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Certification of ANVIL 5000 Mass Properties, ANVIL 5000 Version 1.2 Simple Homogeneous Shapes and Point-Mass Assemblies

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CERTIFICATION OF ANVIL 5000 MASS PROPERTIES
ANVIL 5000 Version 1.2
Simple Homogeneous Shapes and Point-Mass Assemblies

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ABSTRACT

This document evaluates the accuracy of mass properties computations from the ANVIL 5000 CAD system. Mass property results and a measure of their accuracy are given for both individual solid model components and for point-mass assembly sums. The mass properties' accuracies were determined by comparing the results obtained from ANVIL 5000 with either theoretical values or with results from another trusted software package.

ACKNOWLEDGEMENTS

The author wishes to acknowledge a similar study completed by Gregory N. Barnes, a HBCU student from Prairie View A&M University, supervised by Steve Bacca (2833) and mentored by Greg Neugebauer (2854) at Sandia during the Summer of 1988. Barnes' work provided a guideline for this report including the general outline and the geometric shapes used in section 3.1. Also, point mass component data was contributed by Roxy Sippio (2854), and point mass assembly results used for comparisons in section 3.2 were provided by Irene Kolb (2858).

Summary

This report evaluates the accuracy of ANVIL 5000 v1.2 mass properties computations for both solid model components and point-mass assemblies. The accuracy of component mass properties was determined by comparing ANVIL 5000's results with textbook values for several standard shapes. The assembly mass properties were evaluated by comparing ANVIL 5000's results with those from another trusted software package.

For component accuracy, the following table shows the percent error for each mass property averaged across all tested shapes:

AVERAGE PERCENT ERROR FOR ALL EIGHT STANDARD SHAPES

Volume	0.046
Weight	0.034
Center of Mass	
xt	0.09
yt	0.04
zt	0.10
Moments of Inertia	
xt	0.56
yt	0.26
zt	0.91

From the above table it was concluded that ANVIL 5000 can compute mass properties within approximately a +/- 1 percent error band.

In the case of assemblies, it was concluded that ANVIL 5000 can sum assembly mass properties with no significant error.

Table of Contents

1.0 Introduction

Mass properties analysis at Sandia is critical when packaging sub-assembly components in highly sophisticated weapon systems. Sandia's Mass Properties Laboratory measures component mass properties and uses the results to stabilize the weapon systems. A thorough computer-aided mass properties analysis in the early design phase can save substantial amounts of time and money during the laboratory prototype testing process and during the entire product design cycle.

MCS's (Manufacturing Consulting Services) ANVIL 5000 MCAD system is the proposed tool for performing mass properties analysis during the design phase. ANVIL 5000 is currently used at SNLA for all mechanical design layout and detail drawings and is also used extensively by manufacturing personnel in numerical control machining. SNLA currently has over 140 VAX workstations licensed to run ANVIL 5000 which together release hundreds of engineering drawings annually.

ANVIL 5000, a floating point based system, interfaces to several engineering analysis packages including PATRAN for finite element analysis and DRAM for kinematic analysis. Regarding mass properties analysis, ANVIL 5000 has the ability to read point-mass data from externally generated ASCII files for use in summing assembly mass properties. This capability allows designers to incorporate mass property data previously generated by external sources into their analyses on ANVIL 5000. Furthermore, user's can easily share their mass property data.

The objective of this report is to determine the accuracy of ANVIL 5000's current mass properties computations before releasing the software to design engineers for the specific task of analyzing mass properties. This includes 1) outlining a method for thoroughly testing all ANVIL 5000's current mass properties capabilities, and 2) using the test results to make the above determination.

2.0 Method and Procedure

This section describes the method followed for evaluating the accuracy of ANVIL 5000's mass properties computations. ANVIL 5000 currently computes mass properties for both individual components and component assemblies. For both of these, the proposed test method was to compare results from ANVIL 5000 with values from another source known to be valid. The percent error was then determined between the actual values and those given by ANVIL 5000.

For individual components, the exact mass properties were calculated by explicit textbook formulas for several standard shapes, using two cases per shape. Each case was also modeled as a solid model part using Omnisolids, ANVIL 5000's solid modeler. ANVIL 5000 then computed the mass properties for each of these solid model parts, and the results were compared to the theoretical values.

For component assemblies, three point-mass assemblies were modeled on both ANVIL 5000 and on Schlumberger's Applicon Image system which was used by SNLA prior to ANVIL 5000. The resulting ANVIL 5000 assembly mass properties results were then compared with results from The Applicon system. Assembly mass properties were computed on the Image system using a software package called UCMD 92 (UCMD, User Command, is Applicon's CAD applications programming environment), a proven assembly mass properties analyzer.

3.0 Results

This section presents the mass properties test results for each test case from both ANVIL 5000 and the comparison source. The following units apply to all mass properties analysis:

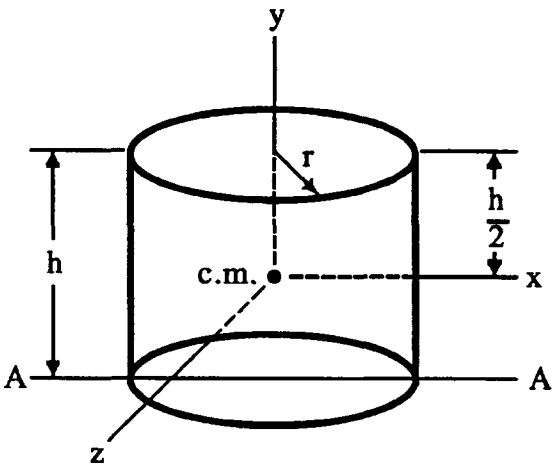
Length	inches (in)
Mass	Pounds mass (lbm)
Density (ρ)	pounds mass per inch cubed (lbm/in^3)
Moment of Inertia	pounds mass inches squared ($lbm\text{-}in^2$)

The following material properties were used for the individual component mass properties analysis:

