System (PGCUS) detail design and procurement effort is continuing with the following activities in progress:

- Size, location and specifications for the control room have been established and subcontracts are out for quote. Panel and instrument inquiries are also out for quote.

- Structural steel fabrication and erection subcontract inquiries are out for quote.

- Civil foundation and building subcontract inquiries are out for quote.

- Sources of steam, demineralized water and cooling water for the PGCUS are being developed by the GE Co.

- Detailed mechanical and electrical design by Braun is continuing.

- Orders have been placed for all Braun-engineered equipment items, and vendor design activities have commenced.

- Planning for the Braun on-site construction facilities has been completed and the Braun field office will be established in August.

- All major PGCUS specifications have been completed by Braun and most have been reviewed and approved by GE.

Negotiation of the GE/Braun contract for construction awaits the results of the requested DOE audit and the DOE response to GE request for funding approval.

Since Braun interim funding lasts only through August, GE is requesting additional interim funding approval by DOE which will carry Braun through October, 1978.

Preparation of the remaining Braun subcontract packages is continuing as well as preparations for ground breaking in September.

Current activity supports the mechanical completion of the PGCUS by May 1, 1979.

## REPORTING CATEGORY V

## Aerodynamic Tests

The objective of these tests is to obtain an understanding of the basic fluid dynamic behavior along the contoured endwalls of the TRV nozzles. Analytical studies and cold air cascade model tests of nozzle step up will be conducted in order to evaluate the flows and the losses in the gas path due to the shape of the nozzle endwalls.

A literature search has been initiated and is in progress. The following conclusions can be reported with respect to the materials which have been reviewed to date.

- There is a decisive drop in stage efficiency if nozzle endwall flare angle is increased. This drop is due mostly to increased secondary flow losses.

- Improvement in aerodynamic efficiency is possible by modification of endwall shape and/or blade profile, particularly in the flow entrance region, where most of flow turning is achieved.

- There is a redistribution of blade surface velocity even at pitch section due to endwall flare angle.

- There is practically no experimental or analytical work available to give guidance for the TRV design.

Due to the complexity of three dimensional flows near nozzle endwalls, the analytical effort will be confined to the use of existing analytical tools which may indicate trend in flow behavior and losses near endwalls, to developing a simple secondary flow analysis to obtain an optimum endwall contour, and subsequently to developing more elaborate secondary flow analysis including endwall boundary layer to revise the previously obtained endwall contour. Verification of the analytical results will be confirmed by testing in a transonic tunnel.

Cold air tests on six different cascade models (Figure 1) are planned for the Transonic Tunnel Test Facility, at three total to exit static pressure ratios in the range of 1.5 to 2.5. Measurements of mean flow field (total and static pressures and flow angle distribution) both upstream and downstream of the cascade models, static pressure distribution along the endwalls and blade surfaces, and flow visualization will be performed. The airfoil will be the tip section of TRV second stage nozzle, at the conical-cylindrical endwall. Design and pretest analysis of two cascade models have been completed. Testing is scheduled to start in December, 1978.

Preliminary investigations relative to model procurement and instrumentation have been initiated. Models will be fabricated at the CR&D manufacturing facility. Testing will be conducted in the CR&D Transonic Test facility.

Flow Angle Probe and chemicals for flow visualization will have to be procured.

Cascade models to be tested will be designed to fit in the CR&D Transonic Tunnel Test Facility. The facility, at present, has an access window

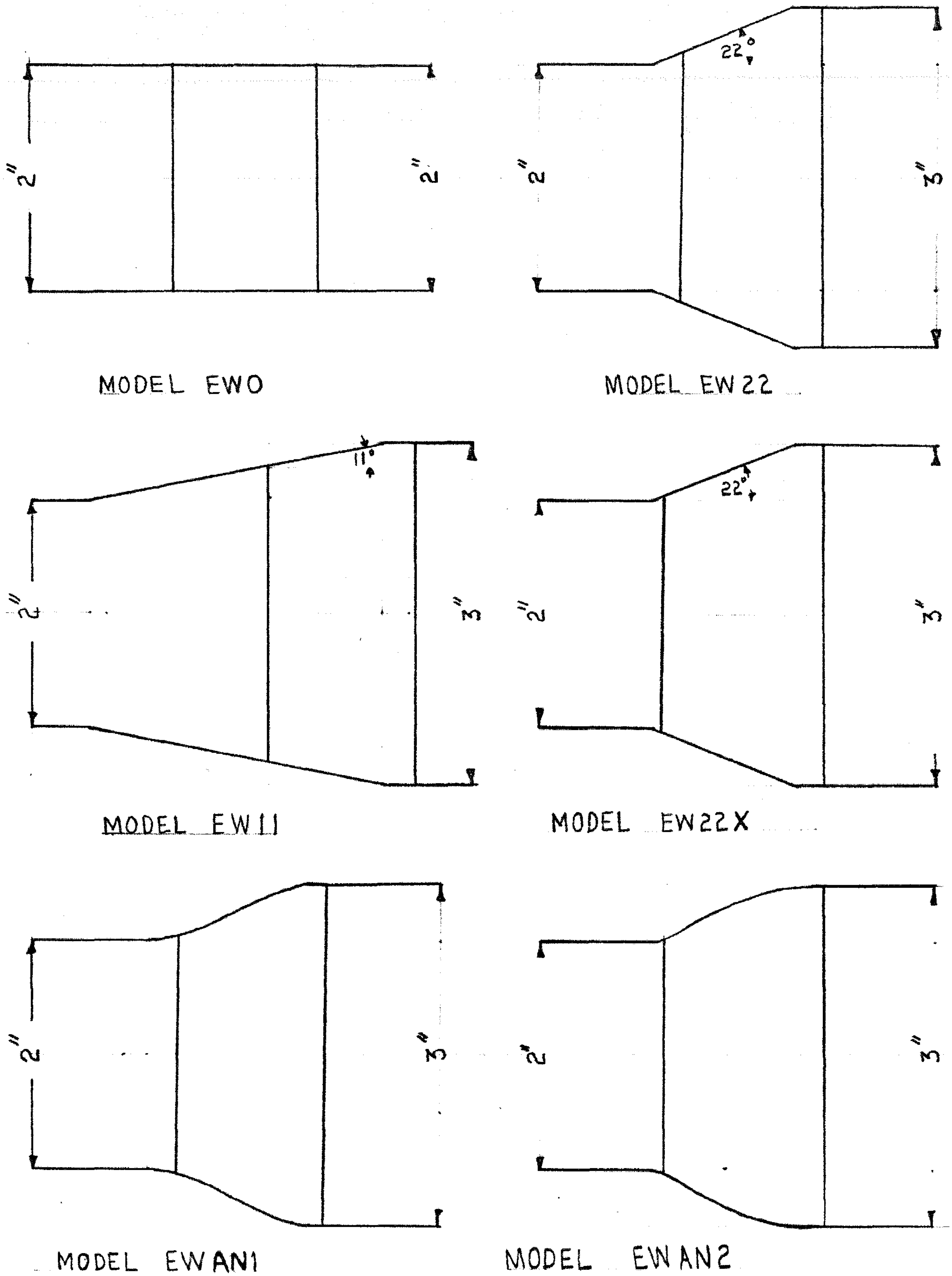


FIGURE 1 CASCADE MODELS FOR AERODYNAMIC TESTS

for downstream traversing only. To accommodate upstream flow measurements and flow visualization, an access window and an extra hole for temperature measurement and flow visualization are needed. No other facility modifications are anticipated.

## REPORTING CATEGORY VI
## Motorized Rig Tests

The horizontal passage specimen with 0.150 inside diameter was installed and spun in the Motorized Test Rig. Excessive vibration due to the inability to adaquately static balance the test specimen rotor in place has required that the rotor be removed. Replacement and realignment of the test rig bearing system has been completed. A balance of the rotor with specimen installed (removed from the rig) will be performed to improve the static balance.

## REPORTING CATEGORY VII
## Air Turbine Tests

All test specimens (vanes) to be used for the heated vane portion of the program have completed machining for instrumentation slots for heaters and thermocouples. Complete instrumentation instructions were written detailing the method of application for the heaters and thermocouples. The two test vanes with the instrumentation slots are now in the instrumentation shop. Figure 2 is a photograph of the two test vanes to be instrumented along with a spare solid vane. Also shown is one of the two vane segments which have been modified to accept the instrumented vanes. The thermocouple and heater slots are visible along with the midspan insulation slots.

