NASA INTERIM REPORT

ORBIT TRANSFER ROCKET ENGINE TECHNOLOGY PROGRAM

ENHANCED HEAT TRANSFER COMBUSTOR TECHNOLOGY - SUBTASKS I & II
TASK C.1

Prepared By:

R. D. Baily
ROCKWELL INTERNATIONAL CORPORATION
Rocketdyne Division

Prepared For:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA-Lewis Research Center

Contract NAS3-23773

H. G. Price, Task Manager

(NASA-CR-179541) ENHANCED HEAT TRANSFER COMBUSTOR TECHNOLOGY, SUBTASKS 1 AND 2, TAST C.1 Interim Report (Rockwell International Corp.) 305 p CSCL 21H

N87-13486

Unclas
G3/20 43493

ROCKETDYNE DIVISION OF ROCKWELL INTERNATIONAL CORPORATION
6633 Canoga Avenue; Canoga Park, CA 91303

1. Report No. CR179541	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle ENHANCED HEAT TRANSFER COMBUSTOR TECHNOLOGY INTERIM REPORT - SUBTASKS I & II, TASK C.1		5. Report Date 16 December, 1986
		6. Performing Organization Code 02602
7. Author(s) R. D. BAILY		8. Performing Organization Report No. RI/RD86-199
		10. Work Unit No. 506-42-21 YOS 2589
9. Performing Organization Name and Address ROCKETDYNE DIVISION ROCKWELL INTERNATIONAL 6633 CANOGA AVENUE CANOGA PARK, CA 91304		11. Contract or Grant No. NAS3-23773
		13. Type of Report and Period Covered INTERIM
12. Sponsoring Agency Name and Address NATIONAL AERONAUTICS AND SPACE ADMINISTRATION WASHINGTON, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

TASK MANAGER: HAROLD G. PRICE
NASA-LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

16. Abstract

Analytical and experimental studies are being conducted for NASA to evaluate means of increasing the heat extraction capability and service life of a liquid rocket combustor. This effort is being conducted in conjunction with other tasks to develop technologies for an advanced, expander-cycle, oxygen/hydrogen engine planned for upper-stage propulsion applications. Increased heat extraction, needed to raise available turbine drive energy for higher chamber pressure, is derived from combustion chamber hot-gas wall ribs that increase the heat-transfer surface area. Life improvement is obtained through channel designs that enhance cooling and maintain the wall temperature at an acceptable level.

Laboratory test programs were conducted to evaluate the heat transfer characteristics of hot-gas rib and coolant channel geometries selected through an analytical screening process. Detailed velocity profile maps, previously unavailable for rib and channel geometries, were obtained for the candidate designs using a cold flow laser velocimeter facility. Boundary layer behavior and heat transfer characteristics were determined from the velocity maps. Rib results were substantiated by hot-air calorimeter testing. The flow data were analytically scaled to hot-fire conditions and the results used to select two rib and three enhanced coolant channel configurations for further evaluation.

The next program phase will include hot-fire calorimeter testing of the selected designs. The program will culminate in design, fabrication, and test of a full scale enhanced combustor.

This report describes the analytical screening of rib and channel candidates, and the experiments and analytical scaling conducted to evaluate the concepts and select the best designs for further testing.

17. Key Words (Suggested by Author(s)) LIQUID ROCKET COMBUSTOR HEAT TRANSFER ENHANCEMENT HOT GAS WALL RIBS COOLING CHANNEL FINS LASER VELOCIMETRY	18. Distribution Statement GENERAL RELEASE

19. Security Classif. (of this report) UNCLASSIFIED	20. Security Classif. (of this page) UNCLASSIFIED	21. No. of Pages	22. Price*

* For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA-C-168 (Rev. 10-75)

FORWARD

This report documents the results of the first two subtasks of a program conducted for the NASA Lewis Research Center by Rocketdyne, a division of Rockwell International. Mr. H. G. Price was the NASA-LeRC Task Manager. At Rocketdyne, Mr. A. T. Zachary was the Program Manager and Mr. R. D. Baily the Project Engineer.