Case 1	Aluminum 6061	ρ = .098
Case 2	Tungsten	ρ = .681

3.1 Individual Components

3.1.1 Right Circular Cylinder



$$I_{xx} = I_{zz} = \frac{m}{12}(3r^2 + h^2)$$

$$I_{yy} = \frac{1}{2}mr^2$$

$$I_{AA} = \frac{m}{12}(3r^2 + 4h^2)$$

Case 1: r = 30 h = 60 ρ = .098

Theoretical
Ixx = Izz = 872826.868
Iyy = 7481388.745

Computed by ANVIL 5000

```
                COMPONENT MASS PROPERTIES
                        ID NUMBER   1
                             NAME   RTCIRCYL1
                             TYPE   OMNISOLID
                     SURFACE AREA   16963.7778
                           VOLUME   169635.8324
                           WEIGHT   16624.3116
                          DENSITY   0.098

                CENTER OF MASS XT   -0.002632
                                YT   29.99936
                                ZT   -0.0000226

  AXIAL MOMENTS OF INERTIA I(XX)    8647205.4986
                           I(YY)    8644244.9877
                           I(ZZ)    7476840.0262
```

Case 2: r = .25 h = .5 ρ = .681

Theoretical
Ixx = Izz = .002437495
Iyy = .002089282

Computed by ANVIL 5000

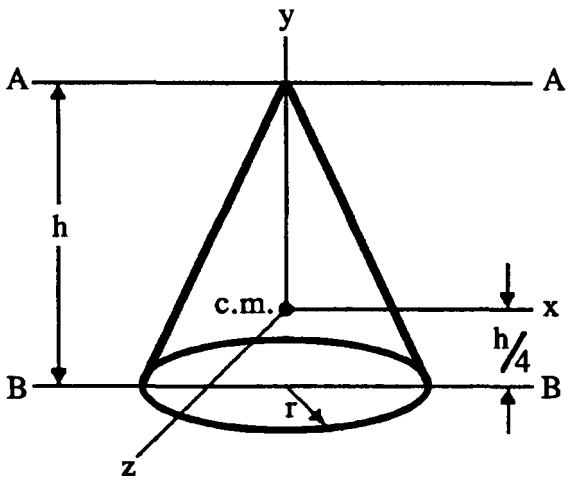
```
                COMPONENT MASS PROPERTIES
                        ID NUMBER   1
                             NAME   RTCIRCYL2
                             TYPE   OMNISOLID
                     SURFACE AREA   1.1780
                           VOLUME   0.09817
                           WEIGHT   0.06685
                          DENSITY   0.681

                CENTER OF MASS XT   -0.0000219
                                YT   .24999995
                                ZT   -0.000000

  AXIAL MOMENTS OF INERTIA I(XX)    0.002415
                           I(YY)    0.002088
                           I(ZZ)    0.002414
```

Percent Error Results

Component Property	Percent Error Case 1	Case 2	Average % Error
Volume	.006	.006	.006
Weight	.005	.006	.0055
Center of Mass			
xt	0	0	0
yt	0	0	0
zt	0	0	0
Moments of Inertia			
Ixx	.93	.93	.93
Iyy	.06	.06	.06
Izz	.96	.96	.96

TOTAL AVERAGE ERROR (TAE) 1.96

3.1.2 Right Circular Cone



$$I_{xx} = I_{zz} = \frac{3m}{80}(4r^2 + h^2)$$

$$I_{yy} = \frac{3}{10}mr^2$$

$$I_{AA} = \frac{3m}{20}(r^2 + 4h^2)$$

$$I_{BB} = \frac{m}{20}(3r^2 + 2h^2)$$

Case 1: r = 30 h = 60 ρ = .098

Theoretical
Ixx = Izz = 1496277.749
Iyy = 1496277.749

Computed by ANVIL 5000

COMPONENT MASS PROPERTIES		
ID NUMBER		1
NAME		RTCONE1
TYPE		OMNISOLID
SURFACE AREA		9148.4358
VOLUME		56540.4425
WEIGHT		5540.9634
DENSITY		0.098
CENTER OF MASS	XT	-0.0058
	YT	45.0000
	ZT	-0.000075
AXIAL MOMENTS OF INERTIA	I(XX)	1495374.1237
	I(YY)	1492356.8916
	I(ZZ)	1493042.8770

Case 2: r = .25 h = .5 ρ = .681

Theoretical
Ixx = Izz = .0004178
Iyy = .0004178

Computed by ANVIL 5000

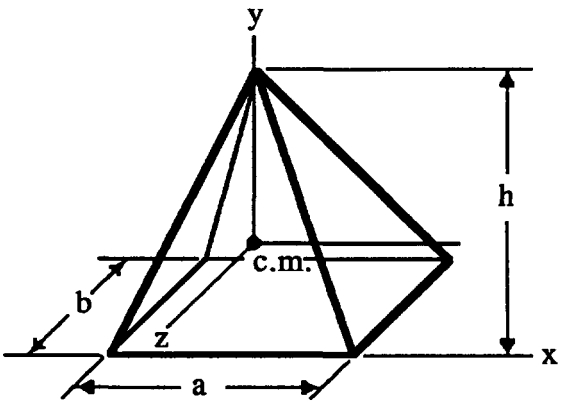
```
                COMPONENT MASS PROPERTIES
                       ID NUMBER  1
                            NAME  RTCONE2
                            TYPE  OMNISOLID
                    SURFACE AREA  0.6353
                          VOLUME  0.0327
                          WEIGHT  0.02228
                         DENSITY  0.681

                CENTER OF MASS XT  -0.00005
                               YT  0.375000
                               ZT  -0.00000

AXIAL MOMENTS OF INERTIA I(XX)  0.0004176
                         I(YY)  0.0004168
                         I(ZZ)  0.0004170
```

Percent Error Results

Component Property	Percent Error Case 1	Case 2	Average % Error
Volume	.014	.014	.014
Weight	.014	.018	.016
Center of Mass			
xt	0	0	0
yt	0	0	0
zt	0	0	0
Moments of Inertia			
Ixx	.06	.07	.065
Iyy	.26	.26	.26
Izz	.22	.22	.22

TOTAL AVERAGE ERROR (TAE) 0.58

3.1.3 Right Rectangular Pyramid



$$I_{xx} = \frac{m}{80}(4b^2 + 3h^2)$$

$$I_{yy} = \frac{m}{20}(a^2 + b^2)$$

$$I_{zz} = \frac{m}{80}(4a^2 + 3h^2)$$

Case 1: $a = b = h = 60$ $\rho = .098$

Theoretical
Ixx = 2222640
Iyy = 2540160
Izz = 2222640

Computed by ANVIL 5000

```
                COMPONENT MASS PROPERTIES
                      ID NUMBER  1
                           NAME  PYRAMID1
                           TYPE  OMNISOLID
                   SURFACE AREA  12656.0753
                         VOLUME  72000.0000
                         WEIGHT  7056.00000
                        DENSITY  0.098

                CENTER OF MASS XT  .3820349
                                YT  .3820349
                                ZT  15.00000

AXIAL MOMENTS OF INERTIA I(XX)  2204568.2676
                        I(YY)  2535527.5533
                        I(ZZ)  2139872.9529
```

