NASA/CR-1998-207063

FINAL
IN-07-CR
OCIT
065227

AlliedSignal
AEROSPACE

NASA CR-XXXXXX
AlliedSignal Engines 21-9041

SIMULATED BLADED MMC DISK LCF VALIDATION
DRAFT FINAL REPORT

H.F. Merrick
AlliedSignal Engines, Phoenix, Arizona
A Unit of AlliedSignal Aerospace

M. Costen
Aerospace Structural Research Corp.

February 1998

Prepared for:
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
Cleveland, Ohio 44135

Under Contract No. NAS3-27564

SIMULATED BLADED MMC DISK LCF VALIDATION

NASA Contract NAS3-27564

Summary

The goal of this program was to evaluate the low cycle fatigue behavior of an SCS-6/Ti-6Al-4V sub-component under bi-axial loading conditions at 316C(600F). A simulated bladed TMC disk was designed having thirty four blades representing the number that would be used in AlliedSignal's JTAGG II impeller. The outer diameter of the bladed ring was 254mm (10.0 inch) and the inner diameter114.3mm (4.50 inch). The outer and inner diameter of the composite zone was 177.8 mm (7.00 inch) and 127.0mm(5.00 inch) respectively. Stress analysis showed that the fatigue life of the bladed composite ring would be about 12000 cycles for the test conditions applied. A modal analysis was conducted which showed that the blades would have sufficient life margin from dynamic excitation.

The arbor design was the same as that employed in the spin-to burst test of NAS3-27027. A systematic stress analysis of each part making up the arbor was undertaken to assure the design would meet the low cycle fatigue requirements of the program.

The Textron Systems grooved foil - fiber process was chosen to make the SCS-6/Ti-6Al-4V core ring based on the success they had in contract NAS3-27027. Fiber buckling, however, was observed at several locations in the first ring made which rendered it unsuitable for spin testing. The fiber buckling was attributed to cracking of the graphite tooling during the consolidation process. On this basis a second ring was made but it too contained fiber buckling defects. Analysis by Textron indicated that the fiber buckling was most likely due to poor placement of the SCS-6 fiber in the etched grooves of the Ti-6Al-4V foil. This was also a contributor to the defects in the first ring. Since there was little indication of control in the process to manufacture a quality ring a third attempt at making a ring was not undertaken.

SIMULATED BLADED MMC DISK LCF VALIDATION

1 INTRODUCTION

Prompted by the DoD/NASA initiative seeking quantum advances in propulsion systems for future turbine engines, research work in recent years has been directed to achieving major advances in component design concepts and materials development. As an active participant in advanced turbine design and materials development, AlliedSignal is committed to attaining substantial improvements in propulsive efficiency by developing compression systems which can provide a high overall compression ratio with the fewest number of rotating parts. The high speeds required place a premium on the materials that can be used in terms of strength and temperature capability.

Metal matrix composites (MMC's) have been identified as a class of materials which are capable of meeting the strength and temperatures required of high speed compressor components and considerable research has been undertaken during past years to develop these composites and understand their mechanical behavior. for convenience much of this work has been conducted using panel material consisting of unidirectionally disposed silicon carbide fibers, e.g., Textron Specialty Divisions's SCS-6 fiber, in a variety of titanium alloy and, more recently titanium aluminide , matrices. Specific titanium matrices include, Ti-6Al-4V, Beta 21S, Ti-6-2-4-2, Ti-1100, the alpha 2 titanium aluminides and more recently orthorhombic titanium aluminides, based on the compound $Ti2AlNb$. The volume fraction of fibers used has been as high as 40 percent by volume. A substantial body of physical and mechanical properties data has now been generated from panel material and is being compiled by the Titanium Matrix Composites Cooperative working under an Air Force/NASA contract to be used for developing a life prediction framework code.

MMC rotating components such as the centrifugal impeller will be designed and fabricated using a unidirectional SiC fiber lay-up. While the high strength SiC fiber will be sufficient to manage the hoop forces generated by high speed rotation, the radial forces, while much lower, are of concern in component design. The [90] MMC mechanical properties determined form panel testing illustrate the high degree of anisotropy of the unidirectional fiber lay-up and the weak interface strength such that debonding at the fiber/matrix interface occurs at quite low stresses. The challenge for the component designer is to work within these broadly limiting parameters. To guide design, more information is needed on the mechanical behavior of MMC's under bi-axial loading conditions, and in particular, cyclic loading.

In a previous contract, NAS3-27027, small diameter MMC rings were made and one burst tested. The test arbor used in this work was designed to allow cyclic tests to be conducted. The objective of this contract is to validate the low cycle fatigue life of a simulated bladed MMC ring reinforced sub-component. The data generated will be used to verify life prediction models that currently exist or are being developed by the MMC Life Prediction Cooperative and Government Agencies.

To meet this goal the program has been divided into two phases. Phase I encompasses the design and fabrication of the simulated bladed MC disk and consists of four tasks. Phase II covers the LCF spin test and analysis of the data.

2. PROCEDURES

2.1 Design of Bladed Disk

A plane stress model approach was chosen for the analysis of the bladed TMC disk. In keeping with the design of the JTAGG II impeller, thirty four blades were employed for the bladed disk design. A rotational speed of 50.000 rpm was used, again based on the likely the JTAGG II impeller requirement.

Several options were examined for the design of the blades taking into account the desire to apply sufficient radial load on the TMC ring so as to induce fiber/matrix debonding an yet achieve reasonable cyclic life at the test temperature.

The material properties used in the analysis were derived from prior AlliedSignal test data conducted on eight ply panel material of the SCS-6/Ti-6Al-4V composite system containing unidirectionally disposed SCS-6 fibers. The fiber volume percent was 35%. The data were reported in Ref.1 and are again referenced in Table I. The data were garnered at 21C(70F) and 316C(600F). Data for "neat" Ti-6Al-4V are given in Table II. This is used to establish the stress state in the blades and the transition zone from the outer diameter of the TMC reinforcement.

In establishing the bladed ring allowable design stresses, the hoop and radial stresses were treated separately. The hoop stress allowable was chosen from the [0] degree LCF data, Fig. 1. For a life of 12000 cycles, the hoop stress will be 1206 Mpa (175 ksi). The [90] tensile data for SCS-6/Ti-6Al-4V indicates that debonding at the fiber/matrix interface occurs at about 124 Mpa (18 ksi) at 316C(600F), the test temperature. Even so, the [90] LCF data, Fig. 2, show that a fatigue life of 12000 cycles will arise when the stresses in uni-directionally transversly loaded panel material exceed the debond stress.

2.2 Design of Spin Test Arbor

The spin test arbor employed the same design as used in contract NAS3-27027. This was successfully spin tested to a speed of about 60,000 rpm at 316C(600F) without incurring physical damage. Such a speed is higher than will be required for the Low Cycle Fatigue tests of this program. A cross-section of the arbor is shown in Figure 3 and consists of a central shaft and two support disks with "soft touch" fingers to maintain light contact with the bladed TMC ring yet not influence the ring stresses. The required clamping pressure, applied through a torque nut and locking washer, is transmitted to the support disks via two "arm" disks. The nickel alloy, alloy 718(AMS 6415), was used to machine the arbor assembly.

Engineering drawings giving more detail of the arbor construction are contained in Appendix 1.

2.3 Fabrication of the Bladed MMC Ring

It was originally planned that the bladed ring would be made in one integral piece with the blades being machined from extra Ti-6Al-4V "neat" foil that was extended from the TMC reinforcing zone. The TMC reinforcing section of the bladed ring has the same design as the ring employed for burst testing in Ref. 1.

The chosen bladed TMC ring fabricator cautioned, however, that problems with fiber bucking would likely be experienced. TSD have experience with the use of Ti-6Al-4V shim stock to build up the outer diameter blade zone but with little success. As a result the more traditional method of making the bladed ring was used. In this case the TMC ring segment would be made first and this would then be bonded into Ti-6Al-4V shell material. Following bonding the bladed ring would be finished machined to the design dimensions.

Figure 4 shows the cross section and the dimensions of the TMC ring reinforcing section of the bladed ring. The OD of the ring is 185mm(7.3 inch) and the ID 114mm(4.5 inch). The TMC core section has an OD of 178mm(7.0 inch) and an ID of 127mm(5.0 inch). The thickness of this ring piece is 6.1mm(0.24 inch).

The outer shell of Ti-6Al-4V was made from forged and annealed stock material. One piece was machined with a recess to receive the TMC ring and with an OD of 267mm(10.5 inch) and a thickness of 12.2mm (0.48 inch). The recess was given a taper of 16 degrees to assure good bonding with TMC ring, which likewise was given a corresponding taper at the OD and the ID. A second disk was machined to form a cover for the TMC ring. This had the same OD but was thinner, 6.4mm (0.25inch).

The Textron spiral grooved-foil preform process (Ref. 2) was used to make the TMC ring segment. This process had been used successfully in contract NAS3-27027 (Ref.1). In this process the Ti-6Al-4V foil material is etched to produce the required spiral groove using photolithography techniques. Both sides of the foil were etch-grooved for making the ring in this case. Some specifics as to the procedure used to make the rings are given in the Appendix 2.

3. RESULTS AND DISCUSSION

3.1 Bladed TMC Ring Mechanical Design Analysis

Several options were considered for the mechanical design of the blades and transition from the TMC reinforcement zone. The essential variables were the filet radius of the blade and the blade width, since these affected the number of blades that could be used and which were fixed at thirty four to simulate the number of blades that would be in the impeller design. Since the blade thickness was fixed by the need to the same as the TMC ring zone, only the blade width could be varied and then only in conjunction with the blade filet radius. The possibility of using a "hammer" head on the blades as a variable to change the blade mass and hence the radial loading on the TMC ring was considered and some preliminary analyses performed. This, however, introduced additional design variables which complicated the issue.

Three basic blade design configurations were analysed in more detail.

Configuration 1: In this case a 2D analysis was made for the ring with 34 blades having a thickness of 6.1mm (0.24 inch) and with a blade filet radius of 3.0mm (0.12 inch). The outer diameter of the bladed ring was 254mm (10.0 inch).

Figure 5 shows the finite element model created for the stress analysis and Figures 6 and 7 the hoop and radial stress distribution calculated using the material properties listed in Tables I and II. For this case, the hoop stress, Figure 6a and 6b, will be 1206 MPa (175 ksi) at the inner diameter of the composite zone and 884 MPa(124 ksi) at the outer diameter of the composite zone. Figures 7a shows the stress distribution for the bladed ring and Figure 7b the radial stress distributions in the composite zone alone. The radial stress in the composite zone reaches a maximum of 172 MPa(25 ksi) in the fibers at the outer diameter of the composite zone. This stress is higher than allowed by the design criteria since it would lead to a lower LCF life than desired.

Configuration 2: To reduce the radial stress in the composite zone of the bladed ring, the filet radius of the blade was increased to 5.1mm(0.20 inch). The blade thickness was maintained at 6.1mm(0.24 inch). The finite element model was adjusted for this design and is given in Figure 8. The results of the analysis for this configuration are shown Figure 9 and 10. The hoop stress was essentially unchanged, however, a reduction in radial stress to 145MPa (21 ksi) was achieved.

Configuration 3: For this design, the filet radius was again increased. This time to 7.6mm(0.3 inch) while at the same time the blade thickness was reduced to 2.5mm(0.1 inch). The finite element model for this configuration is shown in Figure 11 and the stress distributions in Figures 12 and 13. The maximum radial stress at the outer diameter of the TMC zone is now 124MPa(18 ksi) while the maximum hoop stress in the fibers at the inner diameter is 1582 MPa(177 ksi). The maximum value of the hoop stress in the blade root is below the elastic limit of Ti-6Al-4V at 316C(600F), Table II. The hoop stress in the "neat" Ti-6Al-4V at the inner diameter of the bladed ring is close to that which would induce some plastic deformation in this region.

3.2 Arbor Design

A 2D axisymmetric model, Figure 14, was developed to analyse the stresses in the arbor under spin test conditions. the model took into account the arbor shaft, the spacers, the "soft touch" disks and the bladed TMC ring itself. The fingers of the soft touch disks were modeled using plane stress elements. This model was used to determine interactions within the assembly and to assist fatigue life remote from local stress concentrations due to the disk fingers. A 3D model was used for assessing the fatigue life of the arbor in the finger areas.

Fatigue Life in the Finger Location: Using the 3D pie segment finite element model , Figure 15a, analysis showed that the maximum equivalent stress around the fingers would be 889 MPa(129 ksi), Figure 15b. This results in a corresponding fatigue life again in excess of 100,000 cycles. The finger design, therefore, also meets the life requirements.

Interface Loads: The "soft touch" disks were specifically designed to maintain a minimum contact load throughout the cyclic operating range while at the same time not encumbering the bladed disk. The addition of the blades to the TMC ring will increase the radial growth of the TMC ring, however, adequate piloting contact is maintained. Figure 16 lists the calculated interface loads betwen the soft touch disks and the bladed TMC ring at assembly and at the maximum cyclic operating speed.

Fatigue Life Remote From Fingers: The arbor design requires that the arbor be capable of surviving 15,000 cycles between 0 and 50,000 rpm. For locations remote from the soft touch fingers, the 2D axisymmetric model was used to determine the equivalent stress range and the resulting fatigue life. The arbor equivalent stress range caused by a 0 to 50,000 rpm cycle is shown in Figure 17. The highest stress range occurs in the finger bores and is 901 Mpa (130.8 ksi). From the known fatigue properties of the arbor material this stress would would result in a fatigue life of >100,000 cycles. This adequately satisfies the test requirements of this program.

3.3 Modal Analysis of the Simulated Blades

Because of the small dimensional cross-section of the blades, 2.54mm (0.10 inch) by 7.1mm (0.28 inch), a modal analysis was performed to determine whether the simulated blades of the TMC ring would have sufficient life margin from dynamic excitation.

The design of the integrally bladed TMC ring is shown in Figure 18

The 3D finite element model developed for the dynamic analysis, and illustrated in Figure 19 ,was used to determine the modal response of the integral blades. In addition to the low order excitations, the dynamic analysis also considered excitation sources due to the air turbine drive equipment. These were:

- 10/revolution due to the number of nozzles feeding the air turbine,
- 24/revolution due to the number of blades on the air turbine,
- 14/revolution due to the difference between the number of nozzles and vanes.

Figures 20 through 25 illustrate the blade distortions predicted by the modal analysis. The blade first bending mode, Figure 20, occurs in the circumferential direction and is ten percent above the 3/revolution excitation at 50,000 rpm. Although the test facility does not directly cause a 3/revolution excitation, good design practice requires avoiding a high speed crossing with at least ten percent margin. As such, extending the maximum test speed beyond 50,000 rpm should be carefully assessed. All crossings occur below 40,000 rpm and are considered acceptable without dwell time. As a result, the simulated blades satisfactorily meet the dynamic design criteria with the proviso that the speed change between 30,000 and 40,000 rpm be a transient one. This would be the case for the LCF test program.

3.4 Simulated Bladed Ring Fabrication

The test ring was designed to be made in two parts. The TMC ring would be made first and this would be bonded within an outer shell if Ti-6Al-4V from which the simulated blades would be machined. The fiber/Ti-6Al-4V preforms were bonded using vacuum pressing at a temperature of of 899C(1650F) and a pressure of 103 MPa(15 ksi) Details of the fabrication process for the TMC ring are contained in Appendix 2.

First Ring: C-Scan and X-Ray images of the first ring made are shown in Figure 26. These reveal several flaws at the outer diameter of the SCS-6 fiber reinforced region of the ring. The X-Ray image shows that the defects are due to buckling of the fibers.

The largest flaw occurs at the 360 degree mark from the NDE reference mark and extends inward radially approximately 13mm(0.5 inch). At this same radial location some buckling of the fibers at the inner diameter were also evident.

The second pronounced defect is located at the 150/160 degree mark. The fiber buckling here extends inward radially about 5 mm(0.2 inch).

Less pronounced outer diameter fiber buckling was also evident at the 25/30, 100 and 200/210 degree marks.

Such fiber buckling has been experienced in past attempts to make this sized MMC ring (Ref 1) but steps had been taken to overcome this problem by minimizing the amount of unreinforced material at the outer diameter, using tight tolerences for the tooling and by employing a higher CTE graphite center plug material. Examination of the graphite tooling, however, revealed a number of cracks after the hot press cycle. The graphite tooling had been used successfully in three prior ring fabrication operations and had been reworked to provide smooth surfaces contacting the TMC ring. No obvious reason presented itself as to why the tooling failed other than it's useful life may have been exceeded. Whereas, a molybdenum ring was in place to contain the graphite tooling, this was insufficient to constrain the TMC one the graphite tooling cracked. On the basis that the cracking of graphite tooling was the cause of fiber buckling in the vacuum hot press cycle, fabrication of a second ring was undertaken.

Second Ring:

A second MMC ring was made. In this case new graphite tooling was employed. However, this did not solve the problem. X-ray NDE, Figure 27, again revealed a number of defects. At the outer diameter of the MMC core, four symmetrically disposed defects were discernable and again appeared due to fiber buckling. These occurred at the ring positions 65-70 deg., 145-150 deg., 215-220 deg, and 310-315 deg. At the inner diameter of the MMC core, the fibers appeared to be wavy at some locations and in addition fiber buckling is in evidence at the 245 deg. mark.

It is evident that fiber buckling of the first ring was not caused by cracking of the graphite tooling and that some other factor(s) was causing the defects in the MMC ring. Discussions with Textron have revealed that fiber placement during the fiber loading into the etched grooves in the Ti-6Al-4V foils is a probable reason. This part of the overall MMC ring manufacturing process had been performed by the etching vendor who would be less experienced that Textron

SUMMARY AND CONCLUSIONS

1) A simulated bladed TMC ring was designed which met the low cycle fatigue test requirement at 316C(600F). A modal analysis was performed to assure that, because of the flexible nature of the simulated blades, no undue blade vibration would occur during fatigue testing.
2) A stress analysis of the each of the components making up the spin test arbor was conducted. These demonstrated that the arbor was sufficiently robust to perform the low cycle fatigue test. The fatigue life of the arbor is well in excess of that required for testing the TMC simulated bladed ring.
3) Difficulties were encountered in fabricating the TMC core ring. NDE evaluation of the first ring made showed a number of defects due to fiber buckling. The occurrence of these defects was attributed to cracking of the graphite tooling employed in the ring consolidation practice. A second ring, however, made with new tooling again showed defects. Causal analysis revealed that the likely reason for the defects was poor placement of the SCS-6 fiber in the etched grooves of the Ti-6Al-4V foil. This may well have been the true cause of the defects in the first ring. Because it was evident that the TMC ring fabrication vendor did not have repeatable process to manufacture the rings designed for this program, no further attempt were made to make a TMC ring

REFERENCES

1) Merrick,H.F.; Aksoy,S.Z.; Costen,M.; Ahmad,J; "TMC Behavior Modeling and Life Prediction Under Multi-Axial Stresses", Final Contract Report; NAS3-27027, 1997.
2) Lewis,R.C. and Nagy,P; "MMC Ring Fabrication with Grooved Foil Preforms," Proceedings of the Titanium Metal Matrix Composite II Workshop, LaJolla, CA 2-4 June,1993; WL-TR-93-4105, pp 131-157

Table I: Material Properties for the SCS-6/Ti-6Al-4V Composite (Unidirectional Fiber Lay-up)

Temp., C (F)	E (l) GPa (msi)	E (t) GPa (msi)	UTS (l) MPa (ksi)	UTS (t) MPa (ksi)	v (l)	v (t)	CTE (l) (10^{-6})	CTE (l) (10^{-6})
21 (70)	214 (31)	132 (19)	1770 (257)	453 (66)	0.28 (0.28)	0.28 (0.28)	1.94 (1.94)	2.89 (2.89)
316 (600)	200 (29)	130 (19)	1540 (244)	296 (43)	0.28 (0.28)	0.28 (0.28)	2.33 (2.33)	2.99 (2.99)

G7568-12

Table II: Ti-6Al-4V Material Properties

316C(600F) Tensile Properties

Stress, MPa(Ksi)	Plastic Strain
606(87,94)	0.00000
622(90.24)	0.00011
629(91.26)	0.00031
634(92.07)	0.00071
640(92.83)	0.00151
645(93.55)	0.00631
654(94.98)	0.01271
659(95.70)	0.02551
664(96.41)	0.05111

Elastic Modulus and Poison's Ratio

Temperature, C(F)	E(Gpa)	Poison's Ratio
21(70)	116	0.33
93(200)	112	0.33
204(400)	105	0.33
316(600)	97	0.33
427(800)	90	0.33

Coefficient of Thermal Expansion

Temperature, C(F)	CTE
21(70)	4.75E-06
93(200)	4.80E-06
204(400)	5.10E-06
316(600)	5.30E-06
427(800)	5.50E-06

