TID-27260

BIPS GDS
MISCELLANEOUS
DESIGN NOTES

76-311998

June 15, 1976

MASTER

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

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PREFACE

This is a compendium of miscellaneous documents, memos, and progress report extracts for the Brayton Isotope Power System Ground Demonstration System Preliminary Design Review.

It should be noted that the document does not represent a formal interim or final report, but is furnished to aid the customer in evaluating the progress of the ERDA BIPS GDS design.

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(1)

GE HARDWARE PREPARATION AT GE

<u>EHS</u>	<u>EHS LOADING FIXTURE (2)</u>	<u>HSA</u>	<u>HSA</u> <u>HANDLING FIXTURE</u>
<ul style="list-style-type: none">o Modify Capso Bakeout @ 1300°C for 100 hourso Add T/Cs in "clean" roomo Store in Dry N₂o Ship to Phoenix	<ul style="list-style-type: none">o Update designo Fabo Ship to Phoenix	<ul style="list-style-type: none">o Fab (NASA/GE)o Clean TBD (NASA/GE)o Weld on Ductso Install Duct Ins & Bellowso Ship in Shipping Container	<ul style="list-style-type: none">o Designo Fabo Ship

GDS PRE-CONDITIONING AT PHOENIX

- (A) Evacuate chamber to 10^{-6} torr and loop to 10^{-3} torr for 48 hours
- (B) Backfill chamber and HSA w/ research grade argon to _____ torr
- (C) Backfill loop to _____ psia w/research grade argon
- (D) Heat EHS to 400°F in _____ hour
- (E) Motor w/ alternator at _____ rpm for _____ hours
- (F) Turn off EHS
- (G) Purge and repeat steps (B) thru (F) until gas samples are satisfactory

CO < _____ PPM

H₂O < _____ PPM

N₂ < _____ PPM

O₂ < _____ PPM

CONDITIONING AND ASSEMBLY AT PHOENIX

PRE-CONDITIONING & STORAGE*

Vacuum Bakeout (Vac Furnace)

HSA

- o 400°F, _____ hrs
- o Ramp to _____°F
in _____ hrs
- o _____°F, _____ hrs
- o Store in dry N₂

MINI BRU

- o 400°F, 16 hrs
- o Store in dry N₂

MBR BELLOWS & DUCTING

- o 1400°F, 16 hrs
(Ramp time 2 hrs)
- o Store in dry N₂

CB PLENUM, BELLOWS & DUCTING

- o _____°F, _____ hrs
- o Store in dry N₂

SUPPORT STRUCTURE

- o 300°F, 16 hrs
- o Store in dry N₂

GDS ASSEMBLY (CLEAN ROOM)

Assemble Support Structure (AIRPHX)

Install HSA and Plenum (AIRPHX)

Measure for Sizing Ring (AIRPHX & GE)

Remove Plenum (AIRPHX)

Machine sizing ring (AIRPHX/GE)

Weld sizing ring and exhaust duct (GE)

in vacuum dry box

Reinstall plenum and perform closure (GE)

weld (procedure TBD) (GE)

See Assembly procedure

*Storage - Transfer components except support structure from vacuum furnace to dry nitrogen storage at 400°F.

BIPS-GDS

COORDINATION MEMO

TO	C. Alexander R. Frank J. Griffo A. Schaffhauser R. Titran	BCL FROM John Hadley GE, Evendale USERDA, NRA ORNL NASA LeRC	MEMO NO: BIPS-GDS-A0143 DATE: 3-29-76 REPLY BY: _____ ☐ REQUEST ☐ INFORMATION ☐ REPLY TO: _____
SUBJECT: Post Mortem Analysis of GDS System			

COMMENT:

The endurance test of the BIPS-GDS system, although complete enough to demonstrate the system capability, may not answer the questions of long life effects due to physical degradation. Therefore, it is proposed that following the conclusion of Phase I testing, follow-on activity be initiated. This task will include post mortem system evaluation including analysis of samples taken thru the use of gas taps to assess working fluid purity and vacuum environment quality during the test. It will also include destructive analysis, at the conclusion of the test, of test samples strategically located within the system. A detailing of the requirements is presented in this memo. Any suggestions on procedure, methods of performing analysis, and other tests which may be required are solicited. Several tests outlined in the IPP document will serve as background and additional information, e.g., C-103 contamination tests, alternator offgassing, insulation compatibility, Inco 713LC stability, braze joint and recuperator aging, etc.

A. Analysis of GDS System at Teardown

The teardown analysis will consist of a careful examination of the GDS components. All critical subassemblies will be visually examined at magnifications of up to 40X. Also, all deposits, surface coatings and other apparent foreign materials will be analyzed chemically. In addition, the following components will be subjected to the indicated individual assessments:

1. Alternator Stator

An extremely careful visual examination will be made with electrical mapping if necessary. The stator should be weighed at installation and after the run. If any significant changes occur, the cause will be determined.

Nothing contained herein shall be deemed to change the terms of any purchase order or contract.

APPROVED BY: *H.W. Longee*

DATE: 4-5-76

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AIRLA

BIPS-GDS

COORDINATION MEMO

MEMO NO:	BIPS-GDS- A0143
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2. MBR

A section of the recuperator, including a typical braze joint and some parent material at the maximum temperature, might be fabricated to include a sacrificial piece that could be removed without destroying the MBR. A cross section of this area will be examined microscopically and a microprobe trace run to evaluate any diffusion effects in the braze and any surface effects in the parent metal.

3. Turbine Wheel

A slice of the inducer tip could be taken and mounted in cross section. Both light and scanning electron microscopy will be used to examine the surface of the Inco 713LC blade. In addition, a microprobe trace for aluminum and chromium will be run from the surface to the interior of the section.

4. HSA

The primary concern for degradation in the HSA is contamination of the C-103 from impurities in the working fluid and those trapped in the insulation. Cross section samples taken from the HSA could prevent use of this component for future testing. Therefore, HSA evaluation will be based on metallograph, microhardness and and interstitial analysis of special sacrificial samples provided for this purpose.

5. Turbine Plenum

The concerns in this area are the same as for the HSA. A sample for interstitial analysis and microhardness will be placed in a convenient location in the wall.

6. Bellows

One of the C-103 bellows will be subjected to destructive analysis. Again, the examination will be conducted by microhardness and interstitial analysis to determine the degree of contamination from working fluid impurities and gasses trapped within the insulation.

7. Other Areas

The integrity of other areas of the system, such as the bimetallic joints,

BIPS-GDS

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insulation, etc. will be assessed in tests covered by the IPP. These tests will be conducted for up to 5000 hours and should yield more comprehensive data than studying the GDS endurance test hardware.

B. Gas Analysis Taps

The number and location of gas analysis taps has been revised from COORD Memo A0108. Only two taps are being considered at the present time. One tap will be located in the vacuum chamber. The most repeated use of this tap will be to check the gas purity during the backfill cycle. The second tap will be located in the ducting for the working fluid before entry into the HRHX. This will be used to assess the working fluid purity.

The other gas taps in the ducting have been eliminated because of the complexity added to the system and the potential problems in knowing that the gas sample is representative of the system gas. Although a sample of the gas flowing from the alternator cavity would be desirable, the location of the tap and length of the sample line appear to raise a serious logistics problem.

C. Sample Location

Samples of the various materials will be placed at different locations in the GDS to determine the possible effects of the environment. Particularly in the case of the C-103, the tests may be more beneficial than analyzing the gas as the level of contaminants may be below the detection level of the analysis equipment. The test samples will naturally integrate the contaminants absorbed to give a more realistic picture of the average pickup rate.

1. C-103 Specimens

In order to assess variations in the gas content, C-103 specimens will be located in 3 areas: the MBR hot exit, between the HSA and turbine plenum and in the turbine exhaust. The specimen in the MBR hot exit will give an indication of the desorbed gasses from the Hastelloy X and the colder portions of the system. This specimen can be compared to the one in the HSA exit duct to indicate the material absorbed by the HSA structure during test. The specimen located in the turbine exit should indicate if there is significant outgassing from the alternator stator, since the gas stream and contaminants do not pass through the HSA.

BIPS-GDS

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The specimens will be characterized by comparing microhardness measurements, interstitial analysis, room temperature bend and tensile tests to similar tests conducted on the as received material. The impact of the contaminants would be more discernable in these tests than in creep. The additional thermal exposure in a creep test could alter the distribution of the interstitials and affect the test implications. Two samples of 0.060" thick X 3/4" wide by 6" long should be placed in each location to obtain the specimens necessary for test.

2. Superalloys

Superalloy samples, i.e., Hastelloy X and Inco 713LC, will not be necessary if the listed destructive analysis are performed on the system. The primary effects for exploration are surface effects and can best be explored on the hardware which has been exposed to the true environment. For instance, a sample of Inco 713LC in the turbine plenum will not see the same gas velocity effects that the turbine wheel blades will be exposed to. Therefore, no samples of these materials are recommended at this time.

In addition to commenting on the tests to be conducted, any aid in test methods will be appreciated. Two areas of particular significance are the mechanics of obtaining a sample from the vacuum chamber at low pressure and a "standardized" bend test for the C-103 samples.

Please be ready to discuss the post mortem test plan at the next MARSCOM meeting. Since this test work may add significant cost and complexity to the program, the value must be carefully weighed against the test work already outlined in the IPP.

NATURAL FREQUENCY ANALYSIS OF THE BIPS

76-311773

April 8, 1976

1.0 INTRODUCTION

The BIPS consists of a cylindrical radiator which supports four discrete masses by means of interface structures consisting of beams and struts. The four discrete masses are two heat source heat exchangers, the recuperator and the Mini-BRU turbine unit. The BIPS is mounted atop the satellite which is mounted atop the interim upper stage (IUS). The IUS is mounted on the space shuttle.