Case 2: $a = b = h = .5$ $\rho = .098$

Theoretical
Ixx = 0.0000620703
Iyy = 0.000709375
Izz = 0.000620703

Computed by ANVIL 5000

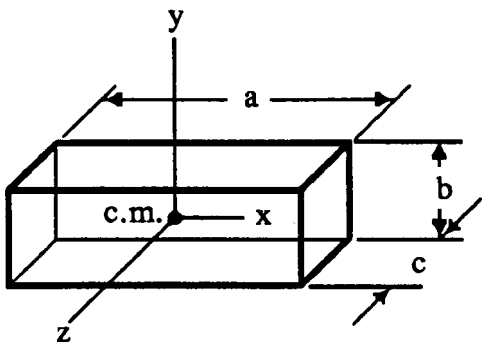
```
                COMPONENT MASS PROPERTIES
                       ID NUMBER  1
                            NAME  PYRAMID2
                            TYPE  OMNISOLID
                    SURFACE AREA  0.9080
                          VOLUME  0.0417
                          WEIGHT  0.0284
                         DENSITY  0.681

                CENTER OF MASS XT  0.0032
                               YT  0.0032
                               ZT  0.1250

AXIAL MOMENTS OF INERTIA I(XX)     0.0006157
                        I(YY)      0.0007081
                        I(ZZ)      0.0005976
```

Percent Error Results

Component Property	Percent Error Case 1	Case 2	Average % Error
Volume	0	0	0
Weight	0	0	0
Center of Mass			
xt	.64	.60	.62
yt	0	0	0
zt	.64	.60	.62
Moments of Inertia			
Ixx	.8	.8	.8
Iyy	.18	.18	.18
Izz	3.7	3.7	3.7

TOTAL AVERAGE ERROR (TAE) 5.92

3.1.4 Rectangular Prism



$$I_{xx} = \frac{m}{12}(b^2 + c^2)$$

$$I_{yy} = \frac{m}{12}(a^2 + c^2)$$

$$I_{zz} = \frac{m}{12}(a^2 + b^2)$$

Case 1: $a = 60$ $b = c = 30$ $\rho = .098$

Theoretical

Ixx = 793800.0
Iyy = 1984500.0
Izz = 1984500.0

Computed by ANVIL 5000

COMPONENT MASS PROPERTIES	
ID NUMBER	1
NAME	RECTPRISM1
TYPE	OMNISOLID
SURFACE AREA	9000.0000
VOLUME	540000.0000
WEIGHT	5292.0000
DENSITY	0.098
CENTER OF MASS XT	0.0000
YT	0.0000
ZT	0.0000
AXIAL MOMENTS OF INERTIA I(XX)	781076.0452
I(YY)	1952690.1129
I(ZZ)	1952690.1129

Case 2: $a = .5$ $b = c = .25$ $\rho = .098$

Theoretical
Ixx = 0.00022168
Iyy = 0.000554199
Izz = 0.000554199

Computed by ANVIL 5000

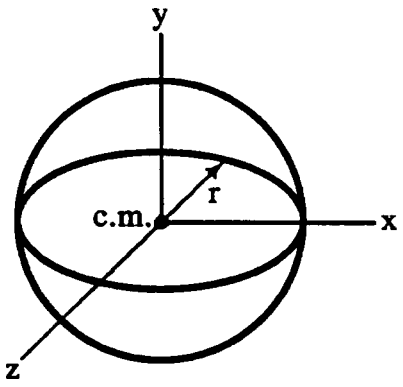
```
COMPONENT MASS PROPERTIES
        ID NUMBER   1
             NAME   RECTPRISM2
             TYPE   OMNISOLID
     SURFACE AREA   0.6250
           VOLUME   0.03125
           WEIGHT   0.02128
          DENSITY   0.681

CENTER OF MASS XT   0.0000
                YT   0.0000
                ZT   0.0000

AXIAL MOMENTS OF INERTIA I(XX)   0.0002181
                         I(YY)   0.0005453
                         I(ZZ)   0.0005453
```

Percent Error Results

Component Property	Percent Error Case 1	Case 2	Average % Error
Volume	0	0	0
Weight	0	0	0
Center of Mass			
xt	0	0	0
yt	0	0	0
zt	0	0	0
Moments of Inertia			
Ixx	1.6	1.7	1.65
Iyy	1.6	1.6	1.6
Izz	1.6	1.6	1.6

TOTAL AVERAGE ERROR (TAE) 4.85

3.1.5 Sphere



$$I_{xx} = I_{yy} = I_{zz} = \frac{2}{5}mr^2$$

Case 1: r = 60 ρ = .098

Theoretical

Ixx = Iyy = Izz = 127682367.9

Computed by ANVIL 5000

```
                COMPONENT MASS PROPERTIES
                      ID NUMBER  1
                           NAME  SPHERE1
                           TYPE  OMNISOLID
                   SURFACE AREA  45195.3051
                         VOLUME  904057.0796
                         WEIGHT  88597.5938
                        DENSITY  0.098

                CENTER OF MASS XT  -0.000304
                               YT  0.0000
                               ZT  -0.0239

AXIAL MOMENTS OF INERTIA I(XX)  127586737.1443
                        I(YY)  127577950.6801
                        I(ZZ)  127687897.8238
```

Case 2: $r = .5$ $\rho = .681$

Theoretical

$Ixx = Iyy = Izz = 0.035657077$

Computed by ANVIL 5000

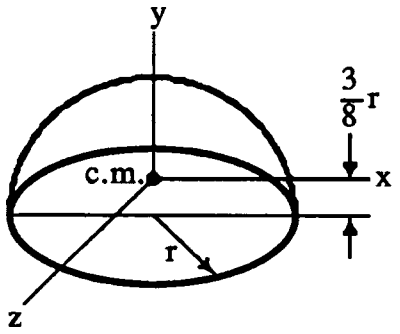
```
                COMPONENT MASS PROPERTIES
                      ID NUMBER  1
                           NAME  SPHERE2
                           TYPE  OMNISOLID
                   SURFACE AREA  3.1386
                         VOLUME  0.5232
                         WEIGHT  0.3563
                        DENSITY  0.681

                CENTER OF MASS XT  -0.0000
                               YT  0.0000
                               ZT  -0.0001

AXIAL MOMENTS OF INERTIA I(XX)  0.035630
                        I(YY)  0.035628
                        I(ZZ)  0.03567
```