AlliedSignal
AEROSPACE

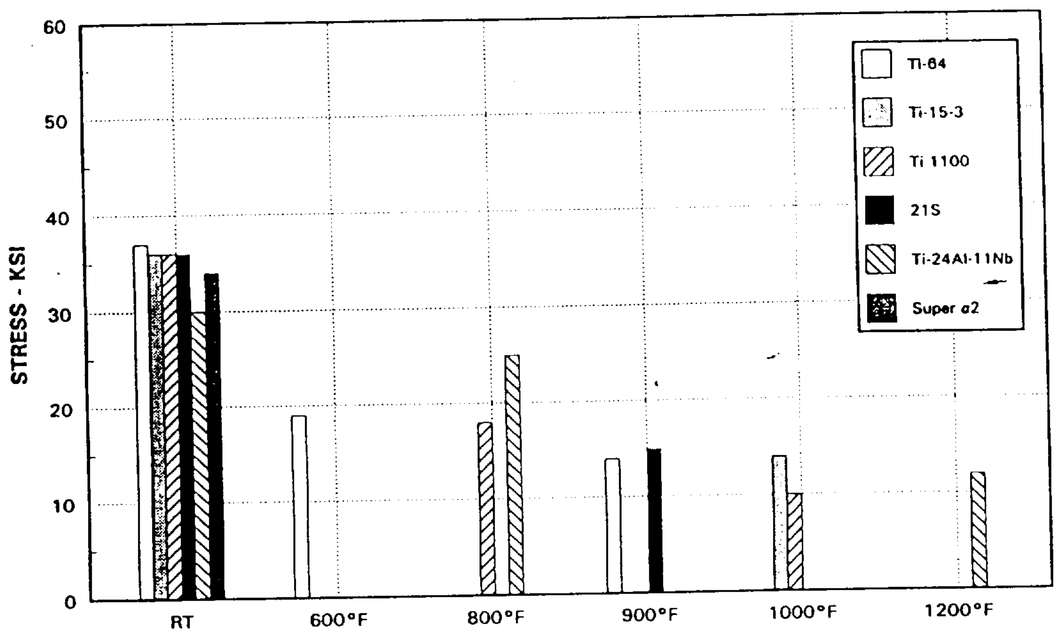


Figure 1: Fiber/Matrix Debond Strengths for various Ti MMC's

AlliedSignal
AEROSPACE

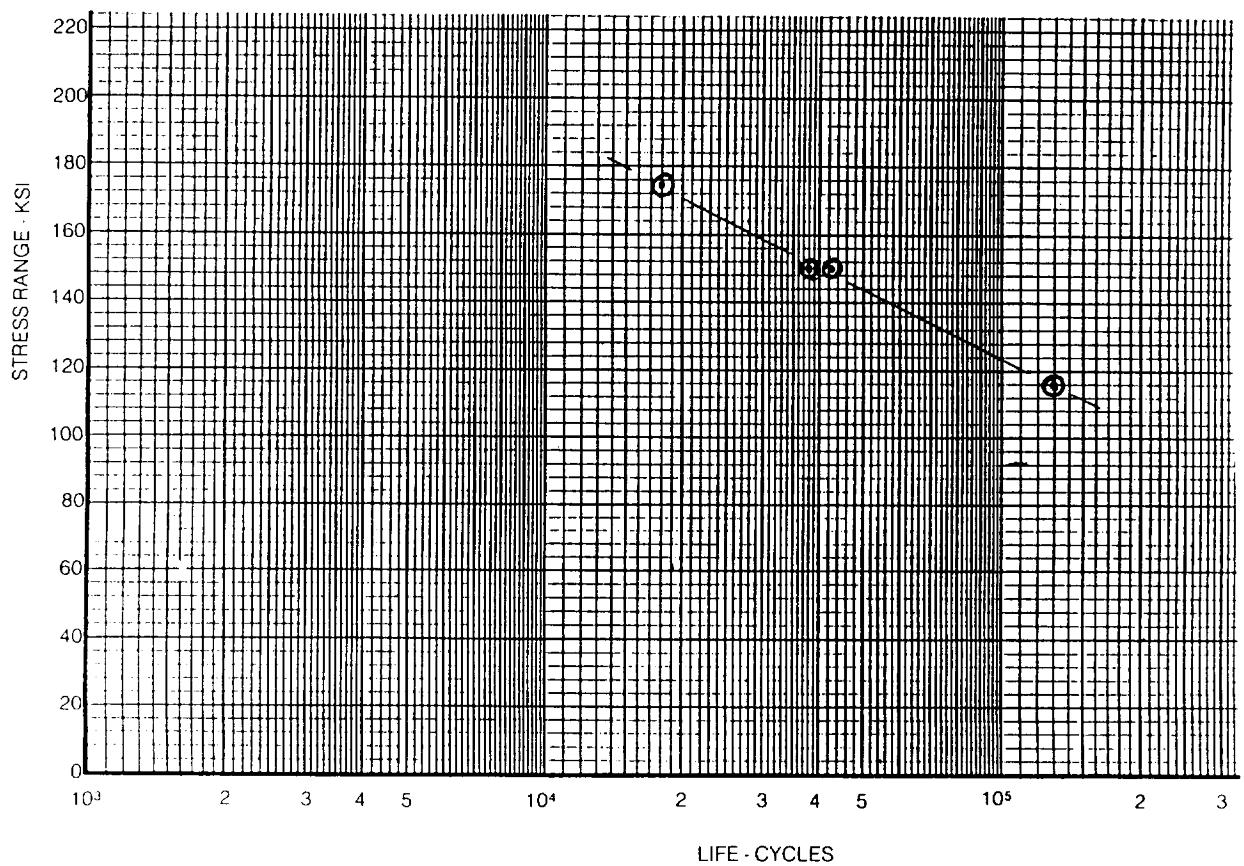


Figure 2a: 700F Longitudinal,[0], LCF Panel Data for SCS-6/Ti-6-4

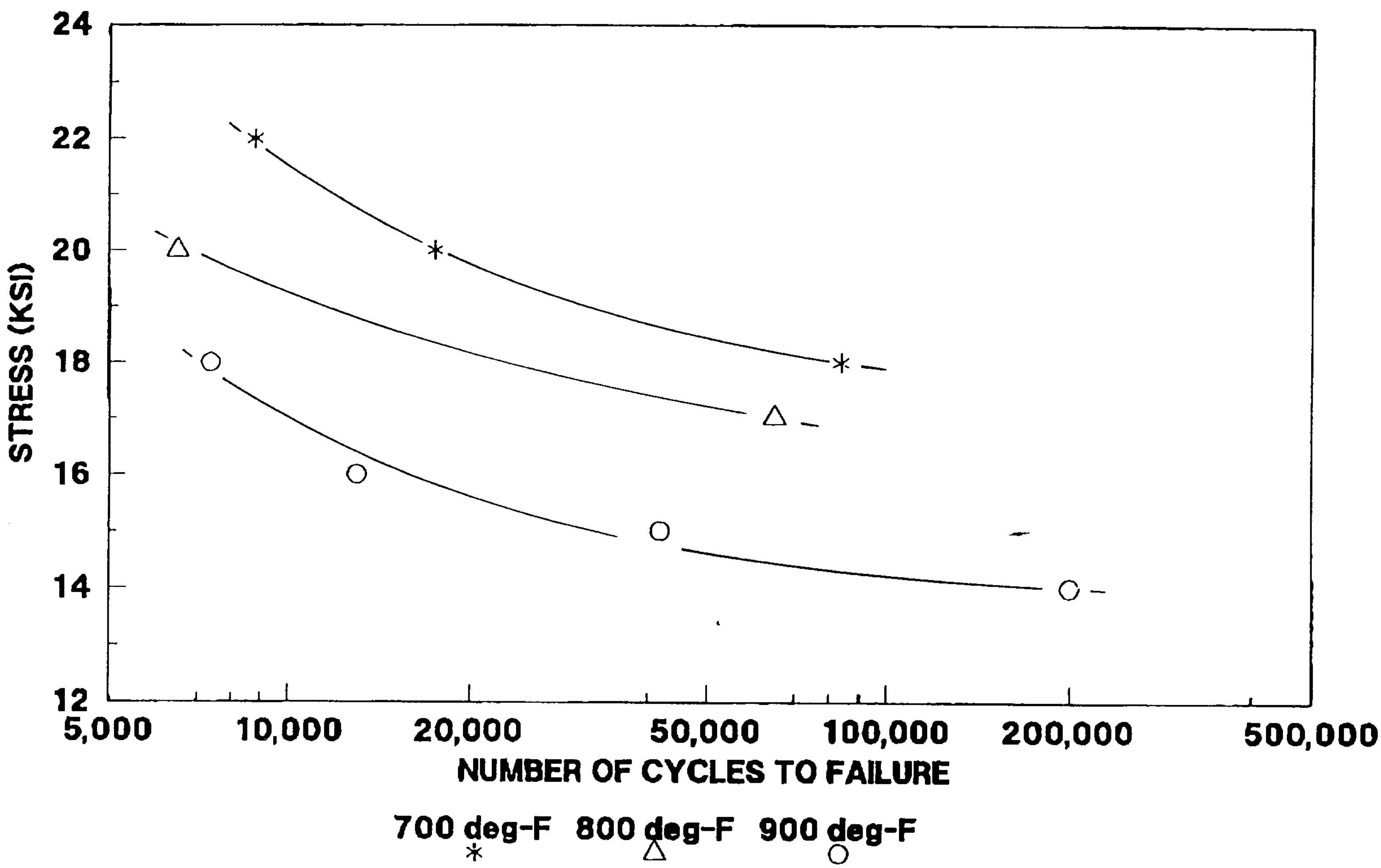


Figure 2b: Transverse, [90], LCF Panel Data for SCS-6/Ti-6-4

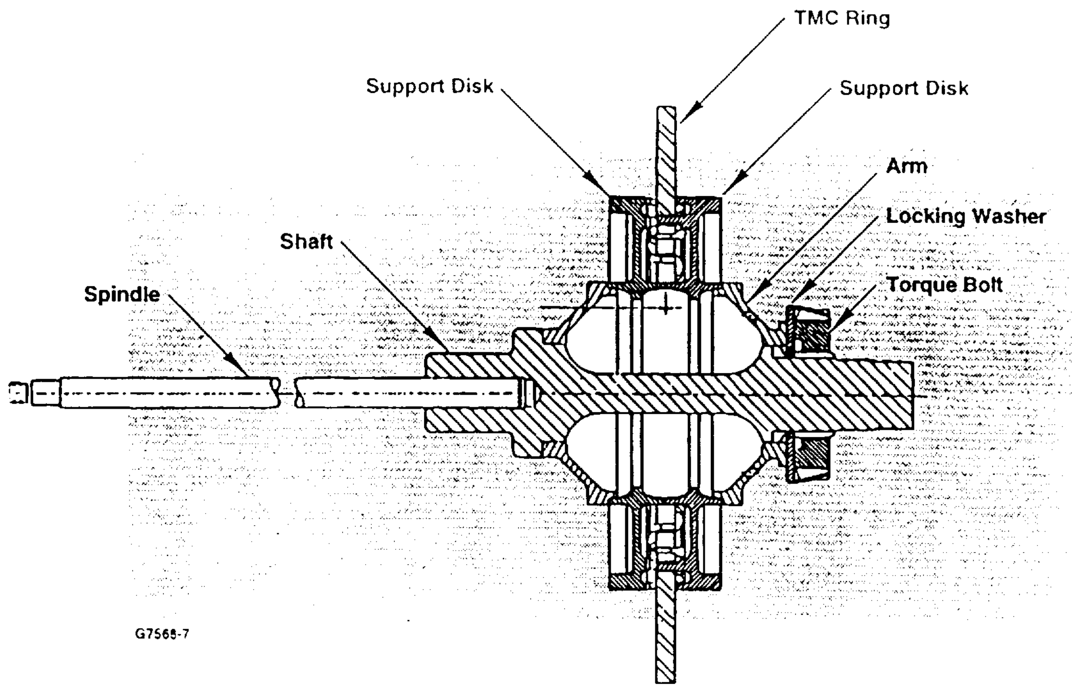


Figure 3: Cross-Section Diagram of the Spin Test Arbor and TMC Ring Assembly

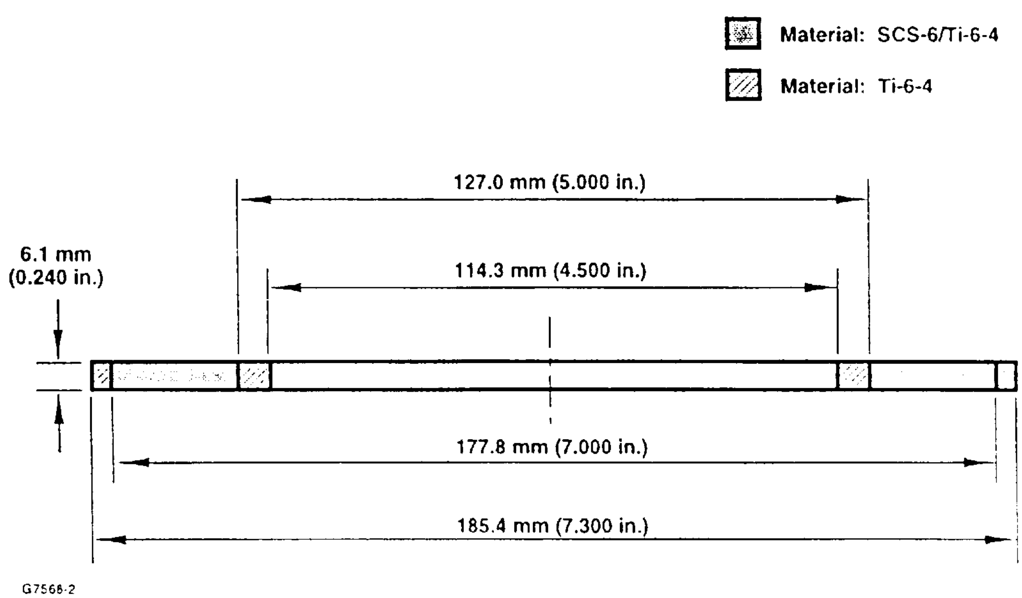


Figure 4: Dimensions of the SCS-6/Ti-6Al-4V TMC Core Ring

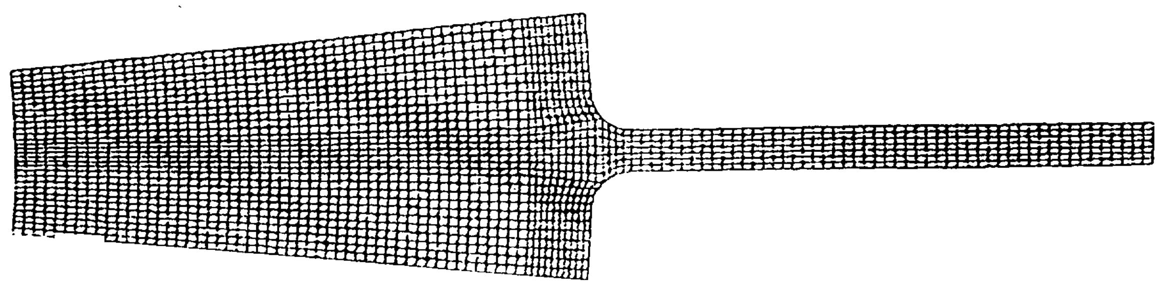


Figure 5: Finite Element Model for the Configuration 1 Bladed Ring

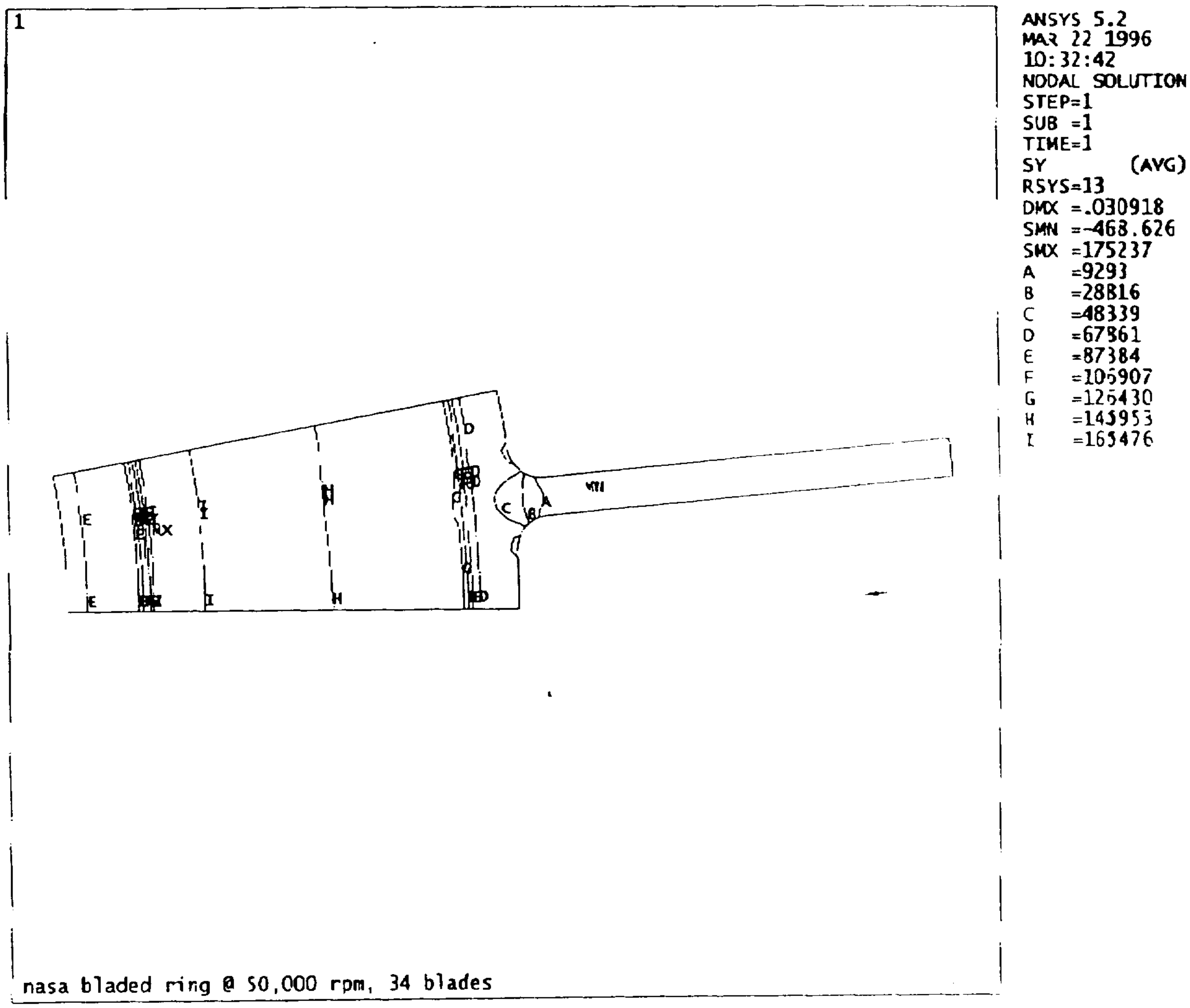


Figure 6a: Hoop Stress Distribution for Configuration 1; Full blade, 0.12-inch filet radius, 0.24-inch blade thickness

AlliedSignal
AEROSPACE

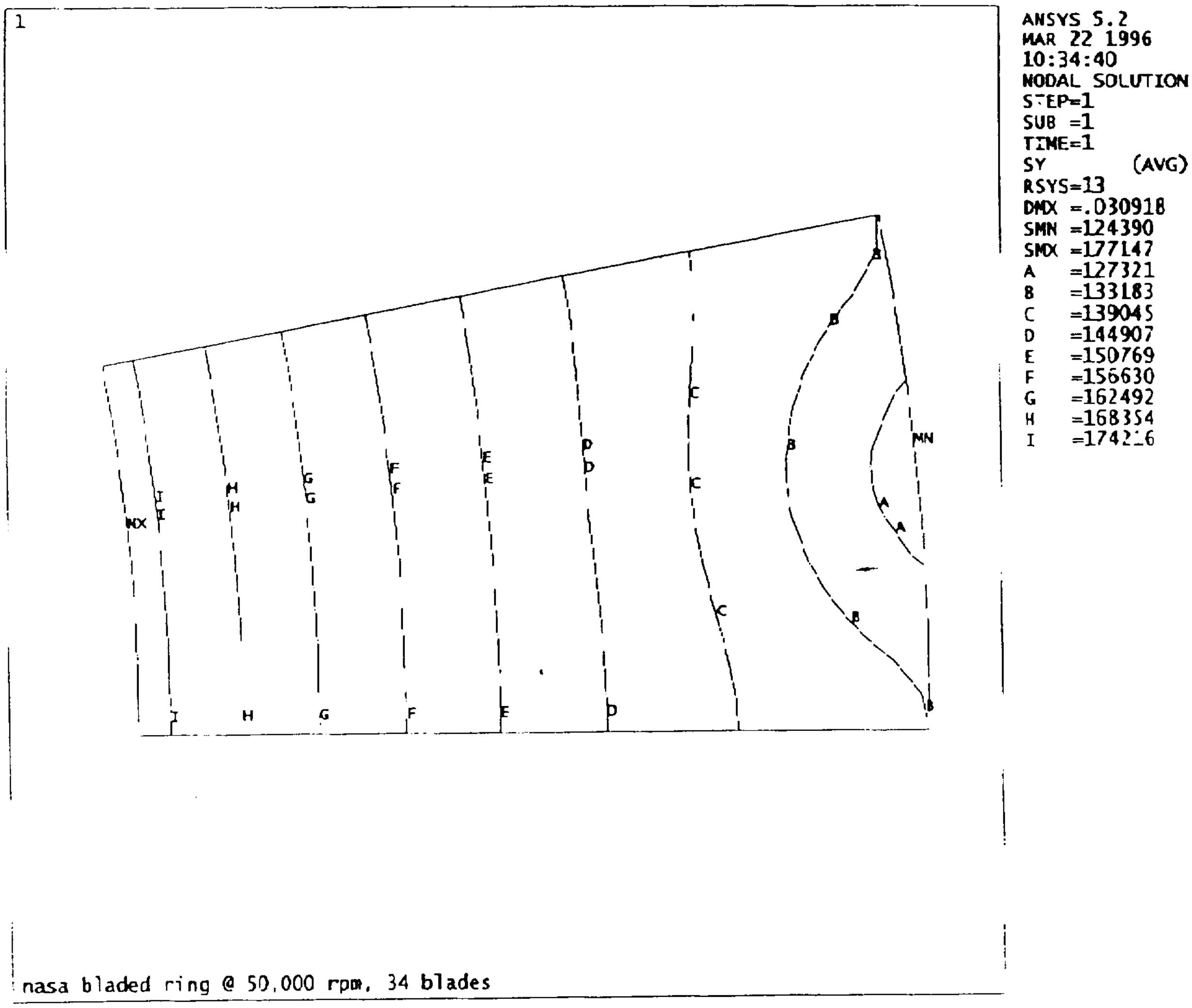


Figure 6b: Hoop Stress Distribution for Configuration 1; MMC ring only

AlliedSignal
AEROSPACE

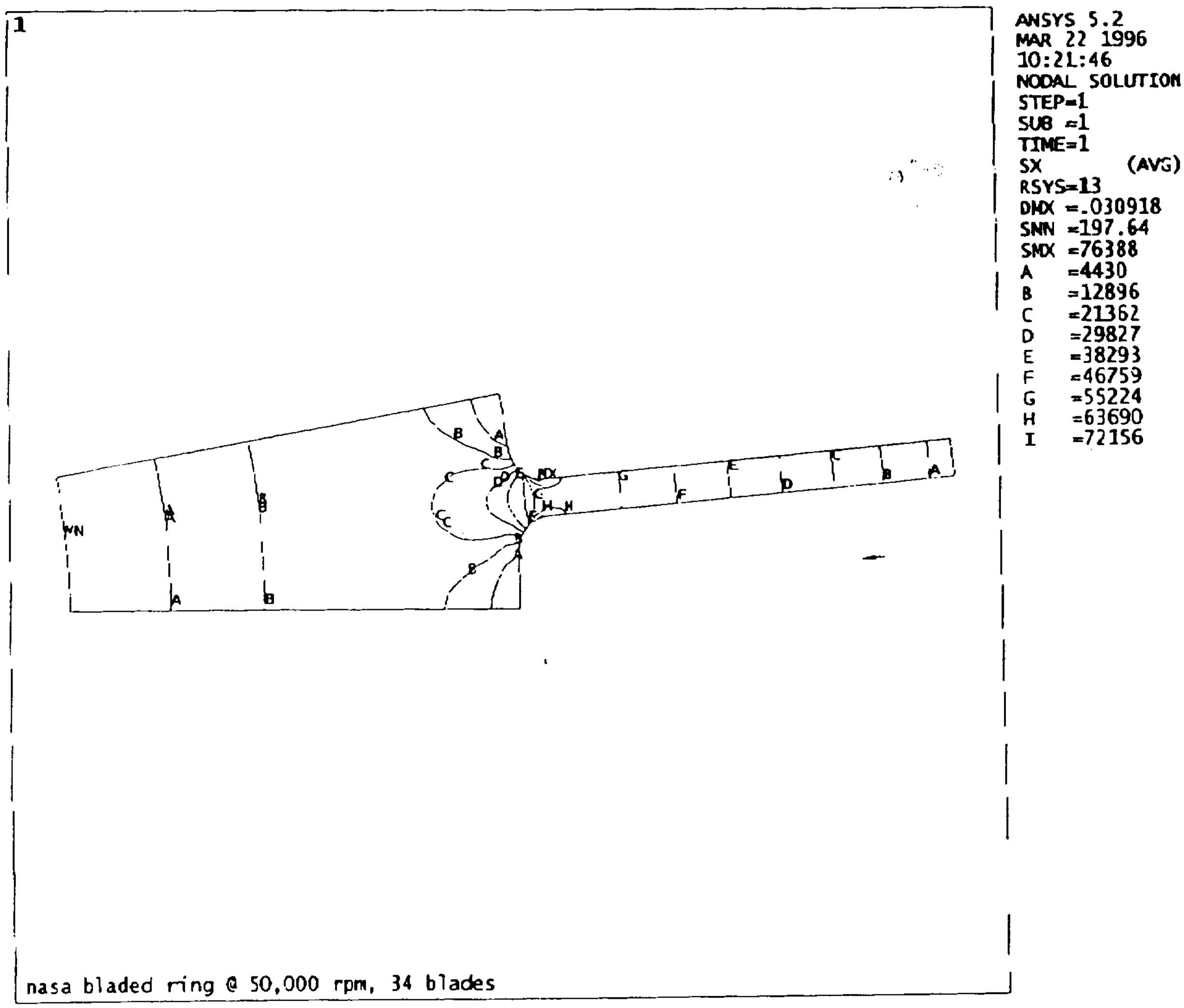


Figure 7 a: Radial Stress Distribution for Configuration 1; Full Blade, 0.12-inch filet radius

