ENGINEERING OPERATIONS REPORT

(NASA-CR-132211) NOZZLE EXTENSION DESIGN STATUS REPORT (Aerojet Nuclear Systems Co., Azusa, Calif.) 104 p HC $7.25

NOZZLE EXTENSION DESIGN STATUS REPORT

PROJECT 143

MAY 1972

AEROJET NUCLEAR SYSTEMS COMPANY
A DIVISION OF AEROJET-GENERAL
ENGINEERING OPERATIONS REPORT

Nozzle Extension Design Status Report

Project 143

May 1972

L. B. Claassen
Nozzle Extension Section

Approved:

C. M. Kawashige, Supervisor
Nozzle Extension Section

L. A. Shurley, Manager
Nozzle, Pressure Vessel and
Nozzle Extension Department
TABLE OF CONTENTS

I. INTRODUCTION

II. SUMMARY

III. TECHNICAL DISCUSSION
   A. BACKGROUND
   B. INTERFACE CONCEPTS

IV. CONCLUSIONS AND RECOMMENDATIONS

FIGURES

Figures 1 through 20 - Interface Concepts

APPENDIXES

Appendix A - Steady-State Thermal Analysis of Several Nozzle/Skirt Interface Concepts - N811OR:72-037

Appendix B - Nozzle-Nozzle Extension Joint Concept No. 30 Stress Analysis N8120R:72-023

Appendix C - Summary of Results of Steady State Stress Analysis of Concepts #1 and #2 - AM-NA-0027

Appendix D - Summary of Results of Steady State Stress Analysis of Concept #12 AM-NA-0030

Appendix E - AGCarb Data Requirements for CY72 Nozzle Extension Flange Concept Selection - N8120:090

Appendix F - Honeycomb Reinforced Liner - Nozzle Extension - N8120:105

Appendix G - Nozzle Extension Open Cell Reinforcement - N8500:M1456
I. INTRODUCTION

This report documents the effort on the following portions of Project 1.4.3 work statements:

f.9. a. Provide design engineering to generate a total of twenty-four (24) new nozzle/nozzle extension joint concepts. Concepts shall be generated which incorporate the "free floating" idea. Both radial and axial "floating" shall be considered. The nozzle extension material of construction shall use AGCarb.101 as a base material.

f.5 Perform the following preliminary (mean values) thermal analyses to support the nozzle extension effort documented in an internal report for subsequent inclusion in the appropriate chapter of the Nozzle Extension Design Report.

c. Perform steady-state analysis in support of flange concept definition. These concepts are to be selected from those initiated in paragraph 9 below. A total not to exceed 20 concepts shall be analyzed. These will be divided into 3 basic groups; one of which will be directly related to the present concepts and two groups will be radical departures from previous ideas. Transient analyses from 5.a above will not be in the basic concept selection criteria.

f.6 Perform nozzle extension structural preliminary (mean values) analyses to support the design and development activities and provide input, as applicable and document in an internal report for subsequent inclusion into the appropriate chapter of the Nozzle Extension Design Report. Specific activities include:
c. Provide nozzle/nozzle extension joint concept selection recommendation. Twelve (12) additional concepts will be analyzed. These concepts would fall into three (3) basic groups; one of which will be directly related to the present concepts and two groups will be radical departures from previous ideas.

Due to NERVA contract cancellation the total scope of work defined above was not completed.

This report will be concerned primarily with the nozzle/nozzle extension interface. Design characteristics of the nozzle extension as a whole will be confined to summarization or to the manner in which they effect the interface. The interface joint concepts, generated prior to program termination, are included as Figures and are discussed in detail in the body of this report.
II. SUMMARY

Twenty possible concepts of a possible nozzle/nozzle extension interface were originated. These concepts are all shown in Section III, Discussion. Not all of the concepts were considered worthy of analysis time. Six of them were thermally analyzed and three were stress analyzed. More would have been analyzed if time had permitted this. These analyses were done to determine which of the concepts would have the best chance of succeeding, that is, they were a screening process which was to allow us to rate one concept against another. This was done because adequate material properties to determine absolute stress levels were not available at the time of the analyses. Plans had been generated to obtain the necessary properties and they were scheduled to be available in June, 1972. A statement of the required properties is shown in Appendix E. A complete, detailed stress analysis, showing reliability values, is not within the scope of the analyses discussed in this report. Before reliability of the concepts could be assessed, much more material data would be required. For the analyses discussed in this report, the latest material properties available in late 1971 were used. Many of the properties were extracted from Reference c.

Though all of the concepts still exhibit some areas of negative margin of safety, concept No. 1 shows good promise, that, with slight modifications, it could have all positive margins of safety.

The Baseline concept is concept #30 and is a holdover from previous years. It will be seen that this rigidly mounted concept is unacceptable and most of the new concepts have some mechanism to allow relative movement to reduce the stresses. Another idea, gained from ALRC and incorporated in some of the concepts, tends to reduce the thermal stresses by adding some sort of thermal barrier to reduce heat flux.

Another significant question, regarding these designs, has to do with the Grafoil seals and insulators. Some additional data was just recently received on Grafoil properties, but it was too late to incorporate in the analyses. The new data were not significantly different from the properties which were used.
III. TECHNICAL DISCUSSION

A. BACKGROUND

In 1969, the fibrous reinforced graphite composite known as AGCarb 101 was proposed as a baseline material for the nozzle extension of the NERVA engine. In March 1970, the fibrous graphite selection was finalized as reported in Reference a.

Because the supersonic stream of gases leaving the nozzle extension generates random frequency excitatory forces to the nozzle extension, it was felt early in the design period that some type of stiffening device might be necessary. Accordingly, an open face cellular structure was added to the shell of the nozzle extension. As dynamic analyses of the engine progressed, however, it became apparent that the open cell reinforcement was not advantageous. Some of the disadvantages are given in Appendix F. Deletion of the open cell reinforcement was accomplished per Appendix G. The overall nozzle extension design is shown on ANSC Drawing 1137992, Rev. C.

It was recognized early in the design period that the most persistent problem source would be the interface between the nozzle and the nozzle extension. Possibly the basic reason for this is the dissimilarity of materials. The nozzle is made of stainless steel (either AISI 347 or ARMCO 22-13-5) which is convectively cooled by the liquid hydrogen from the propellant tank which enters the nozzle torus at the nozzle/nozzle extension interface. The problem mechanism is discussed in Reference b. The nozzle extension is cooled only by radiation to the space environment and thus its mean temperature is considerably hotter than the nozzle. If the nozzle and nozzle extension then are rigidly mated at room temperature on the earth (\(\approx 70^\circ\text{F}\)), the relative movement of the two parts, due to differences in thermal expansion and contraction, will cause thermally induced loading at steady state.

The problem then, which is discussed in this report, is to design an interface, between the nozzle and the nozzle extension, in which the stresses, due primarily to the thermal interference, are reduced to a level which has an acceptable margin of safety, and eventually a sufficiently high reliability.
B. INTERFACE CONCEPTS

The baseline concept, which was developed in previous contract periods, was known as concept #30. This idea is shown in Appendix B as Figure 1. As may be seen in Appendix B, several negative margins of safety exist in this concept, particularly in compression on the corner nearest the hot gas and the metallic nozzle. In this concept, the nozzle extension is rigidly locked to the nozzle and must move with it through all of its thermally induced movements. This is the problem discussed in Reference d. With the knowledge of Concept #30 in mind, it became clear that some type of freedom was needed for the nozzle extension. Thus, it may be seen that all of the following concepts, with the possible exception of concept 3, incorporate some type of freedom of movement. Concepts 1 through 20 follow as Figures 1 through 20.