Percent Error Results

Component Property	Percent Error Case 1	Case 2	Average % Error
Volume	.08	.08	.08
Weight	.08	.08	.08
Center of Mass			
xt	0	0	0
yt	0	0	0
zt	.04	.04	.04
Moments of Inertia			
Ixx	.07	.07	.07
Iyy	.08	.08	.08
Izz	.004	.004	.004

TOTAL AVERAGE ERROR (TAE) 0.354

3.1.6 Hemisphere



$$I_{xx} = I_{zz} = \frac{83}{320} mr^2$$

$$I_{yy} = \frac{2}{5} mr^2$$

Case 1: $r = 60$ $\rho = .098$

Theoretical

Ixx = Izz = 41397017.75

Iyy = 63841183.99

Computed by ANVIL 5000

COMPONENT MASS PROPERTIES

ID NUMBER	1
NAME	HEMISPHERE1
TYPE	OMNISOLID
SURFACE AREA	33859.5031
VOLUME	450940.4174
WEIGHT	44192.1609
DENSITY	0.098
CENTER OF MASS XT	0.0469
YT	22.5961
ZT	-0.0964
AXIAL MOMENTS OF INERTIA I(XX)	4107739.6905
I(YY)	63583388.0621
I(ZZ)	41230255.7382

Case 2: $r = .5$ $\rho = .681$

Theoretical
Ixx = Izz = .011560693
Iyy = .017828538

Computed by ANVIL 5000

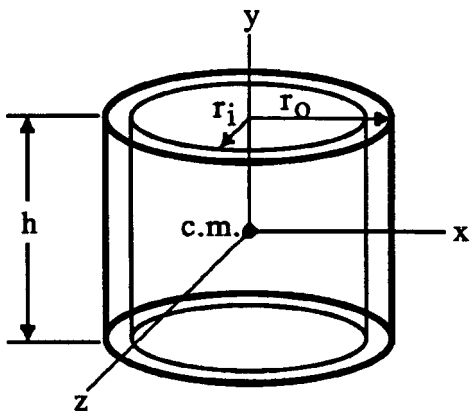
```
                COMPONENT MASS PROPERTIES
                       ID NUMBER  2
                            NAME  HEMISPHERE2
                            TYPE  OMNISOLID
                    SURFACE AREA  2.3476
                          VOLUME  0.2618
                          WEIGHT  0.1783
                         DENSITY  0.681

                CENTER OF MASS XT  -0.0000
                                YT  0.1880145
                                ZT  -0.0000

AXIAL MOMENTS OF INERTIA I(XX)  0.0115334
                        I(YY)  0.0178304
                        I(ZZ)  0.0115309
```

Percent Error Results

Component Property	Percent Error Case 1	Case 2	Average % Error
Volume	.32	.03	.18
Weight	.32	.02	.17
Center of Mass			
xt	.08	0	.08
yt	.43	.27	.35
zt	.16	0	.16
Moments of Inertia			
Ixx	.8	.24	.52
Iyy	.40	.01	.20
Izz	.40	.26	.33

TOTAL AVERAGE ERROR (TAE) 1.99

3.1.7 Thin Circular Cylindrical Shell



$$I_{xx} = I_{zz} = \frac{\rho\pi r_o^2 h}{12}(3r_o^2 + h^2) - \frac{\rho\pi r_i^2 h}{12}(3r_i^2 + h^2)$$

$$I_{yy} = \frac{\rho\pi h}{2}(r_o^4 - r_i^4)$$

Case 1: $r_o = 32$ $r_i = 28$ $h = 60$ $\rho = .098$

Theoretical

Ixx = Izz = 3333928.505

Iyy = 4007807.66

Computed by ANVIL 5000

```
                COMPONENT MASS PROPERTIES
                      ID NUMBER   1
                           NAME   CYLSHELL1
                           TYPE   OMNISOLID
                   SURFACE AREA   24127.4170
                         VOLUME   45238.5459
                         WEIGHT   4433.3775
                        DENSITY   0.098

                CENTER OF MASS XT  -0.0033
                                YT  29.9999
                                ZT  -0.0000

      AXIAL MOMENTS OF INERTIA I(XX)  3313324.3586
                               I(YY)  4007746.3083
                               I(ZZ)  3311810.1107
```

Case 2: $r_o = .6$ $r_i = .4$ $h = .25$ $\rho = .681$

Theoretical
Ixx = Izz = .014463402
Iyy = .027812520

Computed by ANVIL 5000

COMPONENT MASS PROPERTIES

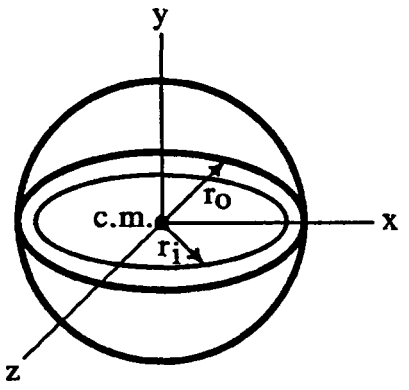
ID NUMBER	1
NAME	CYLSHELL2
TYPE	OMNISOLID
SURFACE AREA	2.8274
VOLUME	0.1571
WEIGHT	0.1070
DENSITY	0.681
CENTER OF MASS XT	-0.0000
YT	0.12499
ZT	-0.0000
AXIAL MOMENTS OF INERTIA I(XX)	0.0144591
I(YY)	0.0278113
I(ZZ)	0.0144486

Percent Error Results

Component Property	Percent Error Case 1	Case 2	Average % Error
Volume	0	.001	0
Weight	0	.001	0
Center of Mass			
xt	0	0	0
yt	0	0	0
zt	0	0	0
Moments of Inertia			
Ixx	.62	.03	.33
Iyy	.002	.004	.003
Izz	.66	.1	.38

