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(Item #7)

ENGINEERING OPERATIONS REPORT

(NASA-CR-132211) NOZZLE EXTENSION DESIGN STATUS REPORT (Aerojet Nuclear Systems Co., Azusa, Calif.) ~~104~~ 106 p HC $7.25 CSCL 20D

N73-24324

Unclas
G3/12 17711

NOZZLE EXTENSION DESIGN STATUS REPORT

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PROJECT 143

MAY 1972

AEROJET NUCLEAR SYSTEMS COMPANY
A DIVISION OF AEROJET-GENERAL

N8500:72-143-F-398
(Item #7)

ENGINEERING OPERATIONS REPORT

Nozzle Extension Design Status Report

Project 143

May 1972

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CLASSIFICATION CATEGORY
Unclassified
L. A. Shurley 5/15/72
CLASSIFYING OFFICER DATE

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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 (≈70°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 a - ANSC Memo 7750:M0807, dated 4 March 1970, from L. A. Shurley to B. Mandell, Subject: Transmittal of Preliminary Skirt Extension Trade Study Report 014.

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

Reference c - Report No. RN-S-0549, dated March 1970, Subject: The Fabrication and Properties of the Fibrous Reinforced Graphite Composite, AGCarb-101

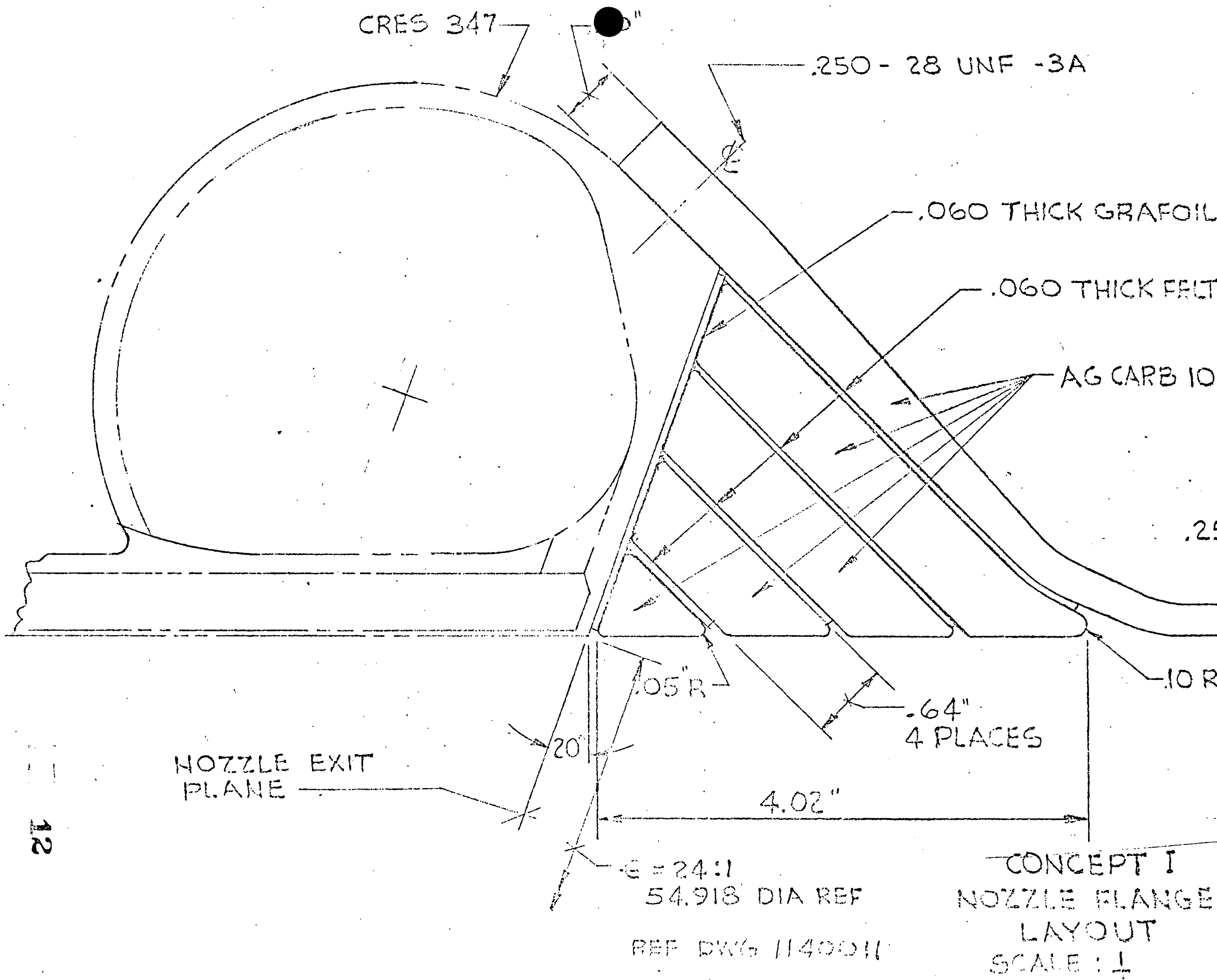
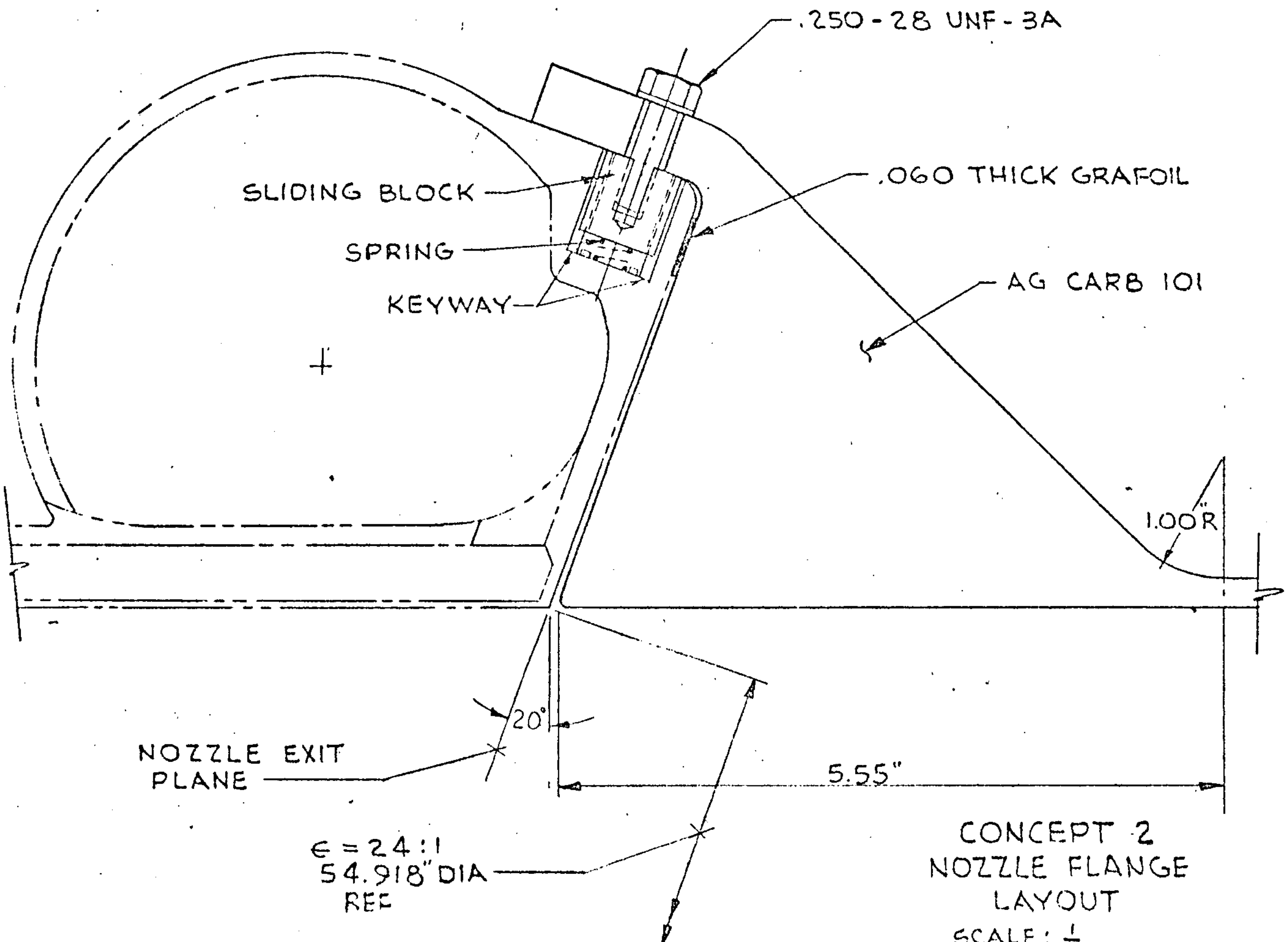

CRES 347
.250 - 28 UNF -3A
.060 THICK GRAFOIL
.060 THICK FELT
AG CARB 101
.25"
.10 R
.05" R
.64"
4 PLACES
20°
NOZZLE EXIT
PLANE
4.02"
ε = 24:1
54.918 DIA REF
REF DWG 1140011
CONCEPT I
NOZZLE FLANGE
LAYOUT
SCALE : 1

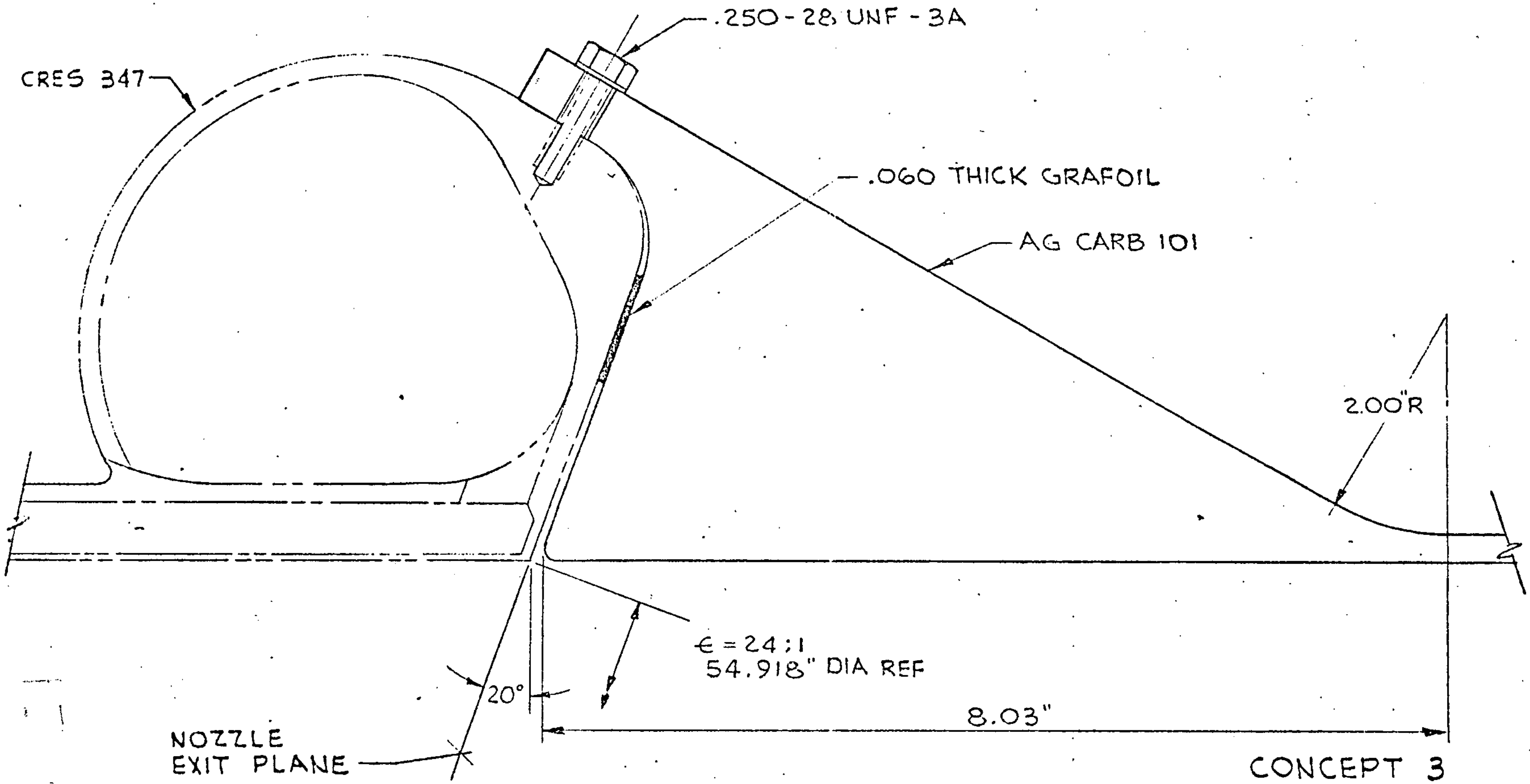
Figure 1



CONCEPT 2
NOZZLE FLANGE
LAYOUT
SCALE: 1/1

• REF DWG 1140012

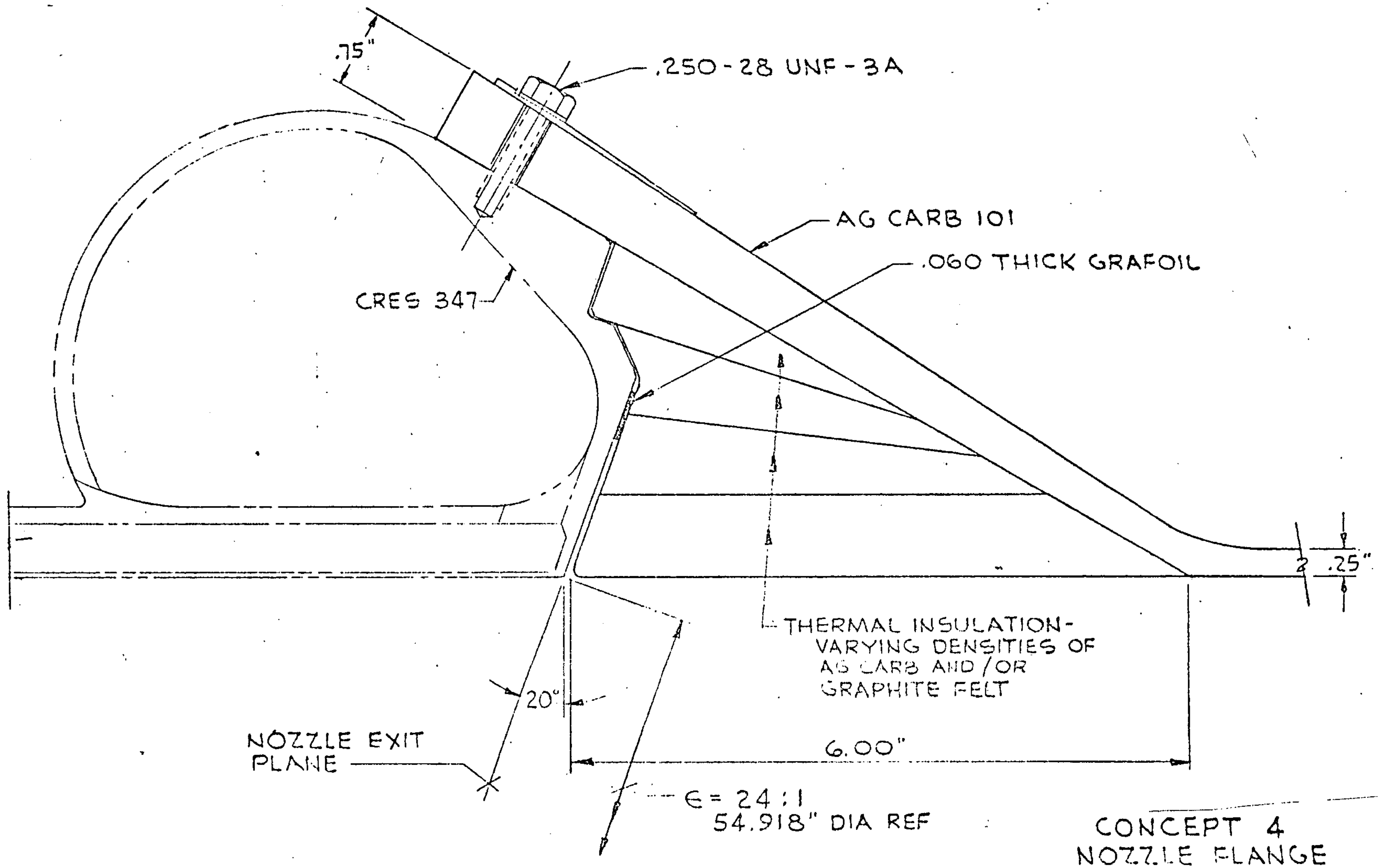
Figure 2



CONCEPT 3
NOZZLE FLANGE
LAYOUT
SCALE 1/1

REF DWG 1140013

Figure 3



CONCEPT 4
NOZZLE FLANGE
LAYOUT
SCALE: 1/1

REF DWG 1140014

Figure 4

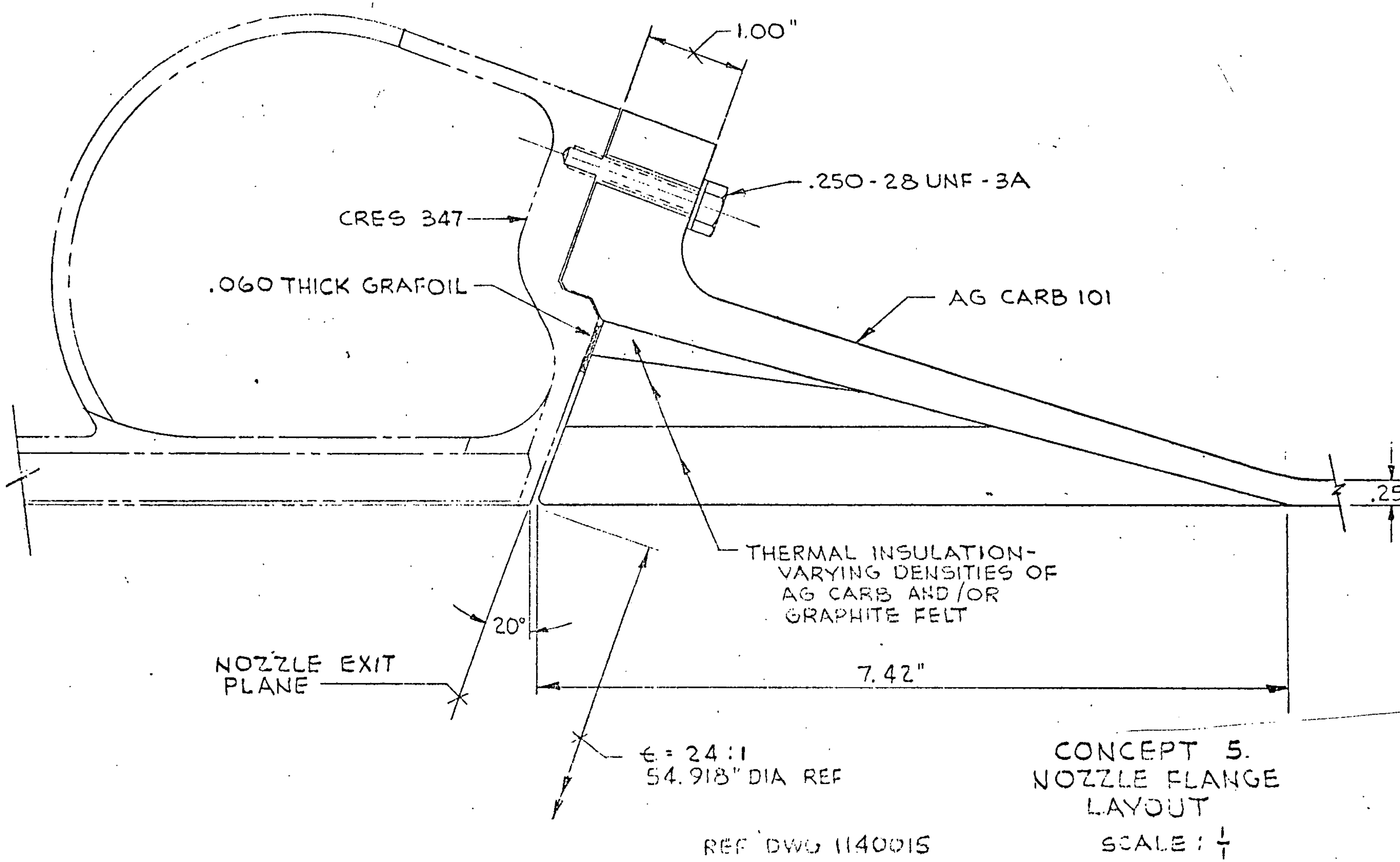
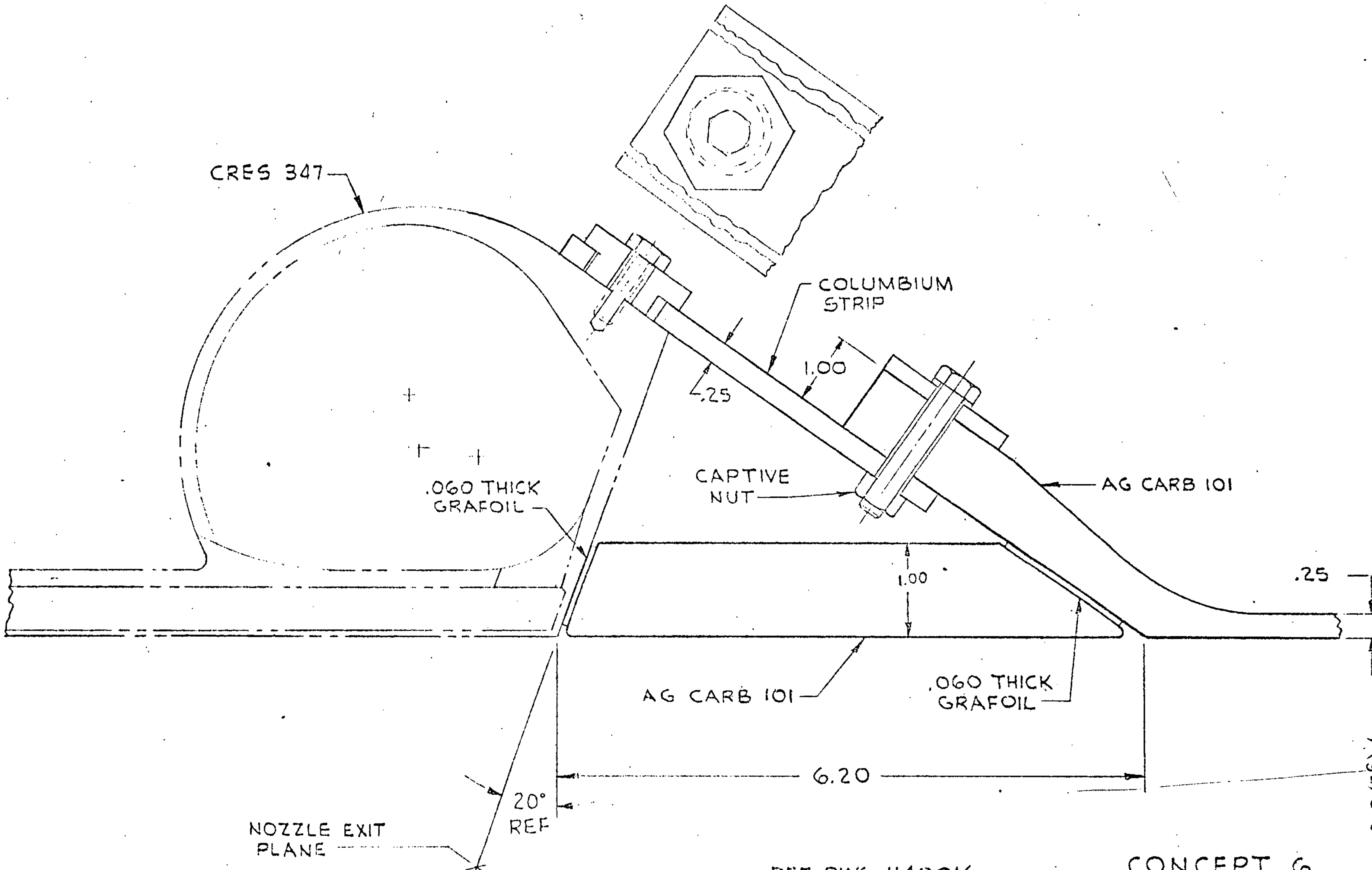
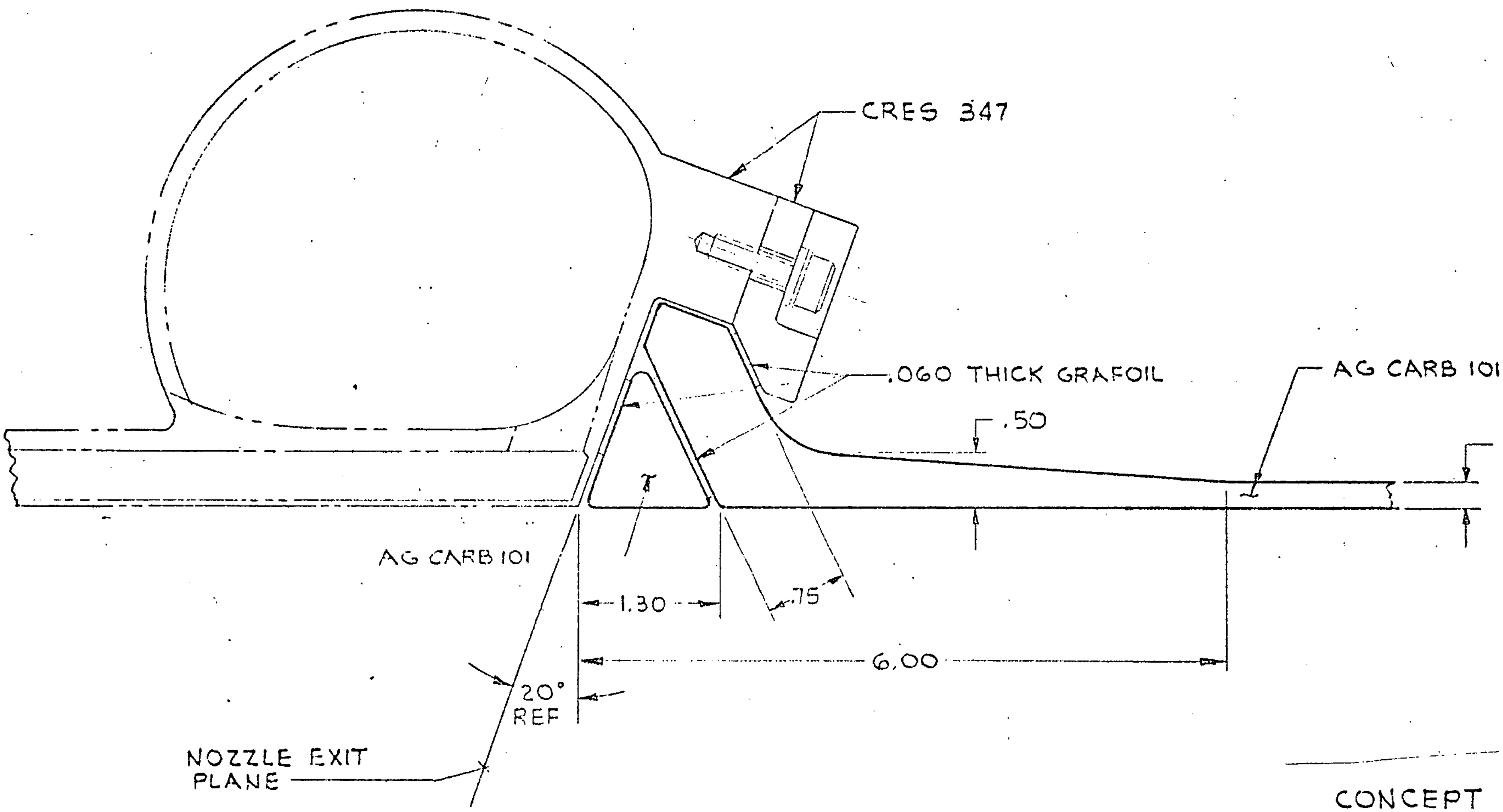