The design criteria requires that the BIPS components and mounting pads should be designed to a minimum limit loading of 50 g's. The BIPS interface structure should be designed to a minimum limit loading of 25 g's. The interface structures must also have sufficient stiffness to maintain the BIPS component natural frequencies above 60 cps which is about five times higher than the fundamental frequencies of the space shuttle. The analysis is based on the following components weights:

HSA	-	180 lbs
Recuperator	-	100 lbs
Mini-BRU	-	38 lbs
Interface Structure	-	42 lbs
Miscellaneous	-	20 lbs
<hr/>		
TOTAL	-	380 lbs

2.0 CONCLUSION

Three materials, namely: aluminum, Lockalloy and Beryllium and various sizes of the interface structures were utilized in the dynamic analysis of the BIPS system. The fundamental frequency varies from 38 cps to 227 cps dependent upon the material and the size of the interface structures. The built-in strength of all the interface structures is in excess of the 25 g's. This limit loading should also satisfy requirements for all other loadings such as prelaunch environment, launch environment, operational environment and crash landing requirements. The BIPS system is considered to have adequate stiffness and strength for the preliminary design phase. The analysis is based upon mechanical properties shown on Table 3. The natural frequencies are very sensitive to variations in these properties.

3.0 RECOMMENDATION

- (a) All interface structures be fabricated from the material Lockalloy for the flight system.
- (b) All the upper interface structure be 1-1/2 in. by 1/16 in. tube. And all lower interface structure be 1 in. by 1/8 in. tube.
- (c) See Figure 3 for the recommended recuperator mounting pad.

4.0 DISCUSSION

The approach to the BIPS fundamental frequencies includes features as follows:

- (1) The natural frequencies of the individual interface structures are first determined. The most critical individual interface structures are the upper tubular beams which

directly carry the weight of the HSA. These beams are subject to bending and twisting. The fundamental frequency is 70 cps for 1-1/2 in. by 1/16 in. Lockalloy tube, which has a section modulus 0.097 in.³. The required section modulus for a limit loading of 25 g's is 0.068 in.³.

- (2) The fundamental frequency of the radiator was determined by using Kalnin's program. The radiator was analyzed as a 0.03 in. cylindrical shell with one end fixed. A discrete mass of 380 lbs was supported at the free end. The fundamental frequencies varies from 70 cps to 570 cps dependent upon the material of construction and the vibration mode. Table 1 summarizes the results.
- (3) A dynamic model as shown in Figure 1 was set up to determine the fundamental frequencies of the interface structures as a system. The model consists of the major interface structures (due to the limitation of the program utilized, it is impossible to include all the beams and struts) the four discrete masses and the simulated radiator. The program used does not have the ability to handle plates and shells. Therefore, the radiator was replaced by six columns which have the same overall lateral and axial stiffnesses as the cylindrical radiator. The interface structures are grouped as upper beams and lower beams depending upon their relative position above or below the upper header. Fundamental frequencies were calculated for three materials and various combination of tube sizes. Table 2 summarizes the results. The computation is extremely time consuming. Basically the fundamental frequencies of the aluminum beams were first calculated. The frequencies for the other materials were ratioed according to the square root of the ratio of the Young's modulus and density. Since the actual system is more rigid than the model itself. It is believed that the results are conservative.

5.0 MOUNTING PADS

All the mounting pads are designed for a limit loading of 50 g's. The recuperator is mounted at three points. Figure 2 shows the mount location and the maximum load at each mount. It is a statically determinate system, which eliminates self induced thermal loads and installation misalignment loads. The HSA is supported at top and the bottom. There are three mounts at the top to carry the weight of the HSA. The lower support takes only the lateral load.

S. Yang
Structures and Installations
Mechanical Component Design
Engineering Sciences

Approved:
T.T. Hamrick

Approved:
T.G. Howell

lh

			DYNAMIC MODEL FOR THE NATURAL FREQUENCY OF THE BIPS	FIGURE 1
PREPARED	S.Y.	3/76		
WRITTEN			AiResearch Manufacturing Company of Arizona	
APPROVED

WT = 100 LBS

MOUNT LOAD FOR A MAXIMUM LIMIT LOAD OF 50g

	NO. 1.			NO. 2		NO. 3
	X	Y	Z	X	Z	X
50g's X DIRECTION	0	0	0	-25g	0	-25g
50g's Y DIRECTION	0	-50g	-16.5g	0	+16.5g	0
50g's Z DIRECTION	0	0	-25g	0	-25g	0

			RECUPERATOR MOUNTS	FIGURE 2
PREPARED	S.Y.	3/76		
WRITTEN				
APPROVED			AiResearch Manufacturing Company of Arizona

FIGURE 3

RECUPERATOR MOUNTS

S.Y. 3/76

PREPARED

WRITTEN

APPROVED

AirResearch Manufacturing Company of Arizona

	LATERAL VIB (CPS)	LONG. VIB (CPS)	RADIAL VIB (CPS)
ALUMINUM	70	210	82
LOCKALLOY	139	417	163
BERYLLIUM	190	170	223

			NATURAL FREQUENCIES OF THE RADIATOR	TABLE 1
PREPARED	S. Y.	3/76		
WRITTEN			AiResearch Manufacturing Company of Arizona	
APPROVED

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TABLE 2
LOWEST NATURAL FREQUENCY OF THE BIPS (CPS)

UPPER LOWER	1-1/2x1/16	1-1/2x1/8	1-3/4x1/16	2x1/16	2-1/4x1/8	3x1/8
1x1/16	A 38 L 74 B 101					
1x1/8	A 42 L 82 B 112	A 56 L 110 B 153				A 70 L 138 B 190
1-1/2x1/16				A 54 L 108 B 149		
1-3/4x1/16			A 55 L 106 B 146			
2x1/16				A 63 L 125 B 171		
2-1/4x1/8					A 84 L 165 B 227	

NOTE: (1) A = ALUMINUM
 L = LOCKALLOY
 B = BERYLLIUM

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TABLE 3
MATERIALS MECHANICAL PROPERTIES

	Density (lb/in. ³)	E (psi)	Y.P. (psi) @ 200°F
Aluminum	0.1	10×10^6	35,000
Lockalloy	0.076	30×10^6	30,000
Beryllium	0.067	50×10^6	46,000

AIRESEARCH MANUFACTURING COMPANY

A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONAIn reply refer to
ES: SJY: 004: 042876

OFFICE MEMO

DATE: April 28, 197

SUBJECT: Stress Analysis Summary of
the BIPS Interface Structures

The Mini-BRU, MBR and HSA are supported by the radiator through interface structures (i.e., beam struts etc). The interface structures are designed not only to a minimum limit load of 25 g's but to provide sufficient stiffness to maintain the BIPS component natural frequencies above 60 cps. The results of a detailed frequency analysis was documented in Report 76-311773. This memo summarizes the stresses in the interface structures due to the 25 g limit loading.

The upper interface structure is composed of 1-1/2 in. x 1/16 in. Lockalloy tubes as shown in Figure 1. The most critically stressed tube is the one which carries the weight of the HSA directly. Location of the critical stress is at the mount as shown in Figure 1. This tube is subjected to bending and twisting.

$$W = 25 \times \frac{90}{3} = 750 \text{ lbs}$$

$$\text{Maximum Bending Moment} = \frac{Wl}{8} = 2380 \text{ in.-lb}$$

$$\sigma_{y.p.} = 35,000 \text{ psi (Lockalloy at } 300^{\circ}\text{F)}$$

$$\text{Required section modulus} = \frac{2380}{35000} = 0.068 \text{ in.}^3$$

$$\text{Available section modulus} = 0.097 \text{ in.}^3$$

$$\text{Twisting moment} = 1.67 \times 1/3 \quad 90 \times 25 = 1253 \text{ in.-lb}$$

$$\text{Shear stress } t = \frac{1253}{2(1.69)(0.0025)} = 6000 \text{ psi}$$

$$\text{Equivalent stress} = 24,820 \text{ psi}$$

$$\text{Margin of safety on tensile yield} = 0.43$$

The lower supporting structure, as shown in Figure 2, carries the weights of the MBR and the Mini-BRU turbine unit. The maximum g loading at the MBR mounts is shown in Table I. A structural model was set up to calculate the force in each strut by using program JPL. The results are shown in Table II. The materials yielding strength at R.T. is 35,000 psi. There is no tube stressed above the yielding strength due to the limit 25 g loading.