TOTAL AVERAGE ERROR (TAE) 0.713

3.1.8 Thin Spherical Shell



$$I_{xx} = I_{yy} = I_{zz} = \frac{8\rho\pi}{15}(r_o^5 - r_i^5)$$

Case 1: $r_o = 32$ $r_i = 28$ $\rho = .098$

Theoretical

Ixx = Iyy = Izz = 2683704.725

Computed by ANVIL 5000

COMPONENT MASS PROPERTIES

ID NUMBER	1
NAME	SPHERESHELL1
TYPE	OMNISOLID
SURFACE AREA	22698.0865
VOLUME	45266.9582
WEIGHT	4436.1619
DENSITY	0.098
CENTER OF MASS XT	-0.0002
YT	-0.0092
ZT	0.0000
AXIAL MOMENTS OF INERTIA I(XX)	2680911.6032503
I(YY)	2683821.6682562
I(ZZ)	2680726.9239911

Case 2: $r_o = .6$ $r_i = .4$ $\rho = .681$

Theoretical
Ixx = Iyy = Izz = .077042106

Computed by ANVIL 5000

```
OMNISOLIDS COULD NOT PERFORM NECESSARY BOLLEAN OPERATION
WITH PRIMITIVES OF THIS SIZE!
```

Percent Error Results

Component Property	Percent Error Case 1	Case 2	Average % Error
Volume	.09	-	.09
Weight	.09	-	.09
Center of Mass			
xt	0	-	0
yt	0	-	0
zt	0	-	0
Moments of Inertia			
Ixx	.1	-	.1
Iyy	.004	-	.004
Izz	.1	-	.1

TOTAL AVERAGE ERROR (TAE) 0.304

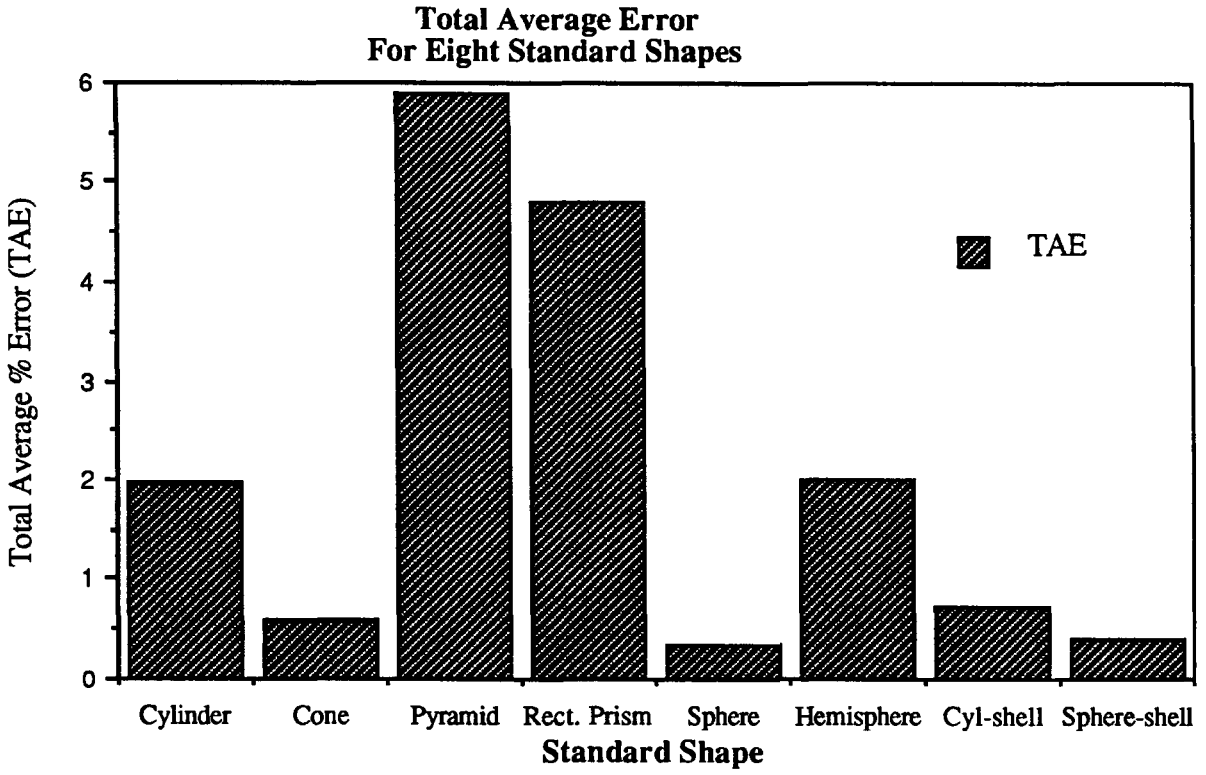
3.1.9 Discussion

From the above results, it is seen that on the average ANVIL 5000 can compute most component mass properties with relatively little error. However, the average error for the axial moments of inertia, particularly the zt component, is great enough for concern. The following table shows the average percent error across all eight standard shapes for each mass property:

AVERAGE PERCENT ERROR FOR ALL EIGHT STANDARD SHAPES

Volume	0.046
Weight	0.034
Center of Mass	
xt	0.09
yt	0.04
zt	0.10
Moments of Inertia	
xt	0.56
yt	0.26
zt	0.91

It is also evident that ANVIL 5000 computes the mass properties for some shapes more accurately than others. For each standard shape a factor of Total Average Error (TAE) was calculated as the sum of the average error of each mass property. The TAE for each standard shape is included in each shape's percent error table. The following graph compare the TAE for each standard shape:



From the above graph, it is seen that ANVIL 5000's computed mass properties are the most accurate for a sphere and least accurate for a pyramid. As would be expected, ANVIL 5000's mass properties computations are most accurate for shapes with rotational symmetry.

3.2 Point-mass Assemblies

For each test assembly, all components were modeled as point-masses in both the ANVIL 5000 and IMAGE UCMD 92 systems. The resulting mass properties for these assemblies are presented below.