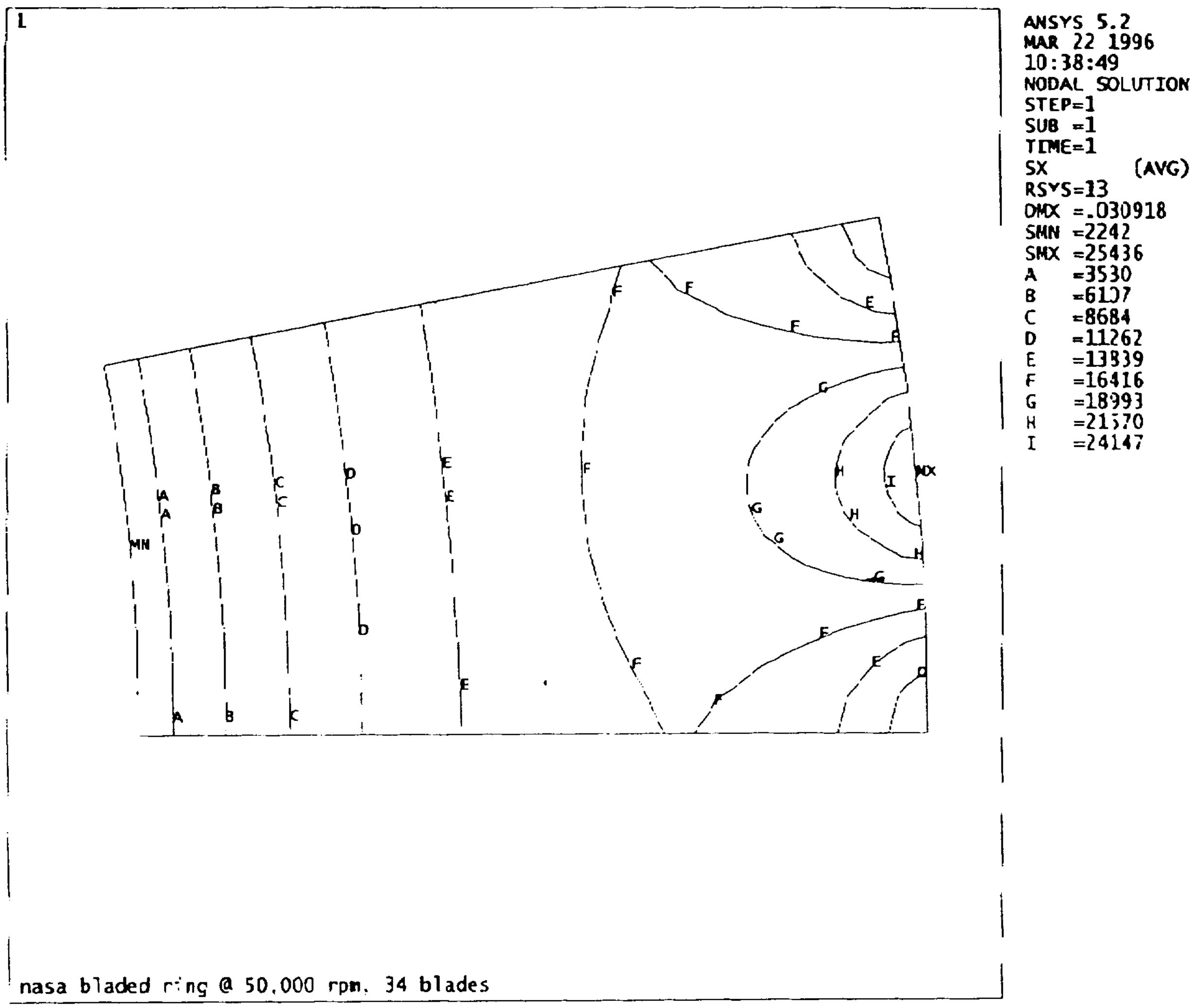


Figure 7b: Radial Stress Distribution for Configuration 1; MMC insert only

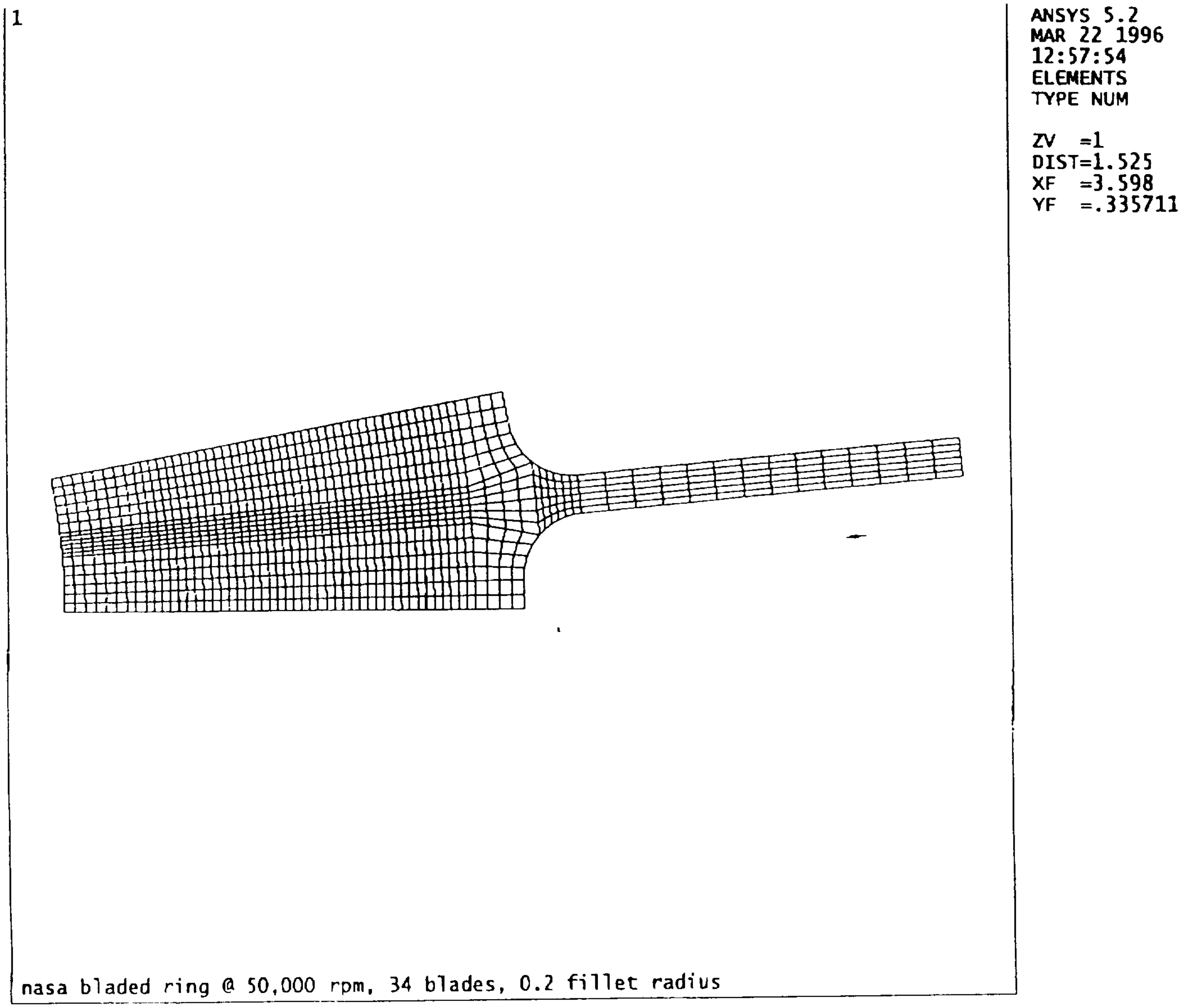


Figure 8: Finite element Model for Configuration 2

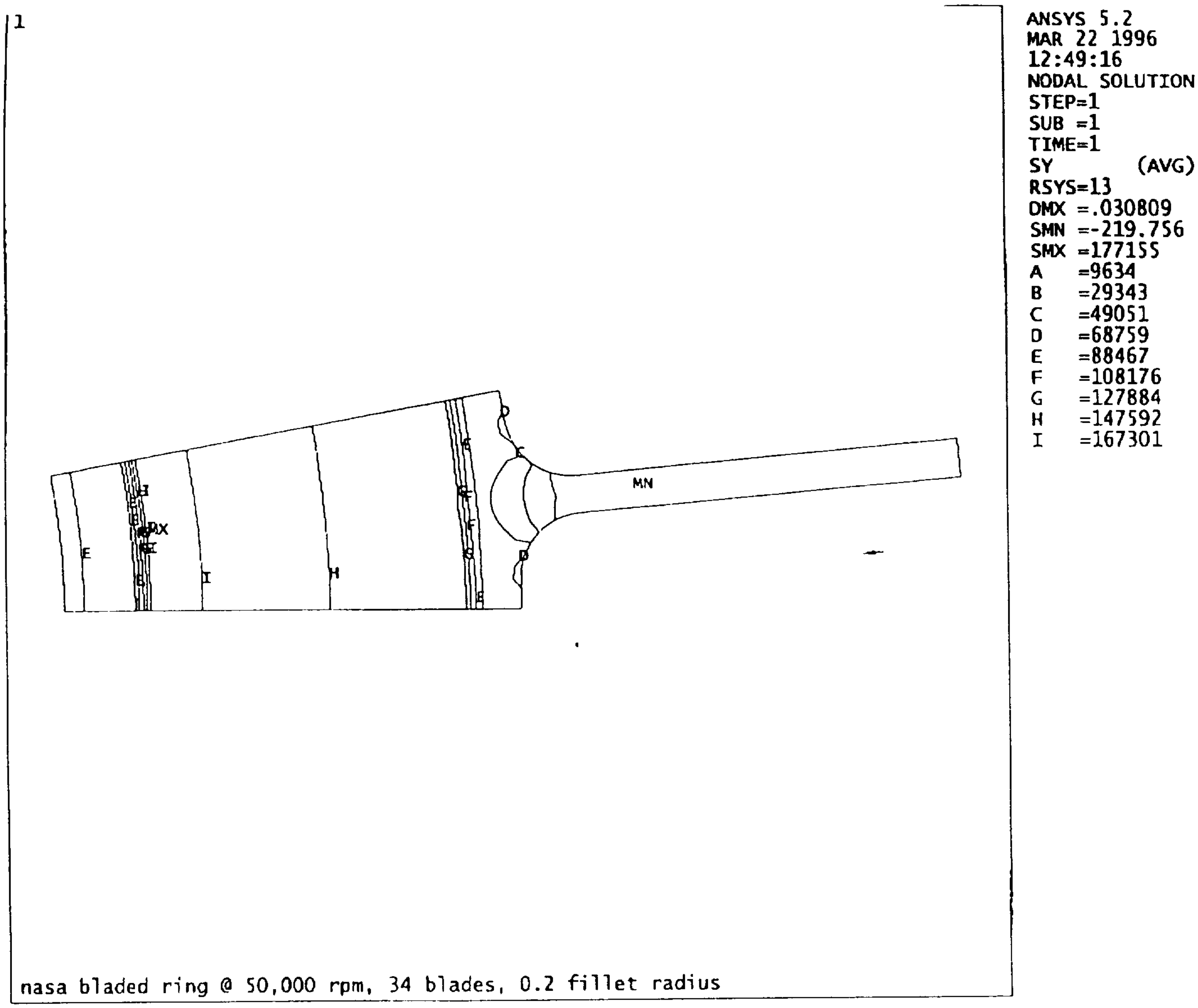


Figure 9a: Hoop Stress Distribution for Configuration 2; Full Blade, 0.20-inch filet radius

AlliedSignal
AEROSPACE

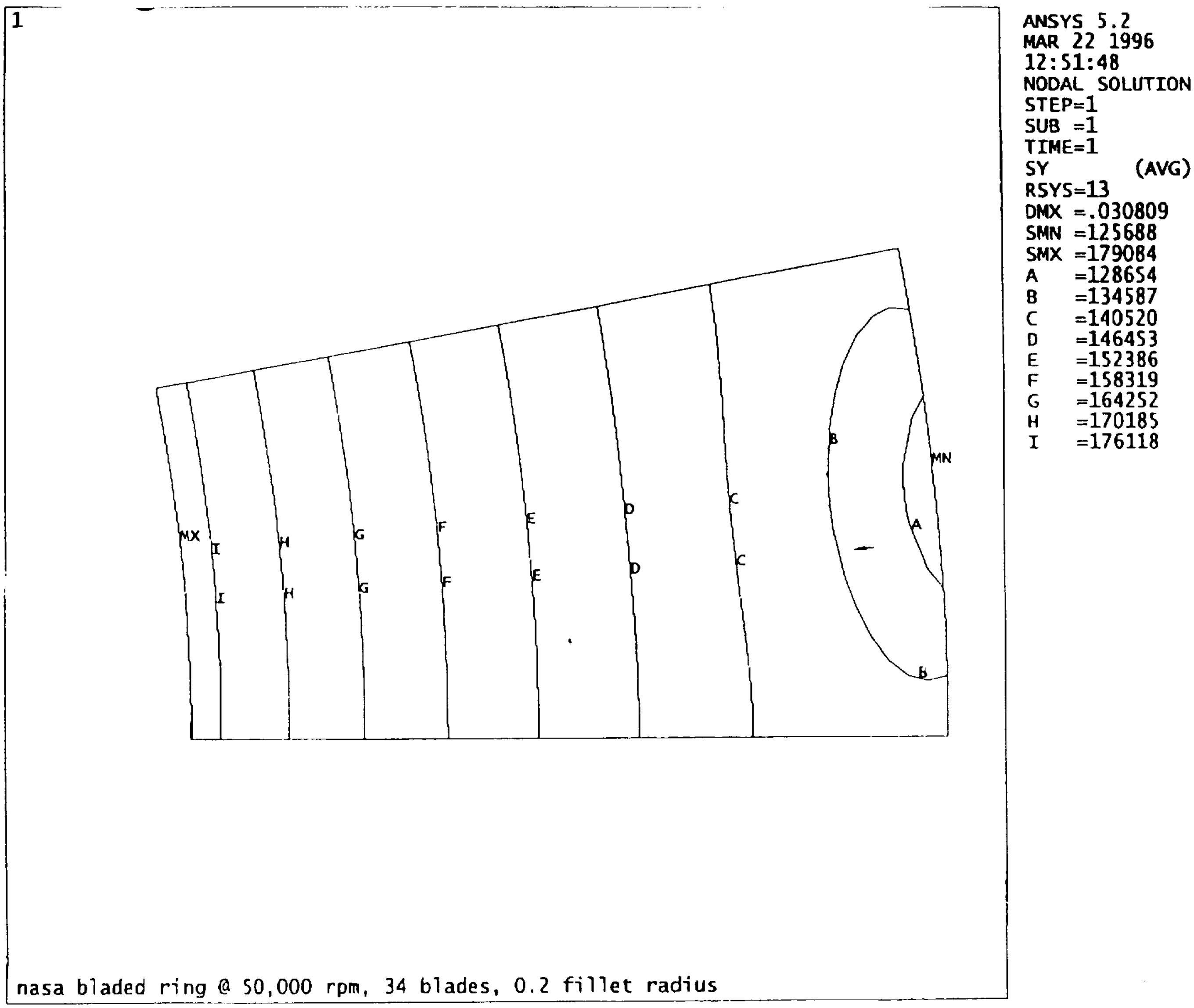


Figure 9b: Hoop Stress Distribution for Configuration 2; MMC ring only

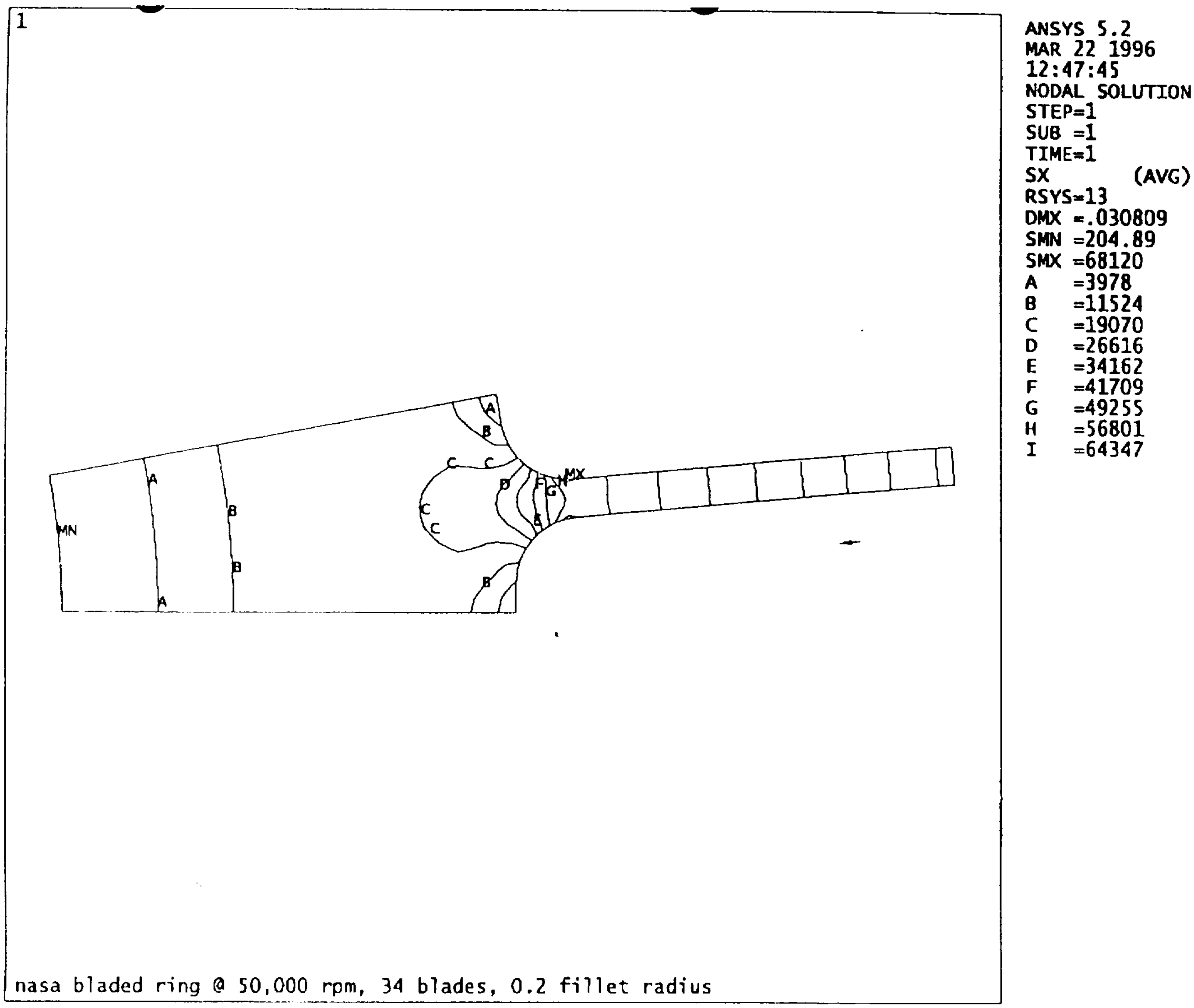


Figure 10a: Radial Stress Distribution for Configuration 2; Full Blade, 0.20-inch filet radius