1.00"
.250-28 UNF-3A
CRES 347
.060 THICK GRAFOIL
AG CARB 101
.25
THERMAL INSULATION-
VARYING DENSITIES OF
AG CARB AND/OR
GRAPHITE FELT
20°
NOZZLE EXIT
PLANE
7.42"
ε = 24:1
54.918" DIA REF
CONCEPT 5.
NOZZLE FLANGE
LAYOUT
SCALE: 1/1
REF DWG 1140015

Figure 5



CONCEPT 6
NOZZLE FLANGE
LAYOUT

Figure 6

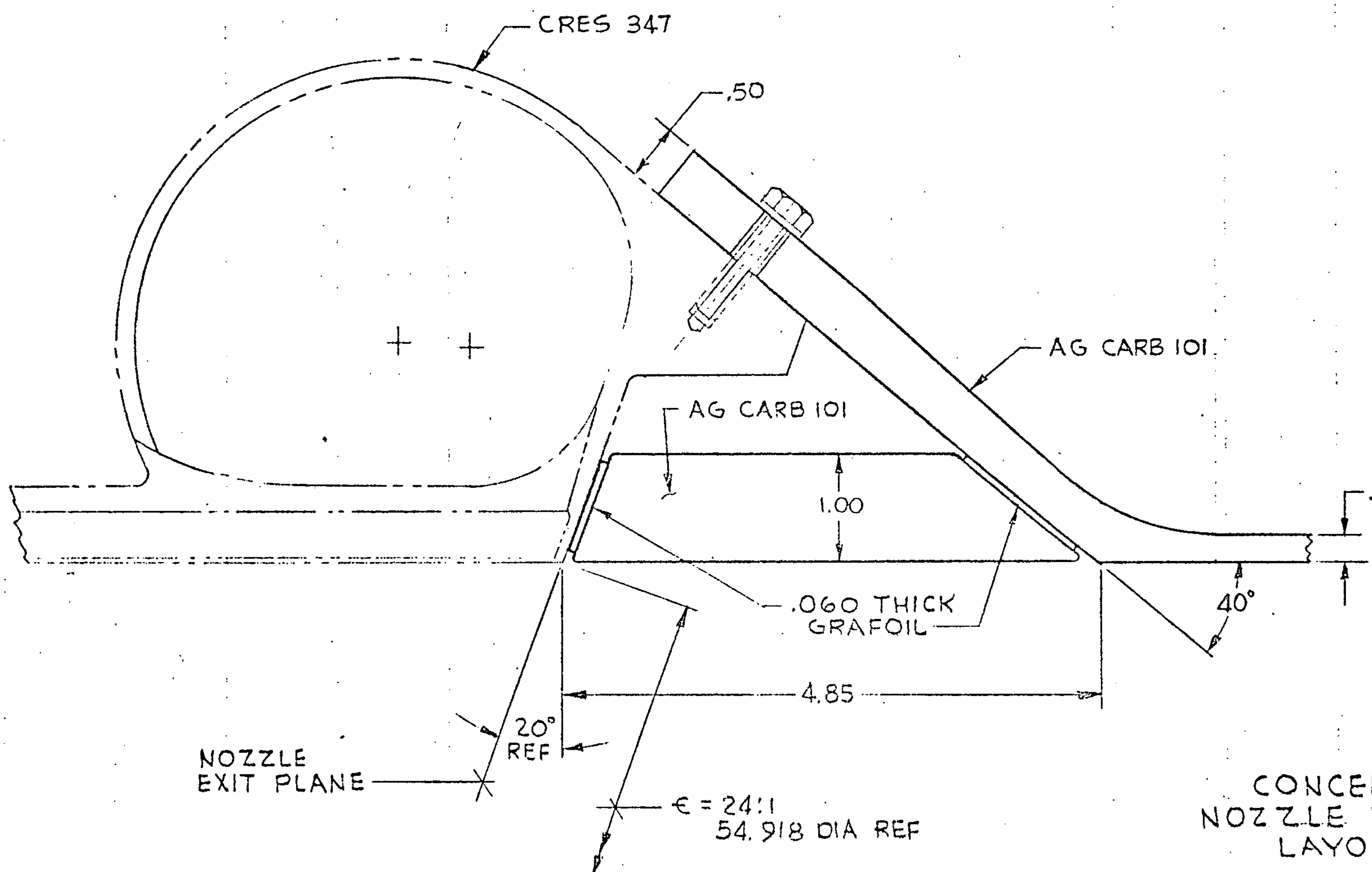


REF DWG 1140017

CONCEPT 7
NOZZLE FLANGE
LAYOUT

SCALE : 1

Figure 7



REF DWG 1140018

CONCEPT 8
NOZZLE FLANGE
LAYOUT

SCALE: 1/1

12-7-71

Figure 8

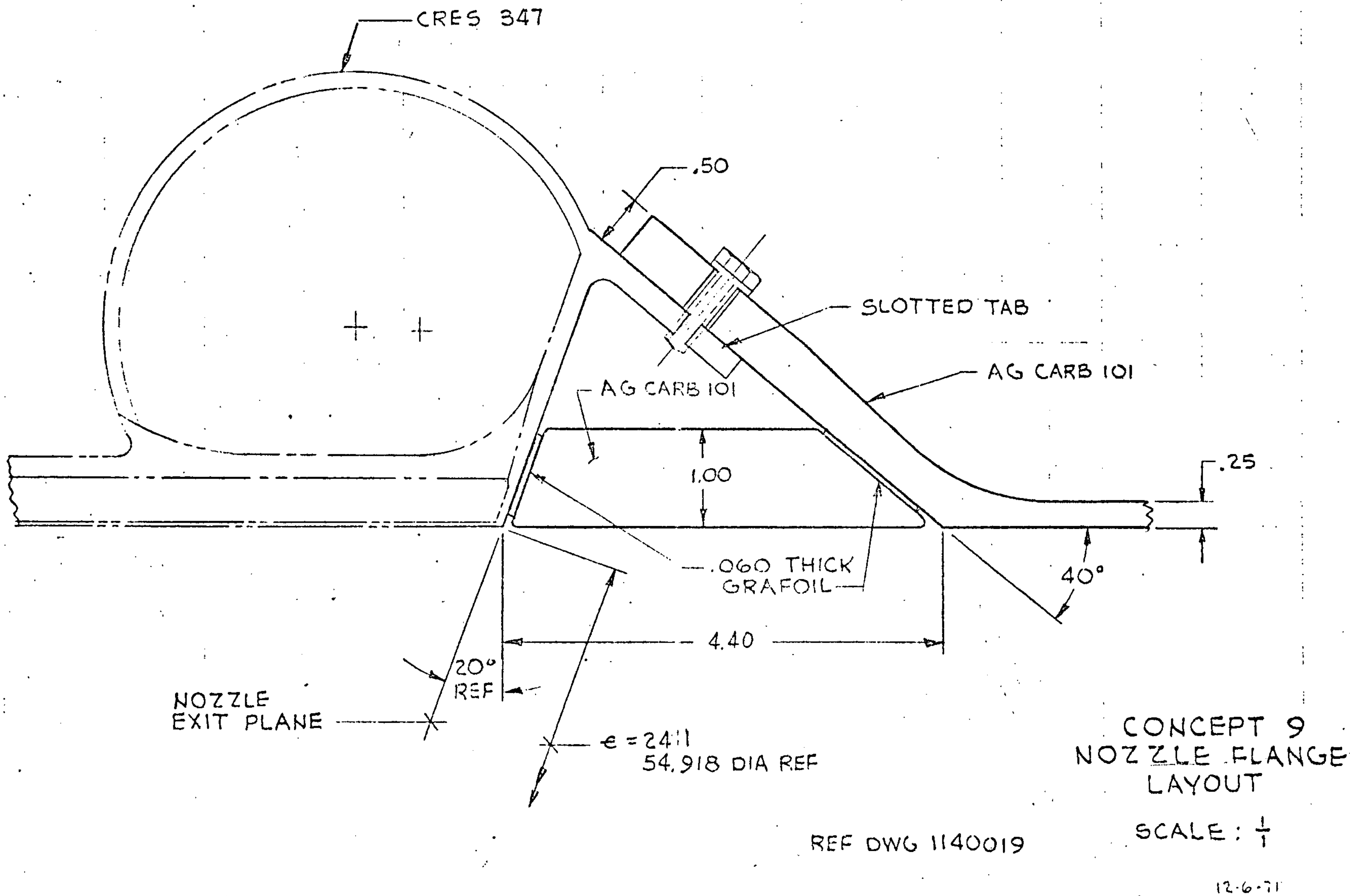

CRES 347
.50
SLOTTED TAB
AG CARB 101
AG CARB 101
1.00
.25
.060 THICK
GRAFOIL
40°
4.40
20°
REF
NOZZLE
EXIT PLANE
∈ = 24:1
54.918 DIA REF
CONCEPT 9
NOZZLE FLANGE
LAYOUT
SCALE : 1/1
REF DWG 1140019
12-6-71

Figure 9

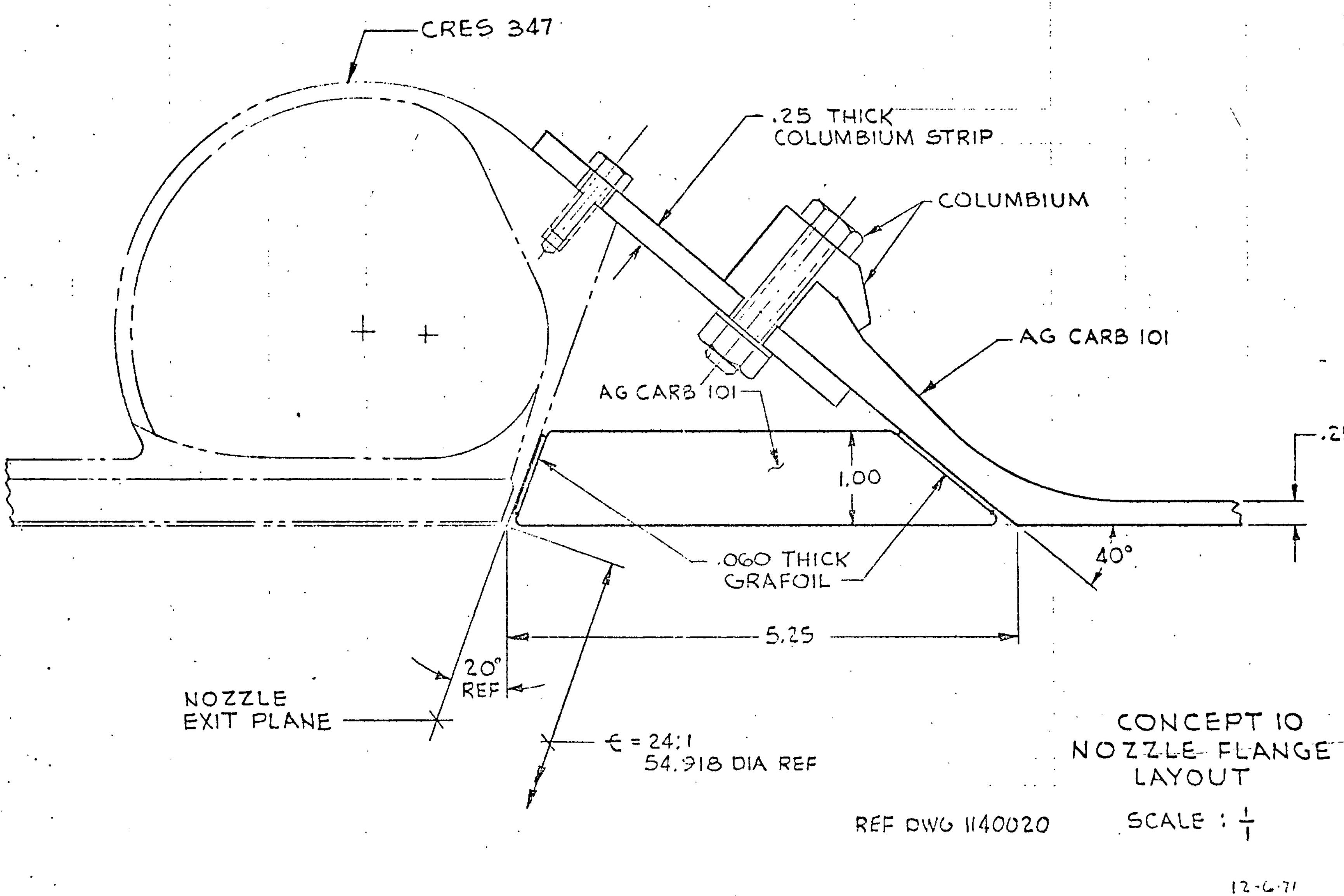
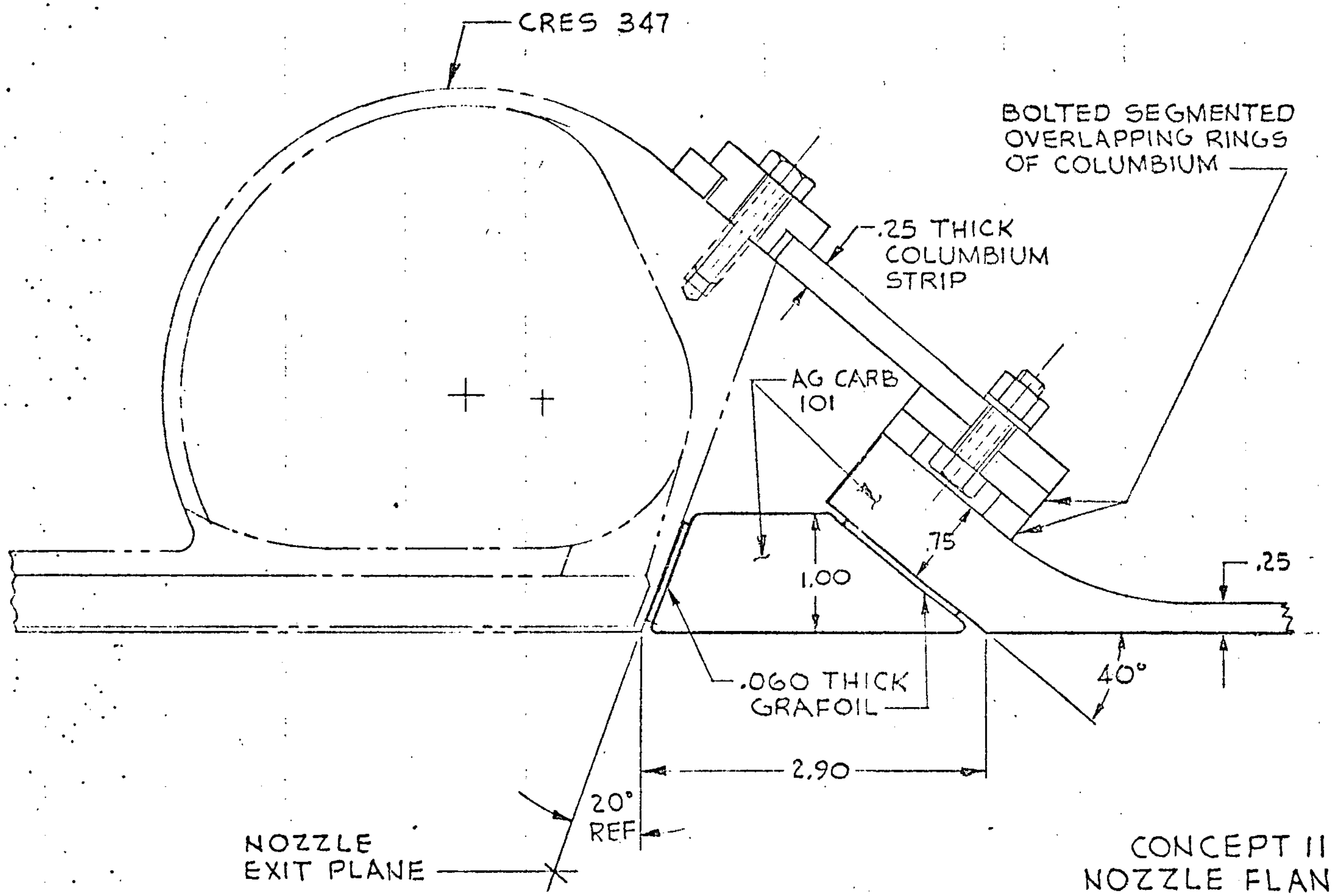

CRES 347
.25 THICK
COLUMBIUM STRIP
COLUMBIUM
AG CARB 101
AG CARB 101
.25
1.00
.060 THICK
GRAFOIL
40°
5.25
20°
REF
NOZZLE
EXIT PLANE
ϵ = 24:1
54.918 DIA REF
CONCEPT 10
NOZZLE FLANGE
LAYOUT
REF DWG 1140020
SCALE : 1/1
12-6-71

Figure 10



REF DWG 1140021

CONCEPT II
NOZZLE FLANGE
LAYOUT
SCALE : 1/1

Figure 11

12-6-71

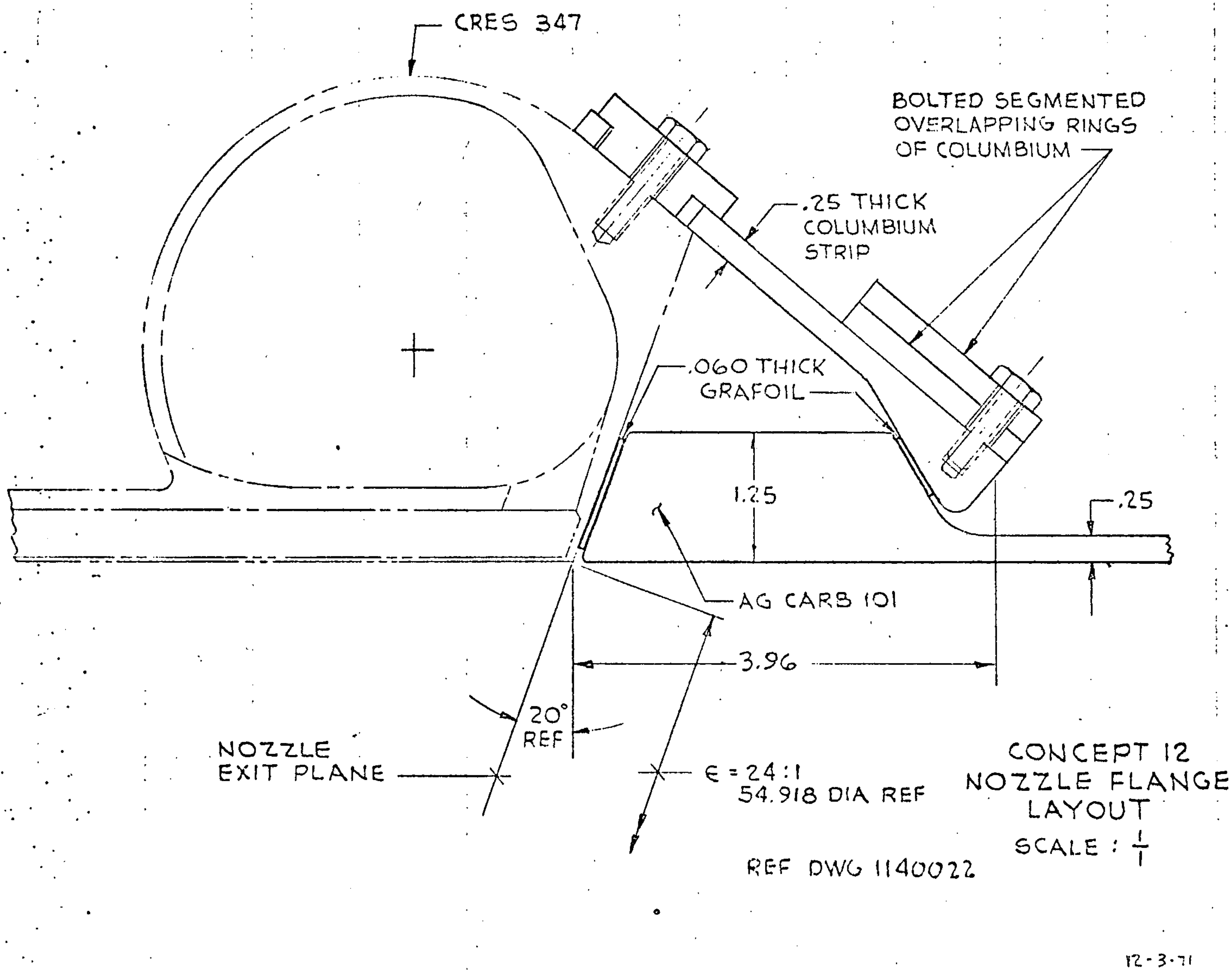
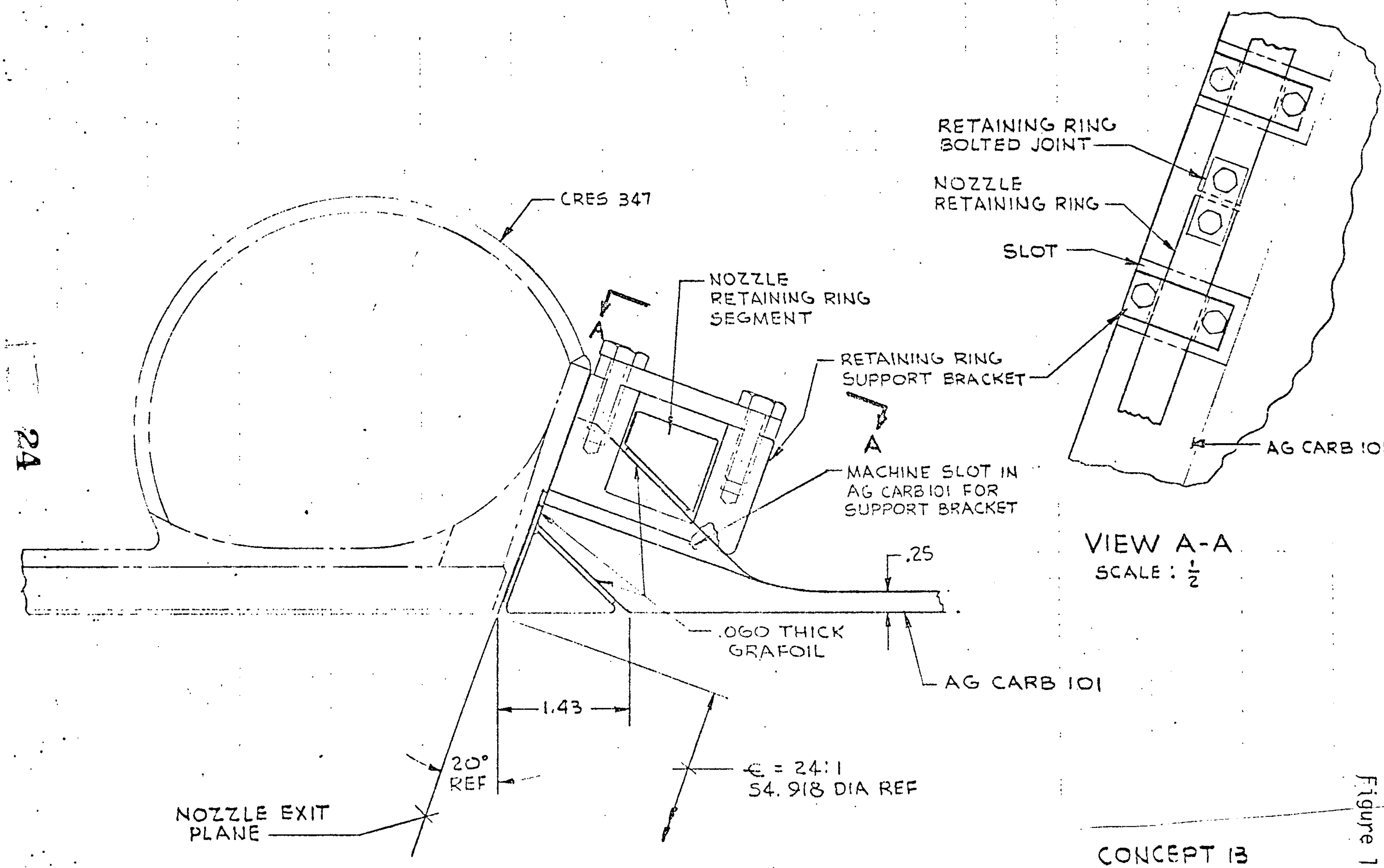

CRES 347
BOLTED SEGMENTED OVERLAPPING RINGS OF COLUMBIUM
.25 THICK COLUMBIUM STRIP
.060 THICK GRAFOIL
1.25
.25
AG CARB 101
3.96
20° REF
NOZZLE EXIT PLANE
ϵ = 24:1
54.918 DIA REF
CONCEPT 12
NOZZLE FLANGE LAYOUT
SCALE : 1/1
REF DWG 1140022
12-3-71

Figure 12



CONCEPT 13
NOZZLE FLANGE
LAYOUT

SCALE : 1/1

Figure 13

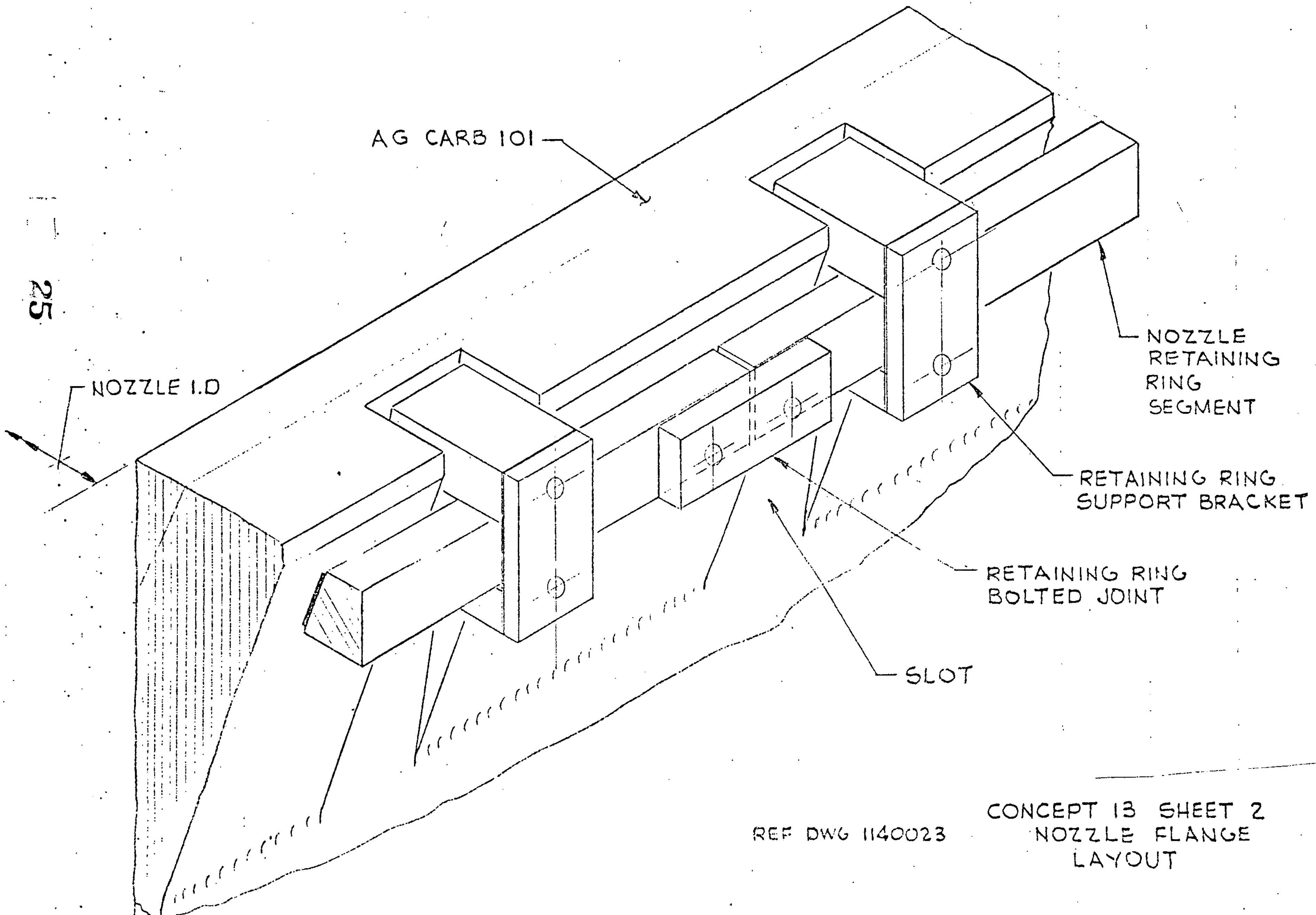


Figure 13 (cont.)