As noted in an earlier status report, the difference between Vane #1 and

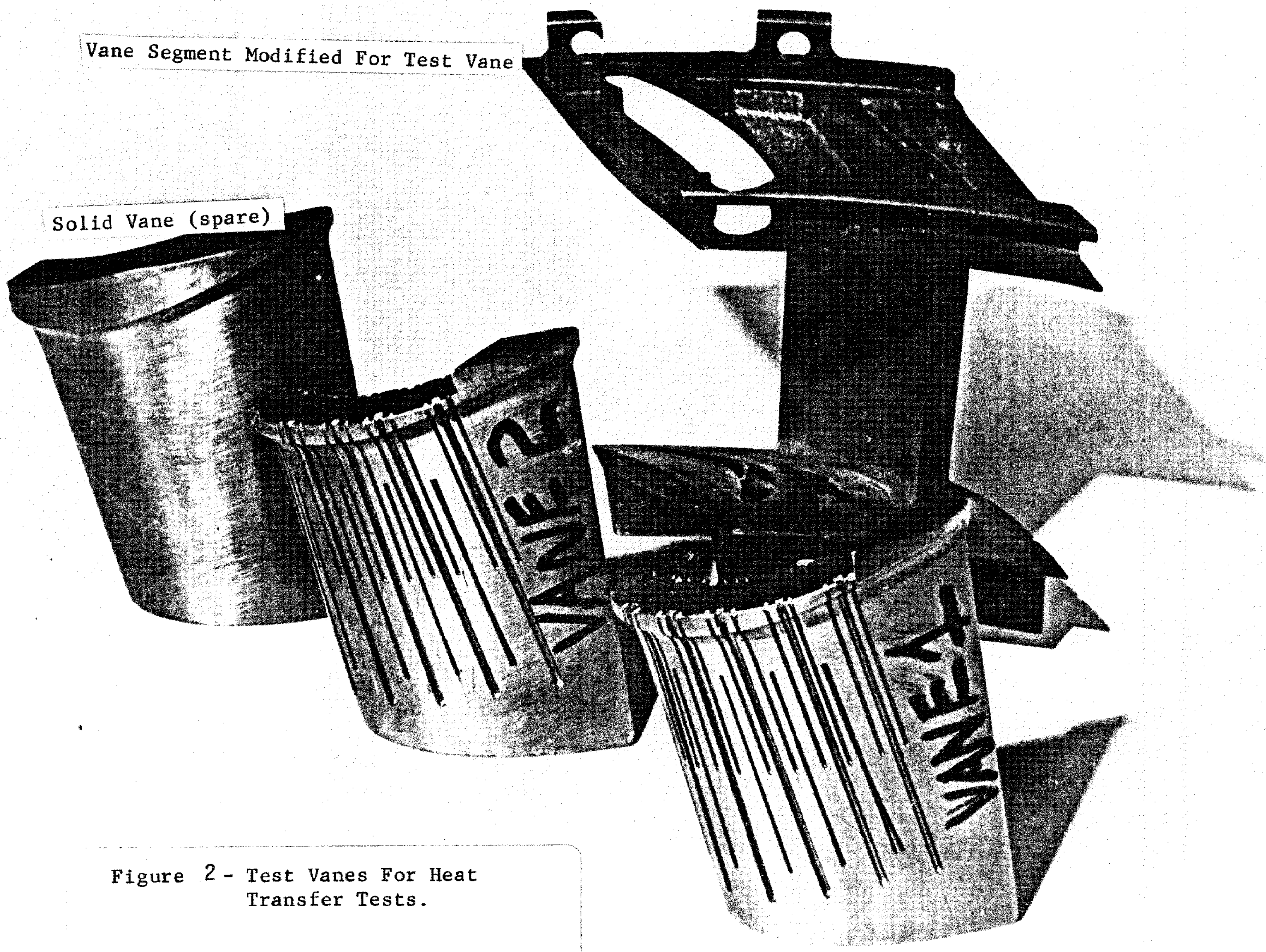


Figure 2 - Test Vanes For Heat Transfer Tests.

Vane #2 is strictly in the approach used to measure the leading edge heat transfer. Vane #1 will have a heater inserted into a hole in the leading edge where as Vane #2 has the leading edge heater placed directly on the surface of the vane at the stagnation point of the airfoil.

Pressure instrumentation for determining the pressure distribution around the pitchline of the vane as well as on the inner and outer endwalls of a vane segment is complete. This instrumentation consists of static pressure taps on the endwalls of a vane segment in locations coinciding with the heater zones on the endwall heat transfer vane segments. Static pressure taps are also located at the pitchline of two vanes corresponding to heater locations on the pressure and suction surfaces. Total pressure probes are located at the pitchline stagnation point of two vanes on another segment to prevent interference of the flow on the vanes with static pressure taps.

The endwall rework on two vane segments for endwall heat transfer is complete and the vane segments are in the instrumentation shop. Detailed instrumentation instructions were written describing the instrumentation application to be performed. Endwall heat transfer instrumentation was outlined in a previous status report. Figure 3 is a photograph of the reworked endwalls showing the slots used to isolate each heater zone. The vane impingement inserts on the inner endwall vane segment have been removed to accommodate the instrumentation leads.

The program is proceeding on the accelerated schedule in order to avoid schedule conflicts in the air turbine rig facility.

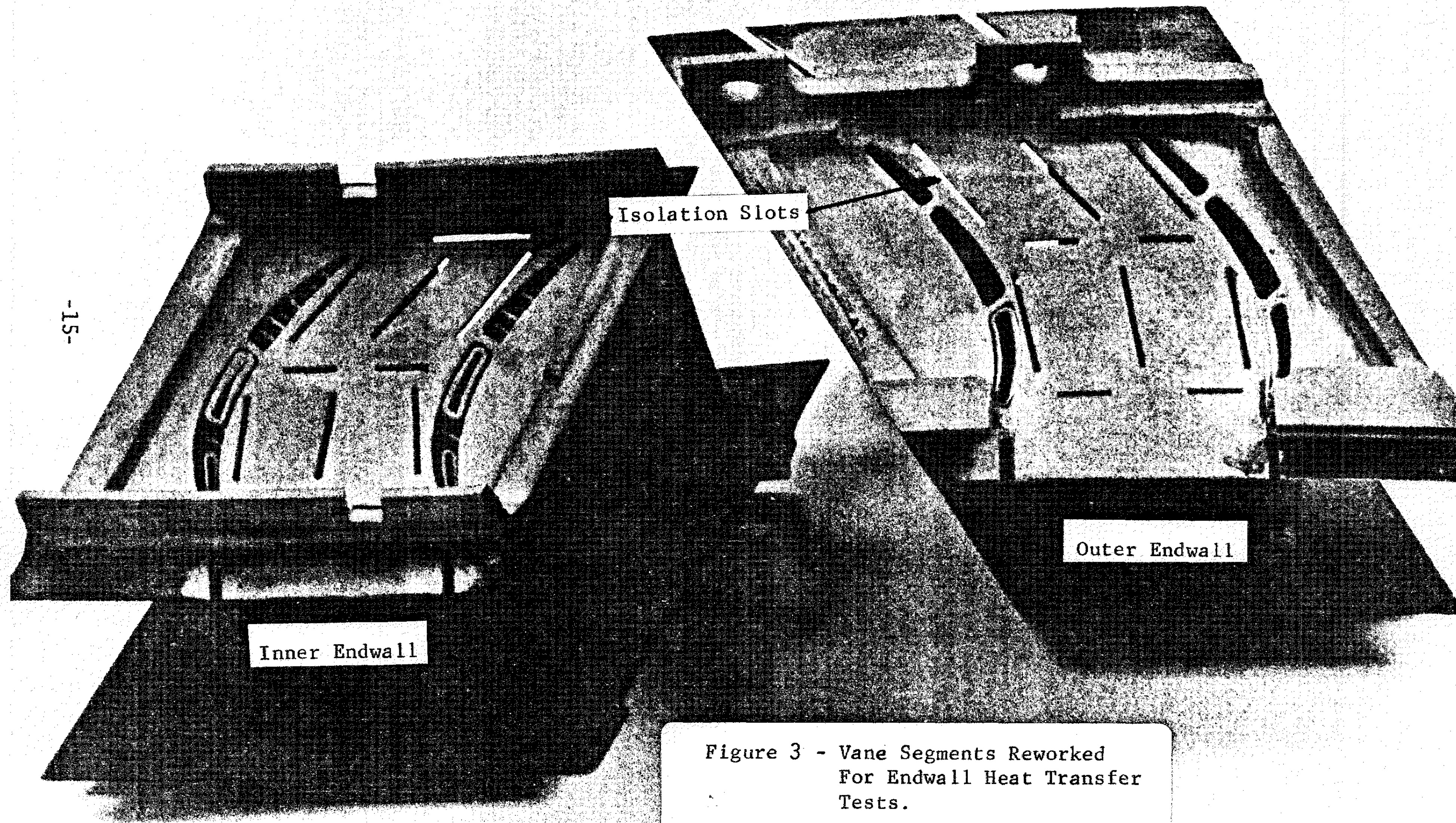


Figure 3 - Vane Segments Reworked For Endwall Heat Transfer Tests.

## REPORTING CATEGORY VIII

## Update Liquid and Gas Fueled Combined Cycle Power Plants

### Low-Btu Gas OPDD

Comparative evaluations of the system options identified in previous monthly reports are continuing. In addition to alternative subsystem arrangements in the overall system, such as a reconsideration of the two-drum/two pressure HRSG, design criteria such as the degree of subcooling in the economizer section are also being reviewed to assure that system cost, performance and operability are optimized.

## REPORTING CATEGORY IX

## Update Reference Turbine Subsystem Designs (PRD)

An update of the PRD gas turbine performance definition is currently in progress.

## REPORTING CATEGORY X

## Update Verification Test System Definition

### Flange to Flange -- System Performance

Last month it was reported that a new TRV status performance run was about to be made. This calculation is nearly complete.

