

# REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

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|------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|------------------------------------|-------------------------------|-----------------------------------------|----------------------------------------------|
| 1. REPORT DATE (DD-MM-YYYY)                                                                                                                                      |              | 2. REPORT TYPE<br>Technical Papers |                               | 3. DATES COVERED (From - To)            |                                              |
| 4. TITLE AND SUBTITLE                                                                                                                                            |              |                                    |                               | 5a. CONTRACT NUMBER<br>F04611-97-C-0034 |                                              |
|                                                                                                                                                                  |              |                                    |                               | 5b. GRANT NUMBER                        |                                              |
|                                                                                                                                                                  |              |                                    |                               | 5c. PROGRAM ELEMENT NUMBER              |                                              |
| 6. AUTHOR(S)                                                                                                                                                     |              |                                    |                               | 5d. PROJECT NUMBER                      |                                              |
|                                                                                                                                                                  |              |                                    |                               | 5e. TASK NUMBER                         |                                              |
|                                                                                                                                                                  |              |                                    |                               | 5f. WORK UNIT NUMBER                    |                                              |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br><br>Air Force Research Laboratory (AFMC)<br>AFRL/PRS<br>5 Pollux Drive<br>Edwards AFB CA 93524-7048        |              |                                    |                               | 8. PERFORMING ORGANIZATION<br>REPORT    |                                              |
| 9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)<br><br>Air Force Research Laboratory (AFMC)<br>AFRL/PRS<br>5 Pollux Drive<br>Edwards AFB CA 93524-7048 |              |                                    |                               | 10. SPONSOR/MONITOR'S<br>ACRONYM(S)     |                                              |
|                                                                                                                                                                  |              |                                    |                               | 11. SPONSOR/MONITOR'S<br>NUMBER(S)      |                                              |
| 12. DISTRIBUTION / AVAILABILITY STATEMENT<br><br>Approved for public release; distribution unlimited.                                                            |              |                                    |                               |                                         |                                              |
| 13. SUPPLEMENTARY NOTES                                                                                                                                          |              |                                    |                               |                                         |                                              |
| 14. ABSTRACT                                                                                                                                                     |              |                                    |                               |                                         |                                              |
| 15. SUBJECT TERMS                                                                                                                                                |              |                                    |                               |                                         |                                              |
| 16. SECURITY CLASSIFICATION OF:                                                                                                                                  |              |                                    | 17. LIMITATION<br>OF ABSTRACT | 18. NUMBER<br>OF PAGES                  | 19a. NAME OF RESPONSIBLE<br>PERSON           |
| a. REPORT                                                                                                                                                        | b. ABSTRACT  | c. THIS PAGE                       |                               |                                         | 19b. TELEPHONE NUMBER<br>(include area code) |
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1 item enclosed

*late  
notification*

✓ spreadsheet  
✓ DTS

MEMORANDUM FOR PRR (Contractor/In-House Publication)

FROM: PROI (TI) (STINFO)

9 June 1999

SUBJECT: Authorization for Release of Technical Information, Control Number: AFRL-PR-ED-TP-FY99-0143  
Bruce Farmer, et. al., "Covering Achievements of the US Air Force Thrust Cell Technologies Program and Light  
Weight Thrust Chamber Assembly Program"

ASM Aerospace Materials Technology Conference

(Public Release)

# Advanced Materials and Processes for Rocket Engines

*Thrust Cell Technologies Program*

*Aeromat99*

Covering Achievements of the US Air Force  
Thrust Cell Technologies Program

and

Light Weight Thrust Chamber Assembly Program

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ASM Aerospace Materials Technology Conference  
Wright Patterson AFB, Ohio  
June 21-24, 1999

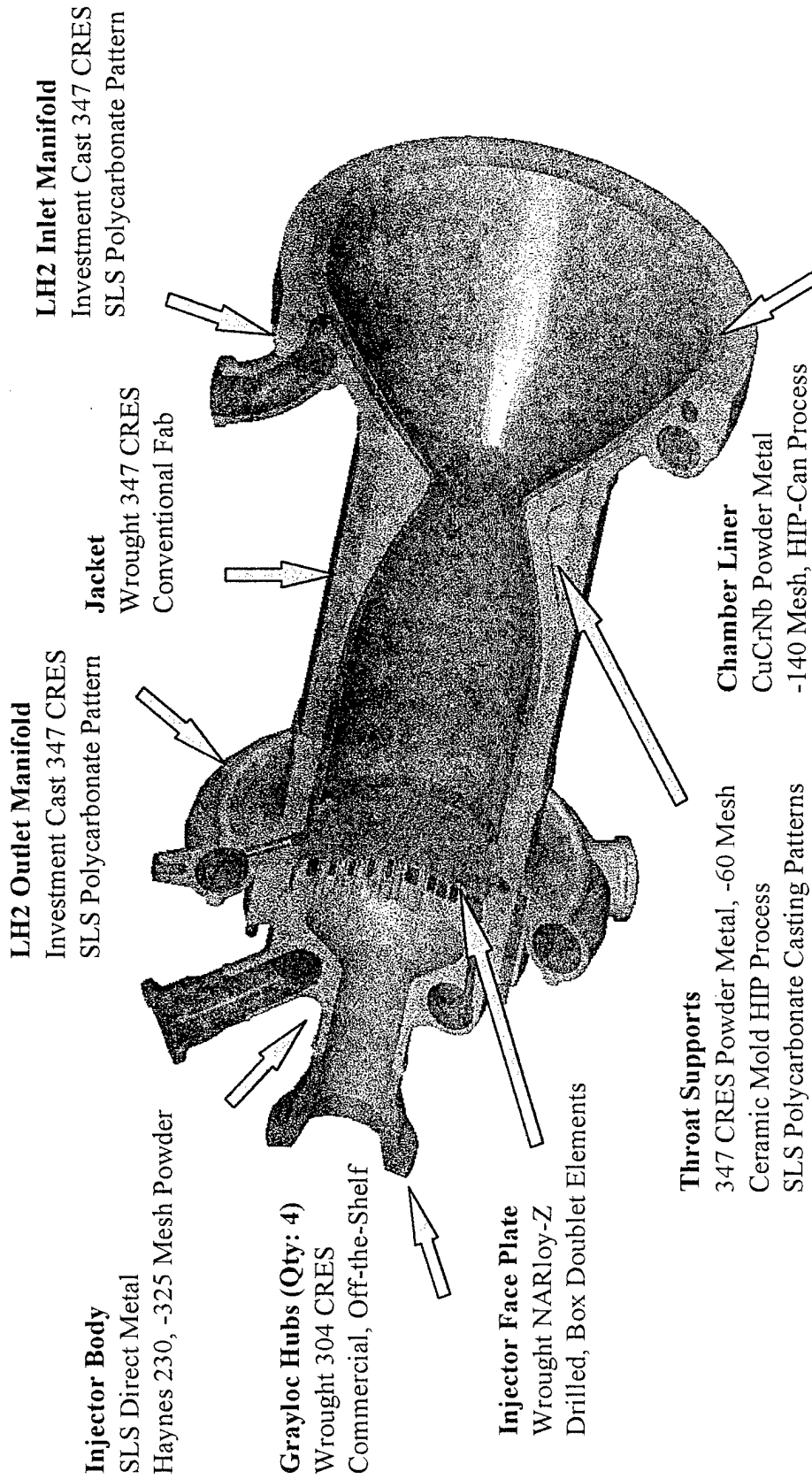
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# Thrust Cell Engine Assembly

