LMSC-HREC TR D951414

(NASA-CR-171137) PRELIMINARY ENGINEERING REPORT FOR DESIGN OF A SUBSCALE EJECTOR/DIFFUSER SYSTEM FOR HIGH EXPANSION RATIO SPACE ENGINE TESTING Final Report (Lockheed Missiles and Space Co.) 150 p N84-31273 Unclas G3/20 20278

PRELIMINARY ENGINEERING REPORT FOR DESIGN OF A SUBSCALE EJECTOR/DIFFUSER SYSTEM FOR HIGH EXPANSION RATIO SPACE ENGINE TESTING

April 1984

FINAL REPORT, CONTRACT NAS8-35051

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MARSHALL SPACE FLIGHT CENTER, AL 35812

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FOREWORD

This preliminary engineering report is for the design of a subscale jet engine driven ejector/diffuser system for installation at MSFC's Cold Flow Calibration Facility, Building 4554. The work was performed by personnel of the Lockheed-Huntsville Research & Engineering Center under the direction of C.J. Wojciechowski, Project Engineer. The effort was conducted for NASA-Marshall Space Flight Center under Contract NAS8-35051. Included herein are analytical results and preliminary design drawings and plans. This document is the final report required under this contract. The NASA-MSFC Contracting Officer's Representative for this study was Mr. K.E. Riggs, EP23.

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NOMENCLATURE

A	area
A^*	sonic or throat area
GN_2	gaseous nitrogen
L	length
M	Mach number
$\dot{m}$, $\dot{w}$	flow rate
NBP	normal boiling point
P,p	pressure
R	radius
RH	relative humidity
r	ejector mass flow to pumped mass flow ratio
T	temperature
U	velocity
$\dot{W}_{BL}$	J-57 air bleed flow rate

Greek

τ	time

Subscripts

c	cell or chamber
D	detonation conditions
e_x,ex	ejector mixing tube exit
j	pertains to ejector
m	mixing tube
s	static conditions
T	total conditions
1, 2	downstream of a normal shock

1. INTRODUCTION

The National Aeronautics and Space Administration long range plans indicate the need for a high expansion ratio, high performance upper stage engine. An altitude simulation test facility will be needed, first to develop the technology for such an engine, and second to provide the development testing for the engine. State-of-the-art steam driven ejector systems are projected to be extremely costly, and as a result NASA has been exploring other less costly means of providing altitude simulation capability. One of the more promising concepts uses the exhaust of conventional jet engines to provide the working fluid for driving the ejectors. In a recent study conducted by Lockheed (Contract NAS8-33981) such a system was found to be analytically feasible. MSFC intends to experimentally demonstrate the concept through the design, fabrication and test of a subscale pilot model.

This document is the final report under this contract. During the course of the design study, several oral presentations were presented to NASA-MSFC at the COR's request. Documentation from these presentations are considered as part of the overall study documentation. Presentations that were given are listed below.

LIST OF ORAL PRESENTATIONS

Date	Title	Documentation
8 Apr 1983	Program Plan	
23 Jun 1983	30 Percent Design Review	LMSC-HREC PR D867208
24 Aug 1983	60 Percent Design Review	LMSC-HREC PR D867272
23 Feb 1984	Program Plan for Amended Scope of Work and Review to Date	LMSC-HREC PR D951319
13 Apr 1984	Full Scale Gasdynamic Safety Analysis	Appendix A (This Report)

2. OBJECTIVES AND REQUIREMENTS

This subscale design effort was initiated on 2 April 1983. In the process of developing the subscale design, significant safety questions arose regarding the performance of a full scale system during an actual hot firing of a space engine, especially hydrogen detonation hazards and how they may be controlled. An added scope of work to this contract was issued by MSFC on 11 January 1984 to study the full scale safety issues. The original and added scope of work objectives are listed below:

- Original Objectives

    1. Design a subscale working model for future full scale testing of OTV engines in a simulated space environment.
    2. Verify that the analyses, design, and performance prediction techniques previously developed are valid and applicable to this concept.
    3. Identify for further consideration areas where the analyses and design techniques may not be complete and fully developed and must be supplemented with test data to be obtained in this facility.
    4. Provide final design drawings for a prototype system.

- Ammended Scope of Work Objectives.

    5. Perform a full scale system safety analysis and determine the mechanisms to suppress detonation by design or operational procedure.
    6. Develop full scale configuration detail to support the above objective and determine the design drivers for adjustable ejectors.
    7. Provide the design data necessary to make modifications to the subscale system for adequate simulation of the full scale safety issues and performance.

8. Determine the sensitivity of the design to engine physical and performance characteristics.

- Secondary Objectives

These objectives are considerations only, and the prototype design will not be compromised because of them:

1. Use as a test facility for OTV thruster engines with 0.5 to 1.0 lbm/sec flow rate.
2. Provide compatibility with Hot Gas II Facility.

- Requirements

The subscale, pilot model gas driven ejector will be designed to the following requirements:

A. Test cell pressure: 0.02 psia

B. Thruster flow rate: 0.50 lbm/sec of gaseous hydrogen

C. Thruster area ratio: 650:1

D. Initial inerting with gaseous nitrogen

E. Capable of being installed at and operating from MSFC's Cold Flow Calibration Facility using a J-57 turbojet engine bleed air and exhaust as the ejector driving medium

F. Provision for adequate simulation of the full scale facility hazard control mechanism.

Requirement E above was changed after contract award to use the J-57 turbojet engine exhaust instead of the MSFC Hot Gas Facility hot air exhaust to drive the ejector system. Detailed design of the J-57 engine controls, fuel tanks and exhaust ducting was beyond the scope of this contract. Sufficient design of the J-57 exhaust ducting to the ejector system was performed however, to enable a systems compatibility analysis to be performed. The last requirement (F) was added because of the amended Scope of Work.

3. ENGINEERING ANALYSIS AND DESIGN

In the course of performing this task special attention was given to defining such issues and concerns as ejector performance, safety issues such as hydrogen detonation hazards, ejector stability and controllability, ejector cooling requirements, and transient operation. The main analytical computer programs which were used in this study are listed in Refs. 1 through 3. The semi-empirical one-dimensional diffuser/ejector design program developed in the Ref. 1 study, was modified in this study to accommodate temperature dependent ratios of specific heats (gamma).

The final subscale ejector/diffuser design as presented herein was driven by the safety analysis results and ejector performance requirements. The mass flows to each ejector stage were dictated by the safety analysis results when the facility is pumping hydrogen (H_2) gas. The main safety criterion arrived at, at the 30 percent design review (Ref. 4), was to design the facility to suppress H_2 detonation hazard potentials. The proposed engineering approach was to:

1. Force the mixture ratio to be out-of-hazard range.
    - First Stage: Operate rich.
    - Second Stage: Operate lean.
    - Third Stage: Dilute second stage effluent to flammability limit.
2. Suppress ignition in first and second stage mixing ducts by operating at low static temperatures and pressures in the presence of condensation fine particulate matter (snow from ambient moisture).
    - First Stage: ($T_s < 200$ K, $T_T < 700$ K, $P_{T,2} < 1.1$ psia)
    - Second Stage: ($T_s < 300$ K; $T_T < 700$ K, $P_{T,2} < 6.6$ psia)

- Third Stage: Barely flammable after mixing, non-detonatable but flammable prior to mixing ($T_a < 660$ K, $T_T < 750$ K, $P_{T,2} < 22.6$ psia)

One of the objectives was to obtain subscale ejector performance data to enable design of a full scale system. Ejector systems are normally point designs, i.e., the blank-off capability and the pumping capability are defined. However, since this was to be a test bed to obtain data for future design, the ejectors had to be designed for variable area ratio to cover the range of anticipated full scale applications. The main reasons for developing and testing variable area ratio ejectors in the subscale design are:

1. Proof-of-concept data can be obtained from a working model.
2. A complete data base can be obtained applicable to full scale design.
3. The full scale ejector/diffuser must accommodate a family of space engines and modes of operation. Each engine will require the ejector system to operate at different ejector driving pressures and flow rates depending on safety considerations and ejector performance.
4. Turbojet engine operation is sensitive to exhaust exit area. Consultation with Pratt & Whitney indicated that this should not be a problem for the jet engine application in this case if the exhaust area can be adjusted to the particular jet engine. Experience has shown that jet engines, although manufactured to the same specifications, have individual characteristics - especially after several years usage - and therefore must be treated separately. Since the jet engines to be used in the prototype, and eventually in the full scale facility, are Air Force surplus engines, they will not be identical in performance. Designing the second and third stage ejector throat areas to be variable will enable fine tuning of the jet engine being used. In addition, the prototype diffuser/ ejector system will not be dependent on a single jet engine. Engine interchangeability is a design feature since the jet engines are surplus Air Force engines.
5. Since the actual ejector throat area (vena contracta) is not known "a priori" due to the compound curvature of the upper

and lower ejector throat surfaces, designing all three ejector throat areas to be variable will facilitate fabrication and assembly of the ejectors to the proper area as compared with the very close tolerance required for a fixed area ratio ejector.

6. The added complication of differential thermal growth between the upper and lower ejector throat surfaces during long duration tests can be adjusted dynamically during the test using real time monitoring of the ejector flow rates. Third stage ejector throat area changes during the tests can be detected by deviation in the low pressure compressor rotor speed falling off the jet engine calibration curve.

3.1 SUBSCALE DIFFUSER DESIGN

The subscale jet engine driven diffuser ejector system at the 90 percent point is shown in Fig. 1. The design of the subscale jet engine driven ejector/diffuser system as presented herein meets all of the requirements presented previously. The features of the subscale design are:

- Three-stage ejector system required to obtain test cell pressure of 0.02 psia
- High pressure compressor bleed air to be utilized to drive the first stage ejector
  - Normal rated power bleed parameters: $P_T \sim 150$ psia: $T_T = 1137$ R; $\dot{W}_{BL} = 8.64$ lbm/sec
  - Military rated power bleed parameters (30 minutes): $P_T = 162$ psia; $T_T = 1182$ R; $\dot{W}_{BL} = 1.65$ lbm/sec
- Turbine exhaust utilized to drive the second and third stage ejectors
  - Normal rated power exhaust parameters: $P_T = 33$ psia; $T_T = 1405$ R; $\dot{W} = 157$ lbm/sec
  - Military rated power exhaust parameters (30 minutes): $P_T = 36$ psia, $T_T = 1500$ R; $\dot{W} = 165$ lbm/sec
- Ejector design to be scale-up of previously tested design.

FMD = Flow measuring device
PFCV = Pressure and flow control valve
CV = Check valve
EMCV = Electromechanical control valve
FLOP = Flow limiting orifice plate

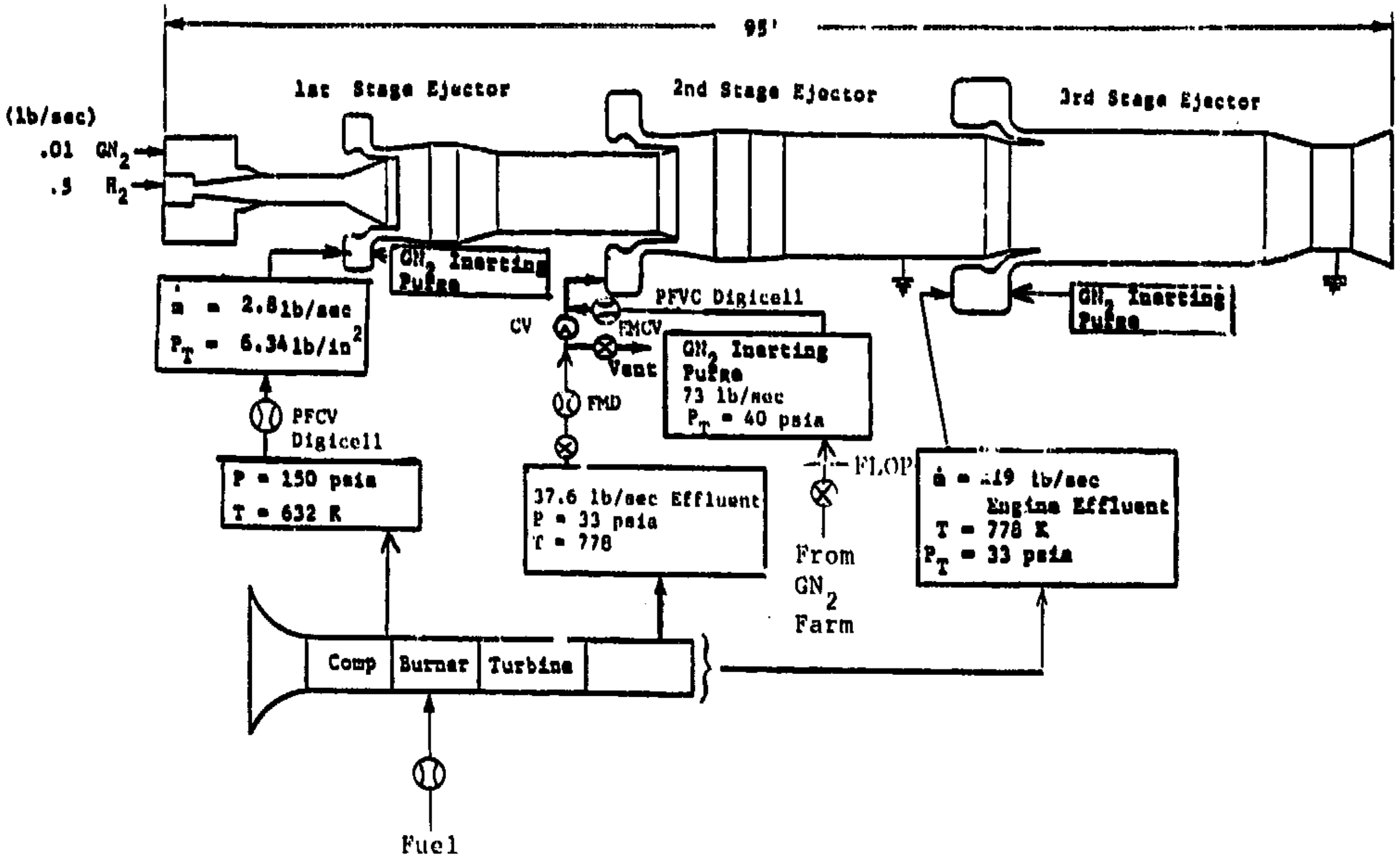
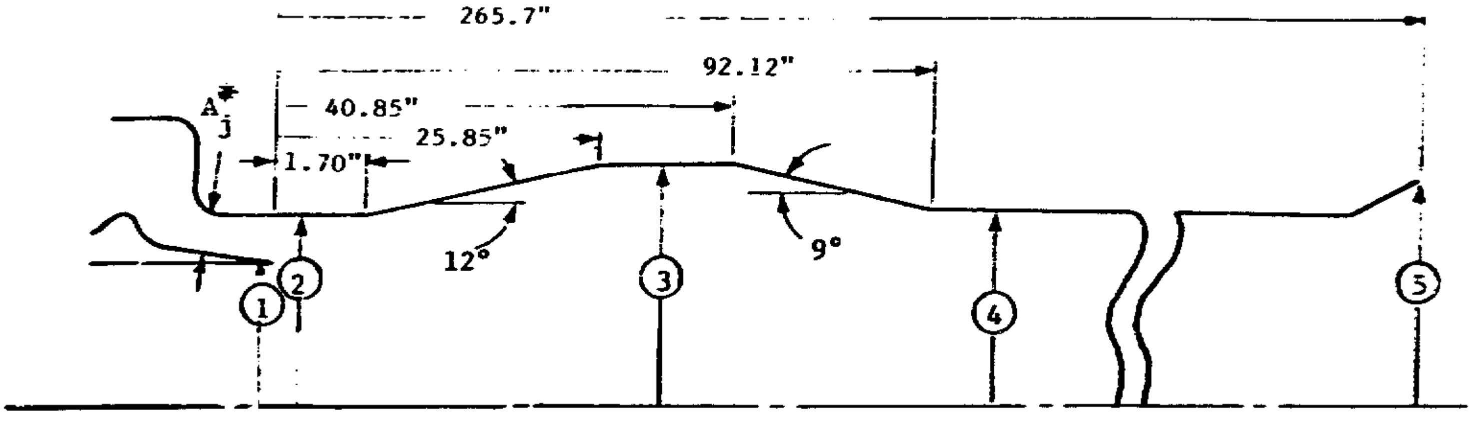


Fig. 1 90 Percent Review - Jet Engine Driven Ejector/Diffuser System

The J-57 turbojet normal rated power level will be used. The design features an altitude test chamber and a 650:1 area ratio H_2 nozzle. To eliminate unnecessary complexities in the subscale model, the H_2 will not be ignited. The H_2 chamber pressure will be 1200 psia. The H_2 nozzle lip pressure will be 0.02 psia. The total pressure of the $H_2 + N_2$ bleed stream entering the first stage ejector will be 3.0 psia, based on the diffuser normal shock recovery pressure.

The design incorporates the rapid turbojet exhaust/GN_2 switchover design which was developed for the subscale as a result of the full scale safety analysis for a full scale abort condition. The rapid switchover design has been incorporated into the second stage ejector for checkout and verification. The design includes a quick acting (100 msec) Electro-Mechanical Control Valve (EMCV) in the jet exhaust vent line, a Digicell Pressure and Flow Control Valve (PFCV) in the GN_2 line and a full ported swing check valve (CV) in the ejector line downstream of the vent line EMCV. The CV will close rapidly (less than 50 msec) on a negative pressure differential of 0.5 psi. The GN_2 operates at 40 psia and the exhaust operates at 33 psia so that the negative differential will be much greater than 0.5 psi. The same electrical signal would operate both the PFVC and the EMCV. The altitude cell and the first and third stage ejectors are fitted with small GN_2 inerting purge lines to completely purge out all cavities where H_2 could accumulate prior to and after the H_2 tests.

The first stage ejector design summary is presented in Fig. 2. The ejector throat area is designed to be variable and can be completely closed off. The ejector area ratio A_3/A_j^* can be varied from 22 to infinity. The design blank off suction pressure and pumping capacity is shown in Fig. 2 along with the characteristic dimensions. The variation of the minimum cell pressure to exit pressure ratio as a function of ejector area ratio is shown in Fig. 3. Shown in Fig. 3 are Lockheed's analytical results for no second throat and for a second throat compared to experimental data. The first stage ejector is a scale up of the ejector 2 design from Ref. 5. The



$R_{①}$ = 9.792"

$R_{②}$ = 10.368"

$R_{③}$ = 15.503"

$R_{④}$ = 11.017"

$R_{⑤}$ = 12.20"

Design Conditions with Condensation Effects

$A_3/A_j^* = 29.52 \qquad A_j^* = 25.58 \text{ in}^2$

$P_{T_j} = 6.34 \text{ psia} \quad T_{T_j} = 1138 \text{ R}$

$\dot{m}_j = 2.79 \text{ lbm/sec}$

$r = \dot{m}_j/\dot{m}_{①} = 5.47$

Blank Off Suction Pressure = 0.02 psia

Pumping Capability = 0.51 lbm/sec at 2.8 psia

A_3/A_j^* = Variable from 22 to infinity

Fig. 2 First Stage Ejector Design Summary

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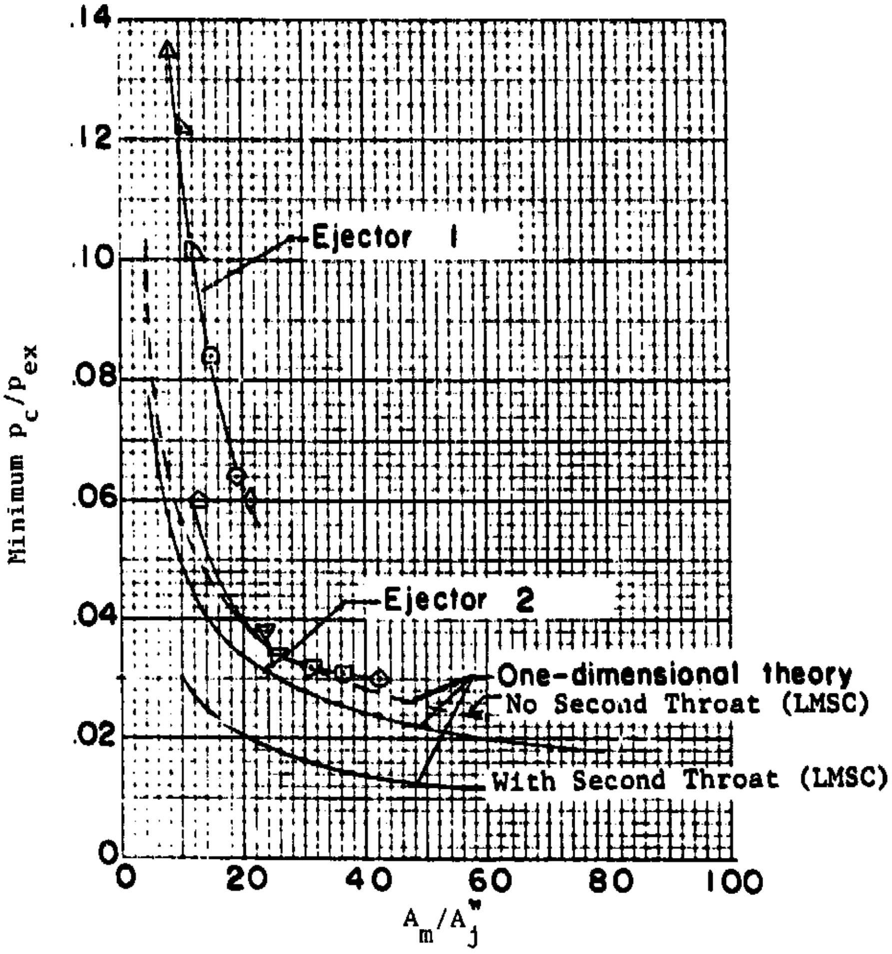


Fig. 3 Variation of Minimum Pressure to Which Ejector will Pump (As a function of ratio of mixing-tube cross-sectional area to ejector-throat area. No flow being pumped (from NASA TN D-23))

ejector 2 design of Ref. 5 was not a second throat ejector design. The first stage ejector performance as a function of ejector total pressure is shown in Fig. 4. The ejector is designed for nominal total pressure of 6.34 psia, at which point the cell pressure will be 0.012 psia without condensation effects. Additional first stage performance data as a function of area ratio is presented in Fig. 5, again without condensation effects. The effects of condensation due to ambient temperature and relative humidity are:

- The primary effect is to add moisture to the ejector driver streams. This moisture condenses in a shock-free condensation front (Wegener and Pouring, Physics of Fluids, Vol. 7, pp. 352-361, 1967), increasing pressure and temperature by release of latent heat to the gas phase in the first and second stages.
- The equilibrium condensed phase is solid (snow), with particle sizes on the order of several hundred Angstroms - a good size for efficient flame suppression.
- Total stream moisture consists of driver engine combustion product and ambient contributions. At low temperatures and humidity, combustion moisture dominates. Under hot, humid ambient conditions air moisture dominates, but does not overwhelm combustion moisture (ratio is approximately 2.5:1 at 100 F, 100% RH corresponding to effluent moisture mole fractions of 0.0876 and 0.0253 (dry air); at design condition (70 F, 50% RH) ratio is approximately 0.5:1, corresponding to an effluent moisture mole fraction of 0.0373.)
- The ejector design can accommodate wide swings in ambient temperature (0 to 100 F) and relative humidity (0 to 100%).

The ejector design ambient conditions are 70 F and 50 percent relative humidity. The calculated onset of water vapor condensation as a function of axial distance from the ejector exit is shown in Fig. 6 for both the first and second stage ejectors. No condensation is predicted for the third ejector stage. The condensation effects on the first stage ejector performance are shown in Fig. 7. The blank off pressure will increase by 28 percent to 0.015 psia which is still comfortably below the 0.02 psia requirement.

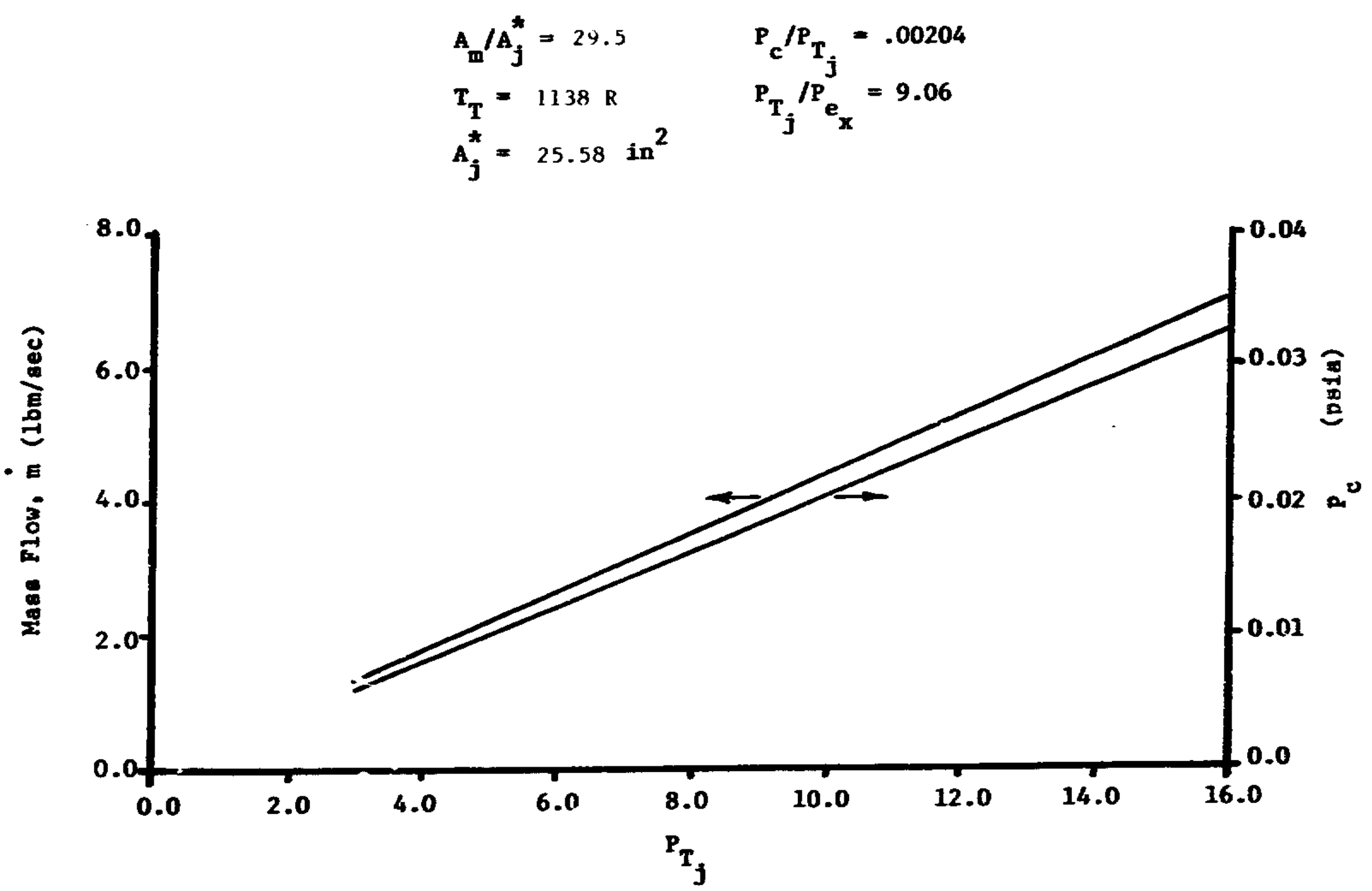


Fig. 4 First Stage Ejector Performance as a Function of Ejector Total Pressure

$\dot{m}$ = 2.79 lbm/sec

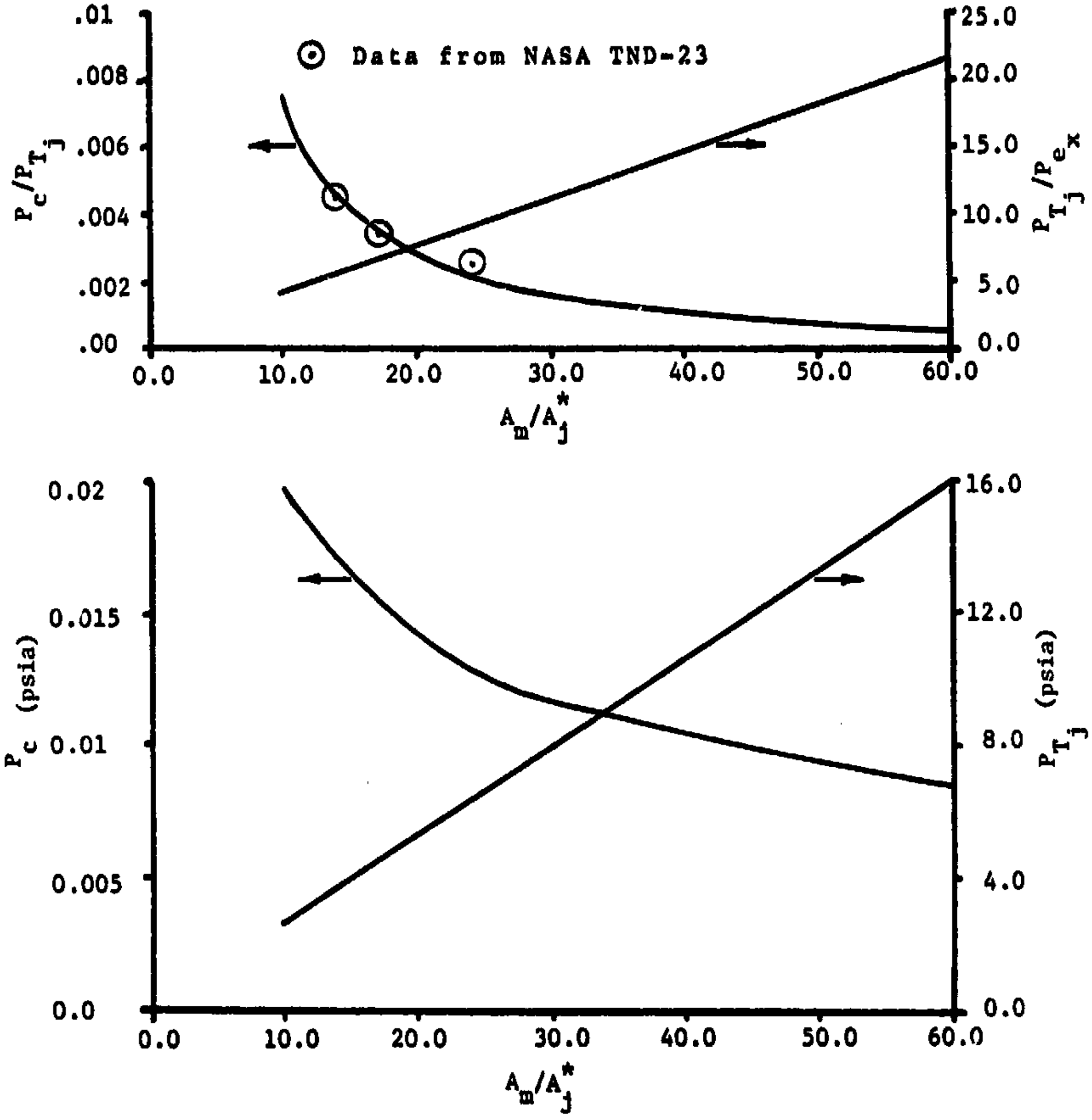


Fig. 5 First Stage Ejector Performance as a Function of Area Ratio

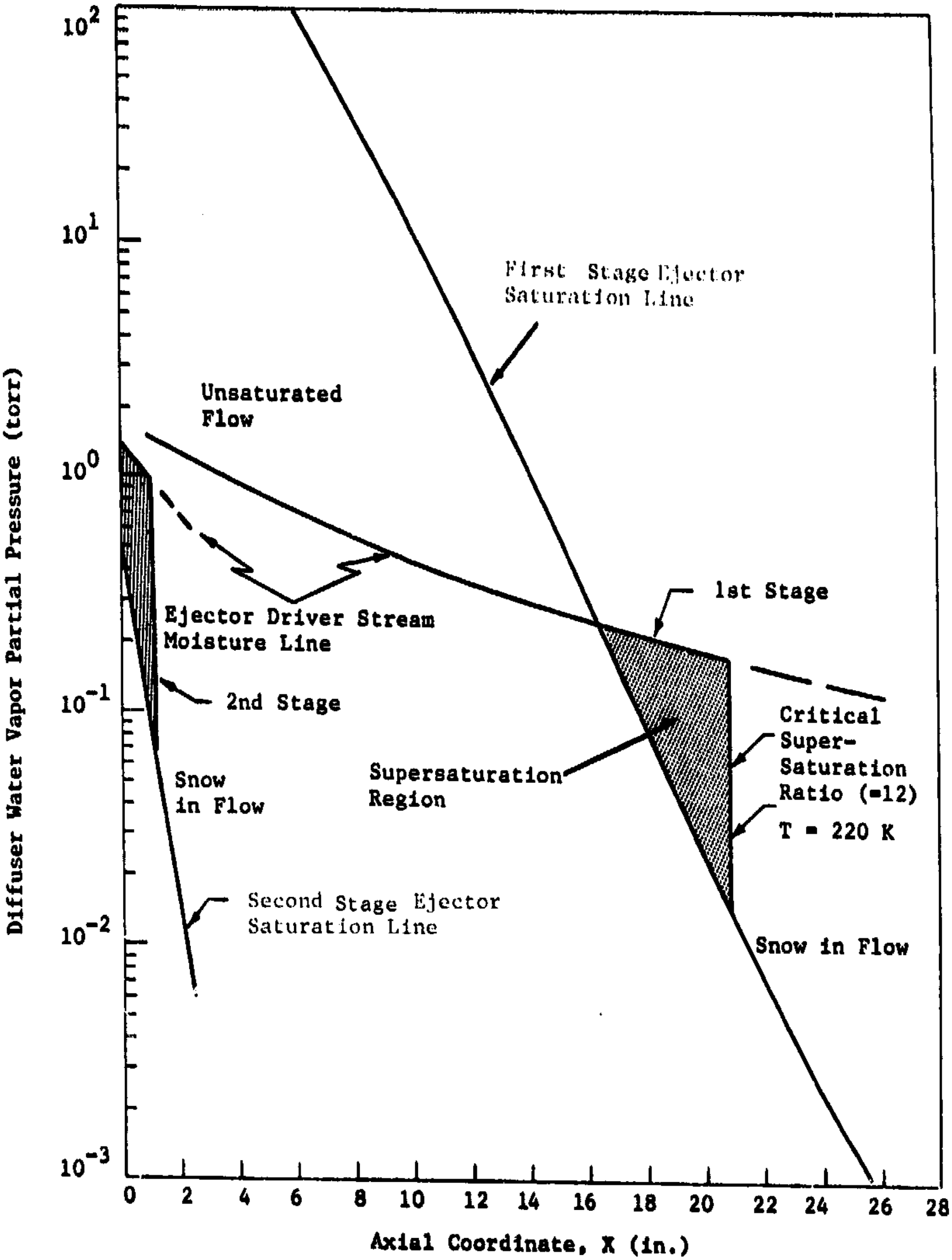


Fig. 6 Water Vapor Condensation (70 F, 50% RH Ambient Air)

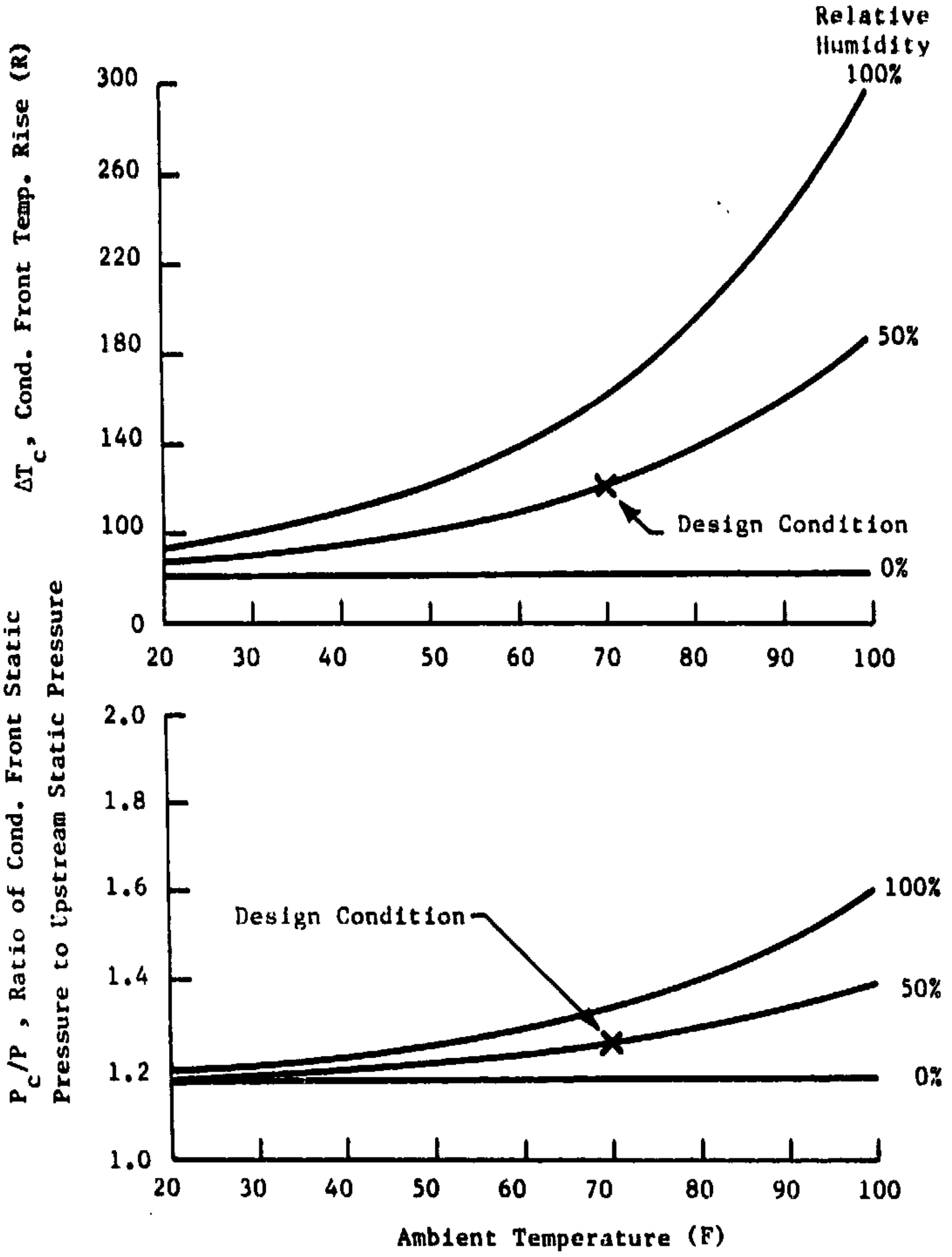


Fig. 7 Effects of Ambient Temperature and Relative Humidity on First Stage Ejector Due to Condensation

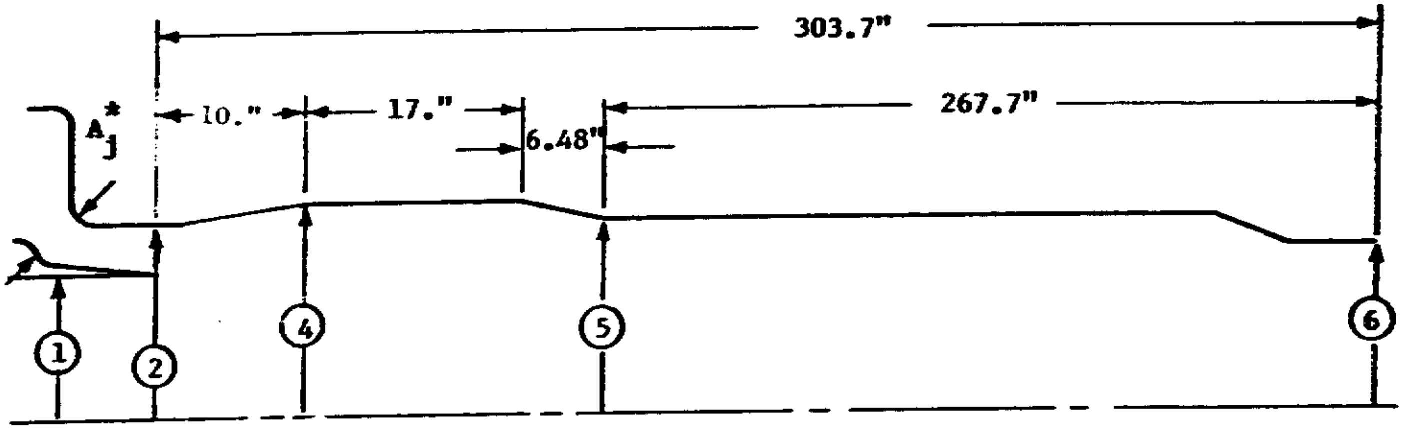
It is of interest to note that the J-57 turbojet engine is already set up with water injection ports at the compressor inlet station. Future full scale space engine hot firing tests could make use of this water injection mechanism to cool the space engine exhaust products. This would relieve some of the diffuser cooling problems and enable the ejectors to operate more efficiently. At the takeoff power setting, the system is capable of 20 gpm water injection rate. The use of water injection at other than the take-off power setting would have to be explored.

The second stage ejector design summary is presented in Fig. 8. The ejector throat area is designed to be variable and can be completely closed off. The ejector area ratio can be varied from 2.38 to infinity. The design blank off suction pressure and pumping capabilities are shown in Fig. 8.

The third stage ejector design summary is presented in Fig. 9. The third stage ejector is designed to operate in all modes of operation. The ejector area ratio can be varied from 2.59 to 10. The third stage ejector is designed to operate by itself using all of the turbojet exhaust products.

3.2 SUBSCALE JET ENGINE DRIVEN EJECTOR/DIFFUSER SAFETY ANALYSIS

The results of this analysis were presented at the 60 percent design review meeting. The key results are presented here. The worst case hazard assessment is presented in Table 1. The main point to be made from Table 1 is that ignition is improbable within the ejector/diffuser tubes. The first stage ejector mixing and explosion hazard analysis results are presented in Fig. 10. The worst case detonation pressures are approximately 8 psia. The second stage ejector mixing and explosion hazard results are presented in Fig. 11. The worst case detonation pressure is 37 psia. It should be pointed out that operating temperatures are too low within the facility to cause a detonation. The facility will be grounded to eliminate a lightning bolt source of energy. However, it is not anticipated that a test would be conducted on threatening weather days.