Although adjustments are required on the fixed losses and turbine cooling flow splits, the performance should change little from the following:

| | TRV-6 GOAL | FEB 78 | AUG 78 |
|---|---|---|---|
| Output (MW) | 72.80 | 69.93 | 71.69 |
| Efficiency (%) | 33.08 | 32.08 | 32.33 |
| Pressure Ratio | 12.00 | 11.80 | 11.92 |

The improvement of the AUG 78 cycle is due to reduced leakages and increased second stage turbine efficiency.

## Steam Cooled Wheelspaces

A study was made of steam cooling the wheelspaces. The advantage of steam cooling the wheelspaces would be a gain in output with a small gain or loss in efficiency depending on how the steam requirement integrates with the steam plant cycle. It has been concluded that the complications in design, in off-design operation and controls, and in departure from present design practice are not justified for the TRV. Accordingly, further consideration of steam cooled wheelspaces will be left for study of the PRD.

## Exhaust Temperature Limit

A 1300°F exhaust temperature limit has been set to avoid the use of Hastelloy X in the exhaust ducting. The penalty for limiting the exhaust temperature to 1300°F is only a small decrease in maximum ambient (from 112°F to 105°F) operating temperatures at which 2600°F firing temperature is available. The benefit is a savings of about $500K per machine by being able to use 347 stainless steel material in the exhaust ducting.

## Control System

The gas fuel system hardware has been the subject of further investigation during this reporting period. The commercial availability of a valve capable of meeting the system requirements is being investigated. Discussions with Fisher Controls Co. have revealed that none of the numerous control valves available from that vendor meet all of the system requirements. One Fisher Control valve does meet all but one of the system requirements: tight shutoff capability with up to 326 PSI pressure drop across the valve. The 326 PSI valve pressure requirement is a function of the gas fuels plant pressure relief valve setting, which was assumed to be 340 PSIA.

Normal operating condition pressure drops are within advertised allowable pressure drops and, hence, Fisher has been requested to comment on the suitability of this valve with the stipulation that the 326 PSI requirement is an emergency type situation and that the valve will not be subject to continuous or frequent operation at these pressures.

It begins to appear that a development program for the gas control valve may be required.

## REPORTING CATEGORY XI
## Technology Readiness Vehicle (GE-TRV)

### Flange to Flange - System Design Summary

There have been few major changes in the flange-to-flange machine in the past month. Minor changes in detail interfaces are in continuous study. The principal areas of configuration study and change are the midbearing-strut-combustor section, the turbine rotor, and the shroud area. The strut loads require substantial strut thickness in an area where flow space is at a premium. One study is being made to see if the combustor fuel nozzle piping can be incorporated in the struts rather than run between them. The turbine rotor is somewhat modified by new wheel design configurations and improvements in the rotor water delivery system.

A new full TRV layout to incorporate all current changes is on the boards now. This layout is expected to show first concepts of the fuel and water manifolding, shroud cooling, the cooled exhaust frame diffuser and the water distribution system.

## Water Distribution and Metering

Water delivery and distribution through the rotor has been improved by the addition of discrete tubes in the aft cone plus lined passages through the rotor to avoid possibilities of stress corrosion cracking.

Construction of the 6X scale nozzle flow test model is underway. This model will enable flow measurement and visualization of the second stage turbine nozzle cooling circuits in the inner and outer endwalls and the vane.

## Rotor Distribution System

The fatigue reduction factor of IN706, due to long term erosion by water along the surface, is not known at this time. Therefore, liners are being planned for the coolant passage within the rotor until such time that the fatigue reduction factor of IN706 can be quantified by test data.

The flow conditions for the axial distribution channels have been estimated to be about 70 fps at a depth of about 40% of the 0.375 in. diameter of the passages.

## Rotor Design

Analysis of the turbine wheel centrifugal loading due to bucket loading, self loads and the water distributor hardware have resulted in larger bore thicknesses than that shown previously. This change is being reflected in the update to the TRV layout which is in process.

Rotor Dynamics

Design effort has begun on the bearings. At present, elliptical bearings seem adequate, although the possibility of a mid tilt pad bearing is not precluded. Oil flow requirements for both tilt and elliptical bearings have been estimated to support the casing design effort.

Laboratory Test Program

A wheel stress analysis and suggestions for safe operation have been generated. The collector and drive hardware have been designed and purchasing activities have been initiated.

Stator Casing Design

MVY diagrams have been generated for the casing and rotor dead weight condition and for the dynamic condition imposed by the loss of two (2) second stage bucket airfoils.

The load path originally chosen for the separation forces at the compressor discharge casing required an increase in the size of the strut with an attendand increase in the pressure drop ahead of the combustor. To resolve the problem, an alternative load path for the separation forces is being investigated which has the promise of reducing the size of the struts in the diffuser area. This will include a change in the cone angle of the bulkhead and possibly move it forward. Bosses will be added if required to maintain a suitable interface with the combustor.

Preliminary sizing of the mid-bearing housing has been initiated.

Combustor Design

Film Cooling Tests

Preliminary results of tests on a model having the proper scale of grooved lip leakage gap have been reduced and plotted. The effect of leakage is to noticeably increase film effectiveness. The effectiveness of the film at the maximum dimensionless length downstream of the slot is 0.37 for no leakage, 0.40 for leakage through a gap of 0.004 inches for the actual combustor scale, and 0.57 for leakage through a gap of 0.015 inches actual combustor scale.

## Pressure Loss Test

The model parts have been received and are being modified, assembled, and instrumented. These parts include the pressure shell, retainer, hooked rib, panel, film cooling plenum and side covers. An order for the inlet plenum has been placed.

## Atmospheric Fuel Nozzle Tests

The drawing of the atmospheric fired fuel nozzle test rig is nearing completion and will be released during the next reporting period. Bid packages have been prepared to solicit vendor quotes for the test rig.

Preliminary test plans have been drafted for the swirler discharge coefficients determination, mixing effectiveness, and flame stability tests using the atmsopheric fuel nozzle test rig.

## Fuel Nozzle Design

The finite element stress analysis of the pilot gas fuel nozzle assembly has been completed for steady state operation at full flow. The analysis shows that design point thermal and pressure stresses in the nozzle assembly are acceptable as defined by the ASME pressure vessel code. The maximum principal stress is 11.3 ksi at a temperature balance of 500°F. The stress at the same point is primarily secondary thermal bending. The maximum allowable combined primary and secondary stress for the nozzle material, 304L stainless steel, at 500°F is 52.2 ksi (3 sigma) per the code. Therefore, the minimum steady state safety factor is 4.6. Primary membrane stress is considerably lower and well below the code limit of 17.4 ksi. The nozzle design should provide long baseload life.

Combustor Pressure Shell Design

The drawing is progressing. It should be completed in the next reporting period.

Combustor Liner Panels

The panel heat transfer and stress analysis has been carried out in a preliminary manner using the finite element model from Phase I PRD, and the dimensions and boundary conditions for the Phase II TRV. The results are considerably better for Phase II conditions than for Phase I. The TRV panel peak stress, exclusive of hot streaks, is 19.4 ksi at a peak temperature of 1232°F.

Combustor Casing

The Sectoral combustor is being designed for fabrication in five parts via the precision investment casting method. They are a corrugated pressure shell, liner panels, panel retainer frame, head end shell, and preheated air swirler.

The corrugated pressure shell casting trials are underway.

There have been three (3) pours of this part to date. The first pour suffered a mold rupture, and the second pour had a substantial mold deflection and resulted in an incomplete casting. These problems have been corrected and the third and most recent pour appears to have produced a highly satisfactory complete part.

The casting trials to date have demonstrated that internal corrugation spacing and panel support details will be maintained to tighter than "catalogue" tolerances. The distance from the internal lip overhang to the opposite wall that backs the retainer tubes, for instance, was within 0.005 inches all the way around both corrugations.

The pressure sheel casting drawings for the final design have been reviewed.

The pressure shell casting tool will be made with the exit end a separate aluminum wax mold piece so that changes to seals, mounts, and the first stage nozzle interface can be easily incorporated without making a completely new tool.

The wall thickness variation in the pressure shell of 0.100 to 0.140 will not be random. It will be repeatable from casting to casting within a few thousandths of an inch and will taper from 0.140 near the thick sections, flanges, gating pads, and such; to 0.100 in the centers of "flat" walls.

The pressure shell will have gating pads running axially down all four sides. The trial piece has these in the center of each side and in three places on the radial inner and outer walls. The gating pads will have to be placed by the casting vendor designer in the final design configuration.

Gating pads may have to be machined off, at least partially, for control of transient temperature gradients and assembly weight, center of mass, and vibration frequency. Pads in the regions where impingement cooling holes penetrate the pressure shell may have to be removed. In some cases, thin ribs that will stiffen the pressure shell may be desirable and can be left uncut as part of the gating pad removal operation.

The "flat" liner panels appear to be simple to cast. The U500 material is difficult to control but is handleable. The corner liner panels will very likely be more difficult to make. A sketch of the liner panel configuration is shown on Figure 4. Note that the corner tabs are on the radial inner and outer sidewalls, and not on the tapered walls. This will allow the taper angle to be nearly the same on all panels.