*Thrust Cell Technologies Program*

*Aeromat99*



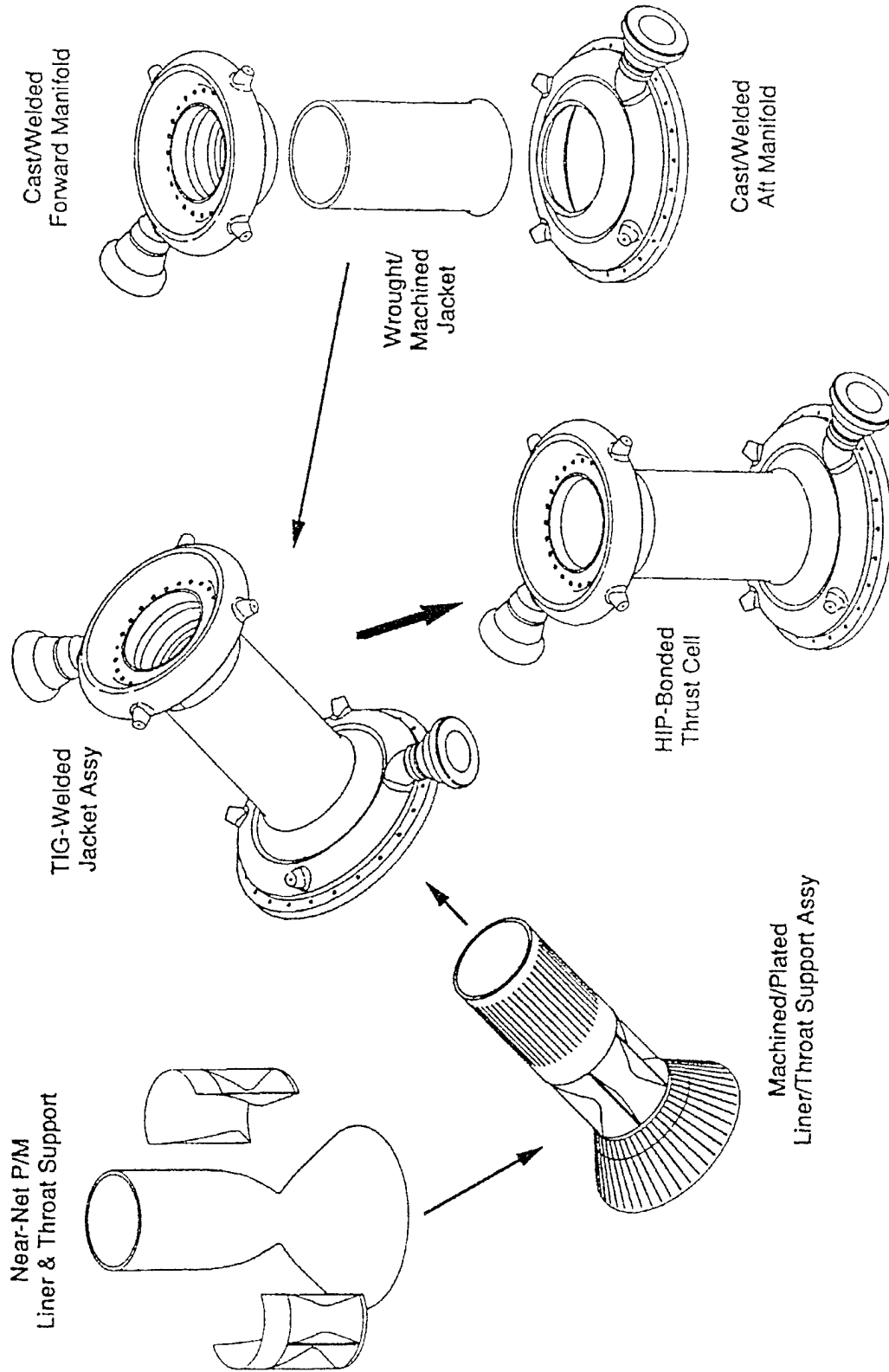
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# Engine Assembly Sequence

Thrust Cell Technologies Program

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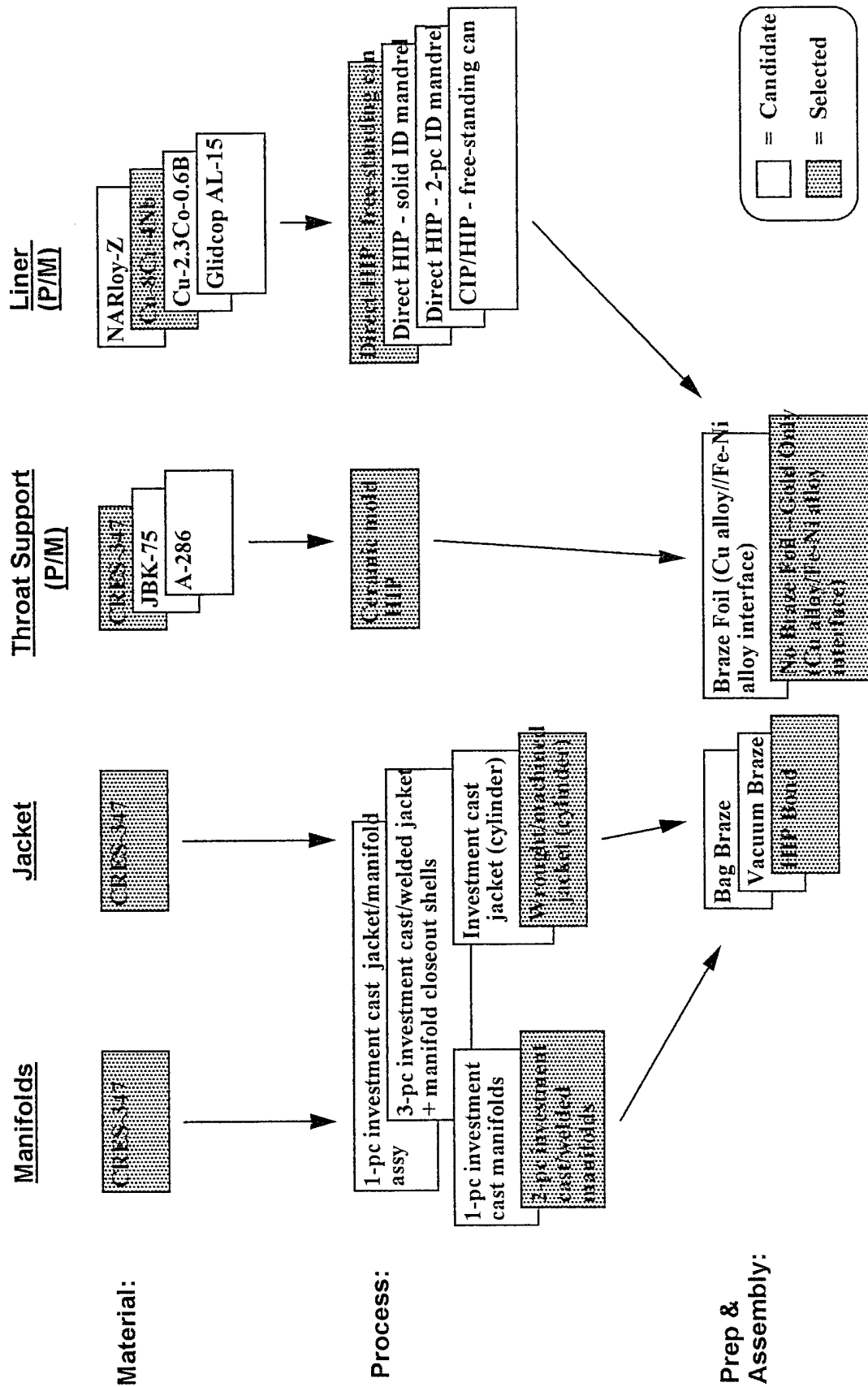
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# Material & Process Selection

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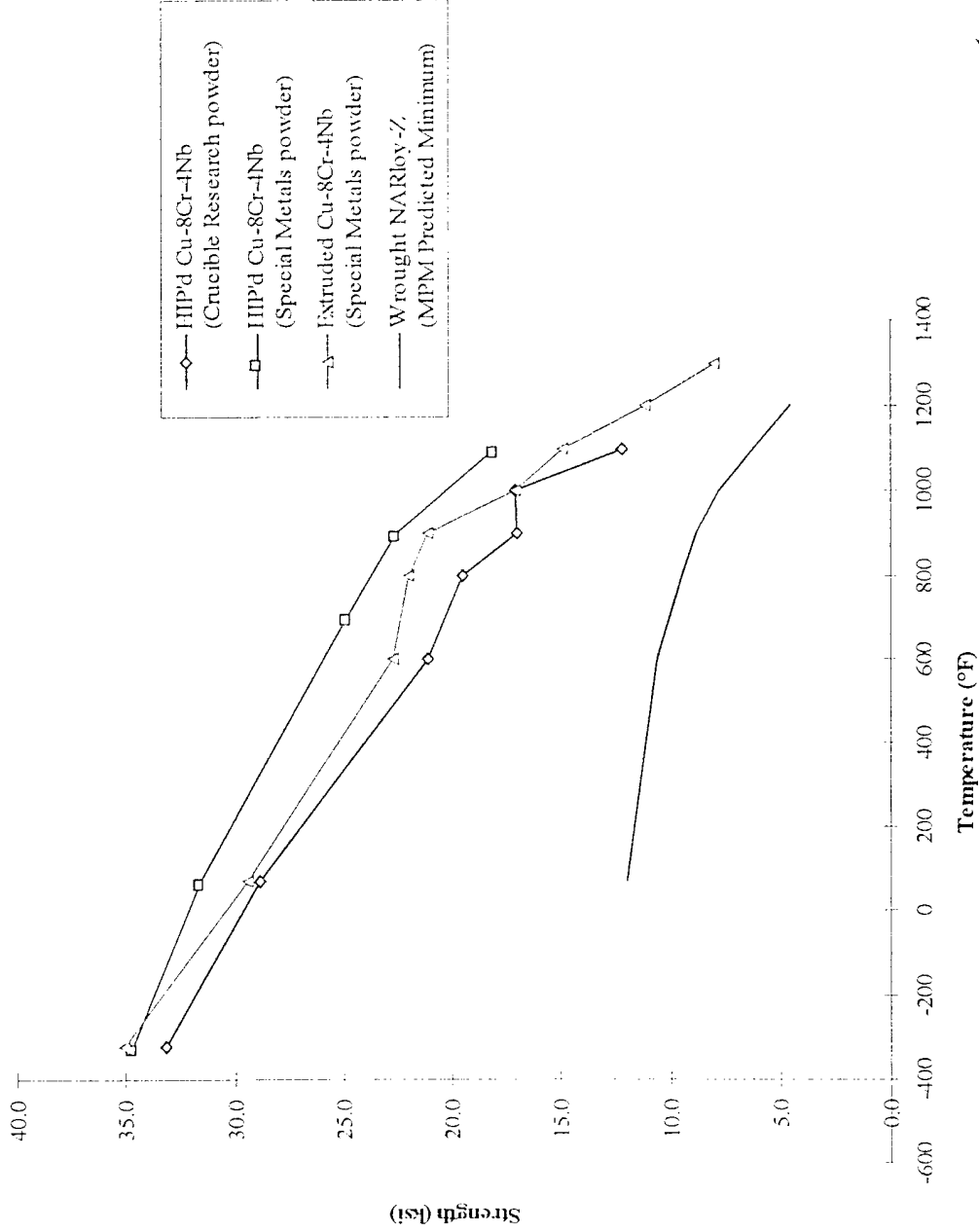
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# Cu-8Cr-4Nb Properties