The work was conducted by personnel in the Engineering and Test function of Rocketdyne. Important contributions to the program were made by:

Mr. G. Defever	Concept Screening and Design
Mr. C. Laren	Thermal Analysis
Mr. R. Morinishi	Aerothermodynamic Analysis
Mr. T. Ferguson	Laser Velocimetry
Mr. K. Hunt	Test Development

TABLE OF CONTENTS

FIGURES

FIGURES (CONTINUED)

TABLES

1.0 INTRODUCTION

The thrust chamber combustor of a high-performance, expander-cycle engine, such as the engine proposed for the advanced OTV propulsion system, serves a dual function. First, it performs the normal function of a combustion chamber of containing the high pressure combustion process and accelerating the combusted gases to sonic velocity for expansion in the exhaust nozzle, thereby producing thrust. The second, unique, function is to provide a majority of the energy required to power the propellant turbopumps used to produce the high chamber pressure. These functions must be accomplished while achieving the overall engine goals for service life, maintainability, packaging, and weight.

In general, a higher chamber pressure leads to higher engine performance due to improved expansion properties of the combustion gases. In an oxygen-hydrogen expander cycle engine, the turbopump turbines are powered by hydrogen (fuel) heated by regenerative cooling of the thrust chamber components. Approximately 75% of the heat input to the hydrogen is derived from the combustor assembly. The remainder is supplied by the regenerative section of the nozzle assembly or by a supplemental heat exchanger such as a turbine gas regenerator.

Significant benefits, in terms of overall system optimization, are derived from obtaining increases in heat load through enhancement of the combustor heat extraction capability. That is, improving the performance of the combustor in its role as a heat exchange device reduces the reliance of the engine on auxiliary components for obtaining the desired system heat load. Since the combustor must already be present to serve as a combustion chamber, the overall complexity of the system is minimized by eliminating or reducing the requirements and size of the other heat exchange components. Further benefits such as reduced engine weight and envelope result from this.

However, a higher combustor heat load must not prevent achievement of other system goals such as overall system performance and service life. For instance, all other things remaining the same, increasing the heat load from the combustor will cause an increase in the hot gas wall material temperature that will reduce the combustor service life. This is an undesirable trend due to the need for a long and maintenance free life in a space based mode of operation. As a result, technology advances that increase the heat extraction efficiency of the combustor must also exhibit the ability to maintain or improve its service life capabilities and maintainability requirements. Enhancements in the coolant channel configuration is one technology area projected to provide such benefits by significantly reducing the hot gas wall material temperature.

Combustor performance has a central role in determining the overall performance of the advanced expander cycle engine. Therefore, developing the technologies for enhancing combustor heat extraction and service life performance is crucial to meeting the goals of the propulsion system technology program.

OBJECTIVE AND APPROACH

The primary objective of this task is to perform a program of analysis, design, fabrication, and testing of an advanced combustion chamber design to increase enthalpy extraction from the combustor of an advanced OTV propulsion system. This program will demonstrate a hot-fire proven combustor assembly that features advanced heat transfer and life characteristics that meet the needs of the advanced OTV expander cycle engine. Specific goals are to optimize engine performance through increased heat extraction efficiency of the combustor while meeting the system requirements for life, maintainability, envelope, weight, and cost. In support of this, an early program objective was to establish a design database, through investigation, test and assessment of the proposed technologies, that will anchor the subsequent analysis.

A series of design, analysis, and laboratory test tasks were performed to evaluate means of enhancing the combustor heat load and service life. These tasks address the main issues that must be resolved in evaluating enhanced combustor concepts. These unresolved issues are:

1. Fluid boundary layer behavior and resulting heat transfer capability;

2. Service life capability of alternate hot-gas wall/coolant channel configurations;

3. Fabricability of these alternate geometries;

4. Test verification of the analysis techniques to be used for future design efforts.

The program will culminate in test of an optimized combustor assembly whose design is based on the results of preliminary technology tasks. Four technical subtasks have been identified to accomplish the program objectives. These tasks and a brief description of each are presented in Table 1-1. Efforts for this task will be supported by hot-fire evaluation of a smooth wall tapered combustor.

TABLE 1-1

ENHANCED HEAT TRANSFER COMBUSTOR TECHNOLOGY

SUBTASKS

I. HEAT LOAD MAXIMIZATION STUDIES (HOT-GAS WALL RIBS)

- HOT-AIR PANEL CHAMBER TESTS
- COLD FLOW BOUNDARY LAYER MAPPING TESTS

II. INCREASED LIFE STUDIES (COOLANT CHANNEL ENHANCEMENTS)

- COLD FLOW BOUNDARY LAYER MAPPING TESTS

III. CALORIMETER INSERT HOT-FIRE TESTS

- HIGH Q TEST OF BEST CONFIGURATIONS

IV. FULL SCALE RIBIFLEX COMBUSTOR

- INCORPORATE FINAL RIB AND CHANNEL CONFIGURATIONS

The smooth wall tapered combustor and the calorimeter insert hot-fire tests will be conducted using the Integrated Component Evaluation (ICE) test system. The ICE is a 15,000-pound thrust engine-type system that operates in an expander cycle mode and incorporates all of the major OTV engine components. This provides an accurate environment for testing advanced combustor technologies.