A bulged out hook arm to increase bearing area but not decrease counter-current backside flow area is a desirable casting feature. This is being studied.

The panel retainer frame should also be U-500. Because of the difficulty of casting U-500 the casting will probably be segmented into eight pieces. This will require at least seven tools. Consideration is being given to a wrought Hastelloy X fabrication, as a possible alternative.

The head end shell will be cast IN718. No further consideration will be given to Hastelloy X because of the inferior cast Hastelloy X properties.

The preheated swirler and sleeves will also be IN718. Plans are being made for welding trials of the cast head end shell and the preheated air swirler walls.

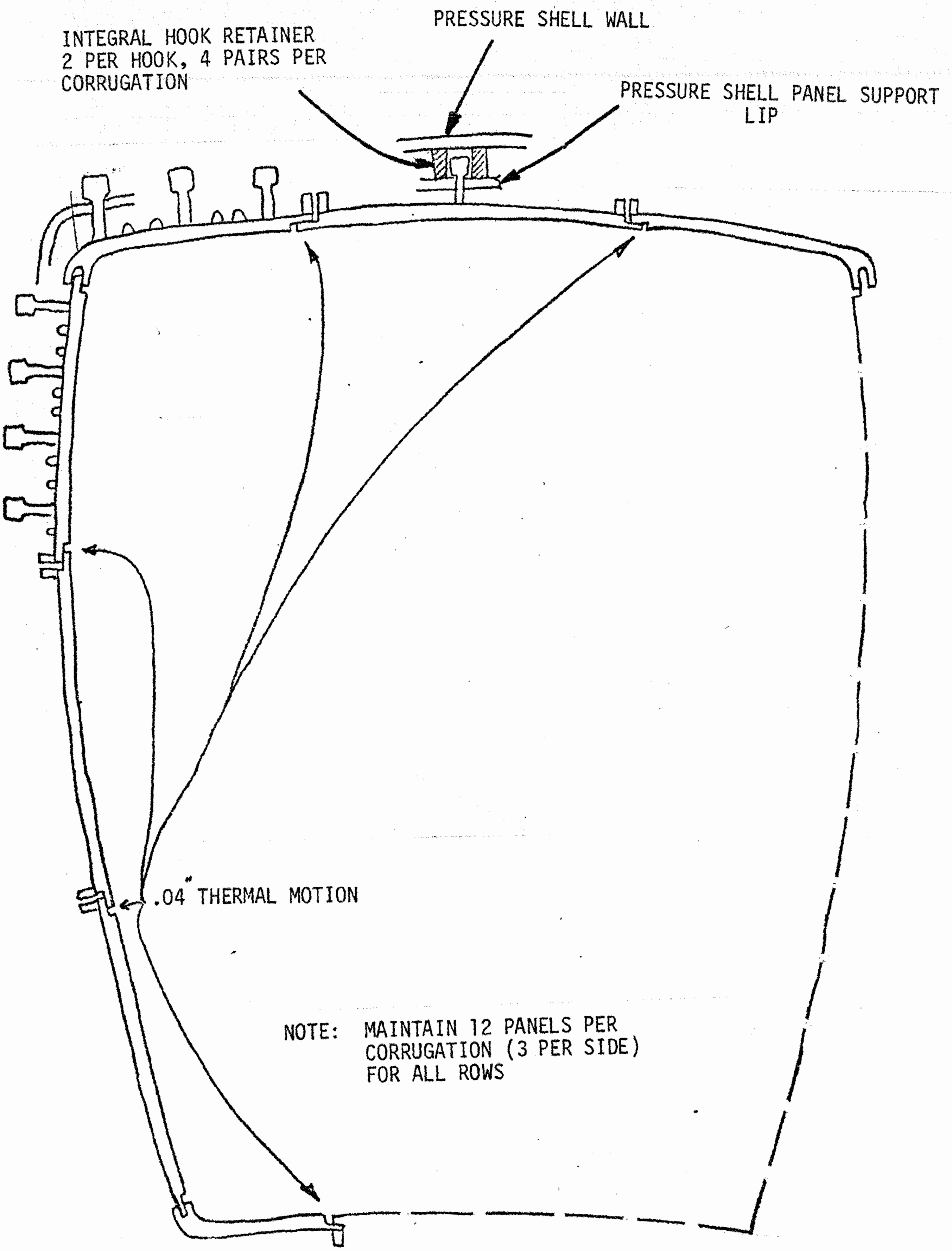


FIGURE 4. LINER PANEL CONFIGURATION

First Stage Nozzle Design

Refinement of the detail layouts for the composite parts following Manufacturing Review has now been completed. A significant refinement has been the simplification of the endwall copper insert dimensioning to permit 3 axis machining rather than 4 axis.

The thermal analysis for the trailing edge portion of the pitch section, reported in June, has now been followed by a thermal strain analysis. The results are now being reviewed. Figure 5 is a plot of the thermal strain in the extreme edge.

Thermal analysis of the extended endwall ANSYS model has now been completed and the resulting isotherms are plotted in Figure 6. Preparations are now being made for strain and low cycle fatigue analysis.

First Stage Nozzle Manufacturing

The request for quote on the copper airfoil has been sent initially to nine (9) vendors. Four (4) additional vendors will be added to the list. No further additions will be made until response is obtained from these vendors and an evaluation of their responses is completed.

An additional list of vendors is being surveyed in order to provide back-up and additional capacity for other sub-contract work.

First Stage Bucket Design

A reference thermal solution of the Leading Edge ANSYS model (6 holes)