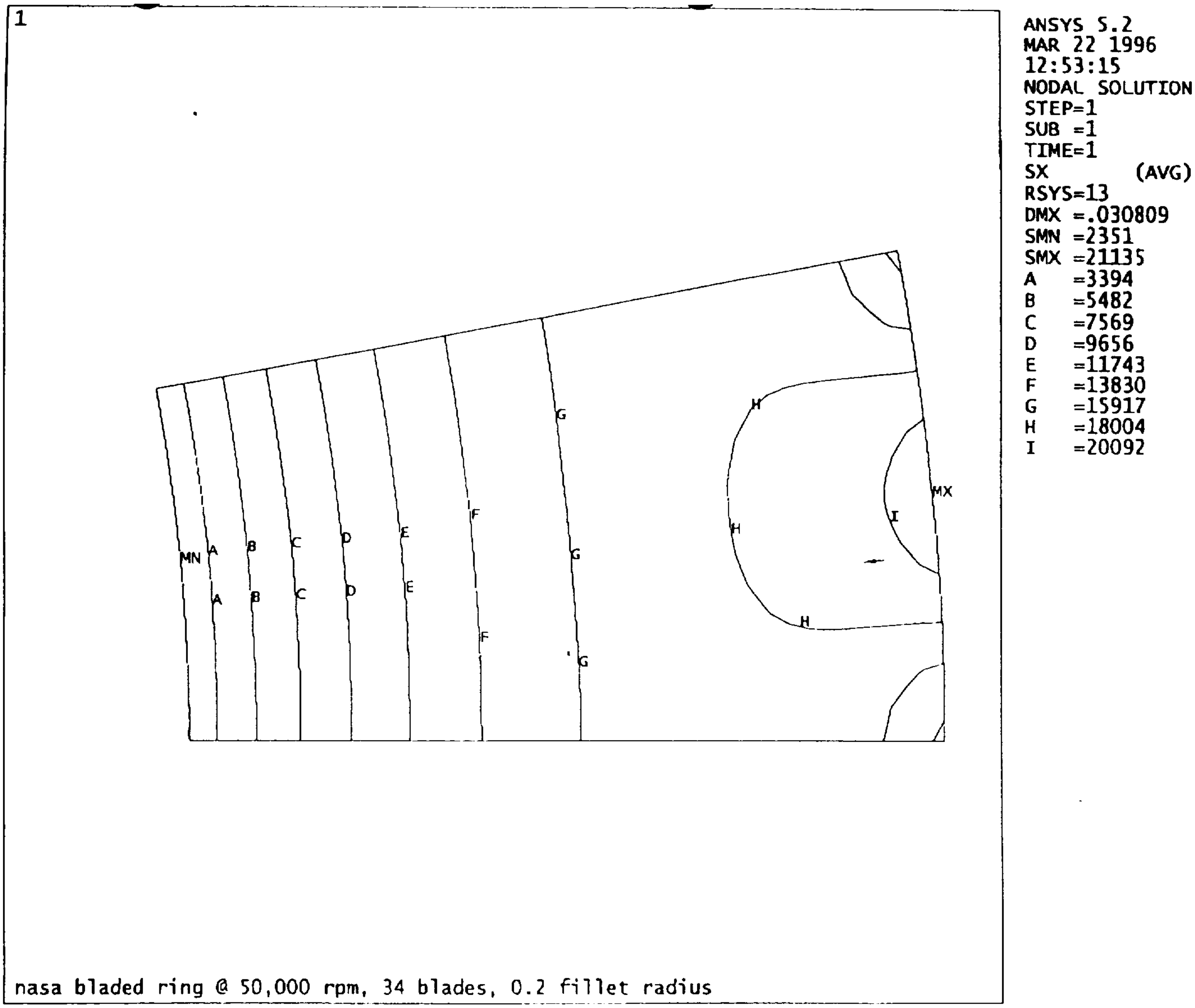


Figure 10b: Radial Stress Distribution for Configuration 2; MMC ring only

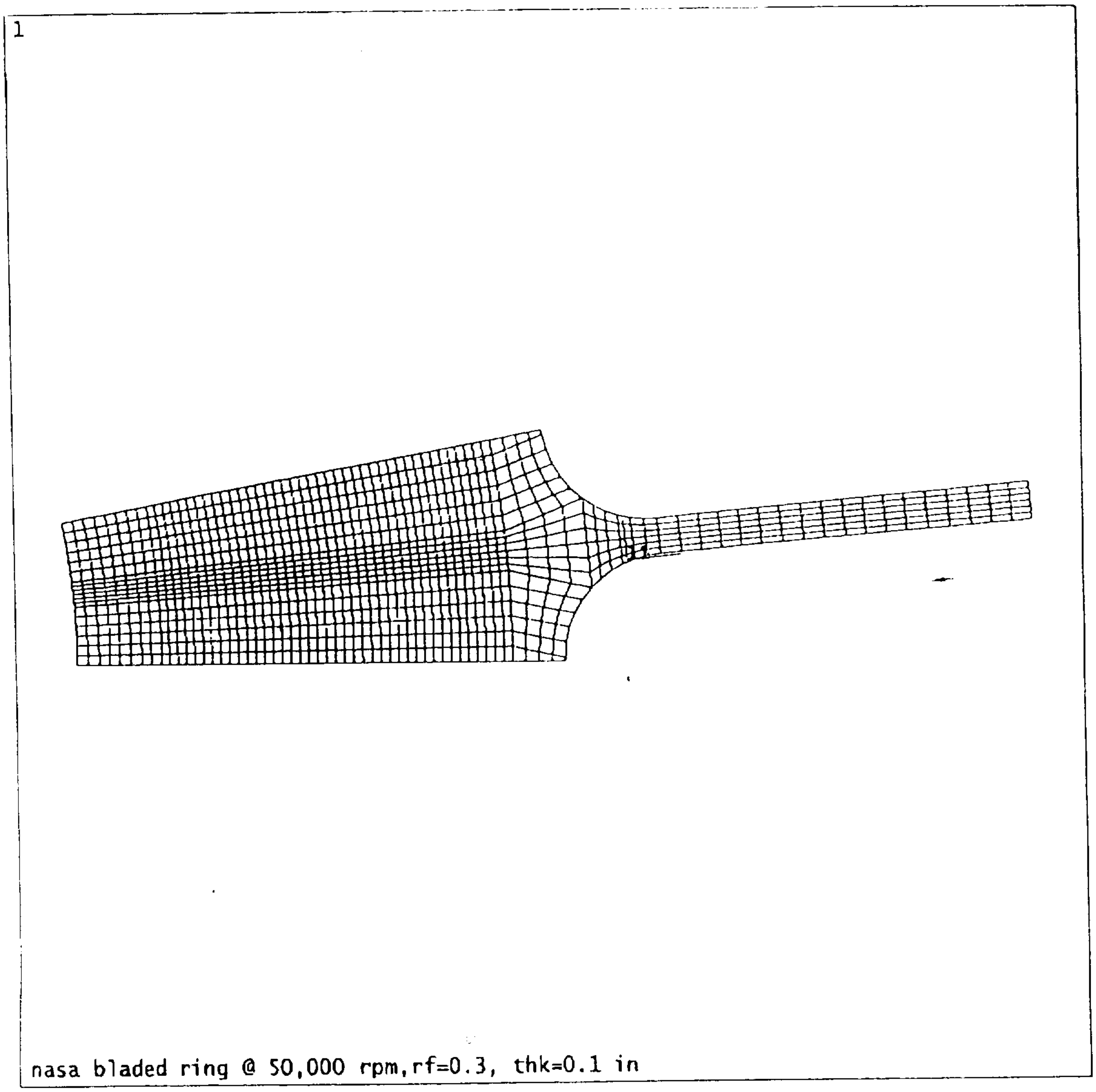


Figure 11: Finite Element Model for Configuration 3

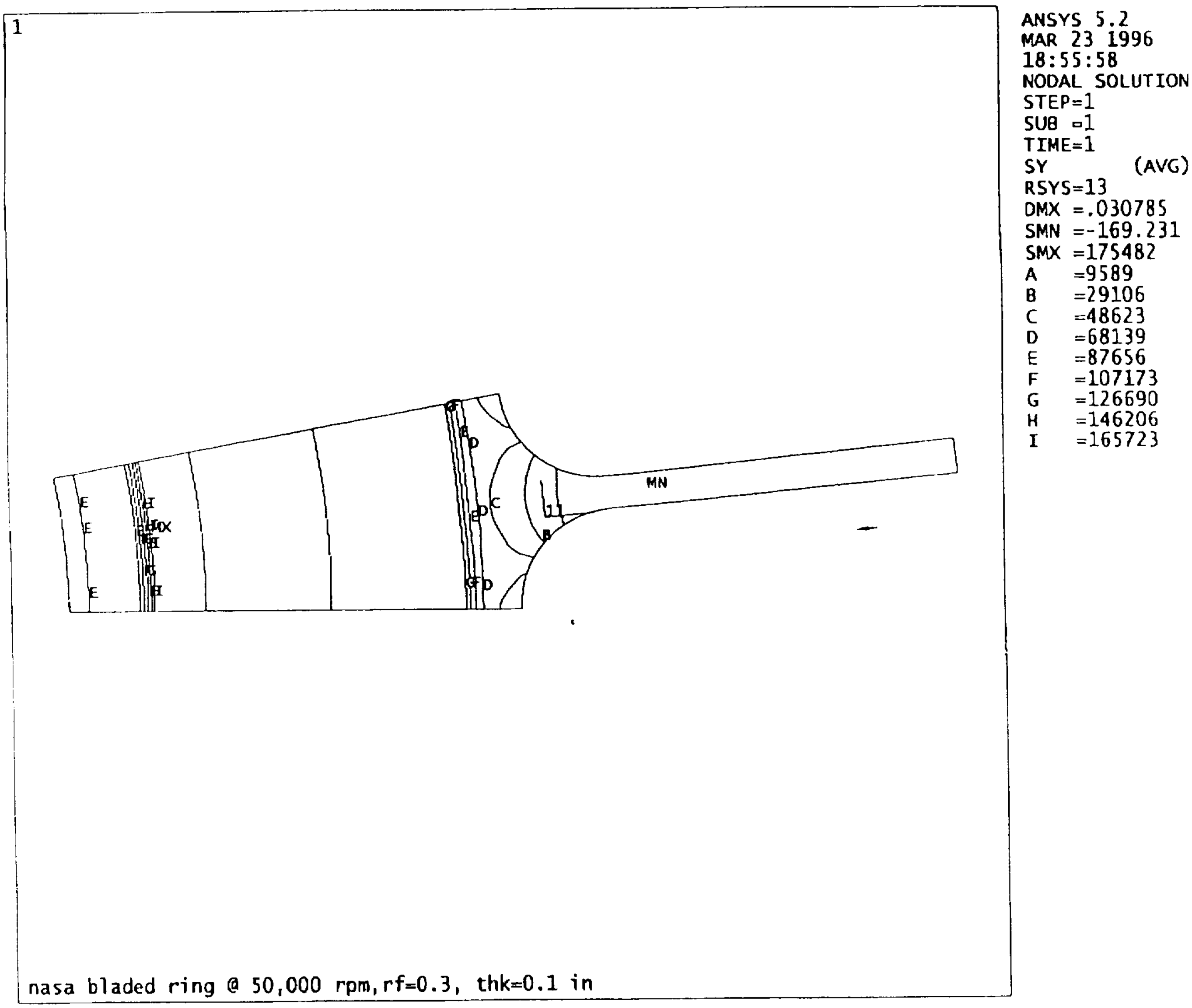


Figure12a: Hoop Stress Distribution for Configuration 3; Full Blade, 0.30-inch filet radius, 0.10-inch blade thickness

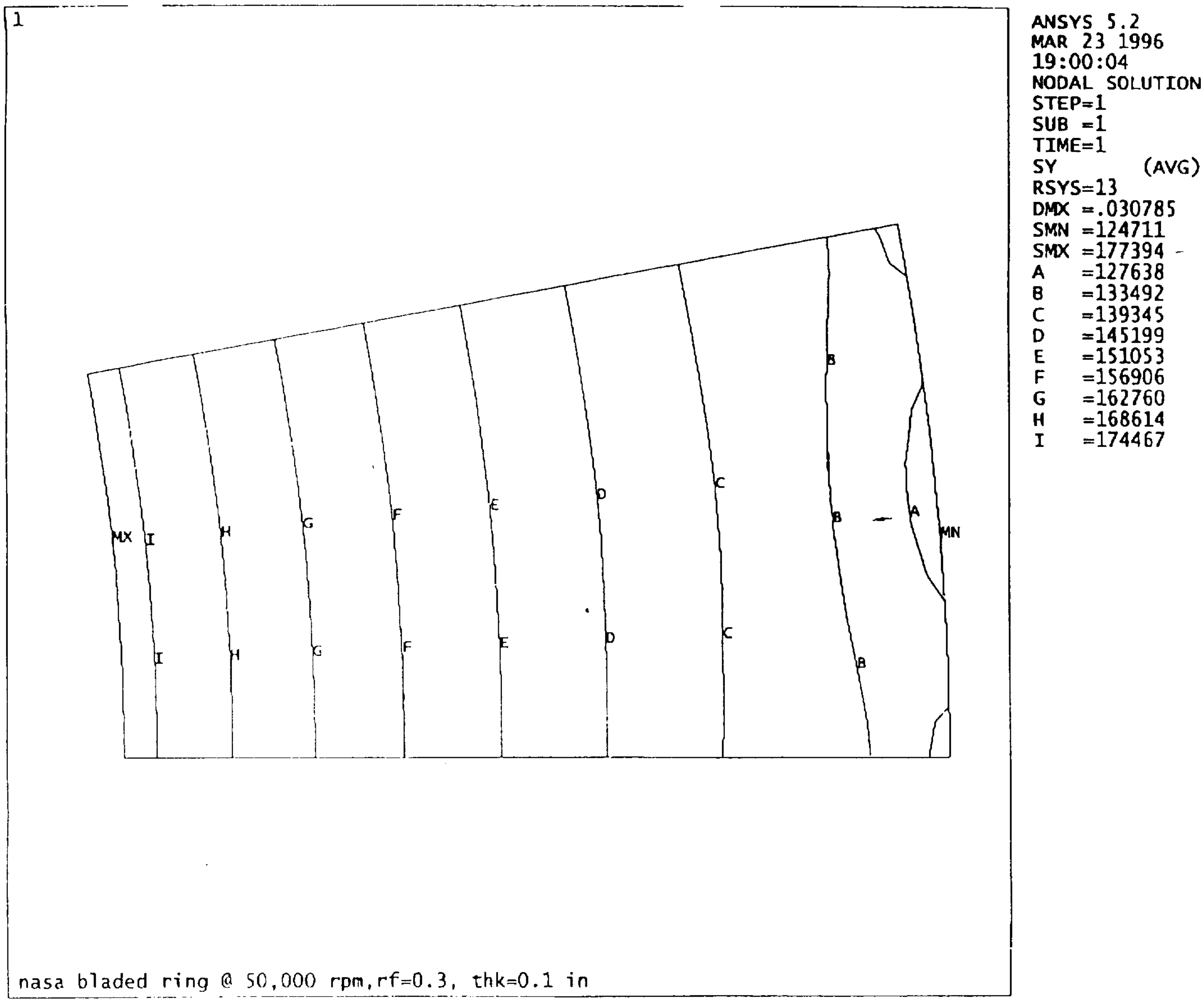


Figure 12b: Hoop Stress Distribution for Configuration 3; MMC ring only

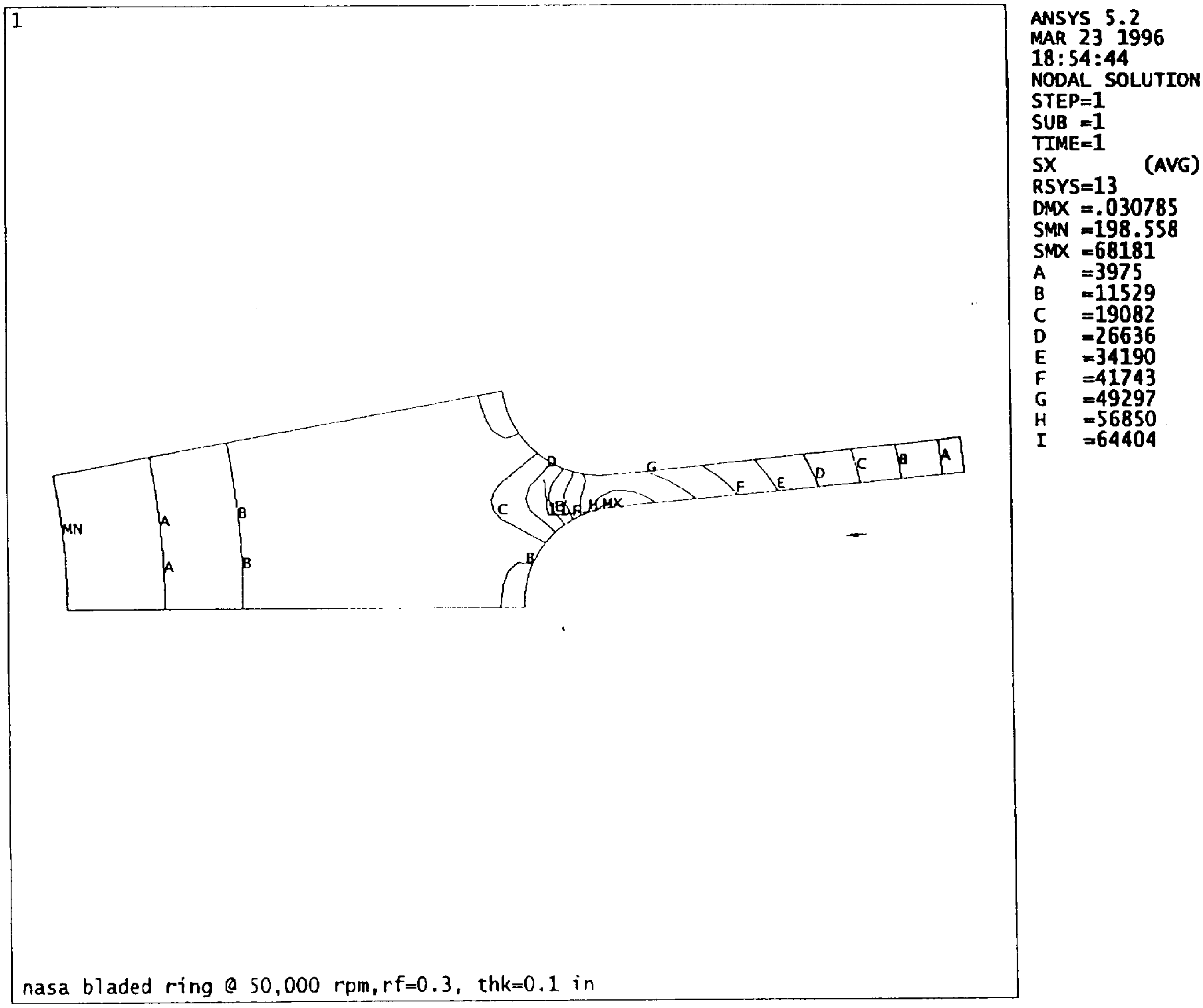


Figure 3a: Radial Stress Distribution for Configuration 3; Full Blade, 0.30-inch filet radius, 0.10-inch blade thickness

AlliedSignal
AEROSPACE

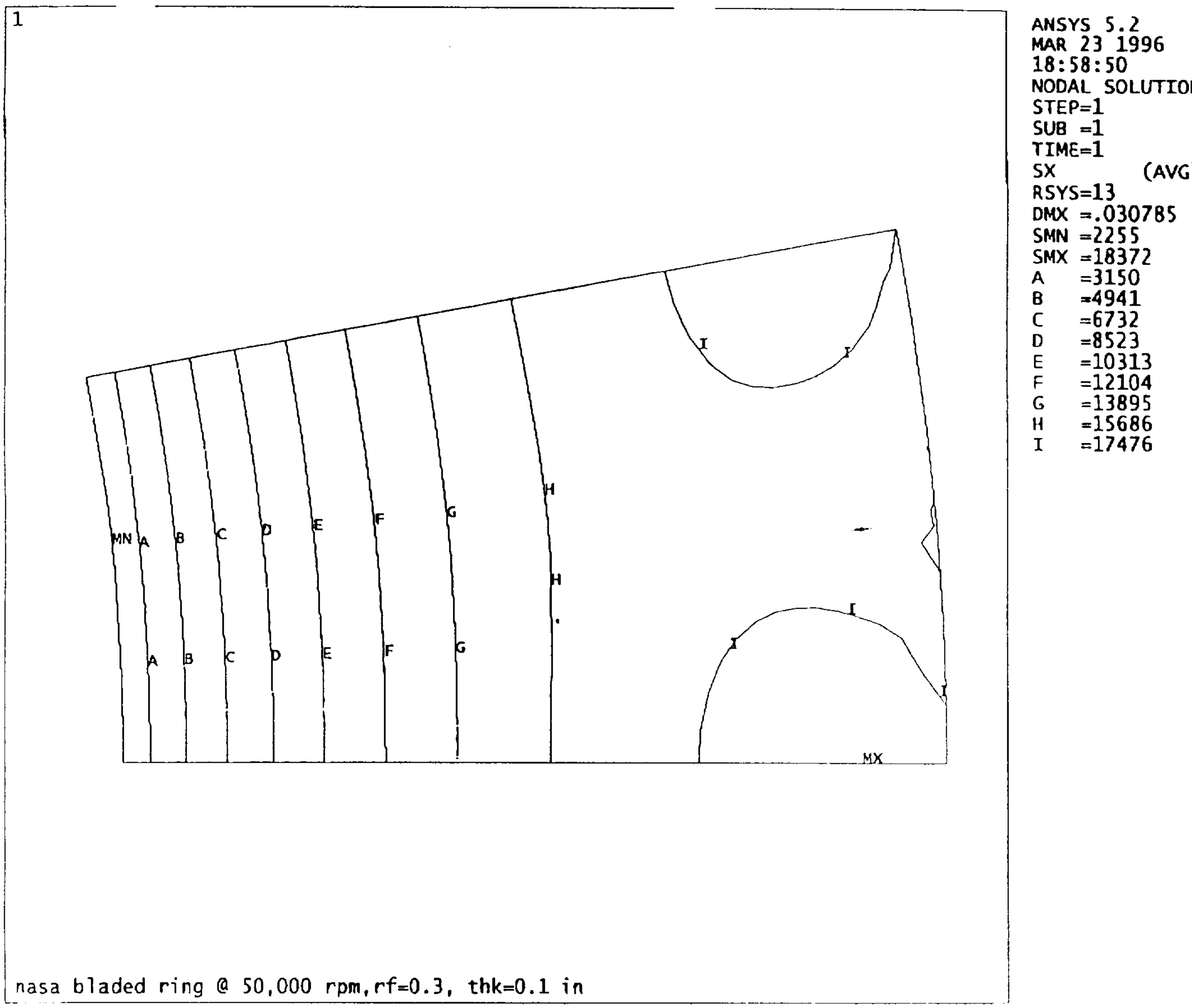


Figure 3b: Radial Stress Distribution for Configuration 3; MMC ring only

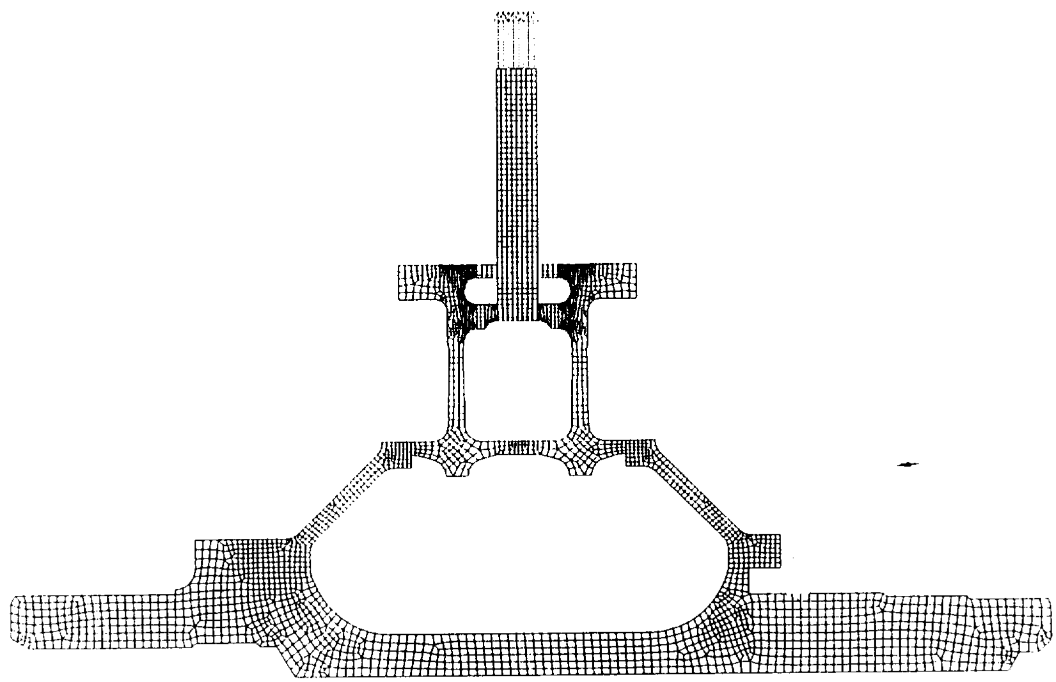
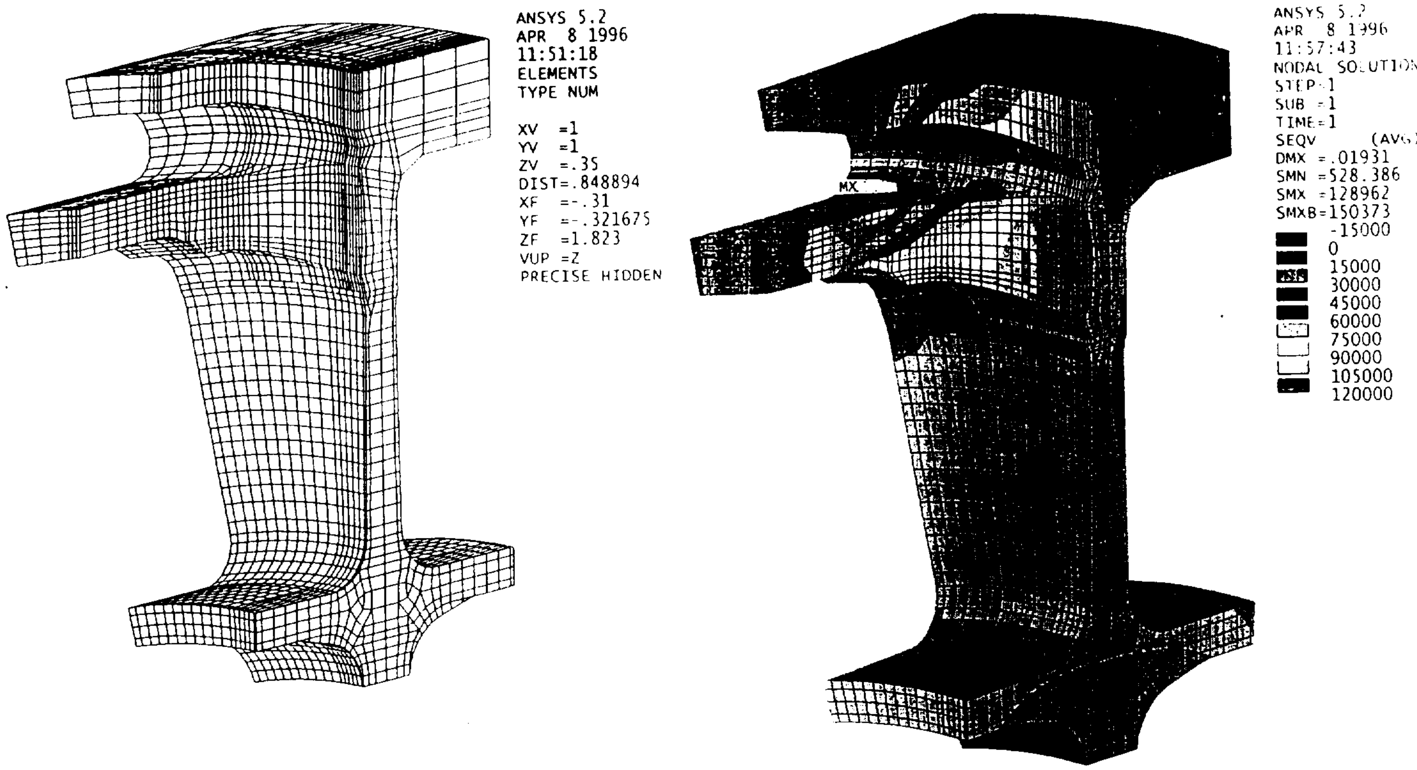