$R_{\textcircled{1}}$ = 12.20"
$R_{\textcircled{2}}$ = 16.0"
$R_{\textcircled{4}}$ = 17.42"
$R_{\textcircled{5}}$ = 16.73"
$R_{\textcircled{6}}$ = 14.33"

Design Conditions with Condensation Effects

$A_{\textcircled{4}}/A_j^* = 11.8$ $\quad A_j^* = 80.86\ \text{in}^2$

$P_{T_j} = 33$ psia $\quad T_{T_j} = 1400$ R

$\dot{m}_j = 37.3$ lbm/sec

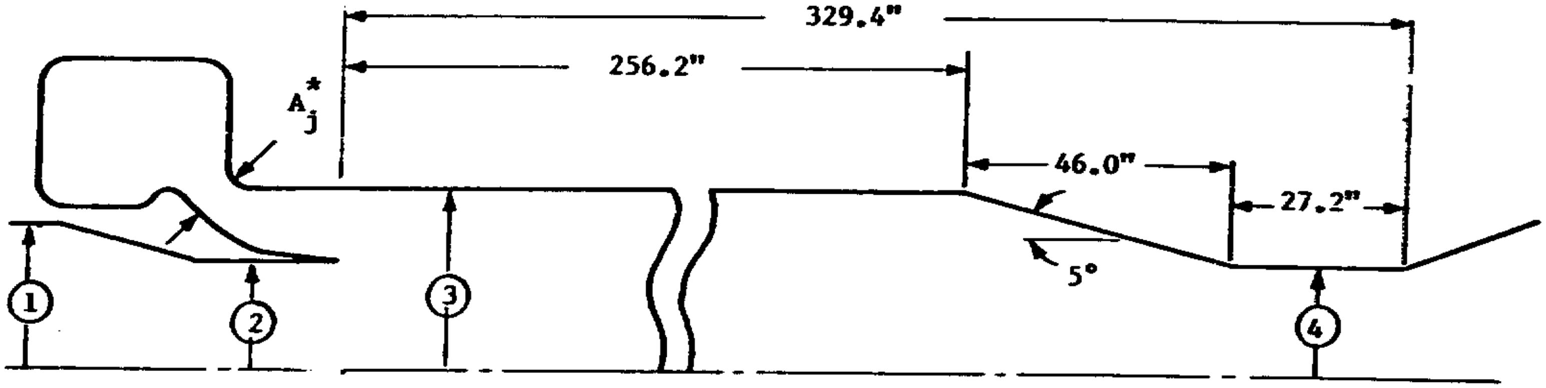
$r = \dot{m}_j/\dot{m}_{\textcircled{1}} = 11.3$

Blank Off Suction Pressure = 0.20 psia

Pumping Capability = 3.3 lbm/sec at 0.82 psia and 802 R

$A_{\textcircled{4}}/A_j^*$ Variable from 2.38 to Infinity

Fig. 8 Second Stage Ejector Design Summary



$R_{①}$ = 16.73"

$R_{②}$ = 14.33"

$R_{③}$ = 18.30"

$R_{④}$ = 14.28"

Design Conditions

$A_3/A_j^* = 4.09$ $A_j^* = 257.31\ in^2$

$P_{T_j} = 33$ psia $T_{T_j} = 1400$ R

$\dot{m}_j = 118.77$ lbm/sec

A_3/A_j^* Variable from 2.59 to 10

$r = \dot{m}_j/\dot{m}_2 = 2.93$

Blank Off Suction Pressure - 0.98 psia

Pumping Capability

40.6 lbm/sec at 5.5 psia and 1235 R

30.5 lbm/sec at 5.5 psia and 2200 R

Fig. 9 Third Stage Ejector Design Summary

Table 1 WORST CASE HAZARD ASSESSMENT

Kinetics Ignition Delay Behind Normal Shock in Duct

$$\tau_{ignition} = \frac{8 \times 10^{-9} \exp 9600/T,K}{P,\ atm} \text{ sec}$$ (NASA TP 1457, Aug 79, Huber et al.)

First Stage: ($T_{S,2}$ = 429 K; M_2 = 0.454; U_2 = 1073 ft/sec; $P_{S,2}$ = 0.821 psia)

$\tau_{ignition,NS}$ = 760 sec
$L_{ignition,NS}$ = 8.2×10^5 ft

No problem, by a wide margin of safety.

Second Stage: ($T_{S,2}$ = 663 K; M_2 = 0.444, U_2 = 801 ft/sec; $P_{S,2}$ = 5.52 psia)

$\tau_{ignition,NS}$ = 4.2×10^{-2} sec
$L_{ignition,NS}$ = 33.5 ft

Safe, with no ignition in duct.

Third Stage: ($T_{S,2}$ = 701 K; M_2 = 0.644; U_2 = 1128 ft/sec; $P_{S,2}$ = 16.7 psia)

$\tau_{ignition,NS}$ = 6.2×10^{-3} sec
$L_{ignition,NS}$ = 7.0 ft

Safe, with potential gentle ignition in open duct downstream of shock.

- The Available Ignition Source (i.e., the Jet Engine Exhaust) Operates at Temperatures Too Low to Ignite the H_2 Fuel Within the Flow Facility.

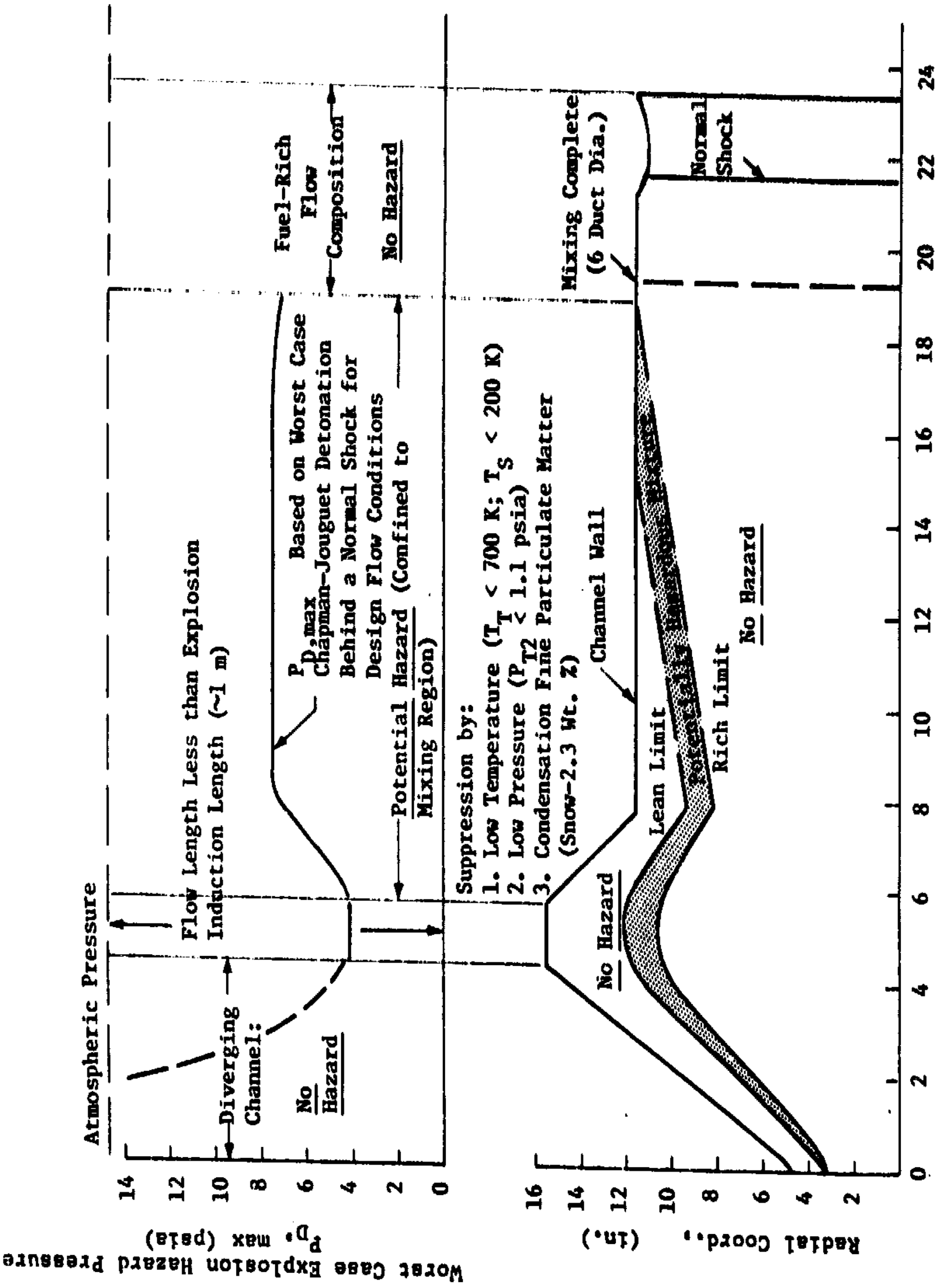


Fig. 10 First Stage Mixing and Worst Case Explosion Hazard Analysis

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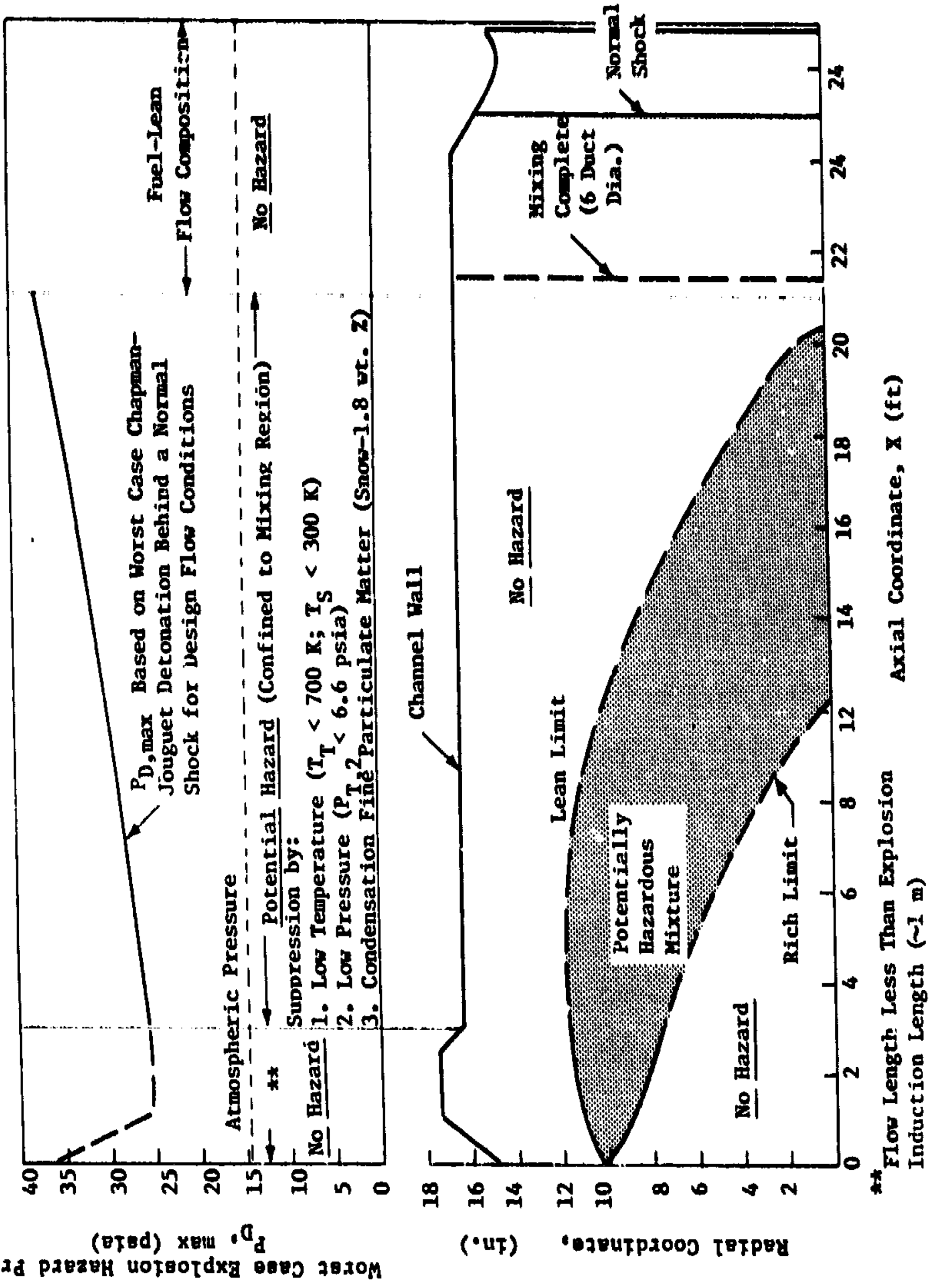

**Flow Length Less Than Explosion Induction Length (~1 m)

Fig. 11 Second Stage Mixing and Worst Case Explosion Hazard Analysis

3.3 FULL SCALE HAZARD CONTROL ANALYSIS

The hazard to be controlled is a potential detonation of unburned space engine hydrogen fuel within the diffuser/ejector duct work. In the past, this hazard has been eliminated by using an inert driver - steam. With the proposed use of jet engine effluent as the driving medium a potential for explosion of mixtures exists, as the jet engines are operated fuel-lean and consequently have an appreciable oxygen content (see Table 2).

Table 2 J-57 TURBOJET ENGINE CHARACTERISTICS

Cruise-Rated Air Flow Rate:	157 lb-sec^{-1} (70 F, 50% RH)
Cruise-Rated Fuel Flow Rate:	7,050 lb-hr^{-1}
Engine Exhaust -	
Total Flow Rate:	158.96 lbm-sec^{-1}
Total Temperature:	1400 R
Total Pressure:	33 psia
Composition -	
N_2	77.03 vol.%
O_2	16.70 vol.%
CO_2	2.51 vol.%
H_2O	3.74 vol.%
NO_x	87 ppm
CO	60 ppm
CH_4	84 ppm

3.3.1 Worst Case Hazard Analysis

To place the potential hazard in perspective consider Fig. 12 in which computed Chapman-Jouguet detonation pressure ratios are plotted as a function of mixture H_2 concentration for mixtures of space engine effluent

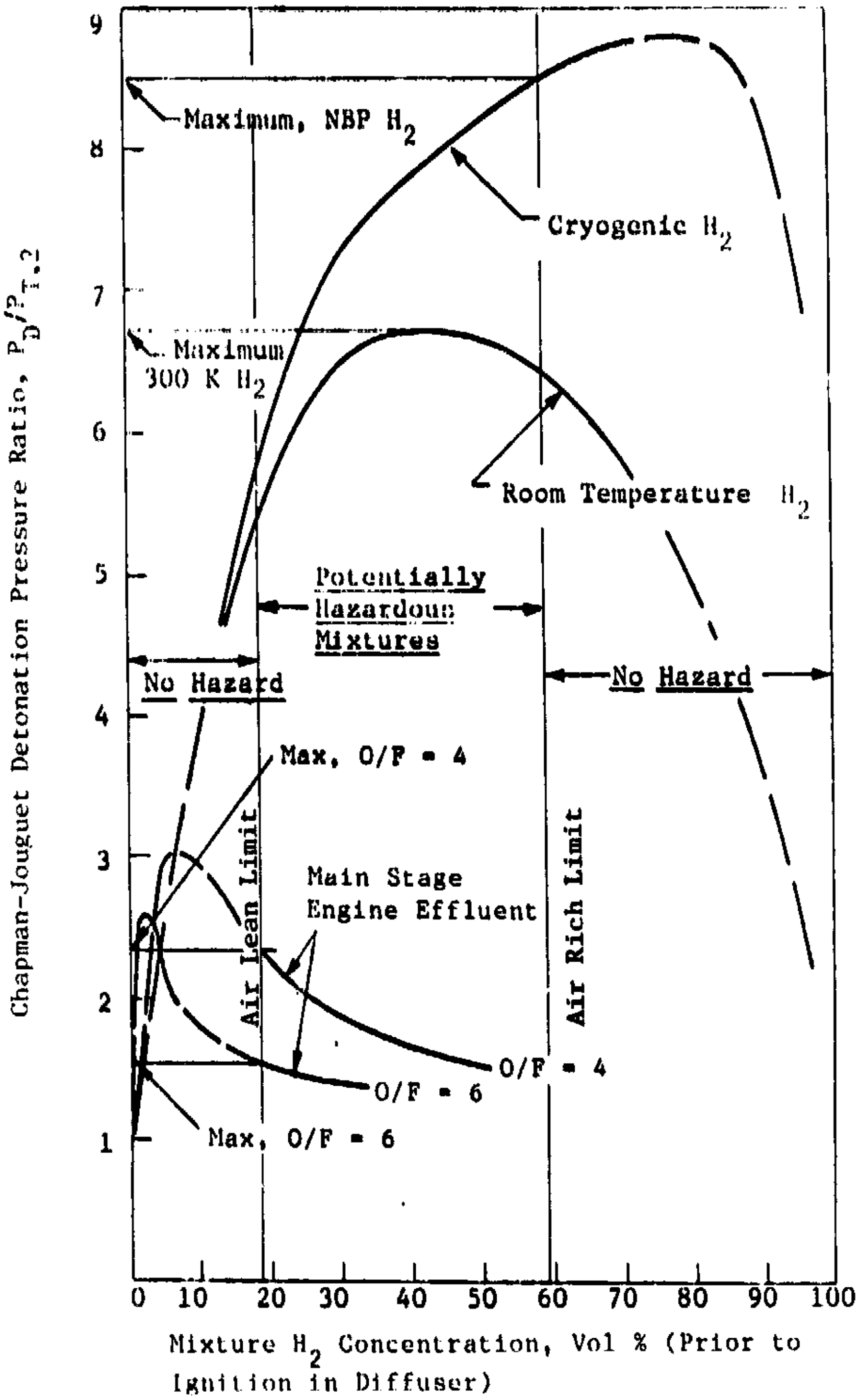

Fig. 12 Hazard Analysis: Worst Case Chapman-Jouguet Detonation Pressure Ratio Characteristics at Prevailing Stream Total Temperatures

and J-57 turbojet driver effluent at 0.5 atm initial pressure*. As is evident from the figure the worst case overpressures occur when 100 percent H_2 is exhausted from the test engine and are higher for cryogenic H_2 than for regeneratively heated H_2 at room temperature. For main stage space engine operation at engine O/F ratios of 4 or 6 a considerable decrease in the worst case detonation pressure ratio results. This is a direct consequence of the higher initial mixture temperature due to combustion in the space engine. Table 3 summarizes the maximum, i.e., worst case, potential detonation pressure ratios for the various space engine effluents considered, using J-57 turbojet exhaust as the diffuser/ejector driver. The corresponding worst case detonation pressures possible in each stage at 10 percent and 100 percent thrust engine operation are also shown in Table 3. These data are based on the calculated pressure distributions for the full scale facility shown in Figs. 13, 14, and 15.

3.3.2 Hazard Control Analysis

- Transient Operations

As is evident from Fig. 12 and Table 3, the maximum potential hazard exists during cold flow operations, which normally are tests of short duration. The highest potential overpressure would occur in the third ejector stage and could approach an upper limit of 272 psia, with cryogenic H_2. (Room temperature H_2 represents somewhat less of a potential hazard, but would however be more readily ignited.) A nearly 100 percent H_2 engine flow can also be encountered during engine startup and shutoff transients, as discussed in more detail in Section 3.3.3.

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*These computations were performed using the NASA-Lewis CEC code (Ref. 2). The detonation pressure ratios were found to be largely insensitive to initial pressure over the range of interest (i.e., subatmospheric) to this study.

Table 3 MAXIMUM CHAPMAN-JOUGUET DETONATION PRESSURES
(P_D = Detonation Pressure; $P_{T,2}$ = Initial Total Pressure
Driver: J-57 Jet Engine Exhaust

Space Engine Condition	$(P_D/P_{T,2})$ max	Worst Case Detonation Pressure (psia)			
		Thrust (%)	1st Stage	2nd Stage	3rd Stage
Cold Flow of Cryogenic H_2	8.5	10 100	39 (Shut Off)	165 124	272 253
Cold Flow of Room Temperature H_2	6.7	10 100	31 (Shut Off)	130 98	214 200
Main Stage, Engine O/F = 4	2.3	10 100	11 (Shut Off)	45 34	74 69
Main Stage, Engine O/F = 6	1.5	10 100	7 (Shut Off)	29 22	48 45

To control the startup/shutoff transient hazard, and also to allow short duration cold flow engine acceleration tests without oxidizer, Lockheed proposes the use of tank farm nitrogen as driver for the first and second diffuser/ejector stages during start/stop transients, and also during short duration cold flow tests without oxidizer flow. Sufficient GN_2 is to be used to dilute the peak H_2 flow in the overall mixture leaving the 2nd stage to below the lean detonation limit (see Table 4), i.e., to about 19 vol.% or less.

Table 4 FLAMMABILITY AND DETONATION LIMITS (Ref. 6)

	Hydrogen-Air	H_2-J57 Jet Engine Effluent*
Flammability Limits (vol.%)	$4.0 < F < 75$	$4.2 < F < 66$
Detonation Limits (vol.%)	$18.3 < D < 60$	$19 < D < 55$

*Estimated, based on effects of dilution of air with N_2, CO_2, and H_2O as reported in Ref. 6.

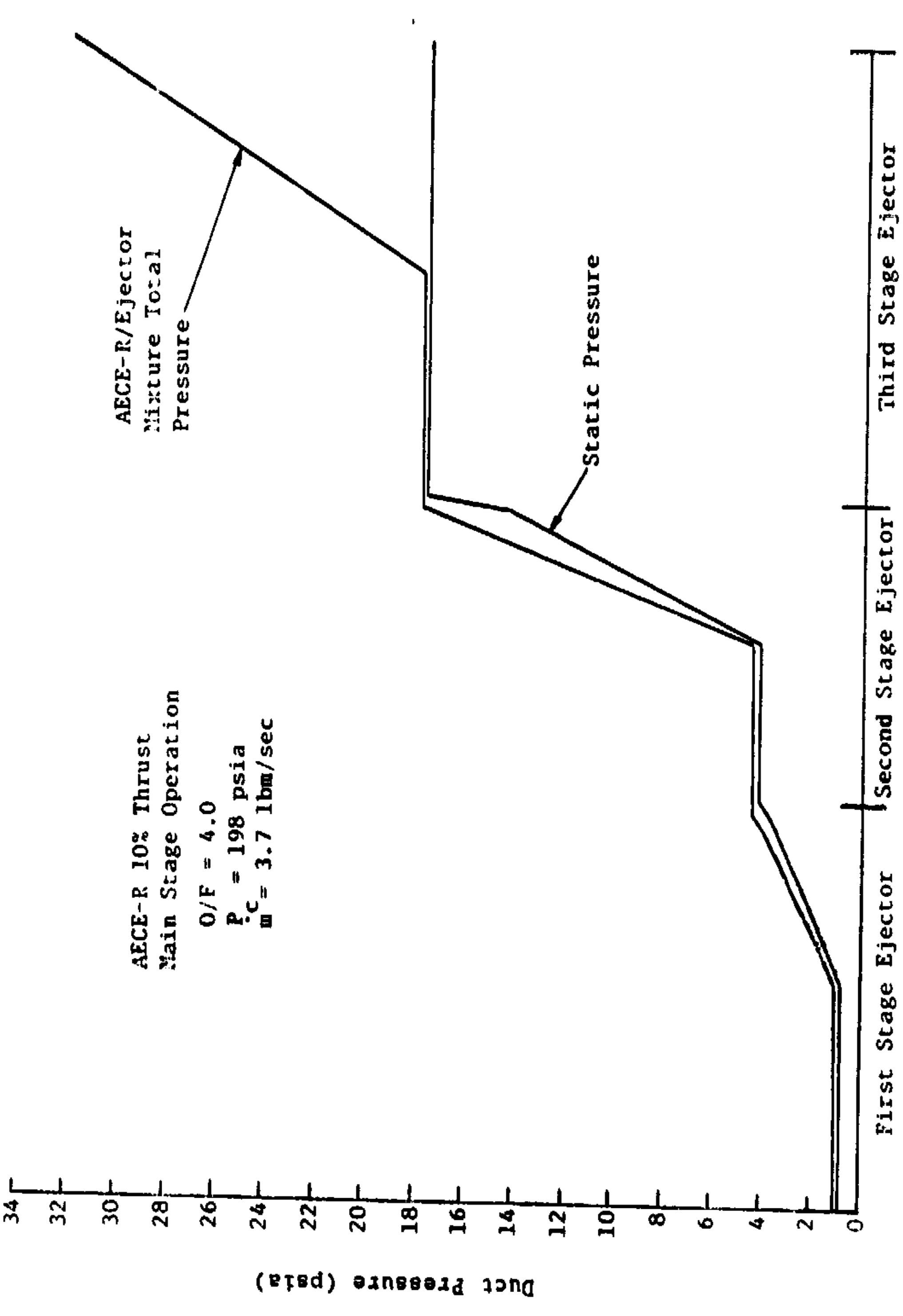


Fig. 13 Full Scale AECE-R 10 Percent Thrust Diffuser/Ejector Pressure Distribution

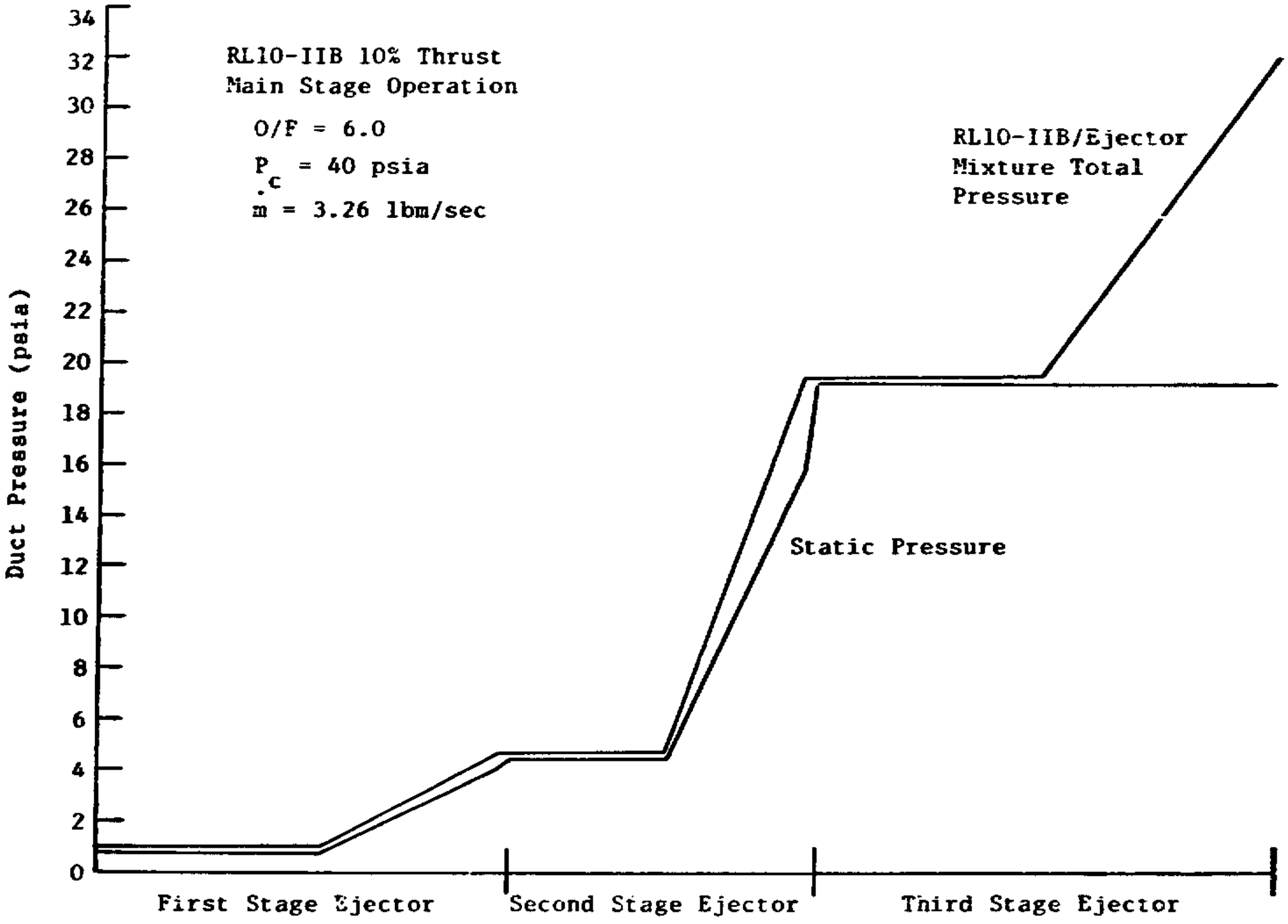


Fig. 14 Full Scale RL10-IIB 10 Percent Thrust Diffuser/Ejector Pressure Distribution

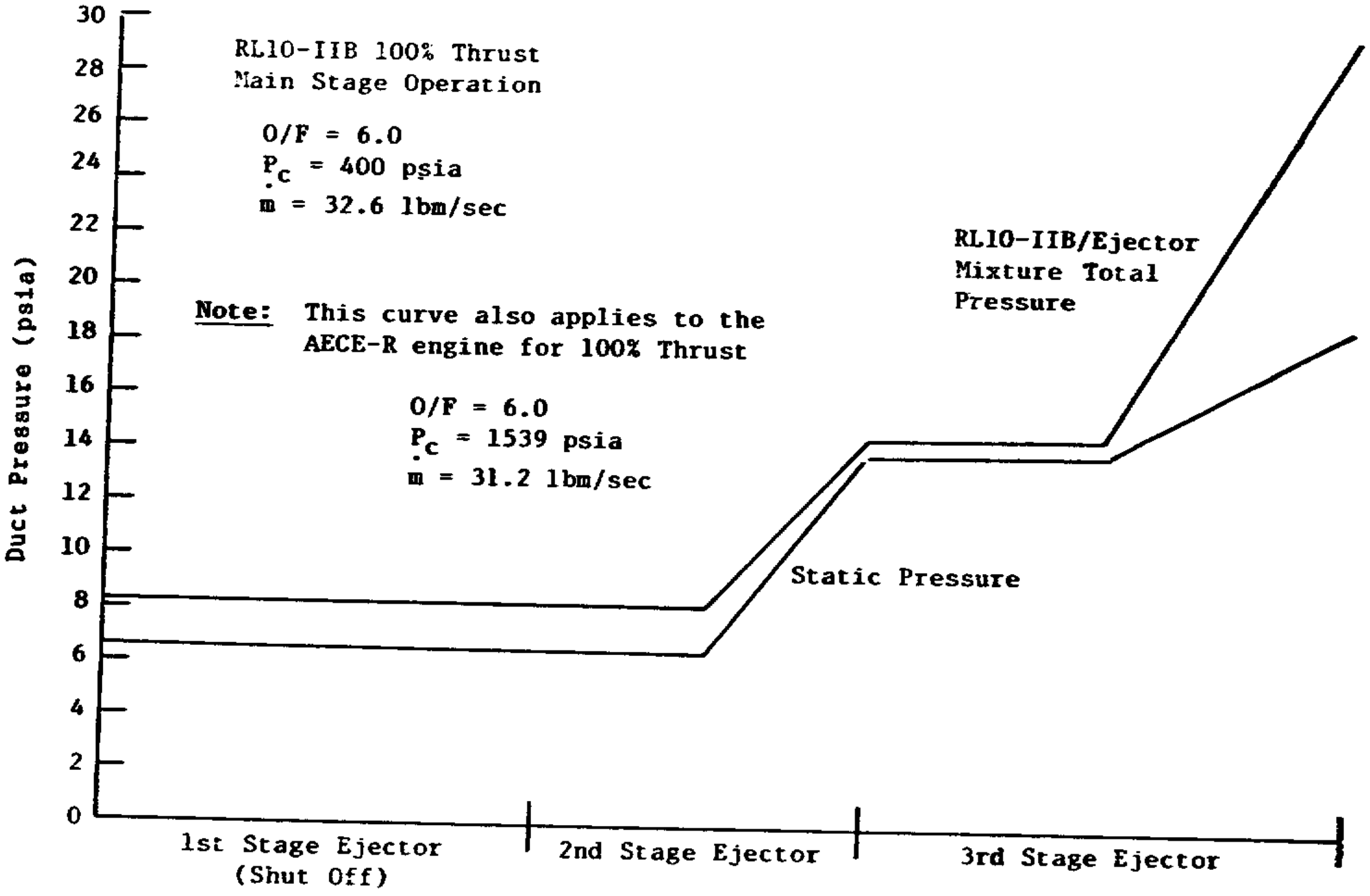


Fig. 15 Full Scale RL10-IIB 100 Percent Thrust Diffuser/Ejector Pressure Distribution

- Main Stage Operation

Long duration tests – 30 minutes or more – are required for the engines in main stage operation, at both low and high thrust levels. Tests of such length preclude use of GN_2 as driver, even in the first and second stages of the diffuser/ejector. Therefore at main stage the J-57 jet engines' exhausts will be used as driver in all of the stages, and the hazard control will be to ensure that the space engine excess fuel is combusted continuously in each of the stages as rapidly as it mixes with the driving medium. Three conditions that must be met simultaneously to achieve this are:

1. Mixture compositions must lie within the flammability limits summarized in Table 4. This is a restriction which is only operative on the fuel-rich side of engine operation in the present analysis. If mixtures are already too lean to burn, they are also too lean to detonate and are no longer a potential hazard. On the rich side of the flammability limits, mixtures exhausting from the space engines with greater than 66 to 75 percent H_2 (Table 4) – corresponding to engine O/F ratios of 2.5 to 2.0 or less – might require further dilution by the driving medium prior to the recommencing of combustion. If other conditions are correct it would seem probable that burning would resume in such mixtures prior to their being diluted sufficiently to enter into the detonable range – 55 to 60 percent H_2. To be prudent, however, engine mixtures entering the diffuser with an O/F ratio less than 2.0 should be regarded as potentially hazardous (see also below).

2. Static pressure must everywhere be higher than the lower ignition limit pressure to assure the continuity of the combustion process. Spark igniter ignition limits for H_2-GOX mixtures at room temperature obtained by Pratt & Whitney (Ref. 7) in a relatively small chamber (4 in. diameter, 15 in. long) are shown in Fig. 16, which indicates a lower limit pressure of 0.2 psia for these conditions. Also shown is the lowest static pressure (from Figs. 13, 14, and 15) in the proposed full scale diffuser facility, i.e., 0.7 psia. The latter pressure is the lowest encountered, in the first stage, at low space engine thrust levels. It is, however, sufficiently high that combustion of hot main stage exhaust proceeds as the gases mix even at the lowest pressure encountered.

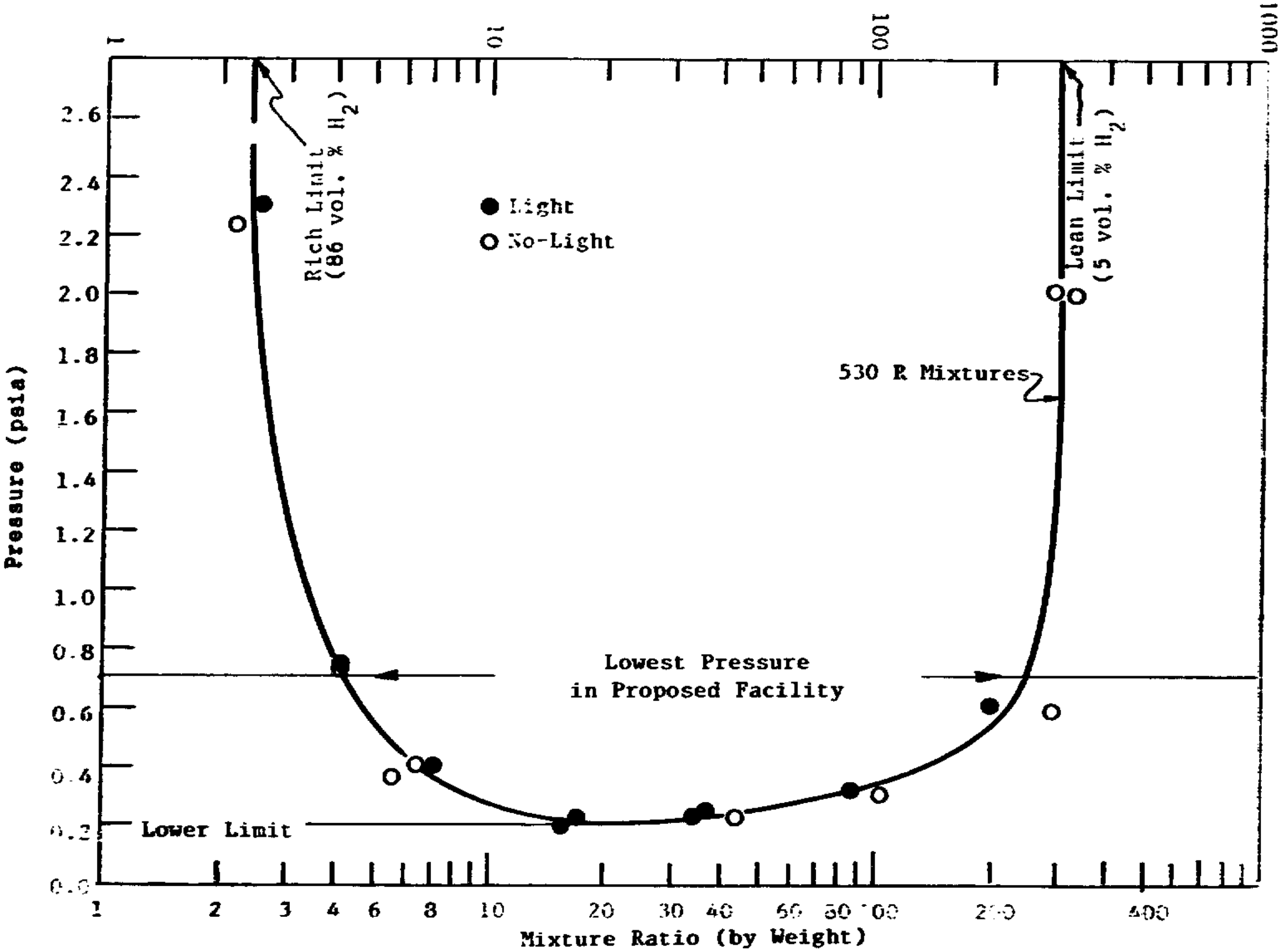


Fig. 16 H_2-GOX Static Ignition Limits (Spark Igniter 4 in. Diameter x 15 in. Long Chamber, PWA FR-303, Nov 61, Ref. 7)

It is useful in this regard to note that the lower pressure limit obeys an inverse response to increases in temperature (exponential response), vessel size and ignition source strength (see, e.g., Refs. 8 and 9). At main stage engine operation all of these factors are operative in a direction to assure continuous combustion.

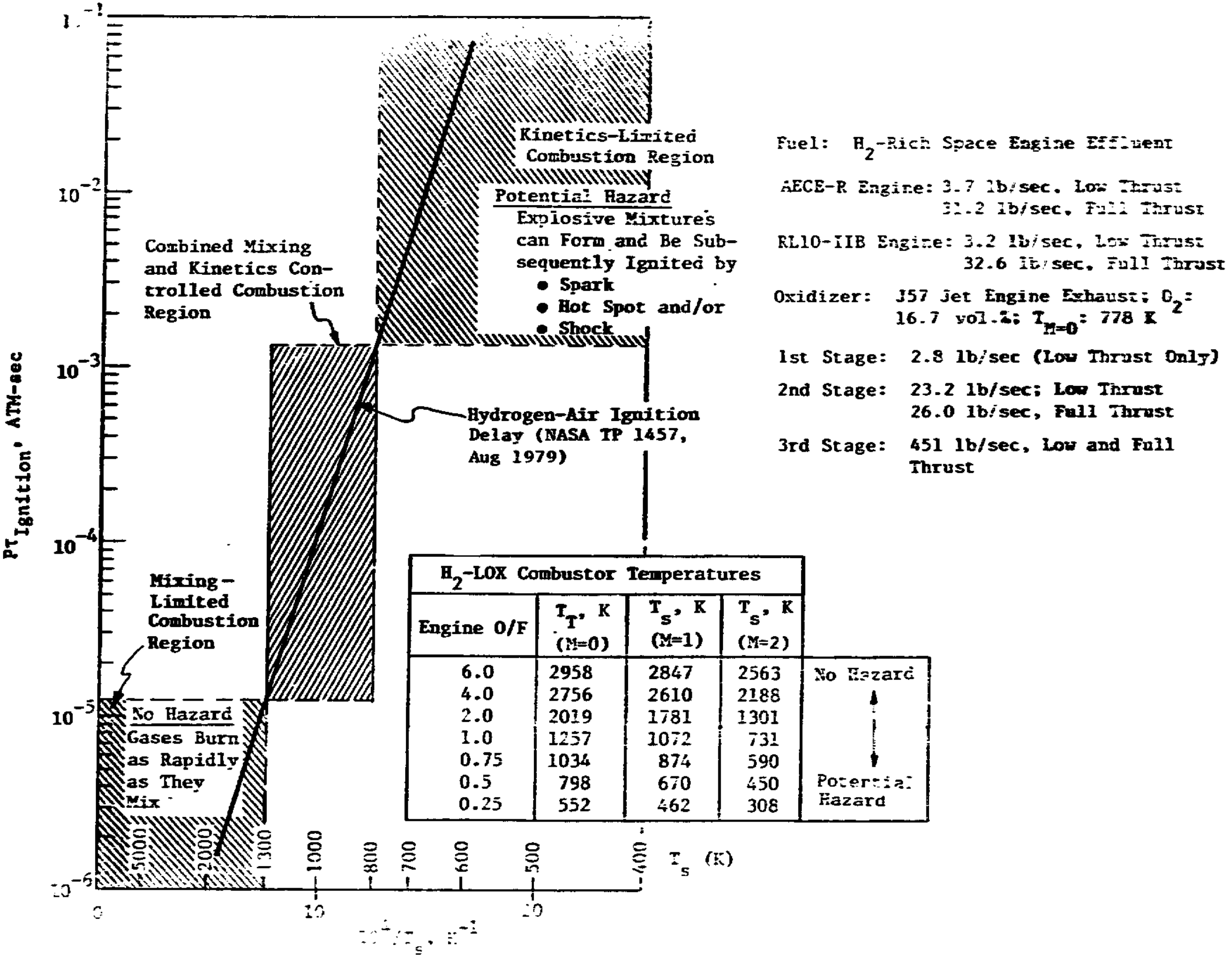
3. Static temperature must be sufficiently high everywhere that kinetics are rapid with respect to mixing. In Fig. 17, hydrogen-air autoignition delay times from Ref. 10 are shown as a function of static temperature. These delay times - inversely proportional to pressure - are a measure of the rapidity of hydrogen combustion.