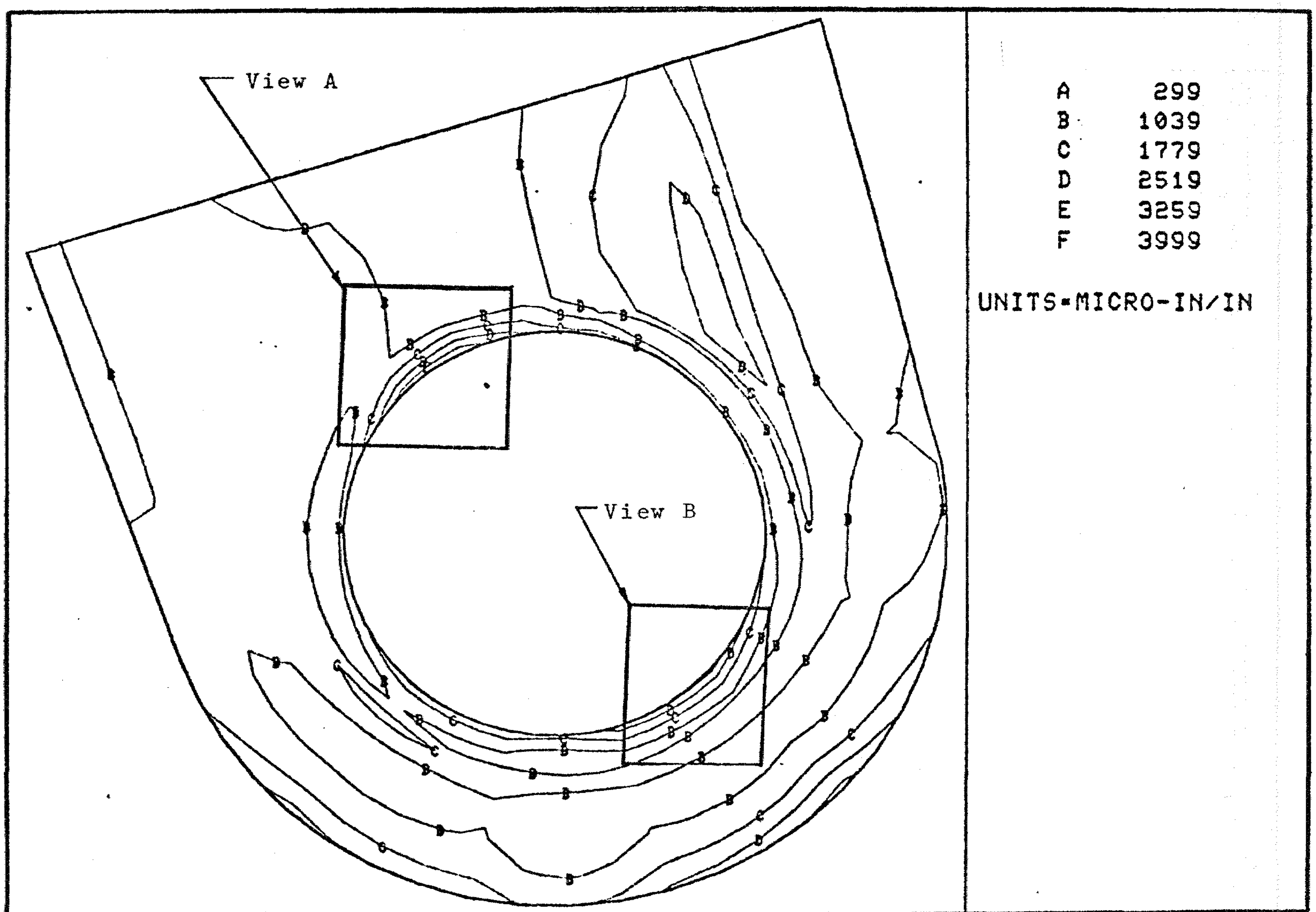


Figure 5
First Stage Nozzle, Trailing Edge
Stress and Strain Analysis

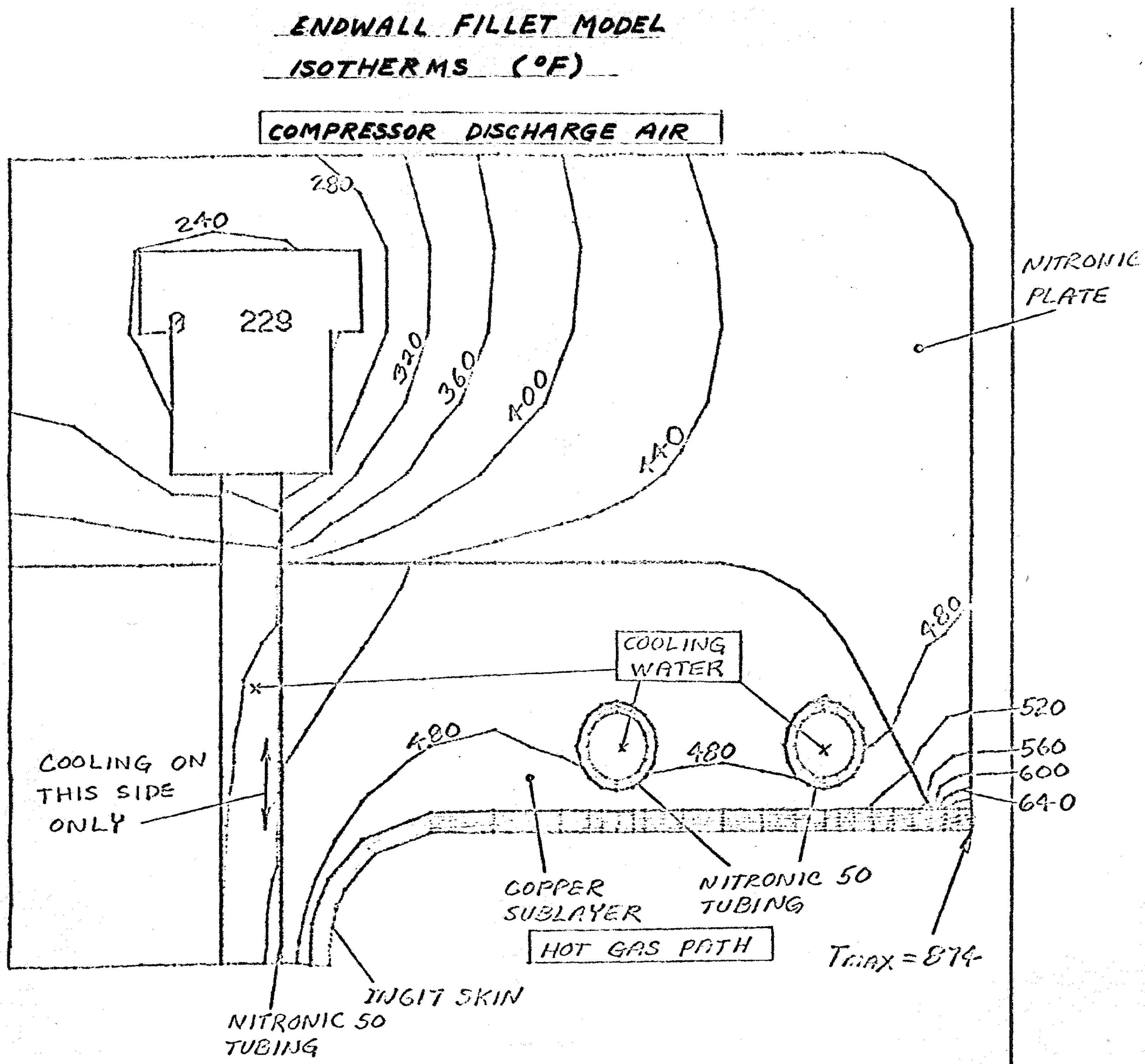


Figure 6 - First Stage Nozzle Endwall Temperature Distribution

was run and is being used to estimate bulk temperatures. Temperatures at the leading edge suction side exceed design limits for skin and copper, indicating the need for a small increase in the number of cooling tubes.

Further parametric study of a suction side cooling passage with copper of reduced thermal conductivity (60% of OFHC) showed a tolerable increase in maximum skin and copper temperature (∿30°F).

Platform cooling configurations were parametrically studied. Design temperature limits can be met with conservative estimates of heat transfer to a partial coverage water film in the horizontal passages. Structures with or without copper are possible. An alternative approach in which a copper layer is used to provide a thermal conduction path to airfoil cooling passages is also being analyzed.

Mechanical design of bucket dovetail, shank and platform has continued.

First Stage Bucket Manufacturing

Support has been provided in evaluating the possible design approaches to obtain a uniform layer of copper. A "ranking" of these approaches has been established and a development program is underway on the prime approach.

First Stage Nozzle and Bucket -- Materials and Processing

Copper Alloy Development

Initial evaluation of candidate Cu alloys for HTTT first stage components has been completed. A technical report will be issued describing the results of these evaluations.

Heat treatment studies of Al-60 to be used for the HGPDTS have been completed and evaluated. Using a vacuum of $10^{-5}$ torr, a heat treat temperature of 1200°F was sufficient to reduce the oxygen level to 155 ppm. This would be an acceptable oxygen level prior to canning and extruding the powder.

Evaluation of TMP (Thermal Mechanical Processing) effects on Cu-5Ni-2.5Ti tensile and rupture properties is continuing. Sheet specimens representing three warm working temperatures (1450°F to 1650°F) are in various stages of machining and testing. Results of these evaluations will be used to assess the potential of TMP for improving Cu alloy properties if needed for future HTTT applications.

Dimensional requirements for manufacturing of endwalls for the composite HGPDTS nozzles has suggested a powder metal approach; hence, the evaluation of P/M (Powder Metallurgy) Cu-MZC. A series of mechanical tests have been performed to evaluate the alloy in the HIPed and heat treated condition versus the wrought material. These tests included high temperature tensile and low cycle fatigue. Favorable results for the Cu-MZC alloy containing 0.47 wt % Zr may change the prime HGPDTS nozzle alloy from Al-60 to Cu-MZC. A firm decision will be made following a detailed microstructural analysis.

If a powder approach is used for the nozzles, a detailed plan will be forthcoming concerning powder production, blending, handling, and storing.

The MIT Copper development program has begun to evaluate the following alloys: Cu-5Ni-2.5Ti, Cu-MZC, CuMZC+$ZrO_2$ and Cu-Cr-$ZrO_2$. Hardness versus temperature shows the Cu-Ni-Ti to have an increase in strength between 1600°F and 1750°F. Aging 1100°F to 1200°F helps to improve this strength even more. Additional work is being done by MIT and GE to define the phases present in this copper alloy. Work has not started on the Cu-MZC alloy containing a dispersion of $ZrO_2$.

GE is currently evaluating the feasibility of plasma spraying a first stage bucket for the HTTT program. Candidate P/M alloys for this spraying include Cu-MZC and Cu-Ni-Ti. Work is continuing in this area.

Cooling Tube Evaluations

Monel 400 and 304L tubes (0.094 in O.D.) were hot isostatically pressed into a IN718/Glidcop copper assembly containing hole sizes ranging from 0.098 to 0.116 in. The purpose of this experiment was to identify the maximum size holes in which the tubes could be expanded without failing. This has been identified as approximately 0.1005" O.D. (based upon base metal ductility). Due to what appears to be tubing failures, these experiments failed. Basic tests and evaluations of the longitudinal properties of thin wall (7 mil) Monel 400, A-286 and IN718 are being conducted at room temperature and the 1750°F HIP temperature. The primary purpose of these tests is to correlate properties in thin wall tubing versus the bulk metal form. When these studies have been completed candidate tube material design limits relative to yield stress, ductility and fracture stress may be quantified.

Meetings were held with metallurgical engineers of the Superior Tube Co. at their plant to discuss the surface quality observed on the as-received 7 mil wall tubes. It was suggested that the degradation observed during high temperature exposure (HIP) had been caused by halogens applied as lubricants during the tube cold drawing processes. It was agreed that, in the future, these materials would be mechanically removed from the ID and OD of the tubes prior to shipment. This should result in an improvement in the quality of the thin wall tubes received from this vendor. However, it is not clear, at this time, whether the halogens are the direct cause of the tube failures observed.

Thick Cladding Development

Room temperature tensile results on IN617 were reviewed. The best ductility obtained was with 50% C.W. (Cold Work) and 2150°F annealed material ∿58% @ 112.3 ksi UTS. No significant differences in strength or ductility were observed between longitudinal and transferse orientations of the sheet material. Tensile results coupled with previously reported Erickson cup data indicate 50% C.W. and 2150°F anneal to be the optimum TMP for IN617 cladding formability.

GTA (Gas Tungsten Arc) welded IN617 and IN671 specimens have been submitted for tensile testing at 1750°F, 1000°F and R.T. to determine the effects of welding on cladding properties.