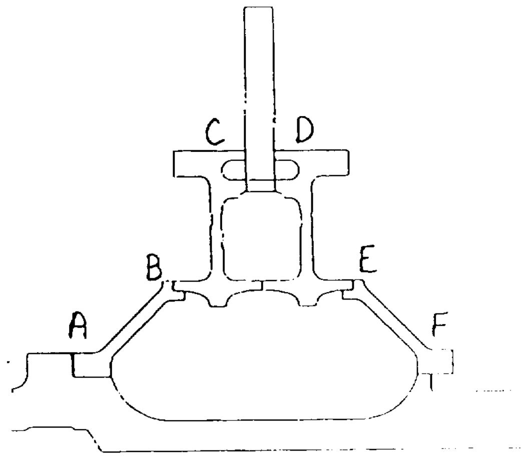
Figure 14: 2D Axisymmetric Model of Arbor and Disk



(a)

(b)

Figure 15: (a) 3D Finite Element Model of the "Soft Touch" Disk and (b) Equivalent Stress Range at the Fingers



Location	Assembly		50Krpm No Blades		50Krpm W/ Blades	
	Rad (lbs)	Axial (lbs)	Rad	Axial	Rad	Axial
A	15,159	25,000	10,813	12,916	10,813	12,916
B	13,060	25,000	2,770	12,916	2,770	12,916
C	6,659	4,298	1,415	1,544	835	1,385
D	6,659	4,298	1,415	1,544	835	1,385
E	13,346	25,000	2,984	12,916	2,984	12,916
F	14,931	25,000	3,757	12,916	3,757	12,916

Figure 16: Spin Arbor Interface Loads

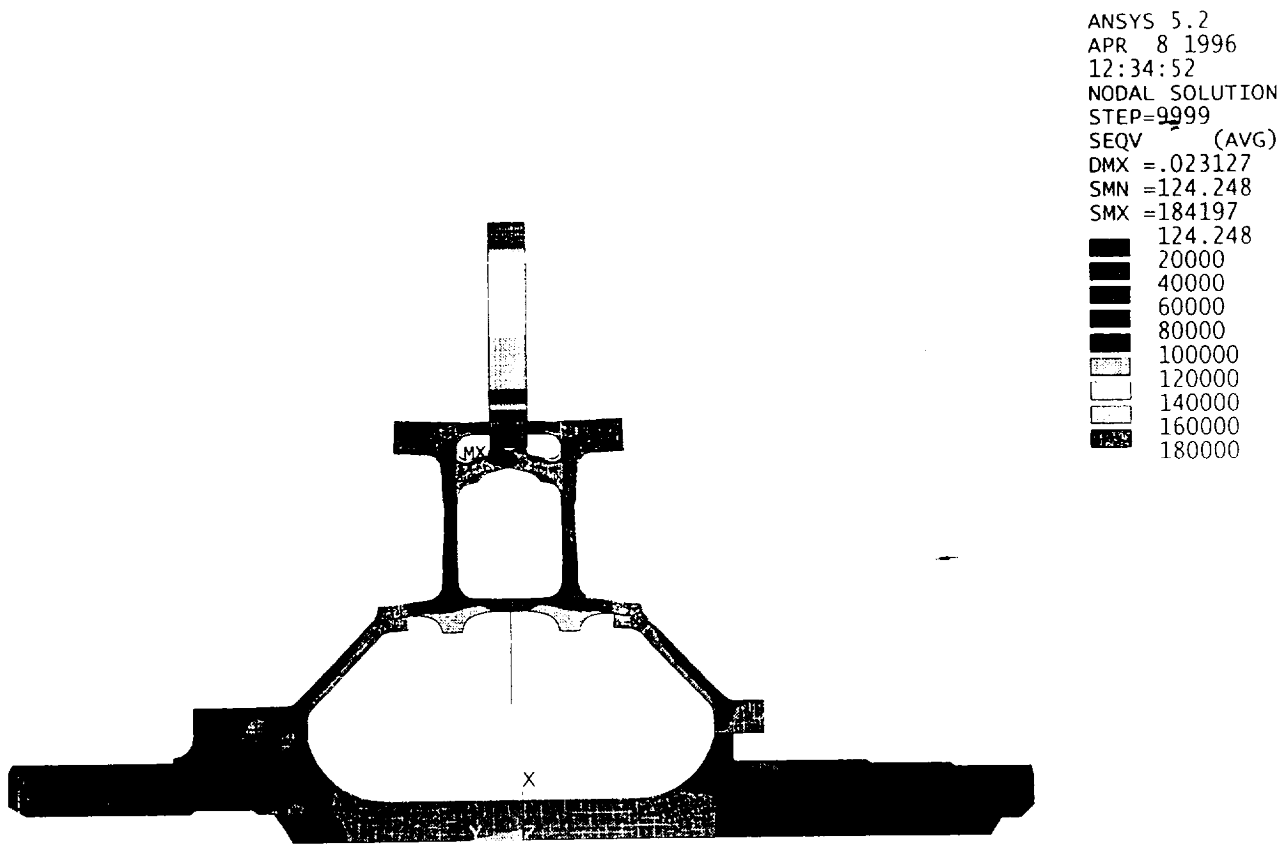


Figure 17: 2D Axi-symmetric Equivalent Stress Range remote From Disk fingers

AlliedSignal
AEROSPACE

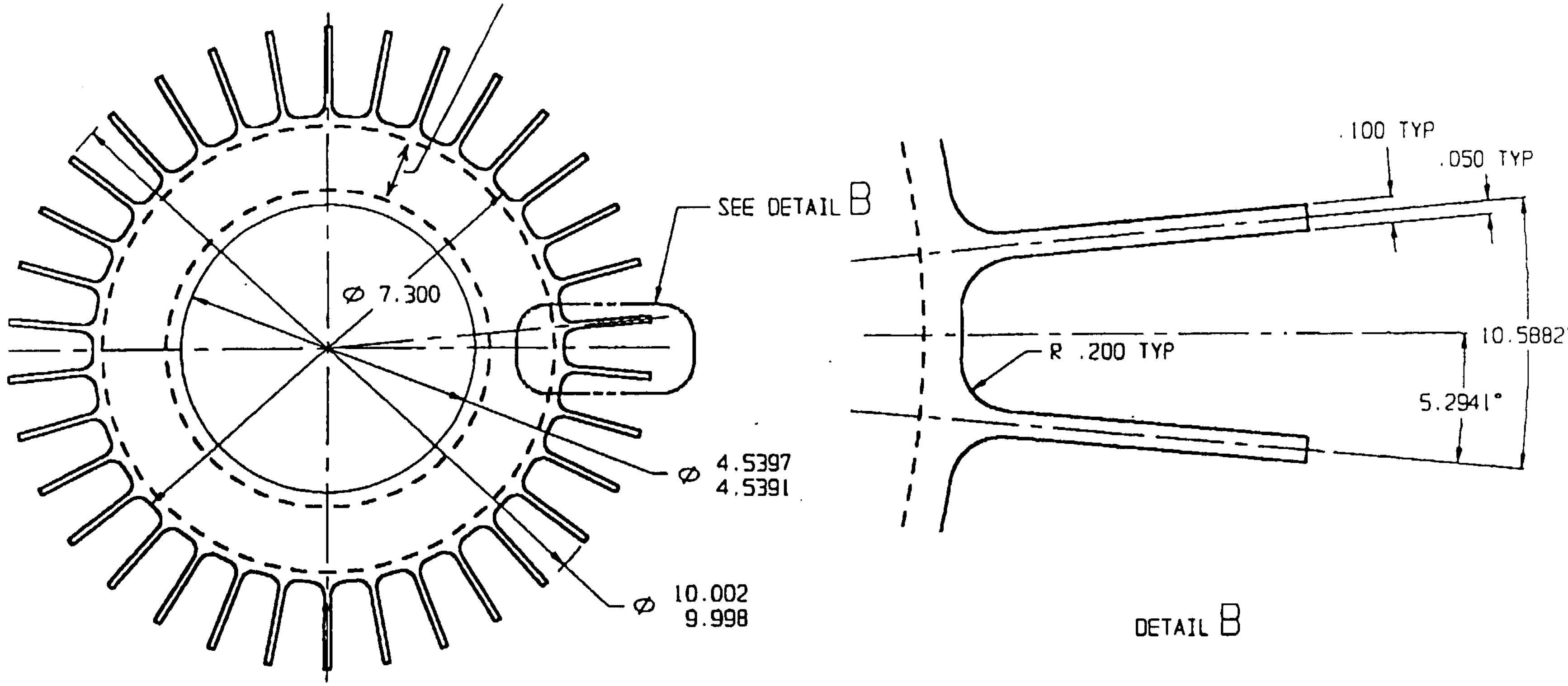


Figure 18 Metal Matrix Composite Reinforced Subcomponent Ring with Integral Simulated Blades.

AlliedSignal
AEROSPACE

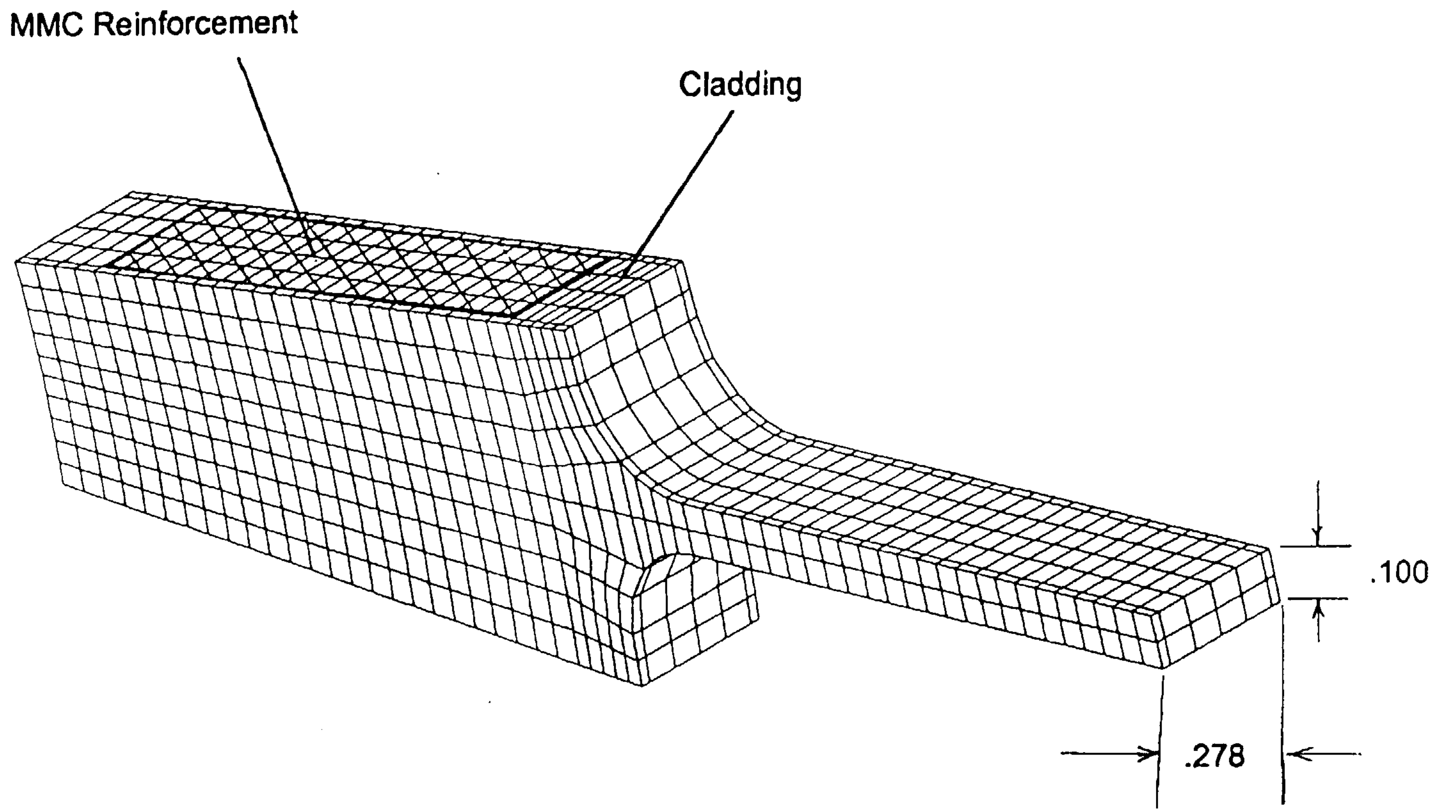


Figure 19 3D Finite Element Model.

AlliedSignal
AEROSPACE

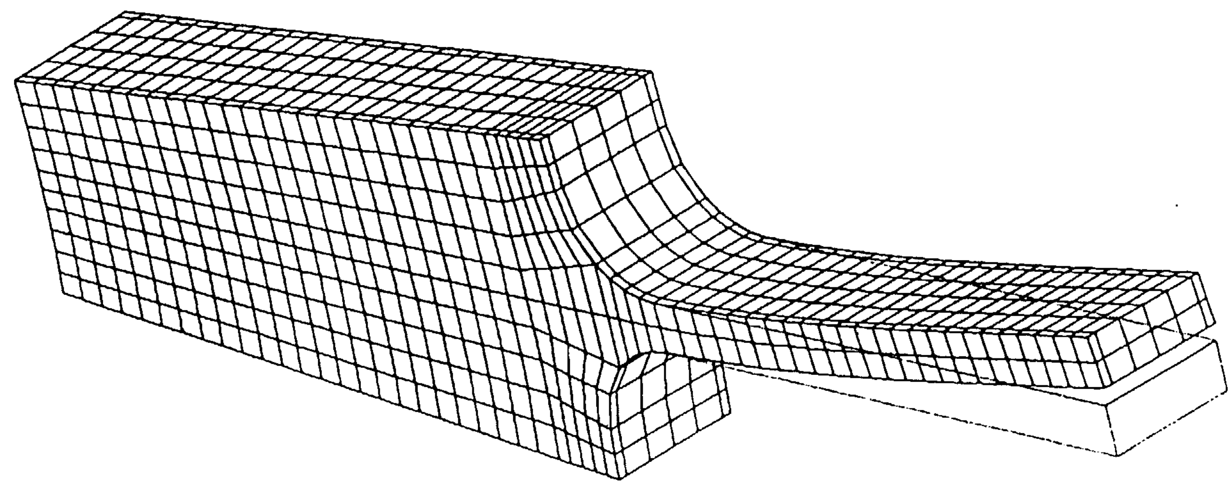


Figure 20: 1st Bending (Circumferential Direction) Mode Shape.

AlliedSignal
AEROSPACE

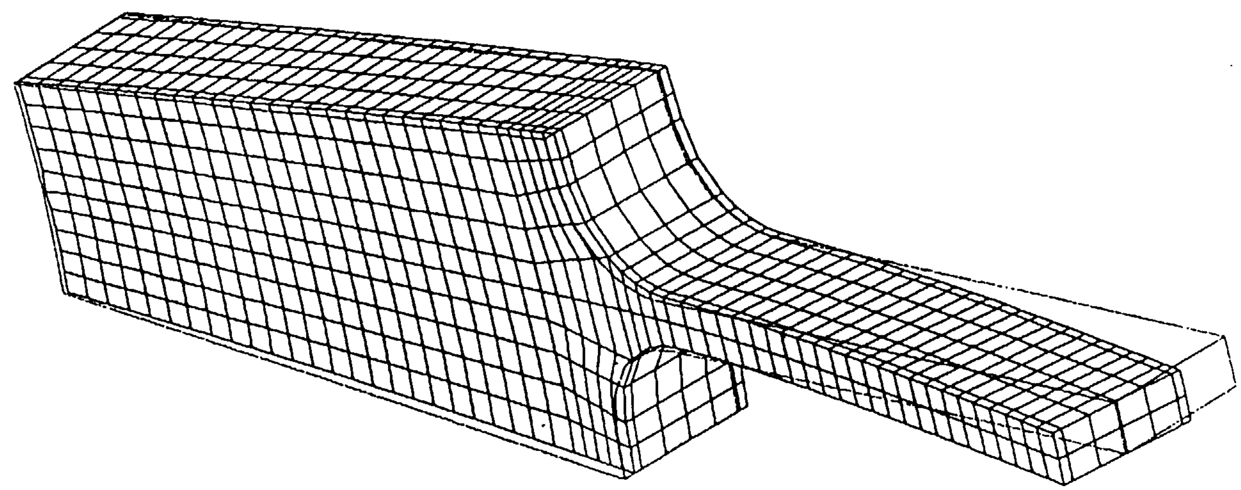


Figure 21: 1st Bending (Axial Direction) Mode Shape.

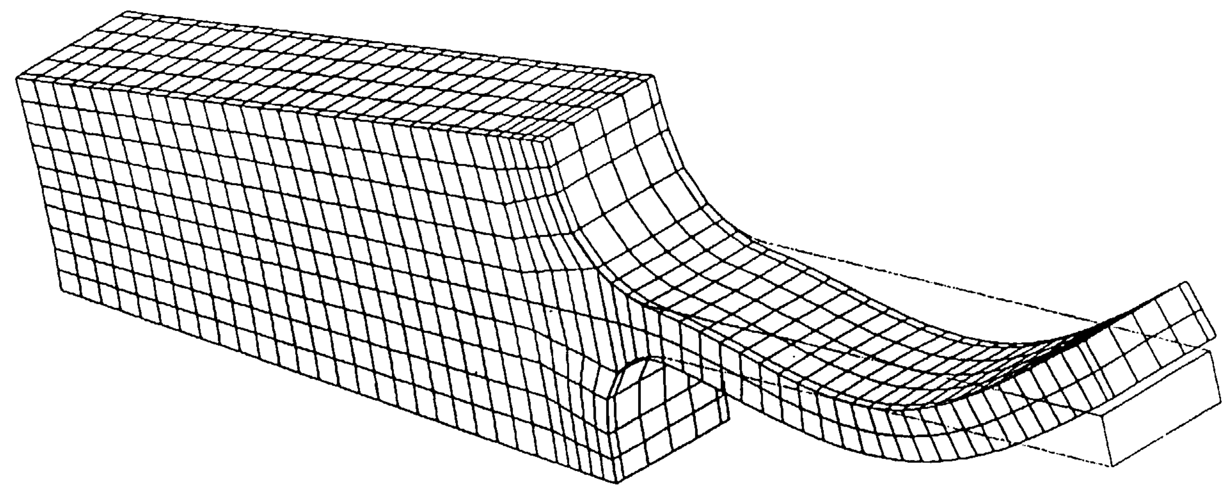


Figure 22: 2nd Bending (Circumferential Direction) Mode Shape.

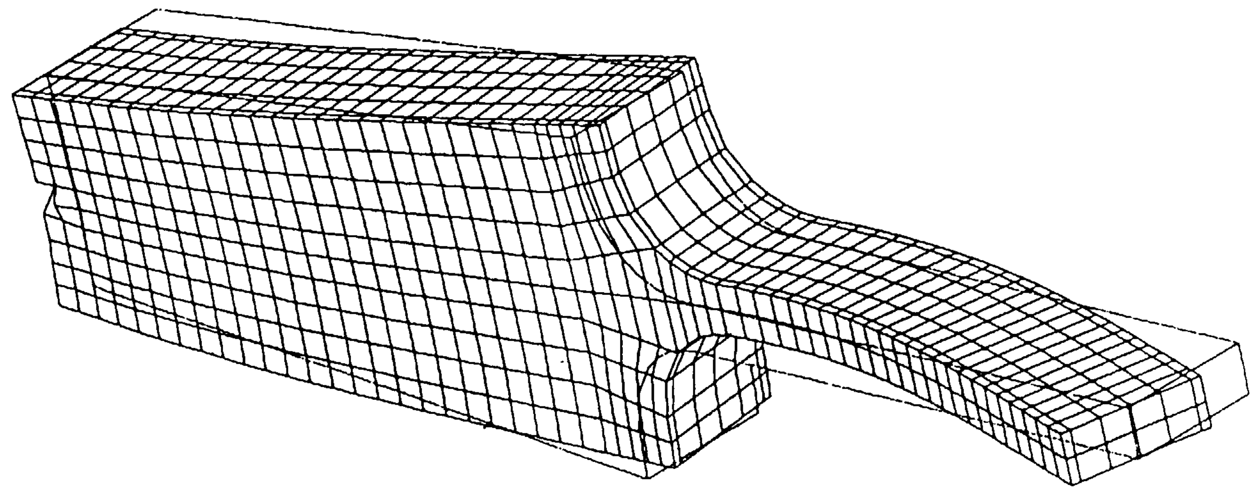


Figure 23: 2nd Bending (Axial Direction) Mode Shape.

AlliedSignal
AEROSPACE

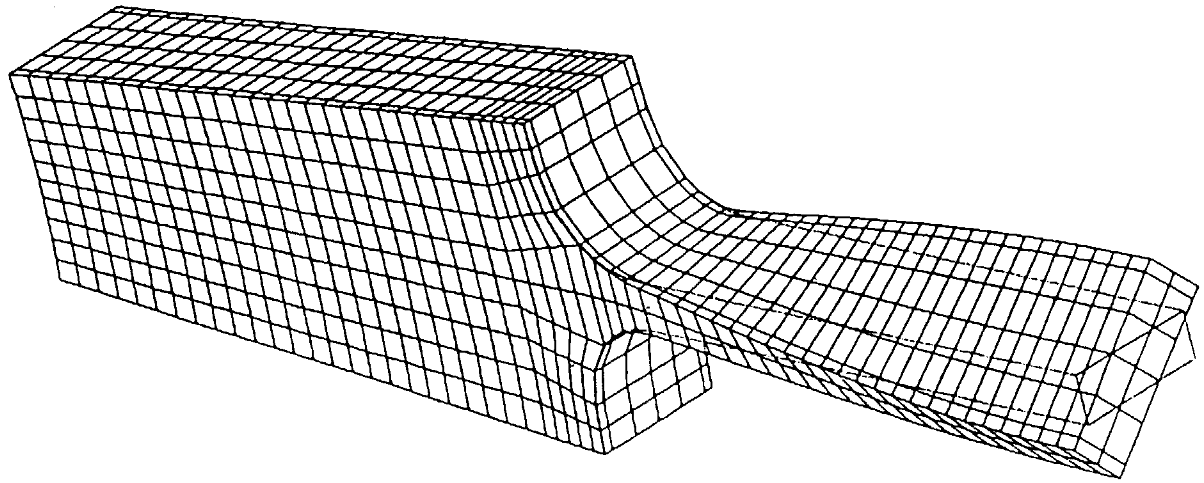


Figure 24: 1st Torsion Mode Shape.