1. Concept #1

This concept was analyzed completely. The thermal analysis may be seen in Appendix A and the structural analysis in Appendix C. The basic idea in this concept was to allow some movement of the inner corner which is exposed to the hot gas and is adjacent to the nozzle. The four Grafoil spacers being somewhat springy (low modulus of elasticity) and having the ability to return to original size after compression, allow each of the concentric, conical rings to grow slightly during operation and return on engine shutdown. Because the Grafoil has a low cross-ply thermal conductivity, the heat flux to the outer shell, and thus its temperature, would be reduced in the area of the fasteners to the nozzle. It may be seen in the isotherm plot, Figure 7 of Appendix A, that this objective was attained. It may also be seen in Appendix C, that the goal of all positive margins of safety was nearly achieved: This is the most promising concept analyzed. It is felt that with some minor modifications, this concept could have all positive margins of safety. The biggest unknown in analyzing this concept, as well as all of the other concepts, is material properties. This is true for both the fibrous graphite and the Grafoil.

2. Concept #2

This concept was an attempt to cut the nozzle extension completely free of the nozzle with respect to relative radial movement. It was thermally analyzed as reported in Appendix A and structurally analyzed as reported
in Appendix C. This idea was not successful at all in attaining positive margins of safety. Apparently when large masses of fibrous graphite are used, the ability of the graphite to move relative to the nozzle is not nearly as important as its ability to move within itself. Large masses of graphite should therefore be avoided, and, conversely, thin shells are desirable. Additionally, a large mass such as this concept, would present possible fabrication problems during outgassing.

3. Concept #3

This concept was thermally analyzed as may be seen in Appendix A. However, after the problems encountered with Concept #2 due to structural inadequacy, it was felt that nothing would be learned by structural analysis. This concept has the poor feature of a large mass of graphite in one piece which was the same drawback as the previous concept.

4. Concept #4

This idea is very similar to concept #1 except the concentric cones lie at a different angle. However, the thermal analysis as shown in Appendix A, indicates that higher temperatures extend out to the outer surface which is undesirable in the fastener area. A structural analysis of this concept was not accomplished, but it would be informative, especially in trying to determine what changes should be made to concept #1.

5. Concept #5

This concept is nearly the same as concept #4 except for the fastener attachment location and angle. However, the angle is the drawback as it would be nearly impossible to fabricate. Some clever method of fabric layup would need to be devised.

6. Concept #6

This was the first of a series of concepts which incorporated Columbium as a structural transition piece between the graphite nozzle extension and
the CRES nozzle. Later ideas appeared much more attractive than the first try and no analysis was made. However, two features which are carried through this whole family of ideas should be discussed here. The internal graphite ring (1.00 thick) is restrained only by compression through the Grafoil. It is relatively free to float and is not a part of the main shell. It carries nozzle extension thrust and contains the hot gas but does not participate directly to fastening the nozzle extension to the nozzle. The other feature is the method of preloading the .060 thick Grafoil seals. If the Columbium strips were to be bolted directly to the nozzle, it would be difficult to preload the seal. The fastener depicted in the concept as holding the Columbium strip is eccentric to the bolt into the nozzle. Therefore, by rotating this eccentric collar, tension can be applied to the Columbium strip which in turn will preload the Grafoil. These eccentric fasteners may be placed as needed around the perimeter of the nozzle. This feature could be used on all ideas of this type.

7. **Concept #7**

This idea is a direct evolution from the previously described concept #30. An attempt was made to incorporate the desirable attributes of concept #1 into the baseline design. The isotherm plots of Figure 11 of Appendix A indicate that the temperatures remain high in the fastening area, however, and this is, from past experience, not desirable. Had time permitted, a structural analysis would have been made to determine exactly what the stress levels were. They should be less than those of the baseline concept #30.

8. **Concept #8**

This concept was a cross between concepts #1 and #6. An attempt was made to thermally isolate the fasteners and allow an internal floating conical piece. No analysis was done on this concept.

9. **Concept #9**

This idea follows directly from concept #8. The slotted tab is thinner than the boss in concept #8 to allow a slight hinge effect where it is joined to the torus. No analysis was done on this concept.
10. **Concept #10**

   This idea follows directly from concept #9 and was an attempt to avoid drilling holes in the fibrous graphite. No analysis was done on this concept.

11. **Concept #11**

   This concept evolved from concept #6 and concept #10. The nozzle extension is clamped to the nozzle and no bolt holes are drilled in the fibrous graphite. Preload is placed on the seals by the eccentric collar which is bolted to the torus. The bolted, segmented, overlapping rings would also be difficult to assemble properly in a manner which would preclude load concentrations. Also, if these Columbium rings were to reach about the same temperature as the graphite, which would be expected, their larger thermal expansion coefficient, would result in loss of preload. No analysis was done on this concept.

12. **Concept #12**

   This concept followed directly from the previous one. However, the flange was combined into the shell to make a one-piece nozzle extension. Thermal analysis of this concept is discussed in Appendix A and structural analysis is discussed in Appendix D. Apparently, it was not a good idea to combine the flange and shell into one piece. The basic idea shown here is still good and should be developed further. In Appendix D it may be seen that the maximum stress occurs in the radius where the cross-sectional area is sharply reduced. A more gradual area reduction should reduce the stress levels. It may be seen that the eccentric collar attachment is used for preload of the seals. Also, the thermal expansion coefficient difference between fibrous graphite and Columbium presents a potential problem.
13. **Concept #13**

U-shaped support brackets are hung from the nozzle torus and extend aft through slots in the outer graphite shell. In the support brackets, a segmented clamping ring goes around the extension to hold it in place. The support brackets are then bolted closed on the O.D. for load carrying purposes. Some method would need to be devised to put tension in the segmented retaining ring to effect a preload on the seals. Page 2 of Figure 13 is an isometric view of this concept with the nozzle removed. No analysis was done on this concept.

14. **Concept #14**

A circular round ring is held to the nozzle by evenly spaced support brackets. The ring is capable of sliding in the bracket to compensate for thermal expansion differences. The support brackets pivot on the internal edge and can be torqued on the external end to provide preload to the seals. A spring tends to keep the nozzle extension centered with respect to the nozzle. No analysis was done on this concept.

15. **Concept #15**

This idea is a direct spinoff of concept #14. It is nearly the same except the flange system is more compact. No analysis was done on this concept.

16. **Concept #16**

This idea is similar to concept #2. It incorporates the use of Columbium as a fastener material and thus is able to reduce the mass of graphite. No analysis was done on this concept.

17. **Concept #17**

This is like concepts #14 and 15. The advantage is that the transition to the nozzle extension shell has been shortened. No analysis was done on this concept.
18. **Concept #18**

   The 1.00 diameter support ring is continuous around the nozzle extension. In concepts such as baseline concept #30, relative motion or shrinkage of the nozzle was bearing directly on the nozzle extension. Through the support linkage of this idea, the shrinkage of the nozzle does not directly load the extension but does it indirectly as the support ring is pulled upward. Analysis is needed to determine if all of the growths remain within the elastic limit of the material. If the support ring were to grow excessively due to internal heat generation, preload of the seal could be lost. No analysis was done on this concept.

19. **Concept #19**

   This is the "button" design. Large Columbium buttons, up to 4.00 inches in diameter are placed in shallow holes. The diameters of the buttons and the holes are closely controlled so that a very slight interference fit is obtained. This would conceivably spread the load over a sufficient area that excessive stresses would not exist in the graphite. A continuous ring around the buttons, holds them in place. No analysis was done on this concept.

20. **Concept #20**

   This idea is identical to concept #12 with one exception. A graphite filament overwrap clamps the Columbium fingers to the nozzle extension rather than a Columbium ring. This will eliminate thermal expansion coefficient difference problems. No analysis was done on this concept.