Diffusion couples of Al-60 and IN617 with various surface preparations are presently being fabricated for HIPing. Examination of the resultant bondlines will be a screening procedure prior to 1000°F tensile testing to determine preferred bonding techniques (e.g., establish the need for an interfacial nickel strike).

In the absence of sufficient 1000°F mechanical property and metallurgical stability data for IN617, a program has been initiated to determine the effect of post-HIP extended 1000°F exposure on tensile and impact properties. IN671 is being investigated concurrently.

Near Net Shape Composite Development

A recanned photo-fabrication simulator has been HIPed at 1750°F/15 ksi/2 hrs. This simulator (NNS-2A) had previously been unsuccessfully HIPed at 1750°F/10 ksi/2 hrs. Examination of transverse and longitudinal sections through NNS-2A revealed that complete bonding of the Al-20Cu laminates (10 mil sheets) had resulted from the higher HIP pressure.

The remaining two cylindrical test specimens have now been HIPed at the higher pressure conditions. They are presently being cut up for metallographic, tensile and stress rupture testing.

Second Stage Nozzle Design

Design work this month has concentrated on the preparation of detailed layouts to permit fabrication of a test nozzle for the HGPTS. This effort has entailed meetings with the vendor to insure castability and to transmit early design information which will permit tooling to begin while the design work is still in progress.

Airfoil layouts with section coordinate charts have been completed for the second stage nozzle. The casting vendor (TRW) now has sufficient information to acquire tooling for the core piece and airfoil wax die block.

Work is continuing on the second stage nozzle casting drawing. The three principal views, the datum system and fixturing points and basic dimensions are essentially complete. The work remaining on the drawing will consist of cutting additional sections to clarify certain areas, the completion of dimensioning, and the incorporation of changes that are agreed upon during discussions with the casting vendor and his tooling vendor.

The pitch section ANSYS model has now been completed and preparations are well underway for thermal and strain analysis.

An ANSYS model of the second stage nozzle fillet area (intersection of airfoil and outer endwall) is being constructed. This model will allow investigation of the mechanical stress concentration effect in this area due to the cantilever type support. The temperature and thermal strain distribution in this complex region will be studied by this model.

The ANSYS flow model of the cooling circuit is now being checked and a large portion of it has been verified by computer.

Second Stage Nozzle Manufacturing

Core tooling has been started, as well as some details of the casting tooling. The final casting tooling dates are now dependent on getting further information to the tooling vendor.

Second Stage Nozzle -- Materials and Processing

Casting Development (TRW)

TRW has ordered the core and casting tooling for the second stage nozzle from Richcraft Tool and Die, Burbank, CA. This tool will be configured to allow TRW's split mold technology to be used in casting this second stage nozzle. Richcraft plans to make the casting tooling in the following pieces: (1) airfoil block, (2) two shroud (endwall) blocks, inner and outer, (3) eight separate dies for the hooks on the endwalls (2 for the inner hooks and six for the outer hooks). The hooks will be mounted in a single injection die block and wax welded to the endwalls after wax injection.

Manifold Joining

Discussions were held with two potential brazing vendors, Pyromet Industries, and Metallurgical Consultants, Inc. to review the joining requirements of the second stage nozzle and to solicit suggestions concerning specific joint configurations and brazing alloys. Both companies recommended the use of a Au base braze alloy and minor joint configuration changes. During these discussions the manufacturing of the manifold covers and manifold pockets were discussed since the cleanliness of the surfaces to be joined and the fitup are critical to achieving an optimum braze joint. Both vendors recommended removal of the EDM recast surface and application of a thin Ni plate. In addition, simplification of the manifold pocket shape and manifold covers was suggested to optimize braze joint fit-up.

Second Stage Bucket Design

Hole sizing and spacing have been addressed. A minimum of 20 peripheral cooling holes in the monolithic structure are predicted assuming .080 in. diameter holes without flow promotion devices i.e. crimps in the "short" tip chord bucket. Smaller, .063 in. dia. holes may be required at the trailing edge. If this size hole were used exclusively, a minimum of 25 cooling passages would be required.

Layout of cooling passages at the pitch, root and tip section is in progress.

Second Stage Bucket -- Materials and Processing

Advanced Casting Development (TRW)

This program is aimed at developing advanced investment casting technology for the second stage TRV bucket application. This work will focus on the problem of coring large L/D (length/diameter) ratio nonlinear cooling holes necessary for water cooling. Since the TRV second stage bucket design does not at this time have sufficient definition to allow construction of the actual bucket shape, an obsolete GE tool for a bucket of the approximate size and shape will be used to develop this casting technology.

Powder Metallurgy and Spar Development (TRW)

This program is aimed at developing a powder metallurgy and spar approach to fabricate the second stage TRV bucket. This work will develop an alternate approach for placing nonlinear cooling passages into large buckets. Primary emphasis will be placed on Hot Isostatic Press (HIP consolidation of a central cast spar around which is located a network of leachable cores embedded in powder IN718. After HIP consolidation, the cores are chemically leached from the structure and the cooling passages are thereby created.

Orders were placed for the steel and IN718 cladding material, the iron and tungsten cores, the IN718 plate, and the IN718 powder. The first three items have already been received. The longest lead time item is the IN718 powder where delivery has been promised by October 25.

Third Stage Nozzle Design

No mechanical design effort was planned or accomplished on this nozzle during the reporting period.

Third Stage Nozzle - Materials and Processing

No significant activity in this period.

Third Stage Bucket Design

Preliminary layout and mechanical design of a tip shroud has continued. Desired constant bending stress contours are being reviewed with the forging vendor.

Aerodynamic design of the airfoil is in progress.

Third Stage Bucket -- Materials and Processing

The IN718 material to be used in this program has been received by Kelsey Hayes. Tests are underway to evaluate the quality of the as-received bar. Further minigrain forging trials have been completed and the results reviewed. Based on these results, tentative plans for the minigrain forging phase have been established.

Metem has STEM drilled 3 samples of IN718. These samples are being examined for IGA and surface roughness. Results from their examinations will be used to establish parameters for the second drilling iteration. A program to study the possibility of notch embrittlement in wrought IN718 has been initiated. A detailed package of information has been provided to the welding and brazing programs to better define the HTTT requirements. A literature survey has been completed on the "Metallurgical Phases of Alloy 718" and a second summary on microstructure control is planned.

Metallurgical Support Studies

Tensile and stress rupture data of the MS9001 (fabricated during Phase I) nozzle (cast 718) and P/M 718 are shown in Tables 1 and 2. The P/M

## TABLE 1

### Tensile Data -- Cast and P/M 718

| Specimen and Heat-Treatment* | Temperature (°F) | UTS (ksi) | .2% YS (ksi) | % Elongation | % Reduction of Area |
|---|---|---|---|---|---|
| A5 (cast) | R.T. | 149.5 | 135.0 | 11.1 | 30.0 |
| B5 " | " | 150.4 | 127.0 | 7.4 | 17.4 |
| C5 " | " | 115.6 | 106.0 | 4.6 | 24.4 |
| D5 " | " | 110.5 | 93.0 | 4.1 | 12.3 |
| E5 (P/M) | " | 183.2 | 158.6 | 4.0 | 10.1 |
| F3 (cast) | " | 136.0 | 125.5 | 13.0 | 26.8 |
| A6 " | 1000 | 116.0 | 113.0 | 7.8 | 21.6 |
| B6 " | " | 120.4 | 105.5 | 6.3 | 15.3 |
| C6 " | " | 102.0 | 85.0 | 16.4 | 39.5 |
| D6 " | " | 108.0 | 89.0 | 13.1 | 30.6 |
| E6 (P/M) | " | 151.0 | 133.0 | 17.6 | 37.0 |
| F4 (cast) | " | 127.0 | 114.5 | 14.0 | 23.8 |

*Heat Treatments:

(A) 2000PF/2hr., AC + 2125°F/15ksi/2hr., FC to 1950°F/1hr., AC + 1925°F/1hr. cool to 1400°F/8hr. FC to 1200°F/8hr., AC

(B) "A" without the 2125°F/15ksi/2hr., FC to 1950°F

(C) "A" plus resolution 1750°F/1hr. FC to 1325°F/8hr. FC to 1150°F /8hr., AC

(D) "B" plus resolution 1750°F/1hr. FC to 1325°F/8hr. FC to 1150°F /8hr., AC

(E) Powder Metal HIP'd 2210°F/15ksi/3hr. FC + 1750°F/1hr., FC + 1325°F/8hr., FC to 1150°F/8hr., AC