TABLE I

MAXIMUM MBR MOUNT LOADS

	NO. 1			NO. 2			NO. 3		
	X	Y	Z	X	Y	Z	X	Y	Z
25 g - Z	0	0	0	0	0	-12.5 g	0	0	-12.5 g
25 g - Y	8.25 g	-25 g	0	-8.25 g	0	0	0	0	0
25 g - X	-12.5 g	0	0	-12.5 g	0	0	0	0	0

TABLE II

STRESSES IN LOWER SUPPORT STRUCTURE
(1 x 1/16 LOCKALLOY TUBE)

<u>Member No.</u>	<u>Loading</u>	<u>Force (lb)</u>	<u>Axial Stress (psi)</u>	<u>Maximum Bending Stress (psi)</u>	<u>Total Stress (psi)</u>
1	25 g-Y	900	4891	18,219	23,110
2	"	1233	6700	25,900	27,140
3	"	1062	5770	20,730	26,500
4	"	10	54	7,806	7,860
5	"	9	49	23,351	23,400
6	"	14	76	27,724	27,800
7	"	168	913	24,536	24,700
8	"	16	87	26,413	26,500
9	"	110	598	19,000	19,600
10	"	111	600	17,900	18,500
11	"	630	3423	18,977	22,400
12	"	450	2446	10,804	13,250
13	"	604	3283	16,067	19,350
14	"	516	2800	13,030	15,830
15	"	708	3848	2,982	6,830
16	25 g-Z	155	843	1,346	2,189
17	25 g-X	253	1375	853	2,228
18	"	340	1847	2,342	4,189
19	"	68	370	2,584	2,954
20	25 g-Y	691	3755	5,097	8,882
21	"	966	5250	5,040	10,290
22	"	792	4300	7,317	11,617
23	"	618	3358	6,097	9,455
24	25 g-Z	616	3347	340	3,686
25	"	472	2562	1,151	3,713
26	25 g-Y	850	4620	3,680	8,300
27	25 g-X	408	2217	3,854	6,071
28	25 g-Y	14	76	3,824	7,900

FIGURE 1. UPPER SUPPORTING STRUCTURE
(1-1/2 X 1/16 LOCKALLOY TUBE)

TOP VIEW

			STRUCTURAL MODEL OF THE LOWER SUPPORTING STRUCTURE	FIGURE 2
PREPARED	SJY	4-76		
WRITTEN			AiResearch Manufacturing Company of Arizona	
APPROVED

PRELIMINARY EVALUATION OF THE MINI-BRU
TURBINE PLENUM IN SUPERALLOY AND THE
CURRENTLY AVAILABLE HEAT EXCHANGER FOR
THE BIPS WORKHORSE SYSTEM

76-311903

May 11, 1976

INTRODUCTION

The Mini-BRU turbine plenum fabricated in superalloy, and the currently available L.A. heat exchanger (P/N X979185), have been examined under the following two operating conditions for the BIPS workhorse system.

<u>Pressure</u> <u>(psia)</u>	<u>Max. Plenum Metal Temp. (°F)</u>	<u>Hours</u>
100	1600	5
50	1400	50

Waspaloy is chosen as the first candidate material for the Mini-BRU turbine plenum and nozzle assembly. The original plenum configuration of CB-103 was modified to cope with the high thermal expansion coefficients and high Young's Modulus of Waspaloy. No detailed creep relaxation analysis was carried out in this report due to the relatively short operating hours.

CONCLUSION

- (1) Based on the estimated metal temperature and material data, the modified turbine plenum in Waspaloy is satisfactory from a stress standpoint for either of the two operating conditions.

- (2) With recommended modification, the currently available heat exchanger can be operated in the workhorse system at either of the two operating conditions.

RECOMMENDATIONS

- (1) The turbine plenum and nozzle assembly should be fabricated according to the modified configuration as shown in Figure 1.
- (2) The plenum skin and nozzle assembly should be fabricated in Waspaloy (A). Creep properties for Waspaloy sheet and forgings are shown in Figures 2 and 3 for heat treat (A) condition.
- (3) The plenum should be fabricated from 0.06 inch sheet.
- (4) The turbine shroud should have uniform thickness instead of being stiffened as in the CB-103 configuration.
- (5) That the turbine nozzle be welded to the shroud in a manner similar to the CB-103 configuration.
- (6) That the L.A. heat exchanger be utilized without electrodes in the top three and bottom three tubes as shown in Figure 4.
- (7) Two 0.063 inch HS-188 plates should be E-beam welded to the top and bottom corrugated sheets of the heat exchanger as shown in Figure 4.

DISCUSSION

(1) Turbine Plenum in Superalloy for the Workhorse System

When superalloy such as Waspaloy is used as the material of construction for the turbine plenum, thermal stress plays an important

role. In order to provide enough flexibility to minimize the thermal stress, the plenum is modified as shown in Figure 1. The turbine plenum and nozzle assembly were analyzed for two different plenum skin thicknesses. Reducing the skin thickness will generally increase the pressure stress and decrease the thermal stress. The net effect is dependent upon the metal temperature and actual thickness used for the plenum. Table I summarizes the stress level in the vane. Table II summarizes the general stress levels in the turbine plenum and its supporting structure. The stress level associated with the 1400°F max. skin temperature and 50 psia are generally lower than the stress levels associated with the 1600°F max. skin temperature and 100 psia pressure. However, the two different skin thicknesses do not significantly change the nozzle stress level, but has a significant effect upon the plenum hoop stress. For the 1600°F operating condition, since the design life is only 5 hours, the elastic stress distribution is all that is needed to be considered. For the 1400°F operating condition, the design life is 50 hours. Creep strength is the criterion. The creep strength of Waspaloy is shown in Figures 2 and 3. In either operating condition, there are no calculated stresses that exceed the material yield strength at temperature or the 0.5 percent creep strength for 50 hours. (The 0.5 percent creep strength is used since 1 percent creep data is not available for sheet.)

(2) The Existing L.A. HSHX for the Workhorse System

This piece of hardware, as shown in Figure 4, was originally designed for very low pressure. If utilized in the workhorse system, the pressure will be much higher. The tube temperature was estimated to be 1750°F and the supporting plate to be 1600°F. As a result of the thermal gradient, high thermal stresses exist at the juncture where the three top and bottom tubes are welded to the two side plates. The central tubes are less critical because of the side plate flexibility. Since this HSHX produce more heat than is needed for the workhorse system, it is recommended not to insert the electrodes in the

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top and bottom three tubes as indicated in Figure 4. The top and bottom plates (0.063 inch flat plate and 0.036 inch corrugated sheet) are subjected to much higher pressure in the workhorse system than it was original designed for. The maximum bending stress at the ends is 39,600 psi under 50 psia, exceeding the yield strength of Hastelloy X at 1400°F. This bending strength can be reduced to a level of 11,360 psi if reinforced with a 0.063 inch HS-188 plate E-beam welded to the corrugated sheets as shown in Figure 4. The added stiffness is also adequate for the 1600°F and 100 psia operating condition for five hours life.

S.J. Yang
Structures and Installations
Mechanical Component Design
Engineering Sciences

Approved:

T.T. Hamrick

Approved:

T.G. Howell

lh

MODIFIED TURBINE PLENUM CONFIGURATION IN WASPALOY

FIGURE 1

46 5493

SEMI-LOGARITHMIC CYCLES A IN DIVISIONS
KEUFFEL & ESSER CO. NEW YORK

KF

(1)

SOURCE: THE ELEVATION-TEMPERATURE
PROPERTIES OF SELECTED
SUPERALLOY; ASTAI DS 7-5

THE CURRENTLY AVAILABLE L.A. HXHS

FIGURE 4

TABLE 1
STRESS LEVELS IN THE VANE ATTACHMENT (REFERENCE FIGURE 1)

Point	R (inch)	1600°F 100 psia				1400°F 50 psia			
		0.04 Inch Plenum		0.06 Inch Plenum		0.04 Inch Plenum		0.06 Inch Plenum	
		Bending Stress (psi)	Shear (psi)	Bending Stress (psi)	Shear (psi)	Bending Stress (psi)	Shear (psi)	Bending Stress (psi)	Shear (psi)
(L.E.) 487	1.876	-2,100	8,700	-3,500	8,100	-5,200	8,700	-6,500	8,100
486	1.804	900	-3,200	1,100	-3,400	800	-1,200	900	-1,400
485	1.75	100	-3,000	0	-2,300	600	-400	400	-800
484	1.70	4,400	14,500	4,400	14,100	3,900	13,500	3,900	13,100
483	1.65	3,800	11,800	4,000	11,500	3,200	10,900	3,500	10,400
482	1.60	4,500	15,700	5,000	15,400	4,300	14,100	4,900	13,700
481	1.55	3,500	14,800	4,600	14,700	4,600	13,500	6,000	13,300
480	1.50	1,300	11,300	3,300	11,600	3,500	14,400	6,100	10,600
(T.E.) 479	1.483	1,100	10,200	4,300	10,800	3,000	8,800	6,900	9,400

- NOTE:** (1) Stress levels reflect pressure and temperature
(2) Yielding strength of Waspaloy at 1600°F = 75 ksi (typ.)
(3) 0.5 percent creep strength of Waspaloy sheet at 1400°F and 50 hour = 51 ksi (typ.) Ref. Figure 2
(4) 0.5 percent creep strength of Waspaloy forging at 1400°F and 50 hours = 47 ksi (typ.) Ref. Figure 3
(5) Stresses shown are for a 40°F margin on temperature

TABLE 2
STRESS LEVELS IN PLENUM

Point	1600°F Max. Skin Temp.; 100 psia					1400°F Max. Skin Temp.; 50 psia				
	Temp. (°F)	0.06 Inch Plenum		0.04 Inch Plenum		Temp. (°F)	0.04 Inch Plenum		0.06 Inch Plenum	
		Bending Stress (psi)	Hoop Stress (psi)	Bending Stress (psi)	Hoop Stress (psi)		Bending Stress (psi)	Hoop Stress (psi)	Bending Stress (psi)	Hoop Stress (psi)
A	1,600	-8,200	-8,700	-3,700	-5,700	1,400	-4,200	-7,100	-8,100	-9,200
B	1,600	200	5,000	1,400	7,000	1,400	600	3,500	0	2,800
C	1,600	3,300	3,700	3,100	4,700	1,400	1,900	2,700	2,700	2,600
D	1,550	-5,900	-13,500	-5,300	-12,300	1,350	-5,200	-14,500	-5,700	-15,500
E	1,440	4,300	-900	1,200	-3,500	1,240	1,900	-1,800	3,200	-500
F	1,400	1,200	-1,800	2,600	-1,500	1,200	-300	-1,400	-1,300	-1,500
G	512	-65,000	-44,800	-65,000	-44,800	512	-59,200	-40,500	-59,200	-38,800
H	1,422	-51,200	-3,600	-52,900	-3,500	1,272	-20,700	4,700	-19,300	4,600
I	1,470	26,900	19,300	25,300	18,400	1,270	19,700	16,900	21,500	17,900

- NOTE:**
- (1) See Figure 1 for point locations
 - (2) Stress levels reflect pressure and temperature
 - (3) The 0.2 percent yield strength of Waspaloy at 1600°F is 75,000 psi
 - (4) The 0.5 percent creep strength of Waspaloy at 1400°F and 50 hrs. is 51,000 psi
 - (5) Stresses shown are for a 40°F margin on temperature

JUSTIFICATION OF THE HRHX

1. The radiator can be simulated with a conventional heat exchanger by use of an appropriate control system in conjunction with a high peak capacity coolant system to control T1 to the level predicted by the FS transient. A reservoir of coolant will effectively increase the capacity of the cooling system for peak loads. The test is actually more rigorous without the sophistication, as it would be a more difficult start as T1 would be at a higher level than that which will exist with an actual radiator simulation.
2. Because of the use of M-foil insulation and the presence of the constant heat flux (MHW) to be rejected, none of the components can approach the sink temperature anyway. The temperature excursions predicted by the current transient analysis would be a worst case for thermal stress but true start up would be less severe and will be simulated by the HRHX.
3. Cryo-panels are complicated, expensive and potentially unreliable. To simulate the true space conditions, a minimum of 4 cylindrical sections (quadrants) with appropriate cooling systems would be required as well as a panel for the open end of the radiator. The entire tank would be insulated on the outside to minimize the size of the coolant system.