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Yield Strength after simulated braze cycle @ 1700°F



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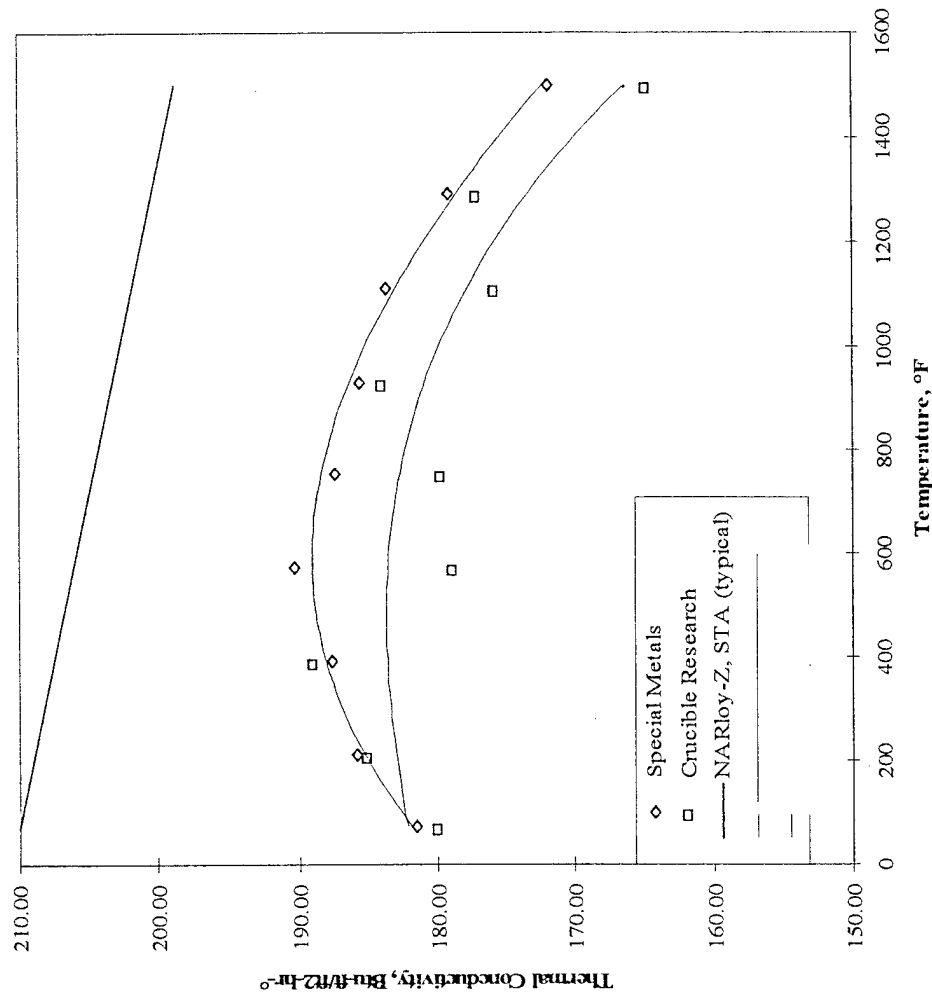


# Cu-8Cr-4Nb Properties

Thrust Cell Technologies Program

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Thermal Conductivity of HIP'd P/M Cu-8Cr-4Nb



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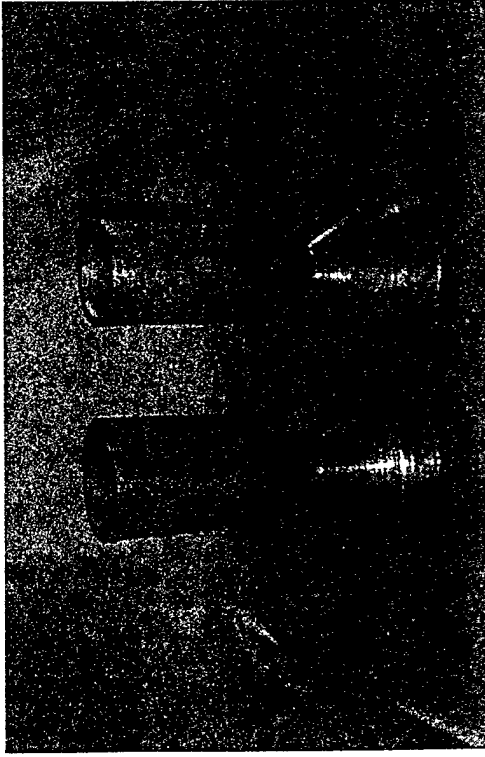
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# Thrust Chamber Liners

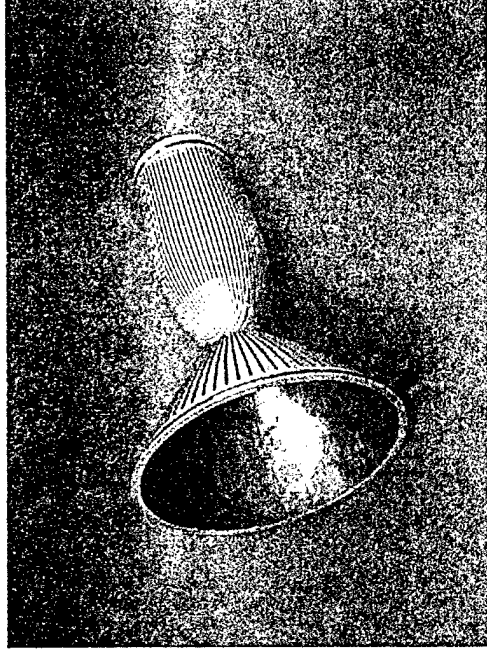
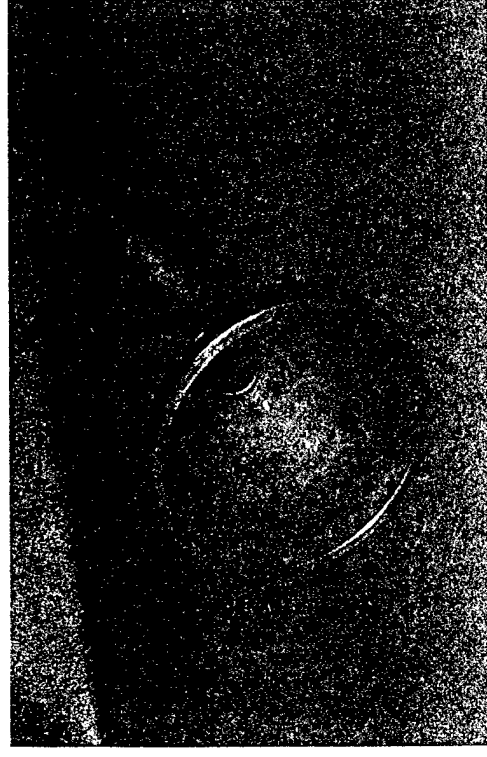
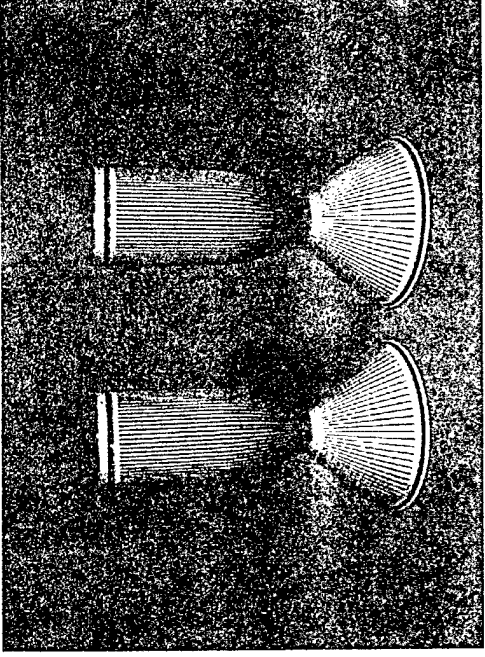
*Thrust Cell Technologies Program*