IV. **CONCLUSIONS AND RECOMMENDATIONS**

   **A. CONCLUSIONS**

   It is felt that a solution to the interface problem between the nozzle and the nozzle extension is possible with minor modifications of some of these ideas. Concepts #1, #12, and #20 show good promise and could be made to work.
B. RECOMMENDATIONS

It is recommended that any future work related to the continuation of nozzle extension design, upon completion of the analytical screening, be augmented by reevaluation of the selected concept(s) in light of the biaxial elastic properties data.
REFERENCES


Reference b - ANSC Memo dated 6 August 1971, from L. Shenfil to W. E. Campbell, Subject: Nozzle-to-Nozzle Extension Joint

Figure 2

CONCEPT 2
NOZZLE FLANGE
LAYOUT

$\xi = 24:1$
54.918" DIA

SCALE: $\frac{1}{4}$

REF Dwg 1140012

SLIDING BLOCK
SPRING
KEYWAY

.250-28 UNF-3A
.060 THICK GRAFOIL
AG CARB 101

NOZZLE EXIT PLANE

20° 5.55"
CONCEPT 4
NOZZLE FLANGE
LAYOUT

REF: DWG 1140014
SCALE: 1:1
Figure 7

CONCEPT 7
NOZZLE FLANGE LAYOUT

REF DWG 1140017
SCALE: 1
Figure 12

BOLTED SEGMENTED OVERLAPPING RINGS OF COLUMBIUM

25 THICK COLUMBIUM STRIP

.060 THICK GRAFOIL

AG CARS 101

3.96

1.25

20° REF

CONCEPT 12 NOZZLE FLANGE LAYOUT

SCALE: 1:1

REF DWG 1140022

CRES 347

NOZZLE EXIT PLANE

ε = 24:1
54.918 DIA REF

12-3-71
CRES 347

SEGMENTED RING

AG CARB 101

CAPTIVE NUT

.060 THICK GRAFOIL

20° REF

.75

6.12

\[ \text{Aspect Ratio} = 24:1 \]

54.918 DIA REF

NOZZLE EXIT PLANE REF

Figure 14
CONCEPT 14
NOZZLE FLANGE LAYOUT

REF DWG 1140024
CONCEPT 19
NOZZLE FLANGE LAYOUT

REF DWG 1140029
SCALE: 1
APPENDIX A

STEADY-STATE THERMAL ANALYSIS OF SEVERAL
NOZZLE/SKIRT INTERFACE CONCEPTS
N8110R:72-037
ENGINEERING OPERATIONS REPORT

STEADY-STATE THERMAL ANALYSIS OF SEVERAL NOZZLE/SKIRT INTERFACE CONCEPTS

PROJECT 143, WORK STATEMENT 5

21 APRIL 1972

E. A. THOMAS

APPROVED:

U. A. PINEDA, MANAGER
APPLIED MECHANICS
ENGINEERING STAFF DEPARTMENT
STEADY-STATE THERMAL ANALYSIS OF
SEVERAL NOZZLE/SKIRT INTERFACE CONCEPTS

I. INTRODUCTION

The purpose of the enclosed analyses is to provide temperature distributions for stress analysis and to determine the feasibility of various joint designs.

II. SUMMARY/CONCLUSIONS

Thermal analyses were performed for full power steady state flight conditions in space. The analyses were performed for design concepts shown on Figures 1 through 6. Nominal values of material physical properties, nuclear heating rates and fluid boundary conditions were used. The effects of solar heating in space were neglected since this heat input is negligible compared to that from the hot gas and from nuclear heating.

The following conclusions can be drawn from these analyses:

1. Thermal gradients are controlled mostly by the heat paths from surfaces heated by hot gas to those cooled by cryogenic hydrogen.
2. The effects of nuclear heating are minor.
3. All design concepts appear to be satisfactory thermally, with the optimum design based upon the results of stress analysis and ease of fabrication.

III. TECHNICAL DISCUSSION

A. METHOD OF ANALYSIS

Axisymmetric thermal networks, based upon the stress analysis models, were constructed for use with computer code D12207, a version of the finite element thermal code which has been expanded to 900 nodes capacity and with punch card output compatible with the finite element stress code input format.

In regions of three-dimensional heat transfer, such as the flange bolts, the heat input from nuclear heat generation was adjusted by the ratio of
actual volume to the apparent volume of an axisymmetric model. The heat transfer from the bolt heads to space by thermal radiation was also adjusted by ratioing the geometric shape factor of the bolt head to space by the ratio of the actual surface area to the apparent surface area of the axisymmetric model.

Interface resistance between mating surfaces was neglected as the assumption of intimate contact produces the highest thermal gradients and therefore the most conservative results.

All exterior surfaces were assumed to be radiating to space with a sink temperature of 70°F.

Surface to surface radiation was considered in regions where its effect is significant. This surface to surface radiation is based upon the assumption that all surfaces involved are gray and diffuse.

B. INPUT DATA

1. Material Physical Properties

   Thermal conductivity, density and emissivity for CRES-347, A-286 and AGCarb-101 were taken from the DRM, Reference 1. Thermal conductivity of AGCarb-101 was taken parallel to the plies as this produces the most conservative results. Thermal conductivity of Grafoil GHA grade (perpendicular to laminates) was taken from Reference 2. Thermal conductivity, density and emissivity of Columbium 129y, used in Concept 12, were taken from Reference 3.

2. Fluid Properties

   Coolant was assumed to be para hydrogen, while the hot gas was assumed to be equilibrium hydrogen. Thermodynamic and transport properties were taken from Reference 4.

3. Convective Boundary Conditions

   The following fluid boundary conditions based upon tube bundle design calculations, Reference 5, were used:
<table>
<thead>
<tr>
<th>Location</th>
<th>Temperature °R</th>
<th>Film Coefficient Btu/sec-in²°R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet Torus</td>
<td>55.8</td>
<td>0.00109</td>
</tr>
<tr>
<td>Coolant Tubes</td>
<td>60.1</td>
<td>0.00109</td>
</tr>
<tr>
<td>Hot Gas Side</td>
<td>3870</td>
<td>0.000235</td>
</tr>
</tbody>
</table>

4. **Nuclear Heating Rates**

Nuclear heating rates (assuming a graphite core) were taken from Reference 6. For metallic materials in which the heating rates were not computed, the rates were estimated by multiplying the rate computed for CRES-347 by the ratio of the material density to the density of CRES-347. For Grafoil, the nuclear heating rate was estimated by multiplying the heating rate in AGCarb-101 by the ratio of the density of Grafoil to the density of AGCarb-101.

IV. **RESULTS**

The results of these analyses are shown in the form of isotherm plots as Figures 7 through 12. All temperatures reported are in degrees Rankine.

V. **REFERENCES**

2. Union Carbide Bulletin No. 713-202 GI
5. AGC Computer Code E25104 Printout LOBE 072
TEMPERATURES IN °E

NOZZLE/SKIRT FLANGE CONCEPT 1 GRAFOIL INSULATORS 11-71

FIGURE 7
TEMPERATURES IN °R

NOZZLE/SKIRT FLANGE CONCEPT 7

FIGURE 11
APPENDIX B

NOZZLE-NOZZLE EXTENSION JOINT CONCEPT NO. 30
STRESS ANALYSIS
N8120R:72-023
ENGINEERING OPERATIONS REPORT

NOZZLE-NOZZLE EXTENSION JOINT

CONCEPT NO. 30 STRESS ANALYSIS

PROJECT 143

1 MARCH 1972

J. G. SCHUMACHER

APPROVED:

K. SATO, MANAGER
ENGINEERING STAFF DEPARTMENT
I. INTRODUCTION

This report constitutes a steady state stress analysis of the NERVA Nozzle to Nozzle Extension Joint Concept Number 30. This design consists of an AGCarb nozzle extension attached to an ARMCO 22-13-5 CRES nozzle by means of 120 clips. Two layup patterns were evaluated for the nozzle extension. One assumes layup parallel to the nozzle centerline and the other assumes a contoured layup pattern (see Figures 1 and 2). Publication of this report partially fulfills Project 143 Work Statement Item Number 98.