As indicated, at static temperatures above 1300 K the product of pressure and ignition delay is approximately 10^{-5} atm-sec or less. Thus even at the 0.7 psia lowest static pressure (first stage, 10 percent thrust) delay times will be shorter than 2×10^{-4} sec for T > 1300 K - corresponding to engine O/F ratios greater than 2.0 accelerated to Mach numbers which are restricted by design to 2.0 or less within the diffuser/ejector facility. Noting that gas residence times in the first, second, and third stages are approximately 5, 10, and 30 msec, respectively, this ensures that the gases burn as rapidly as they mix, under all conditions, for engine O/F ratios of 2.0 or greater.

3.3.3 AECE-R and RL10-IIB Space Engine Transient Characteristics

Operating parameters of five candidate space engines for the orbital transfer vehicle are shown in Table 5 from Ref. 1. Of these advanced engines, two - the AECE-R and the RL10-IIB - were selected for analysis of potential transient operational test hazards in the proposed diffuser facility.

AECE-R engine startup transient and main stage characteristics were derived from ASE data presented in Ref. 11; shutoff data came from Ref. 12. Similar data for the RL10-IIB engine were derived from RL10A-3-3A data



Fuel: H_2-Rich Space Engine Effluent

AECE-R Engine: 3.7 lb/sec, Low Thrust
31.2 lb/sec, Full Thrust

RL10-IIB Engine: 3.2 lb/sec, Low Thrust
32.6 lb/sec, Full Thrust

Oxidizer: J57 Jet Engine Exhaust; O_2: 16.7 vol.%; $T_{M=0}$: 778 K

1st Stage: 2.8 lb/sec (Low Thrust Only)

2nd Stage: 23.2 lb/sec; Low Thrust
26.0 lb/sec, Full Thrust

3rd Stage: 451 lb/sec, Low and Full Thrust

H_2-LOX Combustor Temperatures

Engine O/F	T_T, K (M=0)	T_s, K (M=1)	T_s, K (M=2)	
6.0	2958	2847	2563	No Hazard
4.0	2756	2610	2188	↑
2.0	2019	1781	1301	
1.0	1257	1072	731	
0.75	1034	874	590	↓
0.5	798	670	450	Potential Hazard
0.25	552	462	308	

Fig. 17 H_2-LOX Engine Exhaust Autoignition Characteristics

Table 5 FIVE CANDIDATE SPACE ENGINES FOR THE OTV (REF. 1)

Parameter	Units	AECE-A	AECE-P	AECE-R	ASE	RL10-IIB
Thrust, Full	lb	15000	15000	15000	20000	15000
Thrust, Low	lb	2000	1500	1800	1850	1500
Maximum Test Duration @ MR = 6.0						
Full Thrust	sec	1200	1200	1200	1200	1200
Low Thrust	sec	2500	2500	2500	2500	2500
Gimbal Capability	-	None	None	None	None	None
Propellants		LOX/LH_2	LOX/LH_2	LOX/LH_2	LOX/LH_2	LOX/LH_2
Mixture Ratio, Full Thrust	-	6.0	6.0	6.0	6.0	6.0
Low Thrust	-	6.0	6.0	4.0	2.0	6.0
Nozzle Area Ratio	-	473	642	625	400	205
Engine Envelope:						
Outside Diameter @ Noz. Exit	in.	62.7	66.1	63.25	58.08	73.0
Inside Diameter @ Noz. Exit	in.	60.7	64.1	61.25	56.08	71.0
Length, Gimbal Pad to Noz. Exit	in.	120	114	117	100	110
Length, Gimbal Pad to Inlet Flange						
LOX	in.	12	12	12	27.1	10
LH_2	in.	15	15	15	36.87	10
Engine Weight	lb					
Chamber Pressure, Full Thrust	psia	1200	1505	1539	2028	400
Chamber Pressure, Low Thrust	psia	160	150	198	187	40
Noz. Exit Wall Press., Full Thrust	psia	0.196	0.163	0.172	0.406	0.19
Noz. Exit Wall Press., Low Thrust	psia	0.026	0.016	0.022	0.037	0.019
Total Flow Rate, Full Thrust	lb/sec	31.4	31.2	31.2	43.01	32.6
Total Flow Rate, Low Thrust	lb/sec	4.2	3.2	3.7	4.06	3.26
H_2 Flow Rate, Low Thrust	lb/sec	0.600	0.457	0.74	1.35	0.466
H_2 Flow Rate, Full Thrust	lb/sec	4.49	4.46	4.46	6.00	4.66

presented in Ref. 13. Startup transient, main stage operation, and shutoff transient behavior of the O/F ratio for the AECE-R engine at 10 percent and full thrust are shown in Fig. 18, along with the temporal response of the fuel flow rate at full thrust. Transient, startup and main stage operational data for the RL10-A-3-3A are shown in Fig. 19; detailed shutdown transient data were unavailable for the RL10 engine, other than the manufacturer's specification that on shutdown fuel is vented overboard, with a maximum of 0.25 lb total throughput of H_2 flowing through the engine nozzle.

The cross-hatched areas on Figs. 18 and 19 correspond to times during which the engine O/F ratio drops below 2.0, i.e., times during which a potential hazard exists with J-57 turbojet engine exhaust as the diffuser/ejector facility driving medium (as discussed previously in Section 3.3.2). Figure 20 emphasizes the potential startup and shutdown transient hazards which could occur if the J-57 turbojet engine exhaust were used as the driver during the transients: H_2 concentrations in the flow leaving the second stage would be well above the lower detonation limit, with or without reaction in the diffuser; additionally, static temperatures at Mach 2 would be too low during portions of the startup and shutdown to ensure reaction as the gases mix - resulting in potential detonatable mixtures which could be set off by complex shock structures, hot spots or accidental means such as an electrical discharge. For this, and the previously reviewed reasons, operation during startup and shutdown transients will use inert, gaseous nitrogen as the driving medium.

3.3.4 Space Engine Transient Hazard Assessment and Control

Combining the hazard control analysis (Section 3.3) with the transient characteristics of the space engines considered (Section ?.3.3) results in the transient hazard assessment synopsized in Table 6. For both engines a potential hazard is identified during startup and shutdown transients. The proposed control to eliminate these hazards is to use a purge GN_2 flow as

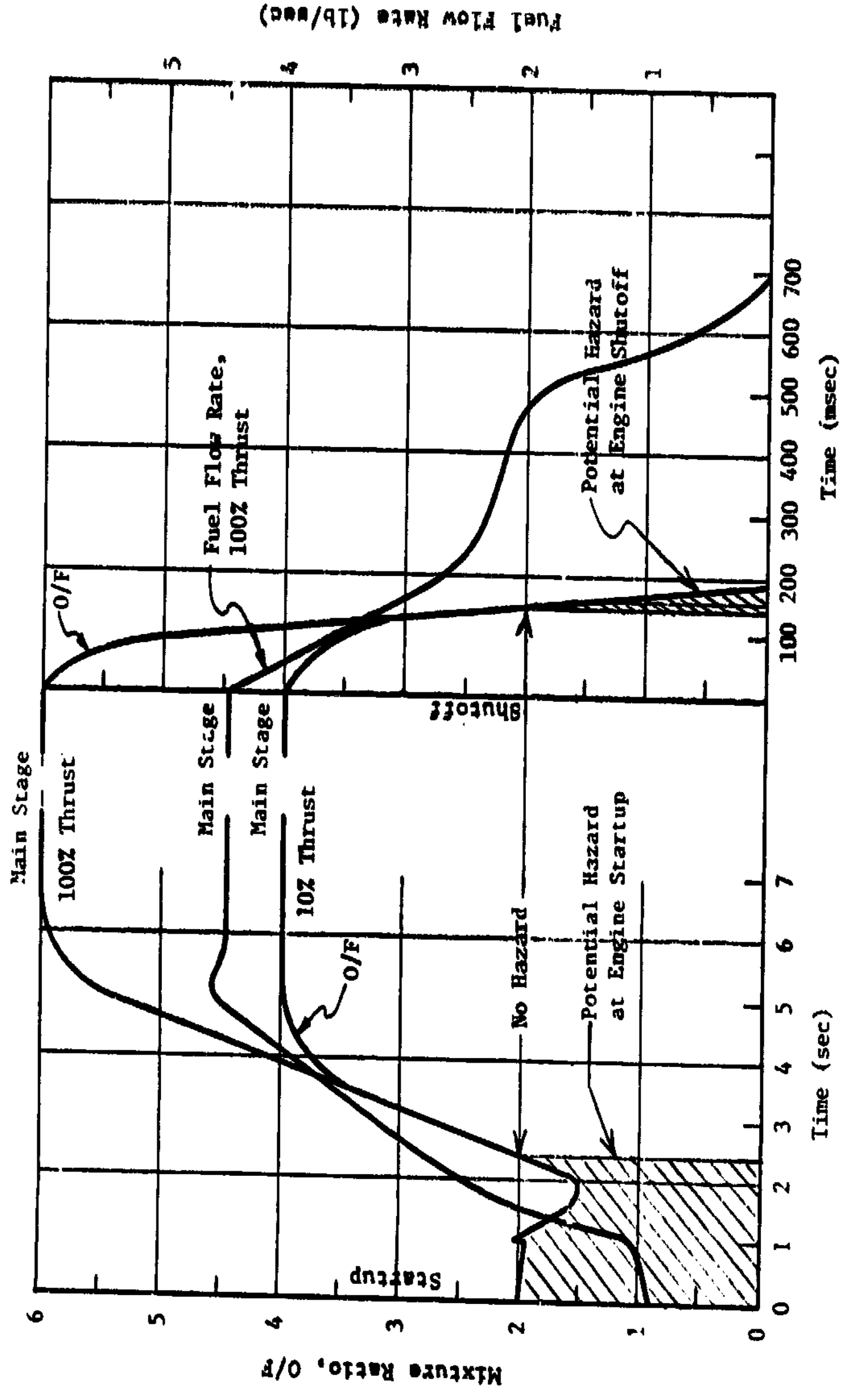


Fig. 18 AECE-R Engine Transient Characteristics (Estimated from ASE Engine Data, Refs. 11 and 12)

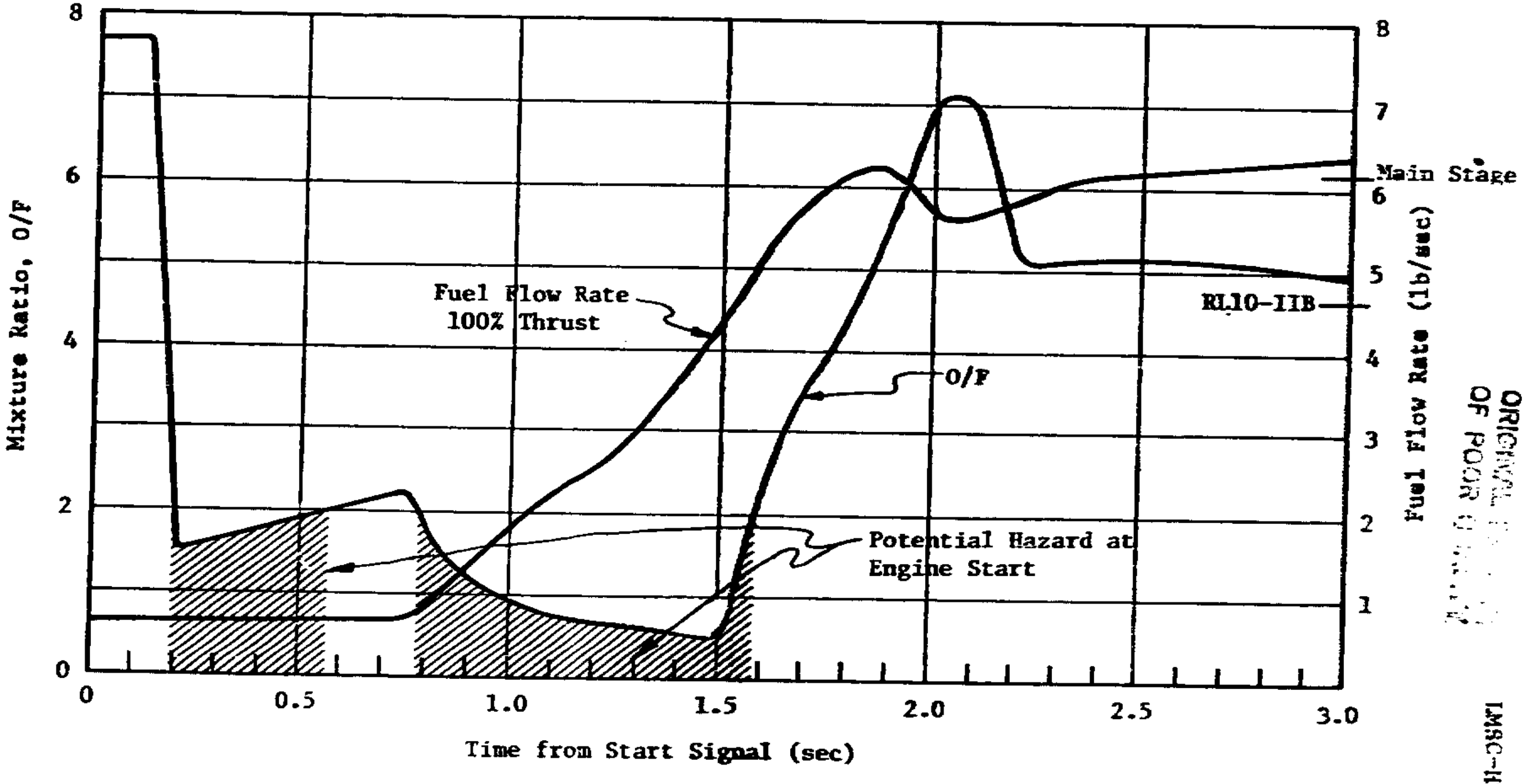


Fig. 19 RL10A-3-3A Engine Start Transient Characteristics (Ref. 13)

(Note: J-57 Turbojet exhaust will not be used as driver during transients.)

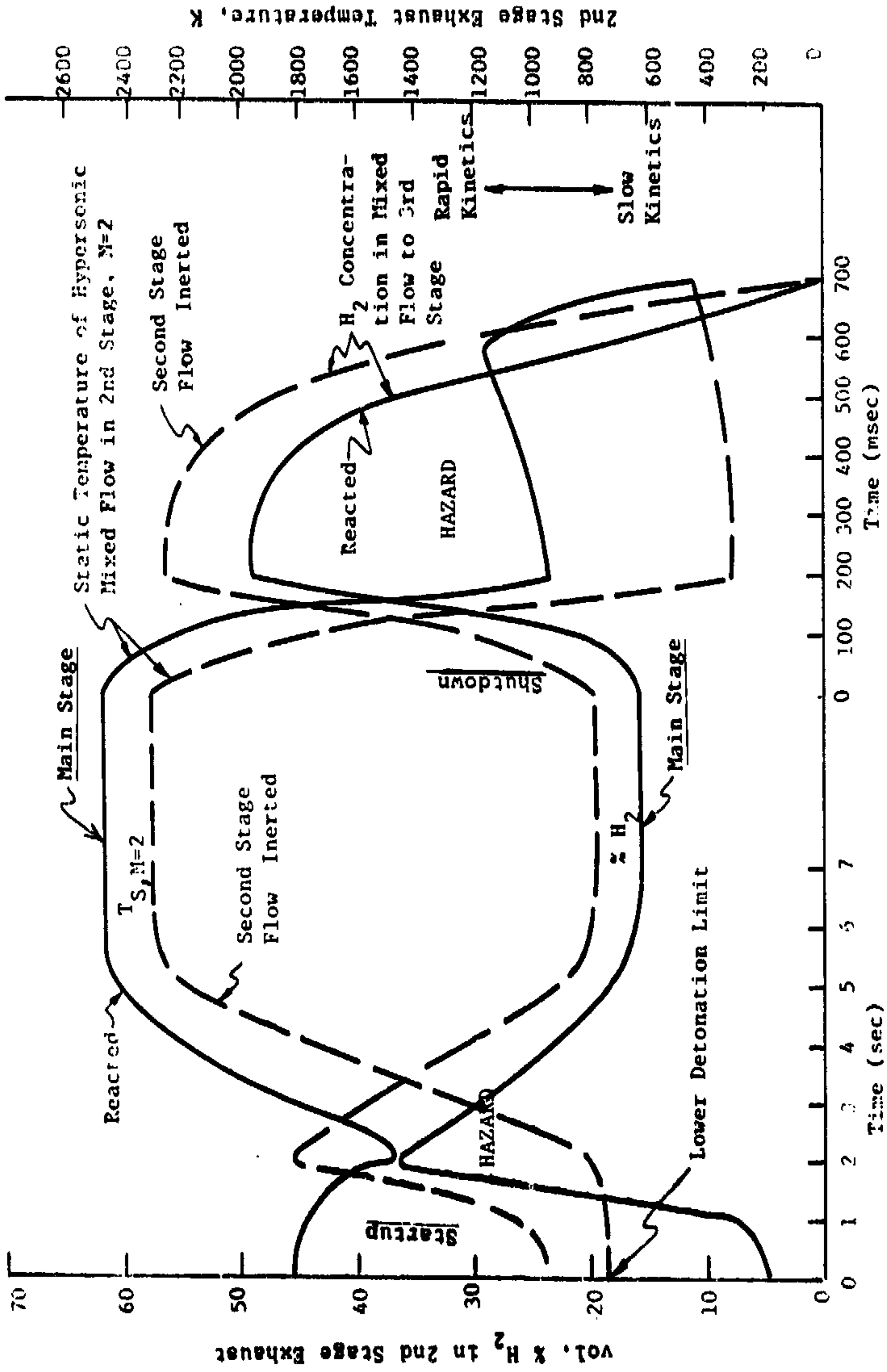


Fig. 20 AECE-R Engine Second Stage Diffuser Transient Characteristics with J-57 Jet Engine Exhaust as Driver (26 lb/sec)

the inert gas driver in the first and second stages during transients, as required. No hazard exists during main stage engine operation.

Table 6 SYNOPSIS OF ENGINE TRANSIENT HAZARD ASSESSMENT

(DIFFUSER DRIVER: J57 JET ENGINE EXHAUST)

AECE-R Engine (Based on ASE Engine Data)

Startup - Potential Hazard, O/F < 2.0 from 0 to 2.4 sec After Start Signal

Main Stage - No Hazard, O/F = 6.0, High Thrust; O/F = 4.0, Low Thrust

Shutdown - Potential Hazard; O/F < 2.0 at Shutoff Signal + 150 msec

RL10-IIB Engine (Based on RL10A-3-3A Engine Data)

Startup - Potential Hazard; O/F < 2.0 from 0.20 to 1.58 sec after Start Signal

Main Stage - No Hazard; O/F = 6.0 for Low and High Thrust Operation

Shutdown - Potential Hazard; Quantitative Transient Data Inputs are Required.

Pratt & Whitney Inputs on RL10 Shutdown:

1. If a graphite nozzle is used, oxidizer-rich shutdown must be avoided to protect hot engine and red hot nozzle.
2. Somewhat in conflict with 1, H_2 is normally dumped overboard on shutdown, with a maximum total of 1/4 lb H_2 flowed through the nozzle on shutdown.

Proposed Control to Eliminate Potential Start/Stop Hazards:

Use a Purge GN_2 Flow as the Inert Gas Driver in 1st and 2nd Stages During Transients, as Required

Temporal response of the diluted, inerted flow leaving the second stage diffuser during 100 percent thrust AECE-R engine run transients with 150 lb/sec of GN_2 as the driving medium is shown in Fig. 21. As is evident, the hydrogen content of the exit stream is diluted well below the lower detonation limit for all times at which the mixture static temperature is significantly above room temperature. (A slightly higher flow of GN_2-170 lb/sec-would ensure an overall H_2 concentration entering the third stage below the detonation limit even during the engine shutoff interval after 190 msec, after which time the oxidizer flow rate is negligible.)

(100% Thrust; Driver: GN_2, 150 lb/sec)

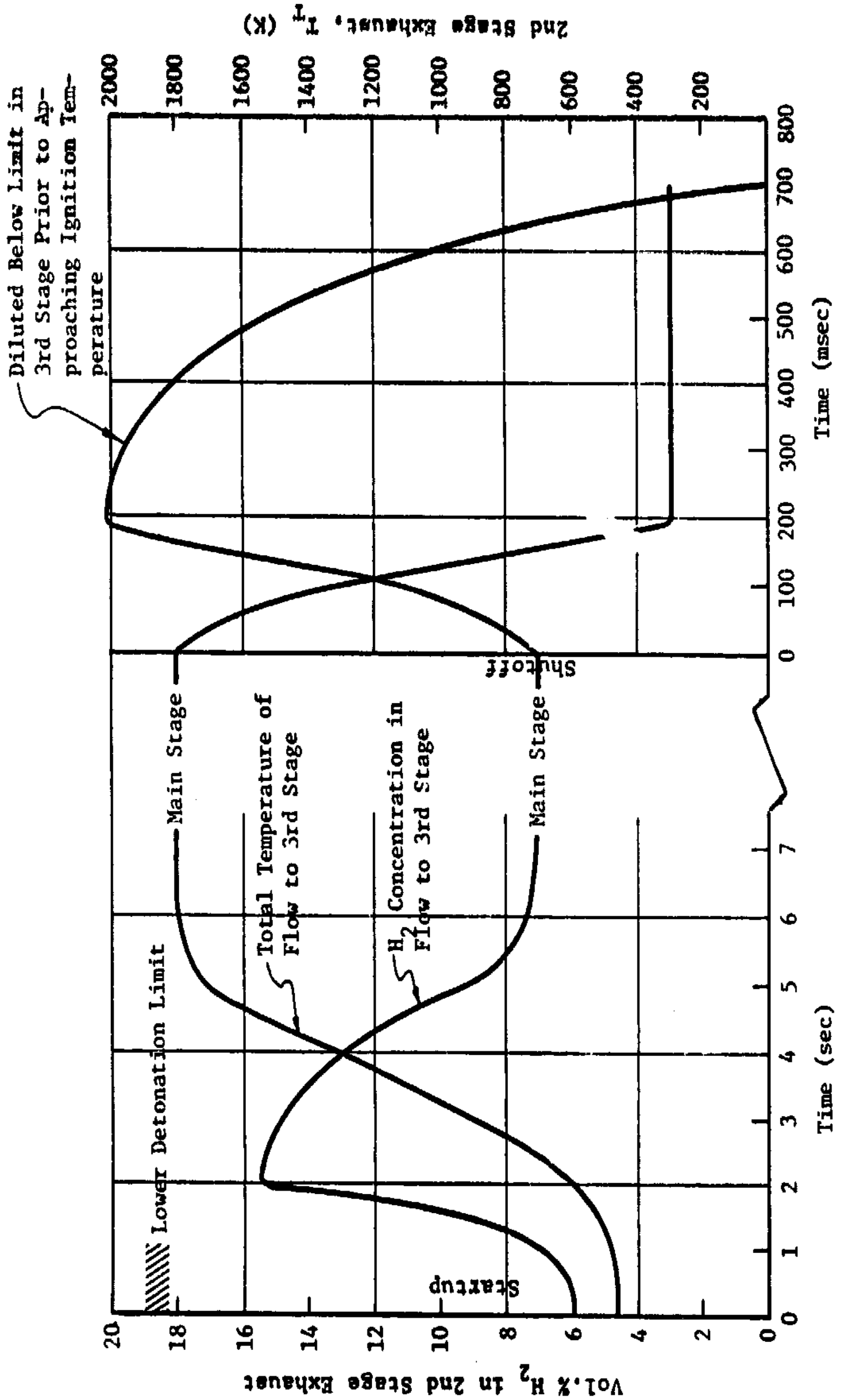


Fig. 21 AECE-R Engine Second Stage Diffuser Transient Operation

Main stage operation of both engines at low and full thrust is summarized for each stage in Tables 7 and 8, respectively, for both J-57 jet engine exhaust and GN_2 driving mediums. In all cases, with the stages being driven by the jet engine's exhaust, excess H_2 is progressively burned at high temperature and the flow ultimately leaves the facility with negligible residual hydrogen. With GN_2 driving the stages: (1) at low thrust, H_2 is diluted in the first two stages to a safe 2.8 or 8.5 percent in the two engines, with a second stage exhaust total temperature of only 955 or 958 K; in the third stage the mixture is further diluted, resulting in a near zero exhaust H_2 concentration of only 0.3 or 0.9 percent from the facility, assuming no further combustion, or to zero if combustion is completed in the third stage; (2) at full thrust, H_2 is diluted in the second stage to a safe 7.4 or 7.1 percent, but at a high total temperature of 1855 or 1806 K; in the third stage combustion continues at high temperature with a resultant negligible H_2 content in the facility effluent. Thus for the vast majority of test operation virtually no H_2 is discharged from the facility, and there is no requirement for an external torch to burn residual H_2.

As discussed previously, start/stop transients are to be controlled by GN_2 flow to the first two stages such that the peak H_2 concentration in the flow entering the third stage is maintained below the lower detonation limit. At low thrust, with 50 lb/sec GN_2 driving the first two stages, the full main stage cold flow of H_2 can be controlled, as also is shown in Table 7. At high thrust, with 150 lb/sec GN_2 driving the first two stages, about 60 percent of the full main stage cold flow of H_2 can be controlled. Thus in the event of a stuck oxidizer valve on startup, provision of an automatic engine shutdown prior to reaching 60 percent of the full rated H_2 flow is required. Alternatively the full thrust transient GN_2 driver flow can be uprated to 250 lb/sec, if a full rated H_2 cold flow requirement is needed for engine acceleration or other tests.

Table 7 LOW THRUST OPERATION

			RL10-IIB Engine Exhaust		AECE-R Engine Exhaust		
Engine Status	Driver (Stages 1 & 2)	Stage	T_T, K	Vol.% H_2	T_T, K	Vol.% H_2	Minimum P_{static} (psia)
Main Stage Burn	J-57s	Engine	2958	29.5	2756	48.6	-
		1	2628	16.9	2565	33.2	0.7
		2	1968	0.1	2310	1.3	4.2
		3	871	Nil	926	Nil	17.6
	• H_2 is burned virtually to completion in first and second stages.						
Main Stage Burn	GN_2 (50 lb/sec)	Engine	2958	29.5	2756	48.6	-
		1	2461	15.4	2304	33.1	0.7
		2	958	2.8	955	8.5	4.2
		3	799-825	0.3-Nil	799-878	0.9-Nil	17.6
	• Flow enters third stage with H_2 well below detonation limit.						
Start/Stop Transients	GN_2 (50 lb/sec)	**Worst Cases:** RL10-IIB Engine: Full Fuel Flow, 0.466 lb H_2/sec AECE-R Engine: Full Fuel Flow, 0.74 lb H_2/sec					
		Engine	300	99.8	300	99.8	
		1	300	56.5	300	67.3	
		2	300	11.5	300	17.1	
	• H_2 flow is diluted with GN_2 to below the detonation limit in stages 1 and 2. The full maximum rated cold H_2 flow at low thrust can be controlled.						

Table 8 100 PERCENT THRUST OPERATION

			RL10-IIB Engine Exhaust		AECE-R Engine Exhaust		
Engine Status	Driver (Stages 1 & 2)	Stage	T_T, K	Vol.% H_2	T_T, K	Vol.% H_2	Minimum P_{static} (psia)
Main Stage	J-57s Not Driven	Engine	2958	29.5	2958	29.5	-
		1	2958	29.5	2958	29.5	-
		2	2872	16.3	2869	15.8	6.5
		3	1545	Nil	1519	Nil	14.0
	• H_2 is burned as rapidly as it mixes in second and third stages.						
Main Stage Burn	GN_2 (50 lb/sec) Not Driven	Engine	2958	29.5	2958	29.5	-
		1	2958	29.5	2958	29.5	-
		2	1855	7.4	1806	7.1	6.5
		3	1324	Nil	1300	Nil	14.0
	• H_2 flow is diluted with GN_2 to well below detonation limit in second stage and burns as rapidly as it mixes in third stage.						
Stop/Start Transients	GN_2 (150 lb/sec)						
	• H_2 flow is diluted and cooled with GN_2 to below the detonation limit in second stage. Up to 60 percent of the full maximum rated cold H_2 flow can be controlled.						

4. SUBSCALE DIFFUSER MECHANICAL/STRUCTURAL DESIGN

The subscale ejector/diffuser system described in Section 3 of this report has been designed. The design details are discussed in this section.

4.1 GENERAL DESCRIPTION

The facility shown in LMSC Drawing R82734 is designed to flow non-combusted H_2 gas through a 650:1 area nozzle into a three stage ejector/diffuser system. The facility will consist of a H_2 chamber, throat, 650:1 area ratio nozzle, altitude cell, H_2 diffuser tube, and the three stage ejector/diffuser system. The altitude cell is designed to be pumped by the H_2 nozzle flow to maintain the required cell pressure during the H_2 flow tests. The ejector expansion area ratio is designed to be adjustable by varying the ejector throat area while maintaining a constant exit area. This is accomplished by translating the outer ejector throat and nozzle surface relative to the fixed inner ejector surface. The outer movable ejector surface is allowed to translate fore and aft being held in position radially by either a three or four pipe support system. By necessity, the third stage ejector has a four pipe support system while the first and second stage ejectors have a three pipe support system. The details of the three pipe support system are shown on LMSC Drawings R82737 and R82738. The ejector outer surface is translated using four equally spaced electrical actuators.

The actuators are capable of handling 5000 lbf each and have a 3 in. stroke for the first and second stage ejectors and a 6 in. stroke for the third stage ejector. The actuator details are not available at this time, although several suppliers are available. The first and second stage ejector throat areas are designed to be completely closed off and inerted with GN_2. The diffusers for the first and second stage ejectors are the efficient "second throat type" diffuser design. The third stage ejector is designed to be "started" and run by itself utilizing all of the turbojet exhaust. This ejector is designed to keep the pumped flow subsonic for better pressure recovery. Start-up should not be a problem since the ejector flow will be exhausting into a duct at an initial pressure of approximately 14.7 psia, thereby effectively limiting the ejector area expansion ratio. A few milli- seconds later, after the ejector has evacuated the upstream duct system the cell pressure will drop to 1.0 psia, and the ejector will operate at an area expansion ratio of 3.1:1.0.

The facility will be mounted on the existing rail and support system located at MSFC's Cold Flow Calibration Facility adjacent to the Hot Gas Facility, Building 4554. The site plan is shown in LMSC Drawing R82733. The plan and elevation view is shown in LMSC Drawing R82732. The ejector inlet piping from the J-57 turbojet engine is shown in planform view in LMSC Drawing R82736. The J-57 piping details other than those shown in R82736 were beyond the scope of this contract as mentioned previously in Section 2. The facility will not require cooling water.

The facility also consists of: (1) a J-57 turbojet engine and its fuel tank and controls; (2) the gaseous hydrogen system (piping and components) and high pressure GN_2 supply lines; (3) overhead hoist system for materials handling; (4) hydrogen leak detectors; (5) remote control Firex system; (6) TV camera surveillance system and communication system; (7) remote control systems from Building 4554; and (8) an instrumentation system with remote readout in Building 4588.

4.2 GOVERNMENT-FURNISHED EQUIPMENT LIST

It was beyond the scope of this contract to develop a detailed GFE list. The following list of GFE equipment required to support this facility is preliminary:

1. One working J-57 turbojet engine complete with fuel tank, starter system, instrumentation, and controls
2. One J-57 turbojet engine support structure
3. Approximately 100 ft of 5 in. GN_2 supply line to the present site from the northeast side of Building 4548 and shutoff valve with downstream bolt flange connection to flow 73 lb/sec
4. Gaseous hydrogen trailer and control system with 1 in. pipe type AN flared fitting for attachment to the facility to flow 0.5 lb/sec
5. A low pressure (150 psig) GN_2 purge line system to flow 2 lb/sec
6. Facility instrumentation system with remote readout in Building 4588
7. Overhead hoist or ground support equipment for materials handling
8. Hydrogen leak detector system
9. Remote controlled Firex system
10. TV camera surveillance system and communication system, and
11. Computer system for remote control and data reduction and plotting.

4.3 MATERIALS AND COMPONENTS SELECTION

The subscale ejector/diffuser facility will be constructed of 304L stainless steel except as noted. The turbojet exhaust ducting will be constructed of 321 stainless steel of 0.060 in. thickness except for the flanged connections which will be thicker. All flange gaskets will be Sepco Grafoil crinkle gasket tape style SG6360. The 1/4 in. by 1/4 in. ejector sliding seals will be fabricated from Sepco Grafoil sheet style SG36 of 0.015 in. thickness. A local supplier of the Sepco products is TENN-VAL, Inc., of Decatur, Alabama. The full ported check valve is AGCO model CV-2 supplied by the Blythe Company, Indian Trail, N.C. The Digicell valves are supplied by Horton Instrument Company, Birmingham, Alabama. The EMCV valve, the electromechanical actuator, and thermal expansion joints will be custom made for this facility.

The thermal expansion joints shown in LMSC Drawing R82736 can be supplied by U.S. Bellows, Santee, California. The electromechanical control valve (EMCV) and the electromechanical actuator specifications and possible suppliers are listed below.

Electromechanical Control Valve (EMCV) Specifications

Opening Time	100 msec
Actuator:	
Solenoid with pressurized GN_2 over hydraulic	
GN_2 pressure available:	4000 psig
Hydraulic pressure available:	2500 psig
Hydraulic flow available:	35 gpm
Valve Type: Butterfly	
Operating Environment	
Temperature:	940 F
Pressure	18 psig
Supplier: The Blythe Company, Indian Trail, N.C.	

Electromechanical Actuator Specifications

Maximum Operating Force	5000 lbf
Operating Voltage	28 Vdc
Stroke Speed	3 in./min.
Stroke	
First and Second Stage Ejector	3 in.
Third Stage Ejector	6 in.
Dimensions:	
Closed Length	10 in.
Outside Diameter	6 in.
Environment:	
Ambient plus capability of being inerted using GN_2 purge to eliminate all explosion hazards	
Potential Suppliers:	Inland Motor, Radford, Va. Plessey Dynamics, Hillside, N.J. Clifton Precision, Clifton Heights, Pa.

4.4 DRAWINGS

A detailed list of all the drawings which were developed for this facility under this contract is listed in Appendix C. Copies of the drawing set will be released at the discretion of Mr. K.E. Riggs, EP23, MSFC Contracting Officer's Representative.

4.5 STRESS ANALYSIS

The detailed stress analysis of each facility drawing is contained in Appendix B. The factors of safety which were used are 1.6 on yield strength and 4.0 on ultimate strength. A safety margin summary is contained in Appendix B and shows that each part has an adequate margin of safety.

5. PLANS

Under this contract, a Preliminary Test Plan, an Instrumentation Plan, and a System Operating Procedure Plan were developed. The preliminary test plan was published under separate cover as Ref. 14. The Instrumentation and Operational Procedures Plans are described in this section.

5.1 INSTRUMENTATION PLAN

The subscale ejector/diffuser facility is shown in Fig. 1. The first stage ejector will operate at the highest duct-to-ejector-throat-area ratios, the second stage ejector will operate at medium ejector area ratios and the third stage ejector will operate at the lowest ejector area ratio. The range of ejector area ratios will be between 3 and 300 considering the full scale design. The purpose of the subscale test is to obtain an experimental data base in a subscale facility which when combined with the analytical models, will yield an empirical data base to define completely the operational data base for high volume, low pressure ejector systems such that a full scale design can be accomplished. The subscale data will define the ejector blank-off capability and pumping capability as a function of ejector-to-secondary mass-flow ratio, ejector driving pressure, and ejector area ratio. Data will be obtained from all three ejector stages and will span the ejector area ratio range from 4 to 300, ejector driving pressure range from 4 to 40 psia, and ejector mass flow ratios from 3 to infinity. The variables which will be measured will be cell pressure, ejector exit and duct pressures, exit static and total pressure, the ejector driving total pressure, the driven mass flow rate (secondary), the ejector mass flow rate, and the ejector throat area. The ejector throat area will be calibrated as a function of ejector axial position. The preliminary test matrix configurations and the test matrix were developed in the test plan (Ref. 14).

The following is a preliminary list of the instrumentation required to conduct the test.

1. J-57 turbojet engine instrumentation as called out in Ref. 15.
2. Flow measuring devices
   a. J-57 air flow data taken by means of a smooth approach inlet mounted on the engine fitted with static and total pressure rakes as defined in ASHAE Fan Test code.
   b. J-57 fuel flowmeter
   c. One 0.5 in. diameter sharp edge orifice to measure the altitude cell GN_2 purge
   d. One 1 in. diameter venturi meter to measure the GH_2 flow
   e. One 3 in. diameter Digicell flow and pressure control valve to measure the first stage ejector mass flow
   f. One 24 in. diameter venturi meter to measure the second stage ejector J-57 mass flow
   g. One 5 in. diameter Digicell flow and pressure control valve to measure the second stage ejector GN_2 flow rate
3. 150 pressure transducers to record pressures throughout the facility
4. Fifty temperature measurement locations throughout the facility
5. Digicell control computer.

Locations of all instrumentation/measurements will be specified during the next phase of the facility development. Drawing No. R82716-1, "Nozzle Piece, First Stage," shows typical instrumentation port (pressure) and thermocouple attachment details.

5.2 OPERATIONAL PLAN

The operational procedure plan will be developed more completely as the facility construction progresses. The preliminary operational plan follows assuming a diffuser/ejector test using gaseous H_2.

5.2.1 Pretest

1. Photograph the facility.
2. Verify that the J-57 fuel tank level is adequate.
3. Verify that the GN_2 pressure is satisfactory.
4. Verify that the GH_2 trailer pressure is satisfactory.
5. Connect instrumentation.
6. Verify that the test instrumentation has been installed per instructions of Test Request Sheet and the Run Time and Test Conditions annotated on the TCP.
7. Schedule the ejector/diffuser test.
   - a. (   ) GN_2 as needed
   - b. (   ) GH_2 as needed
   - c. (   ) Photography
   - d. (   ) Closed Circuit TV
   - e. (   ) Instrumentation
   - f. (   ) Control.

5.2.2 Test Day

1. Verify that the instrumentation and controls are ready for the X-1 hour announcement.
2. Make the X-1 hour announcement.
3. Verify that all ground support equipment is parked and that power is OFF.
4. Check out test stand for proper electrical power.
5. Activate GN_2 system per procedure.
6. Set the following pressure regulators to the proper pressures.
   - a. GN_2
   - b. GH_2
   - c. GH_2 line purge.

7. Set the ejector throat areas in accordance with test request sheet.

8. Activate hydraulic system per procedure.

9. Cycle all valves to verify satisfactory operation.

10. Check that all J-57 engine controls are operating satisfactorily.

12. Verify that cutoff checks are satisfactory.

13. Verify that sequence test has been conducted per procedure.

14. Verify that TV monitors are functioning properly.

15. Verify that video recordings for TV are ready.

16. Activate the J-57 starter air system.

17. Activate the Firex system.

18. Verify that GH_2 leak detectors are active.

19. Verify that data system and controls are ready for X-30 minutes.

20. Give X-30 minute warning announcement.

21. Activate the GH_2 system per procedure.

22. Set up road blocks at test stand.

23. Make X-15 minutes announcement. (Close HGF area to all personnel.)

24. Verify duration timer set at (TBD) second and power switch ON.

25. Intercom tape ON.

26. Open the GH_2 main shutoff.

27. Prepare the GN_2 system for test.

28. Prepare the J-57 control system for test per procedure.

29. Make the X-10 minutes warning announcement.

30. Prepare the GH_2 system for test.

31. Turn data system ON - SLOW

32. Turn video recording ON

33. Adjust the ejector GN_2 flow controller

34. Adjust the GH_2 flow controller.

35. Make X-5 minute warning announcement.

36. Verify that the following systems are ready:

    a. Control
    b. Data system
    c. Cameraman
    d. Analog recorder, and
    e. Test stand.

37. Cutoffs ready - ON

38. Sound X-20 second siren.

39. Set J-57 data systems on FAST

40. Give firing command.

41. Start J-57 engine per procedure.

42. Verify J-57 operation at IDLE power setting.

43. Allow J-57 warmup time.

44. Advance J-57 throttle position to TEST SET position; check J-57 operation per procedure.

45. Verify ejector system operation according to test request.

46. Conduct test per test request.

47. Cutoff

    a. GN_2 purges - ON
    b. Cameras - OFF

48. Deactivate the GH_2 system.

49. Deactivate the GN_2 system.

50. Clear the test stand for designated crew.

51. Turn intercom - OFF.

52. Turn data system - OFF.

53. Turn video recording - OFF.

5.2.3 On Stand Post-Test

1. Perform appropriate post-test check outs of instrumentation and J-57 engine.
2. Deactivate Firex system.
3. Deactivate hydraulics.
4. Reset pressure regulators to 0 psig.
5. Remove road blocks.
6. Make ALL CLEAR announcement.
7. Shut off electrical power to test stand.

5.3 SAFETY PLAN

5.3.1 Grounding Requirements

Grounding requirements for this facility are as specified in the "Safety Manual," AMCR-385-100, 21 April 1970, by Headquarters, U.S. Army Materiel Command, Washington, D.C. 20315, specifically under Section 8, page 8-20, "Tanks and Towers."

5.3.2 Purge Requirements

Since this facility uses hydrogen, the purging requirements for electrical equipment and wiring will be as specified in KSC STD-E-002, Revision A, "Hazard Proofing of Electrical Equipment."

6. REFERENCES

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9. Semenov, N.N., "Some Problems in Chemical Kinetics and Reactivity," Vol. II, Chapter X, translated by M. Boudart, Princeton University Press, Princeton, N.J., 1959.

10. Huber, P.W., C.J. Schexnayder, and C.R. McClinton, "Criteria for Self-Ignition of Supersonic Hydrogen-Air Mixtures," NASA TP 1457, August 1979.