*Cu-8Cr-4Nb Powder Metal Liner Preforms*



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*Finished Liners, Gold Plated*



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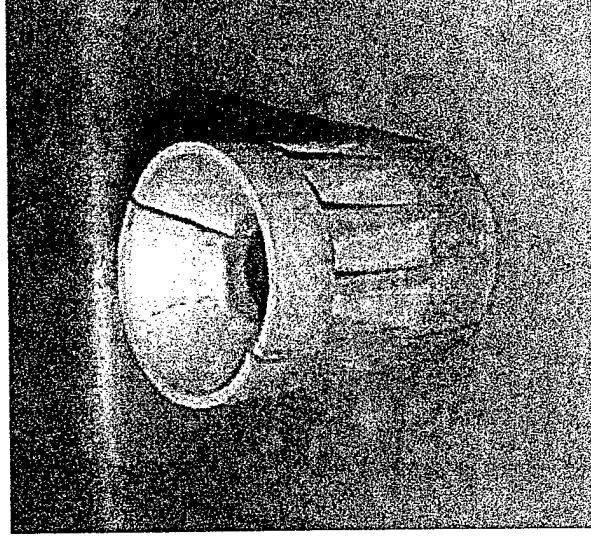
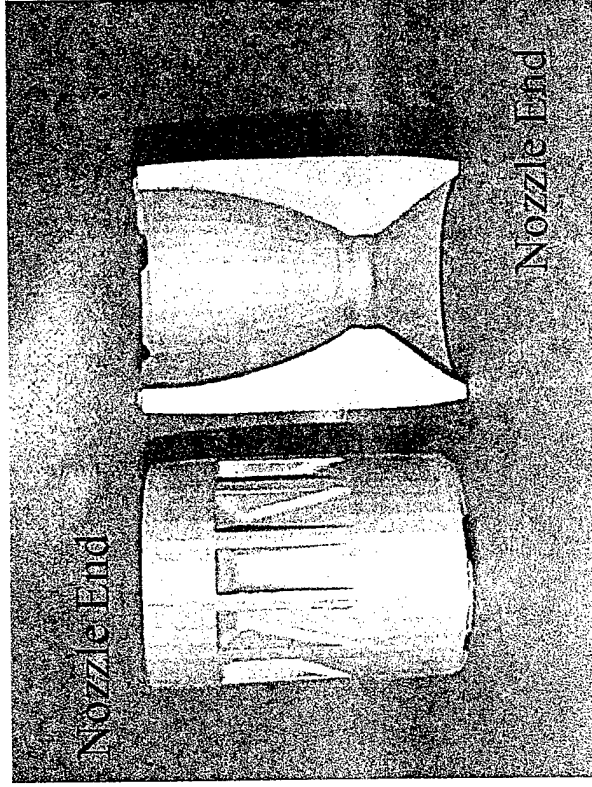
# Throat Support Powder Metal Preforms

*Thrust Cell Technologies Program*

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## *Ceramic Mold Process*

Material: -60 Mesh 347 CRES



- Powder metal affords added flexibility in properties through alloy formulation and control of grain sizes
- Lost-wax investment mold made from SLS polycarbonate patterns
- Mold filled with 347 CRES, packed in pressure transfer medium in a steel can and HIP'ed

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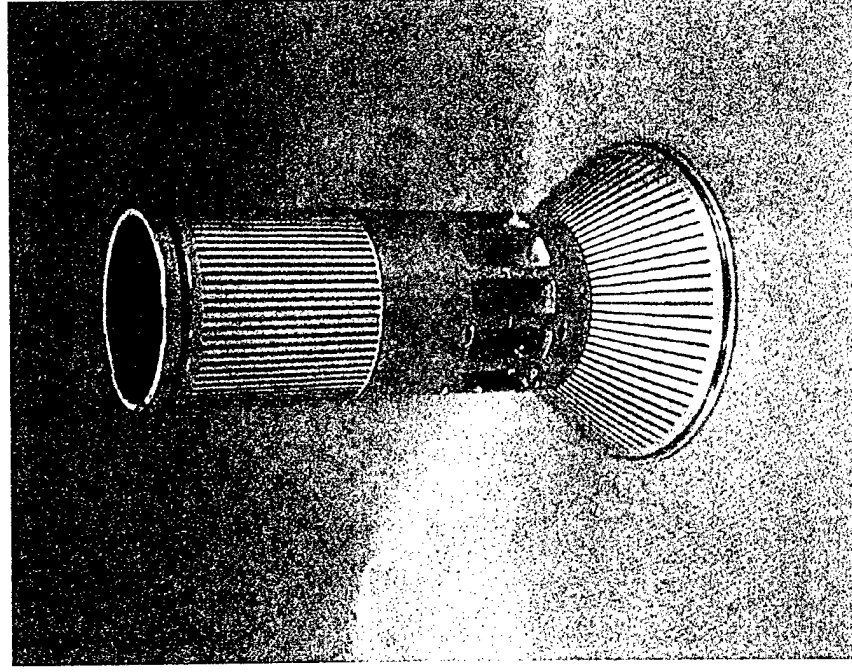
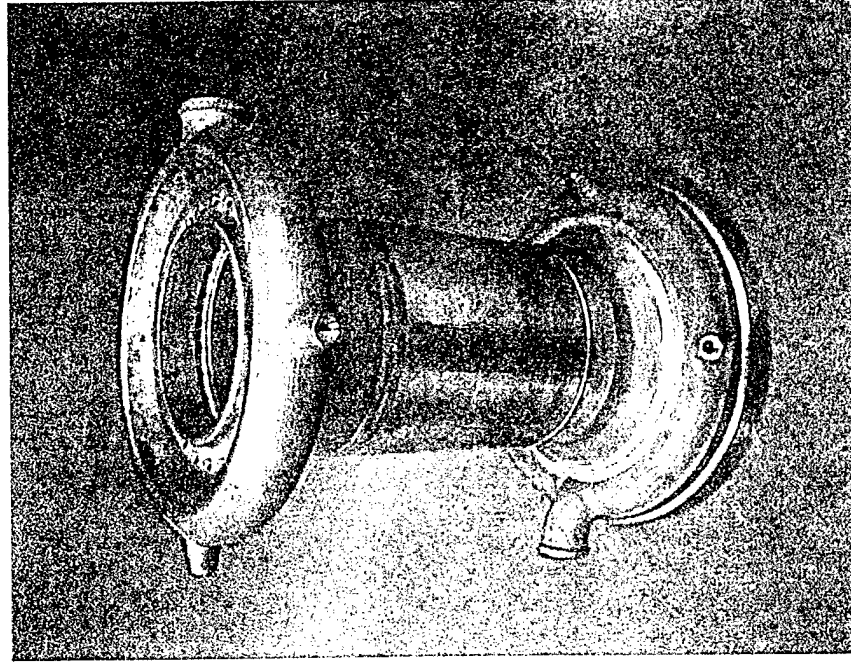


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# Structural Jacket and Liner Subassembly