II. SUMMARY/CONCLUSIONS

A summary of minimum margins of safety is presented in Table I. Since combined stress failure criteria are not yet available for AGCarb material, only uniaxial failure modes were considered in the computation of the margins of safety for the nozzle extension.

For the 3 AGCarb failure modes checked, (block tension, interlaminar shear, and warp compression) all margins were negative for the cylindrical wrap design and 2 were negative for the contoured wrap design.

The nozzle flange (ARMCO 22-13-5 CRES) also shows a negative margin of safety in thermally induced hoop compression, based on an elastic analysis. Further analyses are required in the plastic range to determine the adequacy of the nozzle under thermal cycling.

It is concluded that the Concept 30 joint design is structurally inadequate as currently depicted with the present status of materials test data. With a 25% improvement in minimum block tension strength and with consideration of nonlinear material stress-strain behavior, the Concept 30 design would probably become acceptable. However, it would be more desirable to reduce the over-all stress levels through design modifications which allow more freedom for thermal expansion of the nozzle extension, and reduce thermal gradients in the nozzle.
TABLE I

SUMMARY OF MINIMUM MARGINS OF SAFETY

<table>
<thead>
<tr>
<th>Mode of Failure</th>
<th>AGCarb Nozzle Extension</th>
<th>Cylindrical Wrap</th>
<th>Conical Wrap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block Tension</td>
<td></td>
<td>-.36</td>
<td>-.23</td>
</tr>
<tr>
<td>Interlaminar Shear</td>
<td></td>
<td>-.03</td>
<td>+1.14</td>
</tr>
<tr>
<td>Warp Compression</td>
<td></td>
<td>-.10</td>
<td>-.10</td>
</tr>
</tbody>
</table>

Nozzle (ARMCO 22-13-5)

<table>
<thead>
<tr>
<th>Mode of Failure</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoop Compression</td>
<td>-.45</td>
</tr>
<tr>
<td>Hoop Tension</td>
<td>+.83</td>
</tr>
</tbody>
</table>

III. TECHNICAL DISCUSSION

The Concept 30 nozzle-nozzle extension joint configuration, shown in Figure 1, was analyzed with 2 variations of AGCarb layup, cylindrical and contoured, as shown in Figure 2. The design condition considered was steady state normal operation with specification extreme thermal environment and pressures for the 1137400E NERVA reference engine (Reference 1). The temperature distribution, as determined by a thermal analysis (Reference 2), is shown in Figure 3. The pressure distribution is given in Figure 4 and was obtained from References 1 and 3. Preload was set at 5176 lbs per bolt determined as 85% of ambient temperature bolt tensile yield strength times the bolt thread tensile area.

An axisymmetric orthotropic finite element analysis method, ANSC Program E11405, was employed for the stress analysis of the Concept 30 joint (Reference 4). The structure was modeled for the finite element analysis as shown in Figure 4. The bolt is the only tension member which joins the nozzle flange with the extension flange. Small elements of graphoil material, used as seals and thermal barriers, are used to transmit compression loads which arise from differential
displacements of mating flanges. Enough of the nozzle extension shell and the nozzle jacket were included in the model so that end conditions would not influence the flange deformation.

Material properties were taken from latest revision Data Release Memos when possible or NERVA Program Materials Properties Data Book when DRM's not available. Minimum strengths were used throughout while nominal values of moduli, coefficients of linear thermal expansion and Poisson's ratio were used. Some AGCarb elastic properties, due to the meagerness of test data, were derived using Betti's reciprocity theorem or engineering judgment based on existing data. The derivation of such data is presented in Appendix A. Available uniaxial strength data are also summarized in Appendix A.

The results of the stress analysis are summarized in Figures 5 through 10. The most critical regions are shown in Figures 6, 8 and 10 for the cylindrical wrap nozzle extension, contoured wrap nozzle extension, and nozzle flange, respectively. Minimum margins of safety for the AGCarb flanges are computed below for uniaxial failure modes only since combined stress criteria are not available.

**CYLINDRICAL LAYUP (Ref. Figure 6)**

REGION A: \( T = 1540^\circ F \)

Block Tension = 300 psi

\[
F_{TU_{\text{block}}} = 644 - 3.98(130) = 128 \text{ psi} @ 70^\circ F \text{ (Ref. Appendix A)}
\]

Assume this allowable to be representative at operating temperature

SIL (secondary) = 1.5(128) = 192

\[
\text{M.S.} = \frac{192}{300} - 1 = -0.36
\]
REGION B: $T = 1540^\circ F$

Interlaminar Shear = 1100 psi

$F_{SU} = 1350 - 3.98(160) = 713$ psi @70°F

Assume no temperature effect

SIL (secondary) = 1.5(713) = 1070

$M.S. = \frac{1070}{1100} - 1 = -0.03$

REGION C: $T = 1890^\circ F$

Warp Compression = 8400 psi

$F_{cu_{warp}} = 8720 - 3.98(920) = 5060$ psi @2000°F

SIL (secondary) = 1.5(5060) = 7600

$M.S. = \frac{7600}{8400} - 1 = -0.10$

CONToured Layup (Ref. Figure 8)

REGION A: $T = 1540^\circ F$

Block Tension = 250 psi

$M.S. = \frac{192}{250} - 1 = -0.23$

REGION B:

Interlaminar Shear = 500 psi

$M.S. = \frac{1070}{500} - 1 = +1.14$

REGION C:

Warp Compression = 8400 psi

$M.S. = \frac{7600}{8400} - 1 = -0.10
Minimum margins of safety for the nozzle are computed below according to SNPO-C-1 criteria (Reference 5) and using ARMCO-22-13-5 strength data from Reference 6. The governing design allowable is plotted in Figure 11 as a function of temperature.

**NOZZLE FLANGE** (Ref. Figure 10)

**REGION A:**

Max Hoop Stress = -160,000 psi

\[ T = 240°F \quad F_{TY} = 44,400 \text{ psi} \]

Assume: 1) \( F_{CY} = F_{TY} \)

2) that there is no "peak stress", i.e., all stress is primary + secondary.

\[
\text{M.S.} = \frac{2.0F_{TY}}{f_H} - 1 = \frac{2(44,400)}{160,000} - 1 = -0.45
\]

**REGION B:**

\[ f_{max} = 100,000 \text{ psi} \quad T = -260°F \]

\[ F_{TY} = 91,800 \text{ psi} \]

\[
\text{M.S.} = \frac{2(91,800)}{100,000} - 1 = +0.83
\]

An over-all summary of stresses and "margins of safety" are shown in Table I (reference page 2). It should be noted that a complete failure criteria has not been established for AGCarb material. The margins of safety are based on a comparison of the individual normal stresses in three mutually perpendicular axes to the statistically treated uniaxial strengths in each axis direction. Interlaminar shear stresses are calculated and compared to their allowable strength. No consideration is given to combined stresses at this time, since this must be preceded by the development of a failure theory.

The main contributor to stress is the thermal environment. The heat from the AGCarb flange of the nozzle extension is presently sinking into the aft
nozzle flange at the cold nozzle fuel torus location setting up high thermal
gradients and stresses in the nozzle flange. A more efficient thermal barrier
to preclude this circumstance is recommended. This would also hold more heat
in the nozzle extension flange and reduce stress creating thermal gradients.