Liquid argon would be the coolant and any loss would result in a shutdown - undesirable for the endurance run. The cooling systems for the CRYO panels is much more expensive and complex than the conventional refrigeration system for the HRHX.

The overall result is that it is considerably simpler (and less costly) to accurately simulate expected working fluid transients with the proposed HRHX than by trying to force a transient by simulating space.

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4. With the HRHX, performance mapping is facilitated because steady state is more easily reached than with a system using radiation.

5. Mini-BRU working fluid does not freeze and does not have the undesirable viscosity characteristic of a liquid.

With the quadrant scheme mentioned previously, different sections of the radiator would be maintained at varying sink temperatures to simulate the space environment. The fluid properties of a gas results in stabilization of the flow in a favorable manner, i.e., more gas would travel through the tubes in the cold region of the radiator. This is caused by the positive slope of the viscosity versus temperature curve. It has been shown (Reference Vol. 2, Technical Proposal, P. 6.5-143-116) that a net performance advantage may be expected. In the case of liquid radiators, the slope of this curve is negative and an undesirable flow distribution is possible. Because of the higher viscosity in the colder regions, liquid would tend to be forced into the warmer tubes. This can continue to the point of freezing in the low temperature area. This in turn forces all of the flow through the high temperature area with a consequential performance penalty. Great care must be taken in the design of liquid radiators to prevent this phenomena from starting for it ultimately can result in the loss of up to half of the radiator area.

6. The Mini-BRU working fluid does not have any tricky bypass routes or potential for mixed phase flow. All of the flow which goes through the turbine traverses the radiator.

7. Radiator design is well characterized (AIRLA work in the 1960's and many others) and this component does not have to withstand the thermal stresses as the hotter components must.

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8. Cost and schedule benefit significantly from the technical justification for using a radiator simulator as opposed to the alternative of using a radiator with a space simulator.

GENERAL ELECTRIC

SPACE DIVISION
PHILADELPHIA

PROGRAM INFORMATION REQUEST / RELEASE

CLASS. LTR.	OPERATION	PROGRAM	SEQUENCE NO. 5813	REV. LTR.
PIR NO.				
*USE "C" FOR CLASSIFIED AND "U" FOR UNCLASSIFIED				

FROM R. HARTMAN	TO R. J. HEMLER
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DATE SENT 5/26/76	DATE INFO. REQUIRED	PROJECT AND REQ. NO.	REFERENCE DIR. NO.
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SUBJECT RESPONSE TO PRELIMINARY DESIGN REVIEW ACTION ITEMS

INFORMATION REQUESTED/RELEASED

This PIR responds to CO-ORD Memo G0068 which defines the GE action items resulting from the BIPS Preliminary Design Review (5/6/76) with AIRPHX.

Action Item #1 - Define HRHX leak rate requirements

The design goal for leakage of the working fluid is $< 1 \times 10^{-9}$ scc He/Sec. However, it is planned that the acceptance requirement will be $< 1 \times 10^{-7}$ scc He/Sec at 70 psia internal pressure (operating pressure - see #3). Such a leak rate results in a loss of working fluid = ~ 2 scc / 6000 hrs. Since the HRHX is not a flight component and there

is a make up system for the working fluid, this requirement appears to be reasonable as well as practical. The quantity of air that could enter the HRHX was calculated for the condition wherein a negative pressure differential existed for 6000 hours (worst case). A 1×10^{-7} scc He/Sec leak rate = $1 \times 10^{-7} \frac{\text{scc He}}{\text{sec}} \left(\frac{4}{29} \right)^{\frac{1}{2}} = 3.7 \times 10^{-8} \frac{\text{scc Air}}{\text{sec}}$.

Such a leak rate will result in $\sim 1 \times 10^{-3}$ gram Air / 6000 hrs.

The leakage requirement for the coolant tubes and header will be: "No indication of leakage when pressurized to operating pressures and leak tested with liquid leak detector (SNOOP or equivalent)".

Action Item #2 - Analyze HRHX performance for 3 HSA Conditions

This analysis is scheduled for completion by July 1, 1976.

Action Item #3 - Evaluate increasing HRHX operating pressure requirement from 40 psia to 70 psia

Since the detail design of the HRHX has not been completed, the design operating pressure requirement will be increased to 70 psia (3 HSA condition). The design details will reflect this increase.

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R. Hemler	E. Williams		☐ MOS.	☐ MOS.
C. Kelly			☐	☐ DO NOT DESTROY

The proof pressure test requirement will therefore increase to:

$$P_{\text{Proof}} = 1.75 P_D \approx 125 \text{ Psia.}$$

Action Item #4 - Resolve need for thermal cycle acceptance test of HRHX. Define test details, if required.

There are two types of thermal cycles tests that can be considered; namely, an isothermal cycle test and an in-gradient cycle test. The isothermal cycle test, while the least expensive to perform, has only limited value. In this type of test the HRHX would be placed in a furnace and cycled from ambient temperature to operating temperature. Such a test is not expected to be sufficiently severe.

The more representative (and severe) test is the in-gradient thermal cycle test. This test maintains the in-gradient temperature distribution throughout the HRHX while also providing startup/shutdown operations. Such a test is a meaningful evaluation of the integrity of the HRHX braze joints. It is recommended that such a test be performed as part of the HRHX performance testing at AIRPHX. These tests will be performed using the GDS refrigeration system and can be incorporated into the planned performance tests. It is recommended that a minimum of 3 and a maximum of six startup/shutdown cycles be performed. Helium leak testing (gas side) and liquid leak testing (coolant side) will be used to assess the integrity of the braze joints after thermal cycle testing.

Action Item #5 - Is the capability to service the two HSA's independently during the GDS required?

This capability is not a fixed requirement; AIRPHX foresees no situation wherein one HSA must be serviced independently of the other. If this capability is eliminated it can reduce the pneumatic penetrations through the chamber (from 2 to 1).

It is recommended, however, that this capability be retained. It allows flexibility which is desirable for an engineering test such as the GDS. For example it provides the following capability:

- a) An independent pressure decay test of each HSA to assure adequate leak tightness before backfilling and opening the T/V chamber.
- b) Gas sampling capability of each HSA - This may be a significant diagnostic tool to understand HSA performance.

Since there will be numerous chamber penetrations, the elimination of one resulting in the exclusion of the above capabilities does not seem warranted. It is therefore recommended that the present ACS/gas management system design be retained.

One of the two "Tees" in the gas management plumbing system will be eliminated to simplify the overall system.

Action Item #6 - GE to provide list of ACS hardware supplied by GE and AIRPHX

In summary AIRPHX will be responsible for providing the HSA Emergency Backfill hardware and the hardware connecting the HSA's to the T/V chamber penetrations. GE shall be responsible for providing the ACS/ Gas Management hardware external to the T/V chamber. More specifically the hardware responsibility is presented below:

<u>ACS Component</u>	<u>Part No.</u>	<u>Qty. Required for GDS</u>	<u>Furnished By</u>
HSA GMV	47C313078G1	2	GE (HSA Program)
Flex Hose	TBD	2	AIRPHX
Vent Solenoid	V 70400-100	2	AIRPHX
St. St'l Tubing (inside Chamber)	1/2" dia.	AR	AIRPHX
Pneumatic Chamber Penetration	AN832-8J	2	AIRPHX
Ion Gage & Manual Valve	TBD	2	AIRPHX
Gas Service Cart (GSC)	47J303504 (or equivalent)	1	GE
St. St'l Tubing (GSC to Chamber)	1/2" dia.	AR	GE
Manual Valves (ACS/Gas Mgmt)	NUPRO SS-8BK-TSW	2	GE
Tee-Emergency Backfill to ACS	SS-8-TSW-3 (Cajon)	1	GE
Tee-Ion Gage to HSA	SS-8-TSW-3	2	GE
Backfill Solenoids	V70400-XX (Fail open) Valcor Eng.	2	AIRPHX

<u>ACS Component</u>	<u>Part No.</u>	<u>Qty. Required for GDS</u>	<u>Furnished By</u>
Inert Gas Supply (Emergency Backfill)	-	~20 Std ℓ per charge per HSA	AIRPHX
Dual Stage Regulator (Emergency Backfill)	TBD	1	AIRPHX
Manual Valves (Emergency Backfill)	NUPRO SS-8BK-TSW	5	AIRPHX
Metering Valve (Emergency Backfill)	TBD	1	AIRPHX

Action Item #7 - GE to provide design description and performance characteristics of GSC roughing pump system and backstreaming protection.