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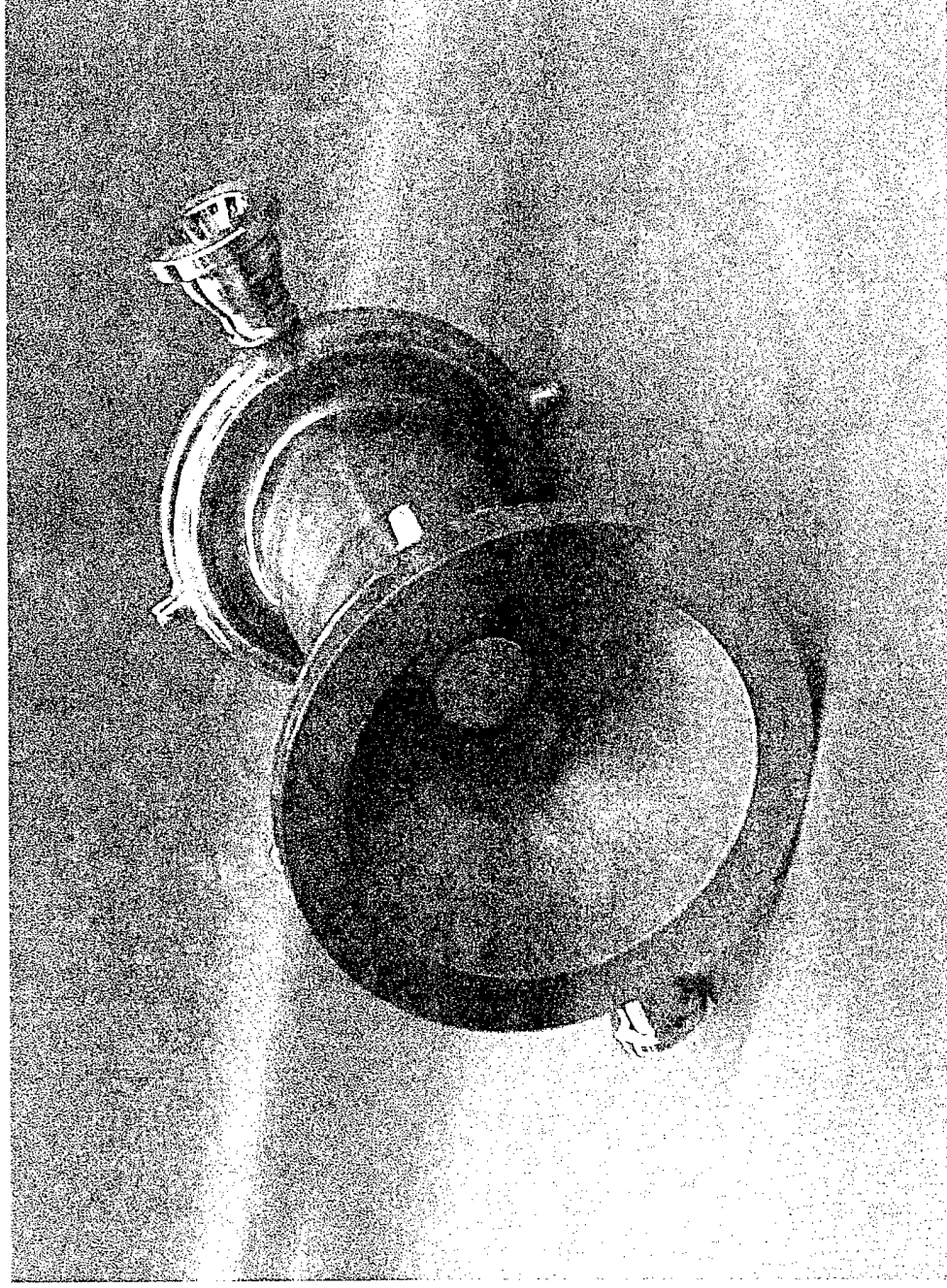
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# Completed Combustion Chamber

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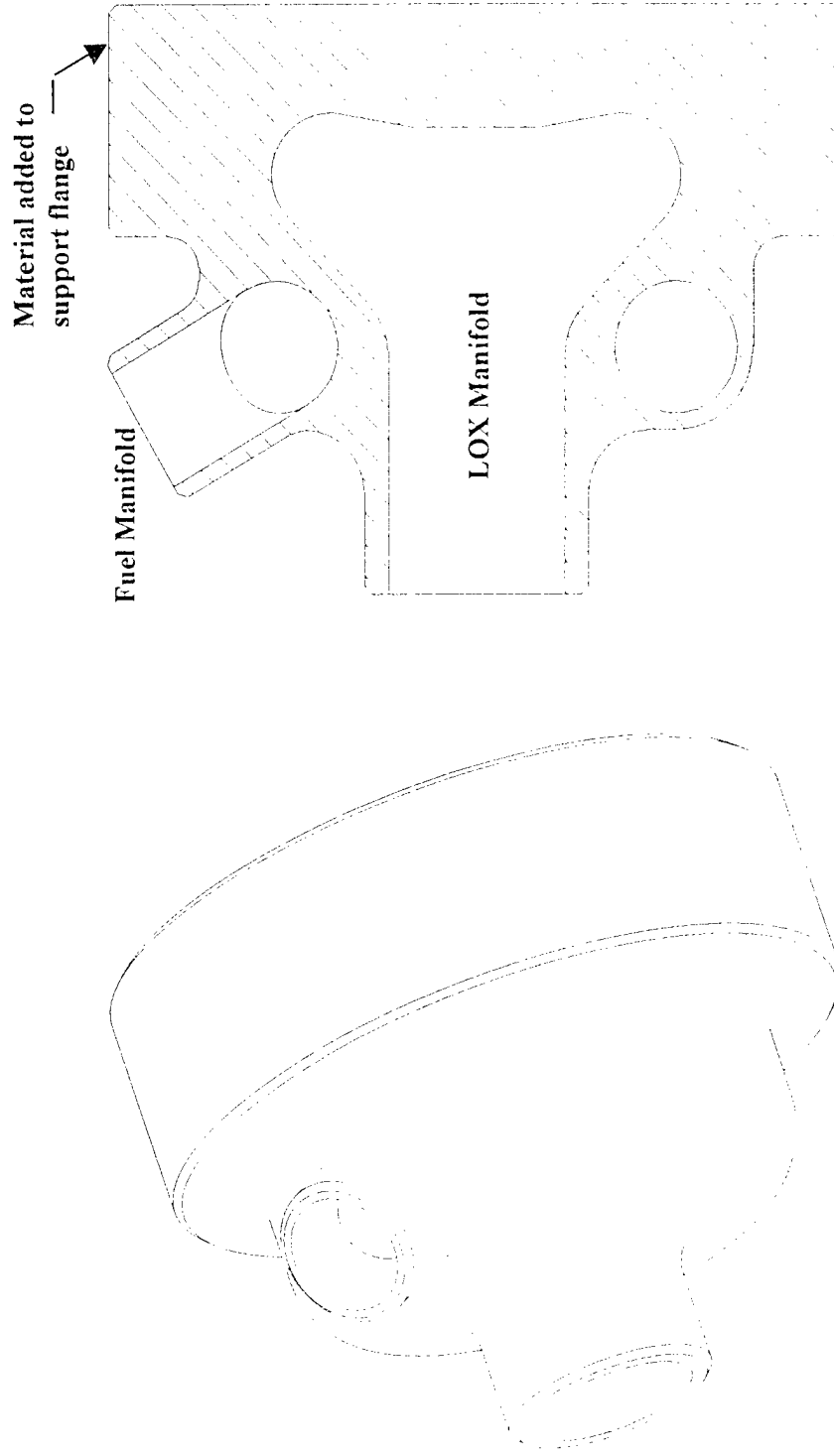
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# Injector Body Preform - Rapid Prototype Model

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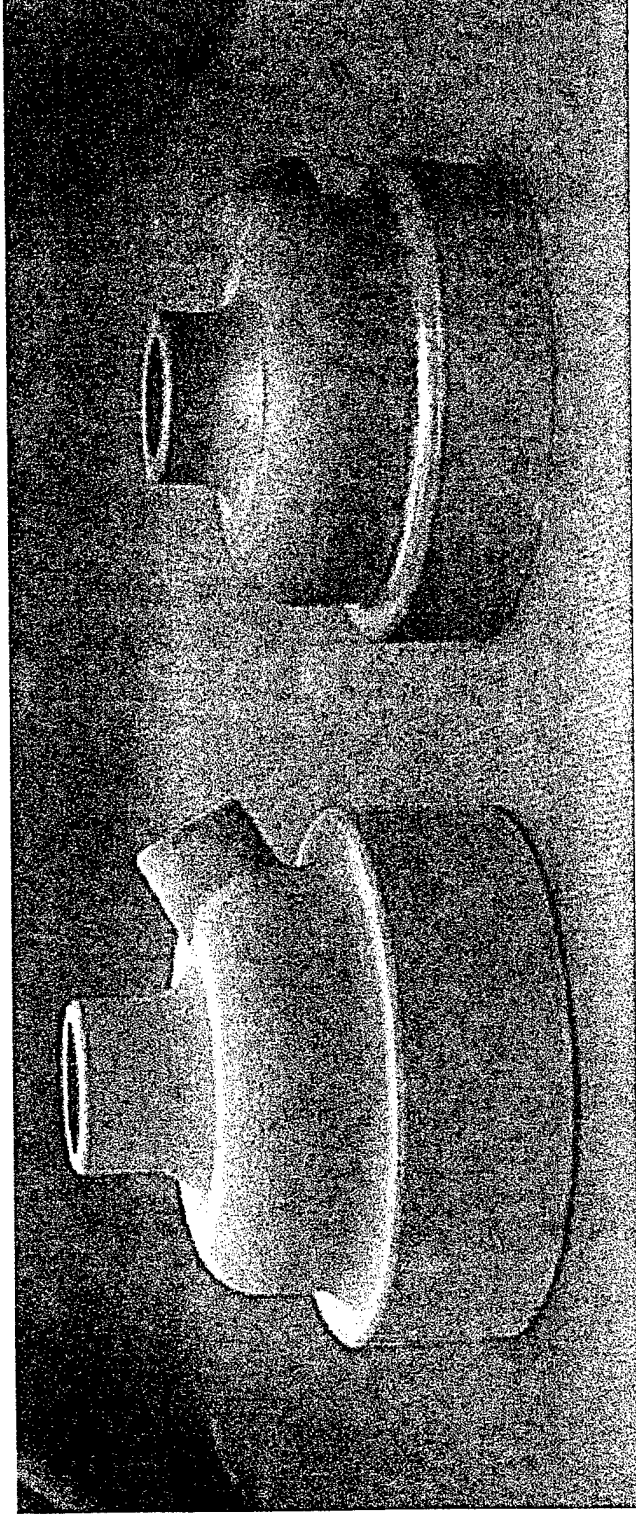
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# SLS Direct Metal, Haynes 230 Injector Body Preform