11. Campbell, R.G., "Advanced Space Engine Powerhead Breadboard Assembly System Study," NASA CR-135232, Rockwell International Corporation/ Rocketdyne Division, March 1978.

12. Martine, A., "ASE Shutdown Transients," Rockwell International Corporation, Letter to Fred Garcia, 9 December 1983, transmitting non-proprietary data to NASA.

13. "Preliminary Specification No. 2289: RL10A-3-3A Rocket Engine Atlas Centaur Installation Model Specification," United Technology, Pratt & Whitney Aircraft/Government Products Division, June 1981; also "Design Report for RL10A-3-3A Rocket Engine," same source, January 1982.

14. Wojciechowski, C.J., "Preliminary Test Plan for a Subscale Jet Engine Driven Ejector/Diffuser System," LMSC-HREC TM D867439, Lockheed Missiles & Space Company, Huntsville, Ala., 23 April 1984.

15. Pratt & Whitney Aircraft Specification No. A-1649-G for Model J57-P-19W Engine, dated 12 October 1955.

Appendix A

FULL SCALE GASDYNAMIC SAFETY ANALYSIS

DESIGN OF A SUBSCALE DIFFUSER FOR HIGH EXPANSION RATIO ENGINE TESTING

FULL SCALE GASDYNAMIC SAFETY ANALYSIS

by
C. J. Wojciechowski
S. C. Kurzius

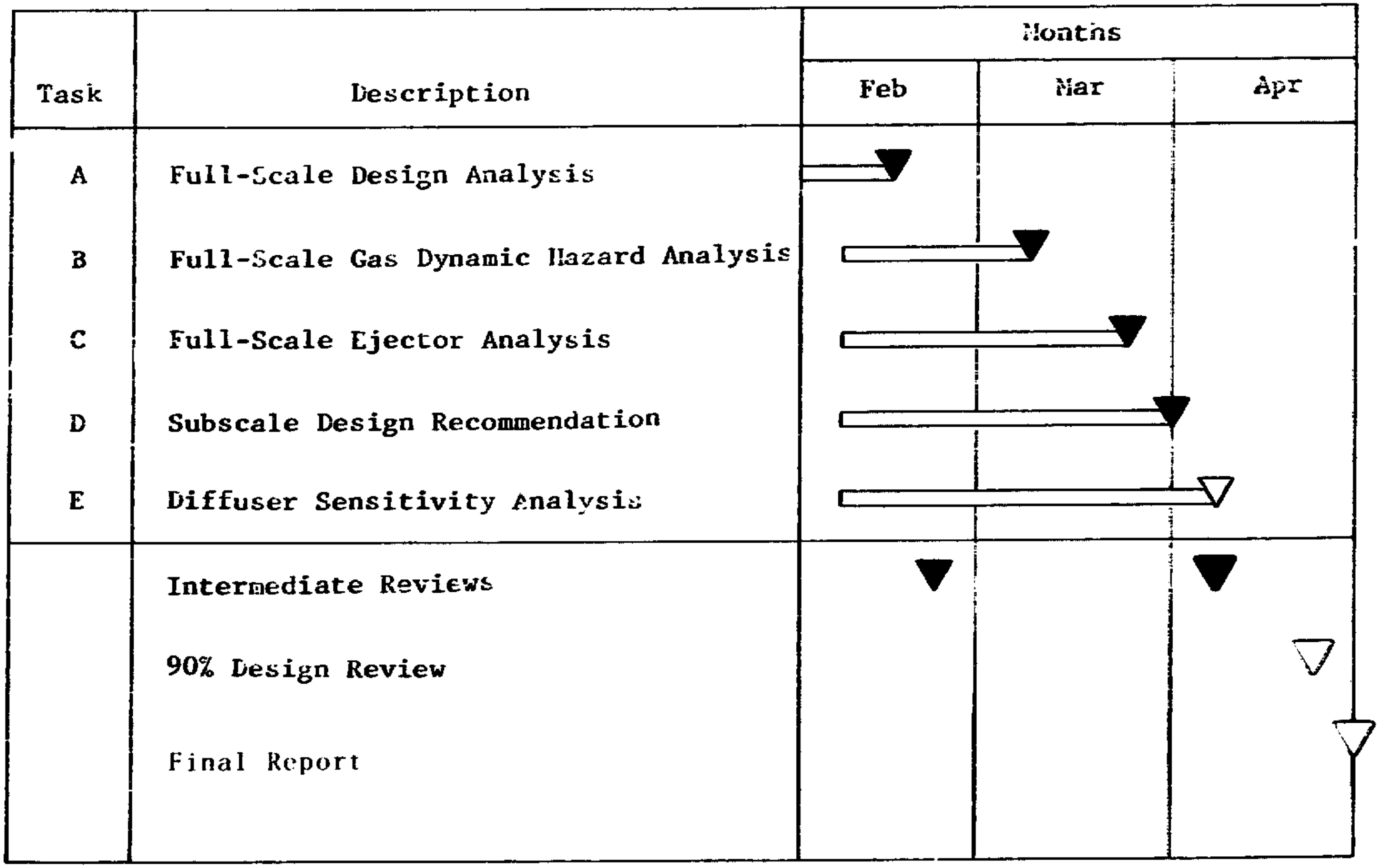
13 April 1984

Lockheed
Missiles & Space Company, Inc.
Huntsville Research & Engineering Center

AGENDA

1. Objective
2. Milestones and Schedule
3. Concept of Preliminary Full Scale Design
4. Technical Issues and Concerns
5. Key Progress to Date
    - Analysis Shows Safe Operation
    - Design Meets All Requirements
6. Future Work

AMENDED SCOPE OF WORK SCHEDULE AND MILESTONES



TECHNICAL ISSUES AND CONCERNS

- Ejector Stability and Controllability
- Transient Operation
- Overall Ejector Performance
  - Scale Effects (Langley, MSFC Prototype – Full Scale)
- Safety
  - Suppression of Hydrogen Detonation to be Evaluated by Analysis and Test Data
  - Facility to be Designed to Detonation Loads

SYNOPSIS OF ENGINE TRANSIENT HAZARD ASSESSMENT

(DIFFUSER DRIVER: J57 JET ENGINE EXHAUST)

AECE-R Engine (Based on ASE Engine Data)

Startup - Potential Hazard, $O/F < 2.0$ from 0 to 2.4 sec After Start Signal

Main Stage - No Hazard, $O/F = 6.0$, High Thrust; $O/F = 4.0$, Low Thrust

Shutdown - Potential Hazard, $O/F < 2.0$ at Shutoff Signal + 150 msec

RL10-IIB Engine (Based on RL10A-3-3A Engine Data)

Startup - Potential Hazard; $O/F < 2.0$ from 0.20 to 1.58 sec after Start Signal

Main Stage - No Hazard; $O/F = 6.0$ for Low and High Thrust Operation

Shutdown - Potential Hazard; Quantitative Transient Data Inputs are Required.

Pratt & Whitney Inputs on RL10 Shutdown:

1. If a graphite nozzle is used, oxidizer-rich shutdown must be avoided to protect hot engine and red hot nozzle.
2. Somewhat in conflict with 1, H_2 is normally dumped overboard on shutdown, with a maximum total of 1/4 lb H_2 flowed through the nozzle on shutdown.

Proposed Control to Eliminate Potential Start/Stop Hazards:

Use a Purge GN_2 Flow as the Inert Gas Driver in 1st and 2nd Stages During Transients, as Required

REVIEW

Primary Concern - Potential Hazard on Startup and Shutdown with Hot, H_2-Rich Engine Effluent Driven by Air-Rich Jet Engine Ejector Streams.

Analysis Path

- Review Engine Performance Data
- Initialize Diffuser Design for Engine Tests
- Evaluate Hazard
- Modify Design and Operation to Eliminate Hazard as Required

Space Engines Analyzed

- RL-10-IIB
- AECE-R

} 10% and 100% Thrust

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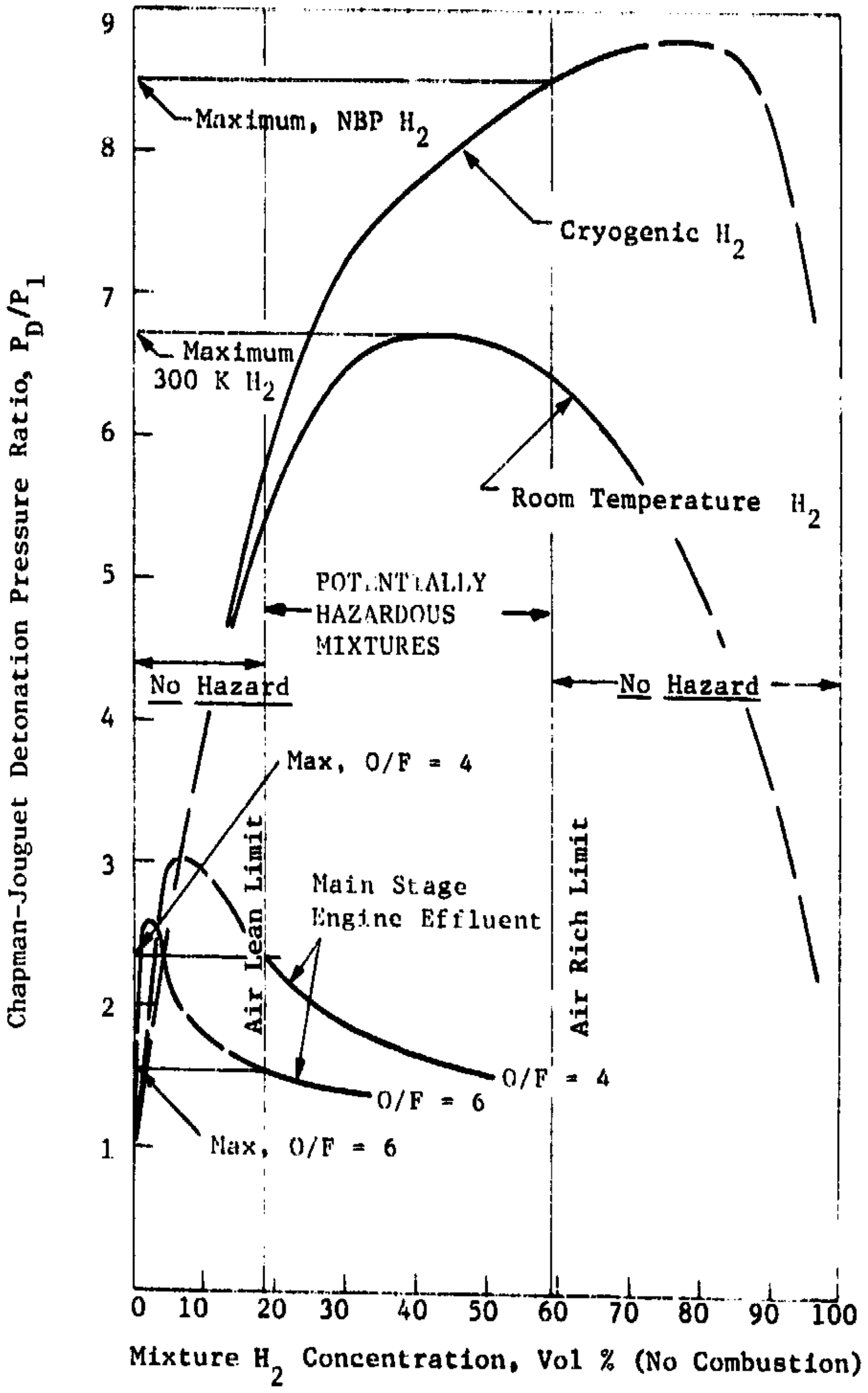
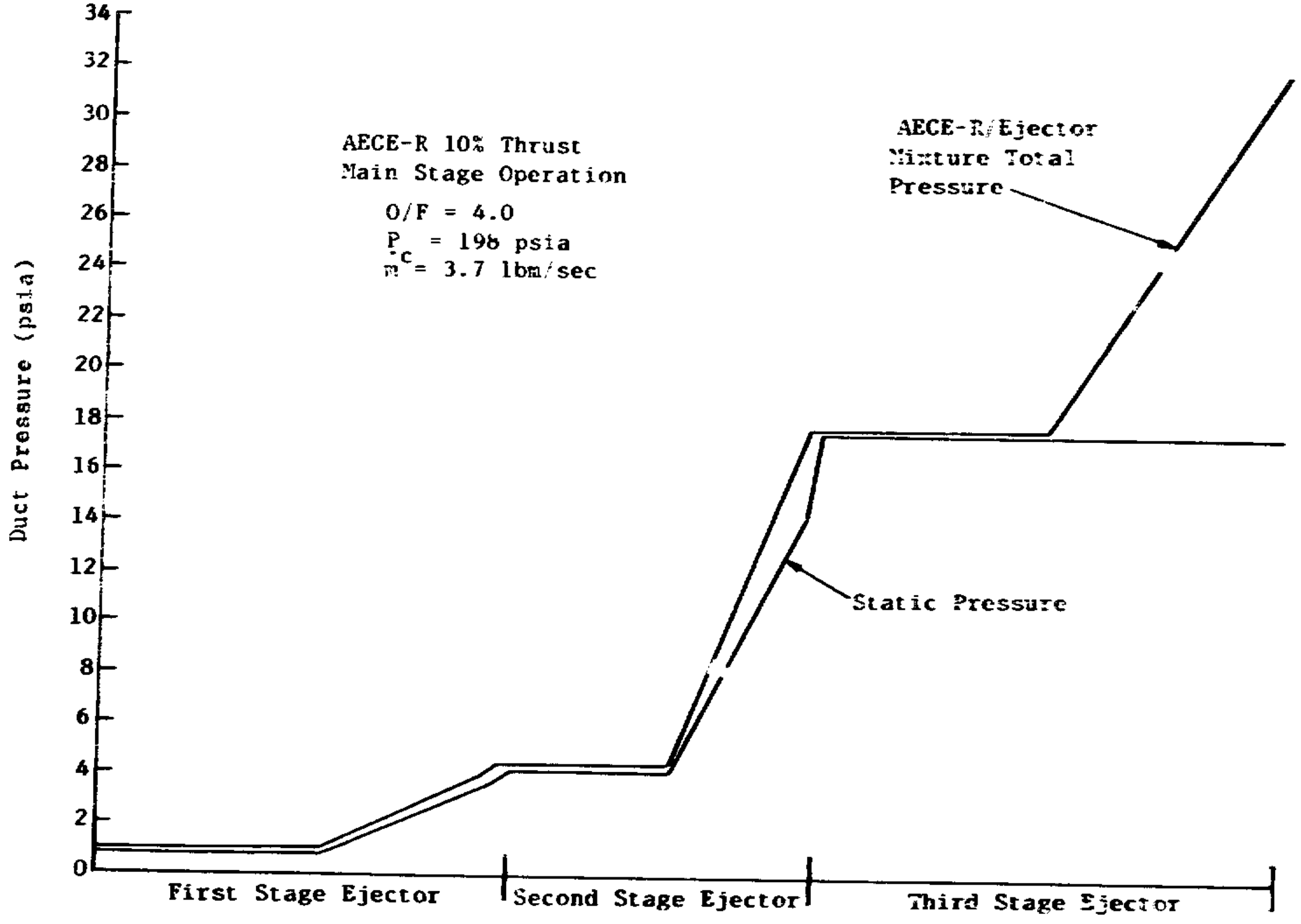
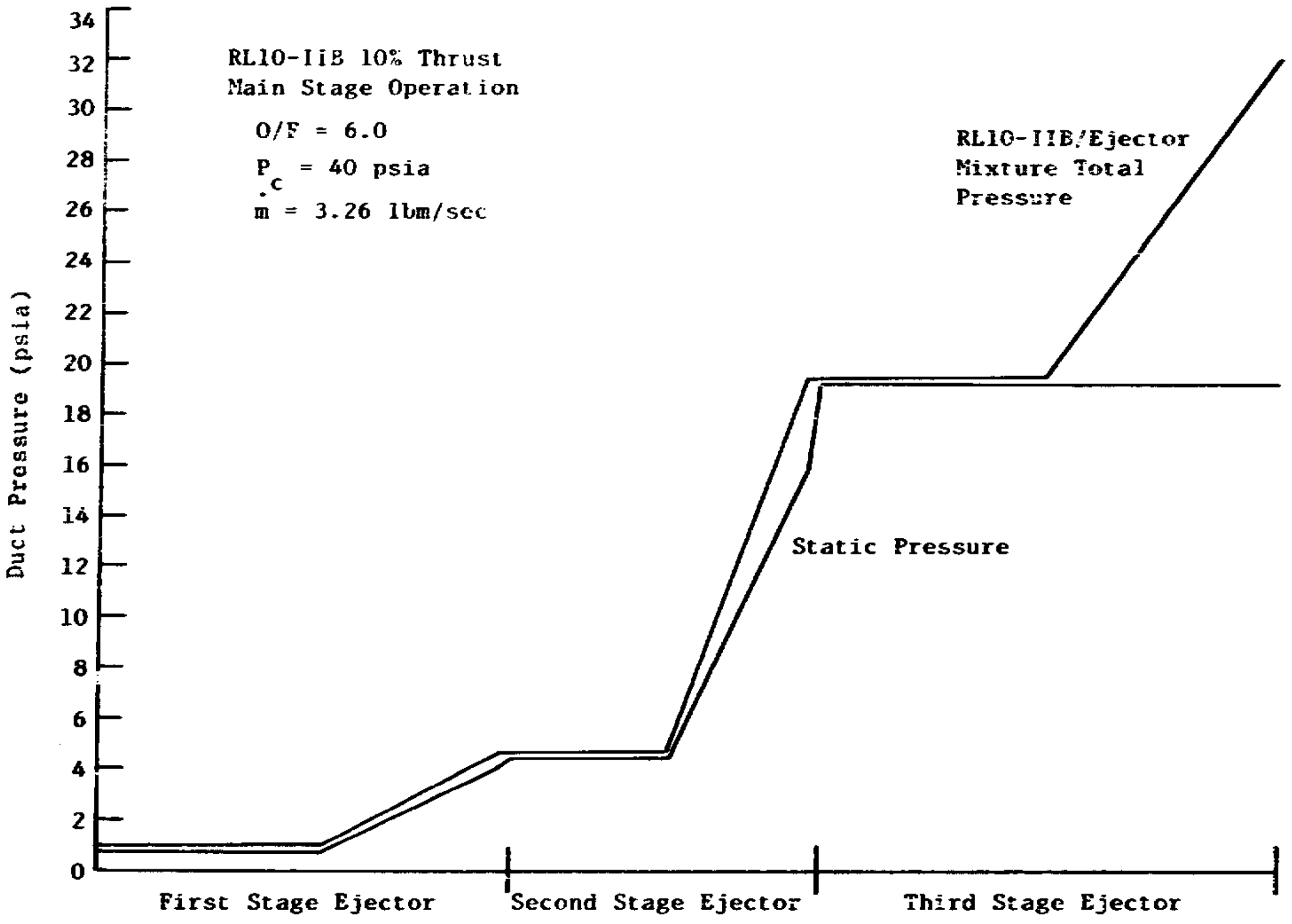
HAZARD ANALYSIS: WORST CASE CHAPMAN-JOUGUET DETONATION PRESSURE RATIO CHARACTERISTICS AT PREVAILING STREAM TOTAL TEMPERATURES



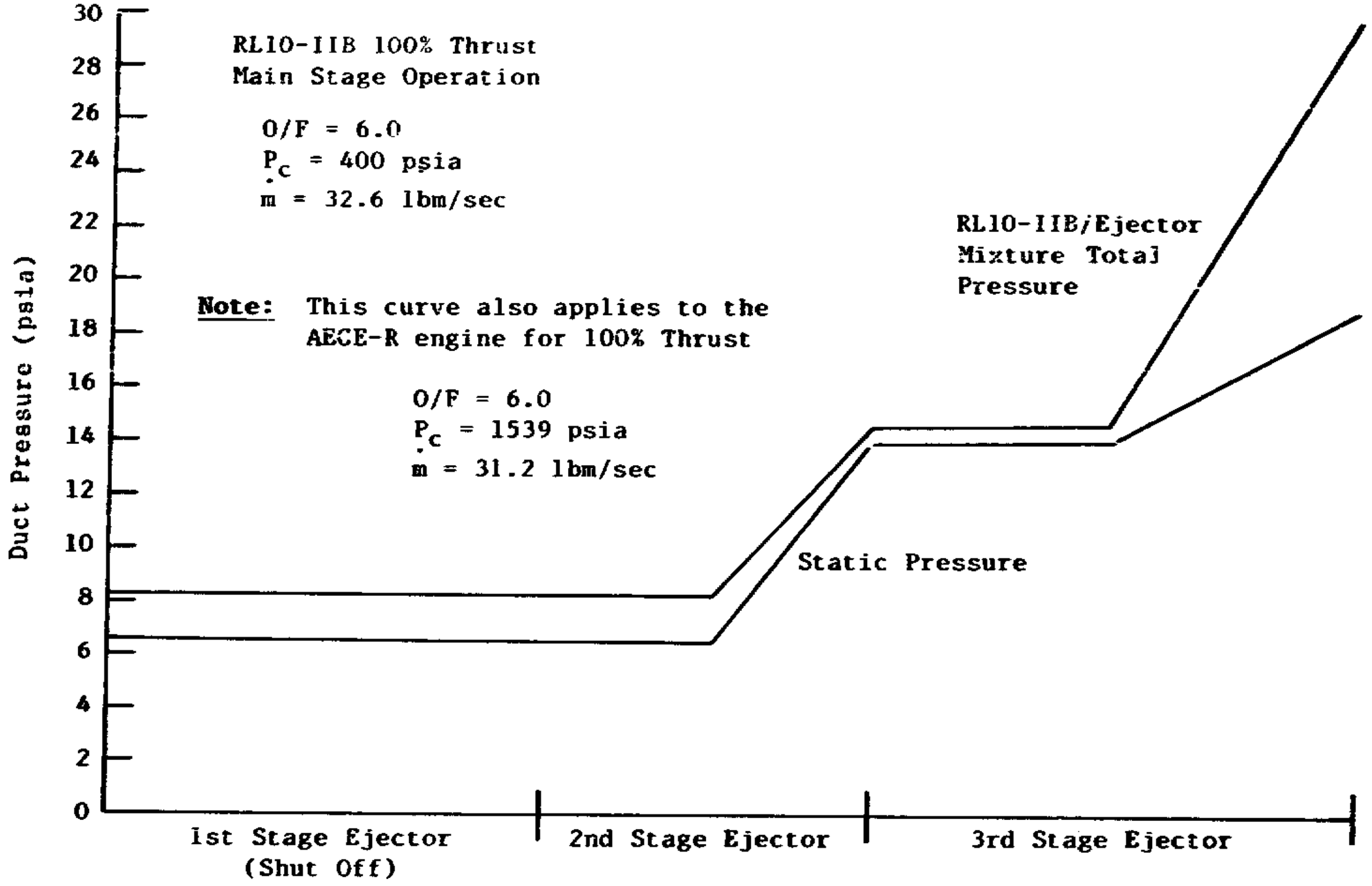
FULL SCALE AECE-R 10% THRUST DIFFUSER/EJECTOR PRESSURE DISTRIBUTION



FULL SCALE 10% THRUST
DIFFUSER/EJECTOR PRESSURE DISTRIBUTION



FULL SCALE RL10-IIB 100% THRUST DIFFUSER/EJECTOR PRESSURE DISTRIBUTION



RL10-IIB 100% Thrust
Main Stage Operation

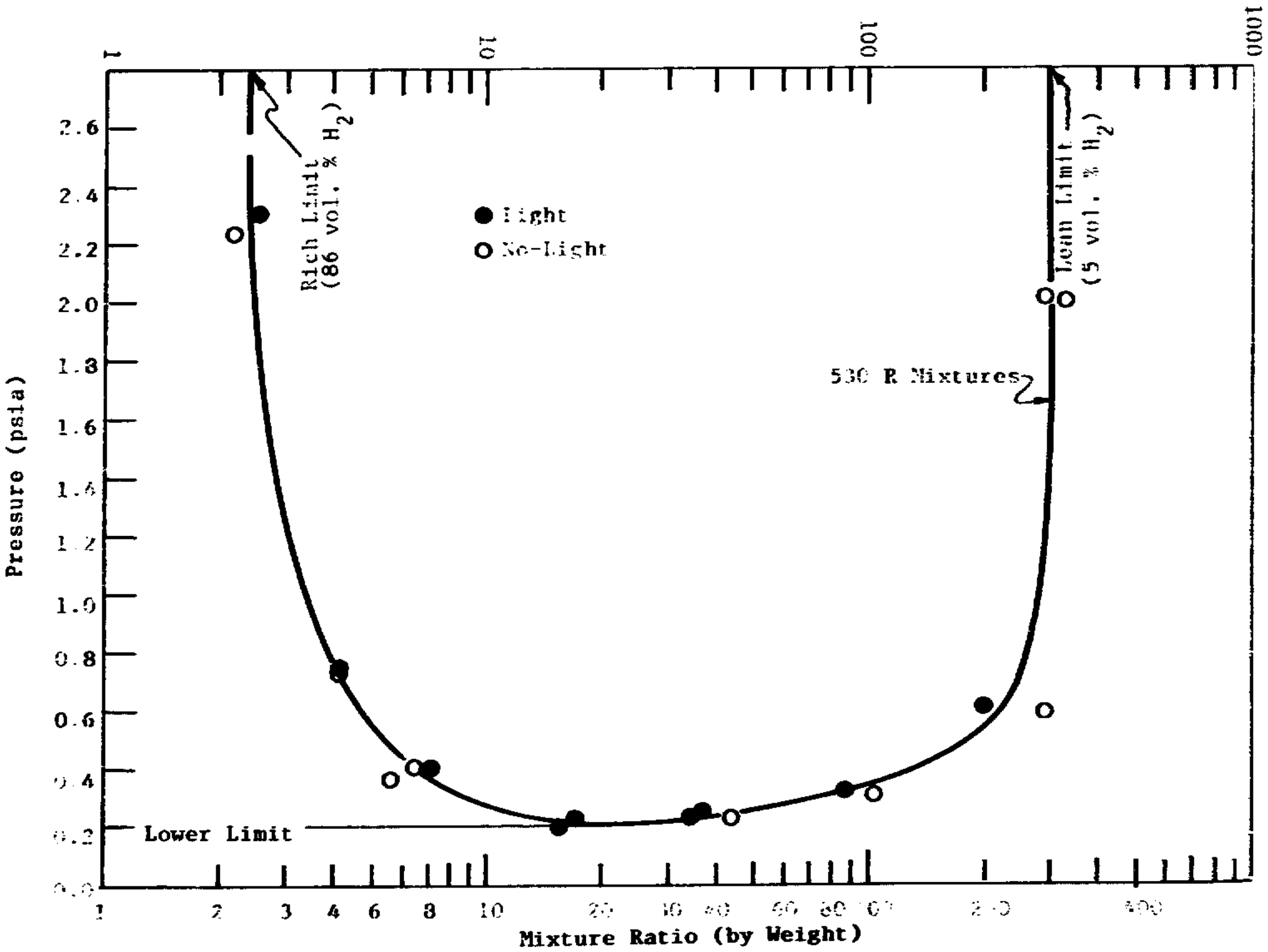
$O/F = 6.0$
$P_c = 400$ psia
$\dot{m} = 32.6$ lbm/sec

Note: This curve also applies to the AECE-R engine for 100% Thrust

$O/F = 6.0$
$P_c = 1539$ psia
$\dot{m} = 31.2$ lbm/sec

H_2-GOX STATIC IGNITION LIMITS

(Spark igniter, 4 in. diameter x 15 in. long chamber, PWA FR-303, Nov 61)



H_2-LOX ENGINE EXHAUST AUTOIGNITION CHARACTERISTICS

Fuel: H_2-Rich Space Engine Effluent

AECE-R Engine: 3.7 lb/sec, Low Thrust
31.2 lb/sec, Full Thrust

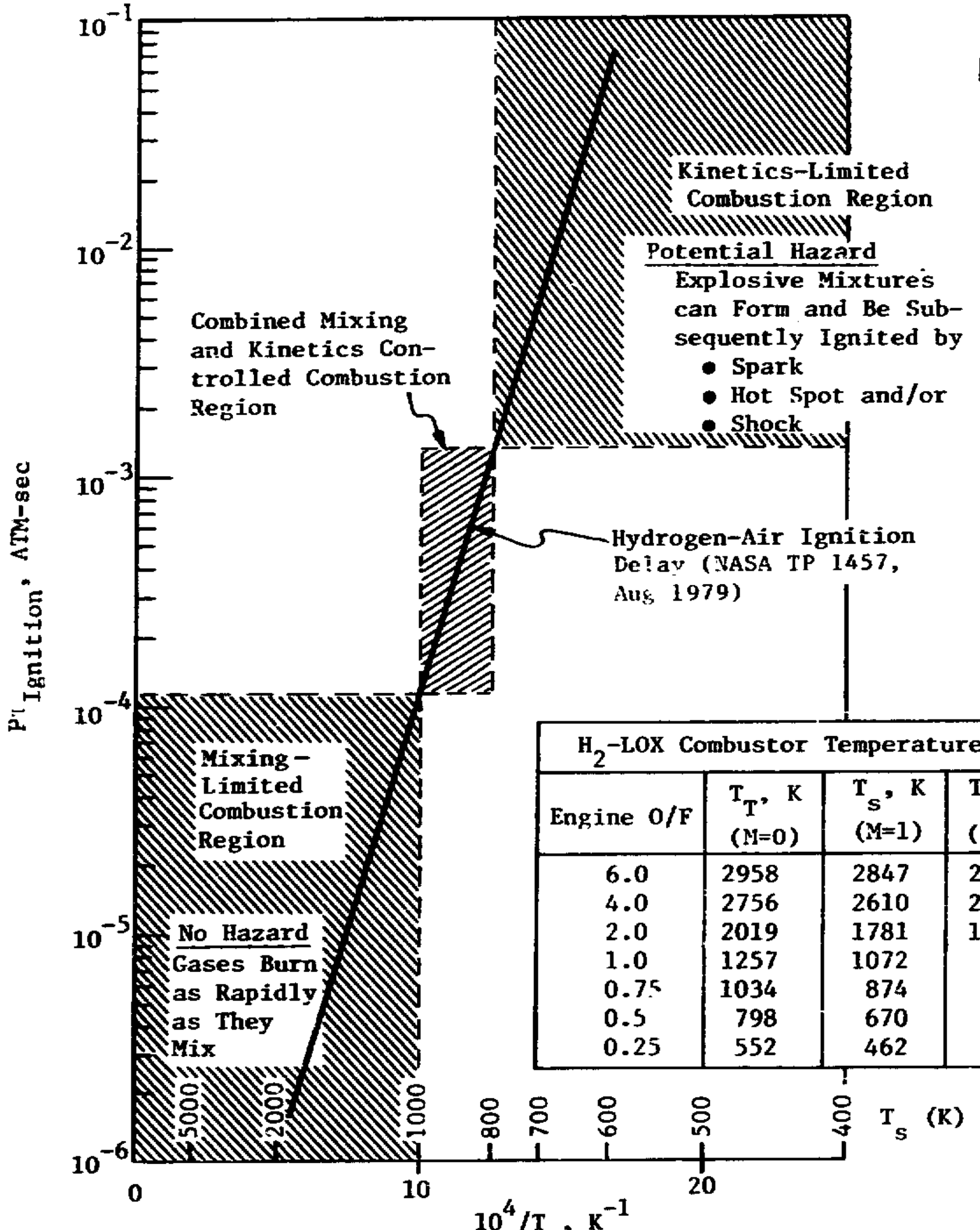
RL10-IIB Engine: 3.2 lb/sec, Low Thrust
32.6 lb/sec, Full Thrust

Oxidizer: J57 Jet Engine Exhaust; O_2: 16.7 vol.%; $T_{M=0}$: 778 K

1st Stage: 2.8 lb/sec (Low Thrust Only)

2nd Stage: 23.2 lb/sec: Low Thrust
26.0 lb/sec, Full Thrust

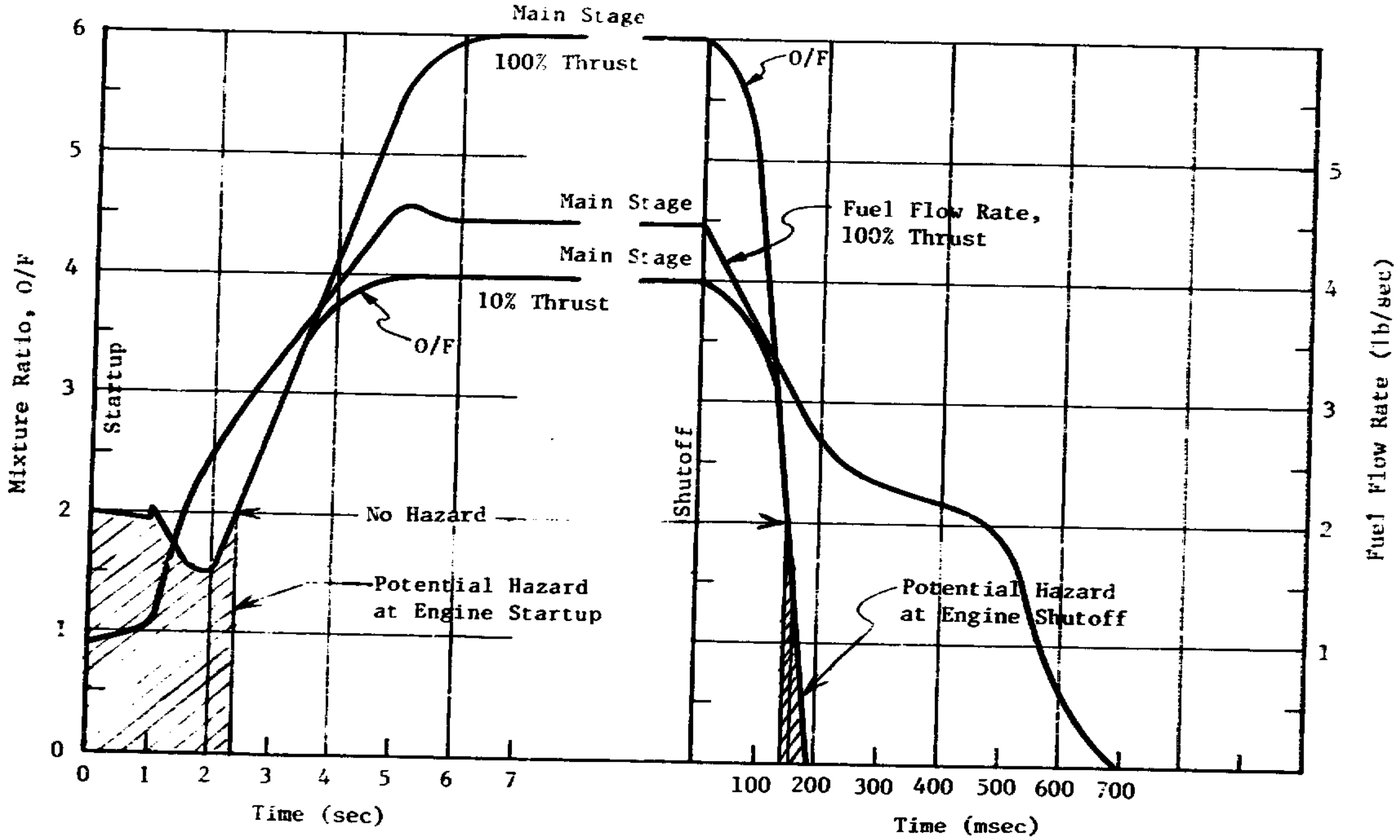
3rd Stage: 451 lb/sec, Low and Full Thrust



H_2-LOX Combustor Temperatures				
Engine O/F	T_T, K (M=0)	T_s, K (M=1)	T_s, K (M=2)	
6.0	2958	2847	2563	No Hazard
4.0	2756	2610	2188	↓
2.0	2019	1781	1301	
1.0	1257	1072	731	
0.75	1034	874	590	
0.5	798	670	450	Potential Hazard
0.25	552	462	308	

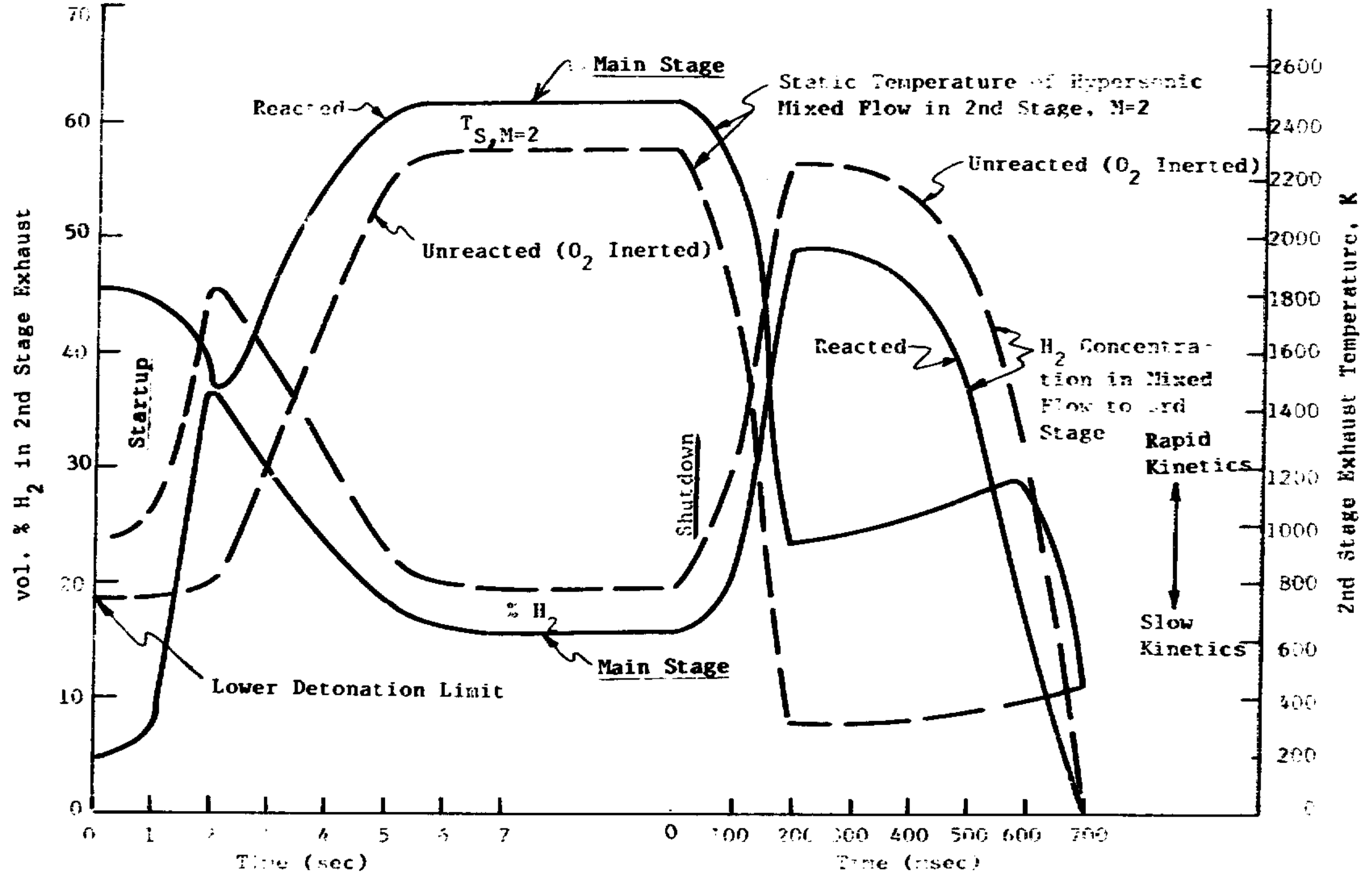
AECE-R ENGINE TRANSIENT CHARACTERISTICS

(Estimated from ASE Engine Data)

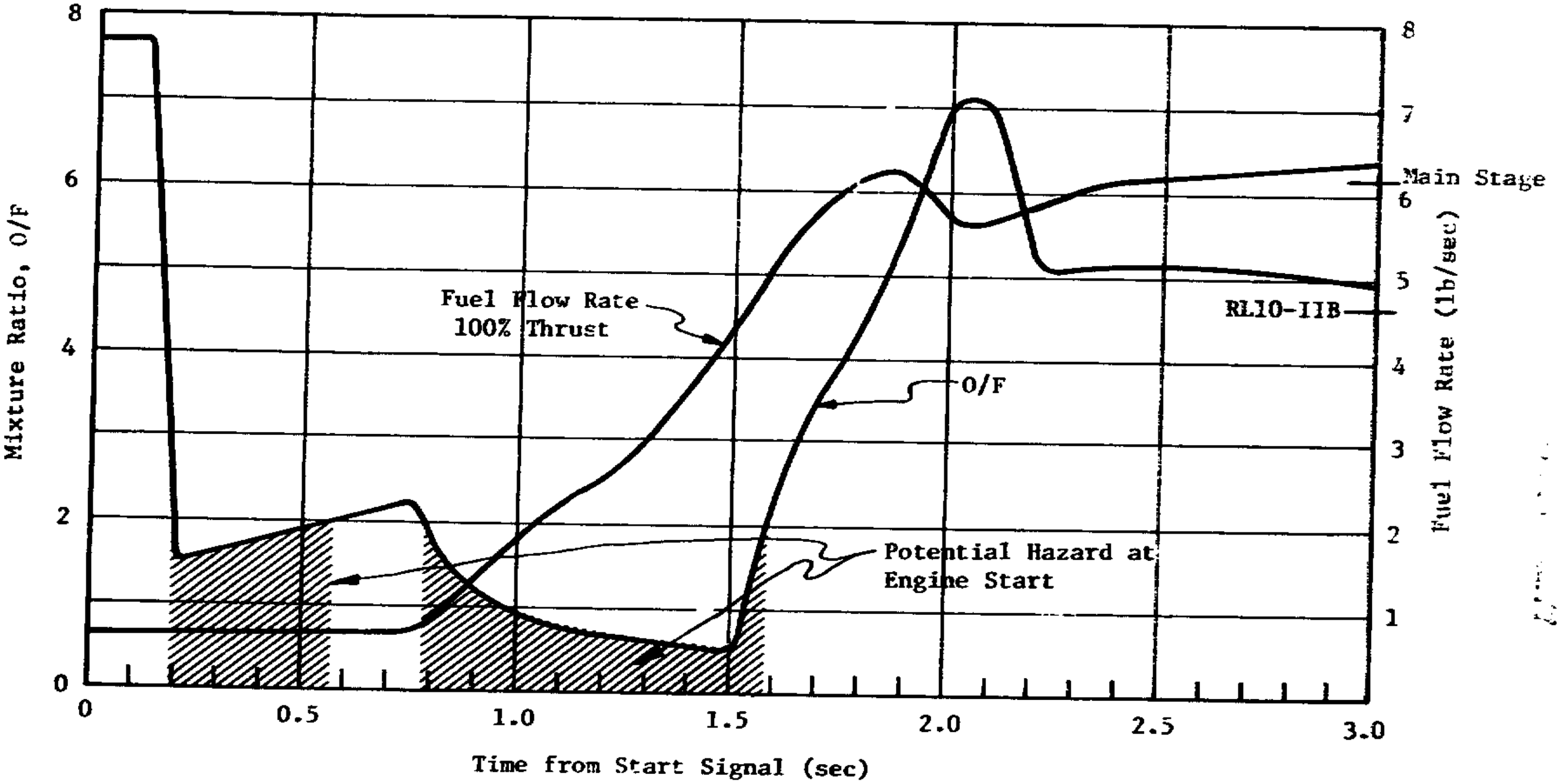


AECE-R ENGINE SECOND STAGE DIFFUSER TRANSIENT CHARACTERISTICS WITH J57 JET ENGINE EXHAUST AS DRIVER (26 lb/sec)

(Note: J57 WILL NOT BE USED AS DRIVER DURING TRANSIENTS)

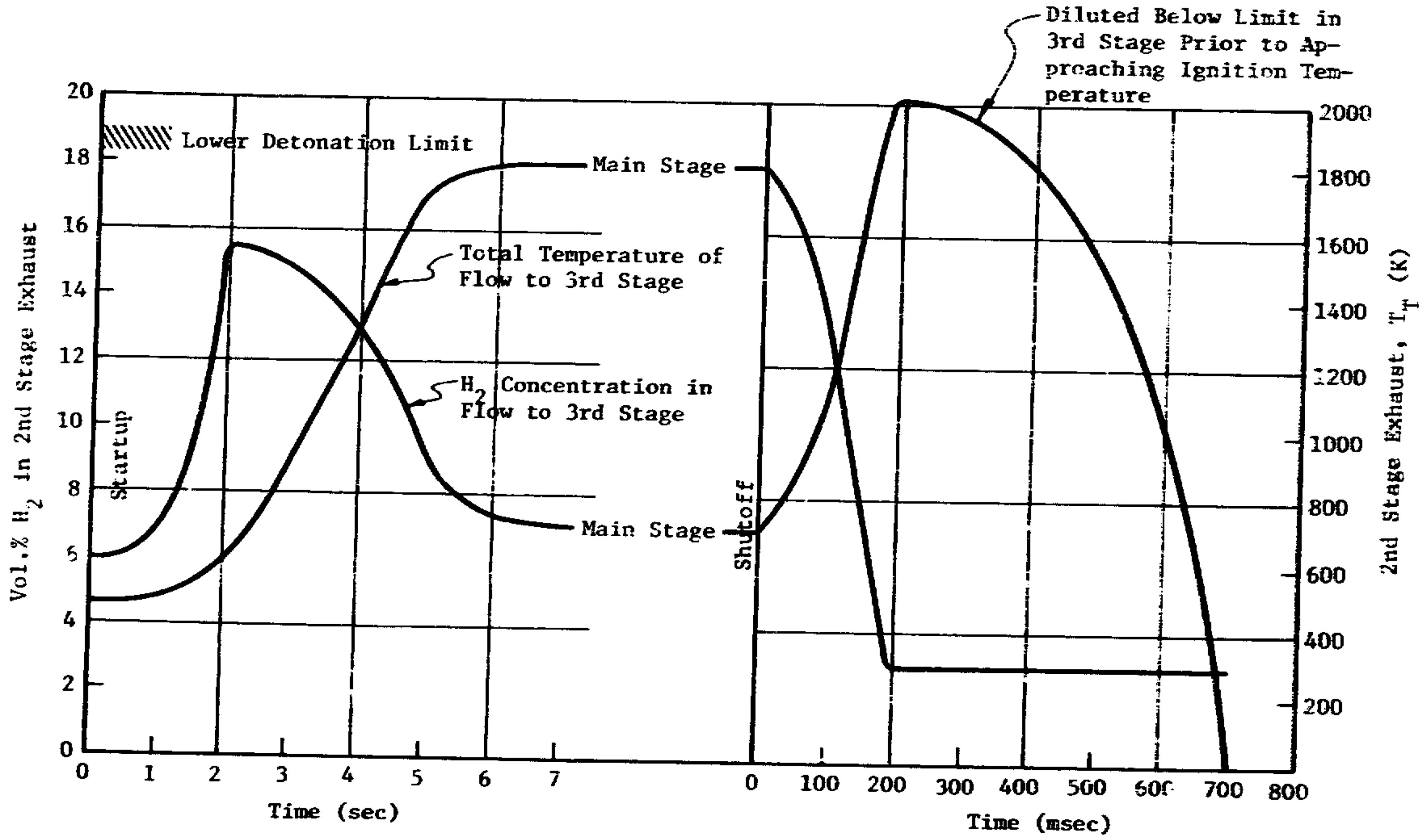


RL10A-3-3A ENGINE START TRANSIENT CHARACTERISTICS



AECE-R ENGINE 2nd STAGE DIFFUSER TRANSIENT OPERATION

(100% Thrust; Driver: GN_2, 150 lb/sec)



LOW THRUST OPERATION

Engine Status	Driver (Stages 1 & 2)	Stage	RL 10-IIB Engine Exhaust T_T, K	RL 10-IIB Engine Exhaust Vol. % H_2	AECE-R Engine Exhaust T_T, K	AECE-R Engine Exhaust Vol. % H_2
Main Stage Burn	J57s	Engine	2958	29.5	2756	48.6
		1	2628	16.9	2565	33.2
		2	1968	0.1	2310	1.3
		3	871	Nil	926	Nil

- H_2 is burned virtually to completion in 1st and 2nd stages.