IV. REFERENCES

to A. D. Cornell, Subject: State Points for the 1137400/Rev. E Reference Engine

2. Memo N8110:M1710, Dated 18 June 1971, J. J. Williams to L. B. Claassen,
Subject: Thermal Analysis of Modifications 1 and 2 to the Mechanical Intremold Liner Joints (W.O. 1190-14-305)


R. W. Kirby, Subject: "Finite Element Stress Analysis of Axisymmetric Solids
With Cylindrical Anisotropy"


6. ANSC Data Release Memo No. 38.01 Rev. 0 Dated 7 August 1970
FIGURE 1 - CONCEPT 30 JOINT CONFIGURATION
a) Cylindrical Layup

b) Contoured Layup

FIGURE 2 - CONCEPT 30 LAYUP PATTERNS
TB = 60.1°R
HL = 0.00109 Btu/in²-sec-°R
TG = 3870°R  TC = 4250°R  PC = 450 psia
HG = 0.000235 Btu/in²-sec-°R

Radiation to 7°R From All External Surfaces

Radiation Constants:  Steel = 0.215E-14 (ε = 0.65)
                     AGCarb-101 = 0.297E-14 (ε' = 0.86)

Conductivity:  (Reference 2)
Radiation Exchange Across Gaps
Radiation Exchange Between Flange and Shell
Nuclear Heating Rates:  Steel = 0.048 Btu/in³-sec
                       Grafoil = 0.0072 Btu/in³-sec
                       AGCarb-101 = 0.011 Btu/in³-sec

FIGURE 3 - TEMPERATURE DISTRIBUTION (°R)
STEADY STATE NORMAL OPERATION
Fig. 4 - CONCEPT NO 30 NOZZLE EXTENSION
a) Warp (Hoop) Stresses (psi)

b) Fill (Axial) Stresses (psi)

FIGURE 5 - STRESS DISTRIBUTIONS - CONCEPT 30
CYLINDRICAL AGCARB LAYUP
STEADY STATE NORMAL OPERATION
c) Block (Radial) Stresses (psi)

![Block stress diagram]

\[ \sigma \]

\[ \text{psi} \]

d) Interlaminar Shear Stresses (psi)

![Interlaminar shear stress diagram]

\[ \tau \]

\[ \text{psi} \]

FIGURE 5 (CONT.)

STRESS DISTRIBUTIONS - CONCEPT 30
CYLINDRICAL AGCARL LAYUP
STEADY STATE NORMAL OPERATION
FIGURE 6 - CRITICAL STRESS REGIONS - CONCEPT 30
CYLINDRICAL AGCARB LAYUP
STEADY STATE NORMAL OPERATION
a) Warp (Hoop) Stresses (psi)

b) Fill Stresses (psi)

FIGURE 7 - STRESS DISTRIBUTIONS - CONCEPT 30
CONToured AGCARB LAYUP
STEADY STATE NORMAL OPERATION
c) Block Stresses (psi)

![Block Stresses Diagram]


d) Interlaminar Shear Stresses (psi)

![Interlaminar Shear Stresses Diagram]

**FIGURE 7 (CONT.)**

STRESS DISTRIBUTIONS - CONCEPT 30
CONTOURED AGCARC LAYUP
STEADY STATE NORMAL OPERATION
FIGURE 8 - CRITICAL STRESS REGIONS - CONCEPT 30
CONTOURED ACCARB LAYUP
STEADY STATE NORMAL OPERATION
FIGURE 9 - HOOP STRESS DISTRIBUTION
NOZZLE FLANGE AREA - CONCEPT 30
STEADY STATE NORMAL OPERATION
FIGURE 10 - CRITICAL STRESS REGIONS
NOZZLE FLANGE AREA
STEADY STATE NORMAL OPERATIONS
**Figure 11**

**Design Tensile Yield Strength (ksi) vs Temperature**

Alloy 22-13-5 SS "ARMCO"

1" Ø Bar

*Typical value reduced by 20%

Ref: DRM 38.01 REV.0 Pg.3

Add 8-7-70

**Temperature (°F)**

-100 0 100 200 300 400 500 600

-20 0 20 40 60 80 100
APPENDIX A

AGCARB MATERIAL PROPERTIES
# AGCARB Material Properties

## Summary

<table>
<thead>
<tr>
<th>TEMP. (°F)</th>
<th>MODULUS (ksi)</th>
<th>POISSON'S RATIO</th>
<th>THERMAL EXPANSION (°F⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ERR</td>
<td>E₁</td>
<td>E₂</td>
</tr>
<tr>
<td>RT</td>
<td>.3</td>
<td>2.0</td>
<td>2.3</td>
</tr>
<tr>
<td>3000</td>
<td>.22</td>
<td>1.5</td>
<td>1.7</td>
</tr>
<tr>
<td>4000</td>
<td>.44</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>5000</td>
<td>.18</td>
<td>.86</td>
<td>.86</td>
</tr>
<tr>
<td>RT</td>
<td>.3</td>
<td>(1.8)</td>
<td>2.3</td>
</tr>
<tr>
<td>2000</td>
<td>(.39)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3000</td>
<td>.44</td>
<td>(1.36)</td>
<td>1.74</td>
</tr>
</tbody>
</table>

*Derived*
III  MATERIAL PROPERTY DERIVATION

A. Fill Modulus

USE VOLUME PERCENTAGE OF CLOTH REINFORCEMENT IN FILL DIRECTION AS BASIS FOR STIFFNESS VARIATION (NEGLECT FILL WEAVING PATTERN)

\[
\begin{align*}
\text{In Warp Direction:} & \quad 27 \text{ Yarns/Inch} \\
\text{In Fill Direction:} & \quad 21 \text{ Yarns/Inch}
\end{align*}
\]

ASSUME

\[
E_{\text{Warp}} = 27 \text{ Yarns/Inch} \\
E_{\text{Fill}} = 21 \text{ Yarns/Inch}
\]

\[
E_{\text{fill}} = E_{\text{warp}} \times \frac{21}{27} = 78\% \times E_{\text{warp}}
\]

FOR TENSION -

\[
\begin{array}{ccc}
T & E_{\text{warp}} & E_{\text{fill}} \\
\text{R.T} & 2.31 & 1.8 \\
2000 & 1.74 & 1.36 \\
3000 & & \\
\end{array}
\]

\text{Refs. 1 & 2}
B. **Shear Modulus**

From Reference 3

\[
\frac{E_R}{E_\theta} = \cos^2 \alpha + \frac{E_R \sin^2 \alpha + \sin^2 \beta (\frac{E_R}{G_R} - \frac{2}{4} \frac{E_\theta}{G_\theta})}{E_\theta}
\]

Where:

- \(E_R\) = Radial Modulus
- \(E_\theta\) = Axial Modulus
- \(E_\alpha\) = Modulus at angle to \(E_R\) and \(E_\theta\)

However, \(E_\alpha\) at angle to \(E_R\) and \(E_\theta\) is unknown. Therefore use \(E_\alpha\) at 45° angle to \(E_R\) and \(E_\theta\) (in plane).

For \(\alpha = 45°\):

\[
\sin \alpha = \cos \alpha = 0.707
\]

\[
\frac{E_\theta}{E_\alpha} = \left(\frac{0.707}{4}\right)^2 + \frac{E_\theta \left(0.707\right)^4 + \frac{1}{4} \left(\frac{E_\theta}{G_\theta} - 2\frac{E_\alpha}{G_\alpha}\right)}{E_\alpha}
\]

From References 2 & 4.