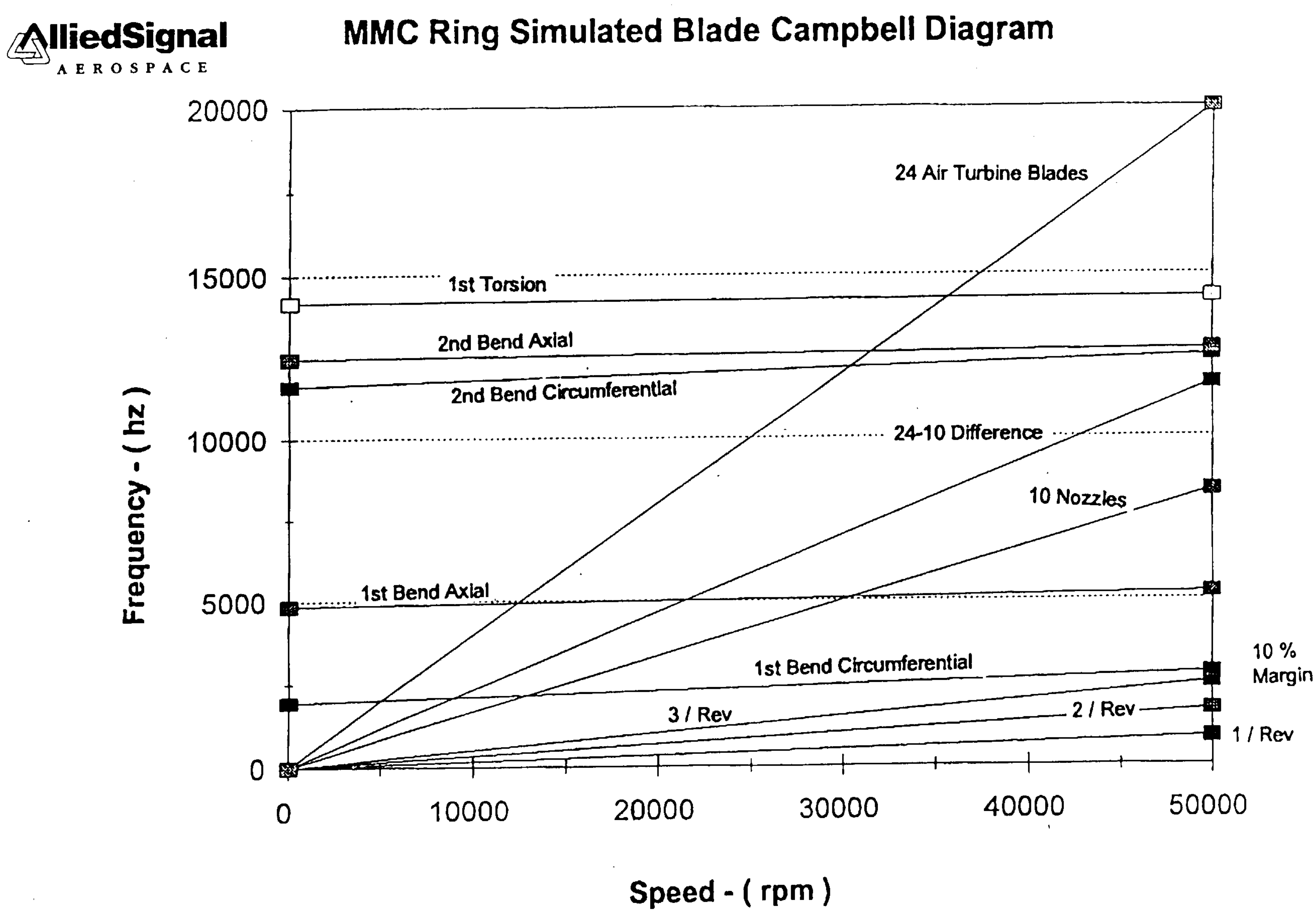
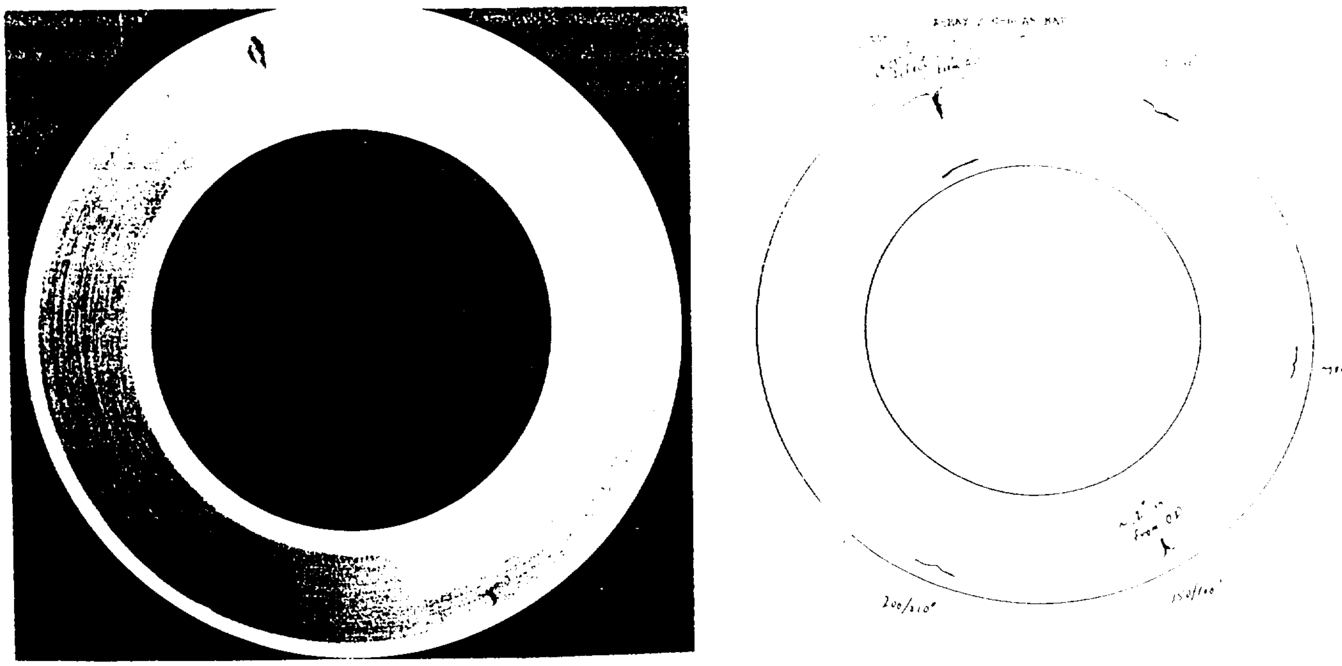
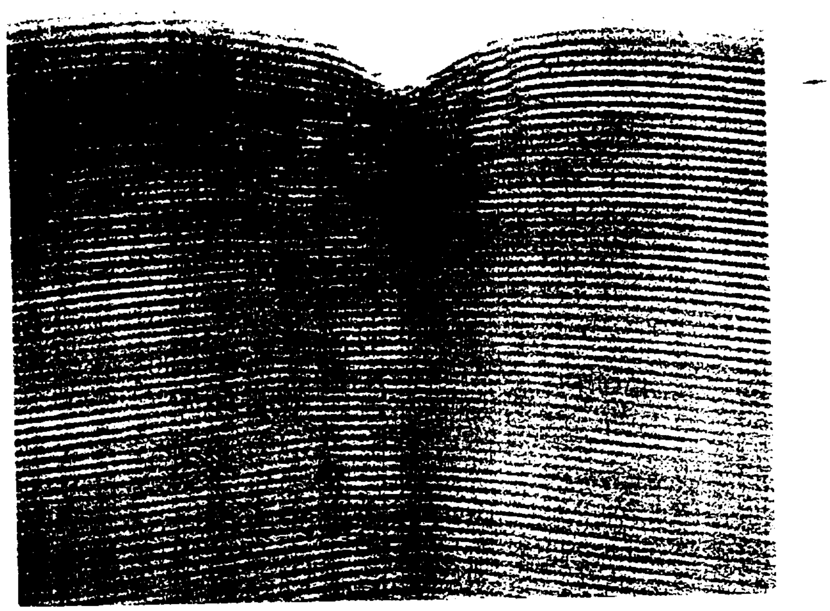


Figure 25: MMC Subcomponent Ring Simulated Blade Campbell Diagram





Fiber Bucking at 350 deg. Mark 7X

Figure 26: X-Ray NDE Images of First Ring Showing Fiber Buckling Flaws.

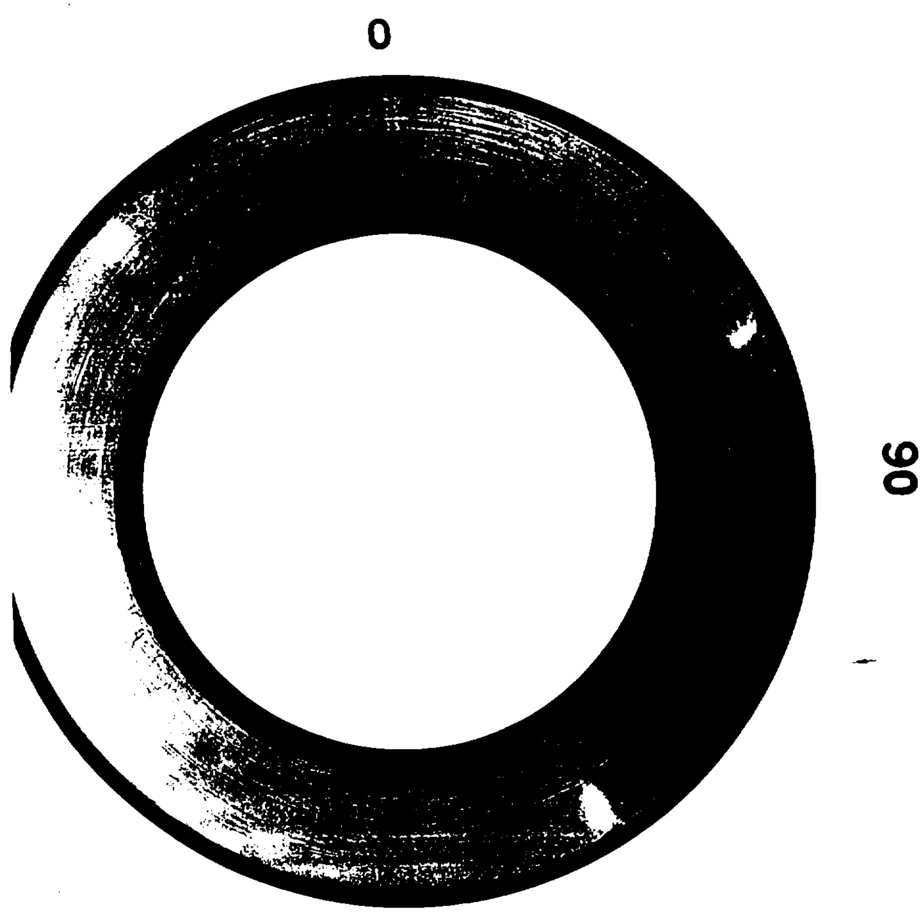
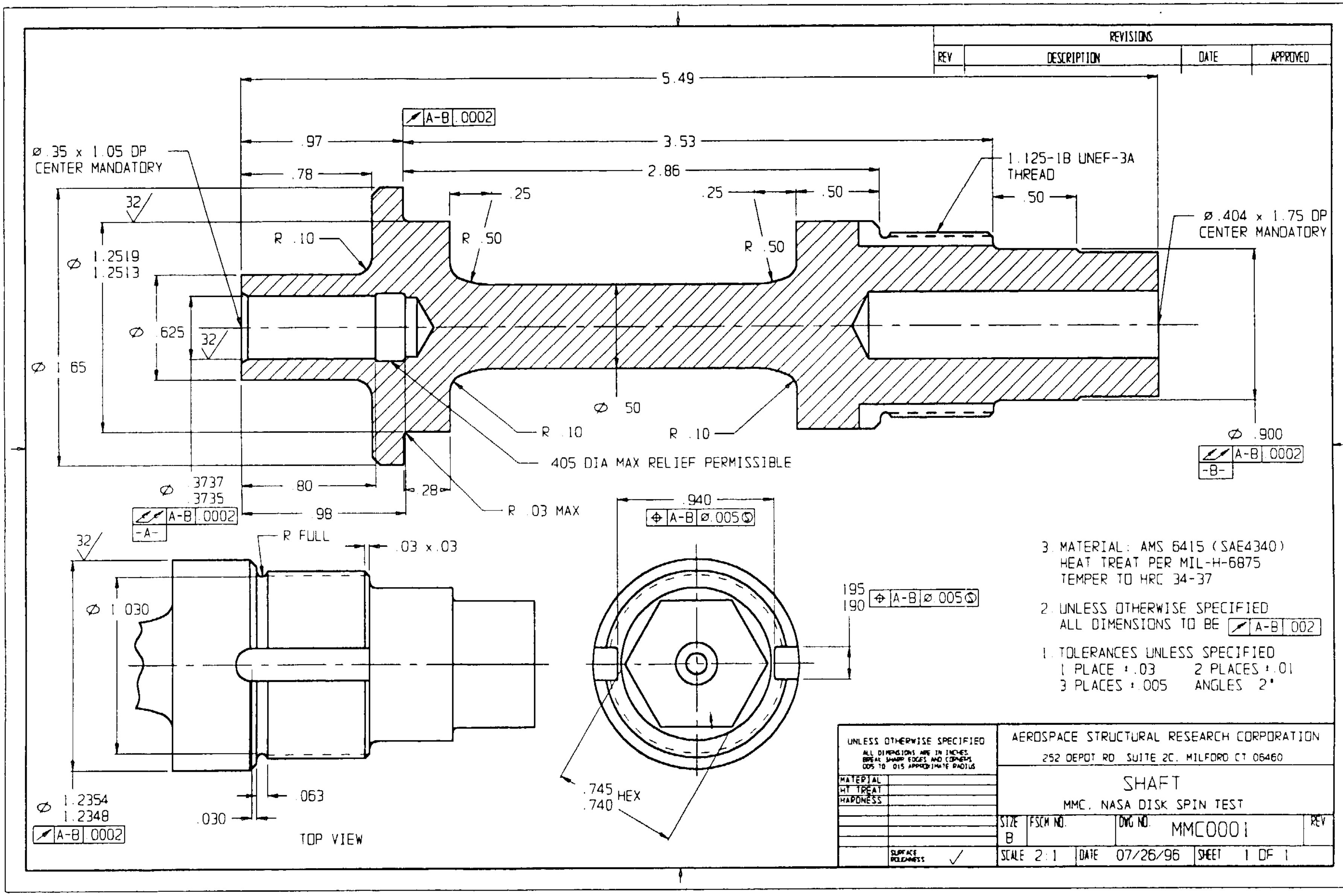
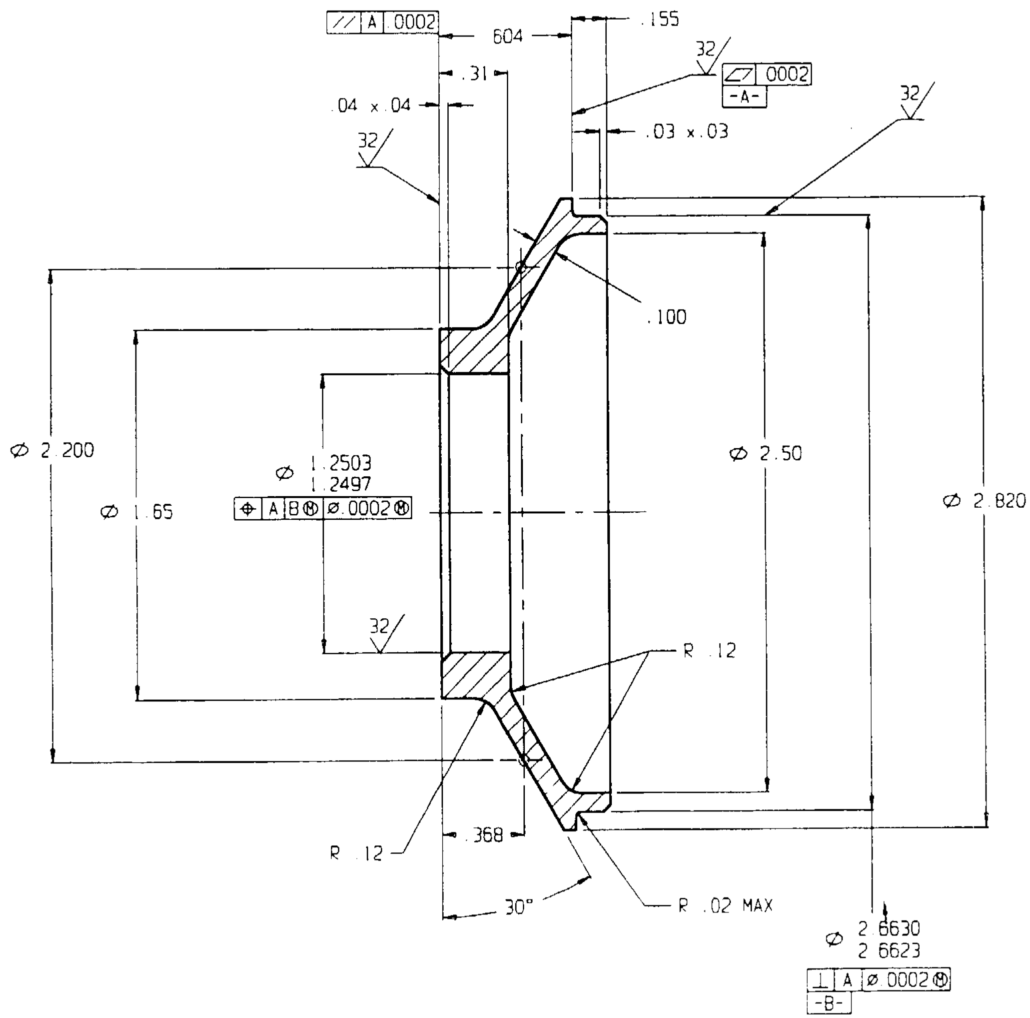


Figure 27: X-Ray NDE Image of Second TMC Ring Fabricated. Defects due to Fiber Buckling are again Evident

Appendix 1

Engineering Drawing of the Spin Test Arbor components and the Simulated Bladed TMC Ring


REVISIONS
REV
DESCRIPTION
DATE
APPROVED
5.49
A-B .0002
.97
3.53
.78
2.86
ø .35 x 1.05 DP
CENTER MANDATORY
1.125-18 UNEF-3A
THREAD
.25
.25
.50
.50
32
ø .404 x 1.75 DP
CENTER MANDATORY
R .10
R .50
R .50
ø 1.2519
1.2513
ø 625
32
ø 65
ø 50
R .10
R .10
405 DIA MAX RELIEF PERMISSIBLE
ø .900
A-B .0002
-B-
ø 3737
3735
A-B .0002
-A-
.80
.98
.28
R .03 MAX
.940
A-B ø .005 S
32
R FULL
.03 x .03
ø 1 030
195
190
A-B ø .005 S
ø 1.2354
1.2348
A-B .0002
.030
.063
TOP VIEW
.745
.740
HEX
3. MATERIAL: AMS 6415 (SAE4340)
HEAT TREAT PER MIL-H-6875
TEMPER TO HRC 34-37
2. UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS TO BE A-B .002
1. TOLERANCES UNLESS SPECIFIED
1 PLACE ± .03 2 PLACES ± .01
3 PLACES ± .005 ANGLES 2°
UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS ARE IN INCHES
BREAK SHARP EDGES AND CORNERS
.005 TO .015 APPROXIMATE RADIUS
MATERIAL
HT TREAT
HARDNESS
SURFACE ROUGHNESS ✓
AEROSPACE STRUCTURAL RESEARCH CORPORATION
252 DEPOT RD SUITE 2C, MILFORD CT 06460
SHAFT
MMC, NASA DISK SPIN TEST
SIZE B
FSCM NO.
DWG NO. MMC0001
REV
SCALE 2:1
DATE 07/26/96
SHEET 1 OF 1



REVISIONS			
REV	DESCRIPTION	DATE	APPROVED

3. MATERIAL: AMS 6415 (SAE4340)
   HEAT TREAT PER MIL-H-6875
   TEMPER TO HRC 34-37

2. UNLESS OTHERWISE SPECIFIED
   ALL DIMENSIONS TO BE ↗| B | .002

1. TOLERANCES UNLESS SPECIFIED:
   1 PLACE ± .03   2 PLACES ± .01
   3 PLACES ± .005   ANGLES 2°

UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS ARE IN INCHES
BREAK SHARP EDGES AND CORNERS
.005 TO .015 APPROXIMATE RADIUS

MATERIAL
HT TREAT
HARDNESS

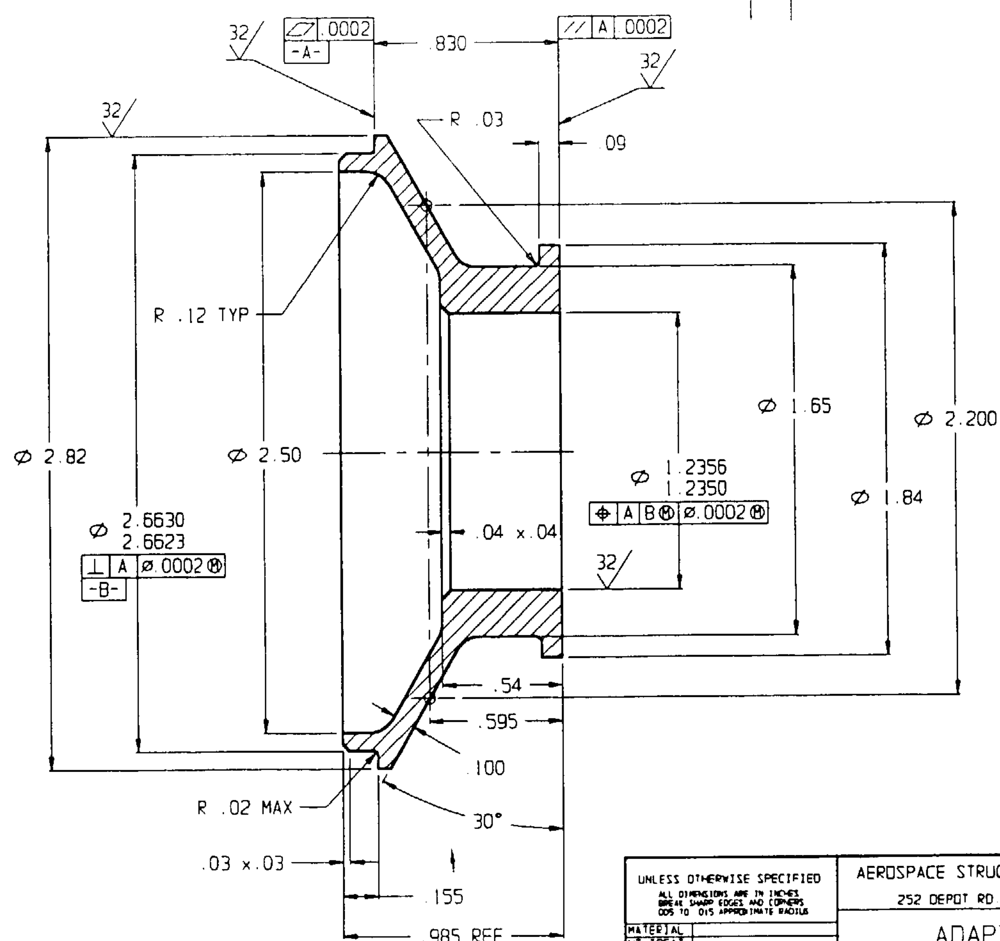
SURFACE ROUGHNESS ✓

AEROSPACE STRUCTURAL RESEARCH CORPORATION
252 DEPOT RD SUITE 2C, MILFORD CT 06460

ADAPTER, UPPER
MMC, SPIN ARBOR

SIZE	FSCM NO.	DWG NO.	REV
B		MMC0002	
SCALE 2:1	DATE 08/03/96	SHEET 1 OF 1	

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED



3. MATERIAL: AMS 6415 (SAE4340)
   HEAT TREAT PER MIL-H-6875
   TEMPER TO HRC 34-37

2. UNLESS OTHERWISE SPECIFIED
   ALL DIMENSIONS TO BE ↗ B .002

1. TOLERANCES UNLESS SPECIFIED:
   1 PLACE ± .03 2 PLACES ± .01
   3 PLACES ± .005 ANGLES ± 2°

UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS ARE IN INCHES
BREAK SHARP EDGES AND CORNERS
.005 TO .015 APPROXIMATE RADIUS

MATERIAL
HT TREAT
HARDNESS

SURFACE ROUGHNESS ✓

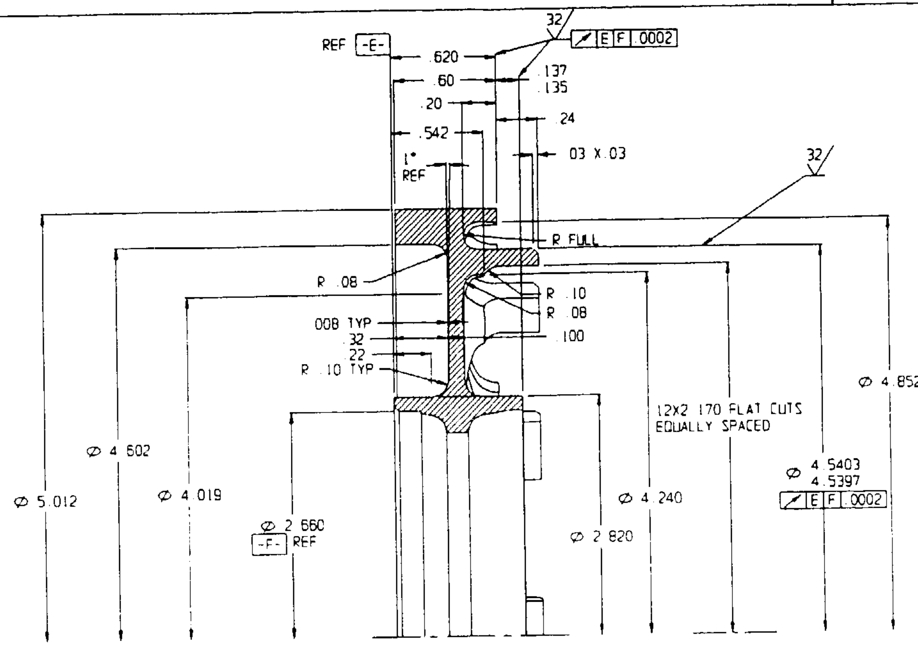
AEROSPACE STRUCTURAL RESEARCH CORPORATION
252 DEPOT RD. SUITE 2C. MILFORD CT 06460