3.2.1 Ballasts (Assembly #1)

Point-mass Component List (ANVIL 5000 FORMAT)

Component #1

```
COMP TYPE = POINT MASS   ID NO = 2          NAME = SC379153B
SURF AREA = 0.0000000    I(XX) = 1.3510000  PI(X) = 0.0000000
VOLUME    = 1.8651000    I(YY) = 0.6699600  PI(Y) = 0.0000000
WEIGHT    = 1.2155000    I(ZZ) = 0.6957700  PI(Z) = 0.0000000
DENSITY   = 0.6517080    I(XY) = 0.0000000  DIR X = 1.0000 0.0000 0.0000
XT C OF M = -11.14100    I(XZ) = 0.0000000  DIR Y = 0.0000 1.0000 0.0000
YT C OF M = -0.0122430   I(YZ) = -0.183760  DIR Z = 0.0000 0.0000 1.0000
ZT C OF M = -0.0235880                      ANGLE = 0.0000000
```

Component #2

```
COMP TYPE = POINT MASS   ID NO = 11         NAME = SC376526E
SURF AREA = 0.0000000    I(XX) = 22.767000  PI(X) = 0.0000000
VOLUME    = 2.7412000    I(YY) = 7.1375000  PI(Y) = 0.0000000
WEIGHT    = 1.7865000    I(ZZ) = 15.702000  PI(Z) = 0.0000000
DENSITY   = 0.6517220    I(XY) = 0.0000000  DIR X = 1.0000 0.0000 0.0000
XT C OF M = -6.498200    I(XZ) = 0.0000000  DIR Y = 0.0000 1.0000 0.0000
YT C OF M = -0.0001362   I(YZ) = 0.0008166  DIR Z = 0.0000 0.0000 1.0000
ZT C OF M = -0.0004962                      ANGLE = 0.0000000
```

Component #3

```
COMP TYPE = POINT MASS   ID NO = 12         NAME = SC381848B
SURF AREA = 0.0000000    I(XX) = 0.1578700  PI(X) = 0.0000000
VOLUME    = 0.2851000    I(YY) = 0.0032245  PI(Y) = 0.0000000
WEIGHT    = 0.0869550    I(ZZ) = 0.1548700  PI(Z) = 0.0000000
DENSITY   = 0.3049980    I(XY) = 0.0000268  DIR X = 1.0000 0.0000 0.0000
XT C OF M = 1.2431000    I(XZ) = 0.0000120  DIR Y = 0.0000 1.0000 0.0000
YT C OF M = -0.629930    I(YZ) = 0.0045381  DIR Z = 0.0000 0.0000 1.0000
ZT C OF M = 2.8679000                       ANGLE = 0.0000000
```

Component #4

```
COMP TYPE = POINT MASS   ID NO = 2          NAME = SC376595C
SURF AREA = 0.0000000    I(XX) = 5.7263000  PI(X) = 0.0000000
VOLUME    = 4.1198000    I(YY) = 2.8867000  PI(Y) = 0.0000000
WEIGHT    = 2.6849000    I(ZZ) = 2.8867000  PI(Z) = 0.0000000
DENSITY   = 0.6517060    I(XY) = 0.0000000  DIR X = 1.0000 0.0000 0.0000
XT C OF M = 6.2640000    I(XZ) = 0.0000000  DIR Y = 0.0000 1.0000 0.0000
YT C OF M = 0.0000000    I(YZ) = 0.0000000  DIR Z = 0.0000 0.0000 1.0000
```

```
ZT C OF M = -0.0235880                          ANGLE = 0.0000000
```

Component #5

```
COMP TYPE = POINT MASS  ID NO = 14          NAME = SC385114A
SURF AREA = 0.0000000   I(XX) = 8.9848000   PI(X) = 0.0000000
VOLUME    = 1.3478000   I(YY) = 0.3141700   PI(Y) = 0.0000000
WEIGHT    = 0.8783700   I(ZZ) = 8.7610000   PI(Z) = 0.0000000
DENSITY   = 0.6517060   I(XY) = 0.2676500   DIR X = 1.0000 0.0000 0.0000
XT C OF M = 4.4205000   I(XZ) = -0.0000266  DIR Y = 0.0000 1.0000 0.0000
YT C OF M = 1.1061000   I(YZ) = -0.0013018  DIR Z = 0.0000 0.0000 1.0000
ZT C OF M = -0.0000926                      ANGLE = 0.0000000
```

Component #6

```
COMP TYPE = POINT MASS  ID NO = 15          NAME = SC379107J
SURF AREA = 0.0000000   I(XX) = 305.38000   PI(X) = 0.0000000
VOLUME    = 41.269000   I(YY) = 156.49000   PI(Y) = 0.0000000
WEIGHT    = 27.000000   I(ZZ) = 200.18000   PI(Z) = 0.0000000
DENSITY   = 0.6542440   I(XY) = 5.1182000   DIR X = 1.0000 0.0000 0.0000
XT C OF M = 3.1291000   I(XZ) = -5.667800   DIR Y = 0.0000 1.0000 0.0000
YT C OF M = 0.0564230   I(YZ) = -2.779300   DIR Z = 0.0000 0.0000 1.0000
ZT C OF M = -0.532170                       ANGLE = 0.0000000
```

Component #7

```
COMP TYPE = POINT MASS  ID NO = 16          NAME = SC377554G
SURF AREA = 0.0000000   I(XX) = 21.987000   PI(X) = 0.0000000
VOLUME    = 9.9975000   I(YY) = 10.905000   PI(Y) = 0.0000000
WEIGHT    = 6.5900000   I(ZZ) = 13.129000   PI(Z) = 0.0000000
DENSITY   = 0.6591650   I(XY) = 0.0337310   DIR X = 1.0000 0.0000 0.0000
XT C OF M = -0.804200   I(XZ) = -0.039718   DIR Y = 0.0000 1.0000 0.0000
YT C OF M = 3.5461000   I(YZ) = -8.458400   DIR Z = 0.0000 0.0000 1.0000
ZT C OF M = 3.4613000                       ANGLE = 0.0000000
```

Component #8

```
COMP TYPE = POINT MASS  ID NO = 17          NAME = SC377555G
SURF AREA = 0.0000000   I(XX) = 73.315000   PI(X) = 0.0000000
VOLUME    = 16.237000   I(YY) = 55.840000   PI(Y) = 0.0000000
WEIGHT    = 10.580000   I(ZZ) = 20.759000   PI(Z) = 0.0000000
DENSITY   = 0.6515980   I(XY) = 0.2380700   DIR X = 1.0000 0.0000 0.0000
XT C OF M = -0.788820   I(XZ) = 0.3386500   DIR Y = 0.0000 1.0000 0.0000
YT C OF M = -2.204600   I(YZ) = 24.422000   DIR Z = 0.0000 0.0000 1.0000
ZT C OF M = 1.9741000                       ANGLE = 0.0000000
```