@ R.T. \(\alpha = 45°\):

\[
\begin{align*}
E_\alpha &= 1.48 \times 10^6 \text{ psi} \\
E_\theta &= 2.31 \times 10^6 \text{ psi} \\
E_\theta &= 1.8 \times 10^6 \text{ psi}
\end{align*}
\]

\(\theta = 0.24\)
SUBSTITUTING -

\[
\frac{2.31}{1.48} = \frac{.25 + 2.31(25) + 25\text{ }2.31}{1.8} - 2 (2.24) \]

or

\[G_{o2} = .52 \times 10^6 \text{ psi} \]

\[T = 3000 \text{ °F} \]

\[E_o = 1.19 \times 10^6 \text{ psi} \]

\[E_0 = 1.74 \times 10^6 \text{ psi} \]

\[E_2 = 1.36 \times 10^6 \text{ psi} \]

\[G_{o2} = .20 \]

\[
\frac{1.74}{1.19} = .25 + \frac{1.74(25) + 25\text{ }1.74}{1.36} - 2 (1.20) \]

or

\[G_{o2} = .438 \times 10^6 \text{ psi} \]

Assume \[G_{o2} = G_{r2} \]

\[T \quad G_{r2} \]

\[R_T \quad 0.52 \times 10^6 \text{ psi} \]

\[3000 \quad 0.44 \times 10^6 \text{ psi} \]

75
C. **Coefficient of Thermal Expansion**

*from Reference 1.*

<table>
<thead>
<tr>
<th>TEMP (°F)</th>
<th>AL to WRAP ( (10^{-6}) )</th>
<th>L (in/in/°F)</th>
<th>AL to WRAP ( (10^{-6}) )</th>
<th>L (in/in/°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>1.6</td>
<td>1.60</td>
<td>2.6</td>
<td>2.60</td>
</tr>
<tr>
<td>2000</td>
<td>3.2</td>
<td>1.60</td>
<td>5.3</td>
<td>2.65</td>
</tr>
<tr>
<td>3000</td>
<td>5.5</td>
<td>1.83</td>
<td>7.8</td>
<td>2.60</td>
</tr>
</tbody>
</table>
D. Poisson's Ratio

FROM REFERENCE 4.

1. Block Specimens

\[ \nu_{de} = \nu_{rad} + \nu_{exp} \]

\[ \nu_{rel} = \nu_{rel,0} - \text{fill} \]

<table>
<thead>
<tr>
<th>T of F</th>
<th>( E_\text{comp}(1251) )</th>
<th>( \frac{\nu_{rel} + \nu_{de}}{2} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>R.T</td>
<td>.30 (10^9)</td>
<td>.11</td>
</tr>
<tr>
<td>3000</td>
<td>.44 (10^9)</td>
<td>.11</td>
</tr>
<tr>
<td>5000</td>
<td>.18 (10^9)</td>
<td>.17</td>
</tr>
</tbody>
</table>
2. **Flat Wrap 45° Bias**

![Diagram of flat wrap 45° bias]

<table>
<thead>
<tr>
<th>Temp (°F)</th>
<th>Ev. (tons, ksi)</th>
<th>$D_{0.01}$</th>
<th>$D_{0.02}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>R.T.</td>
<td>1.48</td>
<td>.40</td>
<td>.16</td>
</tr>
<tr>
<td>3000</td>
<td>1.19</td>
<td>.16</td>
<td>.07</td>
</tr>
<tr>
<td>5000</td>
<td>0.54</td>
<td>.10</td>
<td>.14</td>
</tr>
</tbody>
</table>

78
3. **Flat Wrap w/15° Alternate Layers**

![Diagram of flat wrap with 15° alternate layers]

<table>
<thead>
<tr>
<th>$T^\circ F$</th>
<th>$E_\theta'$ (Tens. (psi))</th>
<th>$\theta^\prime$</th>
<th>$\theta_0^\prime$</th>
</tr>
</thead>
<tbody>
<tr>
<td>87</td>
<td>$1.75 \times 10^4$</td>
<td>.24</td>
<td>.46</td>
</tr>
<tr>
<td>3000</td>
<td>$1.46 \times 10^4$</td>
<td>.20</td>
<td>.24</td>
</tr>
<tr>
<td>5000</td>
<td>$0.55 \times 10^4$</td>
<td>.20</td>
<td>.23</td>
</tr>
</tbody>
</table>

---

79
**AG Carb Material Strengths (Ref 2)**

<table>
<thead>
<tr>
<th>Property</th>
<th>Temperature (°F)</th>
<th>Specimen</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>70°</td>
<td>2000°</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*[Table continues with various entries]*

---

80
APPENDIX A

LIST OF REFERENCES


2. Data Release Memo No. 06.01 Rev. 0 AGCarb-101, Dated 19 December 1969


5. Data Release Memo No. 38.01 Rev. 0 Dated 7 August 1970
APPENDIX C

SUMMARY OF RESULTS OF STEADY STATE STRESS ANALYSIS
OF CONCEPTS #1 AND #2

AM-NA-0027
SUMMARY OF ANALYSIS

Project  143  System/Component  Nozzle Extension  Distribution:
Part  Joint Concepts 1 & 2  Drawing No. 5:1 Sketch Concepts  #1 & #2
Subject  Summary of Results of S. S. Stress Analysis
Reference(s) (1) Data Release Memo No. 38.01 Rev. 0 dtd 7 Aug 1970
(2) Data Release Memo No. 06.01 Rev. 0 AGCarb-101 dtd 19 Dec 1969

OBJECTIVE: To predict structural feasibility and relative merit of N.E. to Nozzle Joint Concepts Numbers 1 and 2.

ASSUMPTIONS: Margins of safety can be calculated by ratioing theoretical stress to uniaxial strengths.
Operating conditions and primary plus secondary stress levels are critical.

REFERENCES (Analysis Methods): Computerized axisymmetric analysis for cylindrical anisotropic material (E11405).

RESULTS AND CONCLUSIONS: A negative M.S. is calculated in block tension for both concepts. The magnitude (highly negative) is mainly due to a very low statistical value for block tensile strength. However, even if average values of allowables were used, a negative M.S. would be predicted. Concept #2 shows a high negative M.S. in interlaminar shear. This situation was precluded in Concept #1 by using smaller thermally isolated free standing rings.

RECOMMENDATIONS AND COMMENTS: Concept #1 appears feasible if block tensile stresses are reduced by varying the layup pattern. In view of this and since the stresses in the nozzle have also been reduced from those of Concept #30, it is recommended that joint Concept #1 be used in transient analyses.
SUMMARY OF MAX STRESSES & M.S.
FOR JOINT CONCEPT #1

<table>
<thead>
<tr>
<th>STRESS</th>
<th>ELEMENT</th>
<th>TEMP.</th>
<th>STRENGTH</th>
<th>M.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode</td>
<td>Magnitude (psi)</td>
<td>No.</td>
<td>(°F)</td>
<td></td>
</tr>
<tr>
<td>WARP</td>
<td>4155</td>
<td>601</td>
<td>510</td>
<td>12,300</td>
</tr>
<tr>
<td>TENSION</td>
<td>1950</td>
<td>467</td>
<td>800</td>
<td>4710</td>
</tr>
<tr>
<td>BLOCK</td>
<td>1320</td>
<td>463</td>
<td>1020</td>
<td>186</td>
</tr>
<tr>
<td>COMPRESSION</td>
<td>2311</td>
<td>530</td>
<td>2500</td>
<td>7600</td>
</tr>
<tr>
<td>WARP</td>
<td>2050</td>
<td>702</td>
<td>2600</td>
<td>++</td>
</tr>
<tr>
<td>BLOCK</td>
<td>1420</td>
<td>499</td>
<td>2025</td>
<td>++</td>
</tr>
<tr>
<td>INTERNAL</td>
<td>1460</td>
<td>466</td>
<td>850</td>
<td>1550</td>
</tr>
<tr>
<td>SHEAR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO.33R MAX</td>
<td>52,000(1)</td>
<td>229</td>
<td>72</td>
<td>$\sigma_T = 104,150$</td>
</tr>
</tbody>
</table>

* Based on assumption that all stresses are primary plus secondary stresses.