An approximately 50-month period will be required to complete the task. The overall task schedule is presented in Figure 1-1.

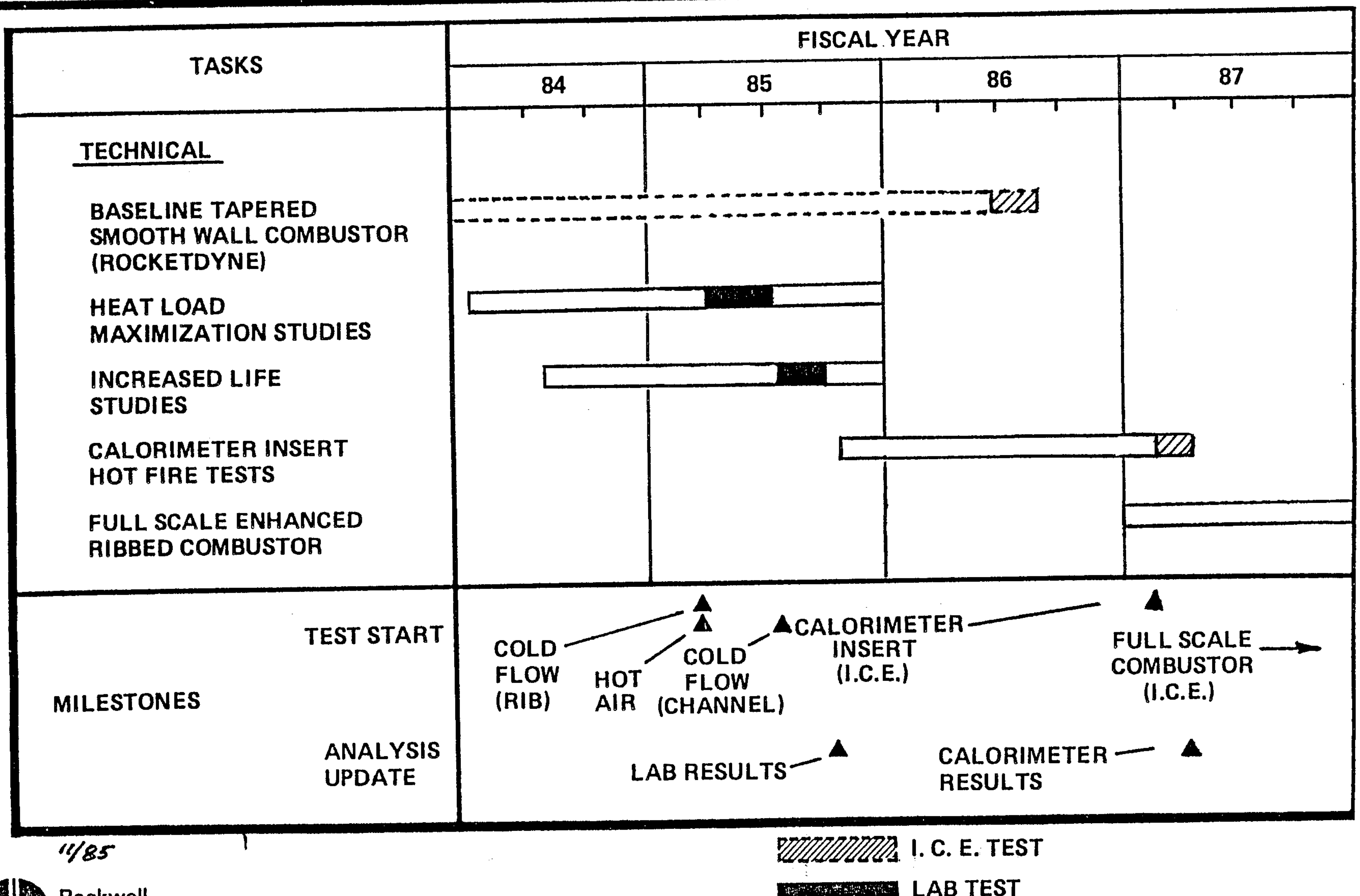
The objective of the two initial subtasks was to evaluate potential hot-gas wall rib (Heat Load Maximization) and coolant-channel (Increased Life) geometries and select configurations to be tested under hot-fire conditions. In particular, the heat transfer characteristics of the designs were determined and the results used to anchor analysis tools.