The roughing pump used in the Gas Service Cart is a Welch - Model 1402B. The pump is a two stage vacuum air pump with 1/2 horsepower motor and vented exhaust. It's free air capacity is 160 ℓ /min. at 525 rpm. The guaranteed vacuum with vent closed is 1×10^{-4} Torr. Built into the pump is a check valve to protect against backstreaming.

A Deltech filter, model 110, is also used to prevent backstreaming of pump contaminants into the system. A design description of the filter and its performance characteristics are enclosed for AIRPHX review. Also enclosed is GE Drawing 47E303491 which defines the GSC roughing pump system as well as the overall GSC plumbing schematic.

Action Item #8 - Provide AIRPHX specifications for GSC regulators and in-line filters

Discussions were held between J. Hatman (GE) and AIRPHX (T. Ashe, G. Miller) to review the GSC regulators and in-line filters. PIR 5344, which provides Mattheson regulator drawings, was furnished to AIRPHX.

Action Item #9a - Provide recommendations to AIRPHX for Modifications to EHS to integrate with HSA

Modfications to the MHW-EHS are required in order to utilize the EHS in the BIPS-HSA. These modifications are required in order to support the HSHX. In addition, when an IHS is used in the HSA, the graphite heat source support assembly must be modified to support the HSHX; the IHS itself requires no modification.

It is desirable that the method of supporting the HSHX be the same for both the IHS and EHS. The design shown in Figure 1 (presented at the design review) is not necessarily compatible with the IHS end cap design. In addition there is concern that the Cb screws, which hold the Cb brackets to the end cap, could seize when removing the EHS or installing the IHS.

The objective of supporting the HSHX in the same manner for IHS or EHS can be accomplished as shown in Figures 2 thru 5. Both designs, for IHS and EHS, are compatible with the present HSHX header bracket design. The support system consists of a vertically slotted Cb ring (fwd and aft ends) to prevent rotational movement and a Cb support ring with "L" shaped slots (fwd end) to provide axial support. A graphite ring nut is used to fix the Cb support rings in place. Alternate methods of fixing the Cb support rings to the heat source support (aft end) are shown in Figures 6 & 7. The potential for seizing the attachment screw, however, is as previously stated. Tungsten and Iridium diffusion barriers are used to prevent Cb/Carbon reactions. Shimming of the heat source has been identified as a method of reducing the tolerance between centerlines of the monoballs and the HSHX ports (Ref. #9b). If the shimming requirements are not excessive, the diffusion barrier shims may be adequate. If greater shimming is required, thicker graphite shims, located between the heat source support and heat source end cap can be used.

To make the EHS compatible with the HSA, the forward EHS end cap must be modified as shown in Figure 4 and the aft heat source support must be redesigned as shown in Figure 5 or 7.

Loading of the EHS into the HSA must be performed before installation of the forward multi-foil insulation packet. This will therefore require routing the EHS T/C's thru the foil insulation after the EHS is installed. For an air loading operation (which is the recommended approach) this is not considered to be a problem. (For an IHS, which has no instrumentation, there is no effect.)

There is concern with respect to the alignment (plane and radial direction) of the eight Cb studs that engage the Cb support rings. An alternate design is proposed and is shown in Figure 8. The design is applicable to the EHS and the IHS. In this concept a graphite receptacle ring is attached to the Cb support bracket. Diffusion barriers are used to prevent Cb/C reactions. The Cb support bracket is modified slightly to allow it to be rotated 90° from the existing design. This therefore permits vertical

MODIFICATIONS TO EHS FOR HSA LOADING

-- CONCEPTUAL DESIGN --

FIGURE 1

IHS/HSHX SUPPORT SYSTEM
(FWD END)

FIGURE 2

-8-

IHS/HSHX INTERFACE
(AFT END)

FIGURE 3

EHS/HSHX SUPPORT SYSTEM
(FWD END)

FIGURE 4

EHS/HSHX INTERFACE
(AFT END)

FIGURE 5

ALTERNATE DESIGN
IHS/HSHX INTERFACE
(AFT END)

FIGURE 6

ALTERNATE DESIGN
EHS/HSHX INTERFACE
(AFT END)

FIGURE 7

-13-

IHS OR EHS/HSX
SUPPORT SYSTEM

LOCK RING DESIGN

FIGURE 8

attachment of the graphite receptacle. The heat source support assembly contains a graphite lock ring which engages the graphite receptacle upon assembly. A graphite set screw and spacer maintain the lock ring in the heat source support assembly during installation. This concept is a proven design that is presently used to secure the end caps to the aero-shell on the MHW-MJS isotope heat source. The design also simplifies the loading operation. For an IHS this means less exposure time for operating personnel. There are, however, several potential problem areas that must be studied further; namely:

- a) routing of the EHS T/C instrumentation through the heat source support
- b) shimming of the heat source, if required.

To summarize, two concepts are being evaluated. Further study is required to make a final selection. However, either approach requires the fabrication of new support hardware for both ends of the EHS. The least time for the purchase of POCO is expected to be 3-4 months. Therefore, timely direction to proceed with the concept selection and detail design effort, as well as material procurement, is essential.

Action Item #9b - GE to provide a recommendation regarding the use of shimming to reduce the HSHX inlet/outlet port location tolerances.

GE has evaluated the use of shimming to reduce the tolerances. These studies show that by shimming in the area of the HSHX support brackets (attached to the heat source) the tolerance can be reduced significantly without seriously affecting the interchangeability of heat sources. The use of shimming in the area noted above would result in the following tolerance stackup using the centerline of the 3 self aligning bearings as the reference plane:

① Monoballs to inlet end of housing	$\pm .0025$ (unchanged)
② Length of housing	$\pm .005$ (unchanged)
③ Location of Outlet Preload Screw	$\pm .005$ (Build dimension - unchanged)
④ Length of Preload Screw	$\pm .005$ (unchanged)
⑤ Thickness of Bearing Disk, Barrier Wafer	$\pm .001$ (unchanged)
⑥ Thickness of heat source support	$\pm .005$
⑦ Heat Source length allowance for measurement & flatness	$\pm .010$ (reduced from ± 0.045)

⑧ Allowance for Shimming Operation	<u>±</u> .0025	
⑨ Location of Inlet Port on HSHX	<u>±</u> .010	(reduced from <u>±</u> .060)
	<hr/>	
Total Tolerance to Inlet Port	<u>±</u> .046	

NOTE: Item (6) replaces the ± .010 on the dimension between the heat source mounting interface and the HSHX mounting interface and Item (8) is an added tolerance. Items (7) and (8) are estimates of what can be achieved.

Action Item #10 - GE to provide part numbers for mating plugs for HSA instrumentation connectors. Also GE to provide definition of EHS Power Feedthrough Connector for chamber.

The mating connector plugs for the W-Re HSA instrumentation are defined as 47D301639P11 through P14 (GE drawing 47D301639 enclosed). These plugs have Hoskins 203/225 contacts and are properly keyed to mate with the instrumentation receptacles on the HSA. The approximate cost per plug is \$350 and the delivery is 4 months. Gulton Industries and GE have designed a crimp/socket T/C contact for attaching the cabling to the connector. That item is defined on Gulton Industries drawing 8982 (Socket, T/C - size #20). These contacts are approximately \$3 each. An alternate approach for connecting the cabling is to use crimp/weld sleeves which are Gulton part numbers 4150-343-10 (Hoskins 225) and 4150-343-12 (Hoskins 203).

An investigation is currently in progress on the MHW-MJS Program regarding the effect of the ceramic inserts in the plugs especially with regard to their effect on the socket tension of the pin. The ceramic insert provides support to the pins to prevent bending during mating. It is recommended that these plugs not be ordered until the investigation has been completed. If it is determined that the ceramic insert is detrimental, GE will identify alternate part numbers.

It is planned to use a Cannon hermetic thru bulkhead receptacle (TBFH-100 or -200 series) to penetrate the vacuum chamber for EHS Power. The TBFH-100 series is for panel thicknesses of 0.117 to 0.312 inch and the TBFH-200 series is for panel thicknesses of 0.375 to 0.750 inch. AIRPHX is requested to provide GE with the thickness of the penetration plate for GDS testing. The connector to be used is TBFH32-17PS which contains four #4 contacts. Two connectors of this type will be required for the GDS. The normal cadmium finish will not be used. A high temperature finish will be specified. The overall dimensions of the connector are shown in attached figure.

Action Item #11 - Can 2400 watts be applied instantaneously to the EHS to simulate IHS loading? If not, why not? What is maximum recommended heatup rate currently?

GE has never applied 2400 watts to an EHS instantaneously on the MHW program. The current maximum allowable heatup rate is:

- 100 watts per hour to 500 watts - 5 hours
- 150 watts per hour 500 to 1250 watts - 5 hours
- 200 watts per hour 1250 to 2400 watts - 6 hours

This is the fastest heatup rate we have ever used at GE and this rate of heatup has only been used on EHS's which were in ETG's which had been fully baked out (processed). The concern with a faster heatup rate is damage to the heating element due to thermal expansion mismatch between the graphite and the alumina supporting parts in the heaters. A transient thermal analysis combined with a stress analysis would be required to determine the heater's capability to be energized to 2400 watts instantaneously.

It should be noted that application of 2400 watts to the EHS instantaneously would not really simulate the insertion of the IHS. A better simulation of this case would be obtained by energizing the EHS to 2400 watts, using the normal heatup rate, outside the HSA and then inserting the EHS into the HSA. This of course would require some kind of loading station or Glove Box/Loading Fixture combination.