** No strength data available

(1) Reference 1
### SUMMARY OF MAX STRESSES & M.S. for Joint Concept #2

<table>
<thead>
<tr>
<th>STRESS</th>
<th>STRENGTH</th>
<th>ELEMENT</th>
<th>TEMP</th>
<th>M.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode</td>
<td>Magnitude</td>
<td>No.</td>
<td>(°F)</td>
<td>(psi)</td>
</tr>
<tr>
<td>TENSION</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warp</td>
<td>5410</td>
<td>518</td>
<td>1040</td>
<td>12,300</td>
</tr>
<tr>
<td>Fill</td>
<td>4970</td>
<td>519</td>
<td>990</td>
<td>4700</td>
</tr>
<tr>
<td>Block</td>
<td>1990</td>
<td>517</td>
<td>1070</td>
<td>186</td>
</tr>
<tr>
<td>COMPRESSION</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warp</td>
<td>580</td>
<td>581</td>
<td>2240</td>
<td>760.3</td>
</tr>
<tr>
<td>Fill</td>
<td>4350</td>
<td>674</td>
<td>3013</td>
<td>**</td>
</tr>
<tr>
<td>Block</td>
<td>1370</td>
<td>594</td>
<td>2400</td>
<td>**</td>
</tr>
<tr>
<td>INTERLAMINAR SHEAR</td>
<td>4410</td>
<td>490</td>
<td>900</td>
<td>1550</td>
</tr>
<tr>
<td>NODAL MAX STRESS (HOOP)</td>
<td>60,000</td>
<td>223</td>
<td>72</td>
<td>2σr = 10.4ksi</td>
</tr>
</tbody>
</table>

* Based on assumption that all stresses are primary plus secondary stresses.

** No strength data available.
## AG Carb Material Strengths (Ref 2)

<table>
<thead>
<tr>
<th>Property</th>
<th>TEMPERATURE (°F)</th>
<th>SPECIMEN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>70°</td>
<td>2000°</td>
</tr>
<tr>
<td>WARP</td>
<td>11.27 ± 3.3 (.65)</td>
<td>11.53 ± 3.98 (798)</td>
</tr>
<tr>
<td></td>
<td>10.45 ± 2.932 (.765)</td>
<td>11.75 ± 3.98 (.99)</td>
</tr>
<tr>
<td>FILL</td>
<td>4.56 ± 4.35 (.325)</td>
<td></td>
</tr>
<tr>
<td>BLOCK</td>
<td>0.644 ± 3.98 (.13)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.638 ± 3.98 (.064)</td>
<td></td>
</tr>
<tr>
<td>E' (GPa)</td>
<td>9.40 ± 3.98 (.16)</td>
<td>8.72 ± 3.98 (.92)</td>
</tr>
<tr>
<td>WARP</td>
<td>9.51 ± 3.98 (.702)</td>
<td>9.16 ± 3.98 (.477)</td>
</tr>
<tr>
<td>LOAD</td>
<td>1.35 ± 3.98 (.116)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.298 ± 3.98 (.067)</td>
<td></td>
</tr>
<tr>
<td>45° 40 WIF</td>
<td>4.43 ± 5.74 (.144)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.02 ± 5.74 (.158)</td>
<td></td>
</tr>
<tr>
<td>90° 0° 45°</td>
<td>8.75 ± 1.75</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9.50 ± 1.9</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX D

SUMMARY OF RESULTS OF STEADY STATE STRESS
ANALYSIS OF CONCEPT #12
AM-NA-0030
OBJECTIVE: To predict structural feasibility and relative merit of N.E. to Nozzle Joint Concept #12.

ASSUMPTIONS: "Margins of Safety" can be calculated by ratioing theoretical stress to uniaxial strengths. Operating conditions and primary plus secondary stress levels are critical. These M.S.'s are an apparent strength/stress ratio for comparative use only. Failure theory is yet undeveloped.

REFERENCES (Analysis Methods): Computerized axisymmetric analysis for cylindrical anisotropic material (Ell405)

RESULTS AND CONCLUSIONS: High negative "Margins of Safety" are predicted on the outside surface in the fillet area of transition from ring to shell structure. Ring is not rigid enough and tries to roll out.

This concept is not structurally adequate or desirable.

See "M.S." summary enclosed.

RECOMMENDATIONS AND COMMENTS: Revise Concept #1 design as reported in AM-NA-0027 and drop this design from further consideration.
### Summary of Maximum Stresses and Minimum Margins of Safety for AG Carb Flange Design Concept #12

<table>
<thead>
<tr>
<th>Stress</th>
<th>Element No.</th>
<th>Temp. (°F)</th>
<th>Strength = 1.5 F* Umin.</th>
<th>Margin of Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warp Tension</td>
<td>679</td>
<td>3030</td>
<td>12,000</td>
<td>+1.40</td>
</tr>
<tr>
<td>Fill Tension</td>
<td>679</td>
<td>3030</td>
<td>4,700</td>
<td>-0.31</td>
</tr>
<tr>
<td>Block Tension</td>
<td>674</td>
<td>3000</td>
<td>186</td>
<td>-0.82</td>
</tr>
<tr>
<td>Interiminer Shear</td>
<td>674</td>
<td>3000</td>
<td>710</td>
<td>-0.61</td>
</tr>
</tbody>
</table>

* Based on assumption that all stresses are primary plus secondary stresses.
APPENDIX E

AGCARB DATA REQUIREMENTS FOR CY72 NOZZLE EXTENSION

FLANGE CONCEPT SELECTION

N8120:090
TO: T. A. Redfield
FROM: J. G. Schumacher

SUBJECT: AGCarb Data Requirements for CY72 Nozzle Extension Flange Concept Selection


ENCLOSURE: Table I and Ground Rules for AGCarb Data Requirements

The enclosed table presents the AGCarb material data required for incorporation in the structural analysis of the 3 nozzle extension flange concepts scheduled for August 1972.