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- Injector body at left is in the “green” state
- Injector body at right is consolidated and HIP’ed to full density, 99.3% of theoretical
- No sagging or significant cracking was observed
- Six green parts built and sintered to achieve success

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# SLS Haynes 230 Properties

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## **Haynes 230 flat and round tensile bars fabricated by SLS**

- As sintered, no surface polishing
- $F_{tu} = 97$  ksi; elongation = 5%
- Sintered and HIP'd
- $F_{tu} = 117$  ksi;  $F_{ty} = 56$  ksi; elongation 25%

## **Wrought Haynes 230 tensile properties**

- Rolled and annealed plate
- $F_{tu} = 125$  ksi;  $F_{ty} = 57$  ksi; elongation = 50%
- Investment casting
- $F_{tu} = 89$  ksi;  $F_{ty} = 47$  ksi; elongation = 35%

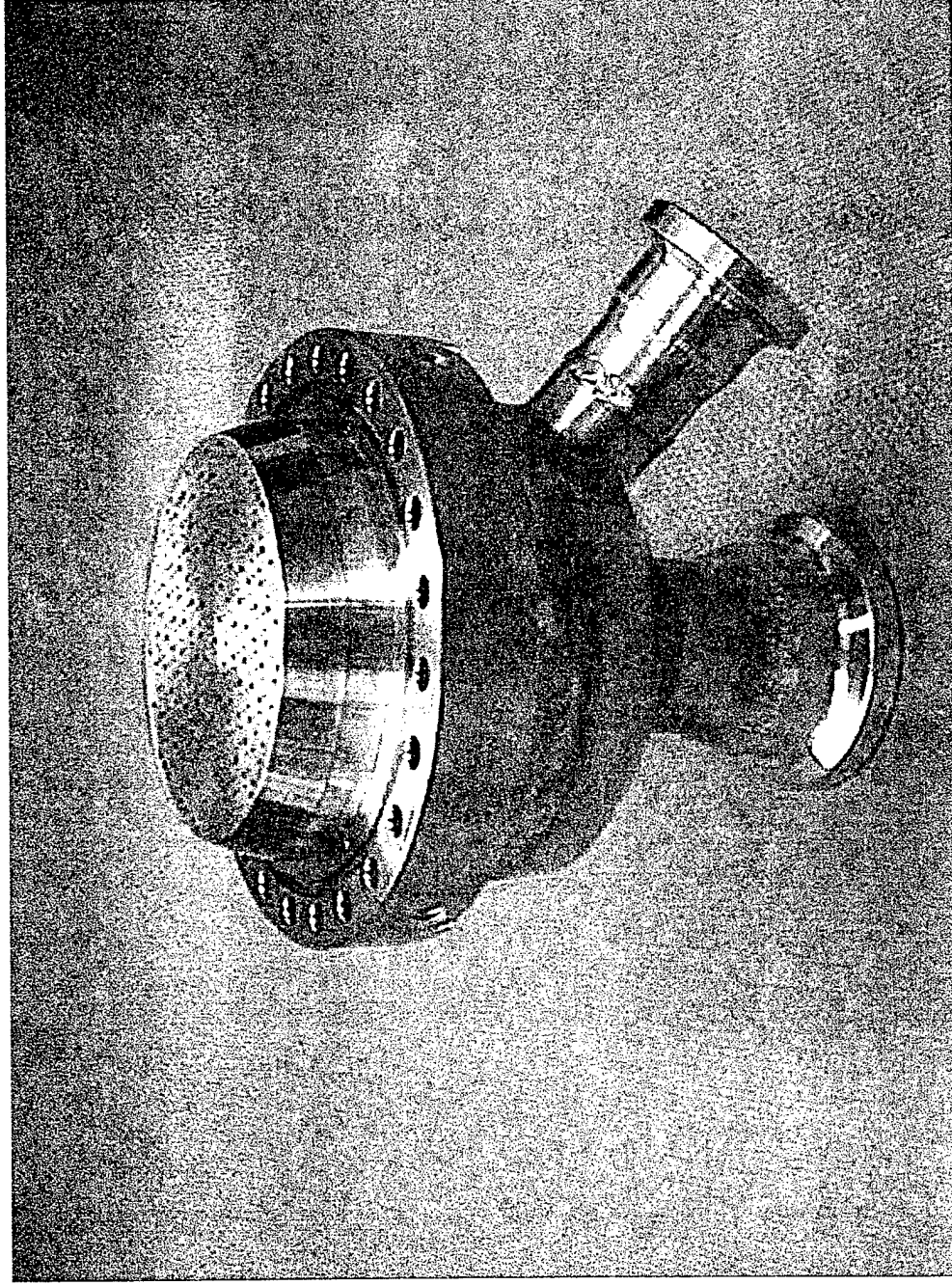
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# Injector Assembly

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# LWTCA Program Summary

*Light Weight Thrust Chamber Assembly Program*

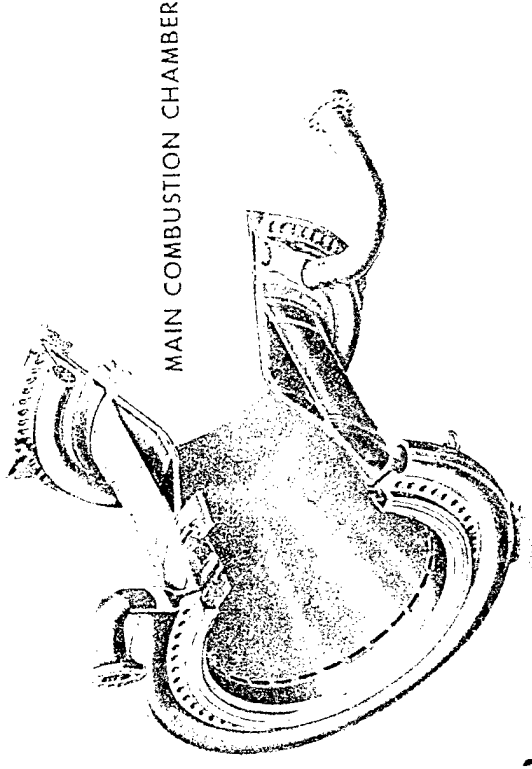
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## Objectives

- Demonstrate technology for 400 Klb thrust LOX/hydrogen booster engine
  - 40% reduction in weight
  - 50% reduction in cost
  - 75% reduction in part count
  - 3% increase in specific impulse

## Hardware

- Chamber and injector MTD's
- Chamber and injector sub-scale, hot-fire test hardware



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# Advanced Materials Baseline Design

*Light Weight Thrust Chamber Assembly Program*

*Aeromat99*

## **Allied Signal AS800 $\text{Si}_3\text{N}_4$ Baseline**

- Throat Supports
  - Two-piece construction
  - Near-net halves, final machined (diamond ground) I.D. and O.D.
  - Compatibility with HIP bonding process
- Structural Jacket
  - Gel-cast forward and aft propellant manifolds
  - Gel-cast structural jacket
  - Final machined I.D. for assembly and HIP bonding
- Chamber Liner made from NARloy-Z
  - Proven liner material, well characterized
  - Joinable to silicon nitride
  - Slotted wall construction
  - Standard aspect ratio channels