ADAPTER, LOWER
MMC, SPIN ARBOR

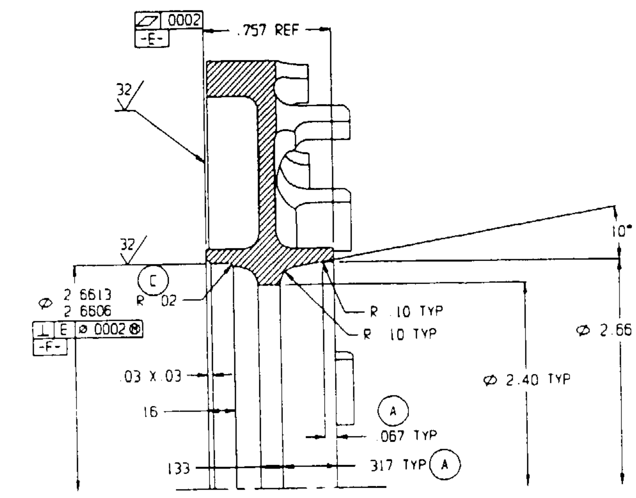
SIZE	FSCM NO.	DWG NO.	REV
B		MMC0003	

SCALE	2:1	DATE	08/03/96	SHEET	1 OF 1

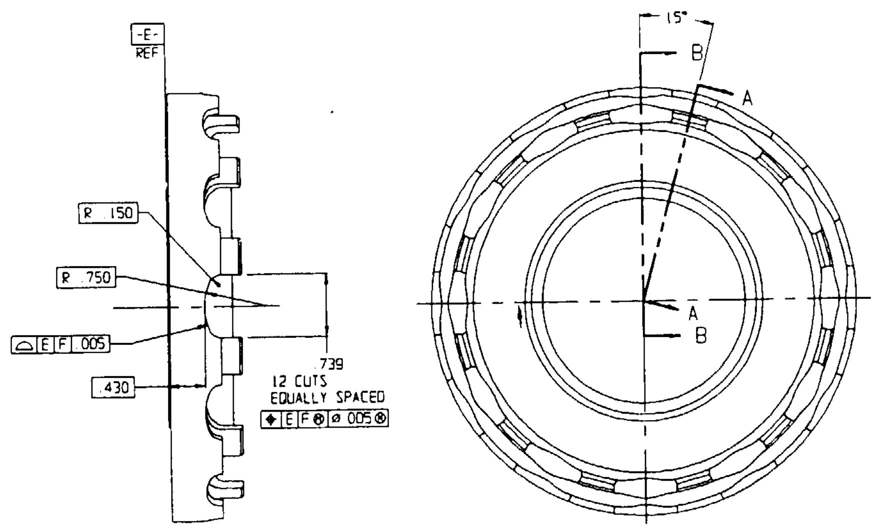
REVISIONS			
REV	DESCRIPTION	DATE	APPROVED
A	.067 WAS .05; .317 WAS .30	9/12/96	MKC
B	REDRAWN	9/13/96	AP
C	ADDED R .02	9/27/96	MKC



SECTION A-A
ROTATED 45° CCW
SCALE 2:1



SECTION B-B
SCALE: 2:1



4. ASSEMBLY REQUIRES 2 PARTS.

3. MATERIAL: AMS 6415 (SAE4340)
HEAT TREAT PER P6000L2.3.4B
HRC 34-37

2. UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS TO BE ⌰ B .002

1. TOLERANCES UNLESS SPECIFIED:
1 PLACE ± .03   2 PLACES ± .01
3 PLACES ± .005   ANGLES ± 2°

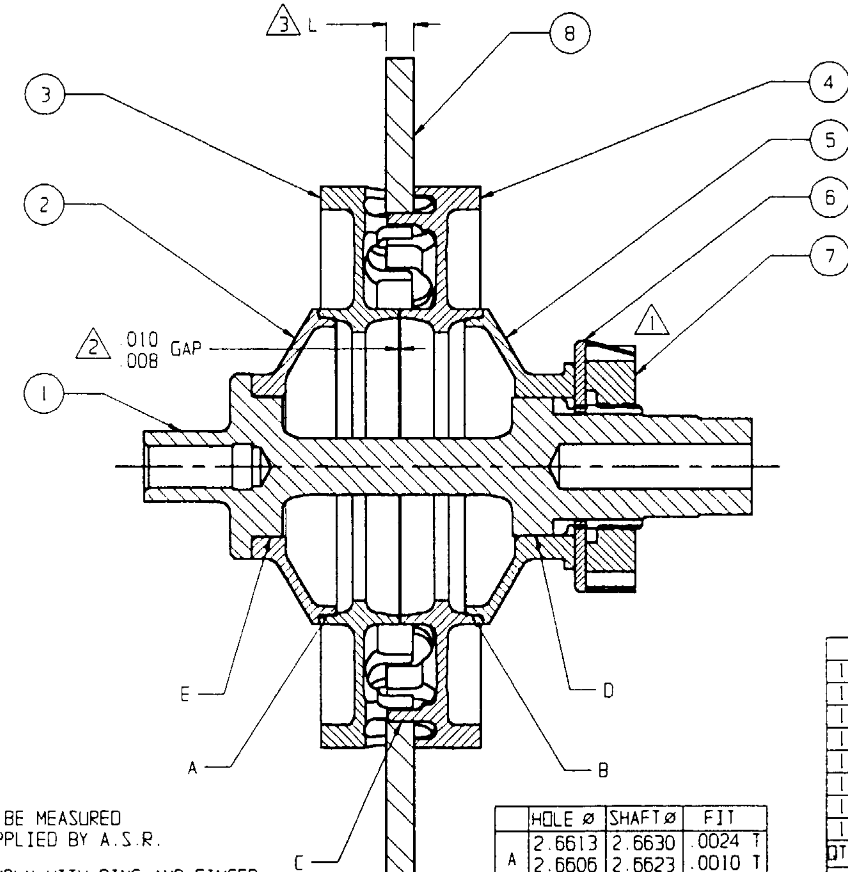
UNLESS OTHERWISE SPECIFIED

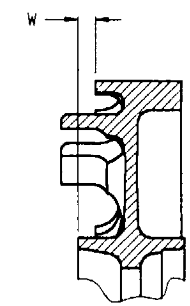
MATERIAL
HT TREAT
HARDNESS

AEROSPACE STRUCTURAL RESEARCH CORPORATION
252 DEPOT RD SUITE 2C, MILFORD CT 06460

FINGER DISK
MMC SPIN ARBOR

SIZE	FSCM NO	DWG NO.	REV
C		MMC0004	B
SCALE 1:1	08/13/96	SHEET 1 OF 1	





$W = \frac{L - GAP}{2}$

FINGER DISK
MACHINING DETAIL
(TYP)

REV	DESCRIPTION	DATE	APPROVED

3 DIMENSION "L" TO BE MEASURED FROM RING OR SUPPLIED BY A.S.R.

2 MAINTAIN AT ASSEMBLY WITH RING AND FINGER DISKS FULLY SEATED AND NO TORQUE ON NUT.

1 LUBRICATE THREADS, NUT BEARING SURFACE AND BETWEEN LOWER ADAPTER AND SHAFT USING MOLYLUBE.

	HOLE Ø	SHAFT Ø	FIT
A	2.6613 2.6606	2.6630 2.6623	.0024 T .0010 T
B	2.6613 2.6606	2.6630 2.6623	.0024 T .0010 T
C	4.5397 4.5391	4.5403 4.5397	.0012 T .0000 L
D	1.2356 1.2350	1.2354 1.2348	.0004 T .0008 L
E	1.2503 1.2497	1.2519 1.2513	.0022 T .0010 T

QTY	ITEM	PART NO	DESCRIPTION	MATL OR NOTE
1	8		RING	
1	7	MMC0006	NUT	
1	6	MMC0007	LOCK CUP	
1	5	MMC0003	ADAPTER, LOWER	
1	4	MMC0004	FINGER DISK	
1	3	MMC0004	FINGER DISK	
1	2	MMC0002	ADAPTER, UPPER	
1	1	MMC0001	SHAFT	

PARTS LIST

UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS ARE IN INCHES
BREAK SHARP EDGES AND CORNERS
.005 TO .015 APPROXIMATE RADIUS

MATERIAL
HT TREAT
HARDNESS

SURFACE ROUGHNESS ✓

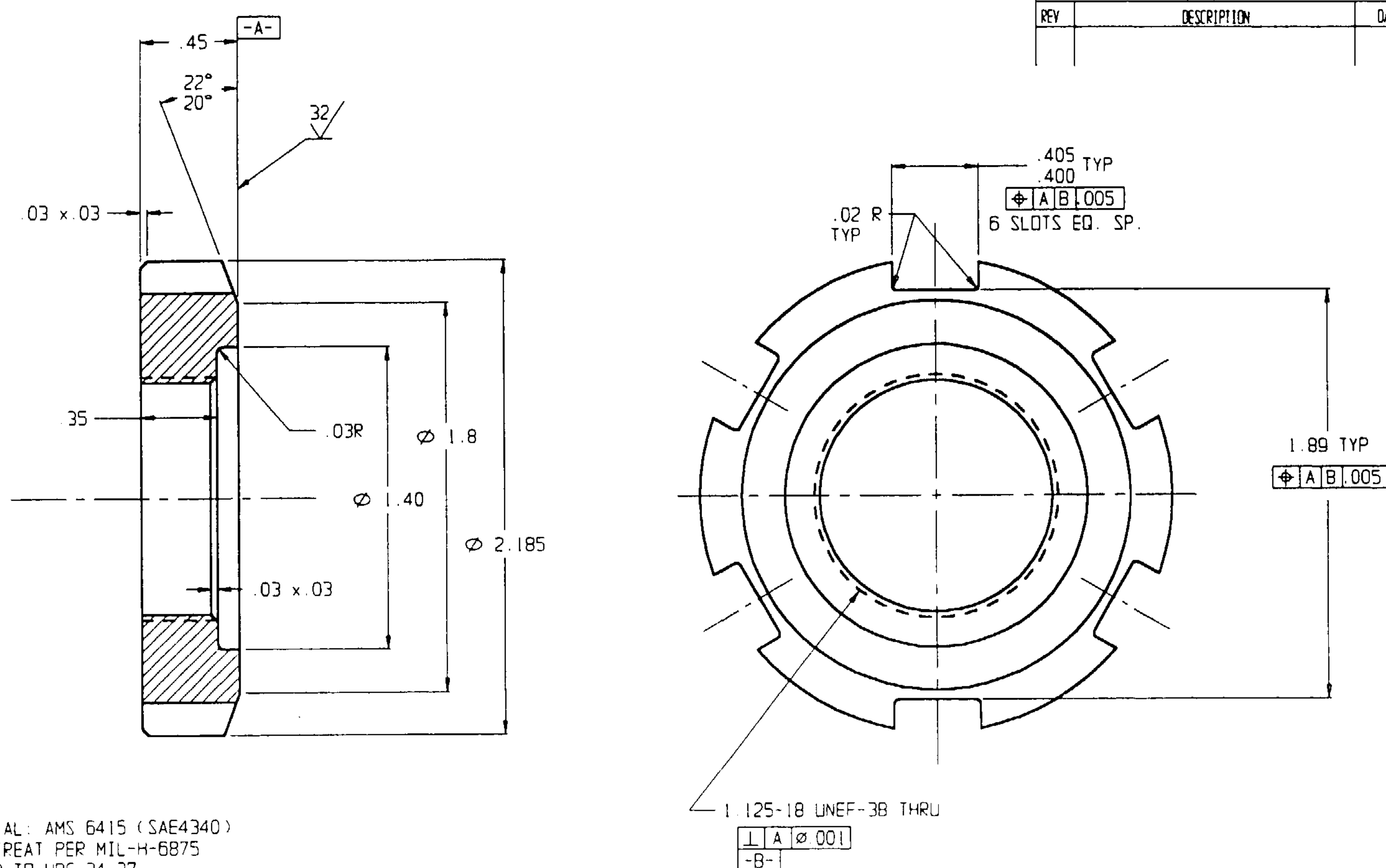
AEROSPACE STRUCTURAL RESEARCH CORPORATION
252 DEPOT RD. SUITE 2C, MILFORD CT 06460

ASSEMBLY
MMC, SPIN ARBOR

SIZE B | FSCM NO. | DWG NO. MMC0005 | REV

SCALE 1:1 | 09/16/96 | SHEET 1 OF 1

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED



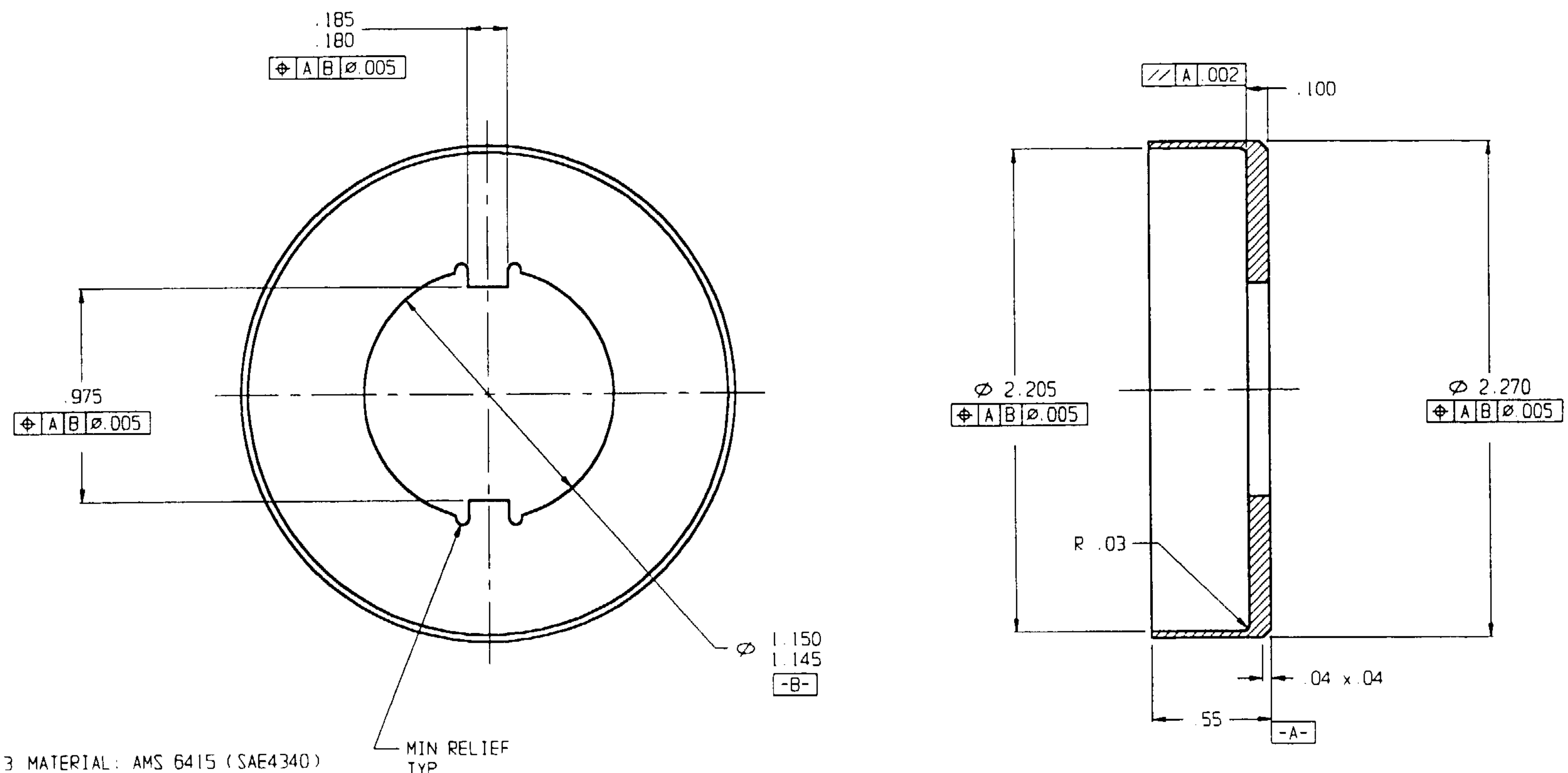
3. MATERIAL: AMS 6415 (SAE4340)
   HEAT TREAT PER MIL-H-6875
   TEMPER TO HRC 34-37

2. UNLESS OTHERWISE SPECIFIED
   ALL DIAS TO BE ⌖ A B Ø.005

1. TOLERANCES UNLESS SPECIFIED:
   1 PLACE ± .03 2 PLACES ± .01
   3 PLACES ± .005 ANGLES 2°

UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES BREAK SHARP EDGES AND CORNERS .005 TO .015 APPROXIMATE RADIUS	AEROSPACE STRUCTURAL RESEARCH CORPORATION 252 DEPOT RD SUITE 2C, MILFORD CT 06460				
MATERIAL HT TREAT HARDNESS	NUT MMC, SPIN ARBOR				
	SIZE B	FSCM NO.	DWG NO. MMC0006		REV
SURFACE ROUGHNESS ✓	SCALE 2:1		10/03/96	SHEET 1 OF 1	

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED



3. MATERIAL: AMS 6415 (SAE4340)
   HEAT TREAT PER MIL-H-6875
   TEMPER TO HRC 34-37

2. UNLESS OTHERWISE SPECIFIED
   ALL DIMENSIONS TO BE ⌖ A B ⌀.005

1. TOLERANCES UNLESS SPECIFIED
   1 PLACE ± .03 2 PLACES ± .01
   3 PLACES ± .005 ANGLES 2°

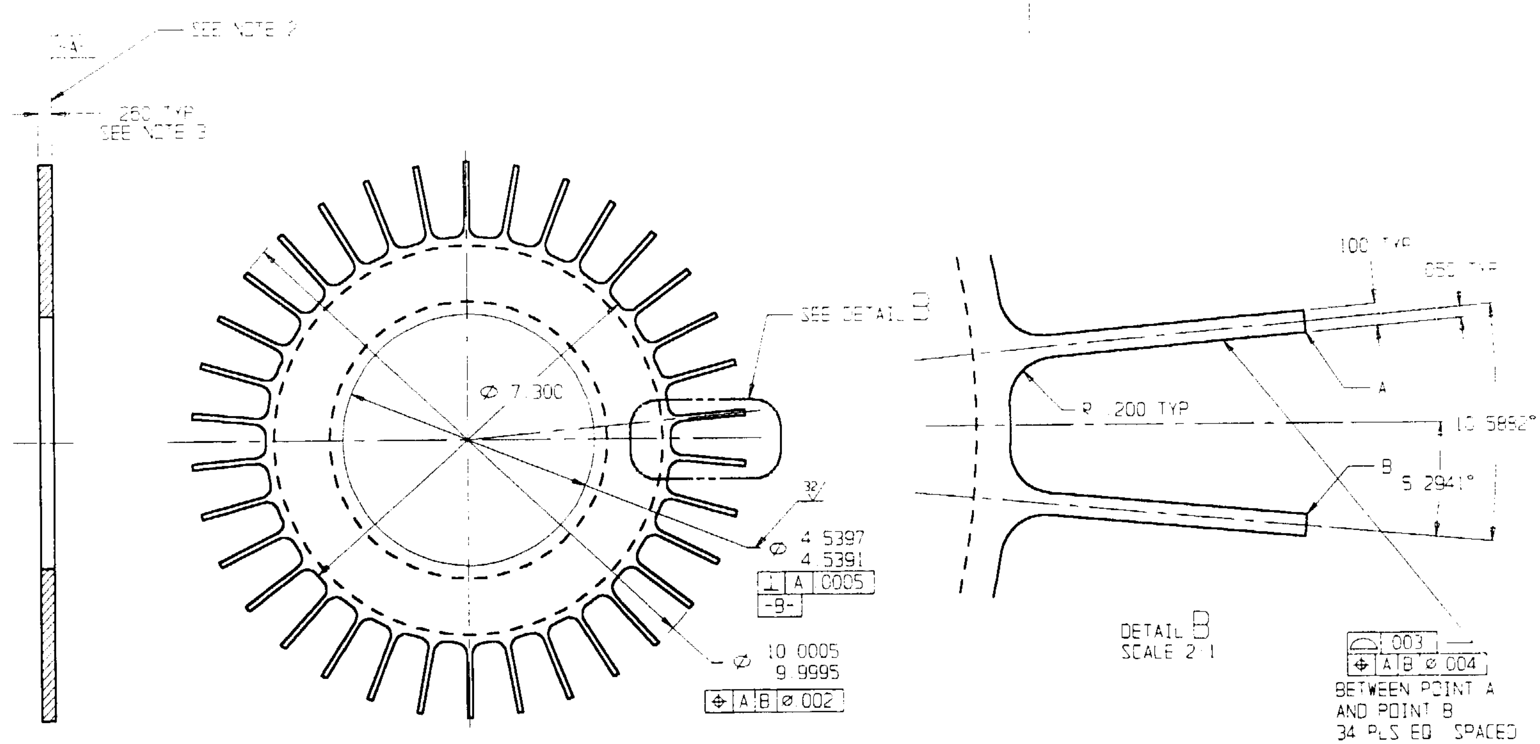
UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS ARE IN INCHES
BREAK SHARP EDGES AND CORNERS
.005 TO .015 APPROXIMATE RADIUS

MATERIAL
HT TREAT
HARDNESS
SURFACE ROUGHNESS ✓

AEROSPACE STRUCTURAL RESEARCH CORPORATION
252 DEPOT RD. SUITE 2C. MILFORD CT 06460

CUP
MMC, SPIN ARBOR

SIZE	FSCM NO	DWG NO	REV
B		MMC0007	
SCALE 2:1	10/03/96	SHEET 1 OF 1	



3. THICKNESS TO BE MEASURED AS RECEIVED. CONTACT A.S.R. TO DETERMINE THICKNESS AND TOLERANCE REQUIREMENT.

2. SURFACE FLATNESS TO BE MEASURED AFTER MACHINING OF FINGERS. CONTACT A.S.R. TO DETERMINE ACTUAL REQUIREMENT.

1. TOLERANCES UNLESS SPECIFIED. ALL UNTOLERANCED DIMENSIONS ARE BASIC.

UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS ARE IN INCHES
BREAK SHARP EDGES AND CORNERS .005 TO .015 APPROXIMATE RADIUS

MATERIAL
HT TREAT
HARDNESS

SURFACE ROUGHNESS 63

AEROSPACE STRUCTURAL RESEARCH CORPORATION
252 DEPOT RD. SUITE 2C, MILFORD CT 06460

RING, BLADED
MMC, SPIN ARBOR

SIZE	FSCM NO	DWG NO	REV
B		MMC0008	
SCALE 1:2	DATE 10/10/96	SHEET 1 OF 1	

Appendix 2

Vendor documentation of the TMC ring fabrication process

W6-2321
LAN R3/1/96 SPECIAL MANUFACTURING ORDER

TEXTRON Systems Division

SHEET 1 OF 1

				ORDER NUMBER
				TRAVELER NUMBER
		ORDER DATE		TOOL IDENTIFICATION
PROGRAM Allied Sig. Ring#2	MAC. NO R2471000000	PART NAME Ti-6-4/SCS-6 Ring		DATE WANTED 10/14/97 / EST. HRS 40
ORIGINATOR R. Lewis	TEL NO. 7511 / ROOM NO. Low. Bld. 9 / SECTION 7321	DWG. NUMBER	QTY 1	SCHEDULED DELIVERY
PROCESS ENG. R. Lewis / TEL NO. 7511	MFG EXPEDITER R. Horton / TEL NO. 7539	APPLICABLE E.C.		APPROVALS
DEFINE END USE. [x] EXPERIMENTAL [ ] TOOL [ ] END PRODUCT	SECURITY CLASS. [ ] SECRET [ ] CONFIDENTIAL [x] NONE	INSPECTION REQMTS. [ ] TEXTRON [x] REQUESTER [ ] WAIVED	MATERIALS CERT. [ ] YES [x] NO MATERIALS SUPPLIED [ ] YES [x] NO	MATERIAL LOCATION Lowell Bldg. 9

INSTRUCTIONS:

OPERATION NUMBER	WORK CENTER	OPERATION DESCRIPTION	EST. HOURS	DATE	STAMP/ INITIALS
10	9-200	Obtain Grooved Ti-6-4/SCS-6 Fiber Preforms			
20	9-250	Obtain Graphite Tooling			
30	9-210	Laser Cut Preforms			
40	9-210	Cut Mo Foils			
50	9-250	Prep. Tooling			
60	9-220	Layup and Assemble into Graphite Tooling			
70	9-250	Load into Vacuum Hot Press			
80	9-250	Consolidate in VHP			
90	9-250	Disassemble			
100	9-310	Acid Etch Mo			
110	9-710	C-Scan			
120	10-780	X-Ray			
130	8888	Machine Ti-6-4 Tooling and MMC Ring			
140	9-310	Clean and Assemble Ring and Tooling			
150	9-250	Bond in Vacuum Hot Press			
160	9-710	C-Scan			
170	9-310	Final Clean			
180	Shipping	Ship			

ORDER CONTROL

MANUFACTURING OPERATION SHEET

OPERATION NUMBER: 0020		
LOT NUMBER:	OPERATION REV:	SHEET

OPERATION: 0020 Locate + clean Tooling

1) Locate 1 set of graphite Tooling per Dwg. # 100830 in vacuum hot press area.