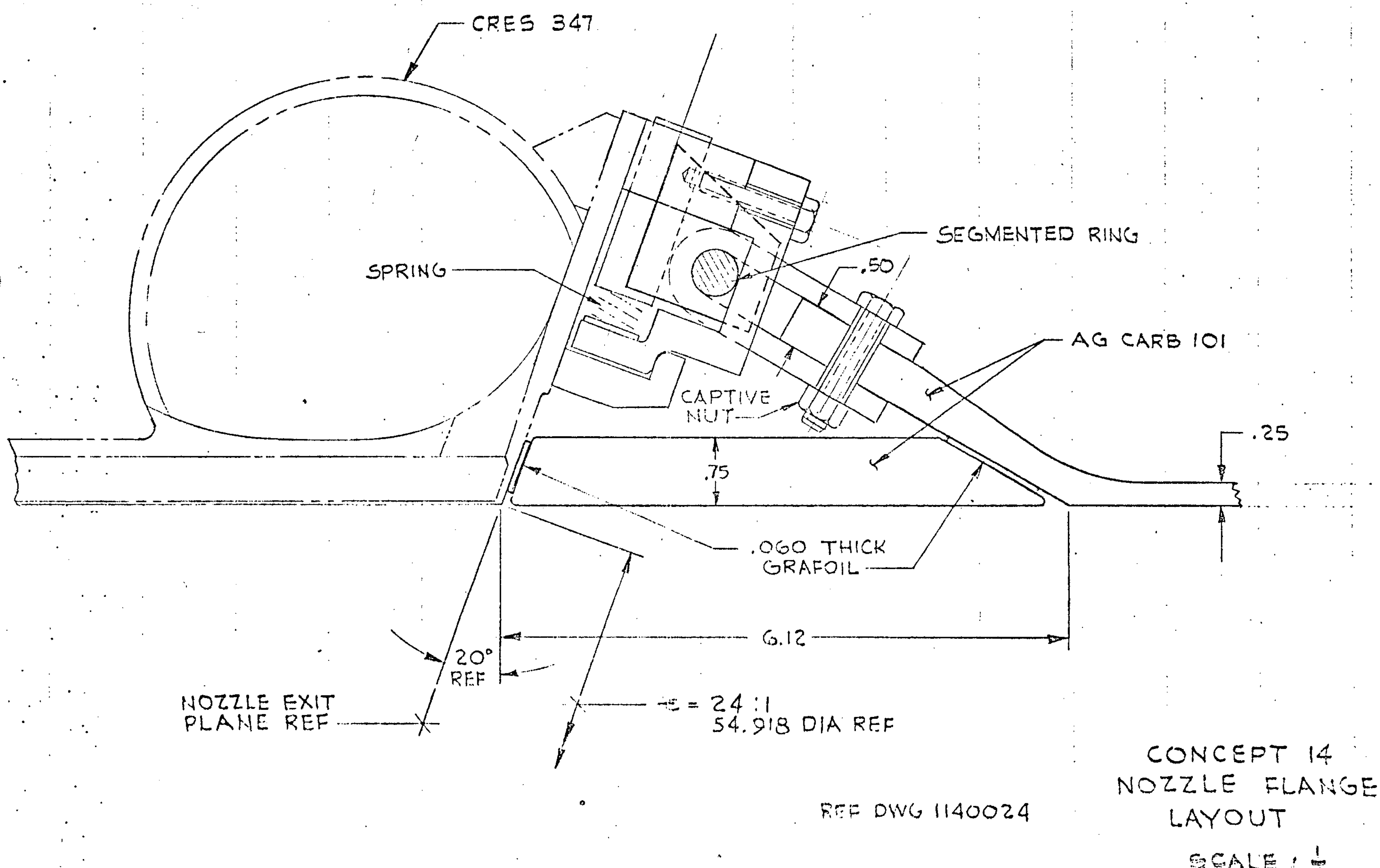
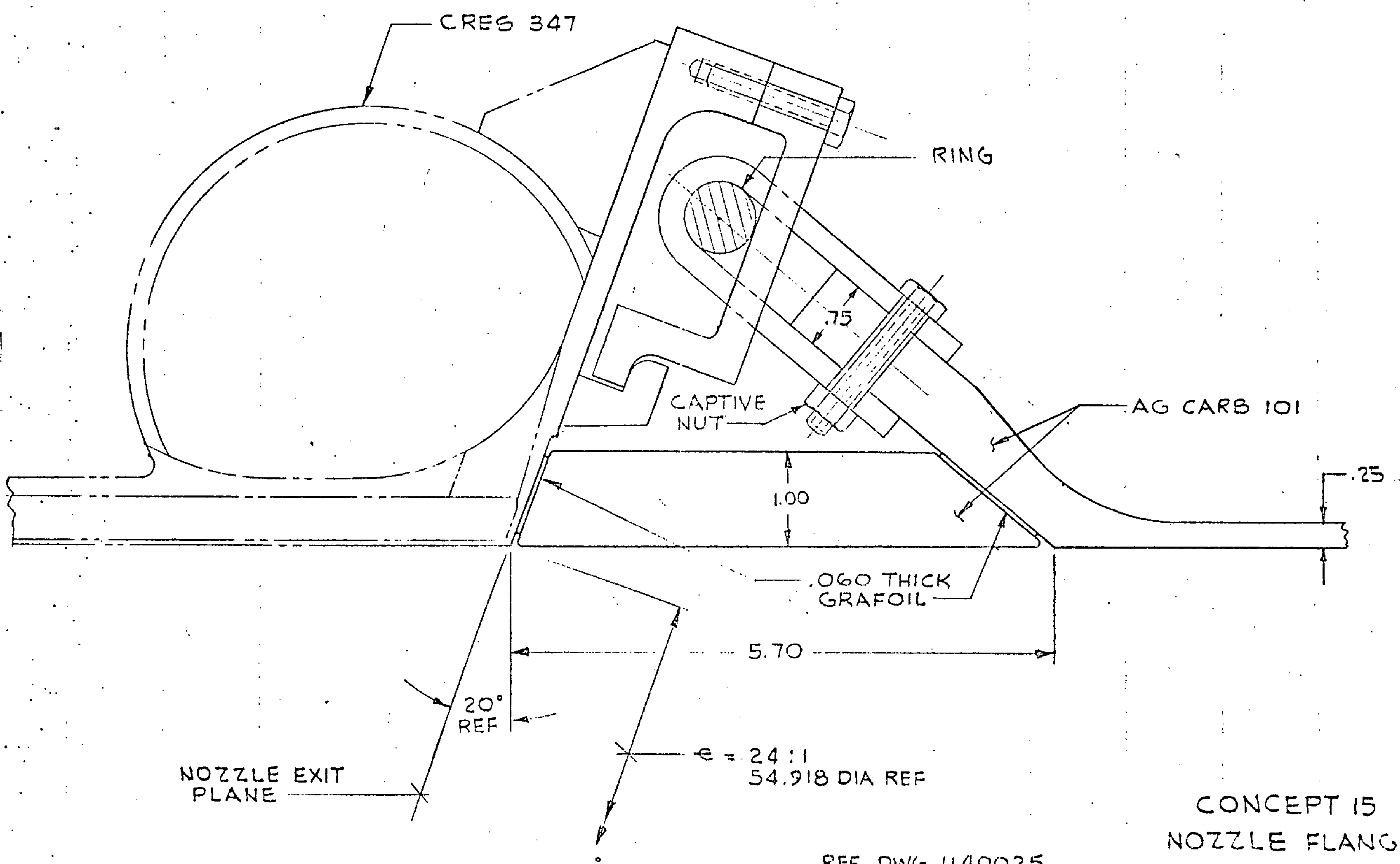
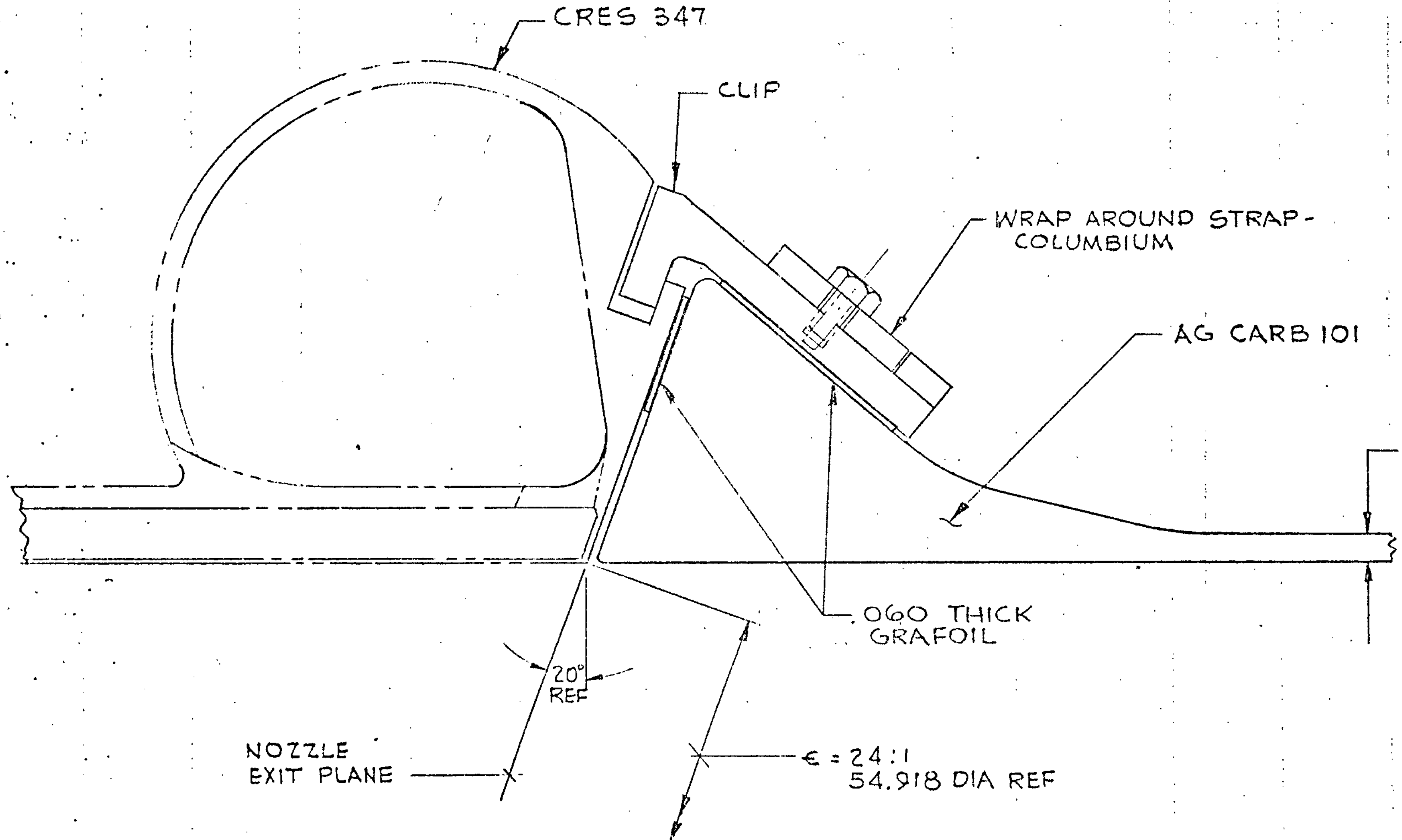

CRES 347
SEGMENTED RING
SPRING
.50
AG CARB 101
CAPTIVE NUT
.25
.75
.060 THICK GRAFOIL
6.12
20° REF
NOZZLE EXIT PLANE REF
ε = 24 :1
54.918 DIA REF
REF DWG 1140024
CONCEPT 14
NOZZLE FLANGE
LAYOUT

Figure 14



CONCEPT 15
NOZZLE FLANGE
LAYOUT
SCALE : 1/...

Figure 15



REF DWG 1140026

CONCEPT 16
NOZZLE FLANGE
LAYOUT

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

Figure 16

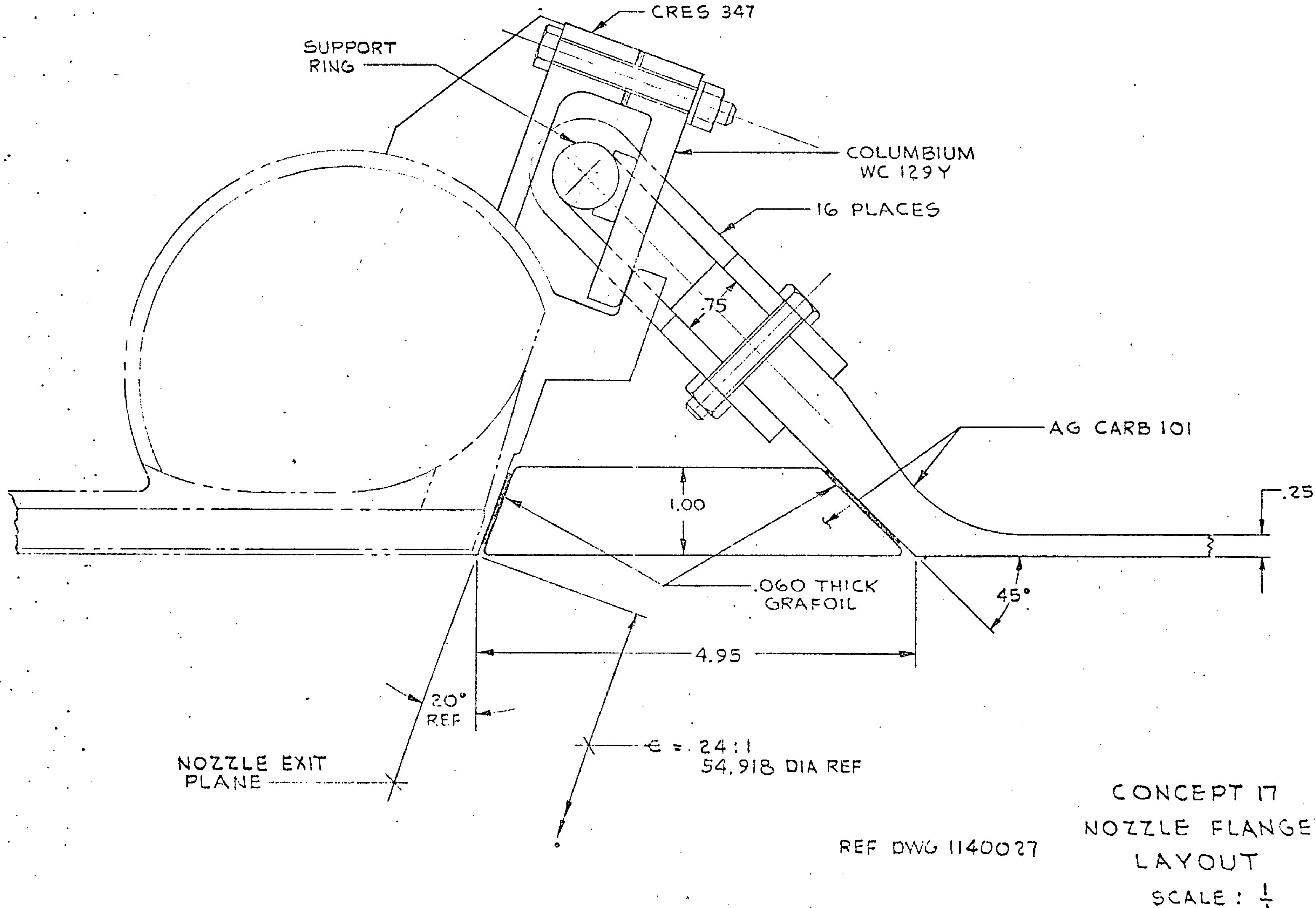

CRES 347
SUPPORT RING
COLUMBIUM WC 129Y
16 PLACES
.75
AG CARB 101
.25
1.00
.060 THICK GRAFOIL
45°
4.95
20° REF
NOZZLE EXIT PLANE
ε = 24:1
54.918 DIA REF
REF DWG 1140027
CONCEPT 17
NOZZLE FLANGE
LAYOUT
SCALE:

Figure 17

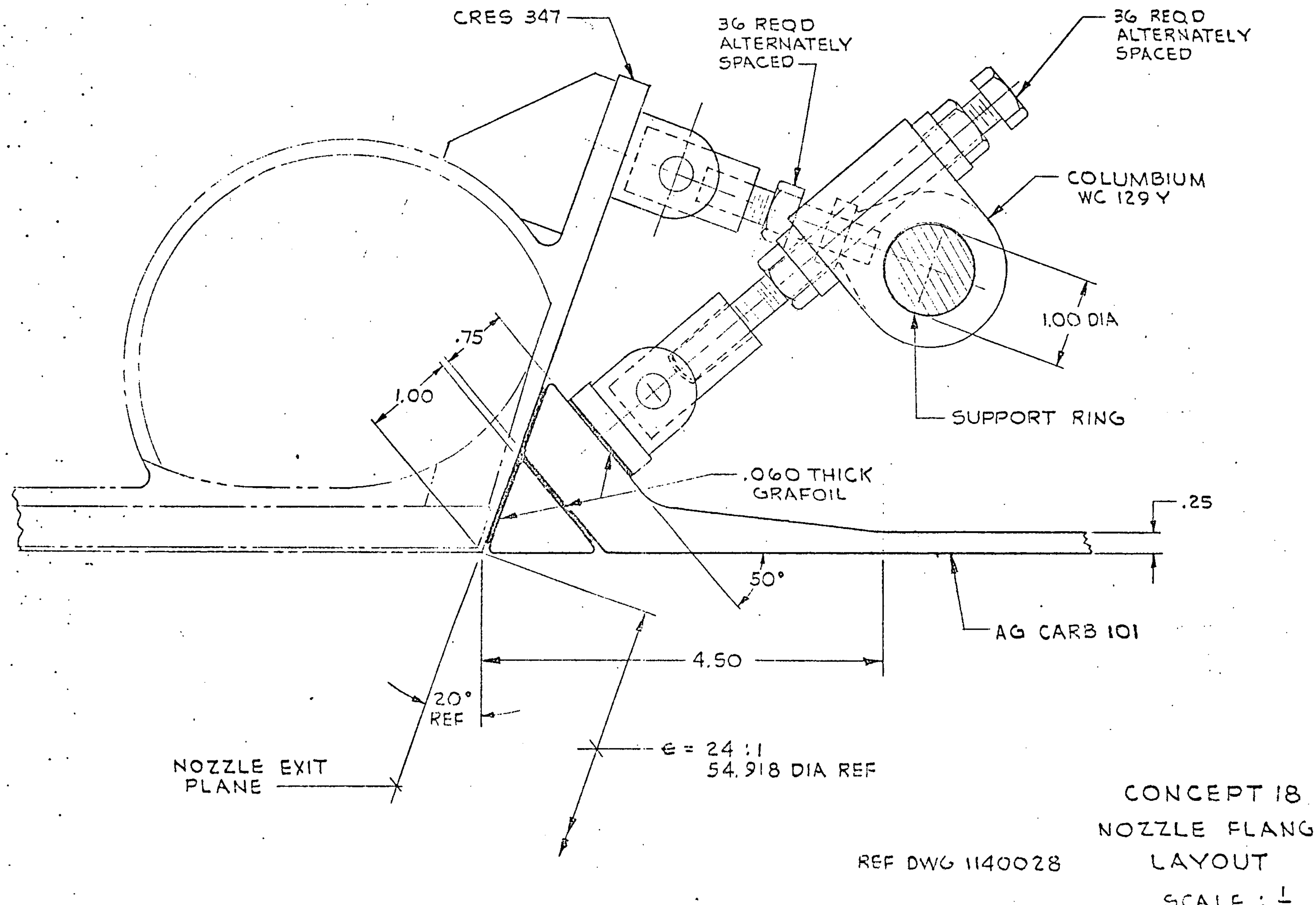

CRES 347
36 REQD ALTERNATELY SPACED
36 REQD ALTERNATELY SPACED
COLUMBIUM WC 129 Y
1.00 DIA
SUPPORT RING
.75
1.00
.060 THICK GRAFOIL
.25
50°
AG CARB 101
4.50
20° REF
NOZZLE EXIT PLANE
ϵ = 24 :1
54.918 DIA REF
REF DWG 1140028
CONCEPT 18
NOZZLE FLANGE
LAYOUT
SCALE : 1/

Figure 18

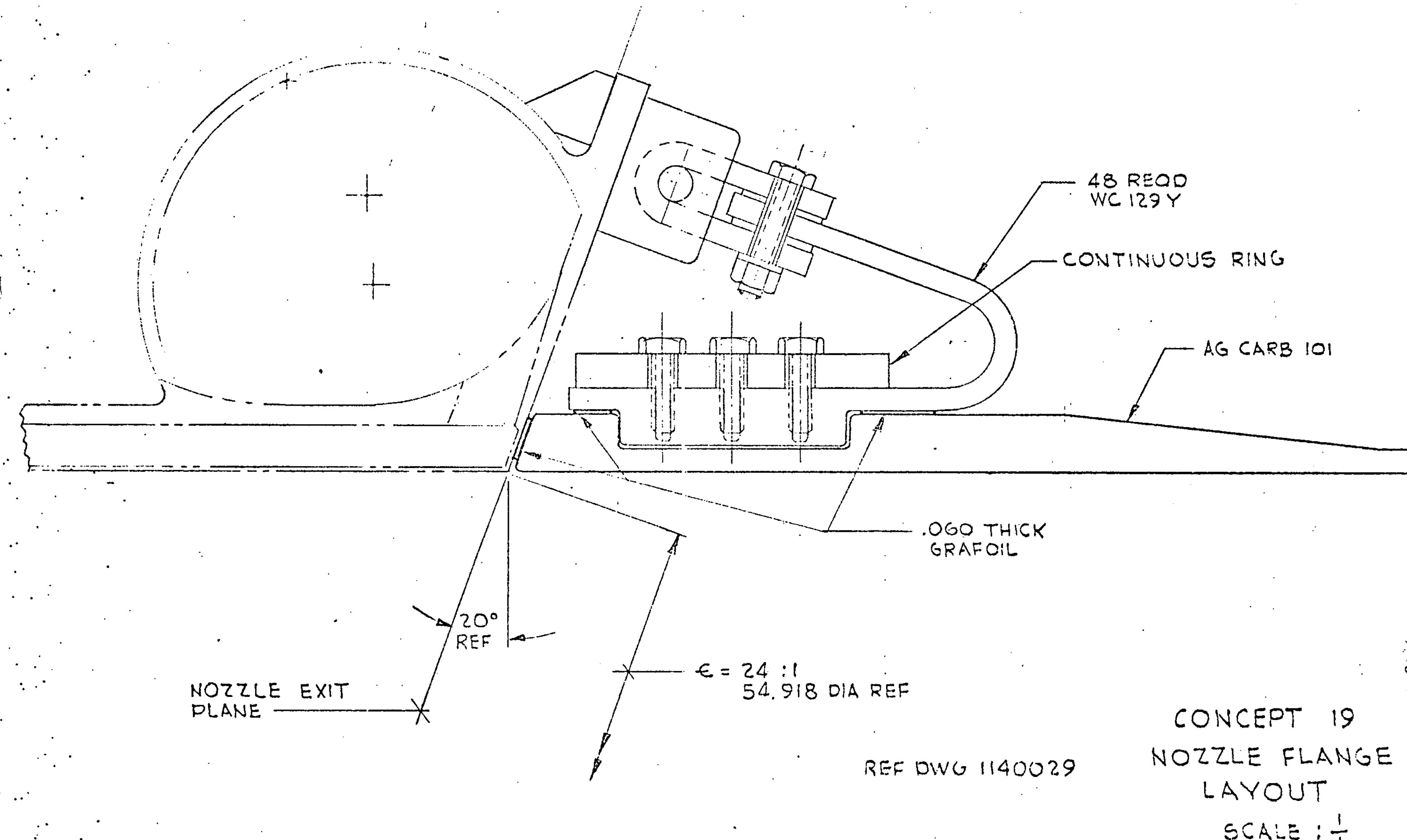

48 REQD
WC 129 Y
CONTINUOUS RING
AG CARB 101
.060 THICK
GRAFOIL
20°
REF
NOZZLE EXIT
PLANE
∈ = 24 :1
54.918 DIA REF
REF DWG 1140029
CONCEPT 19
NOZZLE FLANGE
LAYOUT

Figure 19

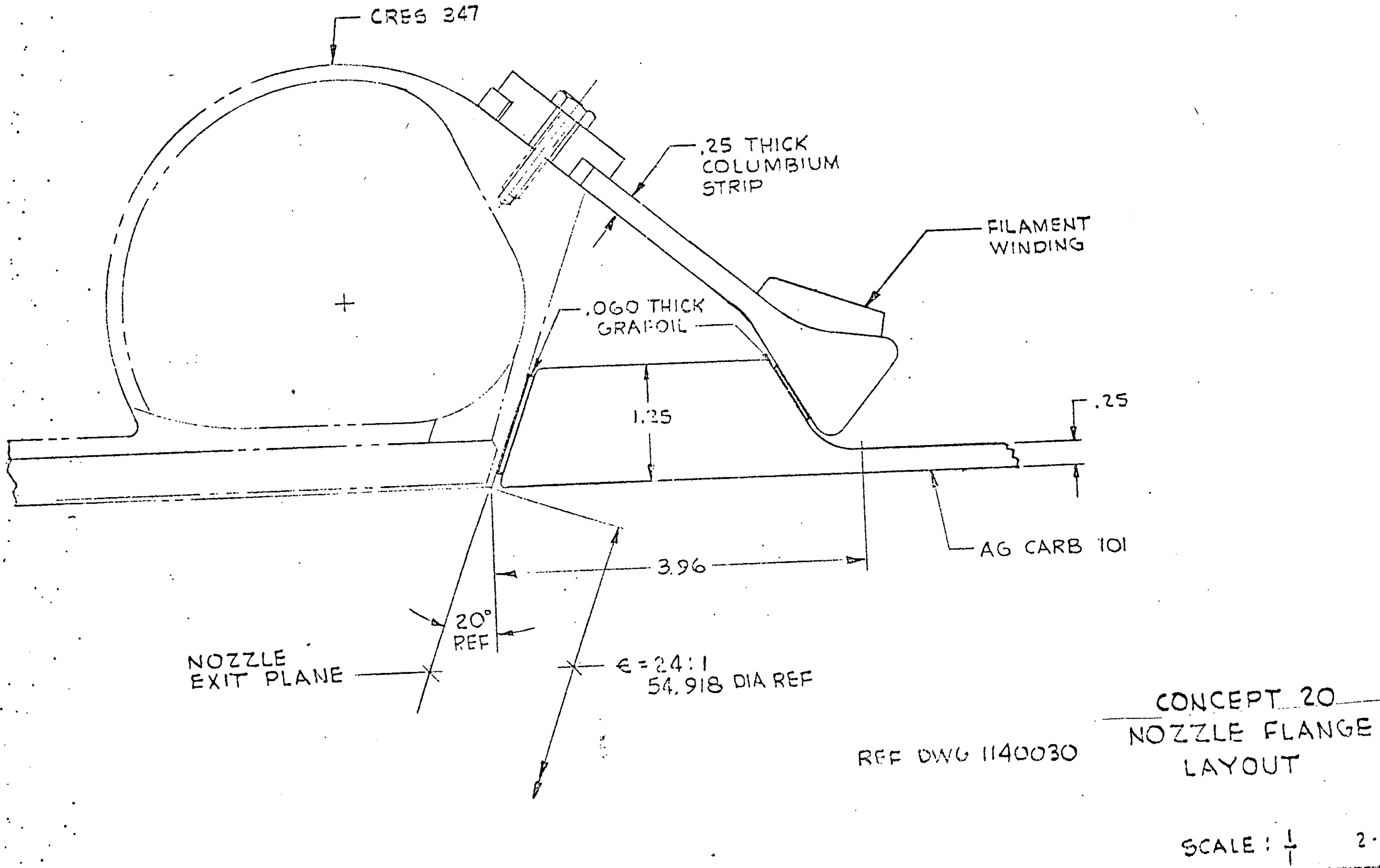

CRES 347
.25 THICK COLUMBIUM STRIP
FILAMENT WINDING
.060 THICK GRAFOIL
1.25
.25
AG CARB 101
3.96
20° REF
NOZZLE EXIT PLANE
∈ = 24:1
54.918 DIA REF
REF DWG 1140030
CONCEPT 20
NOZZLE FLANGE
LAYOUT
SCALE: 1/1
2-17-72

Figure 20

APPENDIX A

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

N8110R:72-037

ENCLOSURE (1)

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

E. A. Thomas

APPROVED:

U. A. Pineda

U. A. PINEDA, MANAGER
APPLIED MECHANICS
ENGINEERING STAFF DEPARTMENT

CLASSIFICATION CATEGORY
Unclassified
WR Thompson 4-19-72
CLASSIFYING OFFICER DATE

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 7°R.