Laboratory test programs were formulated to evaluate flow field and heat transfer properties of the rib and channel designs. The tests were designed to determine whether boundary layer behavior close to the complex geometries prevents full realization of the potential heat transfer enhancement. Prior to the tests, analyses and a comparative selection process were completed to select the test configurations. A flow diagram for this initial phase is presented in Figure 1-2.

0515k

FIGURE 1-1

TASK C.1-ENHANCED HEAT TRANSFER COMBUSTOR
TECHNOLOGY



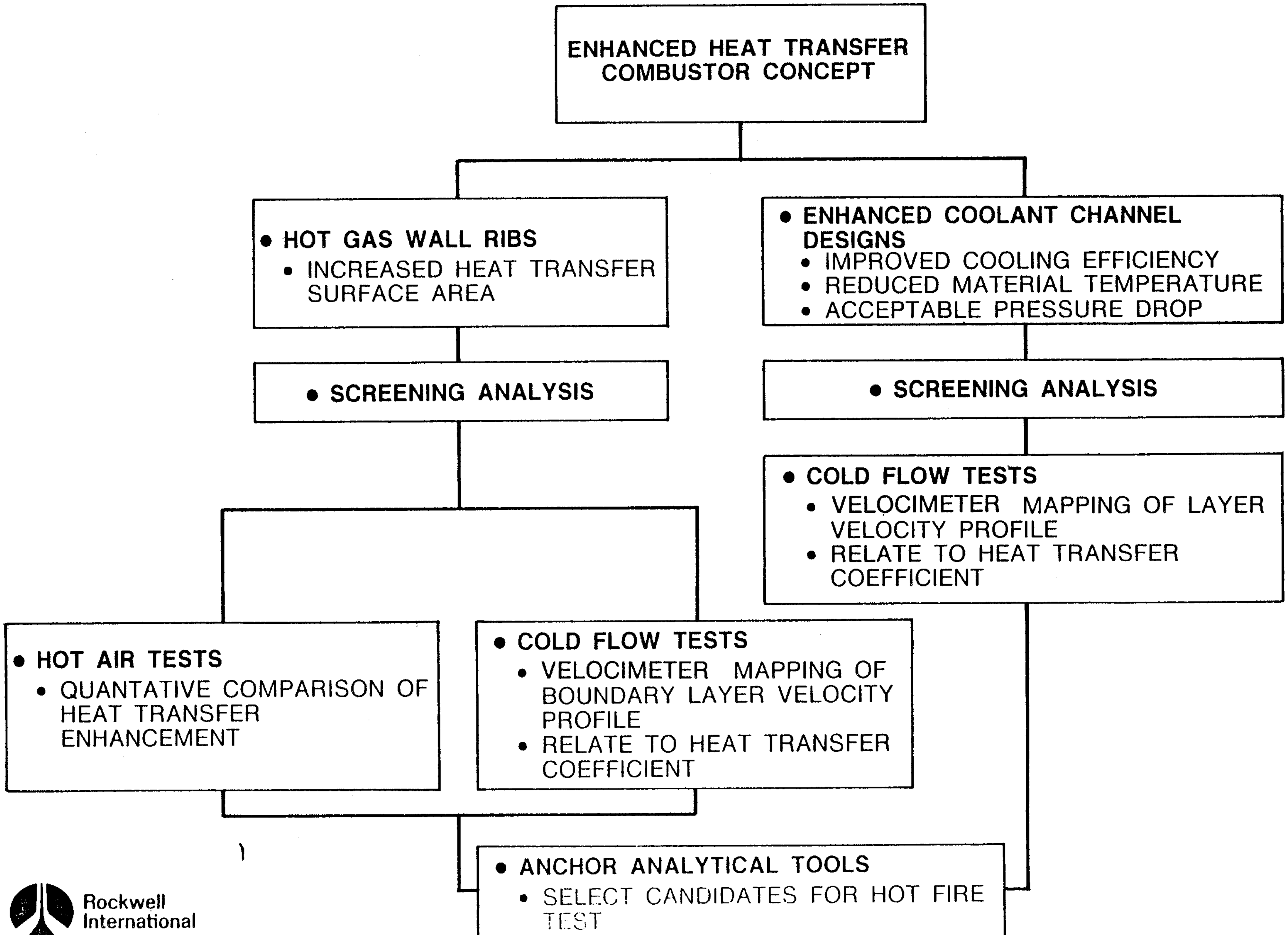
486-475

11/85

Rockwell International
Rocketdyne Division

FIGURE 1-2

SCREENING PHASE TASK FLOW



REPORT ORGANIZATION

Two main sections follow this introduction, one each for the heat load maximization and increased life subtasks. These sections present summaries of the analyses and experimental efforts. Detail data from these tasks are contained in appendicies. A concluding section summarizes the efforts, discusses implications of the results, and introduces further planned efforts.

2.0 SUBTASK I - HEAT LOAD MAXIMIZATION STUDY

OBJECTIVE

The overall objective of this subtask was to assess the use of hot-gas wall ribs to increase the heat extraction capability of an expander cycle engine combustor. Supporting objectives were: screen appropriate rib configuration candidates; evaluate flow characteristics around the candidate ribs; compare the designs at hot-fire conditions; and select the best designs for hot-fire test evaluation.

APPROACH

The approach followed in this subtask is summarized in the left hand side of Figure 1-2. A matrix of candidate rib configurations was formulated based on preliminary studies conducted at Rocketdyne. The matrix featured ribs with varying heights, widths, pitches (spacing), and base geometries (sharp or curved). These candidates were screened by evaluation for heat transfer enhancement, wall temperature, risk of boundary layer build-up, and producibility. Heat transfer analysis was conducted with two dimensional computer models using a uniform heat transfer coefficient for all surfaces. Results of these analyses and the other evaluations were used to select laboratory test configurations.

Two laboratory test programs were identified for hot-gas wall rib flow evaluation. A hot-air program was conducted on exact scale calorimeter panels to obtain a quantitative comparison of heat transfer enhancement. Cold flow velocity mapping tests were conducted to obtain detailed rib flow field characteristics. Velocity profile results were related to boundary layer behavior and heat transfer properties and scaled to hot-fire conditions. The hot-air test results were also used to anchor this process.