Another alternative to approximate IHS insertion would be to preheat the EHS to the expected IHS-in-open-gas temperature and then apply full power to the EHS. This has the disadvantage of also preheating the HSHX, etc. which is not typical of IHS insertion and in addition would also require thermal transient and stress analysis to determine the effect on the heater.

Action Item #13 - GE to provide AIRPHX with pictures of GE supplied hardware.

Pictures of GE supplied hardware will be provided at a later date.

Action Item #14 - GE to evaluate the use of the MHW Converter Shipping Container for transporting the HSA.

A review of the MHW converter shipping container indicates that the container, after modification, can be used to transport the HSA. It was assumed that the ~ 8 inch long ducts would be welded to the HSHX inlet and outlet ports as part of the HSA configuration for shipping. The required shipping container modifications are as follows:

- 1) New center spacer required
- 2) Redesign angle mounts
- 3) Redesign mounting plate to off-set HSA to provide clearance for 8" long HSHX ducts
- 4) Redesign brackets for uniball mounting
- 5) Design supports for HSHX inlet and outlet ducts

Action Item #15 - Can GE define a realistic angularity (concentricity) requirement for the HSHX ports which will considerably reduce the tolerance?

The possibility of tightening the concentricity requirement on the HSHX ports has been explored with Evendale (the manufacturer of the HSHX). For example, the extension of the present 0.020 diameter requirement from the present location at the end of the port to a projected point approximately 8.0 inches away was considered. Until some of the port installation welds are made, it was judged to be extremely difficult

to either make an assessment as to whether the tolerance could be tightened or what program impact (cost/schedule) would result from tightening the tolerance. The degree of weld shrinkage or port weld "springback" which is encountered cannot be estimated at this time. If springback is encountered even extremely tight tolerance fixturing might not provide the intended result. It is recommended that potential duct misalignment be provided for by tailoring the end of the duct and/or the sizing ring during weld prep to compensate for any misalignment resulting from the present concentricity allowance. The amount of tailoring required would be determined at fit-up when the 7.800 ± 0.010 dimension is set.

Action Item #17 - Provide estimate of weld qualification and certification requirements for different GDS assembly approaches

In summary weld qualification and certification will consist of demonstrating the following:

- a) Demonstrate that the weld environment is sufficient to produce quality welds. Weld quality will be assessed by bending specimens which were welded in the environment to be qualified and comparing those results to specimens whose bend performance is determined to be acceptable
- b) Demonstrate the successful fabrication of 3 weld junctures using: prototype weld hardware and production fixturing, accessibility, weld equipment and operator.

The qualification and certification criteria is the same for all GDS assembly approaches being considered. The extent of the development required to achieve reproducible quality welds which satisfy the qualification requirements will vary for the different approaches.

A preliminary plan which outlines the approach for developing a complete weld specification, including certification and qualification requirements, is presented below. Efforts to finalize the above weld specification continue in progress.

Cl03 Weld Development & Certification Plan

Each finished weld shall conform to the requirements of Dwg(s) (later) regardless of type facilities and/or procedures used to affect the junctures. A three phased program is suggested:

Phase 1 - Flat Sheet Welding

Flat sheet specimens, taken from the same lot of materials scheduled for production of finished components, will be butt-welded for the following purposes:

- (1) Evaluate welding atmospheres.
- (2) Establishment of weld atmosphere limitations for specification purposes.
- (3) Establishment of facility leak rate limitations for specification purposes.
- (4) Development of base-line welding parameters and "pre and post" weld handling requirements.
- (5) Provide a means for the comparison of weld quality affected by different facilities.
- (6) Permit investigation of possible weld repair techniques.
- (7) Establish non-destructive testing limitations by comparison to destructive testing results.

Phase II Facility & Operator Qualification

Information obtained from Phase I will be used to upgrade GE tentative specification P8YA11 (attached). Changes will include the following, as a minimum:

- (1) Requirements controlling operation of bag as well as box type welding facilities.
- (2) Requirements for the completion of a minimum of 3 successful junctures of each type joint specified on applicable design drawing(s). Each required weld will be made on material that is typical of that applied to the finished components specified by design and joint configurations and tolerances will match those required for production items. All "pre" and "post" weld handling requirements will be followed as directed by the revised specification. Joint weld accessibility will duplicate that anticipated during actual production welding; steel (or other material) may be used to mock-up adjacent components but the assembled configuration shall require weld fixturing and weld accessibility that duplicates that required for the joining of actual hardware. Evaluation of each required weld will be followed as indicated in the revised specification.
- (3) Means for proving the quality of welding atmosphere may change from that presented in tentative specification P8YA11 but the general approach (presently written) will be used as a guide-line for the finalized form.

- (4) Additional (specific) Q.C. check points will be included in the finalized specification and facility procedure requirements shall be written, approved and followed as verified by signature of appointed Q.C. representatives. It is intended that Q.C. approval of cleaned and fixtured components will be required prior to welding and weld quality and packaging be verified after welding.

Phase III Production Welding

Approval of the finalized specification and successful completion of requirements established, therein, shall qualify facilities and participants for welding of C103 components specified in dwg(s) _____.

Action Item #18 - GE to define required Weld Samples and sizes for AIRPHX by May 12.

The specimens associated with weld development/certification for the GDS which are required by GE can be segregated into five (5) categories: These are:

- a. Material Lot Verification
- b. Evaluation of "Air" vs. "Bag" vs. "Box" Approaches
- Final Weld
- c. Port/Duct Welds
- d. Bellows to Duct Welds
- e. Hastelloy Welds

a. Lot Verification

The reason for these samples is to perform tensile tests on as received and heat treated C-103 at four different temperatures (e.g. RT, 900, 1500 and 2000°F) and bend tests on as received and heat treated C-103 at room temperature. The tensile tests would require 1-3 specimens per temperature (4-12 total). The bend tests would be performed using the specimens from c. below. These tensile and bend tests would be performed to verify that the lot received for weld development is representative of that used to build the actual hardware. These specimens may not be required if the C-103 specification-EMS 57800-, which GE has not yet received, adequately covers the situation or if the actual hardware is manufactured from the same lot of material as the weld development specimens. The results of the lot verification tests would be compared to data available from the government agencies participating in MARSCOM.

b. Evaluation of Alternate Approaches for Duct/Sizing Ring Weld

For these evaluations, GE recommends 2 sheets each 1.5 x 12 x 0.045 (+ .005) for each of the three approaches. Two 1.5 inch specimens would be welded along the 12 inch length by each method. This is In Air, using a bag with glove ports and in the weld chamber. One half the length of each welded specimen would then be heat treated and tests such as bend, metallographic and interstitial analysis performed on both as welded and heat treated samples.

c. Port/Duct Welds

- (1) Parameter development and as received bend specimens

One (1) C-103 sheet 12" x 12" x 0.045" required

- (2) Weld development specimens

Two (2) C-103 sheets 1.5" x 24" x 0.045" required

It is anticipated that the two sheets would be broken up into six (6), four-inch segments. These segments would be welded together to evaluate as welded, heat treated, reworked (2nd pass), filler, penetration and heat treating using the torch. Several specimens would be obtained from each segment to evaluate the properties, characteristics and quality of the welds for each variable.

- (3) Weld Certification

One (1) length of 1.5" I.D. x 0.050" wall x 15" long C-103 Tubing required

Specimens from this tubing would be used to produce and evaluate several welds (3 to 5) using the selected parameters in the actual configuration that will be used on the HSA.

d. Bellows to Duct Welds

Metal Bellows has been requested to supply to GE three (3) specimens of the bellows end ring which will be welded to the "Z" ring on the ducts. These specimens would be actual rings identical to those which will be welded to the end of the bellows (includes same cold work). AIRPHX is requested to provide GE with 3 C-103 "Z" rings for use in certifying the welds between the bellows and the "Z" ring.

e. Hastelloy Welds

For the Hastelloy welds GE recommends the same weld specimens and weld development/certification be performed as for the port/duct welds in c. above. GE has performed and been involved in considerable superalloy welding on programs such as SNAP-27 and MHW. It has been our experience that these superalloy welds require development and certification and should not be taken lightly. Effects such as aging, heat treatment and effects of contaminants must also be considered with superalloys. To be safe, most of our previous superalloy welds have been performed in a "glove box" type atmosphere.

GE recommends that discussions be held between AIRPHX and GE cognizant welding personnel to discuss not only the approach to welding C-103, but also for Hastelloy. We would propose that a meeting be held early in June at a site mutually agreeable to AIRPHX and GE to further discuss the GDS Assembly welding.

Action Item #19 - GE to define the resultant leak rate of two solenoid valves in series.

The solenoid manufacturer, Valcor Engineering, indicates that the leakage across a single backfill solenoid valve seat (V70400-13) is $<1 \times 10^{-5}$ scc He/sec at the operating pressure (25 psia).

For the MHW Program, GE uses two such solenoid valves in series to minimize leakage into the vacuum chamber. Early in the program the chambers used only Ti sublimation pumps which had difficulty pumping the argon which leaked through a single valve. The use of two valves eliminated the problem, however, GE has never measured the resultant leak rate associated with the in-series configuration. These valves are currently in service at GE and if it is important to know the actual leak rate across two valves in series it could be measured.

Action Item #20 - GE to provide FMECA to AIRPHX for Gas Service Cart

A copy of the Gas Service Cart FMECA was sent to AIRPHX on 5/14/76 (COORD G0067).