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:

Location	Temperature °R	Film Coefficient Btu/sec-in^2°R
Inlet Torus	55.8	0.00109
Coolant Tubes	60.1	0.00109
Hot Gas Side	3870	0.000235

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

1. Materials Properties Data Book, ANSC Report 2275, Volume IV DRM Manual
2. Union Carbide Bulletin No. 713-202 GI
3. Wah Chang Albany Corp. Product Data, Columbium, Tantalum and Tungsten Alloys, Jan. 1968
4. Thermodynamic and Transport Properties of Para and Equilibrium Hydrogen, NBS Data, November 1970 Release
5. AGC Computer Code E25104 Printout LOBE 072
6. E. A. Warman and B. A. Lindsey, Nuclear Radiation Environment and Radiation Heating for Graphite and Columbium Nozzle Extension Configurations, ANSC Engineering Operations Report N8140R-72-0003, 4 January 1972

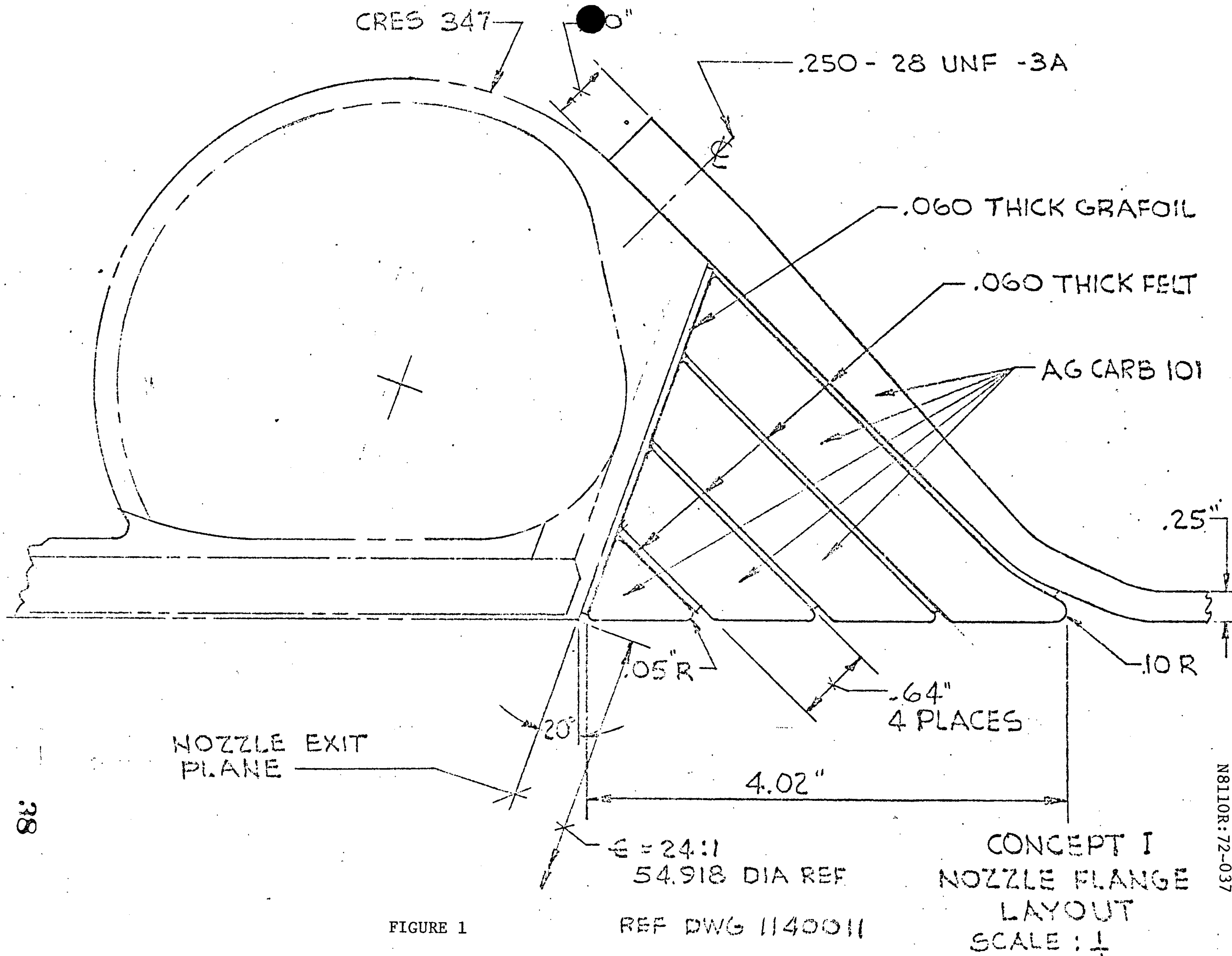


FIGURE 1

N8110R:72-037

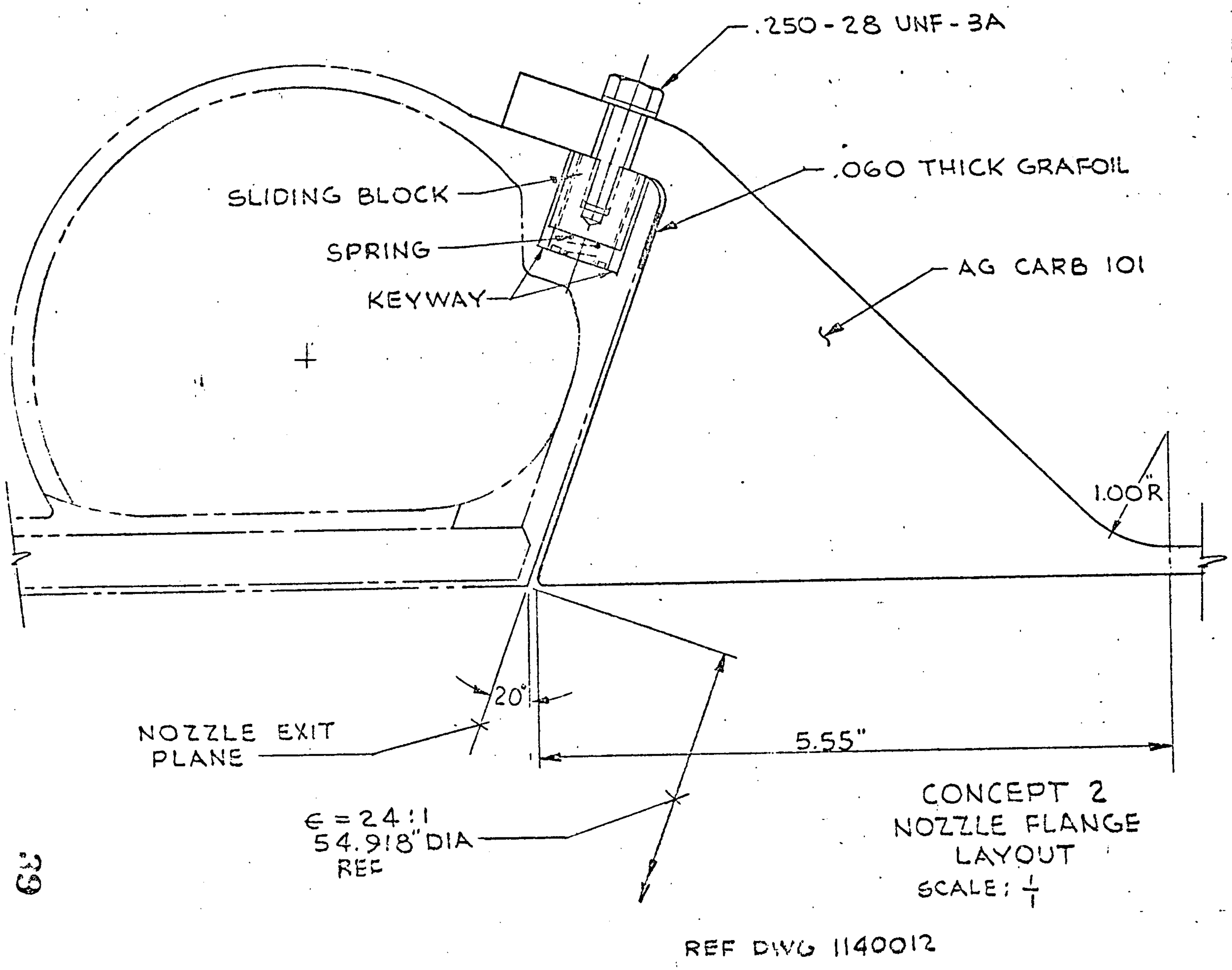


FIGURE 2

N8110R:72-037

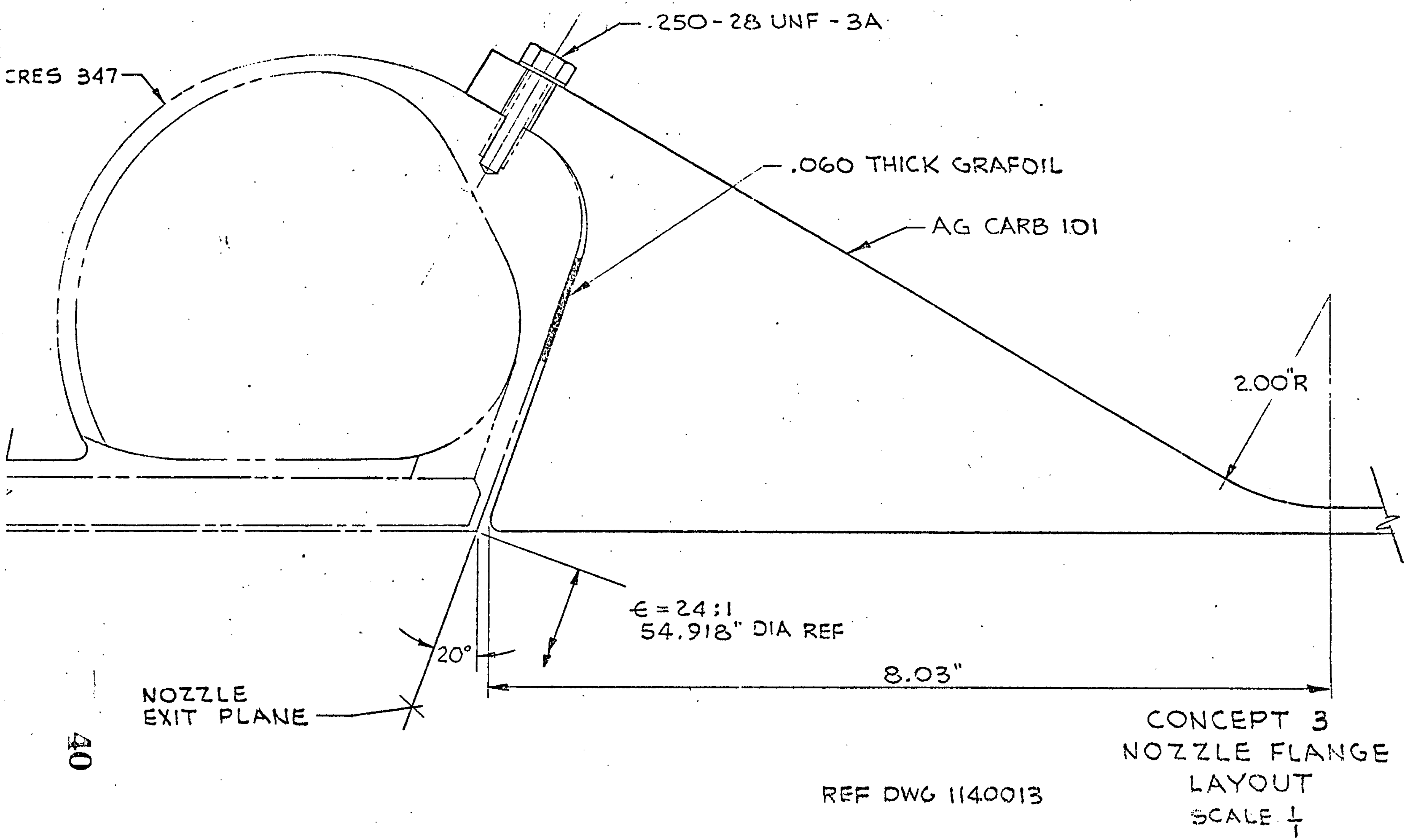

.250-28 UNF-3A
CRES 347
.060 THICK GRAFOIL
AG CARB 101
2.00"R
ϵ = 24:1
54.918" DIA REF
20°
8.03"
NOZZLE
EXIT PLANE
REF DWG 1140013
CONCEPT 3
NOZZLE FLANGE
LAYOUT
SCALE 1/1

FIGURE 3

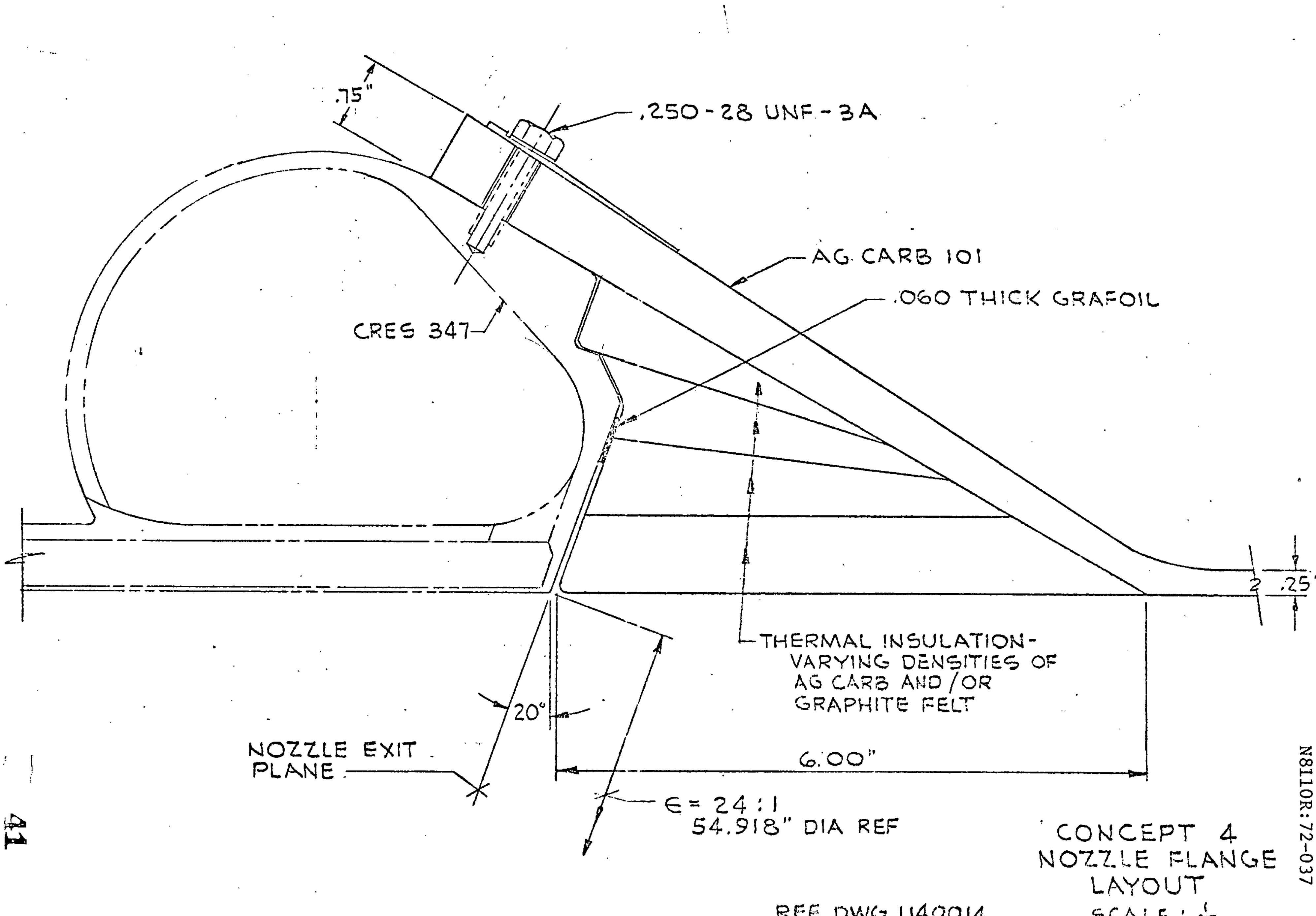

.75"
.250-28 UNF-3A
AG CARB 101
.060 THICK GRAFOIL
CRES 347
THERMAL INSULATION-
VARYING DENSITIES OF
AG CARB AND/OR
GRAPHITE FELT
20°
NOZZLE EXIT
PLANE
6.00"
∈ = 24:1
54.918" DIA REF
2
.25
CONCEPT 4
NOZZLE FLANGE
LAYOUT
SCALE: 1/1
REF DWG 1140014

FIGURE 4

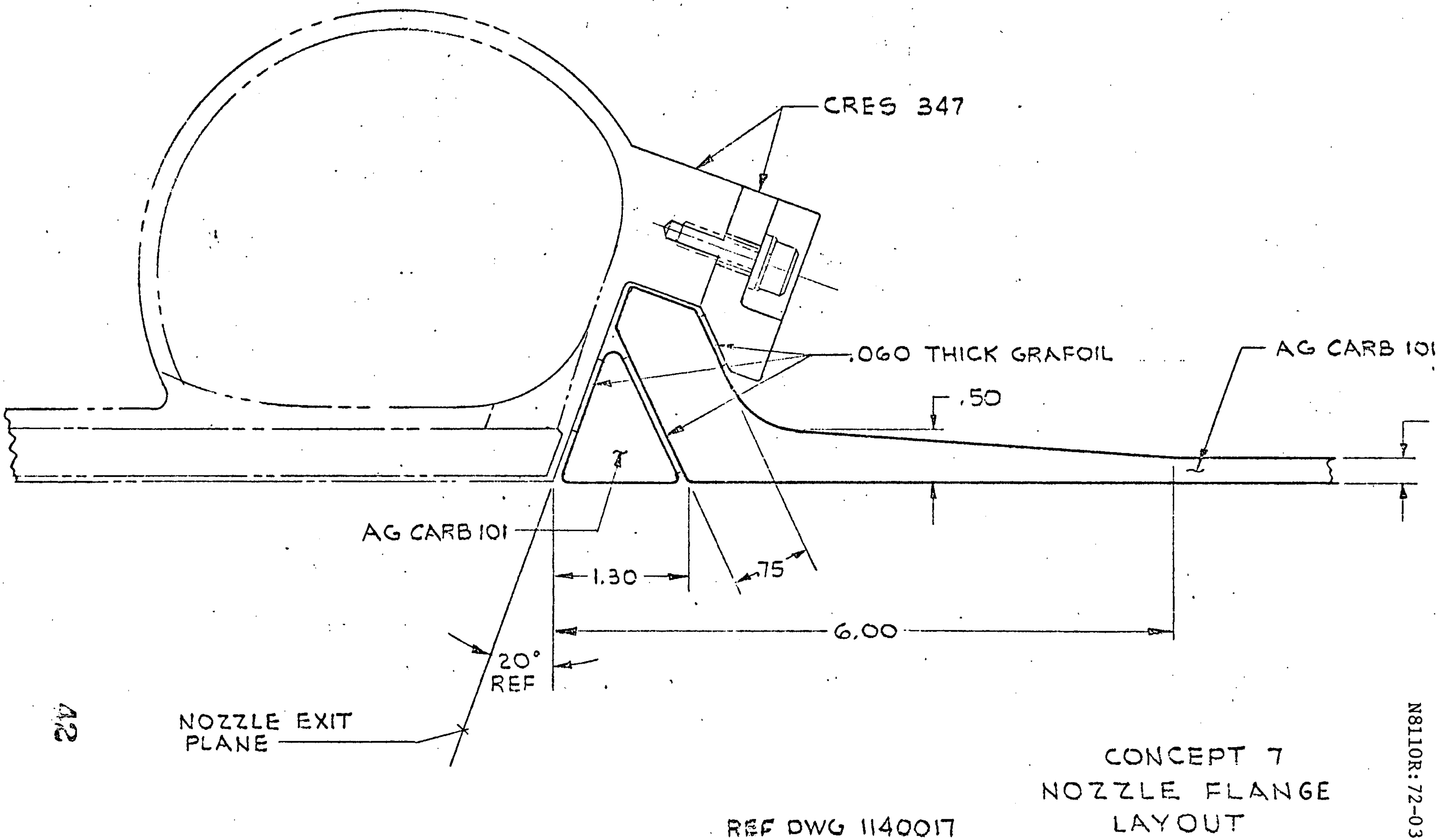

CRES 347
.060 THICK GRAFOIL
AG CARB 101
.50
AG CARB 101
1.30
.75
6.00
20°
REF
NOZZLE EXIT
PLANE
REF DWG 1140017
CONCEPT 7
NOZZLE FLANGE
LAYOUT
SCALE : 1

FIGURE 5

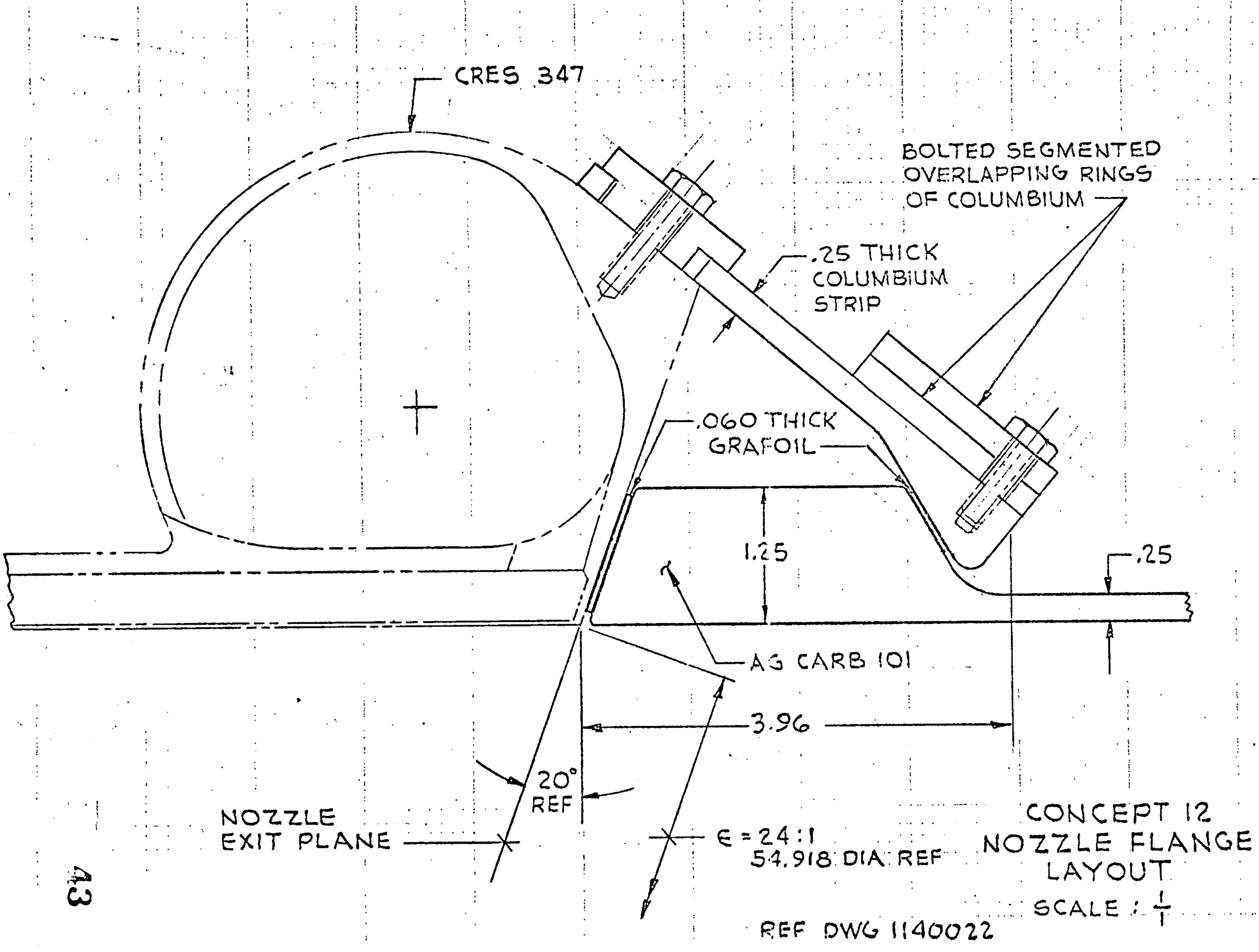
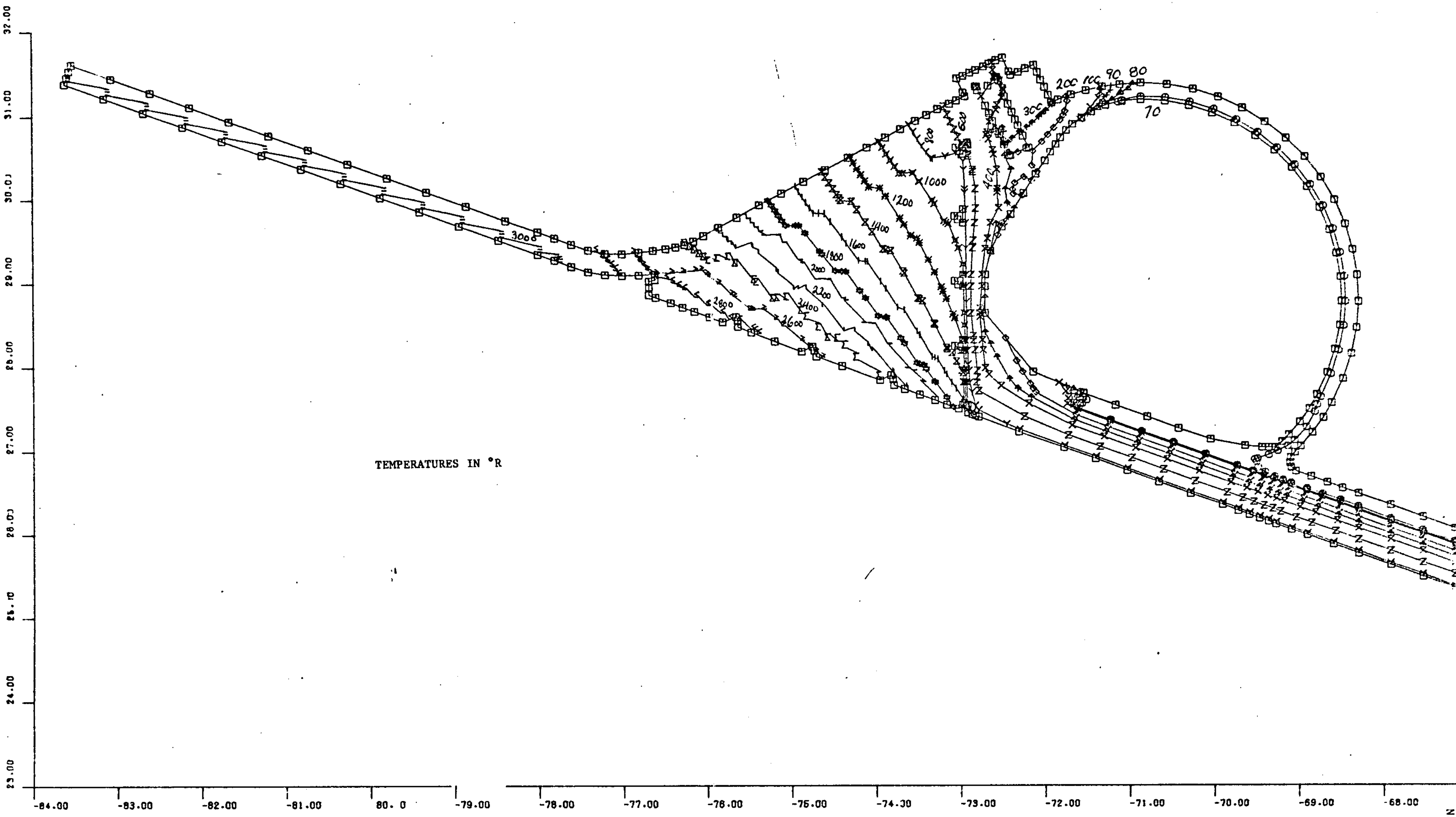