Engine Status	Driver (Stages 1 & 2)	Stage	RL 10-IIB Engine Exhaust T_T, K	RL 10-IIB Engine Exhaust Vol. % H_2	AECE-R Engine Exhaust T_T, K	AECE-R Engine Exhaust Vol. % H_2
Main Stage Burn	GN_2	Engine	2958	29.5	2756	48.6
		1	2461	15.4	2304	33.1
		2	958	2.8	955	8.5
		3	799-825	0.3-Nil	799-878	0.9-Nil

- Flow enters 3rd stage with H_2 well below detonation limit.

Start/Stop Transients — GN_2 — **Worst Cases:**

RL10-IIB Engine: Full Fuel Flow, 0.466 lb H_2/sec

AECE-R Engine: Full Fuel Flow, 0.74 lb H_2/sec

Engine Status	Driver (Stages 1 & 2)	Stage	RL 10-IIB Engine Exhaust T_T, K	RL 10-IIB Engine Exhaust Vol. % H_2	AECE-R Engine Exhaust T_T, K	AECE-R Engine Exhaust Vol. % H_2
Start/Stop Transients	GN_2	Engine	300	99.8	300	99.8
		1	300	56.5	300	67.3
		2	300	11.5	300	17.1

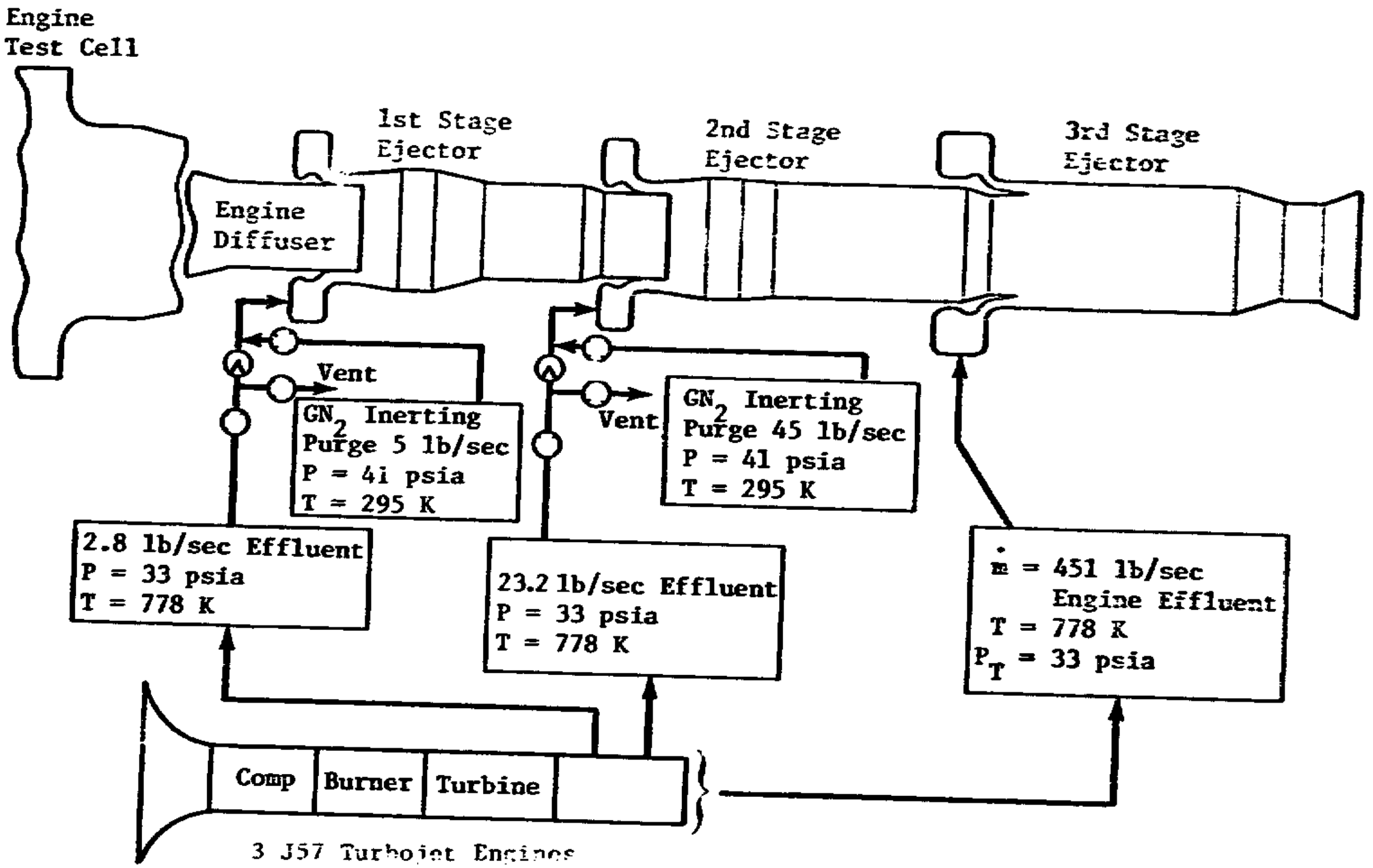
- H_2 flow is diluted with GN_2 to below detonation limit in stages 1 and 2 even with the full maximum rated flow of unburned H_2 at low thrust.

100% THRUST OPERATION

			RL 10-IIB Engine		AECE-R Engine	
			Exhaust		Exhaust	
Engine Status	Driver (Stages 1 & 2)	Stage	T_T, K	Vol. % H_2	T_T, K	Vol. % H_2
Main Stage Burn	J57s	Engine	2958	29.5	2958	29.5
	Not Driven -	1	2958	29.5	2958	29.5
		2	2872	16.3	2869	15.8
		3	1545	Nil	1519	Nil
	● H_2 is burned as rapidly as it mixes in 2nd and 3rd stages.					
Main Stage Burn	GN_2	Engine	2958	29.5	2958	29.5
	Not Driven -	1	2958	29.5	2958	29.5
		2	1855	7.4	1806	7.1
		3	1324	Nil	1300	Nil
	● H_2 flow is diluted with GN_2 to well below detonation limit in 2nd stage and burns as rapidly as it mixes in 3rd stage.					
Stop/Start Transients	GN_2					
	● H_2 in flow is diluted and cooled with GN_2 to below detonation limit in 2nd stage.					

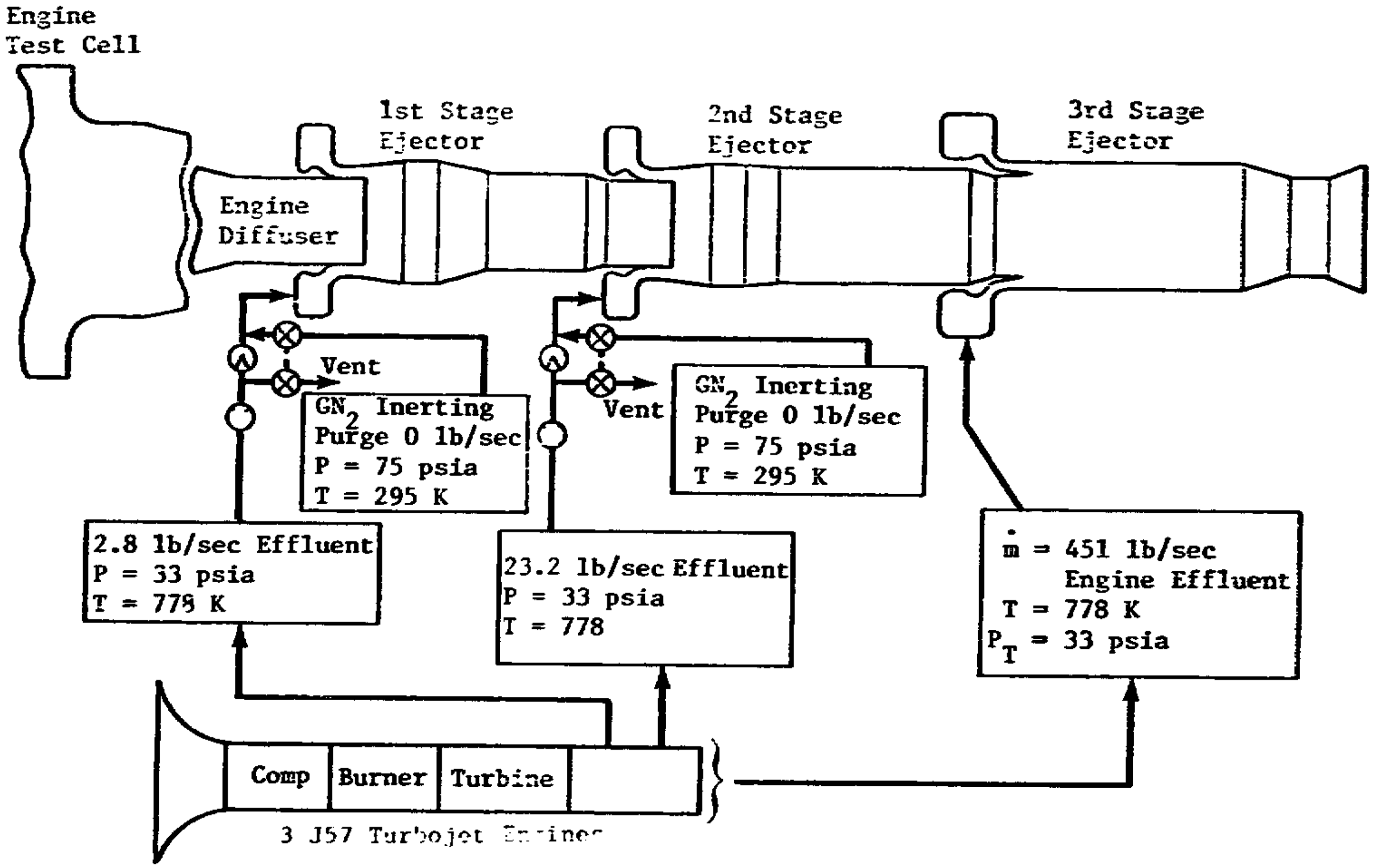
RL10-IIB AND AECE-R STARTUP AND SHUTDOWN OPERATION

FULL SCALE 10% THRUST JET ENGINE DRIVEN EJECTOR/DIFFUSER SYSTEM



RL10-IIB OR AECE-R ENGINE STEADY STATE OPERATION

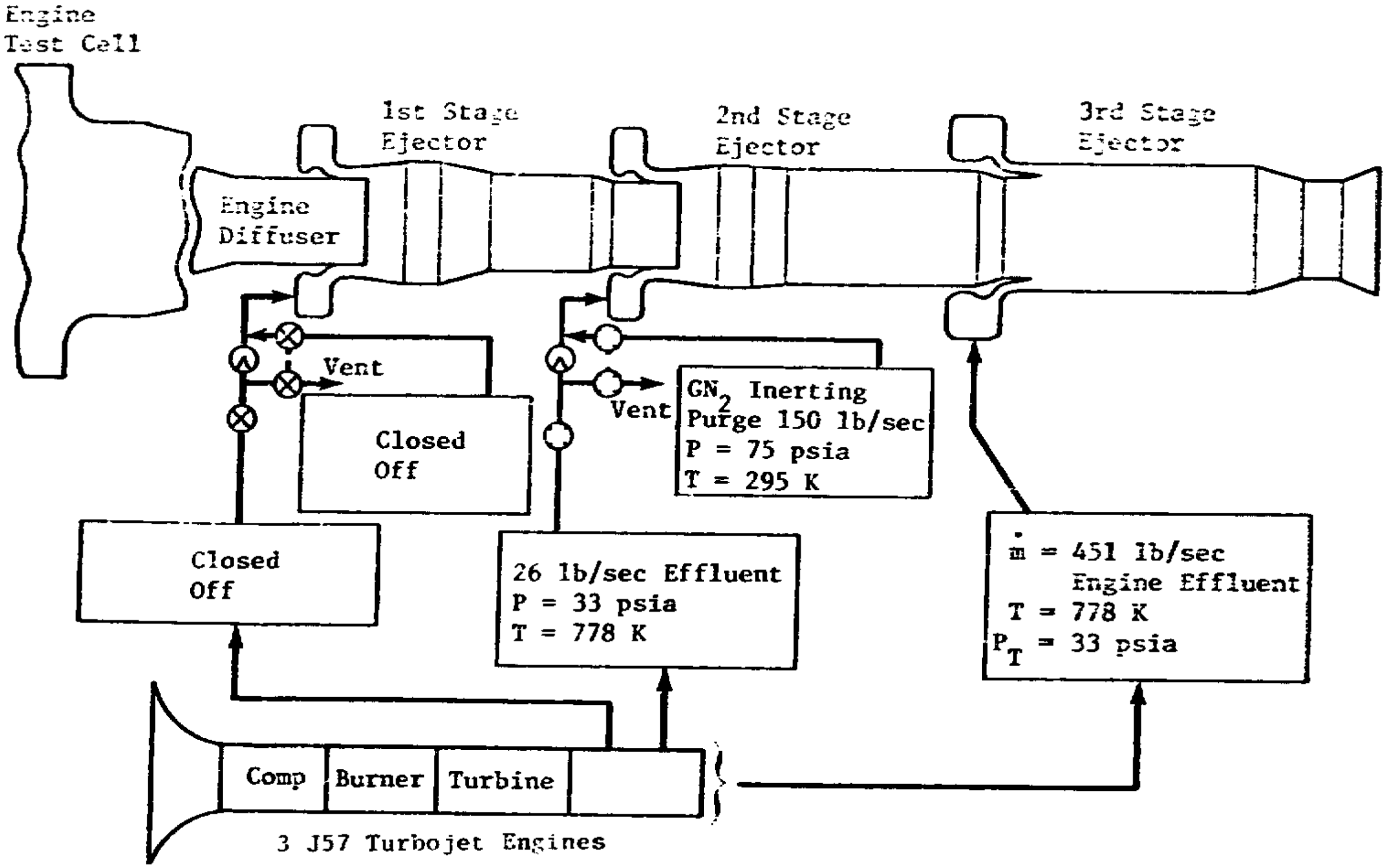
FULL SCALE 10% THRUST JET ENGINE DRIVEN EJECTOR/DIFFUSER SYSTEM



RL10-IIB OR AECE-R ENGINE

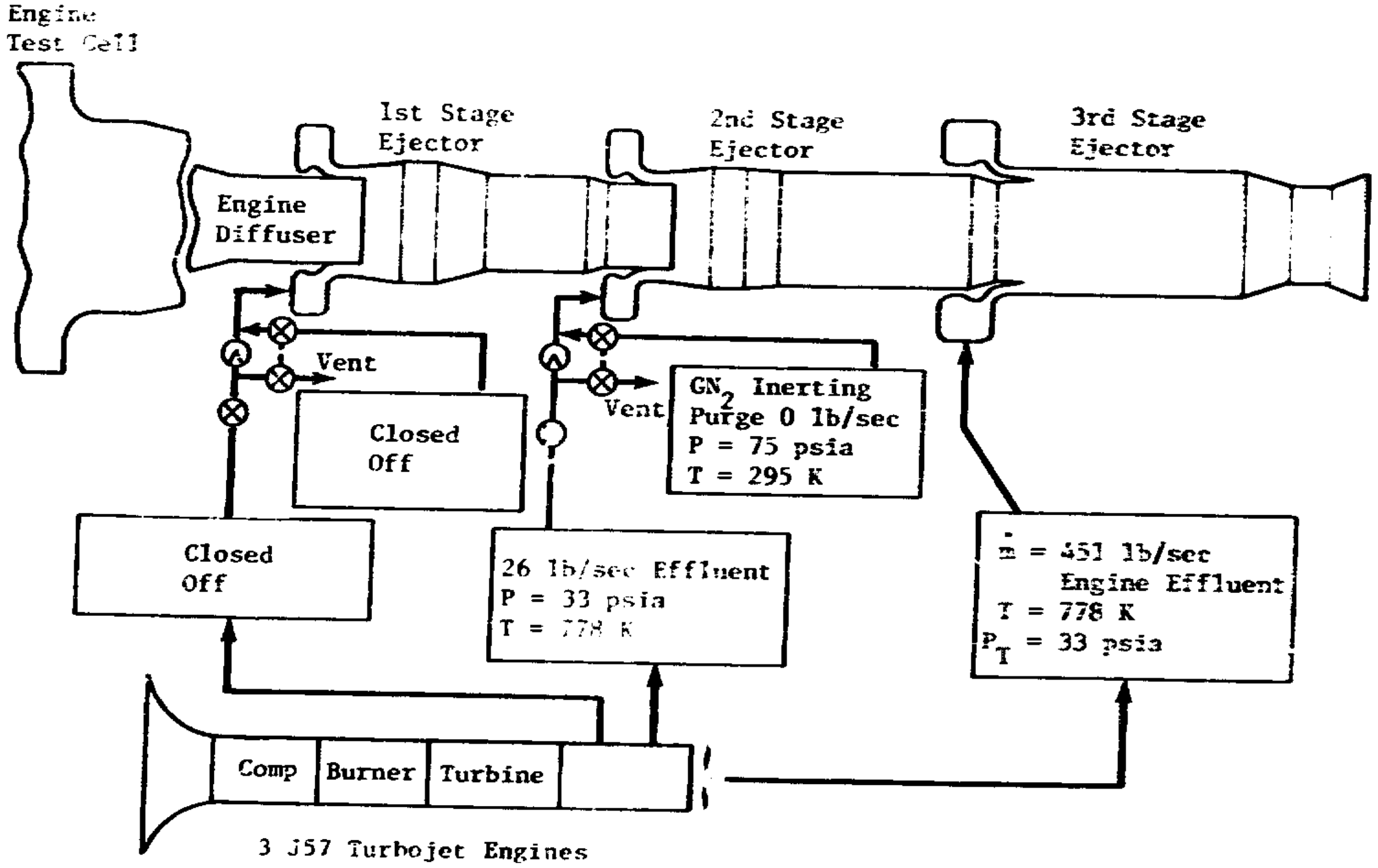
STARTUP AND SHUTDOWN OPERATION

FULL SCALE 100% THRUST JET ENGINE DRIVEN EJECTOR/DIFFUSER SYSTEM



RL10-IIB OR AECE-R ENGINE STEADY STATE OPERATION

FULL SCALE 100% THRUST JET ENGINE DRIVEN EJECTOR/DIFFUSER SYSTEM



Appendix B

ORIGINAL STRESS NOTES
SUBSCALE FACILITY PRELIMINARY DESIGN

by

D.M. Tilley

Structures & Materials Group

FOREWORD

This strength analysis was performed as a preliminary check on the safety and feasibility of the overall design approach as of April 1984. The overall dimensions of the basic structures were used with conservative load assumptions. No attention was given at this time to detailed parts. This limited analysis does not constitute an endorsement of the design for fabrication.

CONTENTS

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Checked by	Date	Title SUBSCALE EJECTOR / DIFFUSER MARGIN SUMMARY - MIN	Model
Approved by	Date		Report No.

DWG	DESCRIPTION	BUCKLING	ULT	YIELD
R82704	ALTITUDE SIMULATION CELL	+11.6	+24.3	+21.6
R82708	ALTITUDE CELL & PLATE	—	+9.35	+8.24
R82701	INLET PLATE		+1.1	+.875
R82702	H2 CYLINDER -	—	+.75	+.56
R82708	ALTITUDE CELL & PLATE	—	+9.35	+8.24
R82709	NOZZLE DISCHARGE TUBE	+1.86	+96.2	+85.8
R82710	EXPANSION SECTION - NOZ. SIM.	+78.6	+36.96	+32.9
R82714	EJECTOR RING - FIRST STAGE	+49.3	+4.03	+3.12
R82716	EXPANSION SECTION - 1ST STAGE	+24.3	+6.33	+5.0
R82715	ADJUSTABLE PLUG ASSY	+22.4	+27.7	+27.7
R82717	FIRST STAGE CONTRACTION SECT.	+10.4	+27.9	+27.9
R82718	1ST TO 2ND STRAIGHT SECTION	+5.6	+30.0	+27.9
R82723A	EJECTOR RING - 2ND STAGE	+25.16	+.43	+.17
R82723	EXPANSION SECTION - 2ND STAGE	+20.0	+10.1	+8.1
R82724	ADJUSTABLE PLUG ASSY	+11.72	+52.2	+18.0
R82726	2ND TO 3RD STAGE STRAIGHT	+.95	+40.1	+7.33
R82728	3RD STAGE EJECTOR RING	+7.52	+10.32	+8.27

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Approved by:	Date		Report No.

DWG	DESCRIPTION	BUCKLING	ULT.	YLD.
R82727	NOZZLE 3RD STAGE EJECTOR	+11.77	+7.18	+2.69
R82729	CONSTANT SECTION - THIRD STAGE	+17.98	+9.03	+2.67
R82731	STRAIGHT SECTION - THIRD STAGE	+1.97	+9.3	+2.67
R82730	EXIT TAPER SECTION	+8.3	+9.29	+2.67
R82706	NOZZLE BODY		+.75	+.56
R807037	STRUCTURAL SUPPORT		+.74	+.84
	SLIDING BEARING PIPE		+1.37	+1.50
	DIAGONAL TURNBUCKLE		+.31	
	TOP OF FRAME BEAM		+1.08	+1.78
	SIDE OF FRAME BEAM		+2.11	+3.17
	FASTENERS TO RAIL		+4.44	

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MATERIAL PROPERTIES 304 L STAINLESS STEEL

304 L ST. ST.	E	F_{TU}	F_{CY}
At RT	28×10^6	70 ksi	25 ksi
312 F (772 R)	27×10^6	59 ksi	22 ksi
440 F (900 R)	25.5×20^6	55 ksi	18 ksi
778 F (1238 R)	23×10^6	51.5 ksi	13.5 ksi

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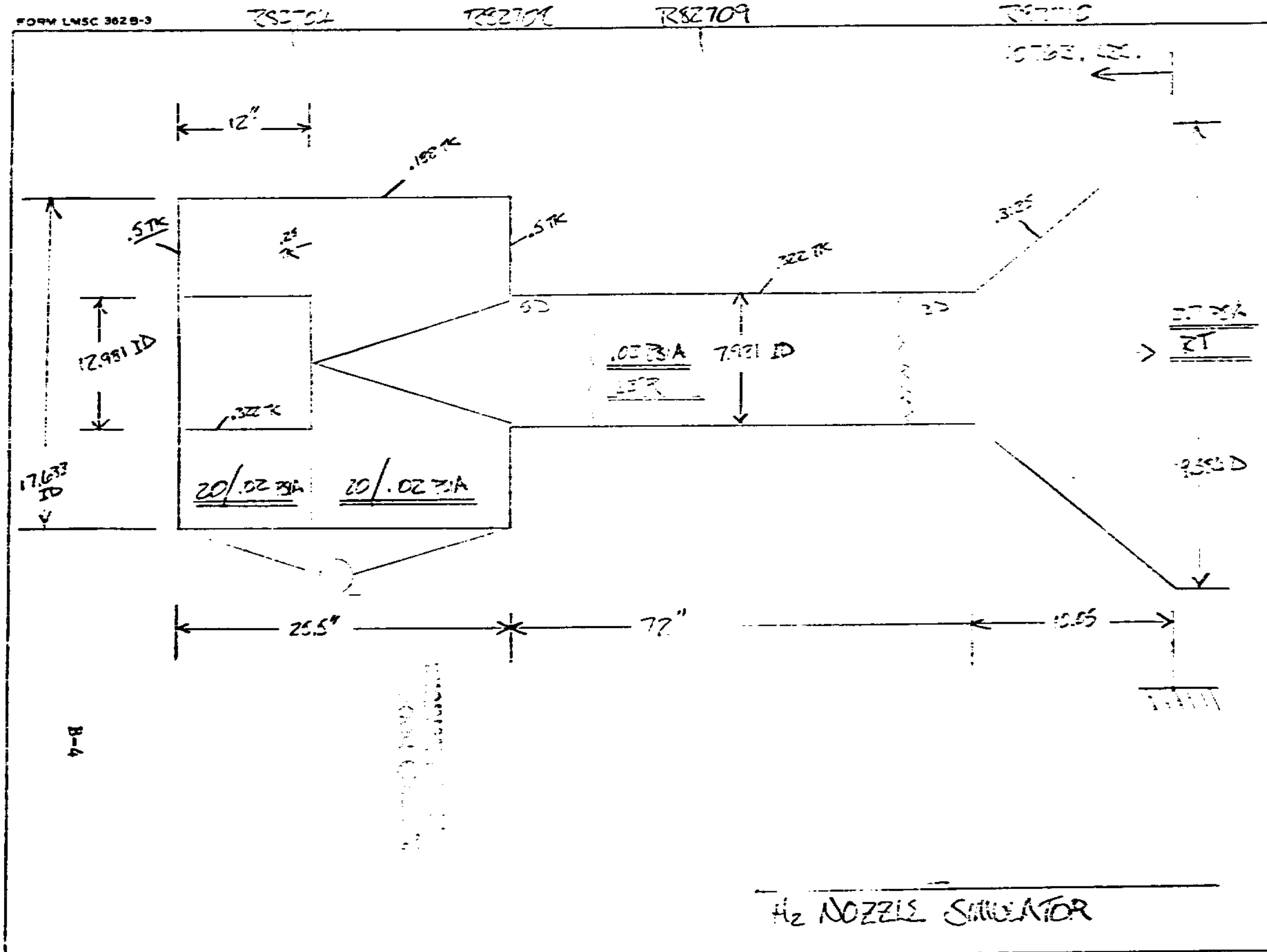

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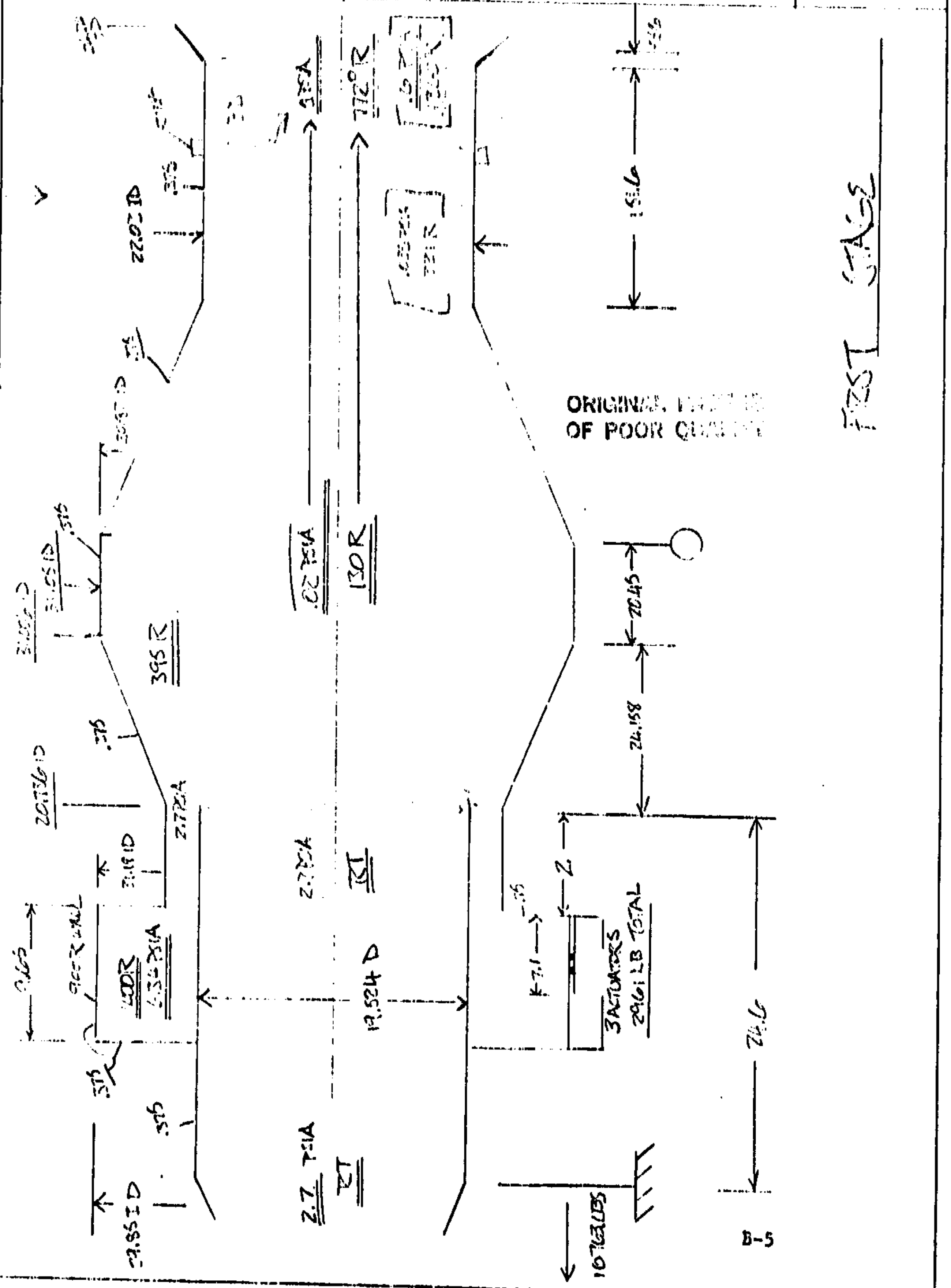

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Approved by:	Date		Report No.

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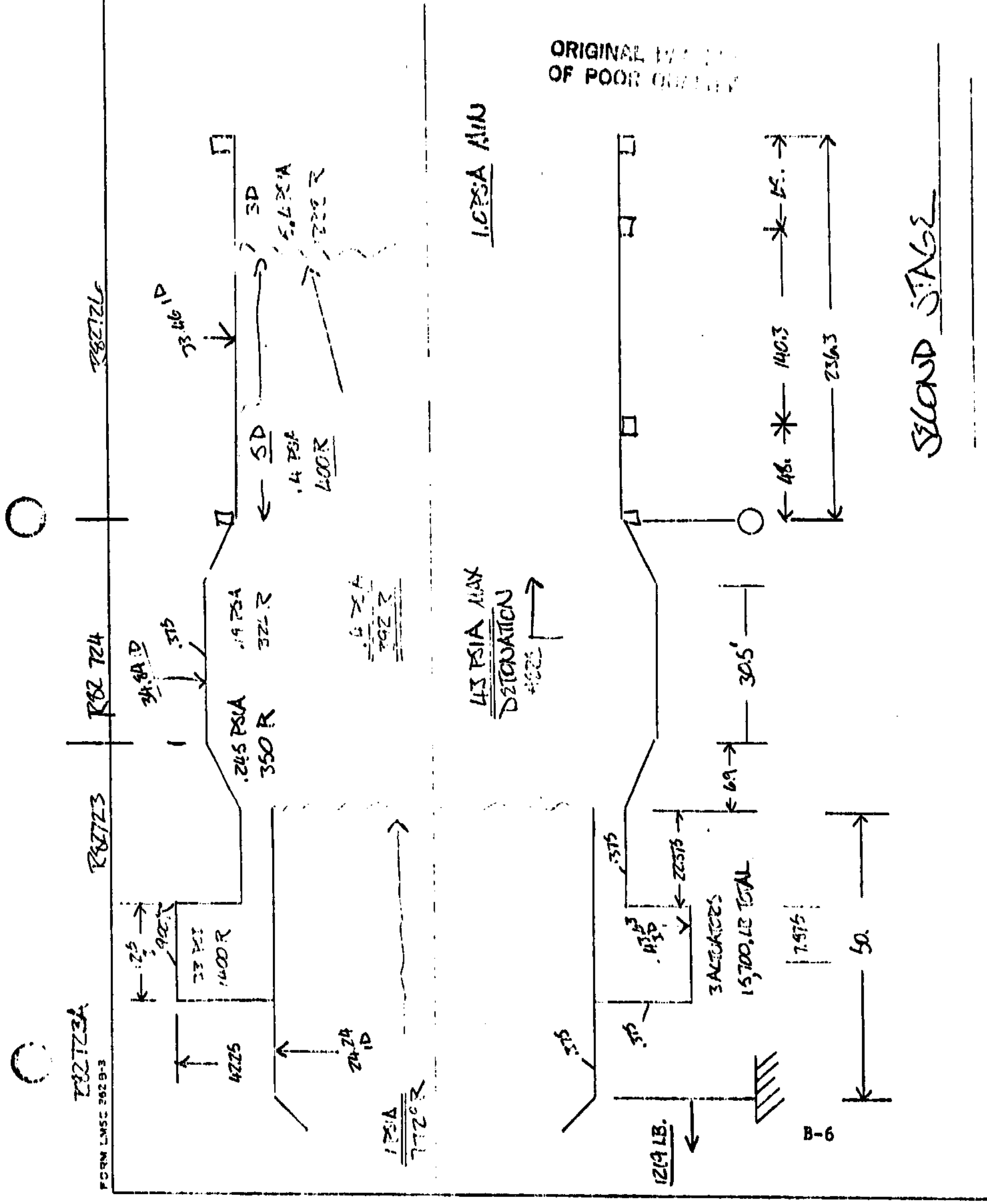

B-6

FORM LMSC 3628-3

Prepared by: [illegible] Date 11/7[illegible]
Checked by: Date
Approved by: Date

LOCKHEED MISSILES & SPACE COMPANY, INC.

Title SUBSCALE EJECTOR/DIFFUSER

Page
Model
Report No.

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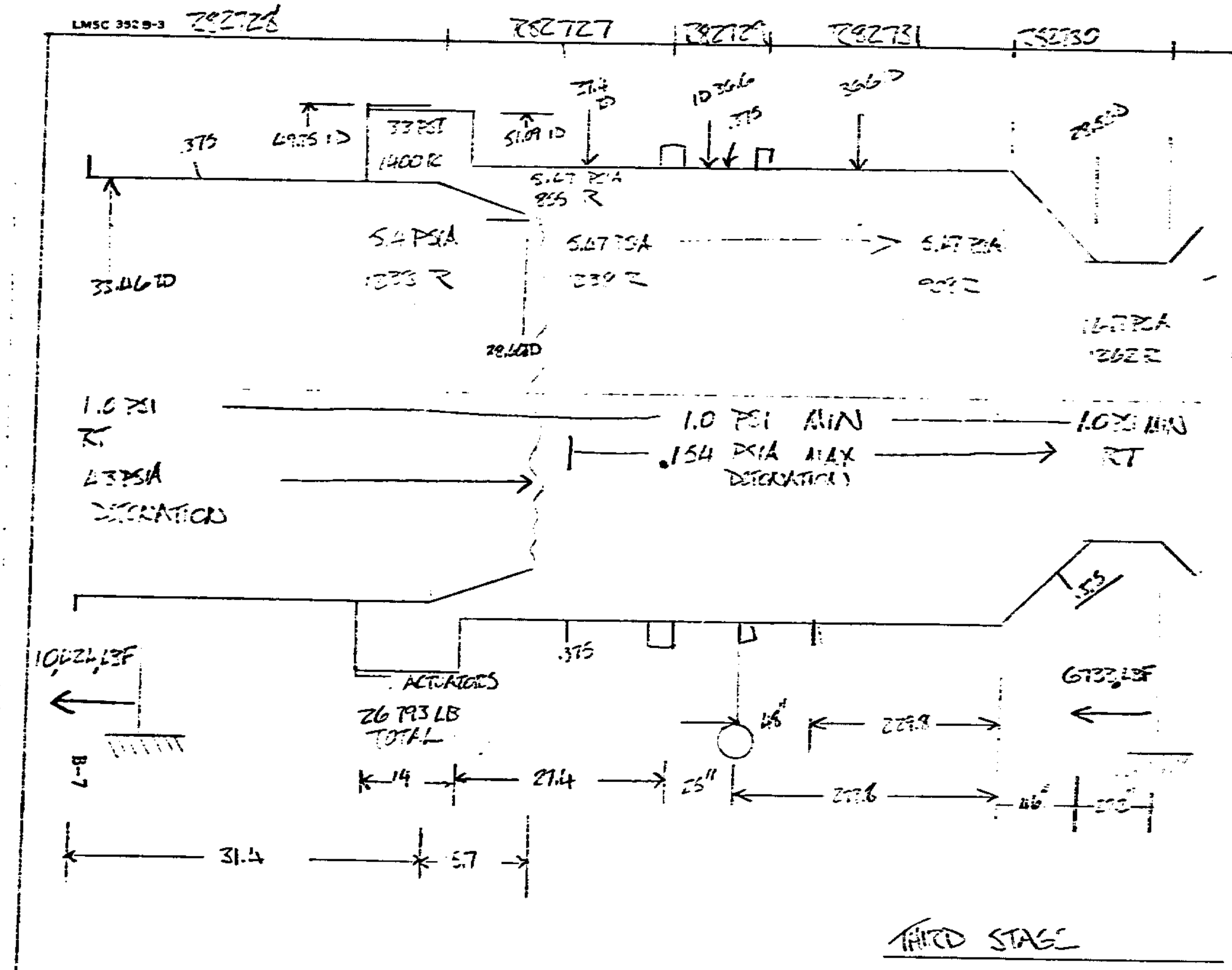
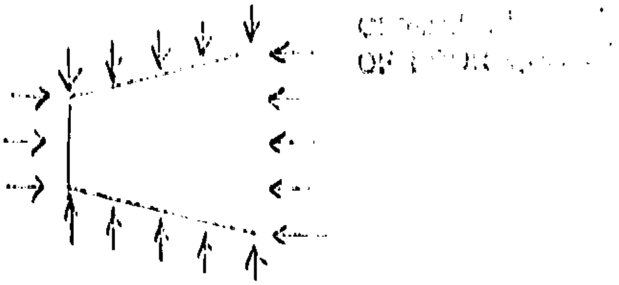


LMSC 3529-3

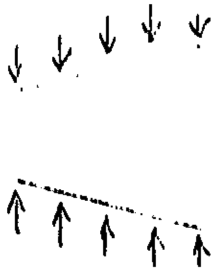
Prepared by: LMT	Date 6/84	**LOCKHEED MISSILES & SPACE COMPANY, INC.**	Page 1.2
Checked by:	Date	Title SUBSCALE EJECTOR/DIFFUSER	Model
Approved by:	Date	AXIAL LOADS	Report No.