J. G. Schumacher
Applied Mechanics Section
Engineering Staff Department
<table>
<thead>
<tr>
<th>Type of Test</th>
<th>Load Direction</th>
<th>Specimen No.</th>
<th>Type</th>
<th>Instrumentation</th>
<th>Measurements</th>
<th>Reduced Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNIAXIAL TENSION</td>
<td>WARP</td>
<td>4</td>
<td>FLAT .25 x .25</td>
<td>STRAIN GAGES IN X, Y, Z DIRECTIONS</td>
<td>Load vs 3 strains to failure</td>
<td>$E_{t1}, E_{t2}, E_{t3}, (E_t)_{c-c}$ curve</td>
</tr>
<tr>
<td></td>
<td>FILL</td>
<td>4</td>
<td>FLAT .25 x .25</td>
<td>STRAIN GAGE IN LOAD DIRECTION</td>
<td>-00-</td>
<td>-00-</td>
</tr>
<tr>
<td></td>
<td>BLOCK</td>
<td>4</td>
<td>RND. .10 x .25</td>
<td>-00-</td>
<td>-00-</td>
<td></td>
</tr>
<tr>
<td>UNIAXIAL COMPRESSION</td>
<td>WARP</td>
<td>4</td>
<td>.05 x .06 x .06</td>
<td>-00-</td>
<td>-00-</td>
<td>$E_c$, etc.</td>
</tr>
<tr>
<td></td>
<td>FILL</td>
<td>4</td>
<td>-00-</td>
<td>-00-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BLOCK</td>
<td>4</td>
<td>.05 x .06 x .06</td>
<td>-00-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHEAR</td>
<td>WARP</td>
<td>7</td>
<td>BAYONET SHAFT</td>
<td>FAILURE LOAD</td>
<td>$F_{t1w}, F_{t2w}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FILL</td>
<td>7</td>
<td>BAYONET SHAFT</td>
<td>FAILURE LOAD</td>
<td>$F_{t1w}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BLOCK (WARP RUN)</td>
<td>7</td>
<td>BEAM</td>
<td>HOLOGRAPHIC</td>
<td>DEFLECTIONS vs. LOAD</td>
<td>$G_{wb}$</td>
</tr>
<tr>
<td></td>
<td>BLOCK (FILL RUN)</td>
<td>7</td>
<td>BEAM</td>
<td>HOLOGRAPHIC</td>
<td>DEFLECTIONS vs. LOAD</td>
<td>$G_{fb}$</td>
</tr>
<tr>
<td></td>
<td>TWIST ALONG FILL AXIS</td>
<td>4</td>
<td>SQUARE</td>
<td>LATERAL STRAIN GAGES</td>
<td>TWIST ANGLE GAGE</td>
<td>$G_{fb}, G_{t1}, G_{t2}, (G_t)_{c-c}$ curve</td>
</tr>
<tr>
<td></td>
<td>ROUND</td>
<td>3</td>
<td>ROUND</td>
<td>TWIST ANGLE GAGE</td>
<td>TORQUE vs. STRAIN, LOAD, and FAILURE</td>
<td>-00-</td>
</tr>
<tr>
<td>COEF. OF EXP.</td>
<td>WARP</td>
<td>2</td>
<td>RECT BARS</td>
<td>$\Delta L / T$ vs TEMP</td>
<td>$A_w$, RT to 1000, 2000, 3000°F</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FILL</td>
<td>2</td>
<td>-00-</td>
<td>-00-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BLOCK</td>
<td>2</td>
<td>-00-</td>
<td>-00-</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*NOT ESSENTIAL TO AUG. 72 ANALYSIS BUT DESIRABLE FOR SCREENING*
AsCaP Data Required for Structural Analysis of August 1972

Guidelines:

1. Data to be reduced by June 30, 1972, for incorporation in stress analyses of 3 selected flange concepts.*

2. Stress analyses to consist of the following steps for each concept:

   (a) Prediction of elastic stress distribution under thermal and mechanical loads based on R.T. mean values of Ew, Et, Gb, Gw, Tw, Tt, Tg, Tw, Tt, Gw, Gt, Gb.

   (b) Comparison of elastic stresses with R.T. mean stress-strain curves in W, E, B directions (or C as the case may be). Estimate secant moduli and effective Poisson's ratios in nonlinear range if required (highly likely).

   (c) Perform one iteration of analyses in nonlinear range.


   (e) Evaluate 3 flange concepts based on margins of safety.

   (f) Fracture analysis of the selected N.E. design should be scheduled for early CY 73. Toughness data and analysis methods to be developed.

   (g) The final nozzle extension analysis (beyond CY 72) requires the following additional data:

      (a) 3D analysis data (Gw, Gt, Gw, Gt) and combined stress failure criteria test data.

      (b) All above data at 2000°F and 3000°F.

      (c) All above data upgraded to category 'A'.

Notes:

* Current plan calls for analysis with one material composition only.

** Heat transfer parameters should be for same material system as stress parameters and of comparable maturity.
APPENDIX F

HONEYCOMB REINFORCED LINER - NOZZLE EXTENSION

N8120:105
TO: L. A. Shurley  
FROM: U. A. Pineda  
SUBJECT: Honeycomb Reinforced Liner - Nozzle Extension  

There have been several discussions and correspondence on the question of whether or not open-face honeycomb reinforcement of the nozzle extension liner section is required.

From our recent discussions on this subject, I am recommending, based on technical justifications and best engineering judgment, that the nozzle extension design should be carried with a plain liner; i.e., eliminate the honeycomb reinforced liner design.

1. From a dynamic standpoint, the plain liner design has natural frequencies well above the engine bending mode excitation frequency. The bell mode types are randomly excited by gas flow through a wide range of frequencies and, consequently, a natural frequency criterion cannot be meaningfully established. Additionally, comparative studies reported to you in the past have shown that the honeycomb has no appreciable effect in increasing the natural frequencies (from first bending up to mode shape 3).

2. If it is found necessary to provide stiffness for handling and for external loading purposes, this could best be accomplished by circumferential ribs (ring stiffeners), not by honeycomb reinforcement.

3. It has been shown that the honeycomb reinforced liner design experiences a much larger radial thermal gradient and, consequently, higher stresses than does the plain liner. Analysis as reported in S-036 issued October 1970 indicated that the hex cell reinforcements are the most critical part of the nozzle extension.
due to excessive interlaminar shear resulting from the large thermal gradients. This analysis showed that the apparent minimum "M.S." of the plain shell will be 30 times higher than that of the honeycomb reinforced design.

4. Honeycomb cells to liner bond sections are areas of high stress concentrations from a structural design standpoint - this is an established fact whether the material be metal, non-metal, or composite. These sections are extremely prone to voids or defects which are potential crack starters particularly in a field of high stress, presence of high stress concentration, and due to the apparently brittle nature of the material.

5. Open faced honeycomb structures in non-uniform stress fields have a tendency to subject the liner to indeterminate deformations due to the non-uniform constraint.

6. Open faced honeycomb cell walls are "buckling"-sensitive.

7. From a fabrication standpoint, the elimination of the honeycomb will offer significant advantages. Aside from the large cost savings in materials and labor, particularly for the thousands of dies required, a number of potential problem areas will be eliminated in the fabrication of the nozzle extension. Since the investigation of these problem areas is part of the current M-6 Development Activities, the severity and the extent of their solution will not be known until the completion of the lab work. The problem areas being investigated include the following:

(a) proper drainage of the pitch from these cells after impregnation.
(b) warpage of cells during carbonization and graphitization.
(c) requirement for pre-forming of cell wall fabric prior to lay-up.
(d) metal die removal from the cell after cure.
(e) requirement for heated dies during lay-up.
(f) effect of surface maceration on cell wall to liner bond strength.

Other major problem areas to be determined cover such factors as variability/reproducibility and the Q.C. inspection aspect on both hex cell and liner.
APPENDIX G

NOZZLE EXTENSION OPEN CELL REINFORCEMENT

N8500:M1456
This memorandum is to inform you that the open cell reinforcement, also known as honeycomb or Intremold I, on the outside surface of the nozzle extension is no longer a part of the design. The requirement for external reinforcement was re-evaluated and determined to be unnecessary (Reference (a)). Coordination with, and concurrence from, SNSO-C on this action has been accomplished.

The following actions must now be taken to eliminate all work on open cell reinforcement:

1. The fracture toughness testing of notched and un-notched tee bars and flat notched and un-notched control specimens is terminated along with all associated crack arrest work.

2. No further tooling effort shall be expended on the reinforcement. Since there is no significant economic advantage from termination of the zinc die contract with Peat Manufacturing Company, this effort shall continue to completion at the current funding level. Work statements 1.4.3.h.12.b and 1.4.3.h.12.c shall be removed from the work statement.

3. Work statement 1.4.3.f.5.b defining the NE thermal analysis (and subsequent stress analysis) shall be revised to remove reference to reinforcement cells. All associated analytical effort shall be terminated.

4. Drawings of the fabrication feasibility nozzle extension (FFNE) and of the baseline flight nozzle extension shall be revised. Other drawings showing open cell reinforcement shall be revised at their next change to show conformance to this memorandum.
5. The C-002 Specification shall be reviewed for potential impact. It is suggested that Project 187 review the M-6 materials plan and consider elimination of all items connected with open cell reinforcement at least where possible economic advantages would be realized.

L. A. Shurley, Manager
Nozzle, Pressure Vessel and Skirt Department
Engineering Operations