FIGURE 6

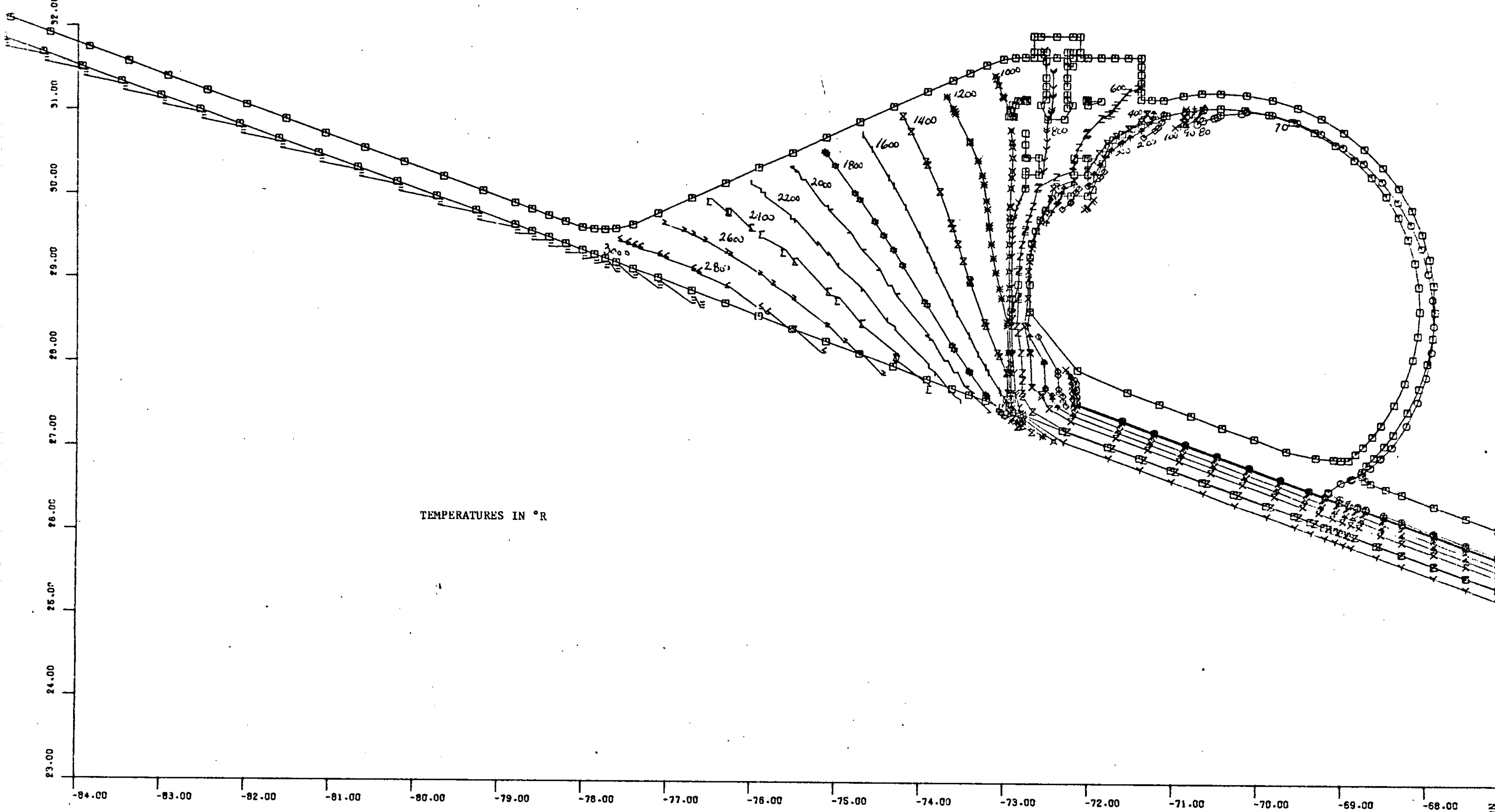
12-3-71



NOZZLE/SKIRT FLANGE CONCEPT 1 GRAFOIL INSULATORS 11-71

FIGURE 7

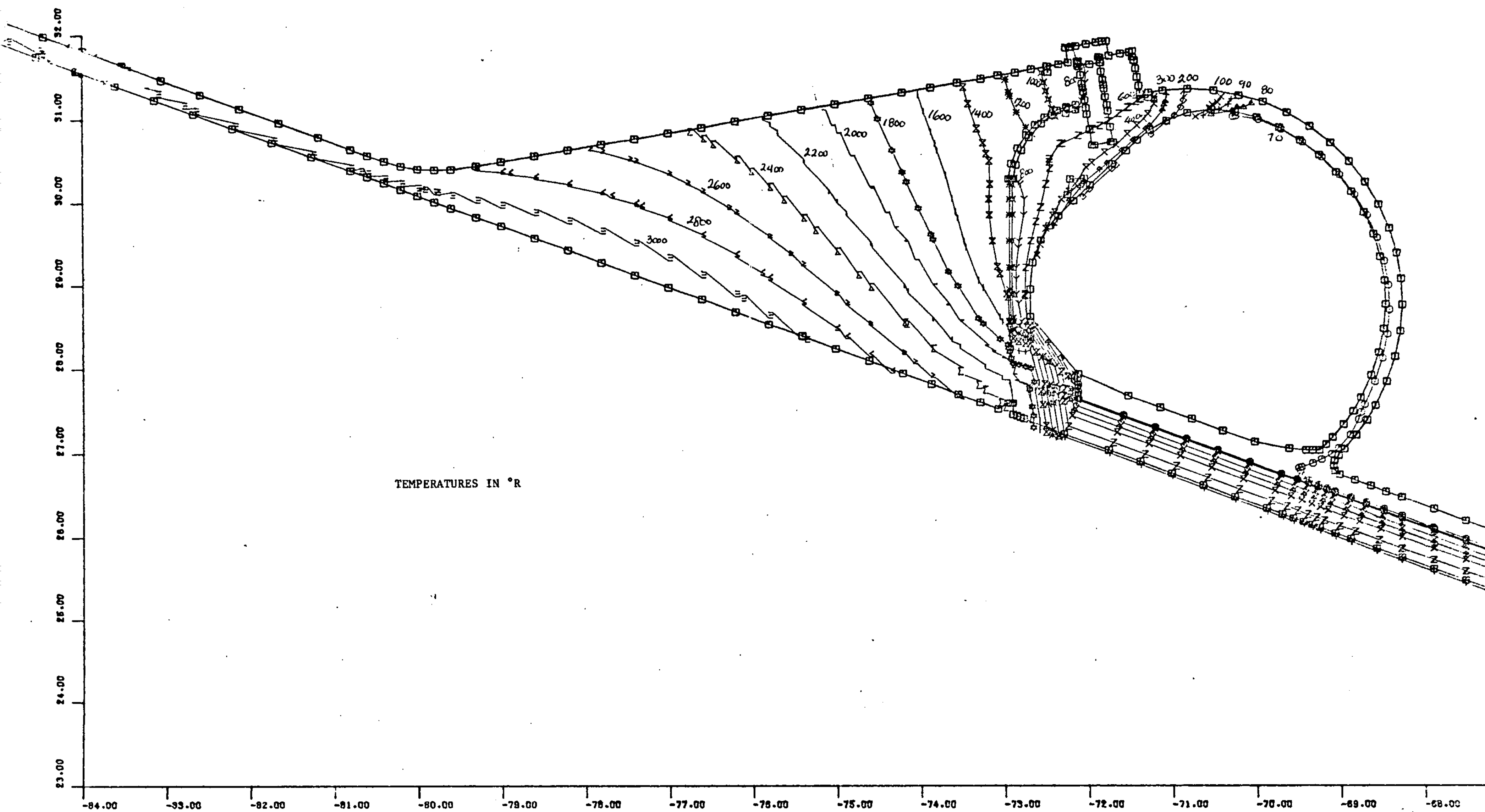
N81IOR:72-037



NOZZLE/SKIRT FLANGE CONCEPT 2 12-71

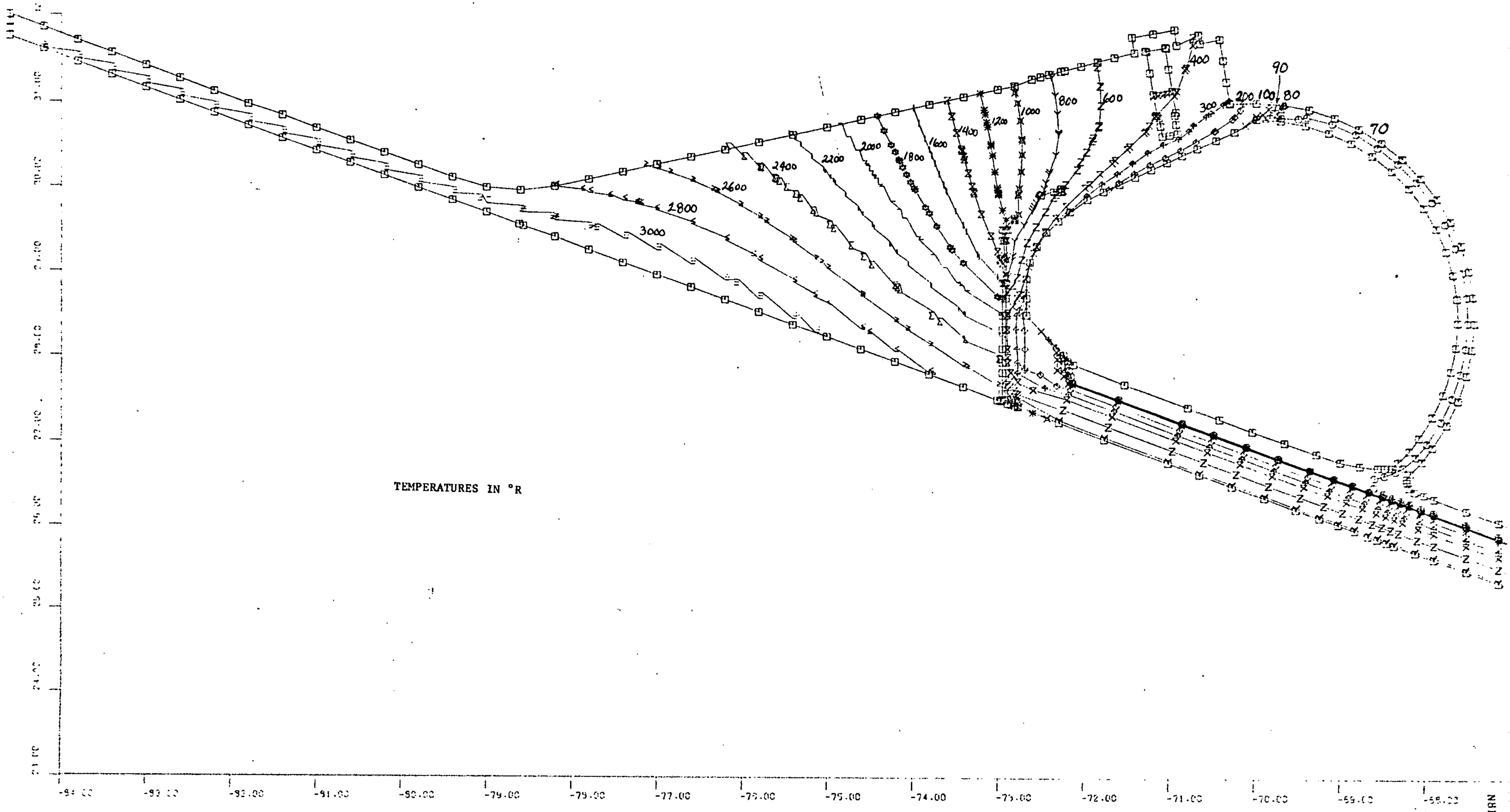
FIGURE 8

NR10R:72-037



NOZZLE/SKIRT FLANGE CONCEPT 3 11-71

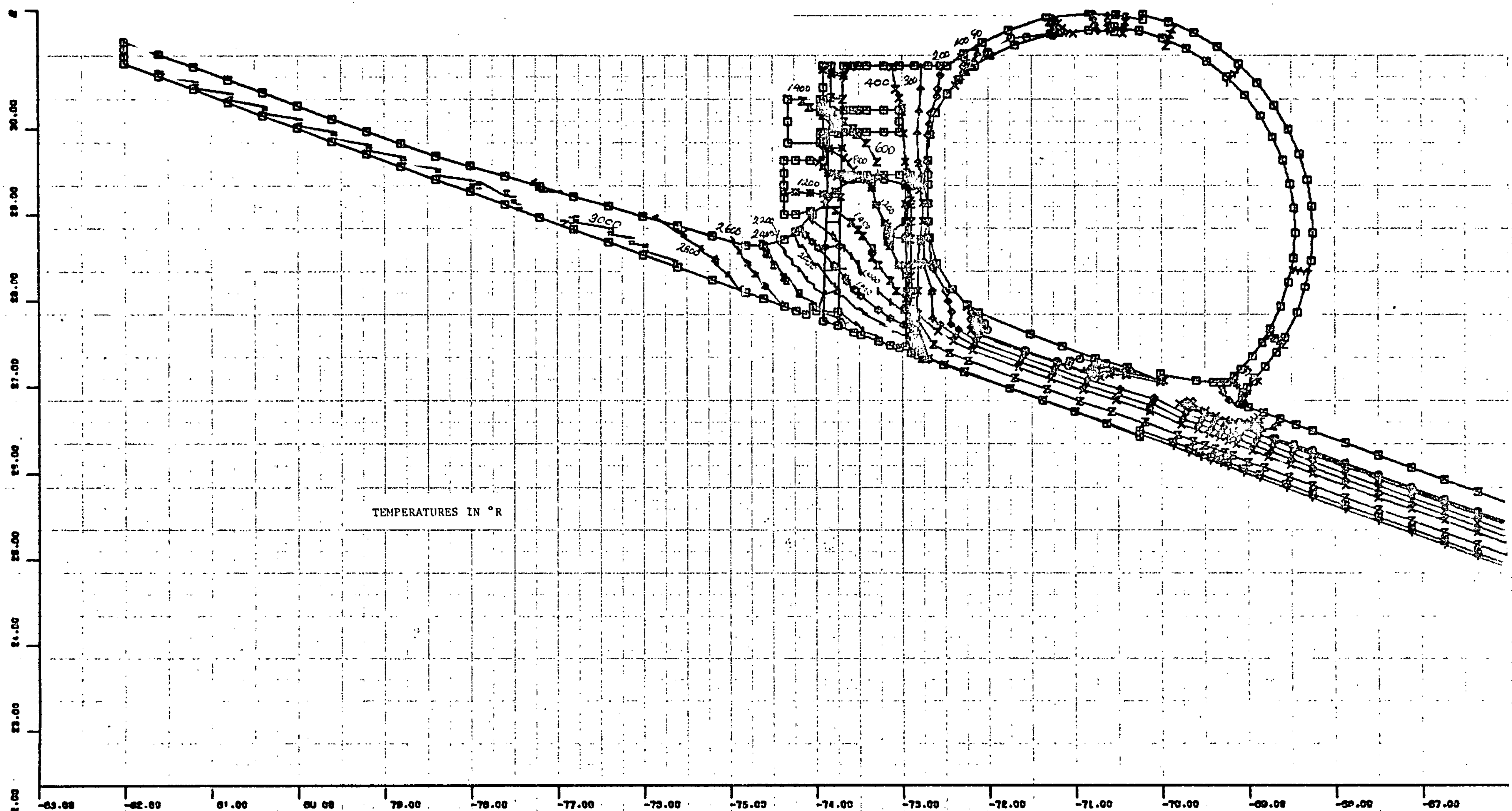
FIGURE 9



NOZZLE/SKIRT FLANGE CONCEPT 4 12-71

FIGURE 10

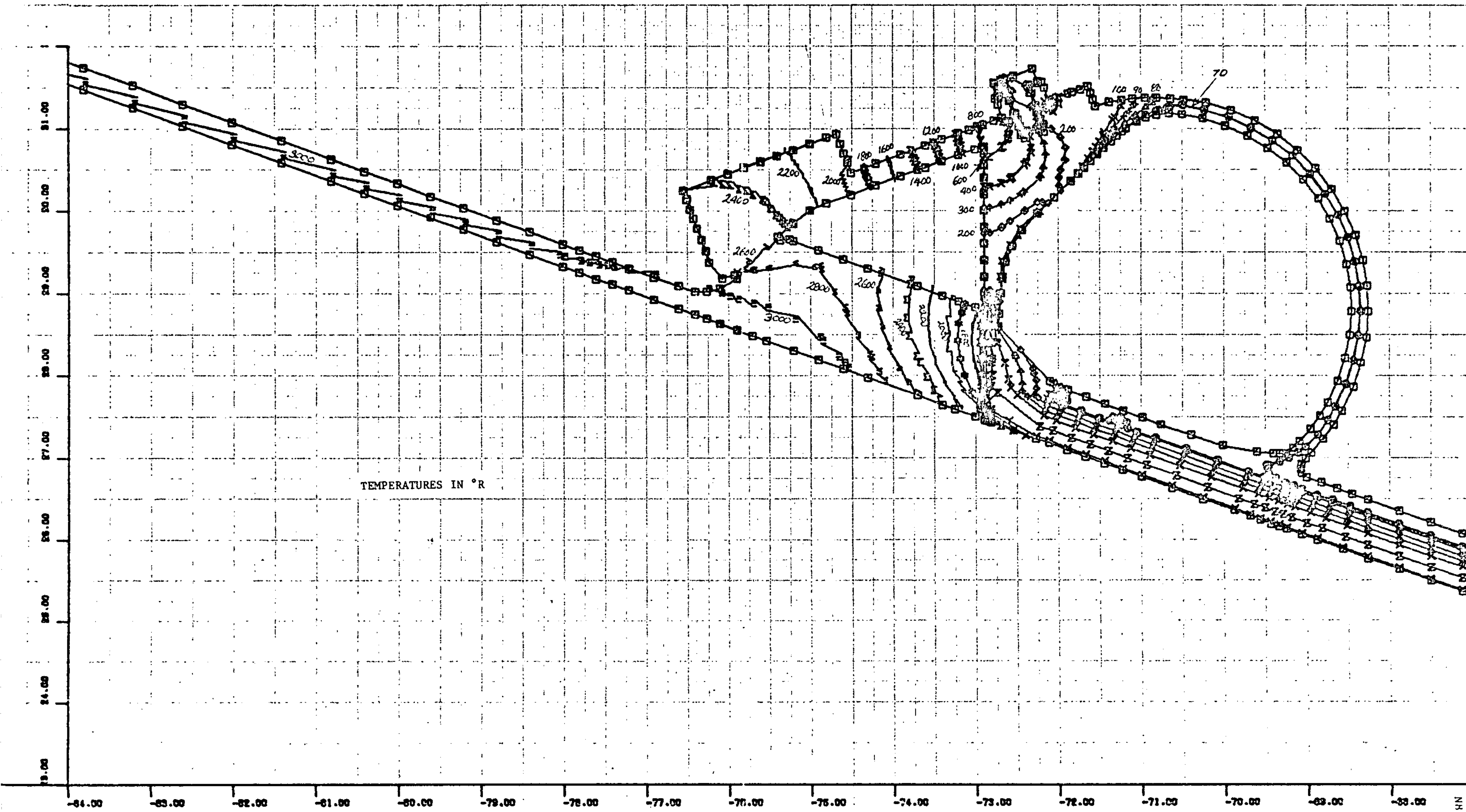
NBIIOR:72-037



NOZZLE/SKIRT FLANGE CONCEPT 7

FIGURE 11

N8110R:72-017



NOZZLE/SKIRT FLANGE CONCEPT 12

FIGURE 12

NR110R:72-037

APPENDIX B

NOZZLE-NOZZLE EXTENSION JOINT CONCEPT NO. 30

STRESS ANALYSIS

N8120R:72-023

ENCLOSURE (1)

N8120R:72-023

ENGINEERING OPERATIONS REPORT

NOZZLE-NOZZLE EXTENSION JOINT

CONCEPT NO. 30 STRESS ANALYSIS

PROJECT 143

1 MARCH 1972

J. G. SCHUMACHER

J G Schumacher

CLASSIFICATION CATEGORY

Unclassified

J W [illegible] 3/[illegible]

CLASSIFYING OFFICER DATE

APPROVED:

K Sato

K. SATO, MANAGER
ENGINEERING STAFF DEPARTMENT

NOZZLE-NOZZLE EXTENSION JOINT CONCEPT NO. 30 STRESS ANALYSIS

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

Mode of Failure	AGCarb Nozzle Extension: Cylindrical Wrap	AGCarb Nozzle Extension: Conical Wrap
Block Tension	-.36	-.23
Interlaminar Shear	-.03	+1.14
Warp Compression	-.10	-.10
	Nozzle (ARMCO 22-13-5)	
Hoop Compression	-.45	
Hoop Tension	+.83	

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.

<u>CYLINDRICAL LAYUP</u> (Ref. Figure 6)

REGION A: $T = 1540°F$

Block Tension = 300 psi

$F_{TU_{block}} = 644 - 3.98(130) = 128$ psi @70°F (Ref. Appendix A)

Assume this allowable to be representative at operating temperature

SIL (secondary) = 1.5(128) = 192

$$M.S. = \frac{192}{300} - 1 = -0.36$$

REGION B: T = 1540°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°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°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.

<u>NOZZLE FLANGE</u> (Ref. Figure 10)

REGION A:

Max Hoop Stress = -160,000 psi

T = 240°F $\quad F_{TY} = 44{,}400$ psi

Assume: 1) $F_{CY} = F_{TY}$

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

$$M.S. = \frac{2.0F_{TY}}{f_H} - 1 = \frac{2(44{,}400)}{160{,}000} - 1 = -.45$$

REGION B:

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

$F_{TY} = 91{,}800$ psi

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

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

1. ANSC Memo N4110:0067, Dated 26 February 1971, W. E. Stephens 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)

3. S039 - CP090290-F1, 75K NERVA Loads Analysis Report, September 1970

4. Report of Computer Program E11405 dated 28 September 1967, by R. W. Kirby, Subject: "Finite Element Stress Analysis of Axisymmetric Solids With Cylindrical Anisotropy"