2) Solvent wipe all surfaces of graphite tooling pieces.

MANUFACTURING OPERATION SHEET

OPERATION NUMBER: 0030

LOT NUMBER:

OPERATION REV:

SHEET

Operation: 0030 Laser Cut Preforms

Using Graphite Tooling Set from Op. 20 to check fit, Laser cut ID/OD of each Preform from Op. 10. Record the TARGET following Settings:

ID Radius	2.244"	(4.500" diam)
OD Radius	3.651"	(7.500" diam)
Focal Length		
Wattage		
N_2 Assist Gas Press.	psi	
Feed Rate	in/min	
Pulse - Time on	sec.	
Time off	sec	
Nozzle Hole Diam.		

Laser cut ID/OD for 33 Fiber Loaded Preforms
1 Unloaded, etched Preform
4 Blank foil pcs. for cover foils

Acid Clean 4 blank foil pcs. per MPT 1002

MANUFACTURING OPERATION SHEET

OPERATION NUMBER: 30

LOT NUMBER:

OPERATION REV:

SHEET

Operation: 30 - cont.

Remove burrs from all laser-cut edges.

MANUFACTURING OPERATION SHEET

OPERATION NUMBER: 0040

OT NUMBER:

OPERATION REV:

SHEET

Operation: 0040 Cut and Clean Mo Cover Foils

Obtain .002"-thick Mo Foil and cut 2 pcs. to fit Tooling; Approximate dimensions

ID = 4.500"

OD = 7.300"

Check fit using Graphite Tooling from Op. 20

Solvent clean Mo Foil pcs. per MPT 1001

MANUFACTURING OPERATION SHEET

OPERATION NUMBER: 0050

OT NUMBER:

OPERATION REV:

SHEET

Operation : 0050 Prep. Tooling

Clean all tooling surfaces with acetone using lint-free wipes.

MANUFACTURING OPERATION SHEET

OPERATION NUMBER: 0060

OPERATION REV:

SHEET

OT NUMBER:

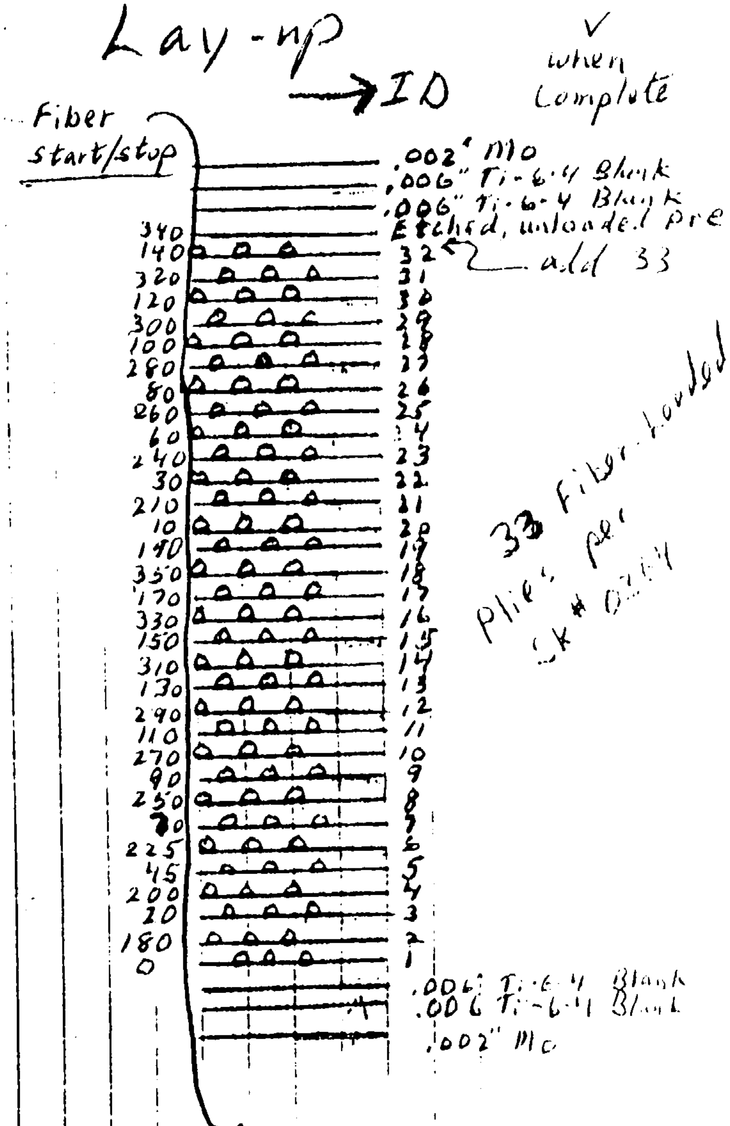
Operation : 0060 Lay-up and Assemble

Assemble Graphite Tooling (op. 20)
Outer Ring, Bottom Inner Rings, and Plug and stack layers into tooling as shown →

Dick Lewis (X7511) to be present for lay-up

Fiber Start/Stop must be offset by ~180° for each ply pair. Rotate each pair by ~20° so that offgas grooves are evenly distributed.

After Lay-up is complete, assemble Top Inner Ring



MANUFACTURING OPERATION SHEET

OPERATION NUMBER: 0070

LOT NUMBER:

OPERATION REV:

SHEET

Operation: 0070 Load Assembly into Logan Vacuum Hot Press

Load assembly from Op. 60 into TSM Vacuum Hot Press. Drill 3 Holes in Graphite Outer Ring for TC insertion. Sketch Tooling Package below;

MANUFACTURING OPERATION SHEET

LOT NUMBER:	OPERATION REV:	OPERATION NUMBER: 0080
		SHEET 1 of 4

Operation: 0080 Run Vacuum Hot Press Cycle

Run vacuum hot press cycle per attached instructions for Ti-6-4/SCS-6 mmc consolidation.

Record Run Data per attached

8149
1-64

MANUFACTURING OPERATION SHEET

PART NUMBER:

OPERATION REV:

OPERATION NUMBER: 8[illegible]

SHEET 2 OF 4

Operation: 812 – Cont.' Vacuum Hot Press Cycle (Ti-6-4/SCS-6)

1. Apply Dead Weight Ram Load (~5 Tons)
2. Start heating when vacuum level is less than 40μ.
3. Heat to 400°F under DWR Load and Hold at 400°F for 1 hour
4. Increase Load to ~~5~~6 Tons (Use high Tonnage Control) = 400 psi
5. Heat to 800°F at approx. 2°F/min (120°F/hr.)
6. Hold at 800°F/6 Tons Load for 2 hrs.
7. Start Diffusion Pump Heater 1 hr. into hold
8. Start Diffusion Pump 1½ hrs. into Hold @ 800°F
9. Heat to 1200°F at approx. 2°F/min (120°F/hr.)
10. Increase Load to 16-17 Tons (1200 psi)
11. Heat to 1400°F in approx. 2 hrs.

Do Leak-up Rate check for 15 mins. after 400° & 800° Holds. If less than 25μ/hr, continue, If not, hold ½ hr. longer & Re-check

13. Heat to 1500°F in approx. 1 hr.

15. Heat to 1600°F in approx. 1 hr.
16. Increase Load to 195 Tons (15 KSI)
17. Heat to 1650°F ± 25°F
18. Hold 3 hrs. @ 1650°F ± 25°F / 195 Tons (15 KSI)
19. At end of hold, reduce Load to 60 Tons (4400 psi)
20. Cool at approx. 240°F/hr (4°F/min) to 1100°F / 60 Ton Load
21. At 1100°F, slowly reduce load to DWR
22. Continue 240°/hr cool to < 800°F under DWR Load
23. Turn off Diffusion Pump
24. Load can be removed and press opened when temperature is less than 600°F

MANUFACTURING OPERATION SHEET

OPERATION NUMBER: 0090

OT NUMBER:

OPERATION REV:

SHEET

Operation: 0090 Disassemble Tooling and Remove mmc Ring.

Separate OD Graphite Ring and Top and Bottom Inner Graphite Rings from mmc Ring - save for re-use if possible. ID graphite plug may have to be destroyed by drilling/cutting to separate mmc Ring.

MANUFACTURING OPERATION SHEET

OPERATION NUMBER: 0100

LOT NUMBER:

OPERATION REV:

SHEET

Operation: 0100 Remove Mo Cover Foils + Mo Reaction Layer

1) Acid Etch Mo Cover foils in Nitric/Water solution
until Mo is completely Removed per MPT 1007 (Rev. B)

2) Acid Etch .5-1.0 mils from top + Bottom surfaces
of ring to remove Mo Reaction zone. Etch in
$HNO_3/HF/H_2O$ per MPT 1002 until
2.0 - 2.5 gms. of material are removed.

7-3143
1-84

MANUFACTURING OPERATION SHEET

PART NUMBER:	OPERATION REV:	OPERATION NUMBER: 0110/0120
		SHEET ____ OF ____

OPERATION: 0110 ULTRASONIC INSPECTION

MOS-43
11/90

STEP 1 Perform "C" SCAN. Include a copy of scan and inspection report in the folder.

OPERATION: 0120 X-RAY

STEP 1 Perform X-RAY. Include a copy of the inspection report in the folder.

NOTES;

7-3143
1-84

MANUFACTURING OPERATION SHEET

PART NUMBER:	OPERATION REV:	OPERATION NUMBER: 130
		SHEET 1 OF 4

OPERATION: 130 Machine Ti-6-4 Tooling and Ring

1.) Obtain 2 pcs. of 11" Ø Ti-6-4 ordered from Presidents Ti and Steel (1 pc. 5/8" thick, 1 pc. 1/2" thick)

2) Send pcs. from step 1 above and MMC Ring from Op. 120 for machining per attached sketches.

MANUFACTURING OPERATION SHEET

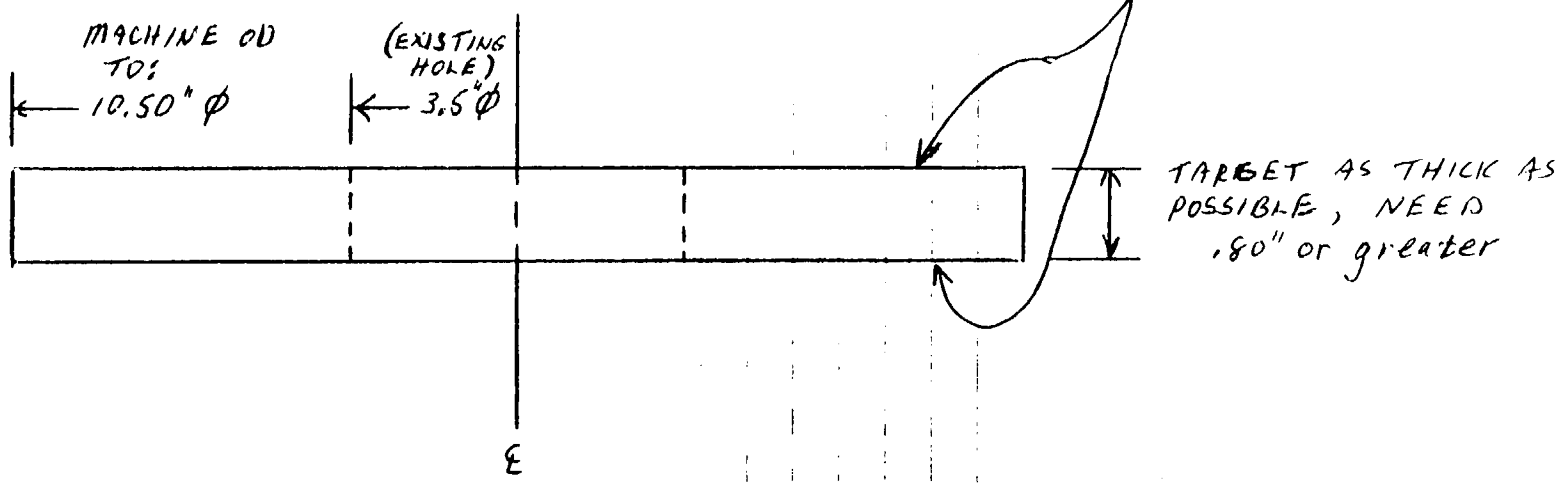
OPERATION NUMBER: 0130

LOT NUMBER:

OPERATION REV:

SHEET 2/4

MACHINE Ti-6-4 FORGED RING:



MANUFACTURING OPERATION SHEET

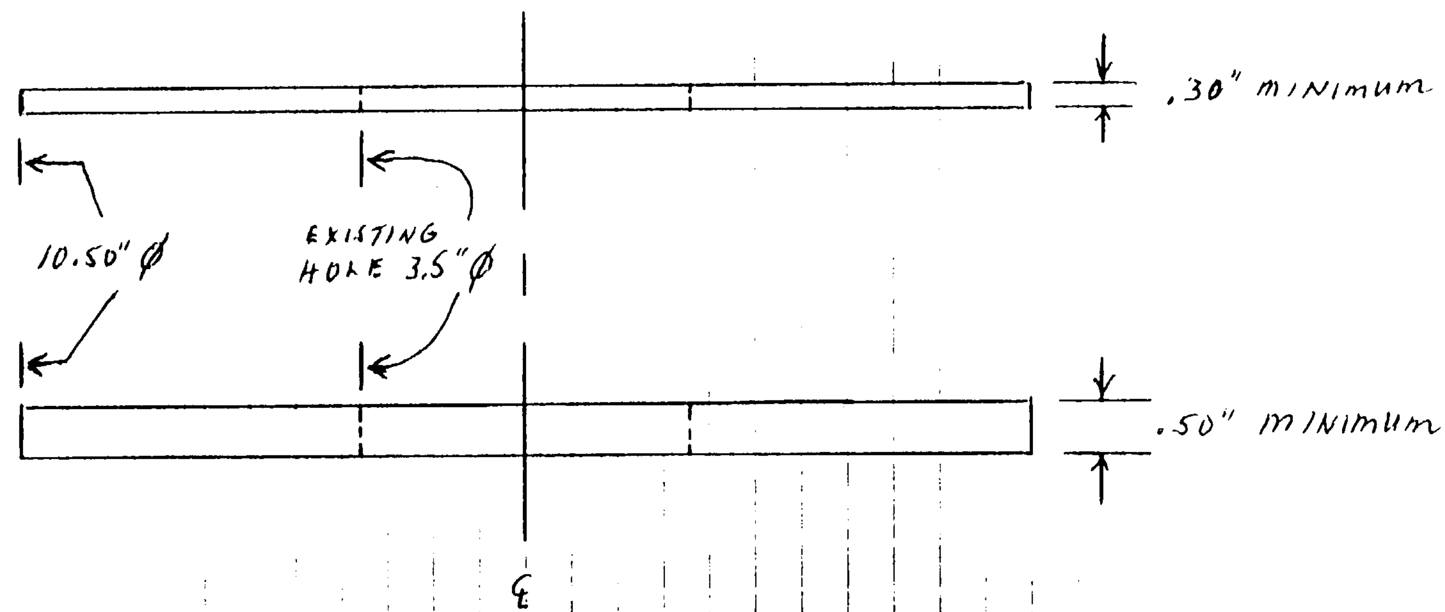
OPERATION NUMBER: 0130

LOT NUMBER:

OPERATION REV:

SHEET 3/4

CUT MACHINED Ti-6-4 RING INTO 2 SECTIONS BY WIRE EDM:



MANUFACTURING OPERATION SHEET

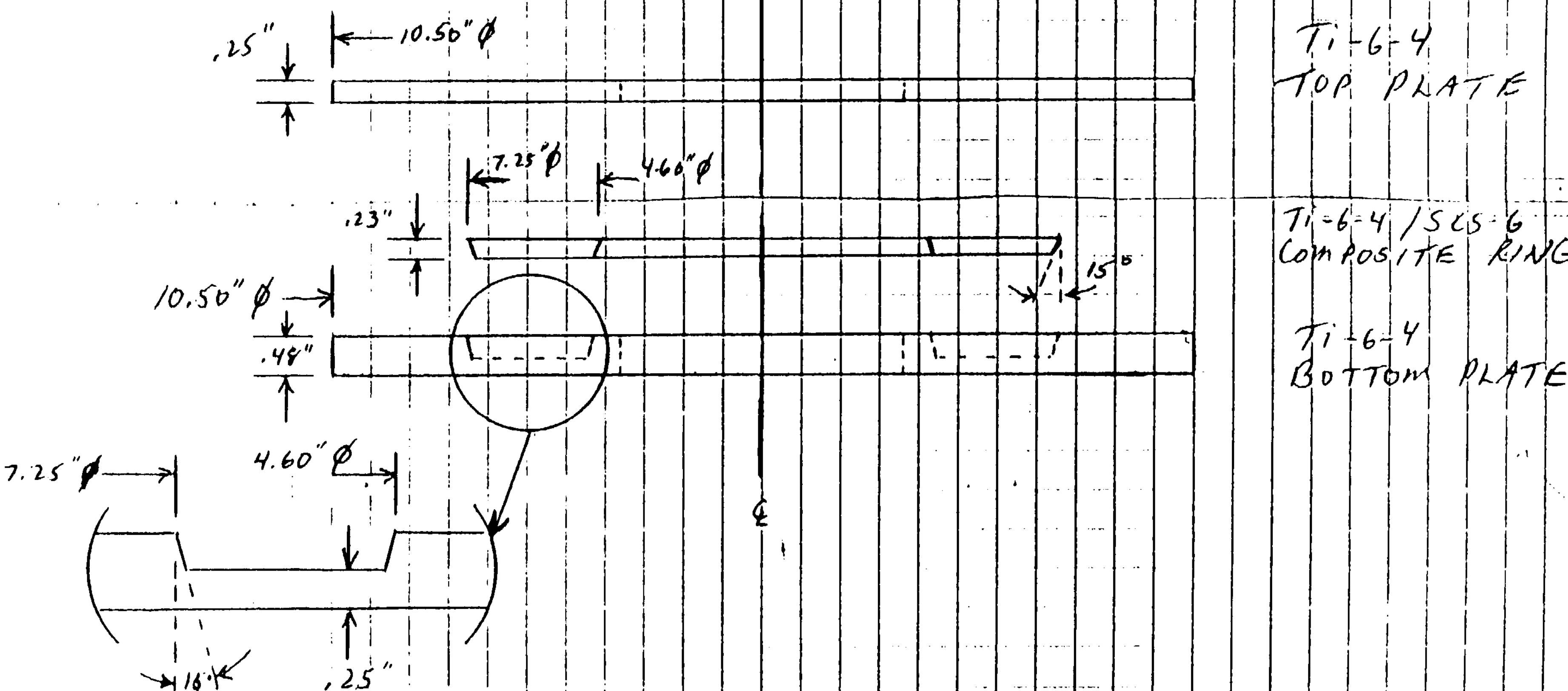
OPERATION NUMBER: 0130

LOT NUMBER:

OPERATION REV:

SHEET 4/4

MACHINE CAVITY IN THICKER Ti-6-4 RING SECTION AND
MACHINE COMPOSITE RING ID AND OD FOR CLOSE FIT:



CAVITY IN BOTTOM
PLATE - MACHINE FOR TIGHT
FIT WITH COMPOSITE RING

7-3143
1-84

MANUFACTURING OPERATION SHEET

PART NUMBER:	OPERATION REV:	OPERATION NUMBER: 140
		SHEET ____ OF ____

OPERATION : 140 Clean and Assemble Ring and Tooling

1) Acid Clean the 3 pcs. from Op. 130 per MPT 1002.

2) Solvent wipe Graphite pcs. and assemble all pcs. together for bonding in Vacuum Hot Press.

7-3143
1-84

MANUFACTURING OPERATION SHEET

OPERATION NUMBER: 150

PART NUMBER:

OPERATION REV:

SHEET ______ OF ______

Operation : 150 Bond in Vacuum Hot Press

1) Load Assembly into Vacuum Hot Press

2) Bond in the following Cycle:

1. Apply Dead Wt. Ram load (~5 Tons)
2. Start Heating when vacuum level is less than 40μ.
3. Heat to 600°F in about 1 hour under DWR Load
4. Increase Load to 19 Tons (High Tonnage Control) = 500psi
5. Hold at 600°F / 19 Ton Load (±100°F) for 1 hour ±5min. — Turn on Diffusion Pump
6. Heat to 1200°F in approx. 2 hours.
7. At 1200°F, increase Load to 192 Tons (5 ksi)
8. Heat to 1600°F in approx. 2 hours.
9. At 1600°F ± 25, increase Load to 431 Tons (11 ksi)
10. Heat to 1650°F in approx. ½ hr.
11. Hold at 1650°F ±25°F / 431 Tons for 2 hrs. ±5min
12. At end of Hold, reduce Load to 150 Tons (4 ksi)
13. Cool in approx. 1½ hrs. to 1100°F / 150 Ton Load
14. At 1100°F, slowly reduce Load to DWR
15. Continue cooling to less than 800°F
16. Diffusion Pump can be turned off anytime after Temp. is less than 800°F and part can be removed anytime after Temp. is less than 600°F.

7-3143
1-84

MANUFACTURING OPERATION SHEET

PART NUMBER:	OPERATION REV:	OPERATION NUMBER: 160
		SHEET ______ OF ______

Operation: 160

C-Scan

7-3143
1-84

MANUFACTURING OPERATION SHEET

OPERATION NUMBER: 170		
PART NUMBER:	OPERATION REV:	SHEET ____ OF ____

Operation : 170 Final Clean

1) Final Clean per MPT 1017

2) Call R. Lewis @ 7511 for final Engineering evaluation

7-3143
1-84

MANUFACTURING OPERATION SHEET

OPERATION NUMBER: 180

PART NUMBER:

OPERATION REV:

SHEET ______ OF ______

Operation: 180 Ship

Ship to: AlliedSignal Engines
Manufacturing Center
111 S. 34th Street
Phoenix, AZ 85034

Attention: P.O. No. P2048786

Ship Via UPS, Collect
800-354-7527