NOTE:

AXIAL LOADS IN THE SUBSCALE EJECTOR/DIFFUSER PIPING ARE ACCOUNTED FOR THROUGH THE CALCULATION OF HYDROSTATIC BUCKLING ALLOWABLE PRESSURES. THEREFORE, WHEREVER A NEGATIVE PRESSURE IS USED IN ANALYZING A PIPE SECTION FOR BUCKLING, AXIAL LOADS ARE ASSUMED AS THOUGH THE ENDS WERE [illegible].



HYDROSTATIC PRESSURE



LATERAL PRESSURE

SINCE AXIAL STRESS DUE TO HYDROSTATIC PRESSURE IS HALF THAT OF HOOP STRESS, AXIAL STRESSES ARE NOT CALCULATED.

— AN EXCEPTION TO THIS IS FOR SECTIONS BETWEEN THE REACTION STATIONS AND THE EJECTORS. THE FLOW ENERGY ENTERING THE SYSTEM AT THE EJECTORS IS REACTED AXIALLY THRU THE PIPING TO THE REACTION STATIONS. THIS AXIAL LOAD WOULD NOT BE ACCOUNTED FOR UNDER THE HYDROSTATIC ASSUMPTION ABOVE.

ALL BUCKLING EQUATIONS ARE FROM NASA STRUCTURES MANUAL, SECTION C 3.0.

Prepared by: TMT	Date 11/11	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page 1.21
Checked by:	Date	Title SUBSCALE EJECTOR/DIFFUSER	Model
Approved by:	Date	INLET PLATE	Report No.

TR 82-701

304 S.S.

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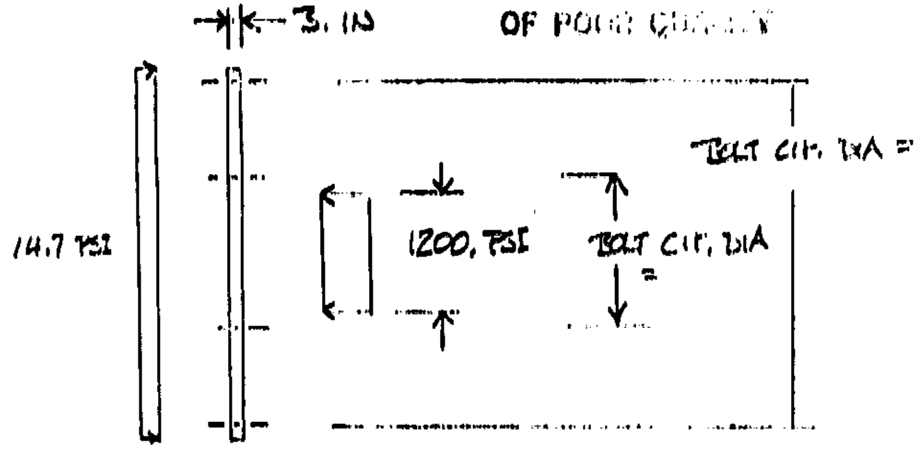

SINCE THE 1200 PSI LOAD OVERSHADOWS THE 14.7 PSI LOAD ALL CONSIDERATIONS WILL BE MADE TO THE LARGER LOAD.

- FOR THE HIGH PRESSURE DIAMETER OF ~ 8 IN. THE 900 LB FLANGE STANDARD GIVES A BLIND FLANGE THICKNESS OF Q = 2½ IN (ZEROX PAGE 110-111) ON ASA B16.5 MATERIAL → ASTM A105 GRADE II
- MATERIAL ASTM A105 GRADE II F_y = 36 KSI (ZEROX P 153)
- F_{TY} RATIO = $\frac{\text{ASTM A105 GRADE II}}{\text{304 L}} = \frac{36}{25} = 1.44$
- THE 900 LB STANDARD HAS A WORKING PRESSURE OF 2160 PSI AT R.T. (ZEROX PAGE 151)
- 2.5 IN. 304 L HAS A WORKING PRESSURE OF 2160/1.44 = 1500 PSI.
- THE 3. IN THICKNESS SHOULD HAVE A WORKING PRESSURE OF AT LEAST (3/2.5) 1500 = 1800.

M.S. = 1800/1200. - 1. = +.5 YLD

WITH A FACTOR OF SAFETY OF 2.

CONTINUED

Prepared by: DMT	Date 4/84	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page 15
Checked by:	Date	Title SUBSCALE EJECTOR/DIFFUSER INLET PLATE	Model
Approved by:	Date		Report No.

R82701

304 L S.S.

ADJUSTING MARGIN CALCULATIONS TO REFLECT 4 & 1.6 ON ULT. & YLD :

$$M.S. = 2(1800)/1.6(1200) - 1. = \boxed{+.875 \text{ YLD}}$$

RATIOING 304 L ULT/YLD STRENGTHS :

$$M.S. = \left(\frac{70}{25}\right) 2(1800)/4(1200) - 1. = \boxed{+1.1 \text{ ULT}}$$

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Prepared by: IMT	Date 4/24	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page Temp. Perm.
Checked by:	Date	Title SUBSCALE EJECTOR/DIFFUSER TEST - AMERICAN STANDARD	Model
Approved by:	Date		Report No.

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PIPE, FITTING AND FLANGE MATERIALS—Continued

Stainless Steels

18-8 Cr Ni Type 304*	A 182	F 304	Flanges	.08	2.0 Max	1.00 Max	18.0/20.0	8.0/11.0	f	75,000	30,000
	A 312	TP 304	Pipe	.08	2.0 Max	.75 Max	18.0/20.0	8.0/11.0	f	75,000**	30,000
	A 403	WP 304	Fittings	Covers Manufactured Fittings. For chemistry other specifications apply							
18-8 Cr Ni Type 304L	A 403	WP 304L	Fittings								
	A 312	TP 304L	Pipe	.035	2.0 Max	.75 Max	18.0/20.0	8.0/13.0	f	70,000	25,000
	A 182	F 304L	Flanges	.035	2.0 Max	1.00 Max	18.0/20.0	8.0/13.0	f	65,000	25,000

WELDING NECK¹

Part No. 24

Pipe Line Type — Part No. 724†

SLIP-ON¹

Part No. 54

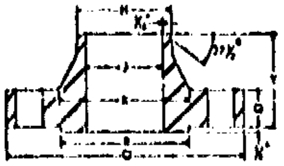
Pipe Line Type — Part No. 754†

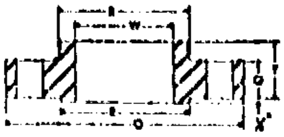
THREADED¹

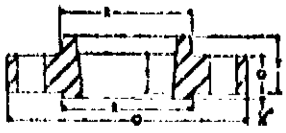
Part No. 64

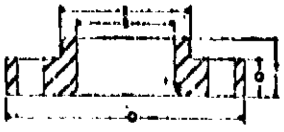
LAP JOINT²

Part No. 114









For sizes ½" through 2½" use 1500 lb. flanges.

3	9½	1½	5	5	4	2½	2¼	1⅛		3.57	3.60	3.50	⅛
4	11½	1¾	6³⁄₁₆	6½	4½	2¾	2¼	1⅛		4.57	4.60	4.50	³⁄₁₆
	13¾	2	7⁵⁄₁₆	7½	5	3⅛	3⅛	2⅛		5.66	5.69	5.56	³⁄₁₆
6	15	2³⁄₁₆	8½	9¼	5½	3⅝	3⅝	2¼		6.72	6.75	6.63	¼
8	18½	2½	10⅝	11¾	6¾	4	4½	2½	rchaser	8.72	8.75	8.63	¼
10	21½	2¾	12¾	14½	7½	4¼	5	2¹¹⁄₁₆		10.88	10.92	10.78	¼

Checked by:	Date	Title SUBSCALE EJECTOR/DIFFUSER	Model
Approved by:	Date	REF – AMERICAN STANDARD	Report No.

ORIGINAL [illegible]
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1.7

PHYSICAL and CHEMICAL REQUIREMENTS of Flange, Bolt, and Nut Steels

Physical and Chemical Requirements, STEEL FORGINGS for FLANGES, at Primary Service Pressure Ratings of 150- to 300-Lb per Sq In. (ASTM A181)

PHYSICAL [illegible]	[illegible]	GRADE II
Tensile strength (min)	60,000 lb per sq in.	70,000 lb per sq in.
Yield point (min)	30,000 lb per sq in.	36,000 lb per sq in.
Elongation in 2 in. (min)	22 per cent	18 per cent
Reduction of area (min)	35 per cent	24 per cent
Phosphorus (max) [1]	0.05 per cent	0.05 per cent
Sulphur (max) [1]	0.05 per cent	0.05 per cent
Manganese (max)	0.90 per cent	0.90 per cent
Carbon (max)	0.35 per cent [2]	0.35 per cent [2]

Physical and Chemical Requirements, STEEL FORGINGS for FLANGES, at Primary Service Pressure Ratings of 150- to 2500-Lb per Sq In.

[illegible]	ASTM A1[illegible]		ASTM A1[illegible]	
	[illegible]		CARBON-MOLY [illegible]	[illegible]
	GRADE [illegible]	GRADE [illegible]	GRADE [illegible]	GRADE [illegible]
Tensile strength (min)	60,000 lb per sq in.	70,000 lb per sq in.	70,000 lb per sq in.	90,000 lb per sq in.
Yield point (min)	30,000 lb per sq in.	36,000 lb per sq in.	40,000 lb per sq in.	65,000 lb per sq in.
Elongation in 2 in. (min)	25 per cent	22 per cent	25 per cent	22 per cent
Reduction of area (min)	38 per cent	30 per cent	35 per cent	50 per cent
Phosphorus (max)	0.05 per cent [1]	0.05 per cent [1]	0.04 per cent	0.04 per cent
Sulphur (max)	0.05 per cent [1]	0.05 per cent [1]	0.04 per cent	0.03 per cent
Manganese	0.90 per cent (max)	0.90 per cent (max)	0.60 to 0.90 per cent	0.60 per cent (max)
Carbon	0.35 per cent	0.35 per cent	0.20 to 0.30 per cent	0.25 per cent (max)
Silicon	[2]	[2]	0.20 to 0.35 per cent	0.50 per cent (max)
Chromium			....	4.00 to 6.00 per cent

PRESSURE TEMPERATURE RATINGS

of American Standard Carbon* Steel Pipe Flange

PRESSURE CLASS	150	300	400	600	900	1500	2500
TEST PRESSURE	425	1100	1450	2175	3250	5400	9000
SERVICE TEMPERATURE							
-20 to 100	275	720	960	1440	2160	3600	6000
150	255	710	945	1420	2130	3550	5915
200	240	700	930	1400	2100	3500	5830
250	225	690	920	1380	2070	3450	5750
300	210	680	910	1365	2050	3415	5690
350	195	675	900	1350	2025	3375	5625
400	180	665	890	1330	2000	3330	5550
450	165	650	870	1305	1955	3255	5430
500	150	625	835	1250	1875	3125	5210
550	140	590	790	1180	1775	2955	4925
600	130	555	740	1110	1660	2770	4620
650	120	515	690	1030	1550	2580	4300
700	110	470	635	940	1410	2350	3920
750	100	425	575	850	1275	2125	3550
800	92	365	490	730	1100	1830	3050
850	82	300	400	600	900	1500	2500
875	75	260	350	525	785	1305	2180
900	70	225	295	445	670	1115	1855
925	60	190	250	375	565	945	1570
950	55	155	205	310	465	770	1285
975	50	120	160	240	360	600	1000
1000	40	85	115	170	255	430	715

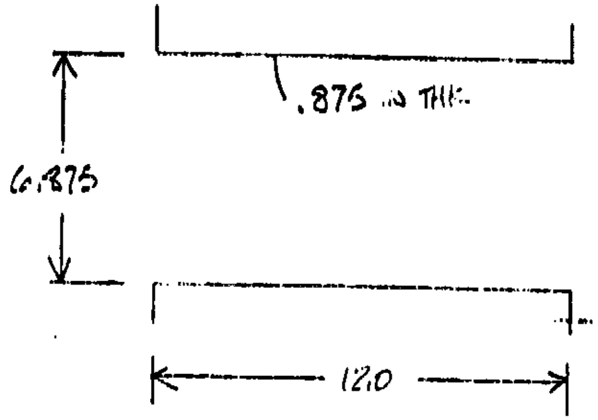
B-12

C-2

Prepared by: TMT	Date 4/84	**LOCKHEED MISSILES & SPACE COMPANY, INC.**	Page Temp. 19 Perm.
Checked by:	Date	Title SUBSCALE EJECTOR DIFFUSER H2 CYLINDER – NOZ. SIMULATOR	Model
Approved by:	Date		Report No.

TR82702

304 L S. S.



LOAD – 1200. PSIA / TCT ?

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HOOP STRESS

$$\sigma = PD/2t = (1200)6.875/2(.875) = 4714. \text{ psi}$$

$$M.S. = 70K/4.(4714) - 1. = \underline{+2.71} \text{ ULT}$$

$$M.S. = 25K/1.6(4.714) - 1. = \underline{+2.31} \text{ YLD}$$

FLANGE THICKNESSES OF 2.5 IN ARE USED WITH THE SAME RATIONALE AS INLET PLATE THICKNESS (TR82701). HERE

$$M.S. = 1500/1200. - 1 = +.25$$

WITH A YIELD FACTOR OF 2 IN THE NUMERATOR,

or $M.S. = 2(1500)/1.6(1200) - 1. = \underline{+.56} \text{ YLD}$

WITH A YIELD FACTOR OF 1.6. & RATIOING THE ULT:

& $M.S. = \frac{70K}{25K}(2)1500/4(1200) - 1. = \underline{+.75} \text{ ULT}$

Prepared by: DAT	Date	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page Temp. Perm.
Checked by:	Date	Title SUBSCALE EJECTOR/DIFFUSER	Model
Approved by:	Date	REF AMERICAN STANDARD	Report No.

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DIMENSIONS of Seamless and Welded STEEL PIPE

ASA-B36.10 and B36.19

NOMINAL PIPE SIZE	OUT-SIDE DIAM.	NOMINAL WALL THICKNESS FOR														
		SCHED 5S	SCHED 10S	SCHED 10	SCHED 20	SCHED 30	STANDARD	SCHED 40	SCHED 60	EXTRA STRONG	SCHED 80	SCHED 100	SCHED 120	SCHED 140	SCHED 160	XX STRONG
1/8	0.405	.....	0.049	.....	.....	.....	*0.068*	0.068	.....	*0.095*	0.095	.....	.....	.....	.....	.....
1/4	0.540	.....	0.065	.....	.....	.....	*0.088*	0.088	.....	*0.119*	0.119	.....	.....	.....	.....	.....
3/8	0.675	.....	0.065	.....	.....	.....	*0.091*	0.091	.....	*0.126*	0.128	.....	.....	.....	.....	.....
1/2	0.840	0.065	0.083	.....	.....	.....	*0.109*	0.109	.....	*0.147*	0.147	.....	.....	.....	0.188	0.294
3/4	1.050	0.065	0.083	.....	.....	.....	*0.113*	0.113	.....	*0.154*	0.154	.....	.....	.....	0.219	0.308
1	1.315	0.065	0.109	.....	.....	.....	*0.133*	0.133	.....	*0.179*	0.179	.....	.....	.....	0.250	0.358
1 1/4	1.660	0.065	0.109	.....	.....	.....	*0.140*	0.140	.....	*0.191*	0.191	.....	.....	.....	0.250	0.382
1 1/2	1.900	0.065	0.109	.....	.....	.....	*0.145*	0.145	.....	*0.200*	0.200	.....	.....	.....	0.281	0.400
2	2.375	0.065	0.109	.....	.....	.....	*0.154*	0.154	.....	*0.218*	0.218	.....	.....	.....	0.344	0.436
2 1/2	2.875	0.083	0.120	.....	.....	.....	*0.203*	0.203	.....	*0.276*	0.276	.....	.....	.....	0.375	0.552
3	3.5	0.083	0.120	.....	.....	.....	*0.216*	0.216	.....	*0.300*	0.300	.....	.....	.....	0.438	0.600
3 1/2	4.0	0.083	0.120	.....	.....	.....	*0.226*	0.226	.....	*0.318*	0.318	.....	.....	.....	.....	.....
4	4.5	0.083	0.120	.....	.....	.....	*0.237*	0.237	.....	*0.337*	0.337	.....	0.438	.....	0.531	0.674
5	5.563	0.109	0.134	.....	.....	.....	*0.258*	0.258	.....	*0.375*	0.375	.....	0.500	.....	0.625	0.750
6	6.625	0.109	0.134	.....	.....	.....	*0.280*	0.280	.....	*0.432*	0.432	.....	0.562	.....	0.719	0.864
8	8.625	0.109	0.148	.....	0.250	0.277	*0.322*	0.322	0.406	*0.500*	0.500	0.594	0.719	0.812	0.906	0.875
10	10.75	0.134	0.165	.....	0.250	0.307	*0.365*	0.365	0.500	*0.500*	0.594	0.719	0.844	1.000	1.125	1.000
12	12.75	0.156	0.180	.....	0.250	0.330	*0.375*	0.406	0.562	*0.500*	0.688	0.844	1.000	1.125	1.312	1.000
14 O.D.	14.0	0.156	0.188	0.250	0.312	0.375	0.375	0.438	0.594	0.500	0.750	0.938	1.094	1.250	1.406	.....
16 O.D.	16.0	0.165	0.188	0.250	0.312	0.375	0.375	0.500	0.656	0.500	0.844	1.031	1.219	1.438	1.594	.....
18 O.D.	18.0	0.165	0.188	0.250	0.312	0.438	0.375	0.562	0.750	0.500	0.938	1.156	1.375	1.562	1.781	.....
20 O.D.	20.0	0.188	0.218	0.250	0.375	0.500	0.375	0.594	0.812	0.500	1.031	1.281	1.500	1.750	1.969	.....
22 O.D.	22.0	0.188	0.218	0.250	0.375	0.500	0.375	.....	0.875	0.500	1.125	1.375	1.625	1.875	2.125	.....
24 O.D.	24.0	0.218	0.250	0.250	0.375	0.562	0.375	0.688	0.969	0.500	1.218	1.531	1.812	2.062	2.344	.....
26 O.D.	26.0	.....	.....	0.312	0.500	.....	0.375	.....	.....	0.500	.....	.....	.....	.....	.....	.....
28 O.D.	28.0	.....	.....	0.312	0.500	0.625	0.375	.....	.....	0.500	.....	.....	.....	.....	.....	.....
30 O.D.	30.0	0.250	0.312	0.312	0.500	0.625	0.375	.....	.....	0.500	.....	.....	.....	.....	.....	.....
32 O.D.	32.0	.....	.....	0.312	0.500	0.625	0.375	0.688	.....	0.500	.....	.....	.....	.....	.....	.....
34 O.D.	34.0	.....	.....	0.312	0.500	0.625	0.375	0.688	.....	0.500	.....	.....	.....	.....	.....	.....
36 O.D.	36.0	.....	.....	0.312	0.500	0.625	0.375	0.750	.....	0.500	.....	.....	.....	.....	.....	.....
42 O.D.	42.0	.....	.....	.....	.....	.....	0.375	.....	.....	0.500	.....	.....	.....	.....	.....	.....

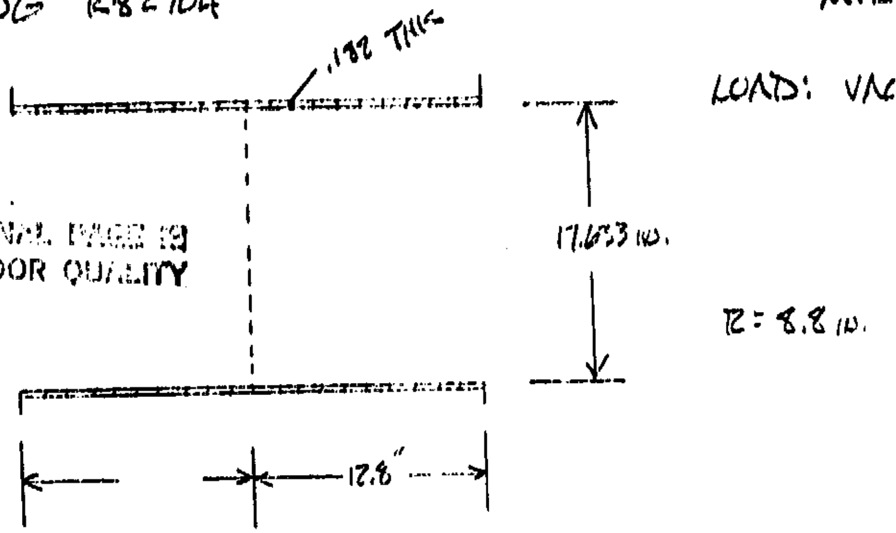
FORM

Prepared by: DMT	Date 4/84	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page 1.11
Checked by:	Date	Title SUBSCALE EJECTOR/DIFFUSER	Model
Approved by:	Date	ALTITUDE SIMULATION CELL	Report No.

DWG R82704

MTL 304L S.S.

LOAD: VACUUM AT RT



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REF. NASA ASTRONAUTIC STRUCTURES MANUAL, SECT C3, P13

$$D = Et^3/12(1-\nu^2) = 28\times10^6(.188^3)/12(.9216) = 16823.$$

$$Z = L^2(1-\nu^2)^{1/2}/RT = 12.8^2\sqrt{.9216}/8.82(.188) = 94.85$$

[illegible]

HYDROSTATIC PRESSURE WHERE $\gamma = .56$ & $kZ = 53.1$

$$M.S. = 919./4(14.7) - 1 = \boxed{+14.6}$$ BUCKLING

HOOP STRESS

$$\sigma = PD/2t = 14.7(17.633)/2(.188) = 689.\ PSI$$

$$M.S. = 70/4(.69) - 1. = \boxed{+24.3}$$ ULT

$$M.S. = 25/1.6(.69) - 1. = \boxed{+21.6}$$ YLD

Prepared by: DMT	**Date** 4/84	LOCKHEED MISSILES & SPACE COMPANY, INC.	**Page** 1.12
Checked by:	**Date**	**Title** SUBSCALE NOZZLE/DIFFUSER	**Model**
Approved by:	**Date**	NOZZLE BODY	**Report No.**

R827016 304 L S.S.

— THE NOZZLE BODY SUPPORT CAN BE CONSIDERED A 'BLIND FLANGE' AND USING THE RATIONALE ON PAGE 1 (FOR THE END PLATE - R827701) THE 2.5 IN. THICKNESS HAS A WORKING PRESSURE OF OF 1500 PSI.

— THIS WORKING PRESSURE HAS A YIELD FACTOR OF SAFETY OF AT LEAST 2. THEREFORE

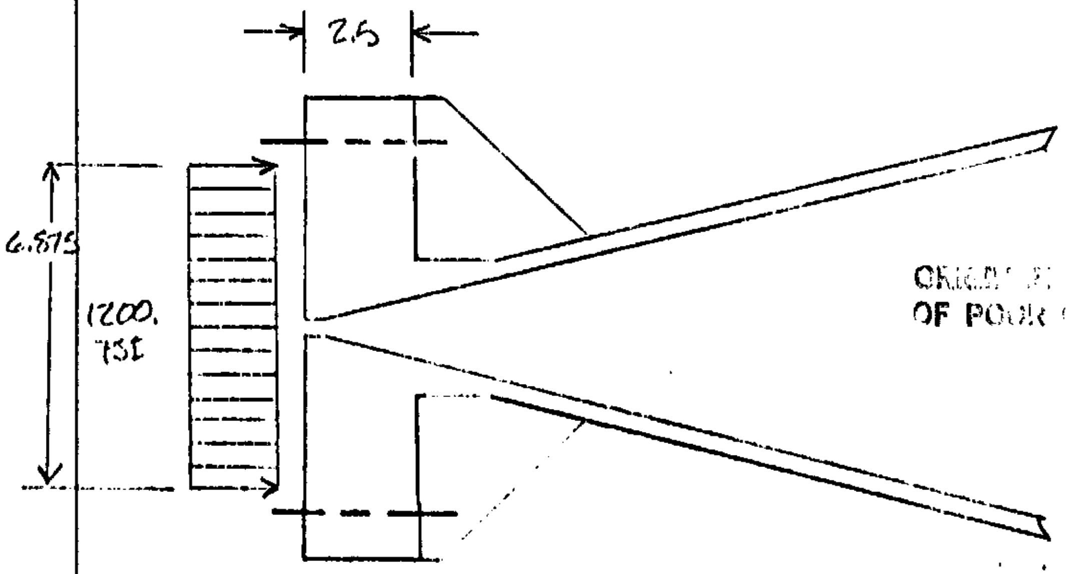
$$M.S. = 2(1500)/1.6(1200) - 1. = \underline{\underline{+.56}}\ YLD$$

RATIOING FOR THE ULT MARGIN:

$$M.S. = \left(\frac{70.}{25.}\right)2(1500)/4(1200) - 1. = \underline{\underline{+.75}}\ ULT$$

CONSERVATIVE

GUSSETS ARE CONSERVATIVELY IGNORED



DRIT	4/81	LOCKHEED MISSILES & SPACE COMPANY, INC.	1.13
Checked by:	Date	Title SUBSCALE EJECTOR/DIFFUSER	Model
Approved by:	Date	NOZZLE BODY	Report No.

TR82706 304L S.S.

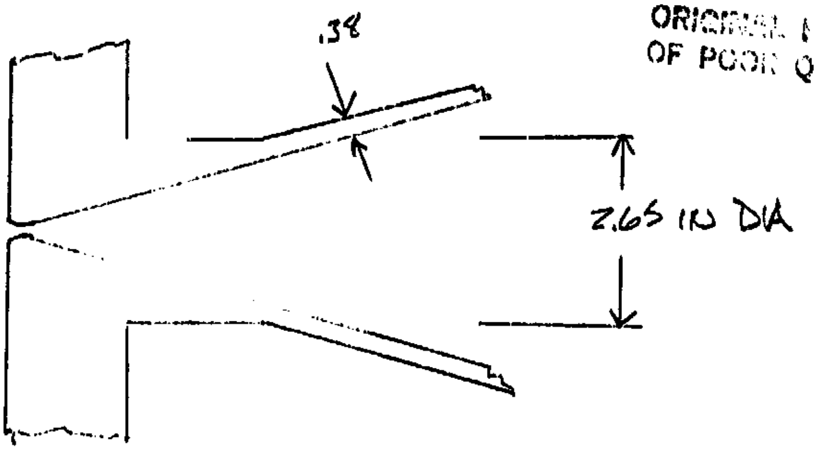
THROAT OF NOZZLE –

ASSUME 1200 PSI AT ID = 2.65 & T = .38 & R.T.
IGNORE GUSSETS

$\sigma = PD/2T = 1200(2.65)/2(.38) = 4184$ PSI

$M.S. = 70/4(4.184) - 1.0 = \underline{\underline{+3.18}}$

$M.S. = 25/1.6(4.184) - 1.0 = \underline{\underline{+2.73}}$



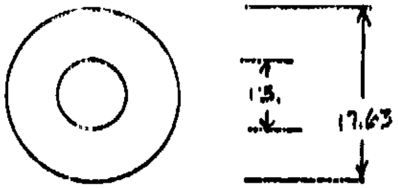
– CONSERVATIVE LOAD - SINCE 1200 PSIA DECREASES FROM ORIFICE TO NOZZLE'S END.

Prepared by: TMT	Date 4/24	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page 2
Checked by:	Date	Title CURTAIN EJECTOR / DIFFUSER ALTITUDE CELL & TRAIN	Model
Approved by:	Date		Report No.

DWG R82708

304L SS

GUIDED EDGES —



THK = .5IN

LOAD = 14.7 PSI NOMINAL PRESSURE AT TGT

PLUS CENTER LOAD = $14.7\pi 6.5^2$ = 1951 LB.

ROARK 5TH ED P336 CASE 1.F $\quad w = 1951/2\pi 6.5 = 47.77$ lb/IN

$$M_{RB} = wa\,L_6/C_8 = 47.8(8.81)\,.028/.228 = 51.74 \text{ IN-LBS}$$

$$L_6 = \frac{13}{4(17.63)}\left[\left(\frac{13}{17.63}\right)^2 - 1 + 2\ln\left(\frac{17.63}{13.}\right)\right] = .028$$

$$C_8 = \frac{1}{2}\left[1-\left(\frac{13.}{17.63}\right)^2\right] = .228$$

$$\text{SO } \sigma_B = 6M/t^2 = 6(51.74)/.25 = 1380.\text{ PSI}$$

CASE 2f $\quad M = qa^2 L_{14}/C_8 = 14.7(8.81^2).0026/.228 = 13.02$ IN-LB

$$L_{14} = \frac{1}{16}\left[1-\left(\frac{13}{17.63}\right)^4 - 4\left(\frac{13}{17.63}\right)^2 \ln\frac{17.63}{13}\right] = .0026$$

$$\text{SO } \sigma_B = 6M/t^2 = 6(13.02)/.25 = 312.6\text{ PSI}$$

$$\sigma_T = 1380. + 312.6 = 1692.\text{ PSI}$$

M.S. = 70./4 (1.69) −1. = +9.35 ULT

M.S. = 25./1.6 (1.69) −1. = +8.24 YLD

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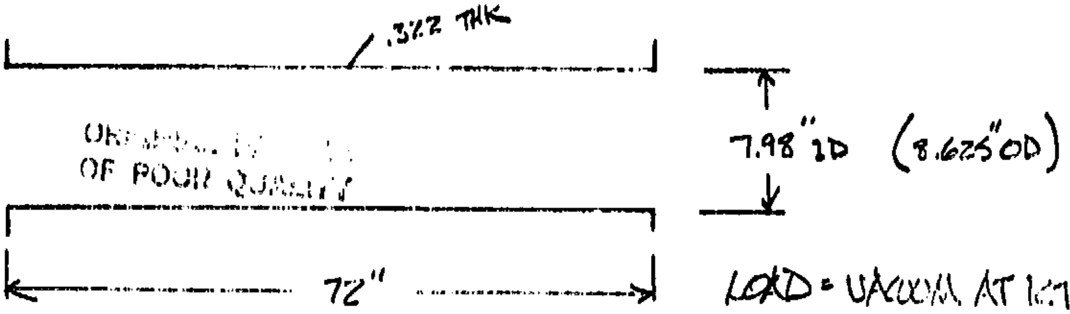
DWG R82709 304L SS



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LOAD = VACUUM AT RT

REF. NASA STRUCTURES MANUAL, SECT C3., P.13

$$D = Et^3/12(1-\nu^2) = 28\,10^6(.322^3)/12(.9215) = 84537.$$

$$Z = L^2(1-\nu^2)^{1/2}/RT = 72^2\sqrt{.9215}/4.3(.322) = 3594.$$

$$P_{CR} = K_p\pi^2 D/RL^2 = 4.5\pi^2 84537/4.3(72)^2 = 168.4 \text{ psi}$$

HYDROSTATIC PRESSURE WHERE $\gamma = .56$ $\gamma Z = 2012.6$
$K_p = 4.5$

$$M.S. = 168.4/4(14.7) = \underline{+1.86} \text{ BUCKLING}$$

HOOP STRESS

$$\sigma = PD/2t = 14.7(7.98)/2(.322) = 180. \text{ PSI}$$

$$M.S. = 70./4(.18) - 1. = \underline{+96.2} \text{ ULT}$$

$$M.S. = 25/1.6(.18) - 1. = \underline{+85.8} \text{ YIELD}$$

Prepared by: DLT	Date 4/84	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page 4
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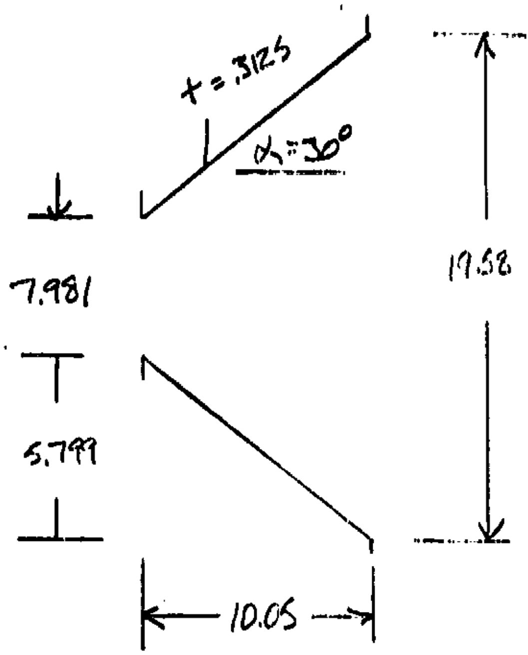
R82710

304L S.S.



LOAD VACUUM AT RT

HYDROSTATIC PRESSURE -- CONSERVATIVE.

REF. NASA STRUCTURES MANUAL, SECT. C3.0, P 67.

BUCKLING - $P_{cr} = .92\, E\, t \Big/ \left(\frac{L}{\rho}\right)\left(\frac{\bar{\rho}}{t}\right)^{5/2}$ where $\bar{\rho} = (9.79+4.)/2\cos 30° = 7.95$

$$= .92\ 28\ 10^6\ .75 \Big/ \left(\frac{10.05}{7.95}\right)\left(\frac{7.95}{.3125}\right)^{5/2} = 4681 \text{ PSI}$$

$M.S. = 4681/4(14.7) - 1. =$ +78.6 BUCKLING

HOOP STRESS - CONSERVATIVE

$$\sigma = PD/2t = 14.7(19.6)/2(.3125) = 461. \text{ PSI}$$

$M.S. = 70/4.(.461) - 1. =$ +36.96 ULT

$M.S. = 25/1.6(.461) - 1. =$ +32.9 YLD

Prepared by: DMT	Date 6/84	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page Temp. Perm.
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Approved by:	Date		Report No.

R82714

AXIAL LOAD ON THE 10.35 IN. CYLINDER DUE TO EJECTOR FLOW:

AXIAL LOAD DUE TO EJECTOR PRESSURE OF 6.34PSIA:

$$P = 6.34\,\pi\left(20.736^2 - 19.584^2\right)/4 = 46.44 \text{ PSI}$$

$$\text{AXIAL STRESS} = \frac{P}{A} = \frac{46.44(2)}{.375(2)\pi\, 19.584} = 2.01 \text{ psi}$$

NEGLIGIBLE

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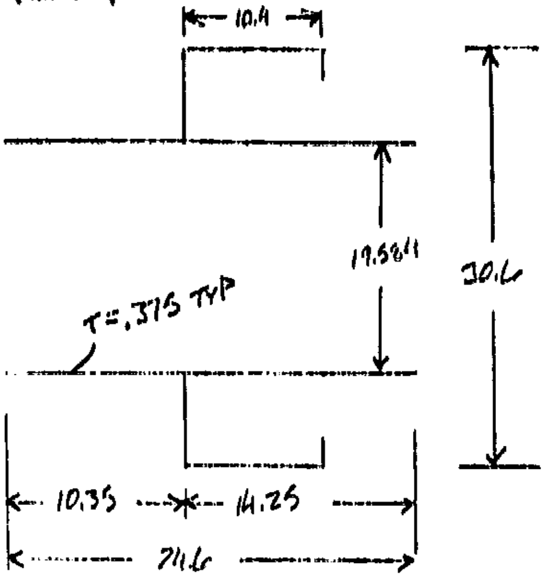
DWG R82714

304L S.S.



LOAD – VACUUM AT 900K
(CONSERVATIVE)

$E = 26 \times 10^6$ psi – 440 F

$F_{cy} = 18.$ KSI – 440F

<u>INNER CYLINDER</u> – BUCKLING REF NASA STRUCTURES MANUAL, C.3, P13

$D = Et^3/12(1-\nu^2) = 26\ 10^6 .375^3/12(.9215) = 123991.$

$Z = L^2(1-\nu^2)^{1/2}/RT = 14.25^2\sqrt{.9215}/9.8(.375) = 53.04$

$P_{CR} = \underline{K_p}\pi^2 D/RL^2 = 6\ \pi^2 123991./9.8(14.25^2) = 3689.$ PSI

HYDROSTATIC

$\gamma = .56$ $\gamma Z = .56(53) = 29.7$ $K_p = 6.$

$MS = 3689/4(14.7) - 1. =$ **+61.7**

<u>HOOP STRESS</u>

$\sigma = PD/2T$ $= (14.7)19.584/2(.375) = 383.8$ PSI

$M.S. = 55/4(.384) - 1. =$ **+34.8 ULT**

$M.S. = 18/1.6(.384) - 1. =$ **+28.3 YLD**

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DWG – R82714

304 L S.S.

OUTER CYLINDER

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BUCKLING:

$D = 26(10^6).375^3/12(.9215) = .123991.$

$Z = 10.4^2\sqrt{.9215}/15.3(.375) = 18.09$

$\tau_{CR} = 4\pi^2 .123991/15.3(10.4^2) = 2957.9$ PSI

HYDROSTATIC

$\gamma Z = .56(18.1) = 10.85 \qquad K = 4$

$M.S. = 2958/4(14.7) - 1. = \quad +49.3$ BUCKLING

HOOP STRESS

$\sigma = PD/2T = (14.7)30.6/2(.375) = 600$ PSI

$M.S. = 55./4(.600) - 1. = \quad +21.9$ ULT

$M.S. = 18./1.6(.600) - 1. = \quad +17.7$ YLD

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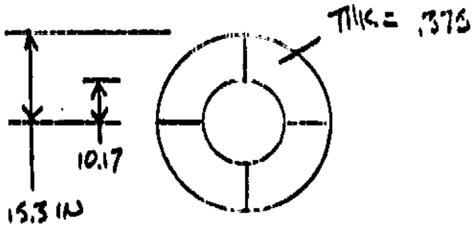
DWG R227114 304 L. S.S.

RING — OUTER CYLINDER END
— ASSUME ALL ACTUATOR LOADS REACTED BY INNER GUSSET.
— VERY CONSERVATIVELY IGNORE INNER GUSSETS FOR THE FOLLOWING PRESSURE LOADING.



LOAD – VACUUM AT 440°F
$E = 26 \times 10^6$ KSI
$F_{TU} = 55$ KSI
$F_{TY} = 18.$ KSI

ORIGINA
OF POOR

REF - ROARK 5TH ED, P340, CASE 2F.

$$M_{RB} = q a^2 L_{14} / C_5 = 14.7 (15.3)^2 .00518 / .279 = 63.96$$

$$C_5 = .5 \left[1 - \left(\frac{10.17}{15.3} \right)^2 \right] = .279$$

$$L_{14} = \frac{1}{16} \left[1 - \left(\frac{10.17}{15.3} \right)^4 - 4 \left(\frac{10.17}{15.3} \right)^2 \ln \left(\frac{15.3}{10.17} \right) \right] = .00518$$

$$\sigma = 6M / t^2 = 6(64.) / .375^2 = 2729.\ \text{PSI}$$

$$M.S. = 55 / 4(2.73) - 1. = \boxed{+4.03}\ \text{ULT}$$

VERY CONSERVATIVE

$$M.S. = 18. / 1.6 (2.73) - 1. = \boxed{+3.12}\ \text{YLD}$$

VERY CONSERVATIVE

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DWG R22716

304L S.S.

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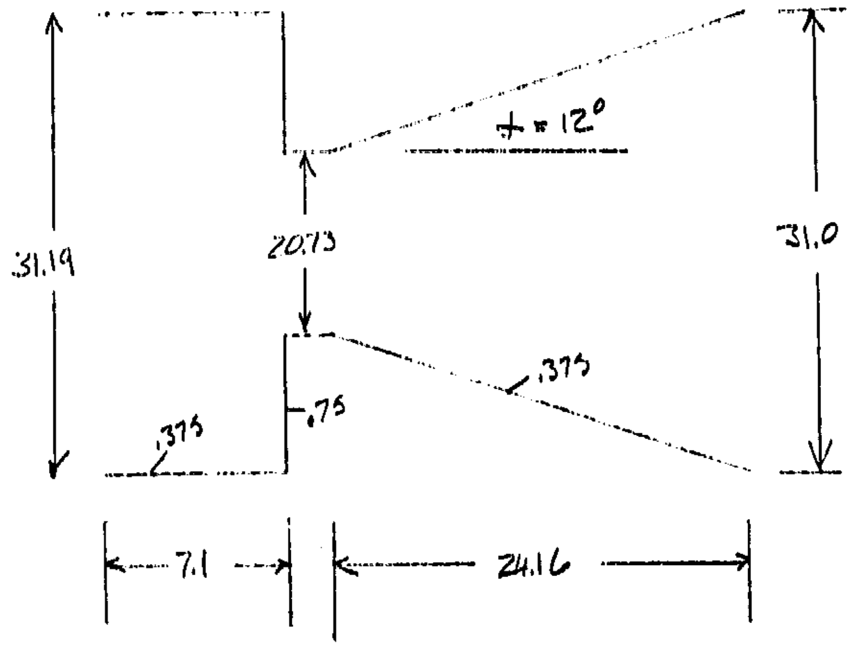

440°F

F_{cy} = 18000 PSI

E = 26 x 10^6

CYLINDER - LOAD = 14.7 - 2.7 = 12 PSIG - SAY 14.7 PSIG AT 440F

REF. NASA STRUCTURES MANUAL, C3., P13

$D = 26 \times 10^6 \, .375^3 / 12(.9215) = 123991.$

$Z = 7.1^2 \sqrt{.9215} / 15.6(.375) = 8.27$

$P_{cr} = \underline{3} \, \pi^2 \, 123991. / 15.6 (7.1)^2 = 4668$ PSI HYDROSTATIC

$\gamma = .56 \quad + \quad \gamma Z = 4.63 \quad K = 3.$

MS = 4668/14.7(4) - 1. = +78.4 BUCKLING

HOOP STRESS $\sigma = PD/2t = 14.7(31.2)/2(.375) = 611.$ psi

M.S. = 55./4(.611) - 1. = +17.0 ULT

M.S. = 18./1.6(.611) - 1. = +17.4 YLD

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DWG R82716

304L S.S.