(F) "A" without 15ksi

Notes: % Elongation per 2 in. gauge length

## TABLE 2

### Stress Rupture Data -- Cast and P/M 718

| Specimen and Heat Treatment | Stress(ksi)/Temp(°F) | HRS | % Elongation | % Reduction of Area | Other |
|---|---|---|---|---|---|
| A1 (cast) | 115/1000 | 164.6 | 5.2 | 27 | Stress Increased, failed at 118ksi |
| A2 " | 120/1000 | 95.5 | 3.3 | 12 | L.M.=32.05 |
| B1 " | 125/1000 | 28.9 | 7.7 | 10 | L.M.=31.3 |
| B2 " | 120/1000 | 829.9 | 3.3 | 20 | L.M.=33.5 |
| C1 " | 101/1000 | F.O.L. | 10.7 | 34 | -- |
| D1 " | 110/1000 | F.O.L. | 14.8 | 30 | -- |
| E1 (P/M) | 120/1000 | 890.7 increased to 130ksi, lasted 330.1 hours DNF | | | |
| F1 (cast) | 120/1000 | F.O.L. | 12.0 | 45 | |
| | | NOTCHED BARS | | | |
| A3 (cast) | 115/1000 | 164.5 increased to 125 ksi, lasted 582.1 hours DNF | | | |
| A4 " | 125/1000 | 500.9, DNF | | | L.M.=33.1+ |
| B3 " | 125/1000 | 20.0 | | | L.M.=31.05 |
| C3 " | 125/1000 | 13.6 | | | L.M.=30.8 |
| D3 " | 125/1000 | 152.1 | | | L.M.=32.4 |
| E3 (P/M) | 125/1000 | 474.3 increased to 135ksi lasted 128.2 hours | | | |
| F2 (cast) | 125/1000 | 17.6 | | | L.M.=30.95 |

Notes: FOL = Failed on Loading
DNF = Did Not Fail
LM = Larson Miller
% Elongation per 1 in. gauge length

specimens are by far superior to the cast material for the 1000°F tensiles, and smooth and notched rupture tests. The microstructure is very "clean" compared to the cast material. For the cast material, the specimens that had the 2125°F treatment, clearly had better ductility over the specimens that did not have this high temperature solution, demonstrating the effect of Laves phase. The resolution treatment at 1750°F was also detrimental to strength and ductility, probably due to growth of $Ni_3Cb$ plates. Metallography has been completed on these heat treatments.

## Non-Destructive Evaluation of Nozzles and Buckets

### NDE Equipment Development (TRW)

Definition of the preliminary ultrasonic system requirements for inspection of composite nozzles and buckets is in progress. Since the program will utilize TRW's existing Ultrasonic Automatic Scanner (AUS) and Ultrasonic Diagnostic Inspection System (UDIS), the main thrust of effort was applied to developing specifications and design of the digital interfacing of the referenced sub-systems.

Specifications for the five axis digital encoders were prepared and sent to prospective vendors for quotations. Preliminary hardware schematics and layouts are being generated and component procurement requisitions are being initiated.

### NDE Simulator Samples

The first of four NDE specimens (NDE-4) for developing inspection techniques has been assembled and HIP diffusion bonded. This sample contains six 0.094" OD X .007" wall 304L tubes inside a composite structure which simulates bucket/nozzle design dimensions (Figure 7). Prior to assembly and HIP, various size defects were placed as indicated in Figure 7 using

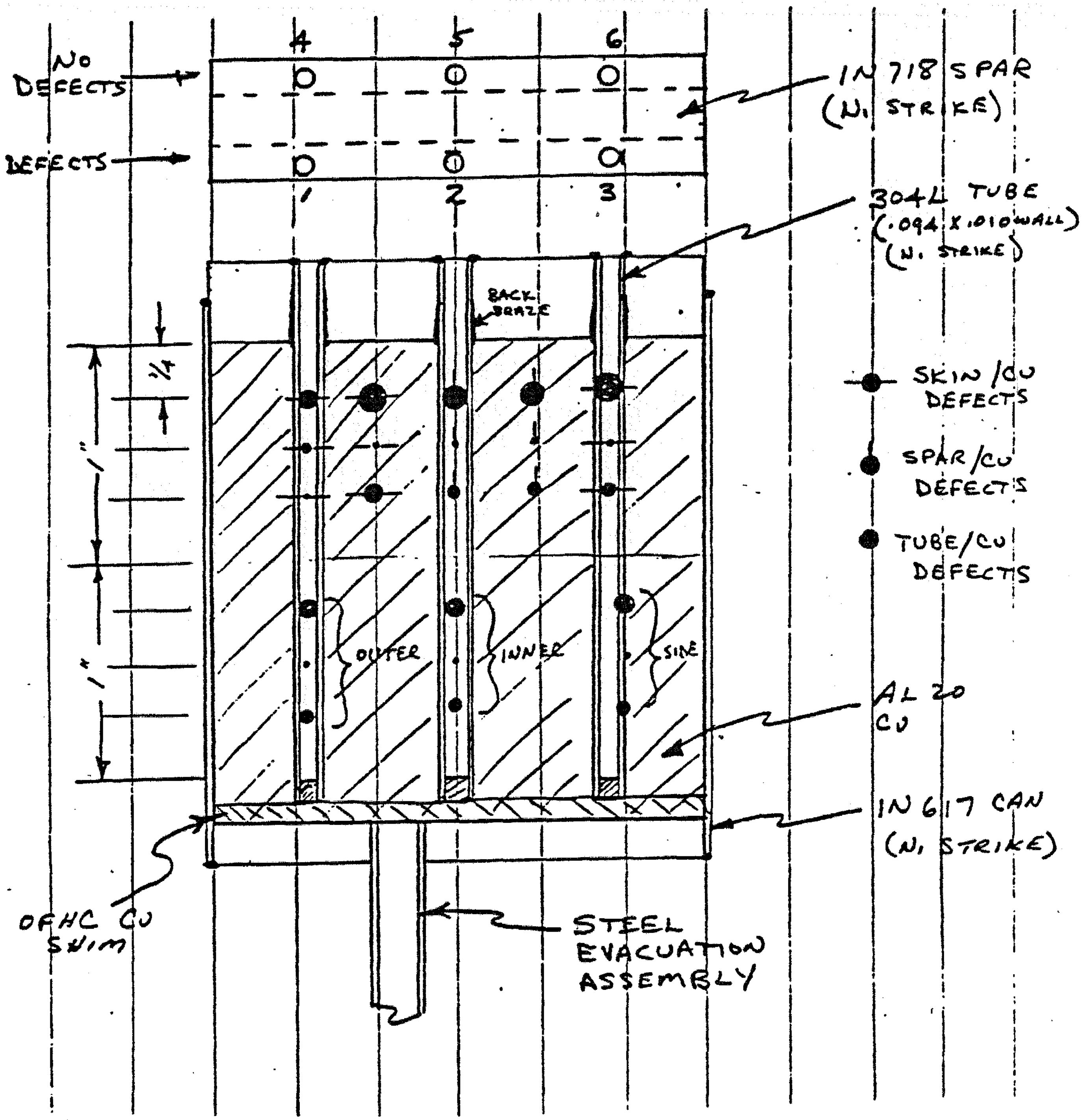


Figure 7. Schematic of NDE-4 specimen showing location of Nicrobraze stop-off/mica flake defects.

a mixture of Nicrobraze stop-off and mica flake to produce unbonded regions. Although a leak occurred in this sample sometime late in the HIP cycle (1750°F/15 ksi/2 hrs), all diffusion bonded interfaces of interest remained bonded and the sample will be used for evaluation of NDE methods. Examination of sections from the top and bottom of this sample revealed possible leaks developed in the .007" wall tubes where fit-ups between the Cu inserts and the endcaps were poor. Subsequent specimens (NDE-5, NDE-6 and NDE-7) will be more precisely machined and assembled to avoid the gaps which can lead to tube ballooning and rupture.

Eddy Current Development

This program will determine the feasibility of using eddy current testing principles to inspect the bond integrity between cooling tubes and their copper substrate in composite buckets and nozzles.

Material to be used in the fabrication of the traverse mechanism has been ordered. Fabrication will be initiated during the next month.

Four 0.070" diameter eddy current probes have been manufactured by Nortec Corp. A composite sample (NDE-4) containing cooling tubes with associated processing type flaws has been supplied to Nortec for probe checkout. This sample will be used to evaluate the probes sensitivity to processing flaws. The cooling tubes in this sample have been measured to be 0.090" diameter, approximately 0.020" larger than the probe diameter. In order to determine the effect of probe to tube diameter, a 0.080" diameter probe will be made and compared with its corresponding 0.070" diameter probe type.

NDE Support Studies

A model has been developed that closely approximates the measured ultrasonic pulse amplitudes reflected from the cooling tubes in the HTTT blade geometry. Using these calculations as a reference, work is continuing to develop a model for flaw size. The flaw size model calculations will also permit a threshold and the ambient acoustic noise level.

Plasma Spray Development

A course particle size of IN671 powder (+400, 325 mesh) was sprayed onto Cu and IN718 rod substrates, with and without the use of the transferred arc.

The non-transferred arc coatings were approximately 53 mils thick; the transferred arc coatings were approximately 33 mils thick.

A preliminary metallographic examination of these coatings indicates that they are quite dense and well bonded to the substrates. The high density of these coatings is somewhat of a surprise because previous (non HTTT Program) experience with other coatings deposited using +400, -325 mesh powder were significantly less dense than those deposited using 400 mesh powder.

Rod and plate substrates of Cu and IN718 were coated using -400 mesh IN617 powder. The deposition conditions used were the same as those reported above for IN671.

Samples from these specimens were examined metallographically. It was observed that the coatings are dense; however, there was evidence of cracking at or near the IN617/IN718 interface for the coatings deposited using the nontransferred arc condition.