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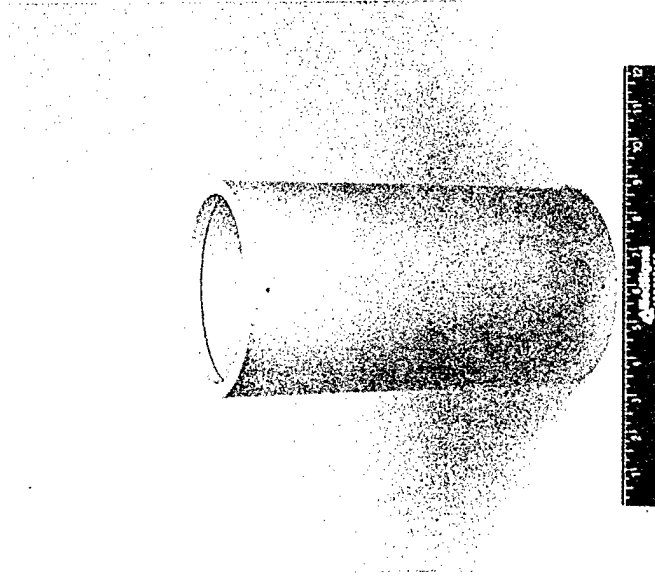


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# Final Machined Cylindrical Braze Specimens

*Light Weight Thrust Chamber Assembly Program*

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- Two 6" Height Specimens  
Delivered 8/98
- One 11.3" Height  
Specimen Delivered 11/98
- Large Component Processing  
Experience will Benefit MTD  
Hardware Development

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# Minimize Post-Bond Stresses

*Light Weight Thrust Chamber Assembly Program*

*Aeromat99*

- **Bond Joint Residual Stress due to CTE Mismatch**
  - Select Geometry to Minimize Free-edge Stress Singularity
    - bondline thickness
    - wedge angle
    - scarf bond ends
  - Selection of Materials
    - Compatibility of bimaterial and braze alloy
    - Include Inelastic Properties
      - temperature-dependent stress-strain curves
      - time-dependent properties