CONE LOAD = -14.7 PSIG & RT

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REF NASA STRUCTURES MANUAL, C3.0, P67

$$P_{cr} = \frac{.92 E \gamma}{\left(\frac{L}{\bar{r}}\right)\left(\frac{\bar{r}}{t}\right)^{3/2}} = \frac{.92(28\times10^6).75}{\left(\frac{24.16}{13.22}\right)\left(\frac{13.22}{.375}\right)^{3/2}} = 1432.65 \text{ psi}$$

$$\bar{r} = (15.5 + 10.365)/2 \cos 12 = 13.22$$

$$M.S. = 1432/14.7(4.) - 1. = \boxed{+24.31}$$

HYDROSTATIC BUCKLING

HOOP STRESS

$$\sigma = PD/2t = 14.7(31.)/2(.375) = 607.6 \text{ psi}$$

$$M.S. = 70./4.(607.6) - 1. = +27.8$$ ULT.

$$M.S. = 25./1.6(607.6) - 1. = +24.7$$ YLD.

FORM LMSC 3528-3

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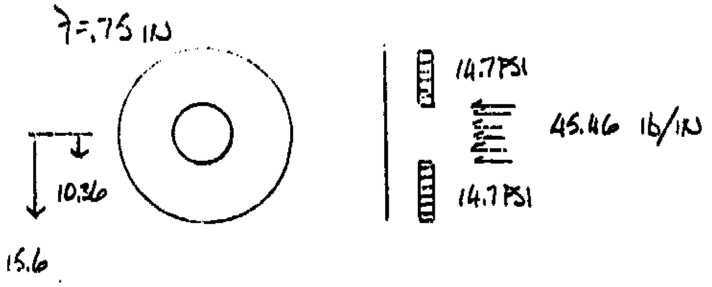
Approved by:	Date	EXPANSION SECTION - 1ST STAGE	Report No.

DWG R82716 304 L S.S.

RING — $a = 15.6 \quad b = 10.36 \quad t = .75$

LOAD = -14.7 PSIG (CONSERVATIVE) & AXIALLY LOADED
INNER EDGE OF $2964/\pi\, 20.73 = 45.46$ lb/IN = w
440°F

REF ROARK - 5TH ED, P 336, CASE 1.F



- INNER EDGE GUIDED
- OUTER EDGE FIXED
- VERY CONSERVATIVELY IGNORE GUSSETS.

$$M = w a L_6 / C_5 = 45.46(15.6)\ .043 / .279 = 109.11$$

$$L_6 = \frac{10.36}{4(15.6)}\left[\left(\frac{10.36}{15.6}\right)^2 - 1 + 2 \ln \frac{15.6}{10.36}\right] = .043$$

$$C_5 = .5\left[1 - \left(\frac{10.36}{15.6}\right)^2\right] = .279$$

CASE 2F

$$M = q a^2 L_{14} / C_5 = 14.7 (15.6)^2 .0052 / .279 = 66.675$$

$$L_{14} = \frac{1}{16}\left[1 - \left(\frac{10.36}{15.6}\right)^4 - 4\left(\frac{10.36}{15.6}\right)^2 \ln \frac{15.6}{10.36}\right] = .0052$$

$$\sigma = 6(109.1 + 66.7)/.75^2 = 1875.\ \text{PSI}$$

$$M.S. = 18000/1.6(1875) - 1. = \underline{+5.}\ \text{YLD}$$

$$M.S. = 55000/4.(1875) - 1. = \underline{+6.33}\ \text{ULT}$$

VERY CONSERVATIVE

Prepared by: TAIT	Date 4/84	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page Temp. 11 Perm.
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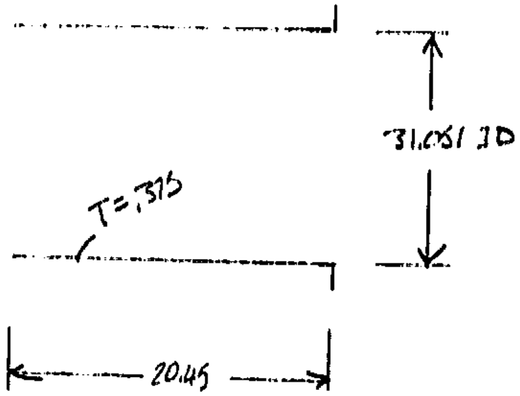
THLOTR82715

304L S.S.

LOAD = -14.7 PSIG AT RT CONSERVATIVE.



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REF. - NASA STRUCTURES MANUAL, C3., P 13

$D = Et^3/12(1-\nu^2) = 28\times10^6(.375)^3/12(.9215) = 133528.$

$Z = L^2(1-\nu^2)^{1/2}/RT = 20.45^2\sqrt{.9215}/15.52(.375) = 68.97$

$P_{cr} = K_p\pi^2 D/RL^2 = \underline{6.5}\,\pi^2\,133528/15.52(20.45)^2 = 1319.7$ psi

WHERE $\gamma = .56$ & $\gamma Z = 38.6$ & $K_p = 6.5$

$M.S. = 1320/4(14.7) - 1. = +22.4$ HYDROSTATIC BUCKLING

HOOP STRESS

$\sigma = PD/2t = 14.7(31.05)/2(.375) = 608.58$ psi

$M.S. = 28000/1.6(609.) - 1. = +27.7$ YLD

$M.S. = 70000/4(609.) - 1. = +27.7$ ULT

Prepared by: DMT	**Date** 4/84	**LOCKHEED MISSILES & SPACE COMPANY, INC.**	**Page** Temp. 13 Perm.
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Approved by:	**Date**		**Report No.**

TC82718

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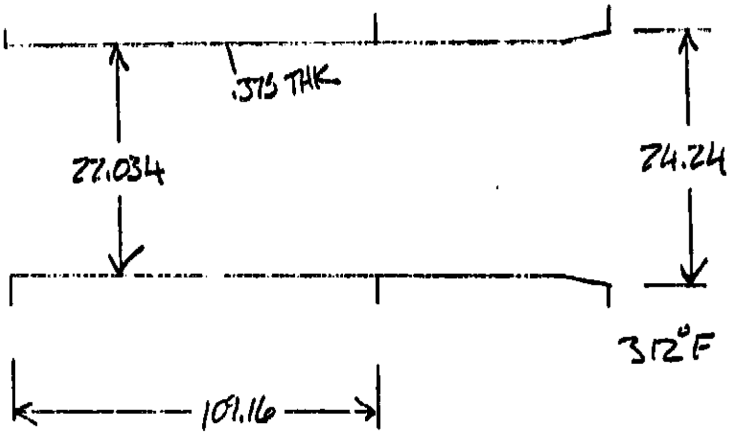
304L - S.S.



LOADS → -14.7 PSIG
312°F
(CONSERVATIVE)

312°F
$E = 27 \times 10^6$ PSI
$F_{TU} = 59$ KSI
$F_{TY} = 22$ KSI

REF: NASA STRUCTURES MANUAL, C3.0, P. 13

$$D = 27\times10^6(.375^3)/12(.9215) = 128746.$$

$$Z = 109.16^2\sqrt{.9215}/11.(.375) = 2773$$

$$P_{cr} = \underline{40}\,\pi^2\,128746./11.(109.16)^2 = 387.76 \text{ PSI}$$

$$Z\gamma = .56(2773.) = 1552. \qquad K_p = 40$$

$$M.S. = 387.8/4(14.7) - 1. = +5.59$$

BUCKLING
HYDROSTATIC

HOOP STRESS - BASED ON MAX DIA

$$\sigma = PD/2t = 14.7(24.24)/2(.375) = 475. \text{ PSI}$$

$$M.S. = 22/1.6(.475) - 1. = +27.9$$

YLD

$$M.S. = 59/4(.475) - 1. = +30.05$$

ULT

FORM LMSC 3928-3

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Approved by:	Date	FIRST STAGE CONTRACTION SECTION	Report No.

R82717

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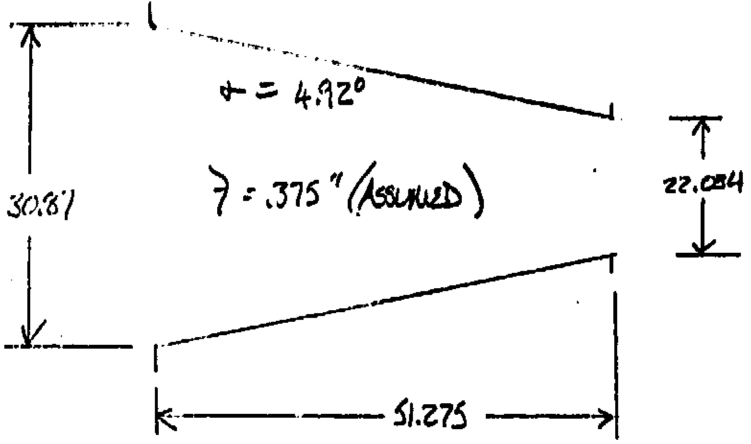

LOAD → −14.7 PSIG
EXT (CONSERVATIVE)

$$\bar{r} = \frac{30.87 + 22.034}{4 \cos 4.92°} = 13.27$$

REF. – NASA STRUCTURES MANUAL, C3.0, P67.

$$P_{CR} = \frac{.92\,E\,t}{\left(\frac{L}{\bar{r}}\right)\left(\frac{\bar{r}}{t}\right)^{5/2}} = \frac{.92\,(28\times10^{6}).75}{\left(\frac{51.275}{13.27}\right)\left(\frac{13.27}{.375}\right)^{5/2}} = 671.\ \text{PSI}$$

M.S. = 671./4.(14.7) −1. = +10.4 HYDROSTATIC BUCKLING

HOOP STRESS

$\sigma = PD/2t = 14.7(30.87)/2(.375) = 605.$ PSI

M.S. = 28000./1.6(605.) −1. = +27.9 YIELD

M.S. = 70000./4.(605.) −1. = +27.9 ULT

Prepared by: DMT	Date 11/84	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page 14	Temp. Perm.
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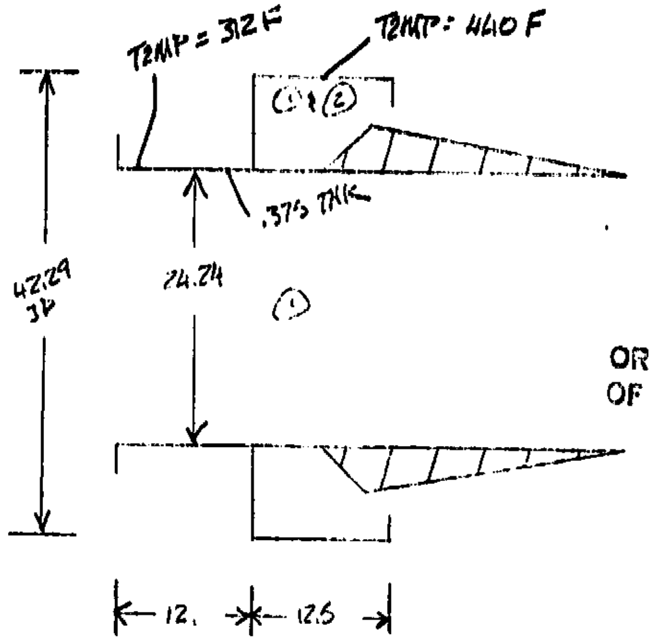
DWG - R82723A

304L - S.S.



LOAD: ① -14.7 PSIG AT 312°F (CONSERVATIVE)

② 33 PSIA = 18.3 PSIG AT 440°F

INNER CYLINDER

BUCKLING REF NASA STRUCTURES MANUAL, C3.0, P. 13

$D = 27 \times 10^6 (.375^3)/12(.9215) = 128746.$

$Z = 12.^2 \sqrt{.9215}/12.12(.375) = 30.41$

$P_{cr} = 5 \pi^2 128746./(12.12(12^2)) = 4010.9$

$Z\gamma = .56(30.41) = 17.$ $K_p = 5.$

$M.S. = 4011/4(14.7) - 1. =$ +67.2 BUCKLING HYDROSTATIC

HOOP STRESS -- SAME AS PREVIOUS SECTION: +27.9 YLD

+30.05 ULT

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TC82723A

AXIAL LOAD IN 12.0 IN CYLINDER SECTION DUE TO EJECTOR FLOW:

$$P = (33-14.7)\pi(32^2-24.2^2)/4 = 6300.\ \text{LB}$$

$$\sigma = P/A = 6300/\pi\,12.1^2 = 13.7\ \text{PSI}$$

THIS WOULD CORRESPOND TO A HYDROSTATIC PRESSURE OF:

$$\sigma = \frac{PD}{4t} = 13.7 = P\,24.2/4(.375)$$

$$\therefore\ P = 0.85\ \text{PSI}$$

SINCE THE HYDROSTATIC BUCKLING OF THIS CYLINDER IS 4010.9* PSI → GOOD BY INSPECTION

* PREVIOUS PAGE.

FORM LMSC 3625-3

Prepared by: CMT	Date 4/84	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page 15 Temp. Perm.
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DWG - TC82723A

304L - S.S.

OUTER CYLINDER BUCKLING - REF NASA STRUCTURES MANUAL (WALL TEMP = 440 F)

$D = 27\times10^6(.375^3)/12(.9215) = 128746.$

$Z = 12.5^2\sqrt{.9215}/21.145(.375) = 18.91$

$P_{cr} = \underline{4}\,\pi^2\,128746/21.145(12.5^2) = 1538.4$ PSI

$\gamma Z = .56(18.91) = 10.6 \qquad K_p = 4$

$M.S. = 1538.4/4(14.7) - 1. = \boxed{+25.16}$

BUCKLING HYDROSTATIC

HOOP STRESS LOAD② (USING MAX POS. PRESSURE, 33 − 14.7 = 18.3 PSIG)

$\sigma = PD/2T = 18.3(42.29)/2(.375) = 1031.87$ PSI

$M.S. = 55.\text{KSI}/4.(1032.) - 1. = +12.3$ ULT

$M.S. = 18.\text{KSI}/1.6(1032.) - 1. = +9.9$ YIELD

Prepared by: TMT	Date 1/84	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page Temp. 16 Perm.
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DWG TC82723A

304L - S.S.

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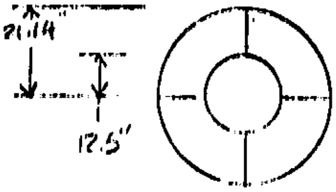
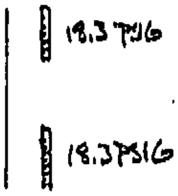
RING





LOAD - MAX ΔP IS 18.3 PSIG
AT 440.F
$F_{TU} = 55$ KSI
$F_{TY} = 18$ KSI

- THE LOADS FROM THE ACTUATORS ARE ASSUMED TO BE REACTED THRU THE INNER GUSSETS.
- VERY CONSERVATIVELY IGNORE THE FOUR INNER GUSSETS WHEN CONSIDERING THE PRESSURE ON THE RING

REF: ROARK 5th EDITION, P 340, CASE 2F. $r_0 = b$

$$M_{RB} = q\,a^2 L_{14} / C_5 = 18.3(21.14^2).008932 / .325 = 224.63$$

$$C_5 = .5\left[1 - \left(\frac{12.5}{21.14}\right)^2\right] = .325$$

$$L_{14} = \frac{1}{16}\left[1 - \left(\frac{12.5}{21.14}\right)^4 - 4\left(\frac{12.5}{21.14}\right)^2 \ln \frac{21.14}{12.5}\right] = .008932$$

$$\sigma = 6M/t^2 = 6(224.6)/.375^2 = 9584.4 \text{ PSI}$$

$$M.S. = 55/4(9.584) - 1. = \boxed{+.43 \text{ ULT}}$$
CONSERVATIVE

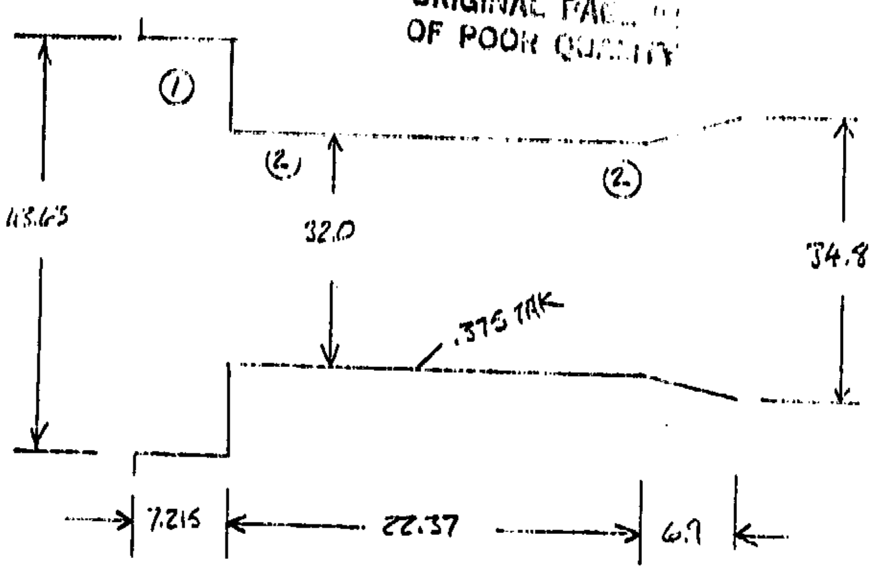
$$M.S. = 18/1.6(9.584) - 1. = \boxed{+.17 \text{ YIELD}}$$
CONSERVATIVE

Prepared by: DMT	Date 4/84	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page 17
Checked by:	Date	Title SMALL EJECTOR / DIFFUSER	Model
Approved by:	Date	2ND EXPANSION SECTION · SECOND STAGE	Report No.

DWG R82723

304L S.S.

ORIGINAL PAGE IS OF POOR QUALITY



LOAD ② 33 PSIA AT 440°F

② 0 PSIA AT RT

BUCKLING OF LARGE DIA CYL — IN VACUUM AT 440°F — CONSERVATIVE REF. — NASA STRUCTURES MANUAL, C3.0, P.13.

$$D = 25.5\times10^6(.375^3)/12(.9215) = 128746.$$

$$Z = 7.2^2\sqrt{.9125}\,/\,21.81(.375) = 6.08$$

$$P_{CR} = 2.6\ \pi^2\,128746./21.81(7.215^2) = 2911.\ \text{PSI}$$

$$Z\gamma = .56(6.08) = 3.4 \qquad K_p = 2.6$$

$$MS = 2911./4.(14.7) - 1. = \quad +48.5 \text{ BUCKLING}$$

HOOP STRESS — USE 33−14.7 = 18.3 PSIG AT 440°F

$$\sigma = PD/2t = 18.3(43.63)/2(.375) = 1064.\ \text{PSI}$$

$$M.S. = 55./4(1{,}064) - 1. = \quad +11.92 \text{ ULT}$$

$$M.S. = 18./1.6(1{,}064) - 1. = \quad +9.57 \text{ YLD}$$

Prepared by: DMT	Date 4/84	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page Temp. 18 Perm.
Checked by:	Date	Title SUBSCALE EJECTOR/DIFFUSER	Model
Approved by:	Date	EXPANSION SECTION - SECOND STAGE	Report No.

DWG R82723

304 L S.S.

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BUCKLING OF LONG CYLINDER - REF. NASA STRUCTURES MANUAL

L = 22.37 IN, R = 16. IN., THICKNESS = .375
LOAD - VACUUM AT RT

$D = 28 \times 10^6 (.375^3) / 12. (.9215) = 133528.$

$Z = 22.37^2 \sqrt{.9125} / 16. (.375) = 79.67$

$P_{cr} = \underline{7.5}\, \pi^2\, 133528 / 16. (22.37^2) = 1234.$

$Z\Gamma = .56 (79.67) = 44.6, \quad K_p = 7.5$

$M.S. = 1234. / 4 (14.7) - 1. = \underline{\underline{+19.98}}$ HYDROSTATIC BUCKLING

HOOP STRESS

$\sigma = PD / 2T = 14.7 (32.) / 2 (.375) = 627. \text{ PSI}$

$M.S. = 70. / 4 (.627) - 1. = \underline{\underline{+26.9}}$ ULT

$M.S. = 28. / 1.6 (.627) - 1. = \underline{\underline{+26.9}}$ YLD

FORM LMSC 382 B-3

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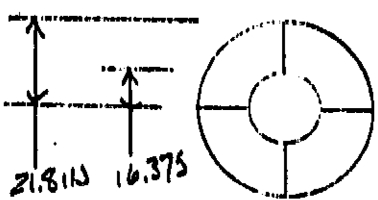
R82723

304L S.S.

CYLINDER RING — ASSUME BRACKETS REACT ACTUATOR LOAD
— VERY CONSERVATIVELY IGNORE BRACKETS IN RING
PRESSURE ANALYSIS BELOW



THK = .66

LOAD = 18.3 PSIG AT 440°F

REF: ROARK 5th ED, PAGE P. 340, CASE 2F. $r_0 = b$

$M_{RB} = q a^2 L_{14}/C_8 = 18.3(21.8^2).00223/.217 = 89.76$

$C_8 = .5\left[1-(16.4/21.8)^2\right] = .217$

$L_{14} = \frac{1}{16}\left[1-\left(\frac{16.375}{21.8}\right)^4 - 4\left(\frac{16.375}{21.8}\right)^2 \ln \frac{21.8}{16.375}\right] = .00223$

$\sigma = 6M/t^2 = 6(89.76)/.66^2 = 1236.$ PSI

$M.S. = 55./4.(1.236) - 1. =$ **+10.12** ULT

$M.S. = 18/1.6(1.236) - 1. =$ **+8.1** YLD

CONSERVATIVE

Prepared by: DMT | Date 11/84

Checked by: | Date

Approved by: | Date

LOCKHEED MISSILES & SPACE COMPANY, INC.

Title SUBSCALE EJECTOR/DIFFUSER
ADJUSTABLE PLUG ASSY.

Page 20 | Temp. | Perm.

Model

Report No.

R82724

304 L S. S.

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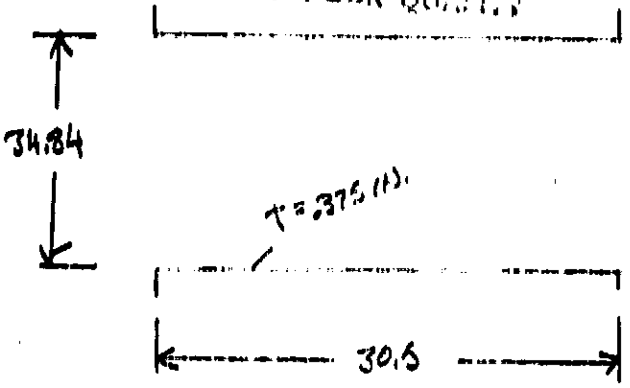


LOAD ① VACUUM AT RT

② 43PSIA BURST
(43 − 14.7 = 28.3 PSIG)
AT RT

[CONSERVATIVELY IGNORE
SLIGHT CONE END.]

BUCKLING - REF NASA STRUCTURES MANUAL, C3.0, P13

$$D = Et^3/12(1-\mu^2) = 28\times10^6(.375)^3/12(.9215) = 133528.8$$

$$Z = L^2(1-\mu^2)^{1/2}/Rt = 30.5^2(.9215)^{1/2}/17.42(.375) = 136.7$$

$$P_{cr} = K_p\pi^2 D/RL^2 = 9.2\pi^2\,133528/17.42(30.5^2) = 748.19 \text{ psi}$$

$$\gamma = .56 \qquad Z\gamma = .56(136.7) = 76.55 \qquad K_p = 9.2$$

$$M.S. = 748.2/4(14.7) - 1. = \quad +11.72$$

BUCKLING HYDROSTATIC

HOOP STRESS — FOR ABOVE LOAD CASE

$$\sigma = PD/2t = 14.7(34.84)/2(.375) = 682.8 \text{ PSI}$$

$$M.S. = 28/1.6(.682) - 1. = \quad +24.62$$ YIELD

HOOP STRESS - FOR BURST PRESSURE OF 28.3 PSIG

$$\sigma = PD/2t = 28.3(34.84)/2(.375) = 1314.6 \text{ PSI}$$

$$M.S. = 70/(1.314) - 1. = \quad +52.2$$ ULT.

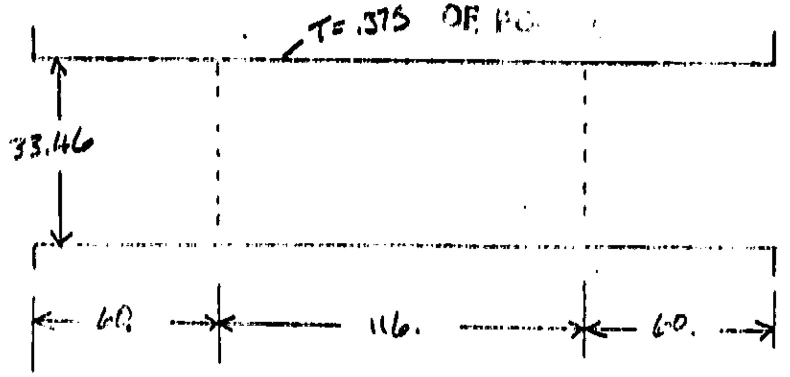
$$M.S. = 25/(1.314) - 1. = \quad +18.9$$ YIELD

FORM LMSC 3828-3

Prepared by: DHT	Date 4/84	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page 21
Checked by:	Date	Title SUBSCALE EJECTOR/DIFFUSER,	Model
Approved by:	Date	SECOND TO THIRD STAGE STRAIGHT SECT.	Report No.

TK827226

304 L S.S.



LOAD — ① VACUUM
AT 778°F

② 28.3 PSIG
AT 778°F

-BUCKLING --- REF NASA STRUCTURES MANUAL, C3.0, P13

$D = 23\times10^6(.375^3)/12(.9215) = 109684.$

$Z = 116.^2\sqrt{.9215}/16.73(.375) = 2058.9$

$P_{cr} = .35.\ \pi^2 109684/16.73(140.3)^2 = 115.$ PSI

$\gamma = .56 \quad \gamma Z = .56(2058.9) = 1152 \qquad \underline{K_P = 35.}$

$M.S. = 115/4(14.7) - 1. = \quad \boxed{+.95}$ HYDROSTATIC BUCKLING

HOOP STRESS — FOR ABOVE LOAD CASE

$\sigma = PD/2t = 14.7(33.46)/2(.375) = 655$ PSI

$M.S. = 13.5/1.6(.655) - 1. = \quad +11.88$ YLD

HOOP STRESS — FOR BURST PRESSURE

$\sigma = PD/2t = 28.3(33.46)/2(.375) = 1262.$ PSI

$M.S. = 51.5/(1.262) - 1. = \quad +40.1$ ULT

$M.S. = 13.5/(1.262) - 1. = \quad +7.33$ YLD

Prepared by: DMT	Date 4/84	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page 22 Temp. Perm.
Checked by:	Date	Title SUBSCALE EJECTOR / DIFFUSER	Model
Approved by:	Date	THIRD STAGE EJECTOR RING	Report No.

TC82728

304L S.S.

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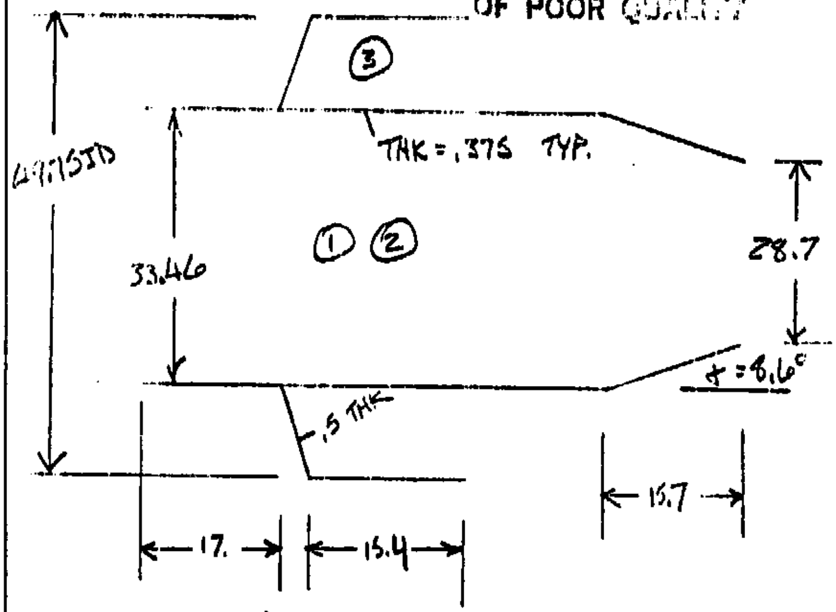

LOAD –

① - 14.7 PSIG @ RT F

② 28.3 PSIG @ RT
BURST [illegible]

③ 18.3 PSIG @ 440°F

INNER CYLINDER – REF. NASA STRUCTURES MANUAL, C3.0, P. 75

BUCKLING (LOAD ①) $D = 28\times10^6(.375^3)/12(.9216) = 133528.$

$Z = 17.^2\sqrt{.9215}/16.73(.375) = 44.21$, $Z^* = .56(44.21) = 24.76$

$P_{cr} = 5.2\,\pi^2\,133528./16.73(17^2) = 1417.$ psi

M.S. = 1417./4 (14.7) − 1. = +23. AXIAL BUCKLING

HOOP STRESS – LOAD ②

$\sigma = PD/2t = 28.3(33.46)/2(.375) = 1262.5$

M.S. = 70./ (1262.5) − 1. = +54.4 ULT

M.S. = 25./ (1262.5) − 1. = +18.8 YLD

LOAD CASE ① $\sigma = 14.7(33.46)/2(.375) = 655.8$ PSI

M.S. = 28./1.6(.655) − 1. = +25.7 YLD

Prepared by: DAIT	**Date** 6/84	**LOCKHEED MISSILES & SPACE COMPANY, INC.**	**Page** 27.1 **Temp.** **Perm.**
Checked by:	**Date**	**Title** SUBSCALE EJECTOR/DIFFUSER THIRD STAGE EJECTOR RING	**Model**
Approved by:	**Date**		**Report No.**

RC 32728

AXIAL LOAD ON 17. IN CYLINDER DUE TO EJECTOR FLOW.

$$P = (33. - 14.7)\frac{\pi}{4}(37.4^2 - 33.46^2) = 4012.7 \text{ LB}$$

AXIAL STRESS

$$\sigma = P/A = 4012.7/.375(\cancel{2})\pi \frac{33.46}{\cancel{2}} = 101.79 \text{ psi}$$

HYDROSTATIC EQUIVALENT PRESSURE:

$$\sigma = \frac{PD}{4t} = \frac{P\ 33.46}{4\ (.375)} \qquad P = 32.4 \text{ PSI}$$

HYDROSTATIC BUCKLING ALLOWABLE (PREVIOUS PAGE) is 1417. PSI

CONSERVATIVELY ADDING THE TWO PRESSURES

$$P_{TOTAL} = 32.4 + 14.7 = 47.1 \text{ PSI}$$

$$M.S. = 1417. \text{ PSI}/4\ (47.1) - 1. = \boxed{+7.52}$$

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R82728

304 L S.S.

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OUTER CYLINDER, LOAD ③

$$\sigma = PD/2t = 18.3(49.75)/2(.375) = 1213.9 \text{ PSI}$$

$$M.S. = 55./4(1.214) - 1. = \quad 10.32$$

$$M.S. = 18./1.6(1.214) - 1. = \quad 8.27$$

OUTER CYLINDER CONE - SEES POSITIVE PRESSURE ONLY
GOOD BY INSPECTION — SEE PAGE 16.

INNER CYLINDER CONE — LOAD ① REF NASA STRUCT. MANUAL

$$\bar{\rho} = (28.66 + 33.46)4 \cos 8.6^\circ = 15.7$$

$$P_{cr} = \frac{.92(23.\times10^6).75}{\left(\frac{15.7}{15.7}\right)\left(\frac{15.7}{.375}\right)^{2.5}} = 1399.3 \text{ PSI}$$

$$M.S. = 1399/4(14.7) - 1. = \quad +22.8$$

HOOP STRESS LOAD CASE ② → SAME AS INNER CYLINDER

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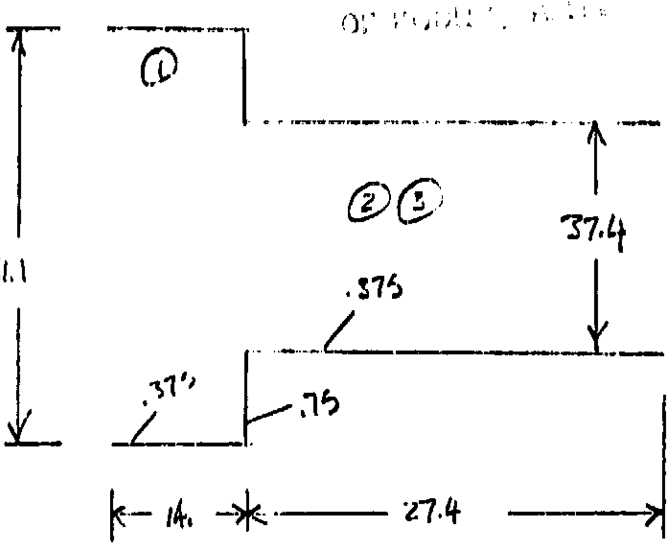
R82727 304L S.S.



LOAD –

CASE ① 18.3 PSIG/440°F

② –14.7 PSIG/RT

③ 139.3 PSIG/RT DETONATION

INNER CYLINDER – BUCKLING – REF. NASA STRUCT MANUAL, C3., P13

LOAD ②

$$D = 28 \times 10^6 (.375^3)/12(.9215) = 133528.$$

$$Z = 27.4^2 \sqrt{.9215}/18.7(.375) = 102.77 \quad \sigma_Z = 57.5, \ K_p = 8$$

$$P_{cr} = 8\pi^2 133528./18.7(27.4^2) = 750.96 \text{ PSI}$$

$$M.S. = 751./4.(14.7) - 1. = \quad +11.77 \text{ BUCKLING}$$

HOOP STRESS LOAD ②

$$\sigma = PD/2t = 14.7(37.4)/2(.375) = 733. \text{ PSI}$$

$$M.S. = 28/1.6(.733) = \quad +22.87 \text{ YLD}$$

LOAD ③ $\sigma = 139.3(37.4)/2(.375) = 6946. \text{ PSI}$

$$M.S. = 70./(6.95) - 1. = \quad +9.07 \text{ ULT}^*$$

$$M.S. = 25/(6.95) - 1. = \quad +2.59 \text{ YLD}^*$$

*FACTOR OF SAFETY = 1.0 FOR DETONATION PRESSURE

Prepared by: DMT	Date 4/24	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page Temp. 25 Perm.
Checked by:	Date	Title SIDEWALL EJECTOR / DIFFUSER	Model
Approved by:	Date	NOZZLE - THIRD STAGE EJECTOR	Report No.

R 82727

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304 L S.S.

OUTER CYLINDER — LOAD ① HOOP STRESS

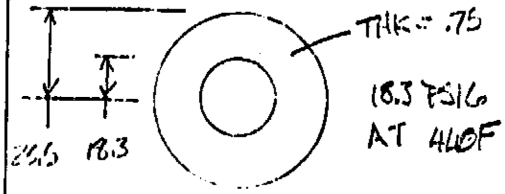
$\sigma = PD/2T = 18.3(51.1)/2(.375) = 1247.$ PSI

$M.S. = 55./4(1.247) - 1. =$ $\boxed{+10.0}$ ULT

$M.S. = 18./1.6(1.247) - 1. =$ $\boxed{+8.02}$ YLD

END RING OUTER CYLINDER — VERY CONSERVATIVELY IGNORE GUSSETS.

LOAD ① - REF. ROARK — 5th ED, PAGE 340. CASE 2f. $r_0 = b$



$M_{RB} = q a^2 L_{14}/C_5 = 18.3(25.5)^2 .0032/.242$

$= 157.57$ IN-LB

$C_5 = .5[1 - (18.3/25.5)^2] = .242$

$L_{14} = \frac{1}{16}\left[1. - \left(\frac{18.3}{25.5}\right)^4 - 4\left(\frac{18.3}{25.5}\right)^2 \ln\left(\frac{25.5}{18.3}\right)\right] = .0032$

$\sigma = 6M/T^2 = 6(157.57)/.75^2 = 1680.7$ PSI

$M.S. = 55./4(1.68) - 1. =$ $\boxed{+7.18}$ ULT

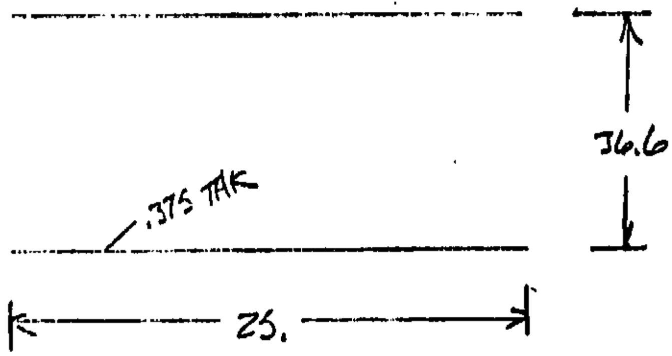
$M.S = 18./1.6(1.68) - 1. =$ $\boxed{+5.7}$ YLD

CONSERVATIVE

FORM LMSC 3629-3

Prepared by: DMT	Date 4/84	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page Temp. 26 Perm.
Checked by:	Date	Title SUBSCALE EJECTOR/DIFFUSER	Model
Approved by:	Date	CONSTANT SECTION - THIRD STAGE	Report No.

R8 2729 304 L S. S.



LOAD —
① -14.7 PSIG/RT
② 139.3 PSIG/RT

BUCKLING — REF NASA STRUCTURES MANUAL, C3.0, P13
LOAD ①

$$D = 28\times10^6(.375^3)/12(.9215) = 133528$$

$$Z = 25.^2\sqrt{.9215}/18.3(.375) = 87.42$$

$$P_{cr} = 8\pi^2\,133528/18.3(25.^2) = 921.8 \text{ PSI}$$

$$\gamma Z = 48.95 \quad K_p = 8$$

$$M.S. = 28/1.6(.922) - 1. = \boxed{+17.98}$$

HOOP STRESS

LOAD ① $\sigma = PD/2t = 14.7(36.6)/2(.375) = 717.3$ PSI

$$M.S. = 28/1.6(.717) - 1. = \boxed{+23.4}$$

LOAD ② $\sigma = PD/2t = 139.3(36.6)/2(.375) = 6{,}797.$ psi

$$M.S. = 70/(6.797) - 1. = \boxed{+9.03}^*$$

$$M.S. = 25/(6.797) - 1. = \boxed{+2.67}^*$$

* FACTOR OF SAFETY = 1.0 FOR DETONATION PRESSURE

Prepared by: TAT	Date 4/84	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page 27
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Approved by:	Date	STRAIGHT SECTION – THIRD STAGE	Report No.

R82731

304 L S.S.

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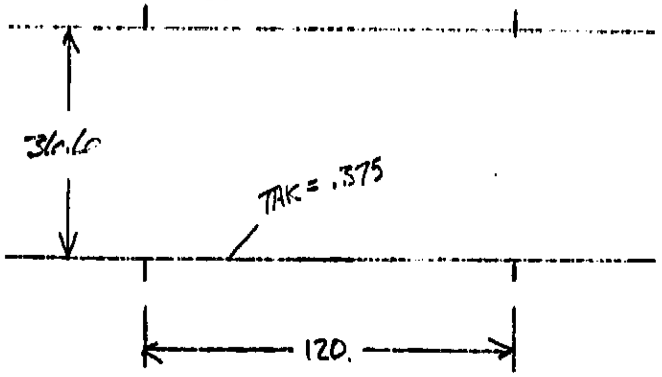


LOAD –

① −14.7 PSIG/KT

② 139.3 PSIG/RET

BUCKLING – REF NASA STRUCTURES MANUAL, C3.0, P13.

LOAD ①

$D = 133528.$ (REF PREVIOUS PAGE)

$Z = 120.^2 \sqrt{.9215} / 18.3(.375) = 2014.$

$P_{cr} = 35 \pi^2 133528. / 18.3 (120.^2) = 175.$ PSI

$\sqrt{Z} = 1127.$ $K_p = 35.$

$M.S. = 175 / 4 (14.7) - 1. =$ $\boxed{+1.97}$ BUCKLING

HOOP STRESS = 717.3 PSI FOR LOAD ① REF PREVIOUS PAGE.

M.S. = +23.4

HOOP STRESS LOAD ②

$\sigma = PD/2T = 139.3\ 36.6 / 2(.375) = 6797$ PSI

$M.S. = 25 / 6.797 - 1. =$ $\boxed{+2.67}$ * YLD

$M.S. = 70 / 6.797 - 1. =$ $\boxed{9.3}$ * ULT

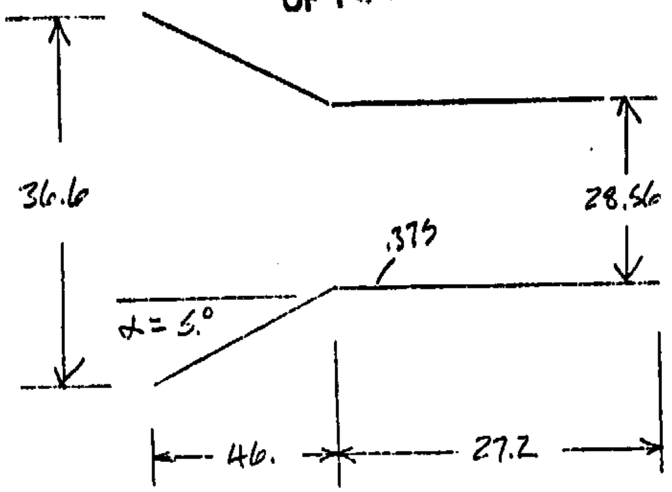
* FACTOR OF SAFETY = 1.0 FOR DETONATION PRESSURE.