The coating substrate bond was very good for the IN617/IN718 specimens deposited using the transferred arc. No tendency toward debonding was observed for any of the IN617/Cu specimens.

This concludes the initial Phase I effort of the Plasma Spray Development Program. This effort has demonstrated the capability to use a plasma sprayed coating of IN671 or IN617 in a thickness of up to 0.030" as an alternate to the sheet metal cladding approach currently used in the prime composite fabrication scheme. Further work is being planned to utilize the plasma spray process to deposit the required high thermal conductivity copper alloy in a composite bucket fabrication scheme.

HTTT Stress Corrosion Cracking (SCC)

Constant extension rate testing of both IN718 and IN706 has not resulted in any environmentally assisted intergranular stress corrosion cracking.

An IN718 CERT (Constant Elongation Rate Test) was run at $1 \times 10^{5}$ in/in/min on a specimen with a graphite felt skirt and a A286 steel skirt positioned from shoulder to shoulder. The uniform elongation was reduced from 19.5% on a specimen which did not contain a skirt to 12.5%. The secondary cracking along the gage section was much more pronounced than on any other specimens. There was also some discoloration on the fracture surface illustrating that surface cracks were present prior to the final fracture. A SEM investigation of the fracture surface is being done.

The first of the tests on IN706 was run at 550°F in 8 ppm $O_2$ water at a nominal strain rate of $5 \times 10^{-5}$ in/in/min. The uniform elongation to failure was 16.5% and the preliminary investigation shows the fracture to be ductile in a shear mode, similar to the IN718 failures.

Both the Instron machine and autoclaves have arrived. In addition, autoclaves for the constant deflection tests have arrived and the machining of the fixtures is almost complete. Pieces of IN718 and A286 plate are being cold rolled to 0.060" for specimens.

## Bucket and Nozzle Corrosion Improvement

Both of the initial 1175°F screening tests have been completed. Specimens exposed to static air for 1000 hours are undergoing X-ray diffraction analysis to determine the nature of their surface oxides. The two batches of specimens exposed in the fused-salt pot furnace test for 484 or 576 hours have been submitted for metallographic evaluation; selected alloys will also be evaluated in X-ray diffraction. Visual inspection indicates that IN671 was the most resistant alloy, followed by Fe-base alloys GE-2541, 446ss and 430ss. A second pot furnace screening test has been initiated with these same alloys at 1100°F to reduce the severity of the attack. Three new sets of alloys have been ordered as chill-cast ingots; these are modifications of IN671, IN617 and IN718 to strengthen weaknesses currently existing in each of these alloys.

## Hot Particulate Erosion

A proposal has been received from AVCO, which uses test facilities consisting mainly of a 500 KW plasma arc heater with provisions for particle injection. The measurement of velocity and concentration of particle field can be made by the use of a double-pulsed-laser shadowgraph technique which has proven successful in their recent work. It is expected that the technical evaluation of the proposals be made shortly.

## Monolithic Alloy Testing

These test programs are aimed at obtaining information on the creep, high cycle fatigue (HCF), low cycle fatigue (LCF) and combined creep/HCF behavior of alloys to be used for monolithic parts in the HTTT. The alloys in the program are cast U500 (combustor hardware), cast IN718 (combustor hardware), cast and HIP IN718 (2nd stage nozzle and bucket and 3rd stage nozzle), and forged IN718 (3rd stage bucket).

The current status of this program is that the IN718 wrought material has been received at the machining vendor. Test samples will be available for creep LCF and HCF testing in early August. The purchase orders for all cast materials have not yet been reissued since the original orders with Misco/Whitehall were cancelled. However, some cast IN718 slabs kept over from another program will be HIPed, aged and made into creep specimens.

Composite Specimen Test

Prediction of parts lives on monolithic parts is a relatively straightforward procedure utilizing fatigue, creep and fracture mechanics techniques. Parts made by combining two or more materials present a more difficult and largely unknown problem when parts lives need to be predicted; especially, under large thermal gradient situations. Hence, to help establish life criteria for composite structures based on the more easily determined properties of the component materials, a test program utilizing a composite sample subjected to a large thermal gradient has been undertaken. These experiments will not only help establish parts lives, but will also identify the most likely failure mode in the composite and help determine the influence of "local" failure on the total sample failure.

During this report period, the heat flux model has been designed and released for manufacturing quotes. The test vendor is evaluating quotes from vendors for manufacture of the graphite heater. When this selection is made, the graphite manufacturer will be visited in order to insure a complete understanding of the heater requirements. The final design review of the test system has been postponed until August 10th.

Base Material Specimen Machining

Additional IN617 material has been sent to Stulen Machine Co. for machining into tensile bars. Material from three heats of Nitronic 50 is being heat treated prior to being sent out for specimen machining.

The wrought MZC copper has arrived. An end was cut off of one of the bars for metallographic examination and for a hardness traverse. If the hardness traverse and the metallographic examination reveal that the bars are uniform then the MZC will be used for mechanical property evaluation.

Physical Properties Test Program

As of this writing, Dynatech has not performed the thermal coefficient of expansion tests on the Al-60 copper. Dynatech has promised that this work will be completed by Aug. 1.

Southern Research Institute has been sent a shipment of material for physical property evaluation. The shipment sent included: Al-60, CuNiTi, A-286, and IN617.

Copper Alloy LCF

Two specimens from HIPed powder MZC were tested at 600°F under two minute tension hold time conditions. The two test results indicated that the powder MZC results were similar to the results obtained on wrought MZC.

Copper Alloy Creep/Rupture Tests

Only one specimen is in test at this time. An MZC specimen loaded at 18 ksi at a temperature of 600°F has been in test over 1500 hours.

Skin Alloy LCF

IN617 is presently being tested. IN671, the alternate skin alloy is not due to be shipped until September 29.

Skin Alloy Creep/Rupture Tests

The following IN617 tests are in progress:

| Stress (ksi) | Temp. (°F) |
|---|---|
| 50 | 1200 |
| 30 | 1200 |
| 60 | 1000 |
| 26 | 1200 |
| 10 | 1200 |
| 40 | 1000 |

Bondline Creep/Rupture Tests

IN617 plates for specimen pre-form fabrication have been received. As soon as the MZC copper sublayer is rolled, the preforms will be HIPed and sent out for specimen machining.

Bondline LCF

A finite element temperature and thermal mismatch analysis has been completed on the concentric tube specimen. The fabrication study on the concentric specimen is in progress. Some pieces for the fabrication study have been machined, but no specimen preforms have been HIPed.

## REPORTING CATEGORY XII

## Program Management

Contract Modifications

- Contract Modification # M017 was received from DOE on June 30,

1978. This modification extended the date for contract definition from June 30, 1978 to July 31, 1978.

Subcontractor Activities

- Munroe - The additional data requested from Munroe was received. An audit of their proposal was initiated and is nearing completion. The findings and the GE recommendation will be made to DOE during the next month.

- C.F. Braun and Co.
  - -- A meeting was held at CF Braun on July 17, 1978 to discuss PGCUS instrumentation.
  - -- Two engineers from CF Braun visited GE Schenectady during FW30 to identify and locate tie-in points between the existing and the new clean up systems, and to clarify any discrepancies between the available physical clean up system drawings and the "as is" plant.

Internal Technical/Program Meetings

- A review of the Mechanics of Materials Programs was conducted on July 12, 1978.

- A review of the First Stage Hot Gas Path Nozzle was conducted on July 6, 1978.

- A review of the Second Stage Hot Gas Path Nozzle was conducted on July 18, 1978.

- The HTTT Monthly Program Review Meeting was conducted on July 21, 1978.

## Miscellaneous

- In response to a request from DOE, GE provided comments to a Mitre Working Paper 12994 (Review of HTTT Program Low Btu Gas Fueled Power Plant, Material and Energy Balance) in a letter dated July 6, 1978.

- GE responded to two seperate DOE requests for additional copies of specific Monthly Cost Reports.

- In a letter dated July 21, 1978, GE responded to a DOE request for "Rough Order of Magnitude" costs to perform several additional tasks for the DOE HTTT Program Manager.

- On July 24, 1978, GE provided Mr. W. Boyam of the Mitre Corp. with the results of a NOx Emission Study.

- On July 28, 1978, a letter was transmitted to the ACO explaining our procedures in regard to intradivision cost transfers under the HTTT contract.

## REPORTING CATEGORY XIII
## Documentation and Reports

The following contract data deliverables were prepared and submitted on schedule:

- On July 10, 1978, the Monthly Technical Progress Report for the month of June 1978 was submitted on schedule.

- On July 14, 1978, a "Preliminary Draft" copy of the Quarterly Technical Progress Report for the period April 1978 thru June 1978 was submitted on schedule to DOE for their review and comments.

- On July 19, 1978, the Contract Cost Report for the month of June 1978 was submitted on schedule.

## REPORTING CATEGORY XIV

## Review and Evaluation

On July 26th and 27th, 1978, General Electric, on the direction of the Program Manager, DOE HTTT Program, conducted a status review of the General Electric program for several DOE representatives and for Dr. Holighaus, a representative from the West German Government. A conference report for this meeting is being prepared.