Action Item #22 - GE to provide the following information:

HSA Thermocouples	- #24 AWG wire (cable) #20 contacts (feedthru)
EHS Power	- #6 AWG wire (cable), #4 contacts (feedthru)
Vent Lines to HSA	- OD = .5 inch Feedthru = AN832-8J
Gas Service Cart	- <u>Amps</u> - Never measured, GSC is fused for 15 amps and 3 amps respectively. <u>Volts</u> - 110 VAC Phase - 1 ϕ
GMS Solenoid Valve	- <u>Amps</u> - 1.5 amps max. <u>Volts</u> - 35 VDC (Energize open) ~5 VDC (Hold open)
Purity of Gas Supply to HSA	- 99.999% Purity 10 PPM max. Impurities
Regulated Pressure to HSA	- TBD

Floor Space Required for GSC - $5' \times 3' = 15 \text{ Ft}^2$

Floor Space Required for PSC - $3' \times 4' = 12 \text{ Ft}^2$ ea

Action Item #23 - GE to define gas purity levels that can be obtained in GSC using roughing pump to evacuate lines.

The following gas purity levels can be achieved by evacuating the GSC with the roughing pump and backfilling the lines with inert gas a total of three times:

O₂ 5 PPM

H₂O 10 PPM

N₂ 15 PPM

PROPOSED MINI-HSA MELTDOWN TESTS

Using Mini-HSA assemblies such as shown on the attached illustration, it is proposed to perform the following tests:

Test No.	Foil Configuration	Test Rationale
1	Repeat initial feasibility test	Initial feasibility was quite crude. Test will be rerun with: 1) ceramic support of tungsten heat source, 2) improved collar, and 3) additional thermocouples.
2	24 columbium plus 36 nickel foils (with T. C. s inside foils)	Address problems of insulation degradation due to vaporization and surface diffusion. In addition, inner Cb foils will provide extra temperature margin to the meltdown point.
3	Molybdenum foil for inner layer	Provide larger temperature margin than current Cb layer (i. e., Cb-Ni at 1175 C and Mo-Ni at 1315 C)
4.	Rhodium plated and polished foils (nickel)	Evaluate any meltdown problems associated with rhodium plating of foils. Rhodium plating has potential of significantly reducing heat losses.
5	120 nickel foils	Test if additional foil layers can be added to HSA (to reduce heat losses) safely.
6	Rhodium plated and polished foils (nickel and columbium)	Evaluate any meltdown problems associated with rhodium plating of foils.

Mini-Meltdown Test Arrangement

FOIL INSULATION/Cb-C-103 COMPATABILITY TEST

1.0 INTRODUCTION

The series of tests described in the following sections has been formulated to verify the planned procedures related to use of refractory material in the proposed plan for operation of the Ground Demonstration System (GDS). The need for tests of this type originates from concerns regarding the gas retention characteristics of the insulation system and intermetallic diffusion phenomena. The test specimens will be prototypical of C-103 components insulated with a Multi-Foil assembly. The test procedure will accurately simulate the contaminant and temperature excursions anticipated during GDS testing.

Post-test materials inspection will determine the effects on material properties which can be expected during the GDS test series.

2.0 SCOPE

The intent of this series of tests shall be to accurately simulate the refractory alloy contaminant exposure and temperature levels expected to be encountered in the GDS test series. A series of "up-to-air" exposures, purge and purification procedures and excursions to operating temperature for a representative time period will be completed. Following completion of contaminant tests the Cb-C-103 test specimen shall be subjected to metallographic examination, hardness measurements, and interstitial chemical analysis to determine the effects of the contamination exposure. A control specimen of Cb-C-103 shall provide a control reference for material properties.

3.0 TEST PROCEDURES

The configuration of the desired test specimen is shown in Figure 1. The specimen shall be installed in a vacuum chamber suitable for the test procedure described in this section.

3.1 Purge Cycle

The following procedure is identical to the proposed purge cycle of the GDS.

- a) evacuate the chamber to at least 10^{-3} Torr, hold 1 hour.
- b) back fill with research grade Argon to at least 100 Torr in 10 minutes, hold 1 hour.

- c) heat specimen to 400°F and stabilize, hold 1 hour.
- d) repeat a)
- e) repeat b)
- f) repeat a)
- g) repeat b)
- h) evacuate chamber to at least 10^{-6} Torr, hold 3 hours.

3.2 Temperature Cycle

Following the purge cycle the specimen shall be heated to an temperature of 1750°F per transient analysis prediction. The hold time at this condition shall be that defined in Section 3.4. The heater power levels to sustain this temperature shall be recorded as a function of time at temperature.

3.3 Contamination Cycle

The contamination cycle shall simulate "up-to-air" exposure of the GDS with the refractory at least than 100°F. During the conduct of the test program the contamination cycle shall consist of an ambient air backfill of the vacuum chamber to at least 500 Torr and a hold time of TBD hours.

3.4 Test Cycle Definition

A total of 20 composite test cycles are desired to simulate the GDS anticipated contamination. The composite test cycle shall be comprized of the following:

- a) A purge cycle as described in Section 3.1
- b) A temperature cycle as described in Section 3.2 for a hold time as described below.
- c) A contamination cycle as described in Section 3.3

The hold time for Item b) above shall be varied as follows:

<u>Cycle</u>	<u>Hold Time (hrs)</u>
1	$\frac{1}{2}$
2 & 3	1
4 - 10	2
11 - 15	10
18 - 20	200

3.5 Material Inspection (Post Mortem)

A sample from the material used to make the C-103 test specimen

should be retained to characterize the material before test. This will be used to compare the microstructure, hardness and interstitial content with the full cross section of the sample exposed to test. It is recommended that the assembly of sample and insulation be potted in a suitable material prior to waxing the cross section for examination so that the physical configuration of the specimen and the foil wraps can be maintained, and any distortion evaluated. The surface of both, exposed foil from the inner wraps, and a piece of unexposed foil should be examined to note the stability of the Zirconia particles and if there is any interaction between the foil and the particles.

The bellows under consideration must operate for a sustained period of time under fluid conditions of high temperature and high pressure; thus short-term elevated temperature properties and material creep behavior will provide a major criterion for the design procedure. The design must also include the capability for proof and burst pressure tests as quality assurance methods; thus room temperature material behavior must be considered. Large thermal movements are generally associated with the application of a typical bellows design, therefore thermal fatigue behavior also will constitute a major design consideration.

Typical Mechanical Properties

Published values of the candidate material properties have been compiled for Hastelloy X, Columbium 103, and AISI 347 and are shown in Table 1 for the required operating temperature. Mechanical properties utilized in the design procedure are obtained by applying the established design criteria specified below to the published values.

1. Service Requirements

The bellows design will be required to operate as a flexible coupling with the capability of handling fluids at a sustained temperature and a sustained pressure. The objective service life for the bellows design is:

7 years or 70,000 hr at sustained fluid conditions with less than 1 percent creep

100 operating cycles from ambient to sustained fluid conditions

2. Stress Requirements

Allowable stresses for these components must take into account the stresses due to pressure containment. The bellows design criteria will provide for short time proof pressures of 1.5 times the working pressure, and burst pressures of 2.5 times the working pressure. The structure must not yield at proof pressure or rupture at burst pressure. This implies that the proof pressure is the governing design condition if the ratio of yield stress to ultimate stress is less than 0.6 (1.5/2.5), and that the burst pressure will govern if the ratio exceeds 0.6. The allowable stress at working pressure is, therefore, the lesser of the following:

$$\sigma_{all} = f_{tu}/2.5$$

$$\sigma_{all} = f_{ty}/1.5$$

Table 2 shows the short time pressure containment stress criteria for the candidate materials.

TABLE 1
MATERIAL PROPERTIES (SHEET METAL)

	Hastelloy X, Temp. = 1300°F (Ref. 1)	CB-103, Temp. = 1600°F (Ref. 2 and 3)	AISI 347, Temp. = 212°F (Ref. 4)
1. Modulus of Elasticity (E), psi	22×10^6	13.0×10^6	27.8×10^6
2. Thermal Expansion Coeff. α , in./in./°F	8.8×10^{-6}	*	9.3×10^{-6}
3. Elongation (e), percent	38	18	36
4. Reduction of Area (RA), percent	*	*	50
5. Yield Stress (0.2 percent), psi	28,000	19,000	26,000
6. Ultimate Stress, psi	65,000	41,000	65,000
7. 70,000-hr Creep Rupture Stress, psi	9,100		
8. 70,000-hr, 1 percent Creep Stress, psi	6,200	4,000**	

*To be supplied later.

**Based on the Dorn-Sherby Parameter (see Ref. 3).

TABLE 2

SHORT TIME PRESSURE CONTAINMENT DESIGN STRESSES

	Hastelloy X	CB-103	AISI-347
1. Room temperature			
Fty/1.5, psi	30,000	26,600	20,000
Ftu/2.5, psi	40,000	23,200	29,600
2. Operating temperature			
Fty/1.5, psi	18,600	12,650	17,300
Ftu/2.5, psi	26,000	16,400	26,000

When the limiting stress is due to bending, a small amount of yielding can be allowed in the outermost fibers, which leads to a modified stress distribution through the thickness. The ideal plastic bending moment is 1.5 times the computed elastic bending moment for the same peak stress. Accordingly, the allowable indicated elastic stress due to bending loads is taken to be 1.5 times the allowable direct stress.

A second important consideration is the combination of stresses due to pressure and thermal motions. It is known that when the sum of stresses due to pressure and thermal motion does not exceed twice the yield stress, plastic strain flow will not occur during repeated cycling of the bellows. When the summation of these stresses exceeds $2 \times F_{ty}$, an amount of plastic strain flow equal to the excess stress divided by the elastic modulus will occur. To account for localization of the plastic flow, a strain concentration factor of 2.0 is used to determine plastic strain range during bellows cycling. This numerical result is then used in the formula for low cycle fatigue: Manson's universal equation for LCF is used for preliminary design purposes.