FORM LMSC 362B-3

Prepared by: DMT	Date 4/84	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page Temp. Perm.
Checked by:	Date	Title SUBSCALE EJECTOR/DIFFUSER	Model
Approved by:	Date	EXIT TAPER SECTION	Report No.

K82730

304 L S.S.



LOAD –

① −14.7 PSIG / RT

② +137.3 PSIG / RT
DETONATION

③ + 2 PSIG / 802°F

$\bar{\rho} = (28.56 + 36.6)/4 \cos\alpha = 16.35$

<u>CONE BUCKLING</u> – REF NASA STRUCTURES MANUAL, C3.0, P.67

$$P_{cr} = \frac{.92\,E\,t}{\left(\frac{L}{\bar{\rho}}\right)\left(\frac{\bar{\rho}}{t}\right)^{5/2}} = \frac{.92(28\times10^6).75}{\left(\frac{46}{16.35}\right)\left(\frac{16.35}{.375}\right)^{2.5}} = 547.1 \text{ PSI}$$

M.S. = 547.1/4(14.7) − 1. = +8.3 BUCKLING

<u>CYLINDRIC BUCKLING</u> – REF AS ABOVE, P13

$D = 28\times10^6(.375^3)/12(.9215) = 128746.$

$Z = 27.2^2\sqrt{.9215}/14.28(.375) = 132.6$

$P_{cr} = 9\pi^2\,128746./14.28(27.2)^2 = 1082.$ PSI

$\gamma Z = .56(132.6) = 74.3 \qquad K_p = 9$

M.S. = 1082/4(14.7) − 1. = +17.4

Prepared by: DMT	Date 4/84	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page Temp. 21 Perm.
Checked by:	Date	Title SUBSCALE EJECTOR / DIFFUSER	Model
Approved by:	Date	EXIT TAPER SECTION	Report No.

R82730

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304 L S.S.

<u>HOOP COMPRESSION - CONE</u> $\sigma = 14.7(36.6)/2(.375) = 717.$ PSI

$M.S. = 28/1.6(.717) - 1. =$ 23.4 YLD

<u>HOOP COMPRESSION - CYLINDER</u> $\sigma = 14.7(28.56)/2(.375) = 560$ PSI

$M.S. = 28/1.6(.56) - 1. =$ 30.25 YLD

<u>LOAD ② DETONATION HOOP STRESS</u>

CONE $\sigma = 139.3(36.6)/2(.375) =$ 6797. PSI

$MS = 70./6.797 \quad -1. =$ +9.29 ULT *

$M.S. = 25./6.797 \quad -1. =$ +2.67 YLD *

CYLINDER $\sigma = 139.3(28.56)/2(.375) =$ 5304. PSI

$M.S. = 70./5.304 \quad -1. =$ +12.19 ULT *

$M.S. = 25./5.304 \quad -1. =$ +3.71 YLD *

<u>LOAD ③ 2 PSIG AT 802°F</u>

CYLINDER $\sigma = 2(36.6)/2(.375) =$ 97.6 PSI

M.S. = HIGH BY INSPECTION

* DETONATION FACTOR OF SAFETY = 1.0

Prepared by: DWT	Date 11/84	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page 30
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Approved by:	Date	PRELIMINARY SUPPORT FRAME CHECK	Report No.

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DESIGN LOADS — APPROXIMATE

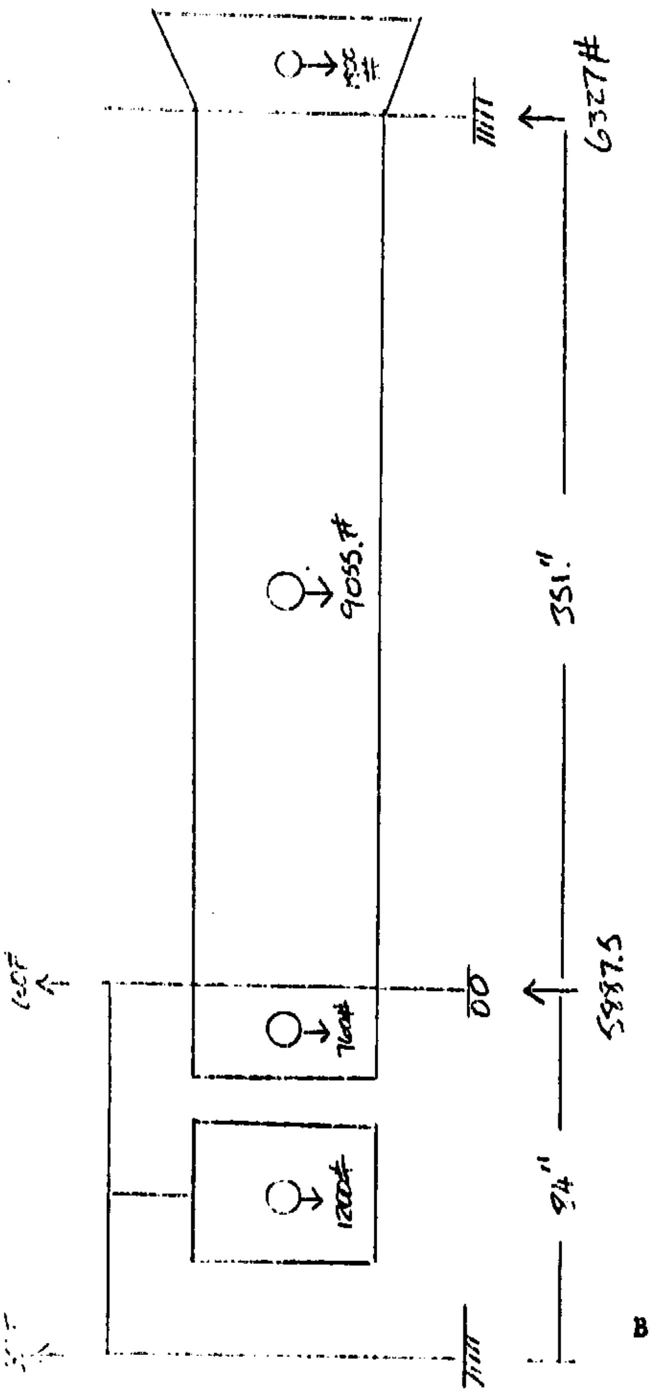
ASSUME MATERIAL IS A-36 STEEL F_{TU} = 57 KSI, F_{TY}/F_{CY} = 36 KSI

A-36 WELD 51 KSI 41 KSI

FACTOR OF SAFETY:

5 ULT

3 YIELD

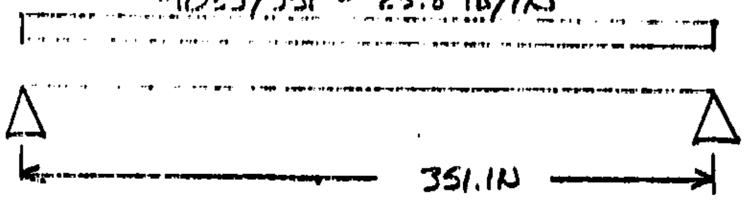


PRELIMINARY ESTIMATE

Prepared by: DMT	Date 1/84	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page 31 Temp. Perm.
Checked by:	Date	Title SUBSCALE EJECTOR DIFFUSER	Model
Approved by:	Date	SUPPORT FRAME	Report No.

DEFLECTION OF 351" SPAN UNDER ITS OWN WEIGHT

9055/351 = 25.8 lb/in



$$\text{MAX } \Delta = 5 w l^4 / 384 EI$$

$$= (5)\,25.8\,(351^4) / 384\,(28 \times 10^6)\,66164.$$

$$= \underline{.0027\text{ IN}}.$$

WHERE NOMINAL SECTION $I = \frac{\pi}{.64}\left(36.6^4 - 35.85^4\right) = 66164.$

AVERAGE

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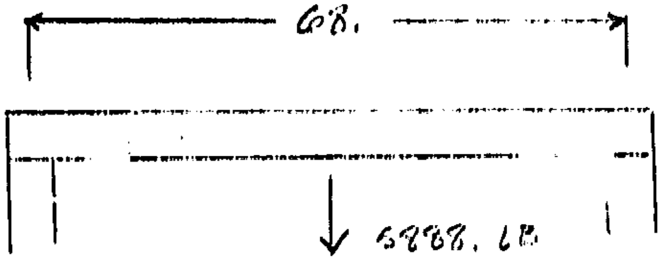
I-BEAM FRAME



ASSUMING ALL* FACILITY WEIGHT REACTED HERE – CONSERVATIVE

BEAM IS 6 W 15.5 $\quad I = 30.1 \quad S = 10.0$

$$M = wl/4 = 5888.(68)/4 = 100096. \text{ IN-LB}$$

$$\sigma = \frac{M}{S} = \frac{100096.}{10.} = 10009.6 \text{ PSI}$$

$$M.S. = 36K/3\,(10.0) - 1. = +.20$$

YLD

$$M.S. = 57/5\,(10.) - 1. = +.14$$

ULT

CONSERVATIVE

* POSSIBLY DURING CONSTRUCTION.

FORM LMSC 3025-3

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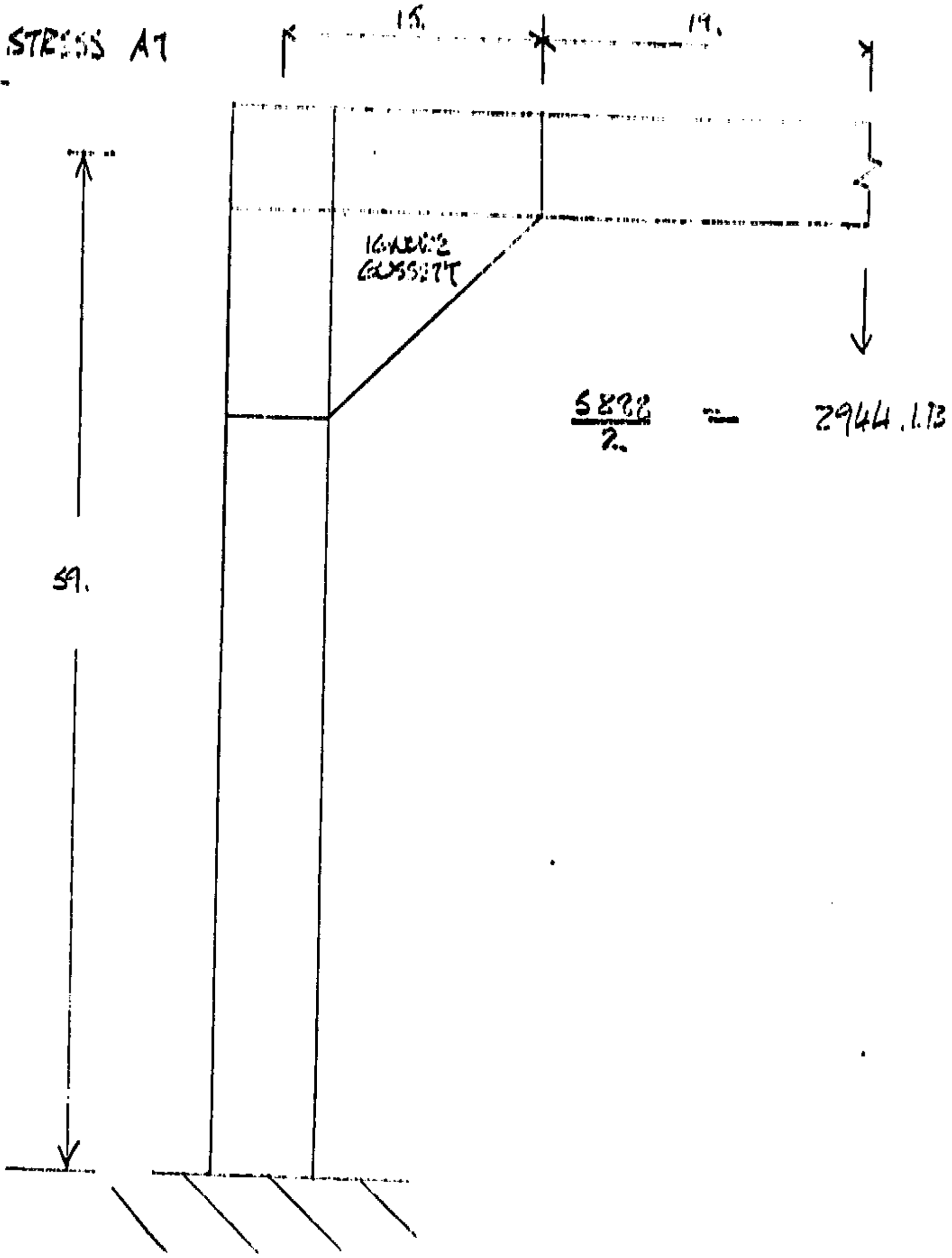
R 82737

I BEAM FRAME — CLOSER LOOK

EVALUATE STRESS AT CORNER —



$\frac{5888}{2} = 2944$ LB

FORM LMSC 3628-3

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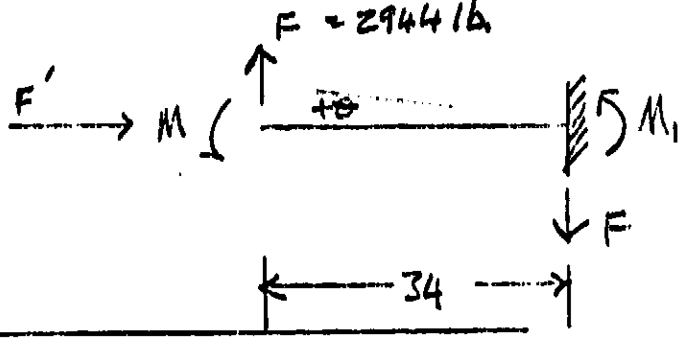
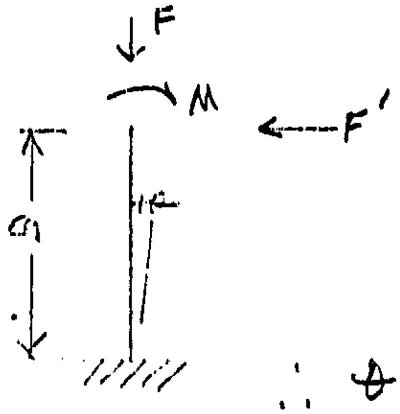
IGNORE GUSSET — CONSERVATIVE



$$\theta = \frac{F l^2}{2EI} - \frac{M l}{EI}$$



$$\theta = \frac{M l'}{EI} - \frac{F' l^{2'}}{2EI}$$

$$\Delta = \frac{F' l^{3'}}{3EI} = \frac{M l^{2'}}{2EI} \qquad F' = \frac{3M}{2l'}$$

$$\therefore \theta = \frac{M l'}{EI} - \frac{3}{4}\frac{M l'}{EI} = \frac{M l'}{4EI}$$

$$\frac{M l'}{4EI} = \frac{F l^2}{2EI} - \frac{M l}{EI} \qquad l' = 59 \quad l = 34$$

$$14.75 M = 2944 \frac{(34)^2}{2} - 34 M \qquad M = 34905 \text{ IN-LB}$$

$$M_1 = 2944(34) - 34905 = 65191. \text{ IN-LB.}$$

$$\sigma = M/S = 65191/10. = 6519. \text{ PSI}$$

$$\text{M.S.} = 36/3(6.52) - 1. = \qquad +.84 \text{ YLD}$$

$$\text{M.S.} = 57/5(6.52) - 1. = \qquad +.74 \text{ ULT}$$

CONSERVATIVE

FORM LMSC 3625-3

Prepared by: DALT	Date 4/84	**LOCKHEED MISSILES & SPACE COMPANY, INC.**	Page 33
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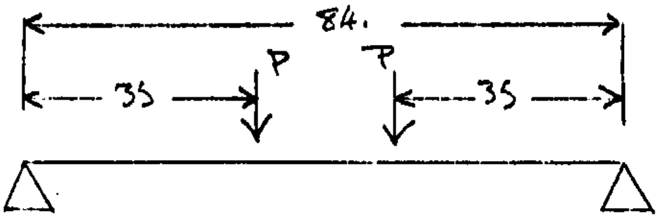
PRELIMINARY R 82737

SLIDING BEARING PIPE → OD = 4.25 IN / ID = 3.15 IN

CASE 1 — PLUG WEIGHT IS SUPPORTED BY 2 SLIDING PIPES
WHAT IS THE DEFLECTION? —

$$I = \pi(4.25^4 - 3.15^4)/64 = 11.18 \text{ IN}^4$$



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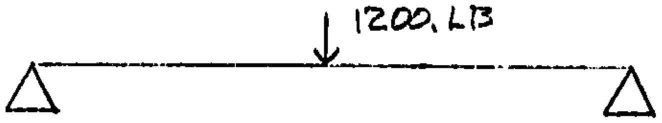
$$2P = \frac{1200}{2}\text{ LB} \qquad P = 300 \text{ LB}$$

$$\Delta_{MAX} = \frac{Pa}{24EI}(3l^2 - 4a^2) = \frac{300(35)(21168. - 4900.)}{24(28)10^6 \; 11.18}$$

$$= .0215 \text{ IN.}$$

CASE 2 — PLUG WEIGHT IS SUPPORTED BY ONE PIPE —



$$M = wl/4 = 1200.(84.)/4 = 25200 \text{ IN}^4$$

$$\sigma = Mc/I = 25200(4.25)/2(11.18) = 4789. \text{ PSI}$$

$$M.S. = 57/5(4.79) - 1. \qquad +1.37$$

$$M.S. = 36/3(4.79) - 1. \qquad +1.50$$

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DIMENSIONS of Seamless and Welded STEEL PIPE

ASA-B36.10 and B36.19

NOMINAL PIPE SIZE	OUTSIDE DIAM.	NOMINAL WALL THICKNESS FOR														
		SCHED. 5S*	SCHED. 10S*	SCHED. 10	SCHED. 20	SCHED. 30	STANDARD†	SCHED. 40	SCHED. 60	EXTRA STRONG	SCHED. 80	SCHED. 100	SCHED. 120	SCHED. 140	SCHED. 160	XX STRONG
⅛	0.405	.....	0.049	.....	.....	.....	0.068	0.068	.....	0.095	0.095	.....	.....	.....	.....	.....
¼	0.540	.....	0.065	.....	.....	.....	0.088	0.088	.....	0.119	0.119	.....	.....	.....	.....	.....
⅜	0.675	.....	0.065	.....	.....	.....	0.091	0.091	.....	0.126	0.126	.....	.....	.....	.....	.....
½	0.840	0.065	0.083	.....	.....	.....	0.109	0.109	.....	0.147	0.147	.....	.....	.....	0.188	0.294
¾	1.050	0.065	0.083	.....	.....	.....	0.113	0.113	.....	0.154	0.154	.....	.....	.....	0.219	0.308
1	1.315	0.065	0.109	.....	.....	.....	0.133	0.133	.....	0.179	0.179	.....	.....	.....	0.250	0.358
1¼	1.660	0.065	0.109	.....	.....	.....	0.140	0.140	.....	0.191	0.191	.....	.....	.....	0.250	0.382
1½	1.900	0.065	0.109	.....	.....	.....	0.145	0.145	.....	0.200	0.200	.....	.....	.....	0.281	0.400
2	2.375	0.065	0.109	.....	.....	.....	0.154	0.154	.....	0.218	0.218	.....	.....	.....	0.344	0.436
2½	2.875	0.083	0.120	.....	.....	.....	0.203	0.203	.....	0.276	0.276	.....	.....	.....	0.375	0.552
3	3.5	0.083	0.120	.....	.....	.....	0.216	0.216	.....	0.300	0.300	.....	.....	.....	0.438	0.600
3½	4.0	0.083	0.120	.....	.....	.....	0.226	0.226	.....	0.318	0.318	.....	.....	.....	.....	.....
4	4.5	0.083	0.120	.....	.....	.....	0.237	0.237	.....	0.337	0.337	.....	0.438	.....	0.531	0.674
5	5.563	0.109	0.134	.....	.....	.....	0.258	0.258	.....	0.375	0.375	.....	0.500	.....	0.625	0.750
6	6.625	0.109	0.134	.....	.....	.....	0.280	0.280	.....	0.432	0.432	.....	0.562	.....	0.719	0.864
8	8.625	0.109	0.148	.....	0.250	0.277	0.322	0.322	0.406	0.500	0.500	0.594	0.719	0.812	0.906	0.875
10	10.75	0.134	0.165	.....	0.250	0.307	0.365	0.365	0.500	0.500	0.594	0.719	0.844	1.000	1.125	1.000
12	12.75	0.156	0.180	.....	0.250	0.330	0.375	0.406	0.562	0.500	0.688	0.844	1.000	1.125	1.312	1.000

Prepared by: HWT	Date 6/21	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page Temp. Perm.
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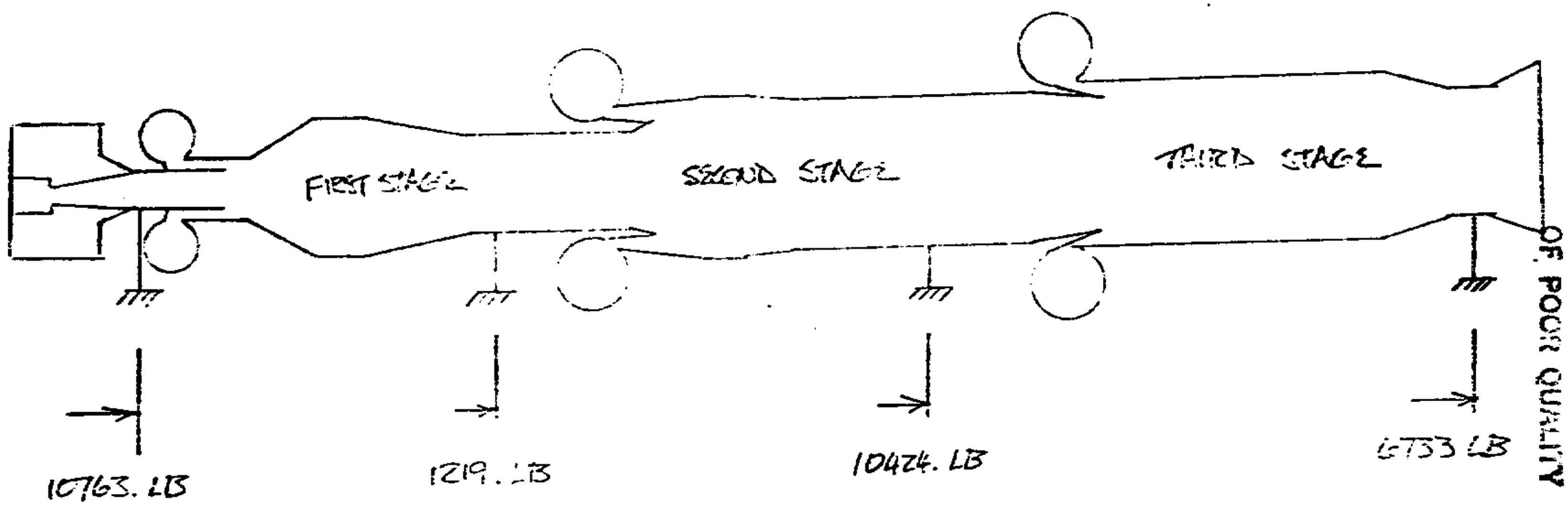
AXIAL REACTIONS

EXERTED ON THE PIPING BY THE SUPPORT STRUCTURE



$$\frac{10763}{(3)\cos 45} = 5073 \text{ LB}$$

DIAG. TURNBUCKLE LOAD

$$\frac{10424.}{(4)\cos 45} = 3685 \text{ LB}$$

DIAG. TURNBUCKLE LOAD

FORM LMSC 382 B-3

Prepared by: TWT	Date 6/84	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page Temp. Perm.
Checked by:	Date	Title SUBSCALE EJECTOR/DIFFUSER	Model
Approved by:	Date	SUPPORT FRAME	Report No.

DIAGONAL TURNBUCKLES REACTING AXIAL THRUST LOADS —

$$\text{MAX MAGNITUDE} = \frac{10763}{(3)\cos 45^\circ} = 5073.\ \text{LB.}$$

CLEVIS MS27120 1.0 IN. DIA
ULT ALLOWABLE = 33100 LB

TURNBUCKLE MS27954 1.0 IN. DIA
ULT ALLOWABLE = 38000 LB.

$$\text{M.S.} = 33.1/5(5.073) - 1. = \boxed{+.31}$$

Prepared by: TAIT	Date 6/84	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page Temp. Perm.
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Approved by:	Date	SUPPORT FRAME	Report No.

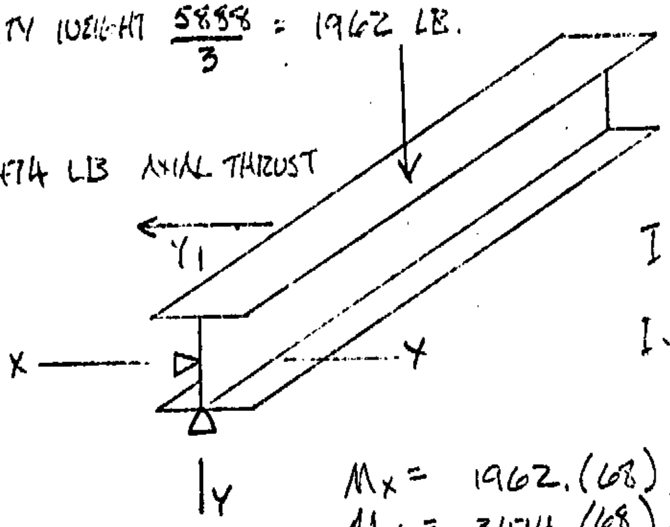
MAX AXIAL REACTION IS 10424 LB BEFORE THIRD STAGE EJECTOR.

ACTING ON TOP OF FRAME:

TOTAL L = 68. IN.

FACILITY WEIGHT $\frac{5888}{3}$ = 1962 LB.

$\frac{10424}{3}$ = 3474 LB AXIAL THRUST



BEAM IS 6W15.5

$I_x = 30.1 \quad S_x = 10.0$

$I_y = 9.67 \quad S_y = 3.23$

$M_x = 1962.(68)/4 = 33354.$ IN-LB

$M_y = 3474.(68)/4 = 59058.$ IN-LB

$$\sigma = \Sigma \frac{Mc}{I} = \Sigma \frac{M}{S} = \frac{33354.}{10} + \frac{59058.}{3.23} = 21619.6 \text{ PSI}$$

$MS = 57/5(21.62) - 1. = -.47$

$MS = 36/3(21.62) - 1. = -.44$

WILL BE REDESIGNED — SEE NEXT PAGE

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Approved by:	Date		Report No.

MAX AXIAL REACTION & MAX FACILITY WEIGHT ACTING ON TOP OF FRAME

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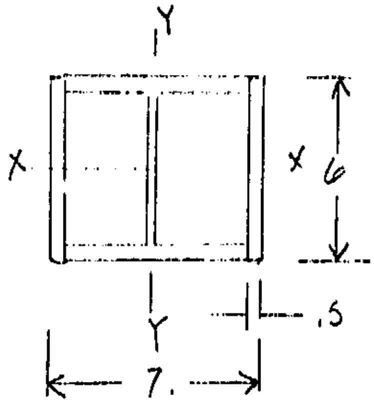
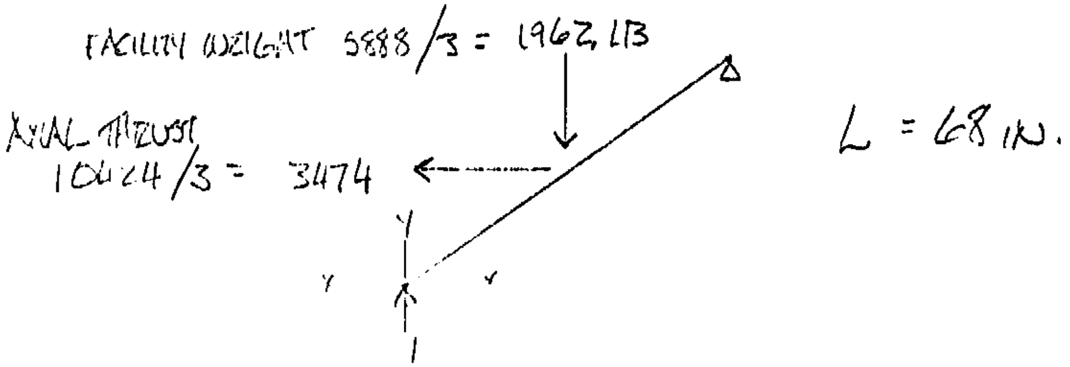


6W15.5 PLUS 1/2 IN. PLATE BOTH SIDES

$$I_x = 30.1 + \frac{1.(6)^3}{12} = 48.1 \text{ IN}^4$$

$$I_Y = 9.67 + \frac{6(7^3 - 5.99^3)}{12} = 73.17 \text{ IN}^4$$

AREA = 4.56 + 6. = 10.56



$$M_x = 1962.(68)/4 = 33354$$

$$M_y = 3474\,(68.)/4 = 59058$$

$$T = \Sigma \frac{Mc}{I} = \frac{33354(3)}{48.1} + \frac{59058(3.5)}{73.17} = 4905 \text{ PSI}$$

AGAINST [illegible] ALLOWABLES:

$$M.S. = 51./5(4.9) - 1. = \boxed{+1.08}$$

$$M.S. = 41./3(4.9) - 1. = \boxed{+1.78}$$

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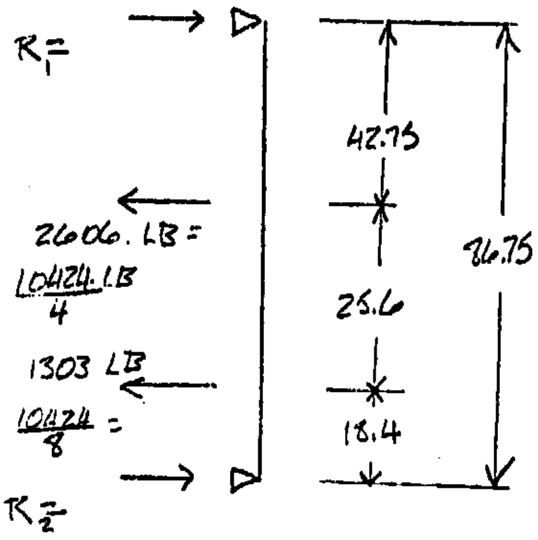
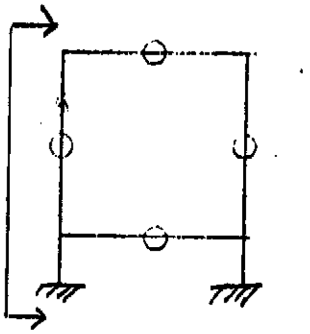
— THIRD STAGE FRAME WHERE AXIAL REACTION IS TAKEN AT FOUR PLACES

— TOP OF FRAME IS GOOD PER PREVIOUS CALCULATIONS.

— SIDE SPANS:

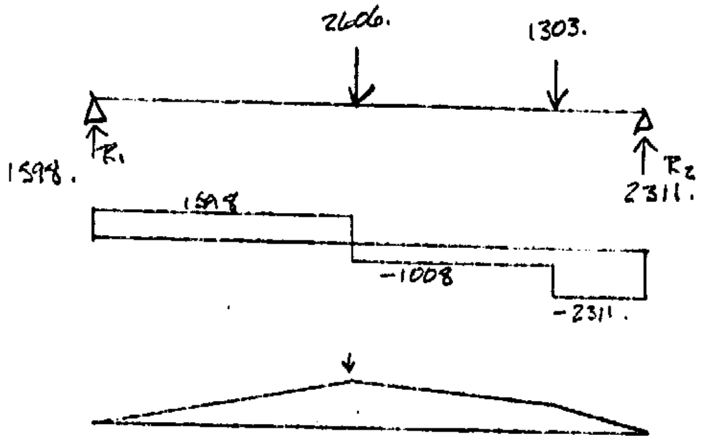


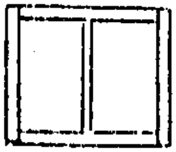


$R_1 + R_2 = 2606 + 1303 = 3909.$ LB

$\Sigma M_{R_1} = 2606(42.75) + 1303(68.35) = R_2\,86.75$

$R_2 = 2310.8$ LB $R_1 = 1598.1$ LB.





MAX MOMENT = 1598(42.75) = 68314. LB

$\sigma = 68314(3.5)/73.17 = 3267.$ PSI   TESTED SECTION

ON WELD   M.S. = 51./5(3.27) −1. = +2.11

M.S. = 41/3(3.27) −1. = +3.17

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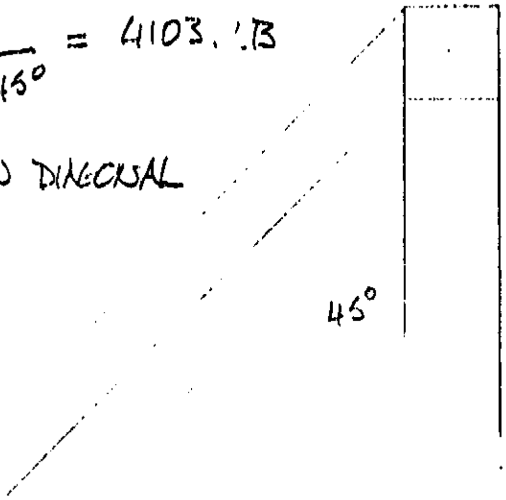
DIAGONAL BRACE AT FRAME

TOTAL AXIAL LOAD = 1598 (PREVIOUS PAGE) + 1303. (TOP REACTION)
= 2901. LB

$\frac{2901}{\sin 45^\circ} = 4103.$ LB

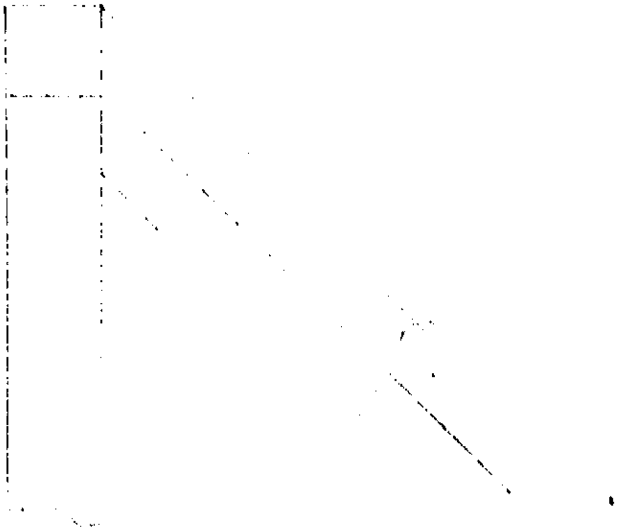
IN DIAGONAL



COMPRESSIVE STRESS:

$\sigma = \frac{P}{A} = \frac{4103}{4.56} = 899.$ PSI

BEAM SHOULD BE IN TENSION ↓
BY REVERSING SLOPE



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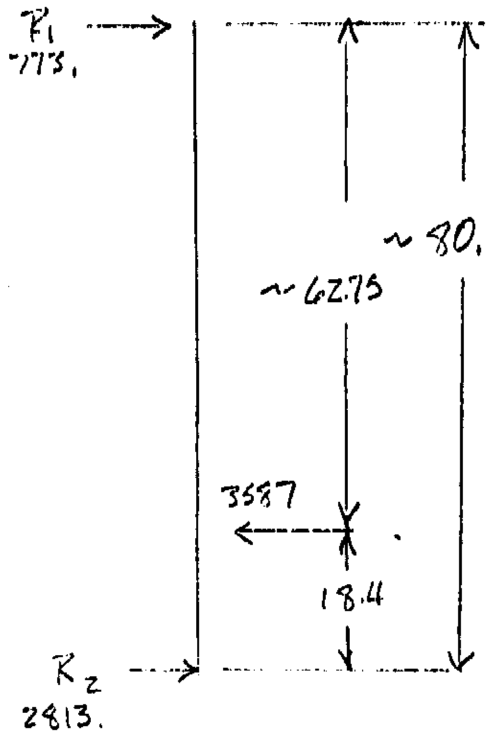
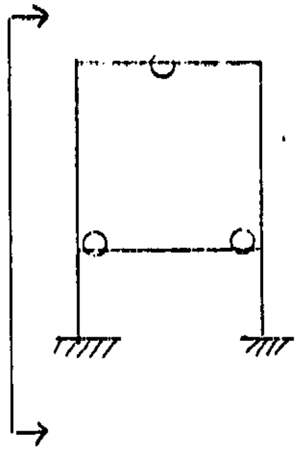
Approved by:	Date		Report No.

— FIRST STAGE EJECTOR WHERE REACTION LOADS ARE TAKEN BY FRAME AT 3 PLACES.





LOAD = 10763./3 = 3587. LB

$R_1 + R_2 = 3587$

$\Sigma M = 62.75(3587) = 80\ R_2$

R_2 = 2813. LB R_1 = 773. LB

MOMENT = 2813(18.4)
= 51759. IN-LB

AT WELD $\sigma = \frac{Mc}{I} = 51759(3.5)/73.17^{*} = 2475.$

$M.S. = 51/5\,(2.48) - 1. = \boxed{+3.11}$

$M.S. = 41/3\,(2.48) - 1. = \boxed{+4.51}$

* STRENGTHENED 61015.5

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Approved by:	**Date**		**Report No.**

FASTENERS TO RAIL

PATTERN OF 8 1/2" 301 ST ST $F_{SU} = 50$ KSI

$P_{ALL_{SU}} = 50 \text{ KSI } \pi .5^2/4 = 9.817$ KSI

MAX FASTENER PATTERN SHEAR LOAD IS 2901. LB FROM DIAGONAL BRACE TO FRAME WITH FOUR AXIAL THRUST LOAD PICKUPS —

$2901/8 = 362.$ LB/FAS SHEAR

$MS = 9.8/5(.36) - 1. = \boxed{+4.44}$

Appendix C

LIST OF DRAWINGS AND BILL OF MATERIALS

SUBSCALE EJECTOR/DIFFUSER DRAWING LIST

Drawing	Number
Site Plan	R82733
Plan & Evaluation	R82732
Subscale Ejector/Diffuser Assembly	R82734
Ejector Inlet Piping Planform	R82736
Inlet Plate - Nozzle Simulator	R82701
H_2 Diffuser - Nozzle Simulator	R82700
H_2 Cylinder - Nozzle Simulator	R82702
Nozzle Body- Detail	R82706
Altitude Simulation Cell - Nozzle Simulator	R82704
Altitude Cell End Plate - Nozzle Simulator	R82708
Nozzle Discharge Tube - Nozzle Simulator	R82709
Expansion Section - Nozzle Simulator	R82710
Ejector Ring 1st Stage	R82714
Nozzle Piece 1st Stage Ejector	R82716
Adjustable Plug Assy 1st Stage	R82715
Compression Section 1st Stage	R82717
1st Stage to 2nd Stage Mixing Tube	R82718
Ejector Ring 2nd Stage Ejector	R82723A
Nozzle Piece 2nd Stage Ejector	R82723B
Adjustable Plug Assy 2nd Stage	R82724
2nd Stage Mixing Tube	R82726
Ejector Ring 3rd Stage Ejector	R82728
Nozzle Piece 3rd Stage Ejector	R82727
Adjustable Plug Assy 3rd Stage Ejector	R82729
Mixing Section 3rd Stage Ejector	R82731
Exit Taper Section 3rd Stage Ejector	R82730
Support Carriage	R82735
Typical Support Buckle	R82738
Structural Support 2nd Stage	R82737

BILL OF MATERIALS
(See Assembly R82734)

Qty Rq'd.	Part or Identifying No.	Nomenclature or Description	Material Specification	Zone	Item No.
1	R82701-1	Inlet Plate	304L	4	1
1	R82700-1	H_2 Diffuser	304L	4	2
1	R82702-1	H_2 Cylinder	304L	4	3
1	R82706-1	Nozzle Body	304L	4	4
1	R82704-1	Alt Simulator Cell	304L	4	5
1	R82708-1	Alt Cell End Plate	304L	4	6
1	R82709-1	Nozzle DischargeTube	304L	4	7
1	R82710-1	Expansion Section	304L	4	8
1	R82714-1	Ejector Ring 1st St.	304L	3	9
1	R82716-1	Nozzle Piece 1st St.	304L	3	10
1	R82715-1	Adj. Plug 1st St.	304L	3	11
1	R82717-1	Compression Sec. 1st St.	304L	3	12
1	R82718-1	1st to 2nd St. Mixing Tube	304L	3	13
1	R82723A-1	Ejector Ring 2nd St.	304L	2	14
1	R82723B-1	Nozzle Piece 2nd St.	304L	2	15
1	R82724-1	Adj. Plug 2nd St.	304L	2	16
1	R82726-1	2nd St. Mixing Tube	304L	2	17
1	R82728-1	Ejector Ring 3rd St.	304L	1	18
1	R82727-1	Nozzle Piece 3rd St.	304L	1	19
1	R82729-1	Adj. Plug 3rd St.	304L	1	20
1	R82731-1	3rd St. Mixing Sec.	304L	1	21
1	R82730-1	Exit Taper Section	304L	1	22
8	Parker Fluid Power Atlanta, Ga.	Parkertron LDT 2" Bore 3" Stroke		2 + 3	23
4	Parker Fluid Power Atlanta, Ga.	Parkertron LDT 2" Bore 6" Stroke		1	24
40	SWRM-14	Rod End Southwest Products Co. Monrovia, Calif.	Super St. Alloy Chrome Plate	1,2,3	25
69	MS27120-11	Clevis, Rod End Turnbuckle	St. Type (Forged)	1,2,3	26
69	MS27954-6	Turnbuckle	St. Type (Forged)	1,2,3	27
10	MS27120-39	Clevis, Rod End	St. Type (Forged)	1,2,3	28
10	MS27954-21	Turnbuckle	St. Type (Forged)	1,2,3	29

NOTE: Pertaining to fasteners:
Bolts will be MS16208; washers will be MS15795; nuts will be MS16203; screw, cap, socket head - hexagon MS16996.