5. NASA Specification SNPO-C-1, "NERVA Program Structural Design Requirements", 19 December 1968

6. ANSC Data Release Memo No. 38.01 Rev. 0 Dated 7 August 1970

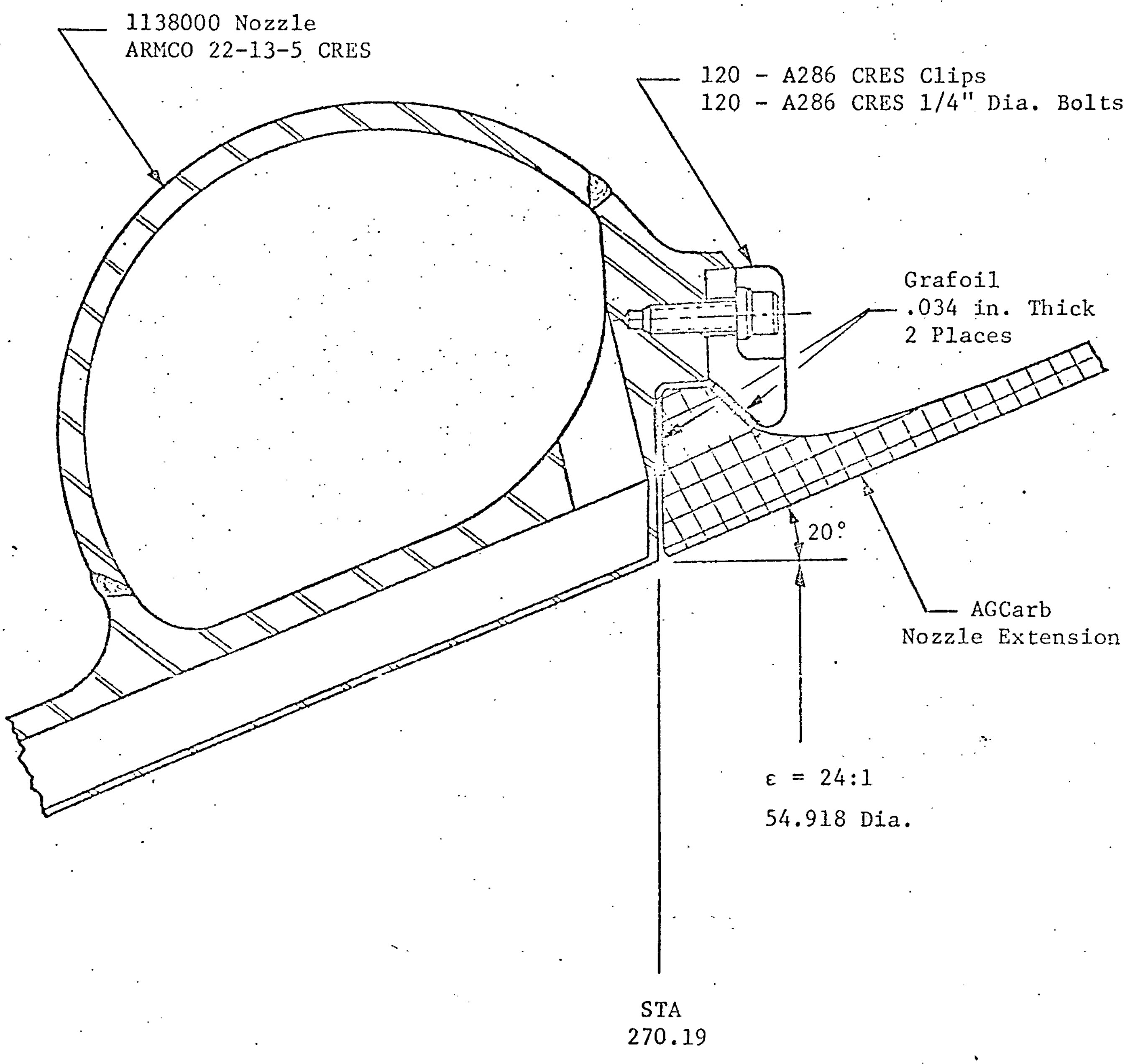


FIGURE 1 - CONCEPT 30 JOINT CONFIGURATION

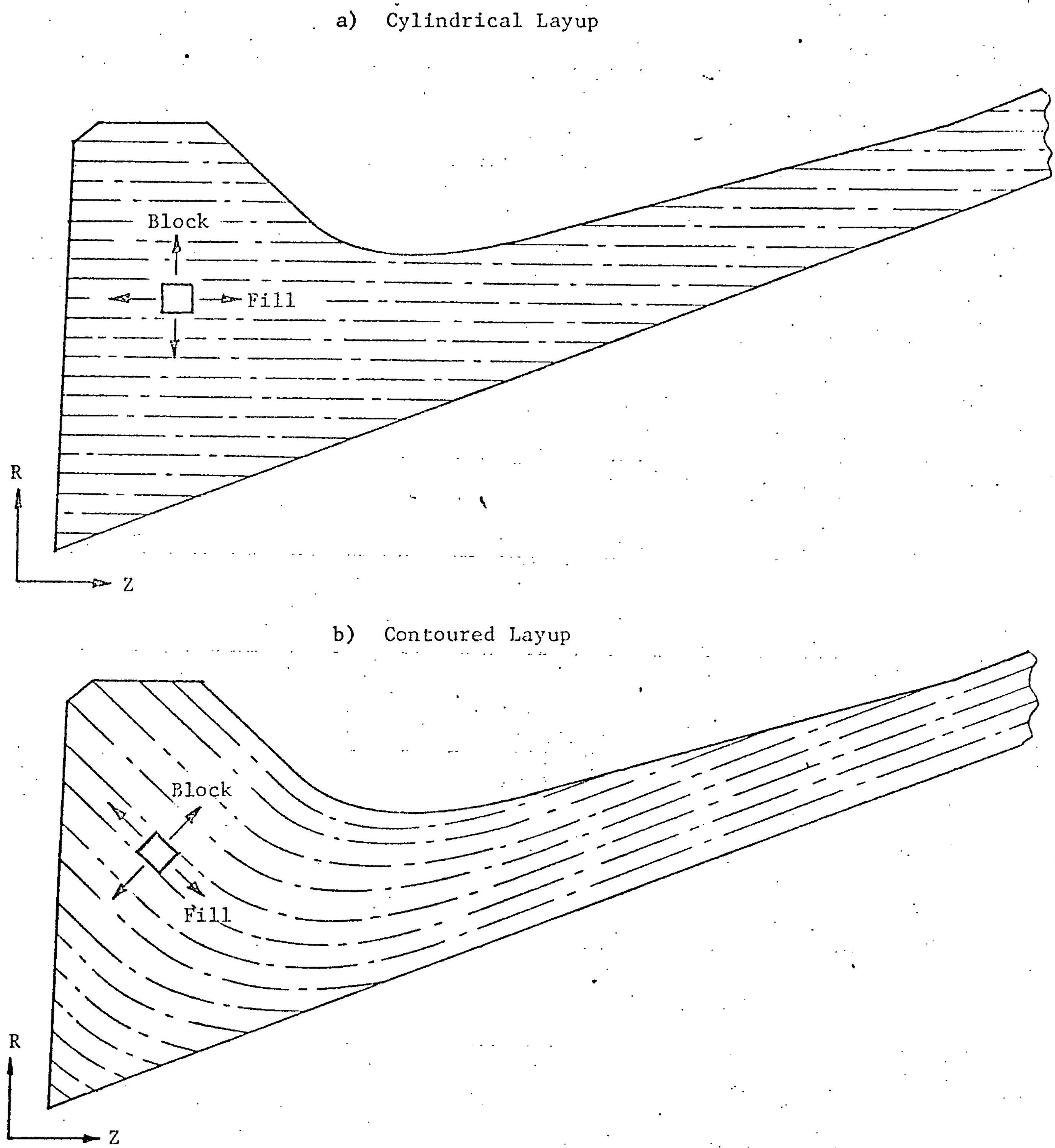
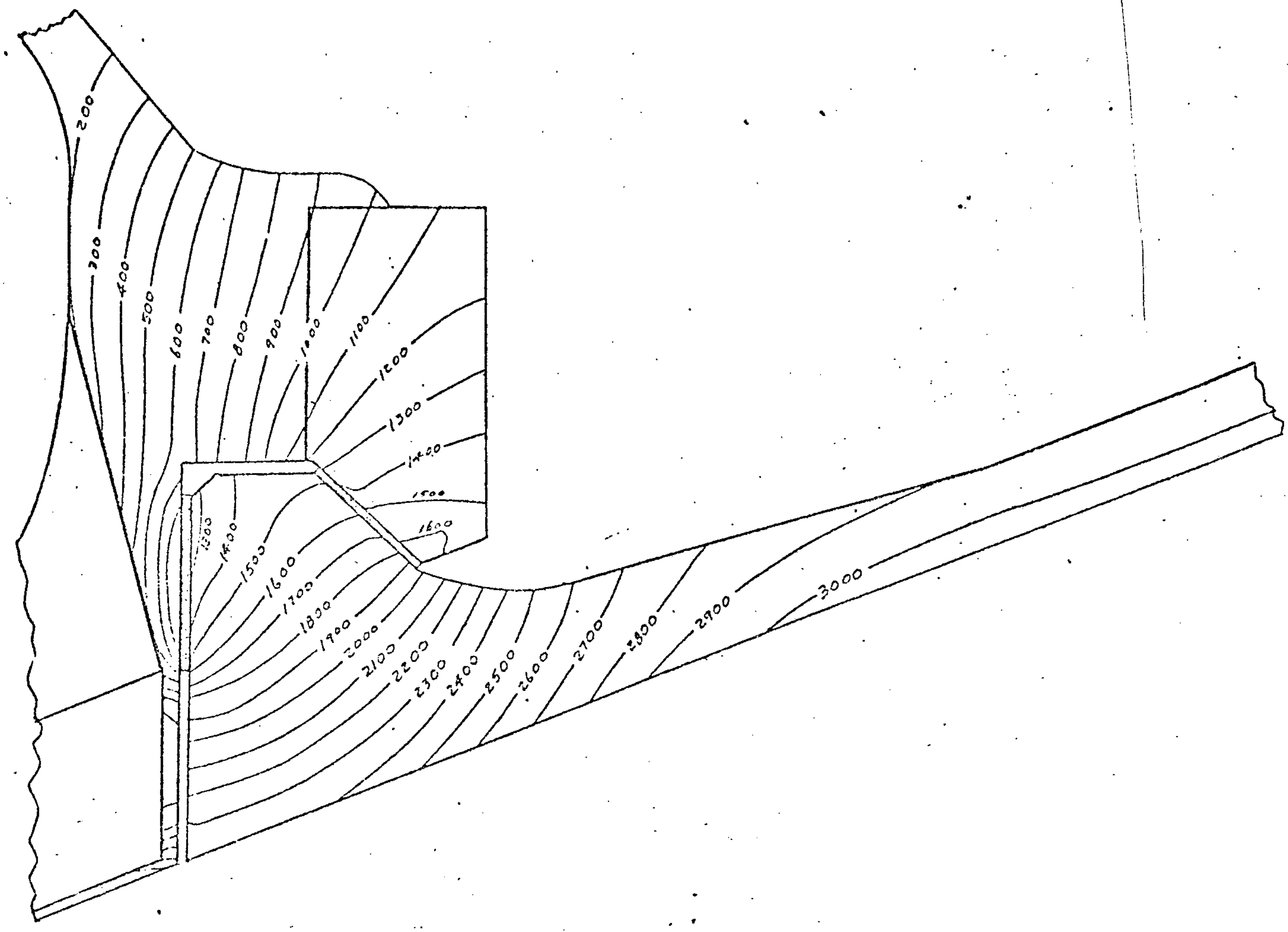


FIGURE 2 - CONCEPT 30 LAYUP PATTERNS



TB = 60.1°R

HL = 0.00109 Btu/in^2-sec-°R

TG = 3870°R TC = 4250°R PC = 450 psia

HG = 0.000235 Btu/in^2-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/in^3-sec

Grafoil = 0.0072 Btu/in^3-sec

AGCarb-101 = 0.011 Btu/in^3-sec

FIGURE 3 - TEMPERATURE DISTRIBUTION (°R)
STEADY STATE NORMAL OPERATION

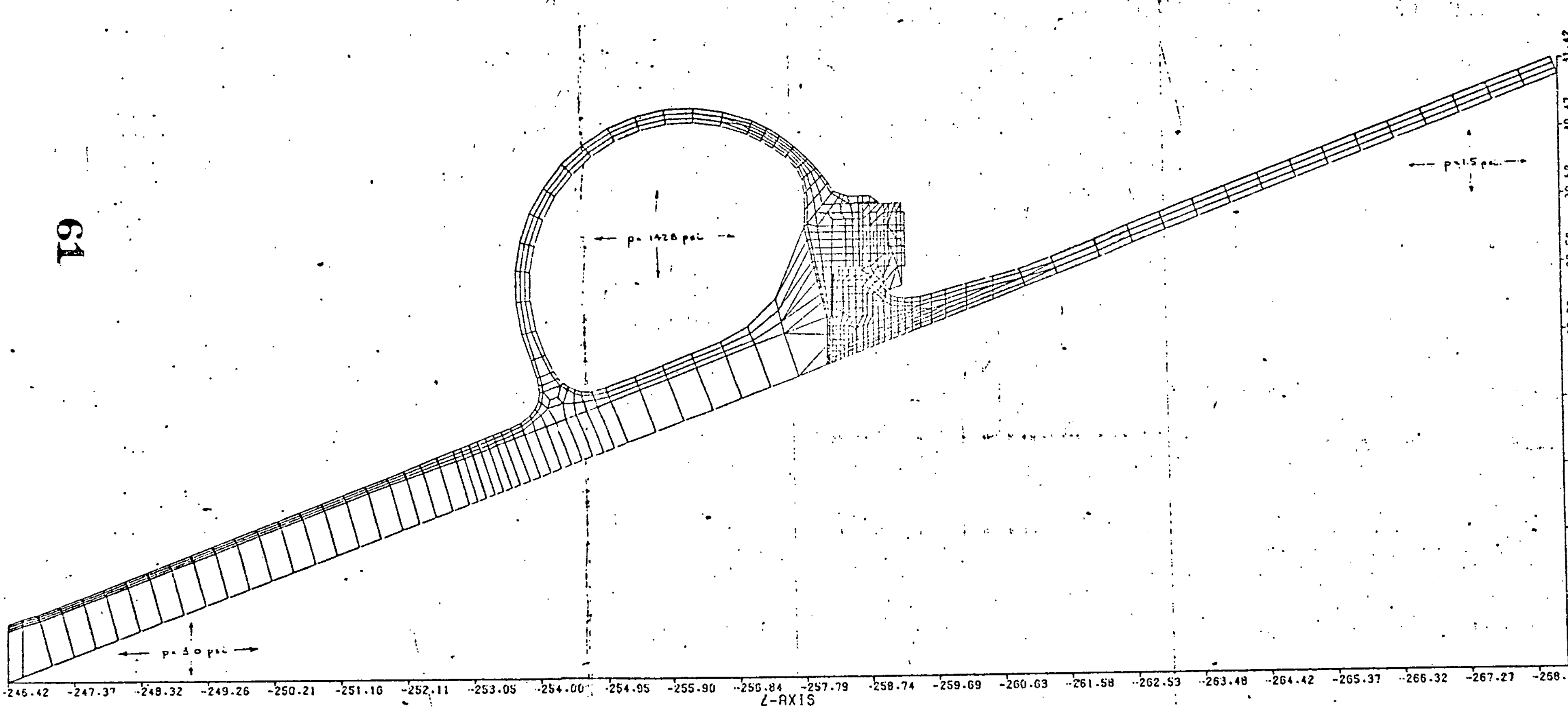
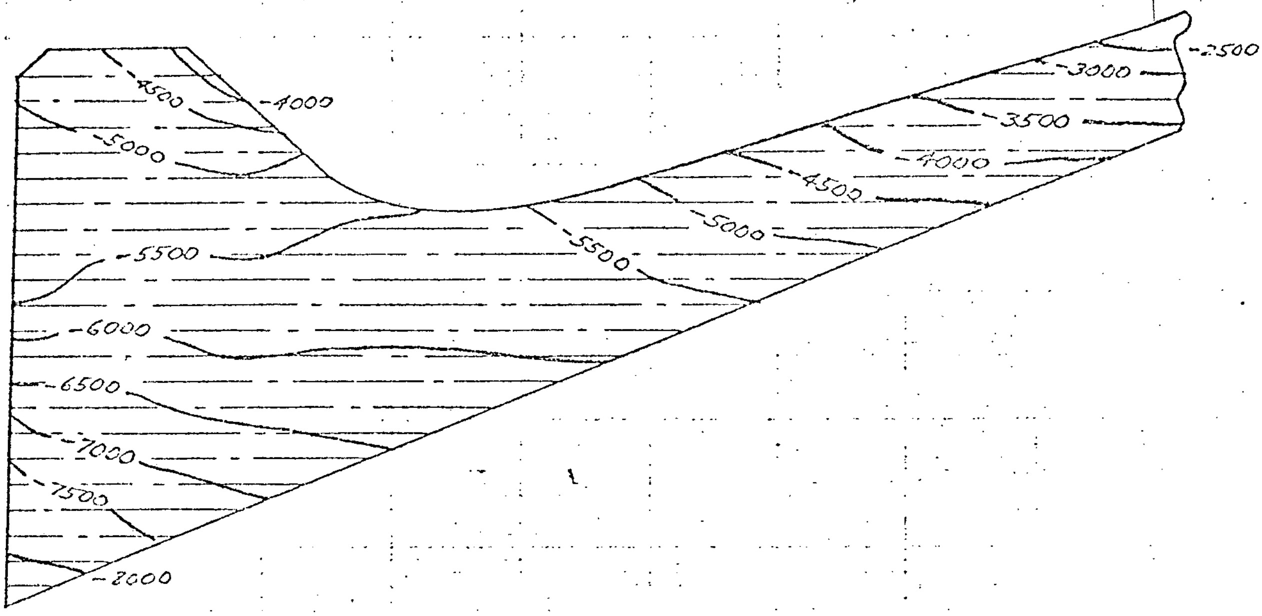


FIG. 4 - CONCEPT NO 30 NOZZLE EXTENSION

a) Warp (Hoop) Stresses (psi)



b) Fill (Axial) Stresses (psi)

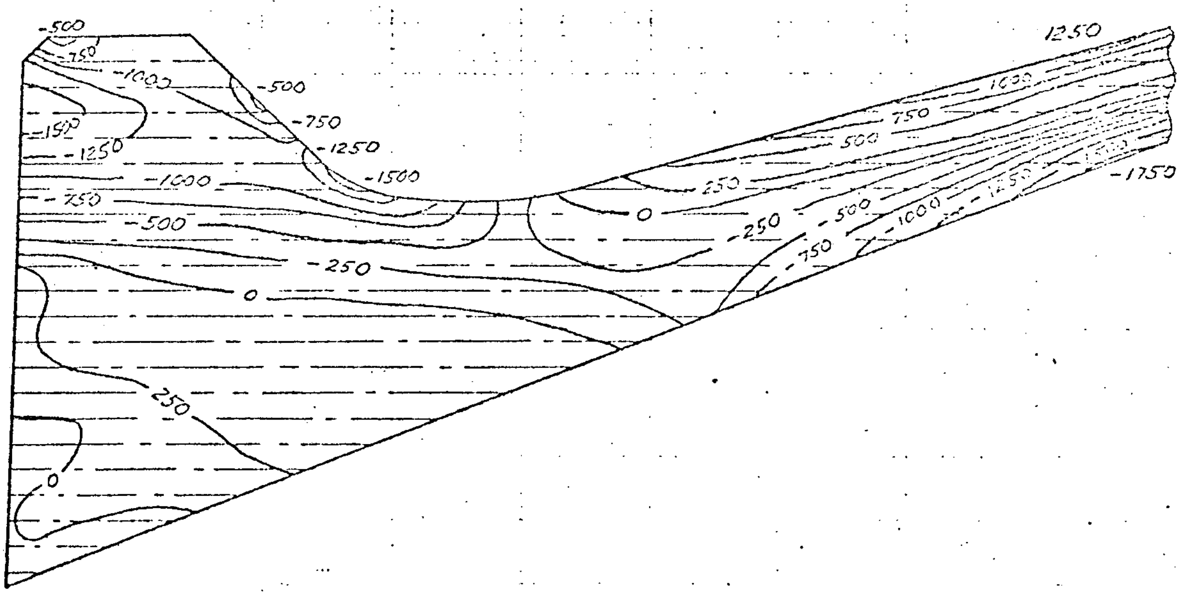
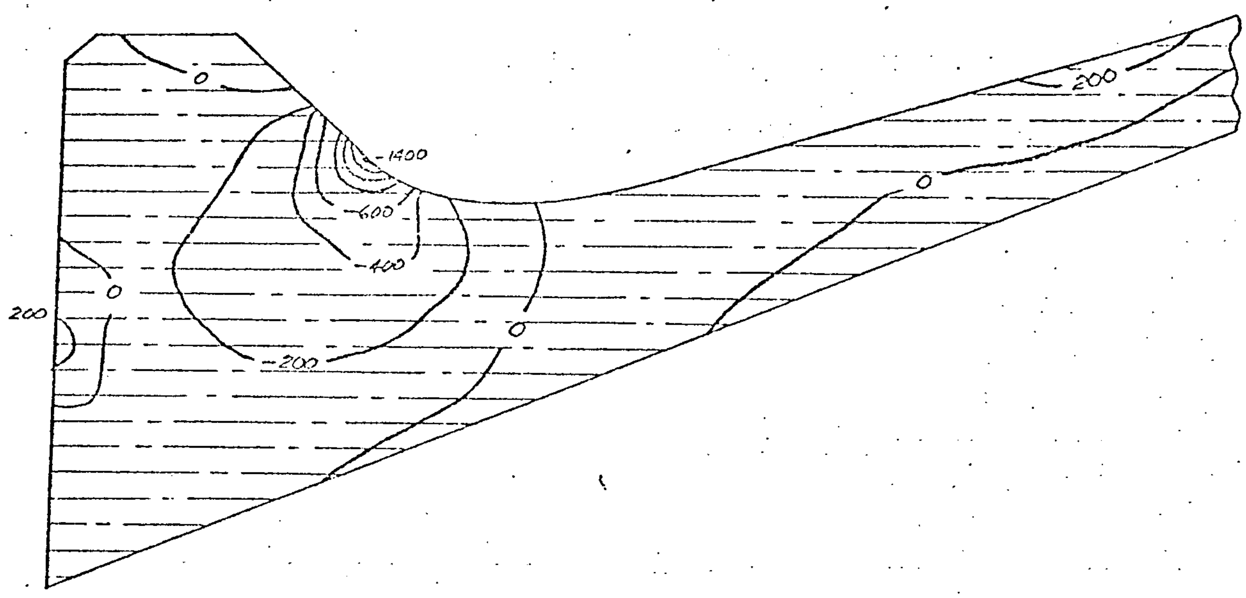


FIGURE 5 - STRESS DISTRIBUTIONS - CONCEPT 30
CYLINDRICAL AGCARB LAYUP
STEADY STATE NORMAL OPERATION

c) Block (Radial) Stresses (psi)



d) Interlaminar Shear Stresses (psi)

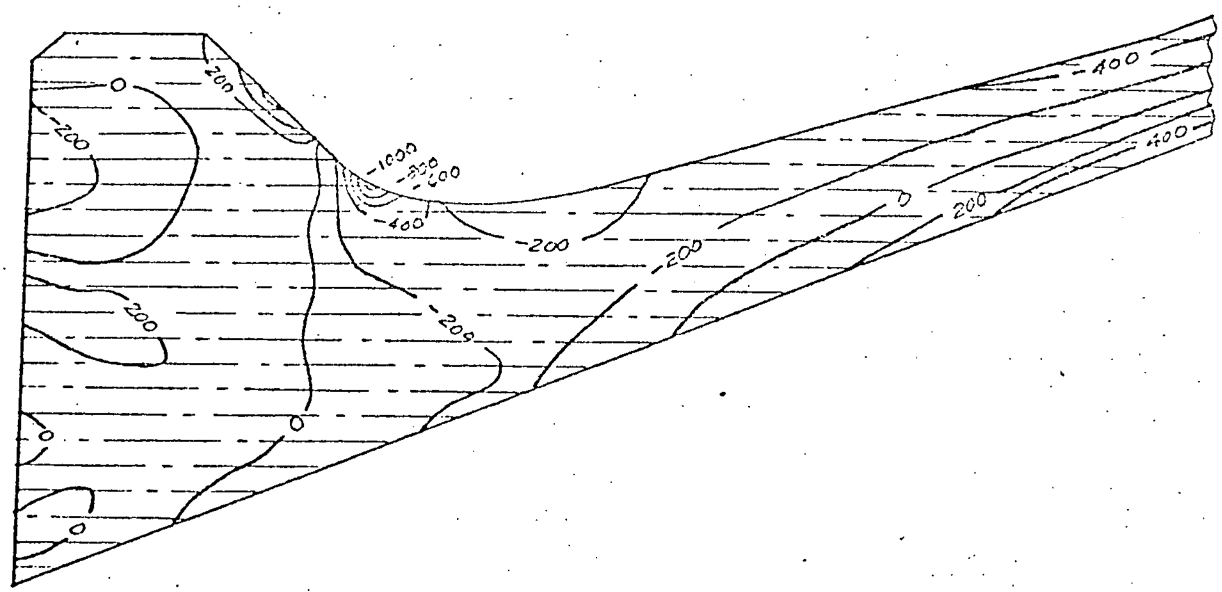


FIGURE 5 (CONT.)

STRESS DISTRIBUTIONS - CONCEPT 30
CYLINDRICAL AGCARB LAYUP
STEADY STATE NORMAL OPERATION

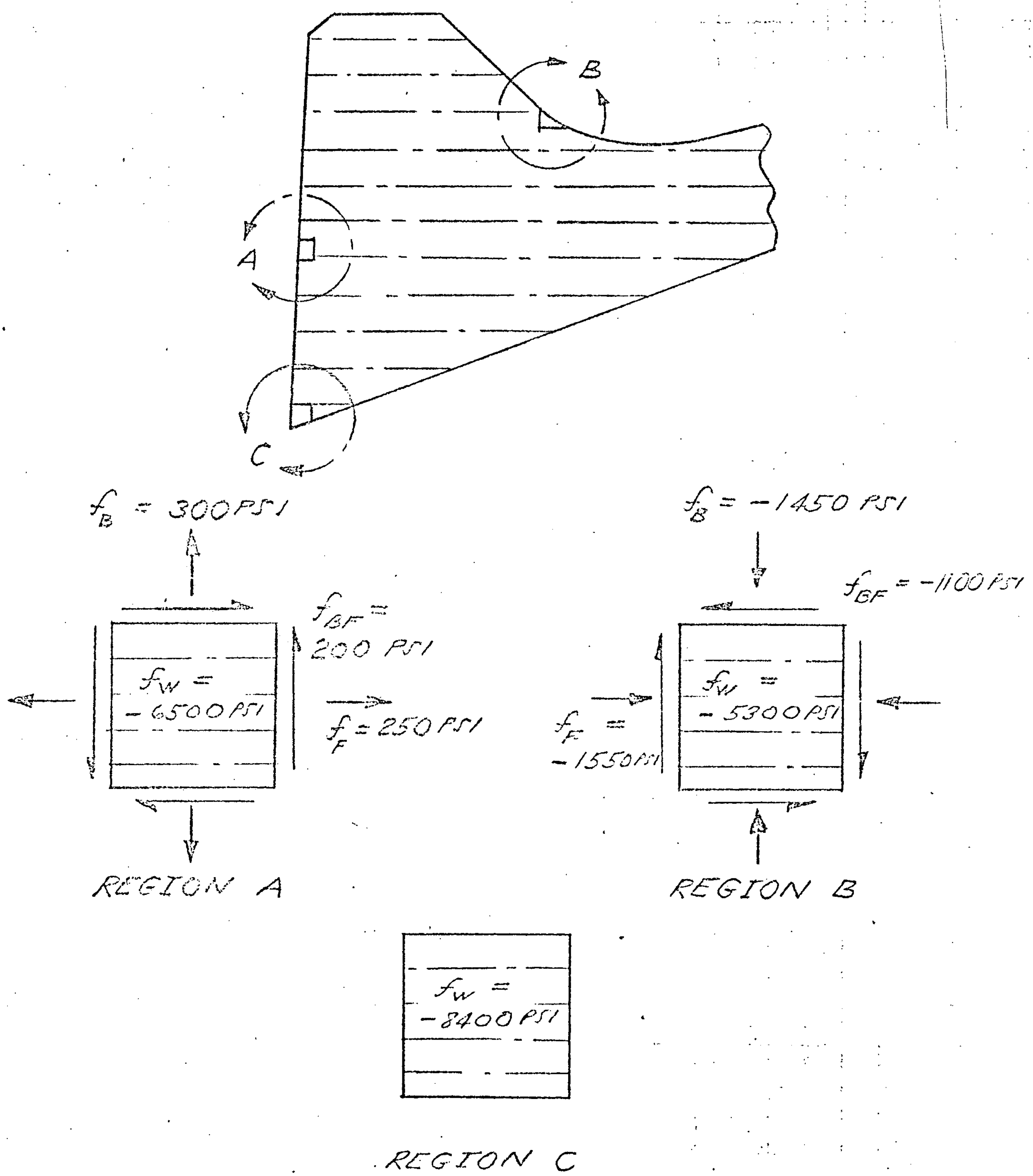
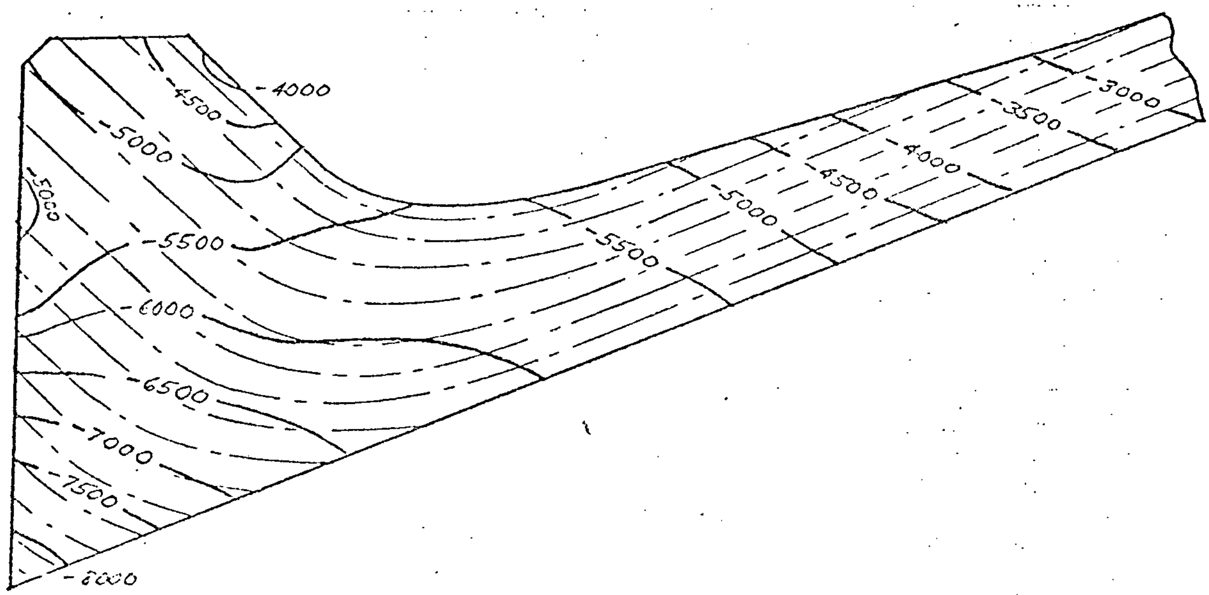


FIGURE 6 - CRITICAL STRESS REGIONS - CONCEPT 30
CYLINDRICAL ACCARB LAYUP
STEADY STATE NORMAL OPERATION

a) Warp (Hoop) Stresses (psi)



b) Fill Stresses (psi)

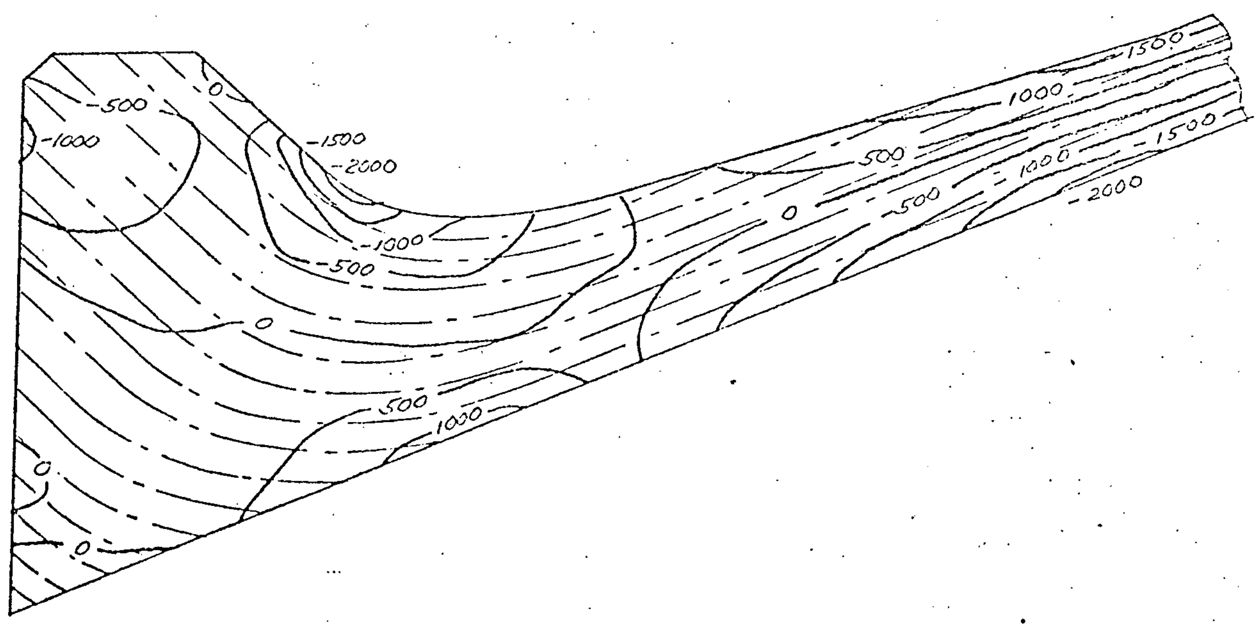
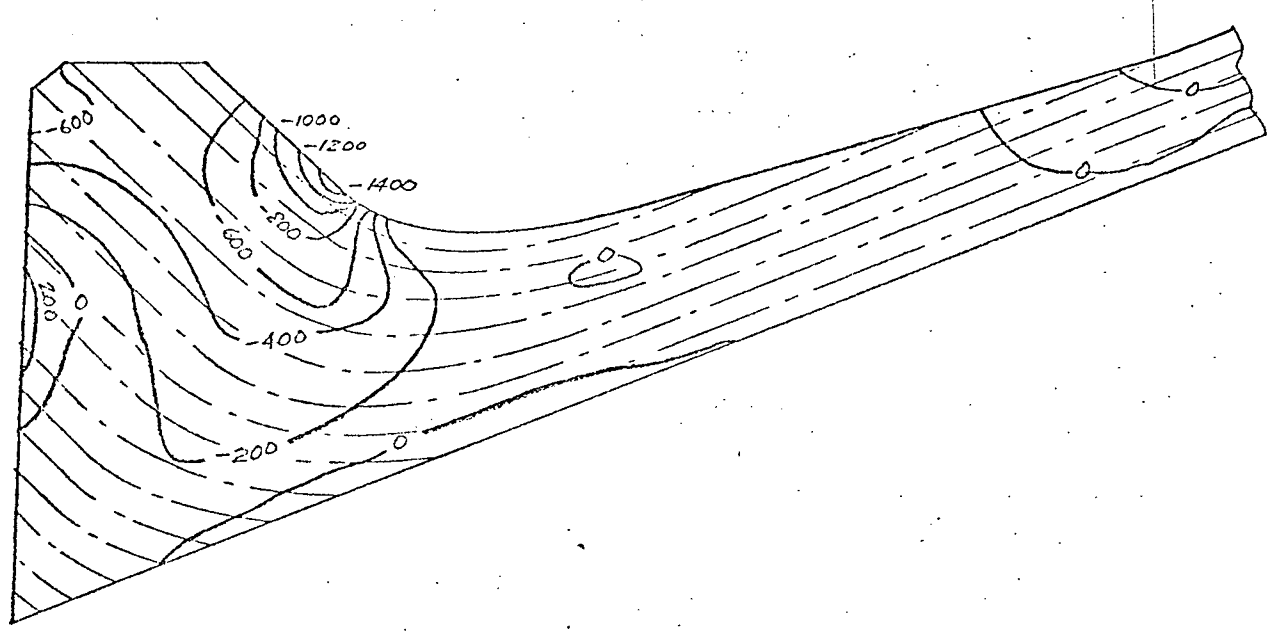