At elevated temperature, all of the above conditions must be satisfied, and in addition, the component must be satisfactory for long time creep effects. There must be a set of creep criteria that is comparable to that for the short time loading. Accordingly, limitations based upon stress to rupture and stress to one percent creep must be established. The objective design life is 70,000 hr and the hot bellows is designed for sustained pressure operation at maximum operating temperature throughout the entire design life. Allowable stresses at working pressure must be the lesser of the following:

$$\sigma_{all} = (1\text{-percent creep stress})_{70,000 \text{ hr}} / 1.2$$

$$\sigma_{all} = \left[(\text{creep rupture stress})_{70,000 \text{ hr}} \right] / 1.5$$

The value of the long term creep stress, will override the short time properties criteria for most materials utilized in the design of bellows.

When the limiting pressure stress is caused by bending, a redistribution of stress occurs both through the thickness and along the length. The steady creep stresses are substantially lower than those indicated by the elastic analysis. By utilizing the plastic moment distribution, an allowable creep stress due to bending can be utilized that is larger than the allowable creep stress due to pure tensile forces.

One additional precaution must be taken when designing for cyclic operation in combination with extended sustained operating time at elevated temperature. The stresses due to thermal motions must not produce a plastic loop of any appreciable magnitude during successive cycles. The following rationale is used to explain this requirement. During the first cycle, the bellows may be permitted to yield due to thermal motions during startup. When allowed to hold for an extended time period, creep relaxation will take place and the stresses initially will decay rapidly, and then progressively more slowly until eventually total stress alleviation takes place. Upon cooldown, the stresses will reappear but in the opposite direction (tension where initially compression, etc.). If a great deal of yielding occurs during the cooldown, the original high thermal stress will reappear on the next heatup, and this will be followed by more creep. This creep will add to that due to sustained loading, and will drastically reduce the life of the unit. This condition will not occur at all if the thermal motion stresses do not exceed the yield of the material. The problem will be largely eliminated if thermal stresses do not exceed more than 1.5 times the yield stress that has been used in the design criteria.

Table 3 summarizes the preliminary high temperature bellows design stresses. These stresses result from application of the design criteria established to satisfy the long term life objectives.

TABLE 3
PRELIMINARY HIGH TEMPERATURE BELLOWS DESIGN STRESSES

	Hastelloy X	CB-103	AISI-347
1. Direct stress due to pressure loading, psi	6,200	4,000	17,300
2. Bending stress due to pressure loading, psi	9,300	6,000	26,000
3. Thermal stress due to transient conditions, psi	42,000	28,400	39,000
4. Combined stress due to pressure and thermal loading, psi	56,000	38,000	52,000

3. Proof Pressure Test Requirement to Qualify for 7 Years Creep Life Stress Levels

$$\text{Proof Pressure}^* = K \times \frac{\text{Yield Stress at R.T.}}{\text{Design Stress}} \times P_{op}$$

$$\text{but never less than } 1.5 \times P_{op} \times \left(\frac{F_{ty} @ 70^\circ F}{F_{ty} @ \text{Design Temperature}} \right)$$

* $K < 1$

Accounts for uncertainties in stress calculations, minimum material properties and weld efficiencies, which provides protection against inadvertently yielding the pressure vessel at proof pressure.

REFERENCES

1. Design Manual, Advanced Propulsion Engines, The Garrett Corporation, January 1969, pp 4-1 to 4-7.
2. Material Properties of WC-103 published by Wah Chang Albany, a Teledyne Company.
3. Document No. 75-31160^h, January 15, 1976, AiResearch Manufacturing Company of Arizona.
4. Material Properties Manual, AiResearch Manufacturing Company of California.

DATE MAY 7 1976
 PART NO. C-103 (FINAL), $N = 2 \text{ PLY}$
 PREPARED BY Dr. Tehal Vishwasach

CALC. NO: 7619 SHEET NO. 1
 MODEL NO. BELLOWS - I
 CHECKED BY _____

BASELINE BELLOWS CONVOLUTION SHAPE

Inside Radius (R), In.	0.9
Mean Radius ($\bar{R}$), In.	0.985
Height (h), In.	0.169
Pitch (w), In.	0.169
Bend Radius (r), In.	0.042
h/R	0.188
w/h	1.0
h/t	15.36
$r_{\min}/t$	3.32
Percentage Elongation	1.19

DATE MAY 7 1976
 PART NO. CB-103 (FINAL) N=2
 PREPARED BY Dr. Teklal Vishwanath

CALC. NO. 1617 SHEET NO. 2
 MODEL NO. BELLOWS
 CHECKED BY _____

ANALYSIS SUMMARY

Material	CB-103
Allowable sustained equivalent direct stress, psi = σ_{ASD}	4000
Allowable cyclic (thermal) equivalent direct stress, psi, = σ_{ACD}	19000
Young's modulus at operating temperature, psi = E_T	13×10^6
Operating pressure, psia = p	100
Operating temperature, °F = T	1600
Proof pressure, psi = P (YIELD)	315
Thickness per ply, in. = t	0.011
Active length, in. = L	3.380
Number of plies = n	2
Number of convolutions = c	20
Extensional deflection capability, in. = δ_A^*	0.126
Extensional stiffness, lb/in. = K_A	725
Lateral (offset) stiffness, lb/in. = K_L	370
Bending stiffness, in.-lb/radian = K_B	1407
Max. nondimensionalized von Mises eq. direct stress, psi/psi/ply = σ_s	34.09
Squirm pressure, psi = p_s	337

PROOF PR. FOR 1% CREEP CRITERIA, psi 1000

DATE JUN 14 1976
 PART NO. 36054124-1 (FINAL)
 PREPARED BY Dr. Telal Vishwanath

CALC. NO. 7619 SHEET NO. 1
 MODEL NO. BELLOWS - II
 CHECKED BY _____

BASELINE BELLOWS CONVOLUTION SHAPE	
Inside Radius (R), In.	0.95
Mean Radius ($\bar{R}$), In.	1.026
Height (h), In.	0.152
Pitch (w), In.	0.114
Bend Radius (r), In.	0.0285
h/R	0.16
w/h	0.75
h/t	25.3
r_{min}/t	3.25
Percentage Elongation	16

DATE JUN 14 1976
 PART NO. 3605424-1
 PREPARED BY Dr. Telal Pishwanath

CALC. NO. 7615 SHEET NO. 2
 MODEL NO. BELLOWS - II
 CHECKED BY _____

ANALYSIS SUMMARY

Material	HAST - X
Allowable sustained equivalent direct stress, $\text{psi} = \sigma_{\text{ASD}}$	6,250
Allowable cyclic (thermal) equivalent direct stress, $\text{psi} = \sigma_{\text{ACD}}$	29,000
Young's modulus at operating temperature, $\text{psi} = E_T$	22×10^6
Operating pressure, $\text{psia} = p$	100
Operating temperature, $^{\circ}\text{F} = T$	1300
Proof pressure, $\text{psi} = P$ (FOR YIELD CRITERIA)	233
Thickness per ply, $\text{in.} = t$	0.006
Active length, $\text{in.} = L$	2.62
Number of plies = n	3
Number of convolutions = c	23
Extensional deflection capability, $\text{in.} = \delta_A$	0.177
Extensional stiffness, $\text{lb/in.} = K_A$	404
Lateral (offset) stiffness, $\text{lb/in.} = K_L$	450
Bending stiffness, $\text{in.-lb/radian} = K_B$	982
Max. nondimensionalized von Mises eq. direct stress, $\text{psi/psi/ply} = \sigma_s$	55.2
Squirm pressure, $\text{psi} = p_s$	242

--- PROOF PR. FOR 1% CREEP CRITERIA, psi --- 720

DATE JUN 14 1976
 PART NO. 3605419-1
 PREPARED BY Dr. Tehal Vishwanath

CALC. NO. 7619 SHEET NO. 1
 MODEL NO. BELLOWS - III
 CHECKED BY _____

BASELINE BELLOWS CONVOLUTION SHAPE	
Inside Radius (R), In.	1.45
Mean Radius ($\bar{R}$), In.	1.537
Height (h), In.	.174
Pitch (w), In.	.1305
Bend Radius (r), In.	.03262
h/R	.12
w/h	.75
h/t	29.0
r_{min}/t	3.94
Percentage Elongation	1.12

DATE JUN 14 1976
 PART NO. 3605419-1
 PREPARED BY Dr. T. Lal. Vishwanath

CALC. NO. 7619 SHEET NO. 2
 MODEL NO. BELLOWS - TTT
 CHECKED BY _____

ANALYSIS SUMMARY

Material	HASTELLOY X
Allowable sustained equivalent direct stress, $\text{psi} = \sigma_{ASD}$	5250
Allowable cyclic (thermal) equivalent direct stress, $\text{psi} = \sigma_{ACD}$	28500
Young's modulus at operating temperature, $\text{psi} = E_T$	21.7×10^6
Operating pressure, $\text{psia} = p$	67
Operating temperature, $^{\circ}\text{F} = T$	1330
Proof pressure, $\text{psi} = P$ (FOR YIELD)	159
Thickness per ply, $\text{in.} = t$	.006
Active length, $\text{in.} = L$	262
Number of plies = n	3
Number of convolutions = c	23
Extensional deflection capability, $\text{in.} = \delta_A^*$	.23
Extensional stiffness, $\text{lb/in.} = K_A$	396
Lateral (offset) stiffness, $\text{lb/in.} = K_L$	957
Bending stiffness, $\text{in.-lb/radian} = K_B$	2037
Max. nondimensionalized von Mises eq. direct stress, $\text{psi/psi/ply} = \sigma_s$	73.46
Squirm pressure, $\text{psi} = p_s$	207

PROOF PR. FOR 1% CREEP CRITERIA, psi 575