ANVIL 5000 Assembly Results

```
ACTIVE ASSEMBLY         ID NO = 10          NAME = BALLASTS
SURF AREA = 0.0000000   I(XX) = 815.2661433PI(X) = 741.1967692
VOLUME    = 77.862500   I(YY) = 882.7689046PI(Y) = 905.9307232
WEIGHT    = 50.822225   I(ZZ) = 1063.653025PI(Z) = 1114.5605806
DENSITY   = 0.6527176   I(XY) = 55.5719324 DIR X = 1.8951 0.3372 0.3850
XT C OF M = 1.3084537   I(XZ) = -123.174866DIR Y = -0.37630.9260 0.0287
YT C OF M = -0.3677379  I(YZ) = 15.9727532 DIR Z = 0.3468 0.1696 -0.922
ZT C OF M = 0.5813814                       ANGLE = 0.0000000
```

IMAGE UCMD 92 Assembly Results

```
NAME: BALLASTS      TYPE  CELL
XCG=  1.30845       YCG=-0.367768       ZCG= 0.581381
IXX=  815.266       IYY=  882.769       IZZ=  1063.65
IXY=  55.5718       IXZ= -123.175       IYZ=  16.1381
WT =  50.8222       VOL=  77.8625       RHO=  0.652718
```

3.2.2 Components (Assembly #2)

Point-mass Component List (ANVIL 5000 FORMAT)

Component #1

```
COMP TYPE = POINT MASS  ID NO = 3          NAME = SA2977
SURF AREA = 0.0000000   I(XX) = 0.0000000  PI(X) = 0.0000000
VOLUME    = 0.1000000   I(YY) = 0.0000000  PI(Y) = 0.0000000
WEIGHT    = 0.1000000   I(ZZ) = 0.0000000  PI(Z) = 0.0000000
DENSITY   = 0.1000000   I(XY) = 0.0000000  DIR X = 1.0000 0.0000 0.0000
XT C OF M = -3.656000   I(XZ) = 0.0000000  DIR Y = 0.0000 1.0000 0.0000
YT C OF M = 0.0000000   I(YZ) = 0.0000000  DIR Z = 0.0000 0.0000 1.0000
ZT C OF M = -4.120000                      ANGLE = 0.0000000
```

Component #2

```
COMP TYPE = POINT MASS  ID NO = 4          NAME = SA3523
SURF AREA = 0.0000000   I(XX) = 0.0000000  PI(X) = 0.0000000
VOLUME    = 0.0870000   I(YY) = 0.0000000  PI(Y) = 0.0000000
WEIGHT    = 0.0870000   I(ZZ) = 0.0000000  PI(Z) = 0.0000000
DENSITY   = 0.0870000   I(XY) = 0.0000000  DIR X = 1.0000 0.0000 0.0000
XT C OF M = 1.1620000   I(XZ) = 0.0000000  DIR Y = 0.0000 1.0000 0.0000
YT C OF M = -2.157000   I(YZ) = 0.0000000  DIR Z = 0.0000 0.0000 1.0000
ZT C OF M = -4.842000                      ANGLE = 0.0000000
```

Component #3

```
COMP TYPE = POINT MASS  ID NO = 5          NAME = RIMU
SURF AREA = 0.0000000   I(XX) = 142.00000  PI(X) = 0.0000000
VOLUME    = 19.340000   I(YY) = 181.00000  PI(Y) = 0.0000000
WEIGHT    = 19.340000   I(ZZ) = 181.00000  PI(Z) = 0.0000000
DENSITY   = 19.3400000  I(XY) = 0.0000000  DIR X = 1.0000 0.0000 0.0000
XT C OF M = -2.244000   I(XZ) = 0.0000000  DIR Y = 0.0000 1.0000 0.0000
YT C OF M = -0.082000   I(YZ) = 0.0000000  DIR Z = 0.0000 0.0000 1.0000
ZT C OF M = -0.039000                      ANGLE = 0.0000000
```

Component #4

```
COMP TYPE = POINT MASS  ID NO = 6          NAME = SA2456R
SURF AREA = 0.0000000   I(XX) = 0.0000000  PI(X) = 0.0000000
VOLUME    = 0.7600000   I(YY) = 0.0000000  PI(Y) = 0.0000000
WEIGHT    = 0.7600000   I(ZZ) = 0.0000000  PI(Z) = 0.0000000
DENSITY   = 0.7600000   I(XY) = 0.0000000  DIR X = 1.0000 0.0000 0.0000
XT C OF M = 1.9400000   I(XZ) = 0.0000000  DIR Y = 0.0000 1.0000 0.0000
YT C OF M = 1.3400000   I(YZ) = 0.0000000  DIR Z = 0.0000 0.0000 1.0000
ZT C OF M = 3.9350000                      ANGLE = 0.0000000
```

Component #5

```
COMP TYPE = POINT MASS  ID NO = 8          NAME = SA24561
SURF AREA = 0.0000000   I(XX) = 0.0000000  PI(X) = 0.0000000
VOLUME    = 0.7600000   I(YY) = 0.0000000  PI(Y) = 0.0000000
WEIGHT    = 0.7600000   I(ZZ) = 0.0000000  PI(Z) = 0.0000000
DENSITY   = 0.7600000   I(XY) = 0.0000000  DIR X = 1.0000 0.0000 0.0000
XT C OF M = 1.9400000   I(XZ) = 0.0000000  DIR Y = 0.0000 1.0000 0.0000
YT C OF M = -1.340000   I(YZ) = 0.0000000  DIR Z = 0.0000 0.0000 1.0000
ZT C OF M = 3.9350000                      ANGLE = 0.0000000
```

ANVIL 5000 Assembly Results

```
ACTIVE ASSEMBLY         ID NO = 10         NAME = COMPONENTS
SURF AREA = 0.0000000   I(XX) = 171.5000682PI(X) = 160.8802639
VOLUME    = 21.047000   I(YY) = 233.1863652PI(Y) = 220.4211115
WEIGHT    = 21.047000   I(ZZ) = 209.9156694PI(Z) = 233.3007274
DENSITY   = 21.047000   I(XY) = -0.0901926 DIR X = 0.9065 0.4209 0.0307
XT C OF M = -1.934464   I(XZ) = 22.8122901 DIR Y = 0.0089-0.0918 0.9957
YT C OF M = -0.084266   I(YZ) = 1.3407310  DIR Z = -0.422 0.9024 0.8700
ZT C OF M = 0.2087559                     ANGLE = 0.0000000
```

IMAGE UCMD 92 Assembly Results

```
NAME:  COMPONENTS   TYPE  CELL
XCG= -1.93446       YCG=-0.842656E-01   ZCG= 0.208756
IXX=  171.500       IYY=  233.186       IZZ=  209.916
IXY=-0.901926E-01   IXZ=  22.8123       IYZ=  1.34073
WT =  21.0470       VOL=  21.0470       RHO=  1.00000
```