FIGURE 7 - STRESS DISTRIBUTIONS - CONCEPT 30
CONTOURED ACCARB LAYUP
STEADY STATE NORMAL OPERATION

c) Block Stresses (psi)



d) Interlaminar Shear Stresses (psi)

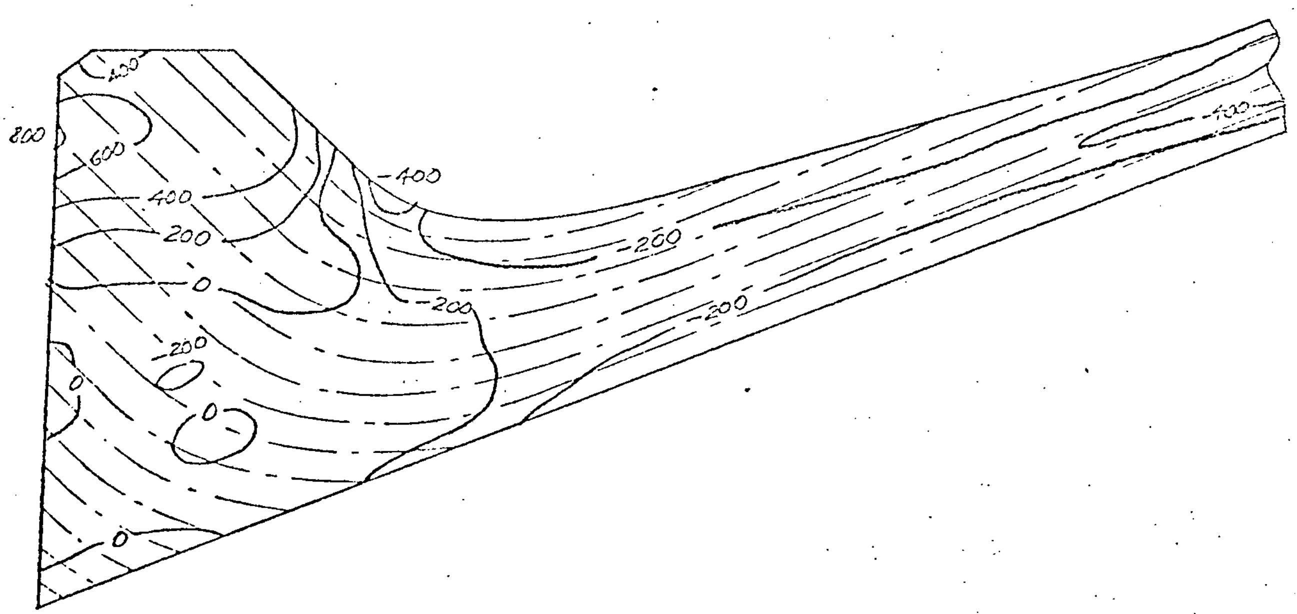


FIGURE 7 (CONT.)

STRESS DISTRIBUTIONS - CONCEPT 30
CONTOURED AGCARB LAYUP
STEADY STATE NORMAL OPERATION

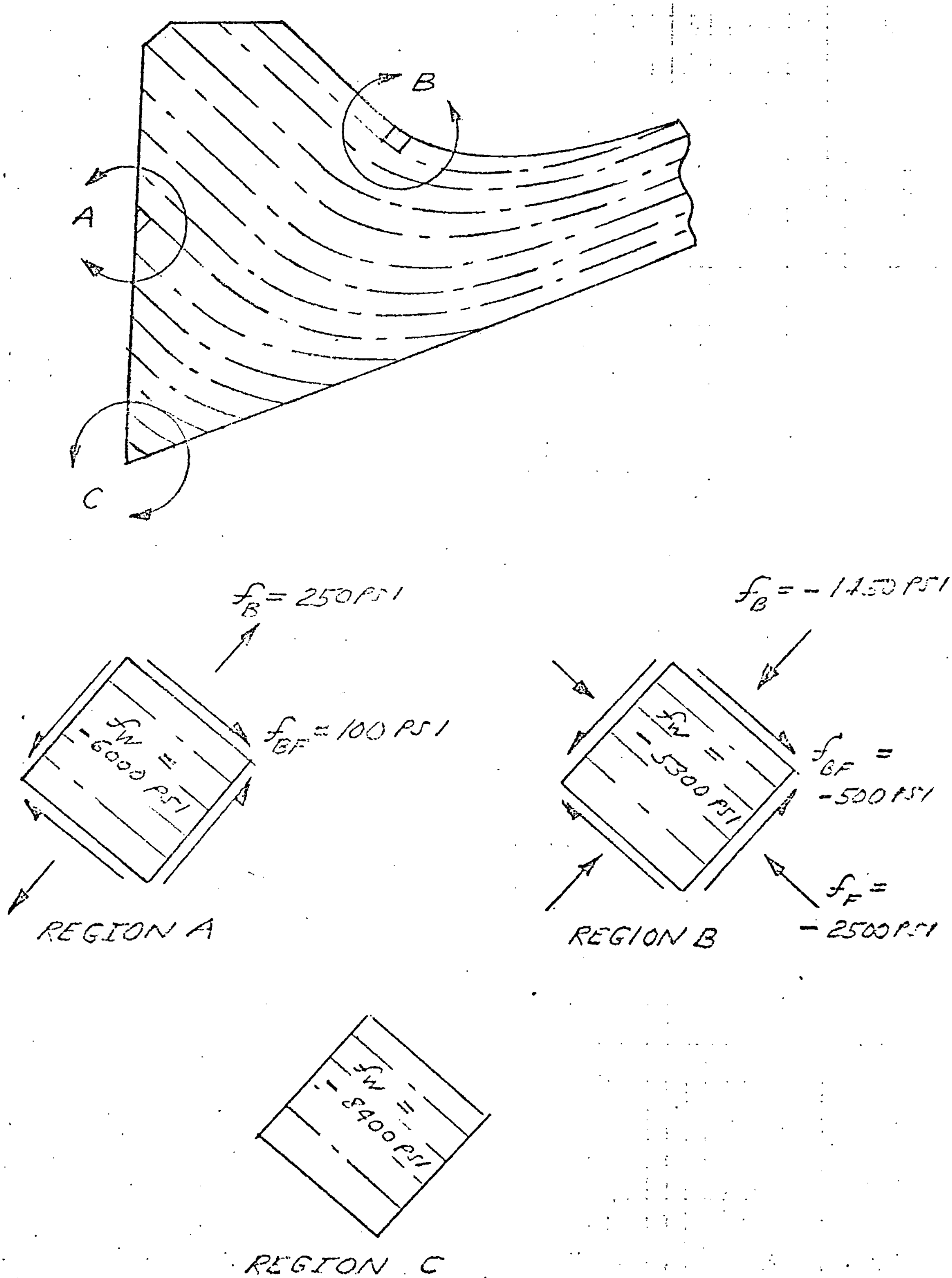


FIGURE 8 - CRITICAL STRESS REGIONS - CONCEPT 30
CONTOURED AGCARB LAYUP
STEADY STATE NORMAL OPERATION

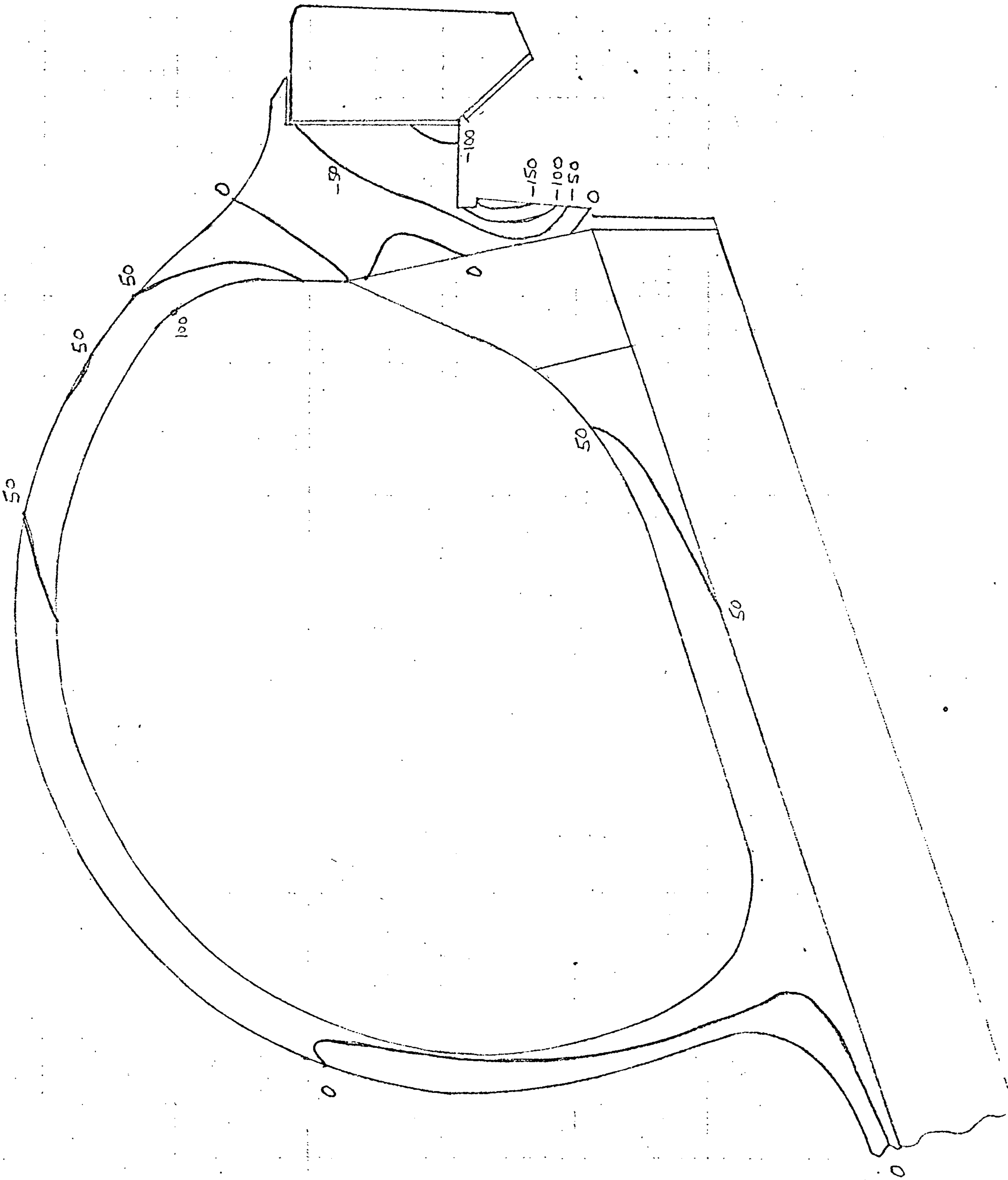


FIGURE 9 - HOOP STRESS DISTRIBUTION
NOZZLE FLANGE AREA - CONCEPT 30
STEADY STATE NORMAL OPERATION

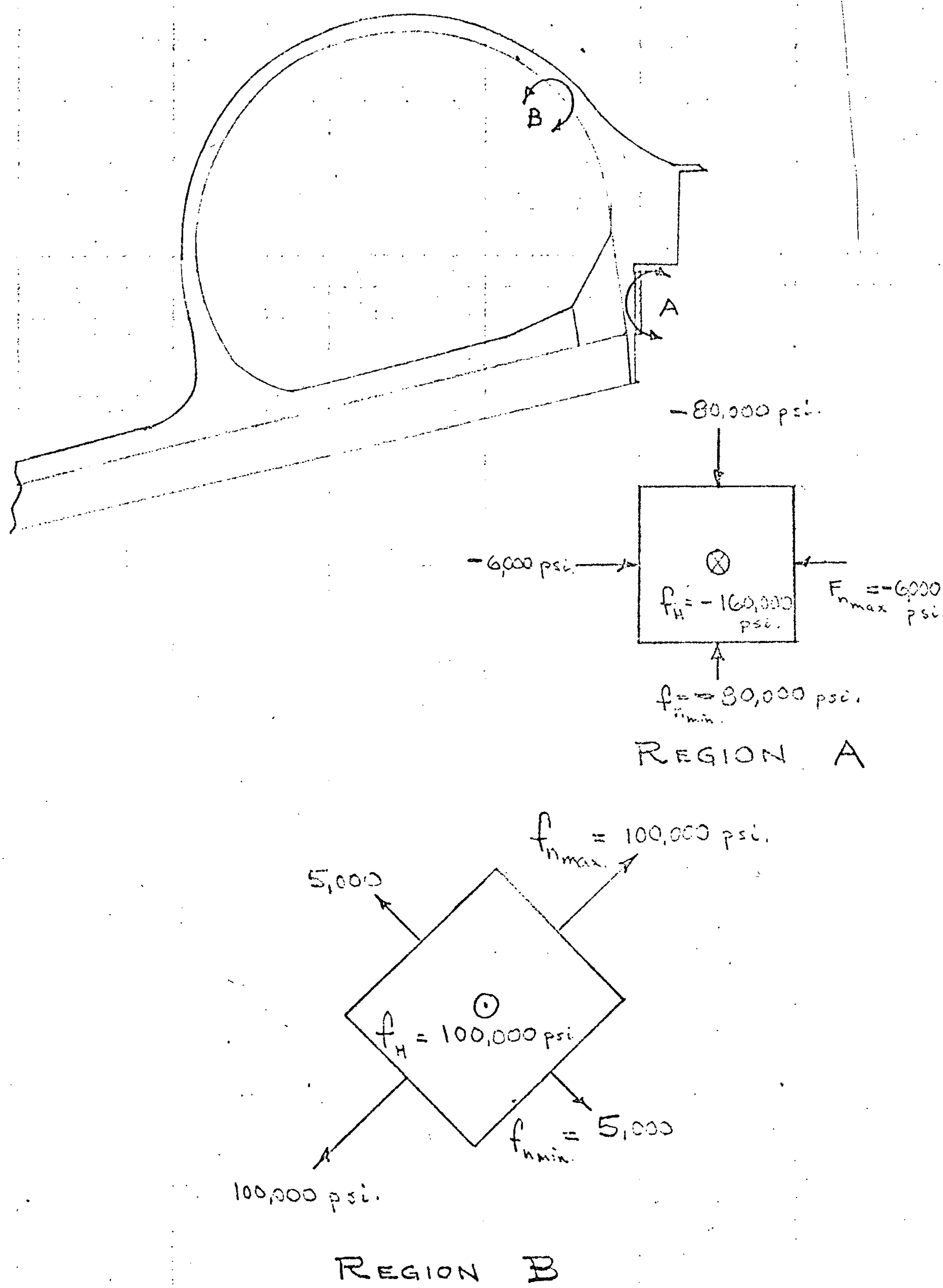
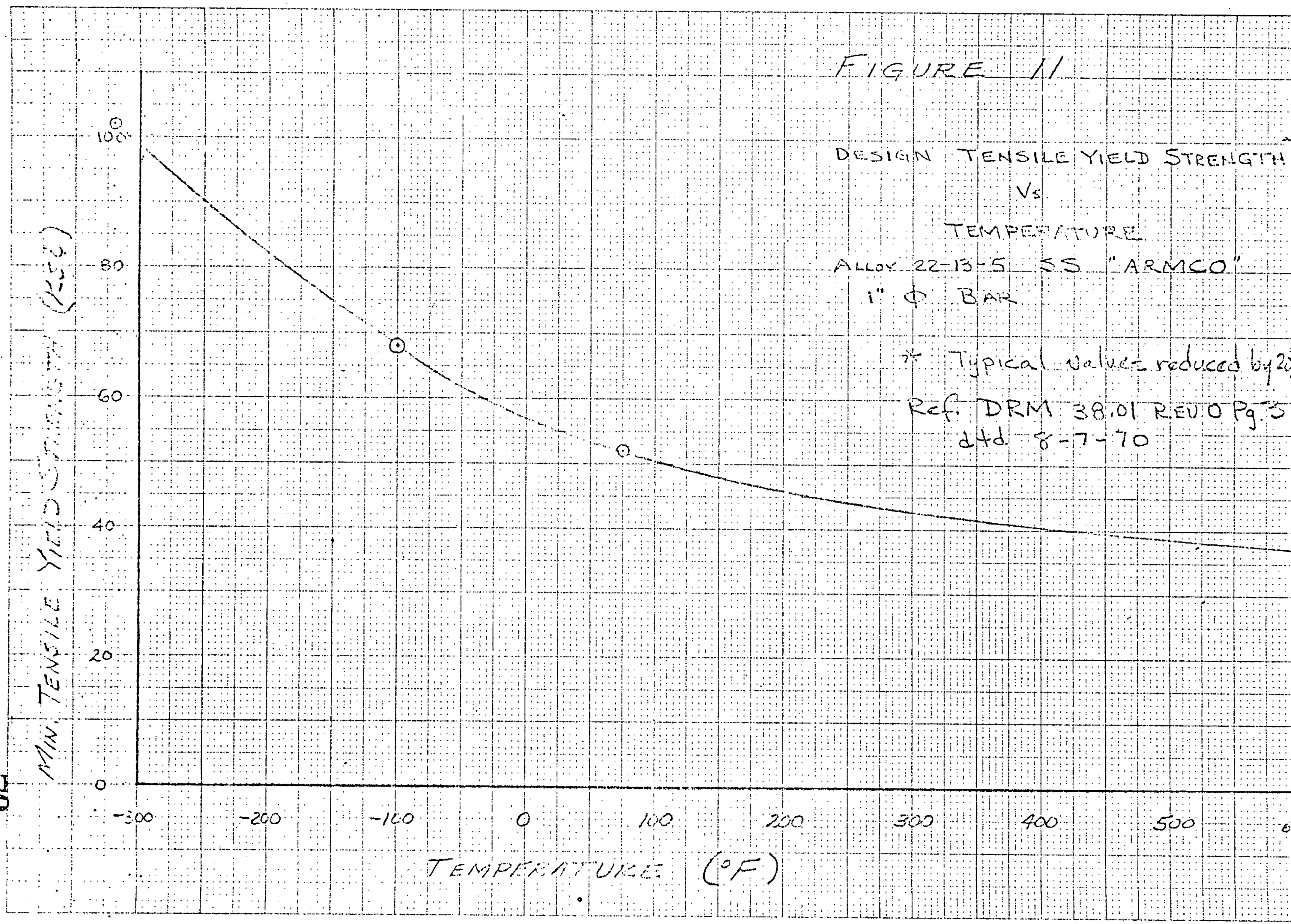


FIGURE 10 - CRITICAL STRESS REGIONS
NOZZLE FLANGE AREA
STEADY STATE NORMAL OPERATIONS

J. G. Schumacher
1 March 1972

FIGURE 11



APPENDIX A

AGCARB MATERIAL PROPERTIES

AGCS-0800-11

REPORT NO.	PAGE	DATE
WS120R:72-023	1 OF 10	

SUBJECT: AGCARB MATERIAL PROPERTIES

WORK ORDER:

BY: STARR

CHK. BY:

DATE:

I. SUMMARY

R ≡ BLOCK
Z ≡ FILL
θ ≡ WARP

	TEMP. °F	MODULUS $\times 10^6$ (PSI) E_{RR}	E_{ZZ}	$E_{\theta\theta}$	G_{rz}	POISSON'S RATIO ν_{zr}	$\nu_{\theta r}$	$\nu_{\theta z}$	THERMAL EXPANSION $\times 10^{-6}$ (in/in/°F) α_{RR}	α_{ZZ}	$\alpha_{\theta\theta}$
EARLIER MODEL NO. 30	R.T.	.3	2.0	2.3	.8	.187	.31	.32	2.6	1.6	1.6
	3000	.22	1.5	1.7	.6	.187	.31	.32	2.6	1.6	1.6
UNCOOLED NOZZLE (ALRC)	R.T.	.3	1.5	1.5	.56	.11	.41	.11	2.8	1.72	1.72
	3000	.44	1.54	1.54	.57	.11	.31	.11	2.63	1.85	1.85
	5000	.18	.86	.86	.33	.17	.44	.17	2.63	1.85	1.85
REVISED MODEL NO. 30	R.T.	.3	(1.8)*	2.31	(.52)*	(.46)*	.46	.24	2.6	1.6	1.6
	2000	(.39)							2.65	1.6	1.6
	3000	.44	(1.36)*	1.74	(.44)*	(.24)*	.24	.20	2.6	1.83	1.83

* DERIVED

II MATERIAL PROPERTY DERIVATION

A. FILL MODULUS

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

IN WARP DIRECTION :
27 YARNS/INCH
IN FILL DIRECTION :
21 YARNS/INCH

Ref. 1

ASSUME

$E_{WARP} \propto 27$ YARNS/INCH

$E_{FILL} \propto 21$ YARNS/INCH

$$\therefore \quad E_{FILL} = E_{WARP} \times \frac{21}{27} = 78\% \times E_{WARP}$$

FOR TENSION –

T°F	E_{WARP}	E_{FILL}
R.T	2.31	1.8
2000		
3000	1.74	1.36

Refs. 1 & 2

B. SHEAR MODULUS

FROM REFERENCE 3.

$$\frac{E_R}{E_\alpha} = \cos^4\alpha + \frac{E_R}{E_Z}\sin^4\alpha + \frac{\sin^2 2\alpha}{4}\left(\frac{E_R}{G_{RZ}} - 2\nu_{RZ}\right)$$

WHERE:

E_R = RADIAL MODULUS

E_Z = AXIAL MODULUS

E_α = MODULUS AT ANGLE TO E_R, E_Z.

HOWEVER, E_α AT ANGLE TO E_R & E_Z IS UNKNOWN. THEREFORE USE E_α AT 45° ANGLE TO E_θ & E_Z (IN PLANE).

FOR $\alpha = 45°$

$\sin\alpha = \cos\alpha = .707$

$2\alpha = 90°$

$$\frac{E_\theta}{E_\alpha} = (.707)^4 + \frac{E_\theta}{E_Z}(.707)^4 + \frac{1}{4}\left(\frac{E_\theta}{G_{\theta Z}} - 2\nu_{\theta Z}\right)$$

FROM REFERENCES 2 & 4.

@ R.T. $\alpha = 45°$

$E_\alpha = 1.48 \times 10^6$ PSI

$E_\theta = 2.31 \times 10^6$ PSI

$E_Z = 1.8 \times 10^6$ PSI

(TENSILE)

$\nu_{\theta Z} = .24$

SUBSTITUTING –

$$\frac{2.31}{1.48} = .25 + \frac{2.31}{1.8}(.25) + .25\left[\frac{2.31}{G_{\theta z}} - 2(.24)\right]$$

OR

$$G_{\theta z} = .52 \times 10^6 \text{ PSI}$$

@ $T = 3000\,°F$

$E_\alpha = 1.19 \times 10^6$ PSI

$E_\theta = 1.74 \times 10^6$ PSI

$E_z = 1.36 \times 10^6$ PSI

$\nu_{\theta z} = .20$

$\therefore$

$$\frac{1.74}{1.19} = .25 + \frac{1.74}{1.36}(.25) + .25\left[\frac{1.74}{G_{\theta z}} - 2(.20)\right]$$

OR

$$G_{\theta z} = .438 \times 10^6 \text{ PSI}$$

ASSUME $G_{\theta z} = G_{Rz}$

T	G_{Rz}
R.T.	0.52×10^6 PSI
3000	0.44×10^6 PSI

C. COEFFICIENT OF THERMAL EXPANSION

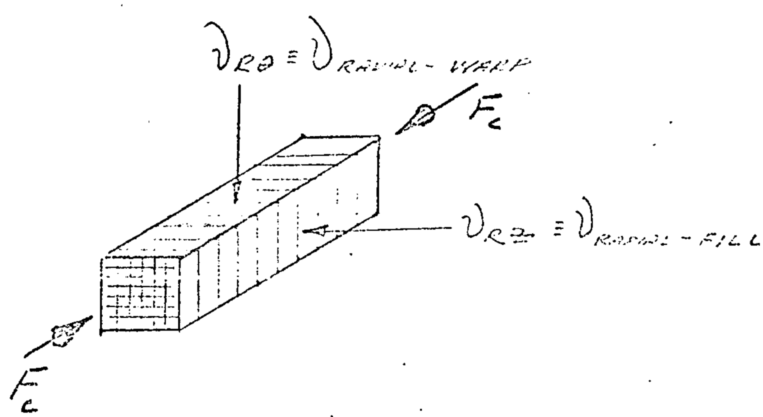
FROM REFERENCE 1.

TEMP °F	ΔL // TO WRAP (10^{-3})	α // (10^{-6}) (IN/IN/°F)	ΔL ⊥ TO WRAP (10^{-3})	α ⊥ TO WRAP (10^{-6}) (IN/IN/°F)
1000	1.6	1.60	2.6	2.60
2000	3.2	1.60	5.3	2.65
3000	5.5	1.83	7.8	2.60

D. POISSON'S RATIO

FROM REFERENCE 4.