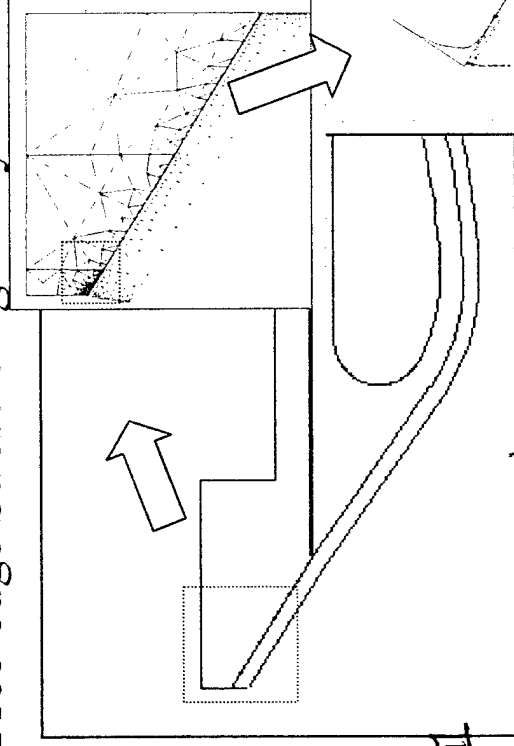


FIGURE 1-1  
BOND JOINT GEOMETRY  
AND STRESS SINGULARITY

FIGURE 1-2  
BOND JOINT GEOMETRY  
AND STRESS SINGULARITY

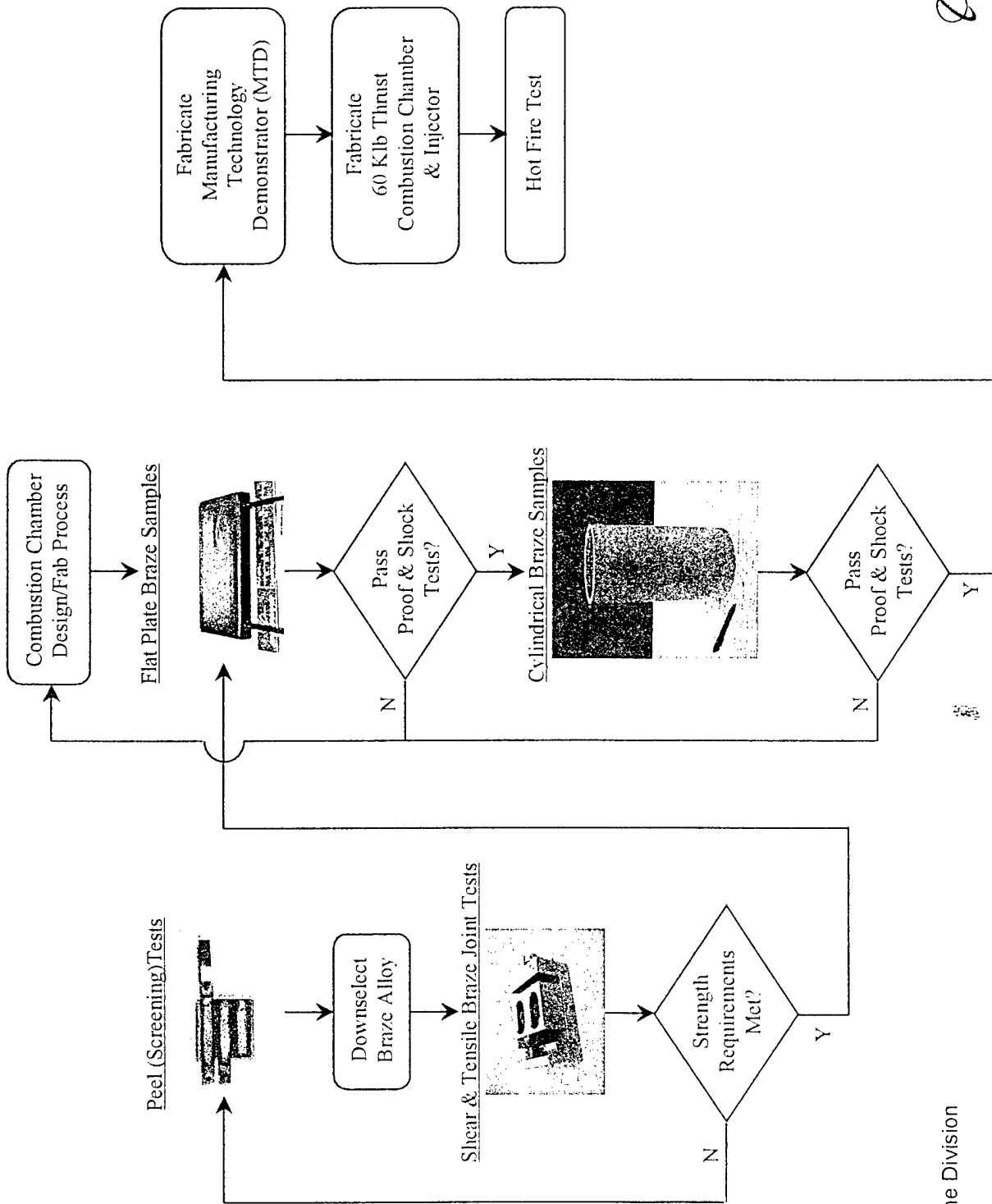
FIGURE 1-3  
BOND JOINT GEOMETRY  
AND STRESS SINGULARITY

FIGURE 1-4  
BOND JOINT GEOMETRY  
AND STRESS SINGULARITY

# Combustion Chamber Joining Logic

Light Weight Thrust Chamber Assembly Program

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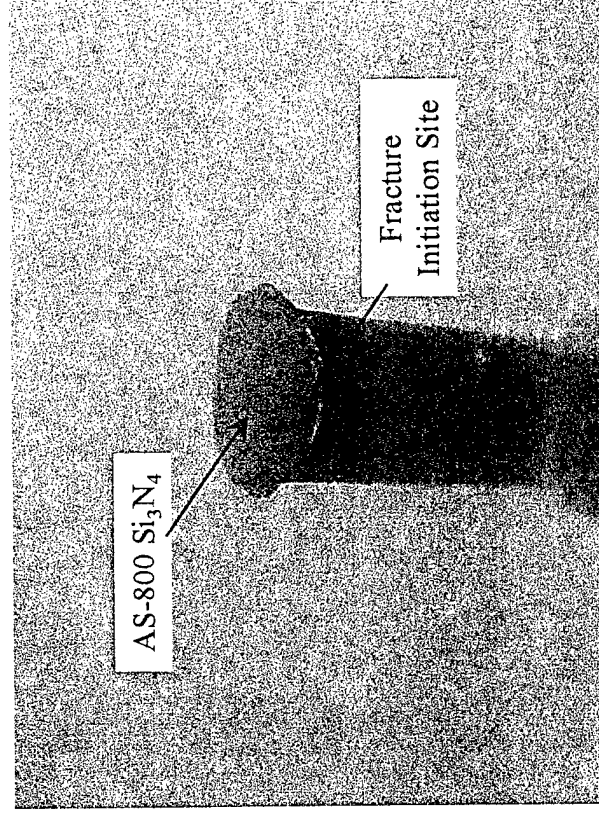
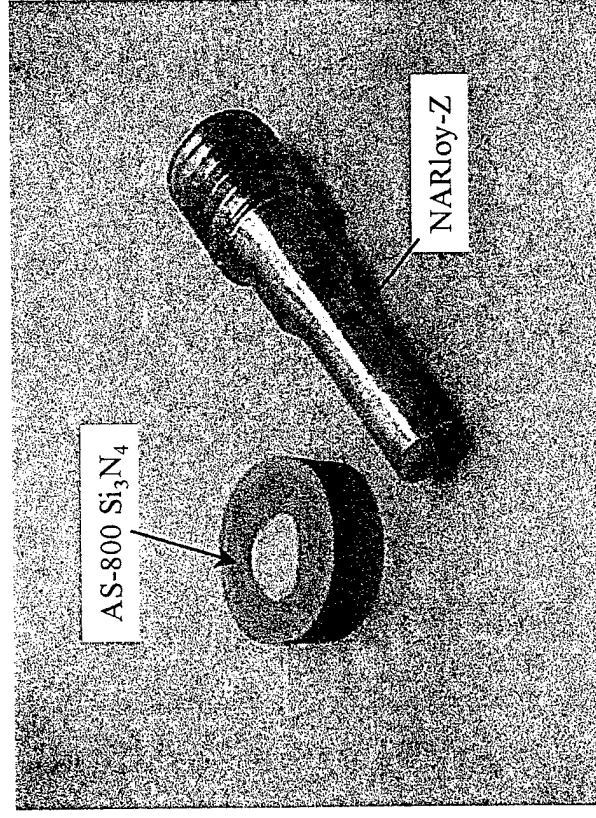
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# Fracture Behavior - "New" Tensile Specimen

*Light Weight Thrust Chamber Assembly Program*

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- Higher joints strength correlates with full braze fillet 360 degrees

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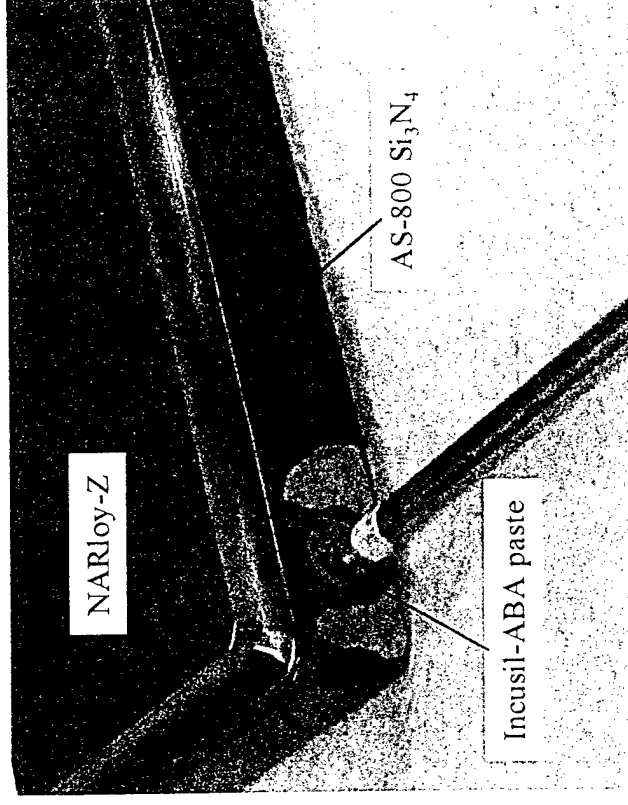
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# Design Features

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- Edges of NARloy-Z plate chamfered to reduce residual stress concentration at free edges
- Corners rounded to reduce stress concentration
  - Crack initiated at corner of silicon nitride plate in first braze sample
- Stainless steel tubes brazed with Incusil-ABA paste during same braze cycle



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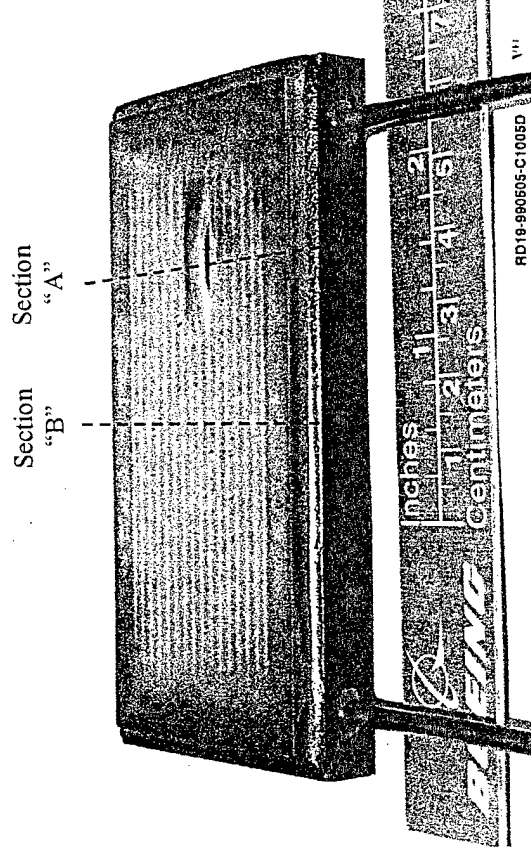
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# Destructive Testing

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- Survived 5 proof pressure cycles at 7700 psig
- Pressured to failure at 10,500 psig
- Cross-sectioned to determine failure mode



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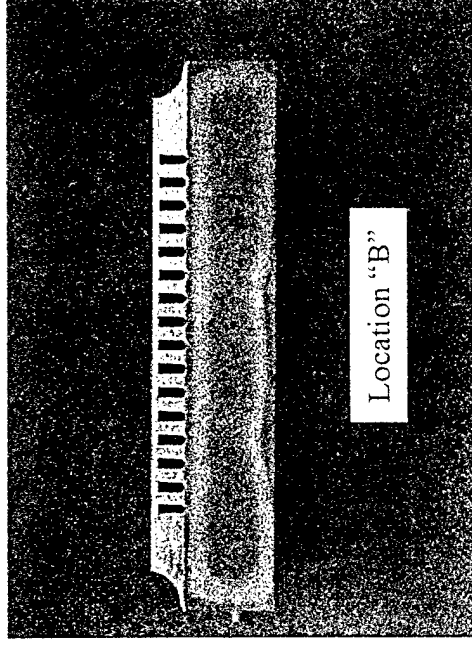
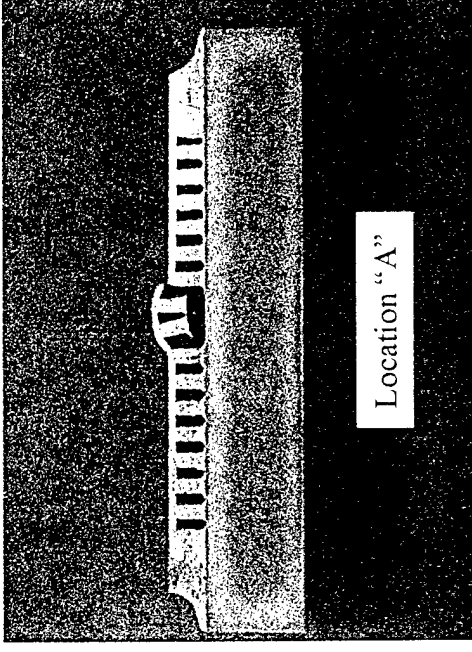
# Destructive Testing (cont.)

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- Failure initiated in braze joint
- Evidence of excessive pressure during brazing
  - Excessive braze fillets
  - Little in any braze alloy left in joint

*Little if any .... ?*



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# Future Work

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*Light Weight Thrust Chamber Assembly Program*

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- Determine sensitivity of brazing pressure to joint quality i.e., fillet size, braze alloy thickness in joint
- Conduct cryogenic flow tests, i.e. LH<sub>2</sub>, to simulate transient loads from CTE and delta-T differences during start-up
- Scale up from flat plate to cylindrical braze samples
- Fabricate manufacturing technology demonstrator (MTD) and hot-fire quality, sub-scale combustion chamber

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