3.2.3 Mtplates (Assembly #3)

Point-mass Component List (ANVIL 5000 FORMAT)

Component #1

```
COMP TYPE = POINT MASS  ID NO = 91         NAME = SC379108F
SURF AREA = 0.0000000   I(XX) = 13.068000  PI(X) = 0.0000000
VOLUME    = 9.8844000   I(YY) = 11.427000  PI(Y) = 0.0000000
WEIGHT    = 0.9686700   I(ZZ) = 1.6842000  PI(Z) = 0.0000000
DENSITY   = 0.0979999   I(XY) = 0.0000000  DIR X = 1.0000 0.0000 0.0000
XT C OF M = -1.757900   I(XZ) = -0.0000805 DIR Y = 0.0000 1.0000 0.0000
YT C OF M = 3.8953000   I(YZ) = 0.0365710  DIR Z = 0.0000 0.0000 1.0000
ZT C OF M = -0.046546                      ANGLE = 0.0000000
```

Component #2

```
COMP TYPE = POINT MASS  ID NO = 92         NAME = SC379108F
SURF AREA = 0.0000000   I(XX) = 13.457000  PI(X) = 0.0000000
VOLUME    = 9.5909000   I(YY) = 11.796000  PI(Y) = 0.0000000
WEIGHT    = 0.9399100   I(ZZ) = 1.6991000  PI(Z) = 0.0000000
DENSITY   = 0.0980002   I(XY) = -0.0002926 DIR X = 1.0000 0.0000 0.0000
XT C OF M = -1.758000   I(XZ) = 0.0000198  DIR Y = 0.0000 1.0000 0.0000
YT C OF M = -3.807100   I(YZ) = 0.0018794  DIR Z = 0.0000 0.0000 1.0000
ZT C OF M = 0.0001716                      ANGLE = 0.0000000
```

Component #3

```
COMP TYPE = POINT MASS   ID NO = 93          NAME = SC375246S
SURF AREA = 0.0000000    I(XX) = 526.73000   PI(X) = 0.0000000
VOLUME    = 47.744000    I(YY) = 273.91000   PI(Y) = 0.0000000
WEIGHT    = 31.100000    I(ZZ) = 298.54000   PI(Z) = 0.0000000
DENSITY   = 0.0980002    I(XY) = 1.9335000   DIR X = 1.0000 0.0000 0.0000
XT C OF M = -3.357100    I(XZ) = -1.592200   DIR Y = 0.0000 1.0000 0.0000
YT C OF M = 0.0788130    I(YZ) = 0.2036400   DIR Z = 0.0000 0.0000 1.0000
ZT C OF M = -0.076577                        ANGLE = 0.0000000
```

Component #4

```
COMP TYPE = POINT MASS   ID NO = 94          NAME = SC375247S
SURF AREA = 0.0000000    I(XX) = 458.56000   PI(X) = 0.0000000
VOLUME    = 49.411000    I(YY) = 144.49000   PI(Y) = 0.0000000
WEIGHT    = 32.300000    I(ZZ) = 331.01000   PI(Z) = 0.0000000
DENSITY   = 0.6537010    I(XY) = 2.4941000   DIR X = 1.0000 0.0000 0.0000
XT C OF M = 1.2220000    I(XZ) = 1.8927000   DIR Y = 0.0000 1.0000 0.0000
YT C OF M = -0.176320    I(YZ) = 0.1413700   DIR Z = 0.0000 0.0000 1.0000
ZT C OF M = -0.600900                        ANGLE = 0.0000000
```

ANVIL 5000 Assembly Results

```
ACTIVE ASSEMBLY          ID NO = 90          NAME = MTPLATES
SURF AREA = 0.0000000    I(XX) = 1045.737827PI(X) = 741.1967692
VOLUME    = 116.63030    I(YY) = 781.9866750PI(Y) = 905.9307232
WEIGHT    = 65.308580    I(ZZ) = 998.1222122PI(Z) = 1114.5605806
DENSITY   = 0.5599624    I(XY) = -14.3615846DIR X = 0.0540 0.4825 0.8742
XT C OF M = -1.054229    I(XZ) = -38.3201765DIR Y = 0.9985-0.0246 0.0480
YT C OF M = -0.0466879   I(YZ) = 2.4222703  DIR Z = 0.0016 0.8755-0.4831
ZT C OF M = -0.3343441                       ANGLE = 0.0000000
```

IMAGE UCMD 92 Assembly Results

```
NAME:  MTPLATES      TYPE  CELL
XCG= -1.05423        YCG=-0.466879E-01   ZCG= -0.334344
IXX=  1045.74        IYY=  781.987       IZZ=  998.122
IXY= -14.3616        IXZ= -38.3202       IYZ=  2.42227
WT =  65.3086        VOL=  116.630       RHO=  0.559962
```

3.2.4 Discussion

From the above results, it is seen that for all the mass properties in all three assemblies, there is no error between the ANVIL 5000 results and those from IMAGE's UCMD 92.

4.0 Conclusions

From the above results, it is concluded that ANVIL 5000's mass properties analysis for basic solid shapes is reliable within the limits of approximately +/- 1 percent worst case error. This value can be used to determine whether or not ANVIL 5000's mass properties analysis is sufficiently accurate for the particular part being modeled.

Also, it is concluded that ANVIL 5000 can sum assembly mass properties for point-mass component assemblies with the same accuracy as IMAGE's UCMD 92, the system currently in use. Therefore, all assembly mass properties analysis planned to be performed on the IMAGE system can be done on ANVIL 5000, assuming that the model can be accurately created on ANVIL 5000.

Distribution

2542	R. N.	Harris
2814	P. F.	Chavez
2814	D. P.	Peterson
2850	D. L.	McCoy
2851	L. K.	Grube
2852	D. J.	Klinetobe
2853	R. L.	Williams
2854	R. E.	Thompson
2854	S. F.	Cancilla
2854	S. J.	Fellows
2854	Y. M.	Holling
2854	G. L.	Neugebauer
2854	T. M.	Rice
2854	G. M.	Rodriguez
2854	S. E.	Wagner
2855	J. A.	Lovato
2857	W. B.	Bopp
2858	W.	Drozdick
3141	S. A.	Landenberger (5)
3141-1	C. L.	Ward (8) for DOE/OSTI
3151	W. I.	Klein (3)
7483	W. C.	Burd
8524	J. A.	Wackerly