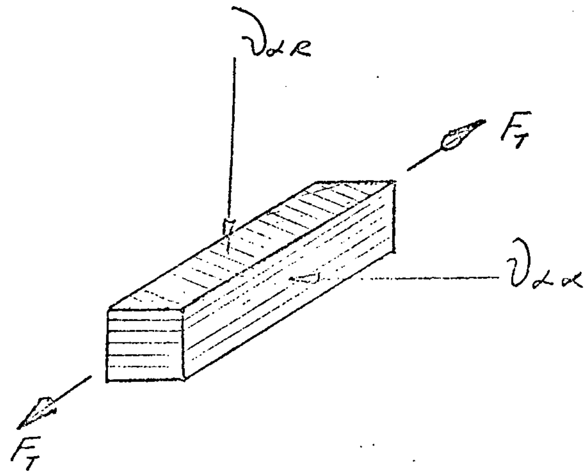
1. BLOCK SPECIMENS



T °F	E_R COMPR (PSI)	$\frac{\nu_{RZ}+\nu_{R\theta}}{2}$
R.T	.30 (10⁶)	.11
3000	.44 (10⁶)	.11
5000	.18 (10⁶)	.17

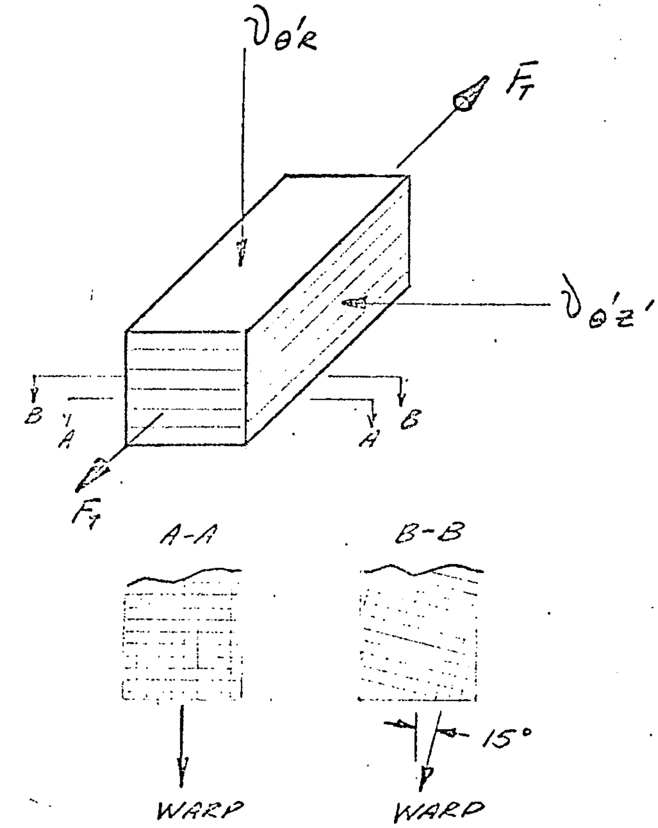
SUBJECT		DATE
		WORK ORDER
BY	CHK. BY	DATE

2. FLAT WRAP 45° BIAS



T °F	E_α TENS. (PSI)	$\nu_{\alpha\alpha}$	$\nu_{\alpha R}$
R.T.	1.48	.40	.16
3000	1.19	.16	.07
5000	0.54	.10	.14

3. FLAT WRAP W/15° ALTERNATE LAYERS



T °F	$E_{\theta'}$ TENS. (PSI)	$\nu_{\theta' z}$	$\nu_{\theta' R}$
R.T.	$1.75(10^6)$	.24	.46
3000	$1.46(10^6)$	.20	.24
5000	$0.55(10^6)$	.20	.23

SUBJECT

DATE

WORK ORDER

BY

CHK. BY

DATE

AG Carb Material Strengths (Ref 2)

PROPERTY		TEMPERATURE (°F) 70°	2000°	3000°	SPECIMEN
ULT. TENSILE STRENGTH (ksi)	WARP	11.27 ± 3.3 (.665)	———	———	1" Plate
		10.45 ± 2.932 (.765)	11.53 ± 3.98 (.798)	12.78 ± 5.74 (.84)	1" dia.
		11.40 ± 2.94 (1.09)	11.75 ± 3.93 (.89)	13.46 ± 3.98 (1.07)	1/4" Plate
	FILL	4.56 ± 4.35 (.325)	———	———	1" dia.
	BLOCK	0.644 ± 3.98 (.13)	———	———	1" dia.
		0.638 ± 3.98 (.064)	———	———	1/4" Plate
F_{CU} (ksi)	WARP	9.40 ± 3.98 (.76)	8.72 ± 3.98 (.92)	9.13 ± 3.98 (.59)	1" Plate
		9.51 ± 3.98 (.702)	9.16 ± 3.98 (.477)	9.07 ± 3.98 (.65)	1/4" Plate
INTER-LAMINAR SHEAR (ksi)	WARP LOAD	1.35 ± 3.98 (.16)	———	———	1" Plate
		1.298 ± 3.98 (.067)	———	———	1/4" Plate
F_{TU} (ksi)	45° to W&F	4.43 ± 5.74 (.144)	———	———	1" dia.
		4.02 ± 5.74 (.158)	———	———	1/4" Plate
FATIGUE 10^7 cycles		8.75 ± 1.75	———	———	1" Plate
		9.50 ± 1.9	———	———	1/4" Plate

APPENDIX A

LIST OF REFERENCES

1. "Fabrication and Properties of the Fibrous Reinforced Graphite Composite, AGCarb 101," Aerojet-General Corp., Liquid Rocket Divn., August 1969

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

3. MIL-HDBK-17, "Plastics for Flight Vehicles" Part I Reinforced Plastics, 5 November 1959

4. "Thermal and Mechanical Evaluations of AGCarb Material", Final Report to ALRC, Southern Research Institute, 21 February 1971

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

AEROJET NUCLEAR SYSTEMS COMPANY
SACRAMENTO, CALIFORNIA

APPLIED MECHANICS SECTION N8120

ANALYSIS NO. AM- NA-0027

DATE 11 February 1972

SUMMARY OF ANALYSIS

Project 143 System/Component Nozzle Extension

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

Distribution:

L. B. Claassen
C. M. Kawashige
J. G. Schumacher
L. A. Shurley

*Summary Sheet Only
File: AM-1200-310

Engineer J. E. Jellison Approved J. G. Schumacher

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.

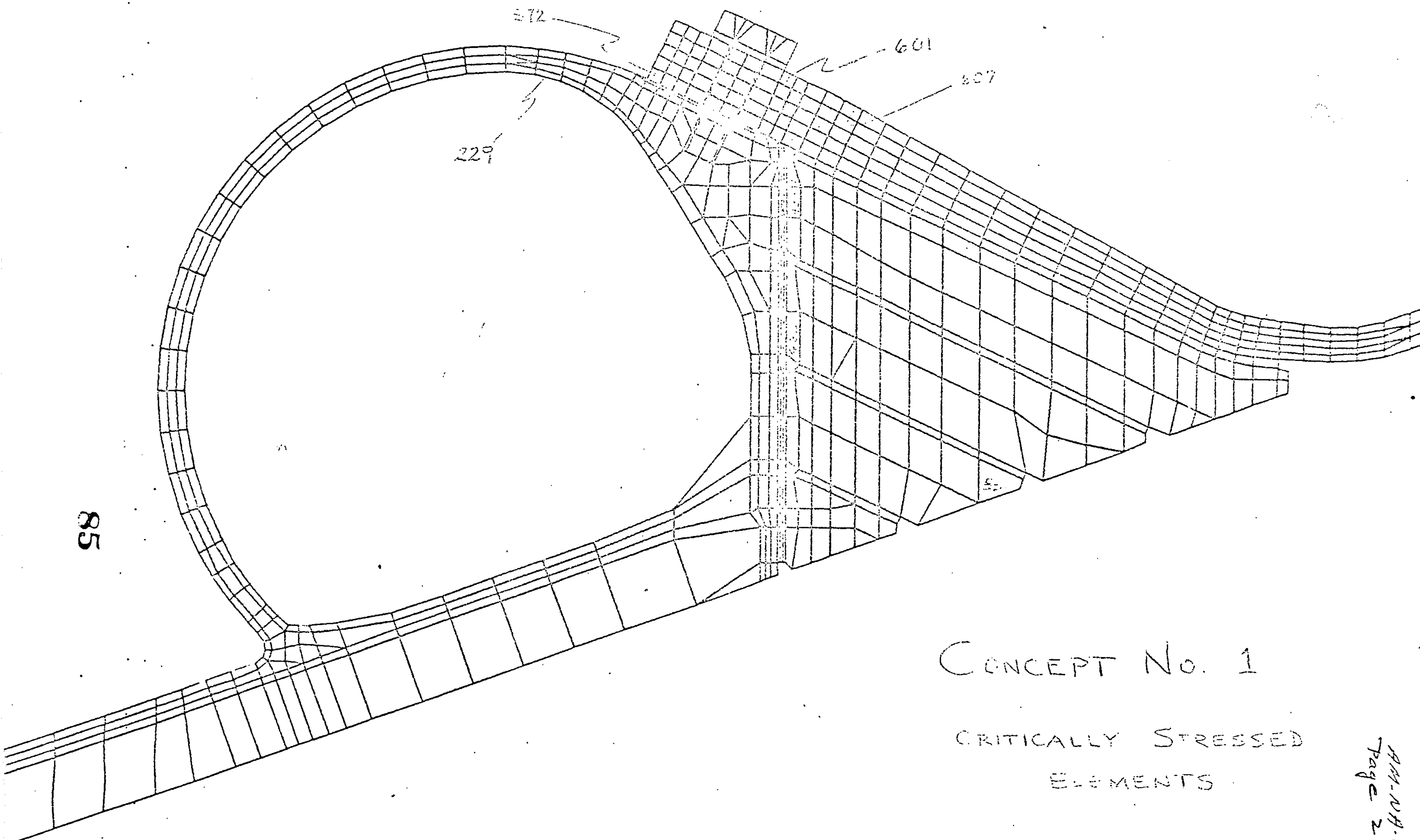
SUMMARY OF MAX STRESSES & M.S.'s
FOR JOINT CONCEPT #1

STRESS Mode		STRESS Magnitude (psi)	ELEMENT No.	TEMP. (°F)	STRENGTH $= 1.5^{*} F_U$ (psi)	M.S.
TENSION	WARP	4155	601	510	12,300	+2.96
	FILL	1950	467	800	4710	+1.41
	BLOCK	1320	463	1020	186	−0.86
COMPRESSION	WARP	2311	530	2500	7600	+2.29
	FILL	2050	702	2600	**	——
	BLOCK	1420	499	2025	**	——
INTERLAMINAR SHEAR		1460	466	850	1550	+0.06
Nozzle Max Stress (Hoop)		52,000(1)	229	72	$2F_{TY} = 104$ ksi	+1.0

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

** No strength data available

(1) Reference 1



CONCEPT NO. 1

CRITICALLY STRESSED ELEMENTS

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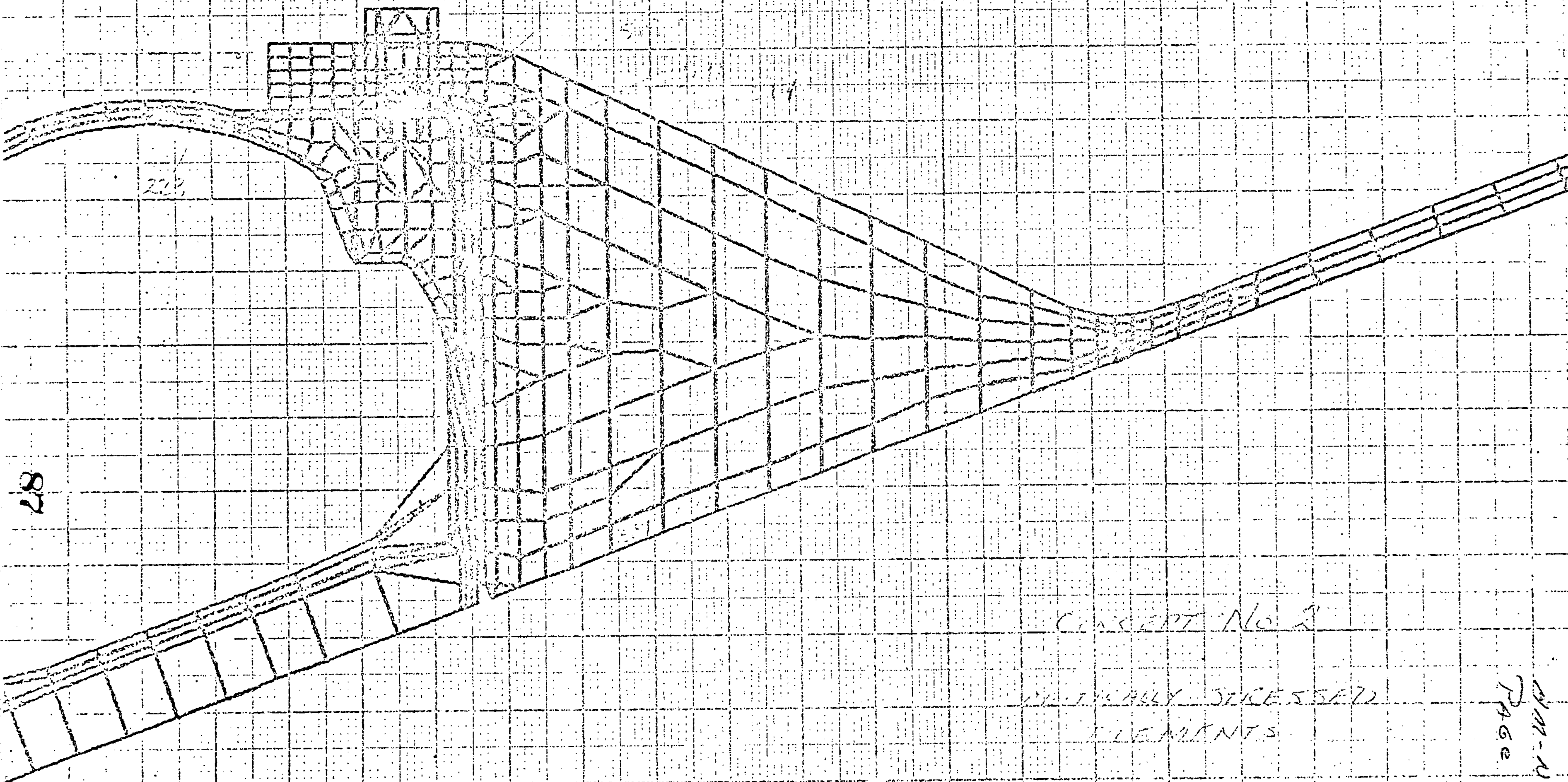
AM-NH-0027
Page 2 of 5

SUMMARY OF MAX STRESSES & M.S. FOR JOINT CONCEPT #2

STRESS Mode		STRESS Magnitude (psi)	ELEMENT No.	TEMP. (°F)	STRENGTH $=1.5^{*} F_{U_{min}}$ (psi)	M.S.
TENSION	WARP	5410	518	1040	12,300	+1.27
TENSION	FILL	4970	519	990	4700	−0.05
TENSION	BLOCK	1990	517	1070	186	−0.91
COMPRESSION	WARP	580	581	2240	7600	+HIGH
COMPRESSION	FILL	4350	674	3013	**	—
COMPRESSION	BLOCK	1370	594	2400	**	—
INTERLAMINAR SHEAR		4410	490	900	1550	−0.65
NOZZLE MAX STRESS (HOOP)		60,000	223	72	$2F_{TY} = 104$ KSI	+0.73

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

** No strength data available.



CONCEPT No 2

STRESSED

ELEMENTS

UM-NA-0027
Page 4 of 5

SUBJECT | DATE

WORK ORDER

BY | CHK BY | DATE

AG Carb Material Strengths (Ref 2)

PROPERTY		TEMPERATURE (°F) 70°	2000°	3000°	SPECIMEN
ULT. TENSILE STRENGTH (ksi) F_{TU}	WARP	11.27 ±3.3(.665)	—	—	1" Plate
		10.45 ±2.932(.765)	11.53±3.98(.798)	12.78±5.74(.84)	1" dia.
		11.40±2.94(1.09)	11.75±3.98(.89)	13.46±3.98(1.07)	1/4" Plate
	FILL	4.56±4.35(.325)	—	—	1" dia.
	BLOCK	0.644±3.98(.13)	—	—	1" dia.
		0.638±3.98(.064)	—	—	1/4" Plate
F_{CU} (ksi)	WARP	9.40±3.98(.76)	8.72±3.98(.92)	9.13±3.98(.59)	1" Plate
		9.51±3.98(.702)	9.16±3.98(.477)	9.07±3.98(.65)	1/4" Plate
INTER-LAMINAR SHEAR (ksi)	WARP LOAD	1.35±3.98(.16)	—	—	1" Plate
		1.298±3.98(.067)	—	—	1/4" Plate
F_{TU} (ksi)	45° to W&F	4.43±5.74(.144)	—	—	1" dia.
		4.02±5.74(.158)	—	—	1/4" Plate
FATIGUE $(10)^4$ cycles		8.75 ± 1.75	—	—	1" Plate
		9.50 ± 1.9	—	—	1/4" Plate

APPENDIX D

SUMMARY OF RESULTS OF STEADY STATE STRESS

ANALYSIS OF CONCEPT #12

AM-NA-0030

AEROJET NUCLEAR SYSTEMS COMPANY
SACRAMENTO, CALIFORNIA

APPLIED MECHANICS SECTION N8120

ANALYSIS NO. AM- NA-0030

DATE 21 April 1972

SUMMARY OF ANALYSIS

Project 143 System/Component Nozzle Extension

Part Joint Concept #12 Drawing No. 5:1 Concept Sketch

Subject Summary of Results of S.S. Stress Analysis

Reference(s) Data Release Memo No. 06.01, Rev. 0, AGCarb-101, dtd. 19 December 1969

Distribution:
L. B. Claassen
C. M. Kawashige
U. A. Pineda
L. A. Shurley

*Summary Sheet Only

File: AM- 1200-0310

Engineer J. E. Jellison Approved J. Nevenzel

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 (E11405)

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.

SUBJECT: ENCLOSURE 1 Summary of Results of S.S. stress analysis of N.E. Joint Concept #12

DATE: 4-20-72

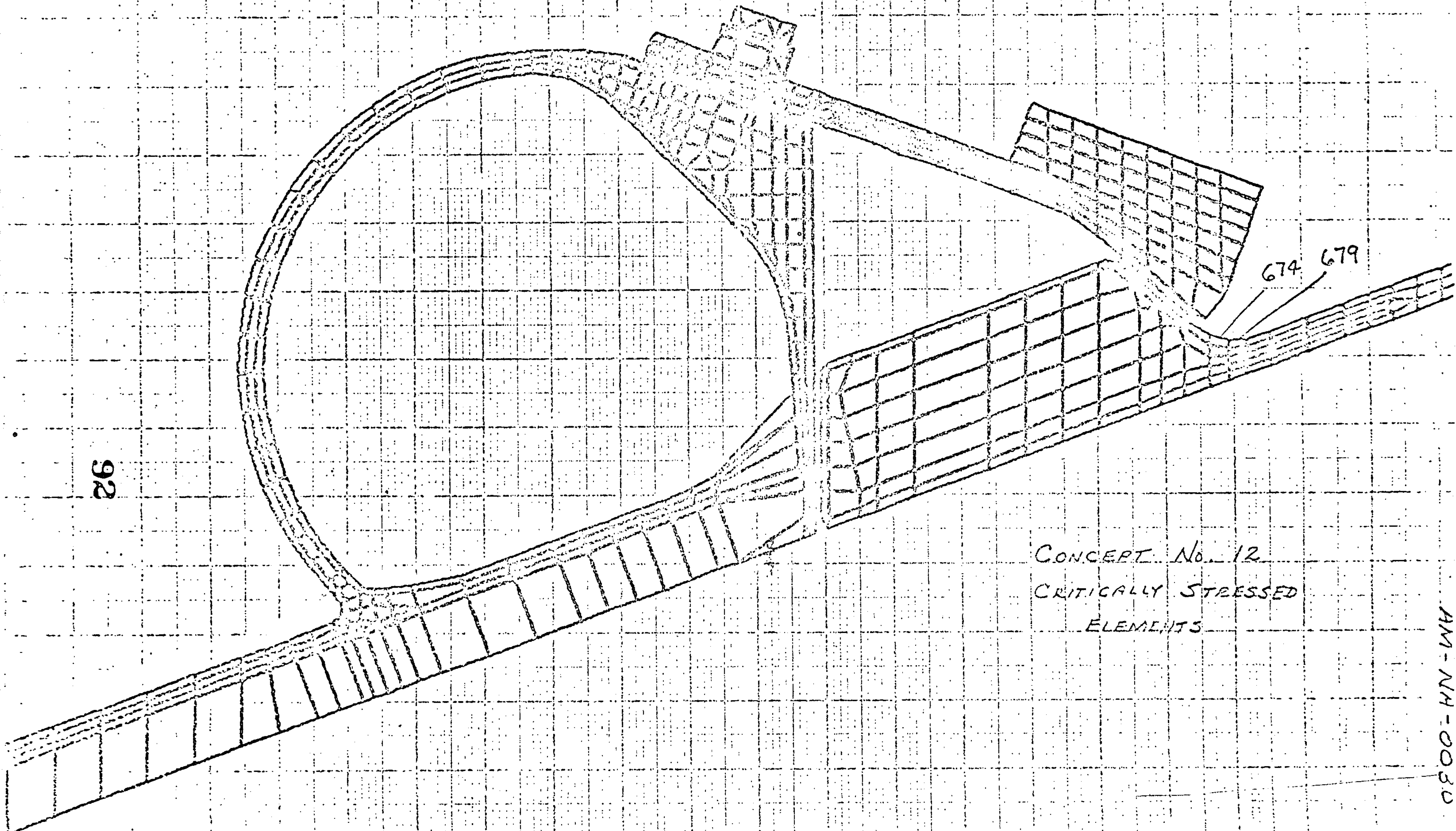
WORK ORDER

BY: JEJ | CHK. BY: J.N. | DATE: 4-21-72

SUMMARY OF MAXIMUM STRESSES AND MINIMUM MARGINS OF SAFETY FOR AG CARB FLANGE DESIGN CONCEPT #12

STRESS		ELEMENT No.	TEMP. (°F)	STRENGTH $=1.5^{*}F_{U_{MIN.}}$	"MARGIN OF SAFETY"
Mode	Magnitude (psi)				
Warp Tension	5,000	679	3030	12,000	+1.40
Fill Tension	6,800	679	3030	4,700	-0.31
Block Tension	1,020	674	3000	186	-0.82
Interlaminar Shear	1,840	674	3000	710	-0.61

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



CONCEPT NO. 12
CRITICALLY STRESSED
ELEMENTS

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AM-NH-0030

APPENDIX E

AGCARB DATA REQUIREMENTS FOR CY72 NOZZLE EXTENSION

FLANGE CONCEPT SELECTION

N8120:090

AEROJET NUCLEAR SYSTEMS COMPANY

SACRAMENTO, CALIFORNIA

TO: T. A. Redfield

28 October 1971
JEJ:jm N8120:090

FROM: J. G. Schumacher

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

DISTRIBUTION: L. B. Claassen, J. E. Jellison, C. M. Kawashige, U. A. Pineda, C. W. Robson, L. A. Shurley, J. W. Starr, L. M. Swope, E. F. Thacher

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

J. G. Schumacher
Applied Mechanics Section
Engineering Staff Department

CLASSIFICATION CATEGORY
Unclassified
J G Schumacher 10/29/71
CLASSIFYING OFFICER DATE

C2

TABLE I - ROOM TEMPERATURE TEST DATA FOR AUGUST 1972 STRUCTURAL ANALYSIS

TYPE OF TEST	LOAD DIRECTION	SPECIMENS NO.	SPECIMENS TYPE	INSTRUMENTATION	MEASUREMENTS	REDUCED DATA
UNIAXIAL TENSION	WARP	4	FLAT .25 x .25	STRAIN GAGES IN W, F, B DIRECTION	LOAD VS 3 STRAINS TO FAILURE	E_{TW}, F_{TUW}, ν_{WF}, ν_{WB}, $(\sigma\text{-}\epsilon)_W$ CURVE
		3	FLAT .25 x .50	STRAIN GAGE IN LOAD DIRECTION	LOAD VS ~~B~~ STRAIN TO FAILURE	E_{TW}, F_{TUW}, $(\sigma\text{-}\epsilon)_W$ CURVE
	FILL	4	FLAT .25 x .25	- DO -	- DO -	E_{TF}, F_{TUF}, ν_{FW}, ν_{FB}, $(\sigma\text{-}\epsilon)_F$ CURVE
		3	FLAT .25 x .50			E_{TF}, F_{TUF}, $(\sigma\text{-}\epsilon)_F$ CURVE
	BLOCK	4	RND. 1.0 Φ x .75 T	- DO -	- DO -	E_{TB}, F_{TUB}, ν_{BW}, ν_{BF}, $(\sigma\text{-}\epsilon)_B$ CURVE
		3	RND. 0.75 Φ x .75 T			E_{TB}, F_{TUB}, $(\sigma\text{-}\epsilon)_B$ CURVE
UNIAXIAL COMPRESSION	WARP	4	0.5 SQ. x 1.0 L			E_{CW}, ETC.
		3	0.25 SQ x 0.5 L			
	FILL	4	- DO -	——— DO ———	——— DO ———	——— DO ———
		3				
	BLOCK	4	0.5 SQ x 0.75 L			
		3	0.25 SQ x 0.5 L			
SHEAR	WARP *	7	BAYONET SHR.		FAILURE LOAD	F_{SUWB}
	FILL	7	BAYONET SHR		FAILURE LOAD	F_{SUFB}
	BLOCK * (WARP BEAM)	7	BEAM	HOLOGRAPHIC	DEFLECTIONS VS. LOAD	G_{WB}
	BLOCK (FILL BEAM)	7	BEAM	HOLOGRAPHIC	DEFLECTIONS VS. LOAD	G_{FB}
	TWIST ALONG FILL AXIS	4	SQUARE	2 ROSETTE STRAIN GAGES TWIST ANGLE GAGE	TORQUE VS STRAINS & ROTATION TO FAILURE	G_{FB}, G_{FW}, F_{SU}, $(\tau\text{-}\gamma)$ CURVES
		3	ROUND	TWIST ANGLE GAGE	TORQUE VS ROTATION TO FAILURE	- DO -
COEF. OF EXP.	WARP	2	RECT. BARS		$\Delta L/L$ VS TEMP	α_W, RT TO 1000, 2000, 3000 °F
	FILL	2	- DO -		- DO -	α_F - DO -
	BLOCK	2	- DO -		- DO -	α_B - DO -

* NOT ESSENTIAL TO AUG. '72 ANALYSIS BUT DESIRABLE FOR SCREENING

95

N 3120:090 ENCL. SHT 10

SCHUMACHER 10/27/71

AGCARB DATA REQUIRED FOR STRUCTURAL ANALYSIS OF AUGUST 1972

GROUNDRULES:

(1) DATA TO BE REDUCED BY JUNE 30, 1972 FOR INCORPORATION IN STRESS ANALYSES OF 3 SELECTED FLANGE CONCEPTS.*

(2) ABOVE 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 E_W, E_F, E_B, G_{FB}, ν_{FB}, $\nu_{W,F}$, ν_{WB}, α_W, α_F, α_B.

(b) COMPARISON OF ELASTIC STRESSES WITH R.T. MEAN STRESS-STRAIN CURVES IN W, F, B DIRECTIONS (T 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.

(d) COMPARE MAXIMUM STRESSES FROM (c) WITH R.T. 99-95 UNIAXIAL STRENGTHS F_{TUW}, F_{TUF}, F_{TUB}, F_{CUW}, F_{CUF}, F_{CUB}, $F_{SU_{FB}}$. COMPUTE MARGINS OF SAFETY.

(e) EVALUATE 3 FLANGE CONCEPTS BASED OF MARGINS OF SAFETY.

(3) A FRACTURE ANALYSIS OF THE SELECTED N.E. DESIGN SHOULD BE SCHEDULED FOR EARLY CY 73. TOUGHNESS DATA AND ANALYSIS METHOD TO BE DEVELOPED.

(4) THE FINAL NOZZLE EXTENSION ANALYSIS (BEYOND CY 72) REQUIRES THE FOLLOWING ADDITIONAL DATA:

(a) 3D ANALYSIS DATA (G_{WF}, G_{WB}, F_{SUWF} F_{SUWB}) 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 ANALYSYS 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

AEROJET NUCLEAR SYSTEMS COMPANY

SACRAMENTO, CALIFORNIA

TO: L. A. Shurley

14 December 1971
UAP:jm N8120:105

FROM: U. A. Pineda

SUBJECT: Honeycomb Reinforced Liner - Nozzle Extension

DISTRIBUTION: W. E. Campbell, C. M. Kawashige, T. A. Redfield, K. Sato, J. G. Schumacher, J. J. Stewart, File

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

CLASSIFICATION CATEGORY
Unclassified
U A Pineda 12-14-71
CLASSIFYING OFFICER DATE

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.

U A Pineda

U. A. Pineda, Supervisor
Applied Mechanics Section
Engineering Staff Department

APPENDIX G

NOZZLE EXTENSION OPEN CELL REINFORCEMENT

N8500:M1456

AEROJET NUCLEAR SYSTEMS COMPANY
SACRAMENTO, CALIFORNIA

TO: Distribution DATE: 16 December 1971
LBC:1m:N8500:M1456

FROM: L A Shurley

SUBJECT: Nozzle Extension Open Cell Reinforcement

DISTRIBUTION: W E Campbell, L B Claassen, O J Demuth, H Derow, J E Jellison, C M Kawashige, J A Lampman, J D Mockenhaupt, U A Pineda, R P Radtke, T A Redfield, J G Schumacher, J J Stewart, L M Swope, E F Thacher, E A Thomas, C V Wieg, Jr., J J Williams

REFERENCE: (a) Memo N8120:105, U A Pineda to L A Shurley, dtd 14 December 1971
Subj: "Honeycomb Reinforced Liner-Nozzle Extension"

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.

CLASSIFICATION CATEGORY
Unclassified
C M Kawashige 21 Dec 71
CLASSIFYING OFFICER DATE

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
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