SCREENING ANALYSIS

The first objective in Subtask I was to screen candidate hot-gas wall rib geometries utilizing available boundary layer and heat transfer modeling techniques. The six best rib configurations were to be selected for the two lab tests planned; 1) the hot-air calorimeter panel tests, and 2) the cold-air flow boundary layer mapping tests. A matrix of 21 rib geometries was analyzed, covering a full range of rib geometry variations, including rib height, base width, rib pitch (spacing), and radiused contouring. These 21 rib types are depicted in Figure 2-1. The 21 rib geometries were evaluated in four categories: Heat transfer enhancement; boundary layer risk; producibility; and structural/life considerations. A scale of 0 to 10 was used for each rating category, with zero indicating an unacceptable risk or benefit, and ten being an optimum condition within that category. Criteria for determining ratings within each category are included in Appendix A.

Rating of each rib type with respect to heat transfer enhancement was based on comparisons against a conventional smooth walled combustor. This evaluation was conducted using two-dimensional finite difference Differential Equation Analyzer Program (DEAP) ribbed combustor models of the various rib geometries. These model results, contained in Appendix A, were in the form of two-dimensional "slices" of the hot-gas wall and combustor liner at discrete axial stations. Rib designs were rated in terms of a heat transfer "enhancement factor", relating rib potential compared to a smooth wall liner, and the steady state temperature profile. A graph depicting typical rib enhancement factors verses rib height is included as Figure 2-2. Rating of ribs in this category resulted, as expected, in the taller ribs being rated highest, due mainly to increased hot-gas surface area.

A comparison of heat transfer enhancement was made for orientation of the rib over the land area or over the coolant channel. No difference in enhancement was noted. Therefore, from a heat transfer standpoint the cases are equivalent and can be interchanged. Structural considerations will be used to select the best approach following Subtask 3 of the task.

FIGURE 2-1

RIB GEOMETRY SELECTION MATRIX

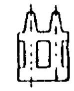
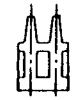
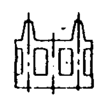
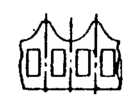
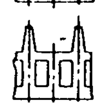
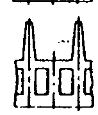
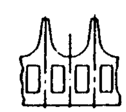
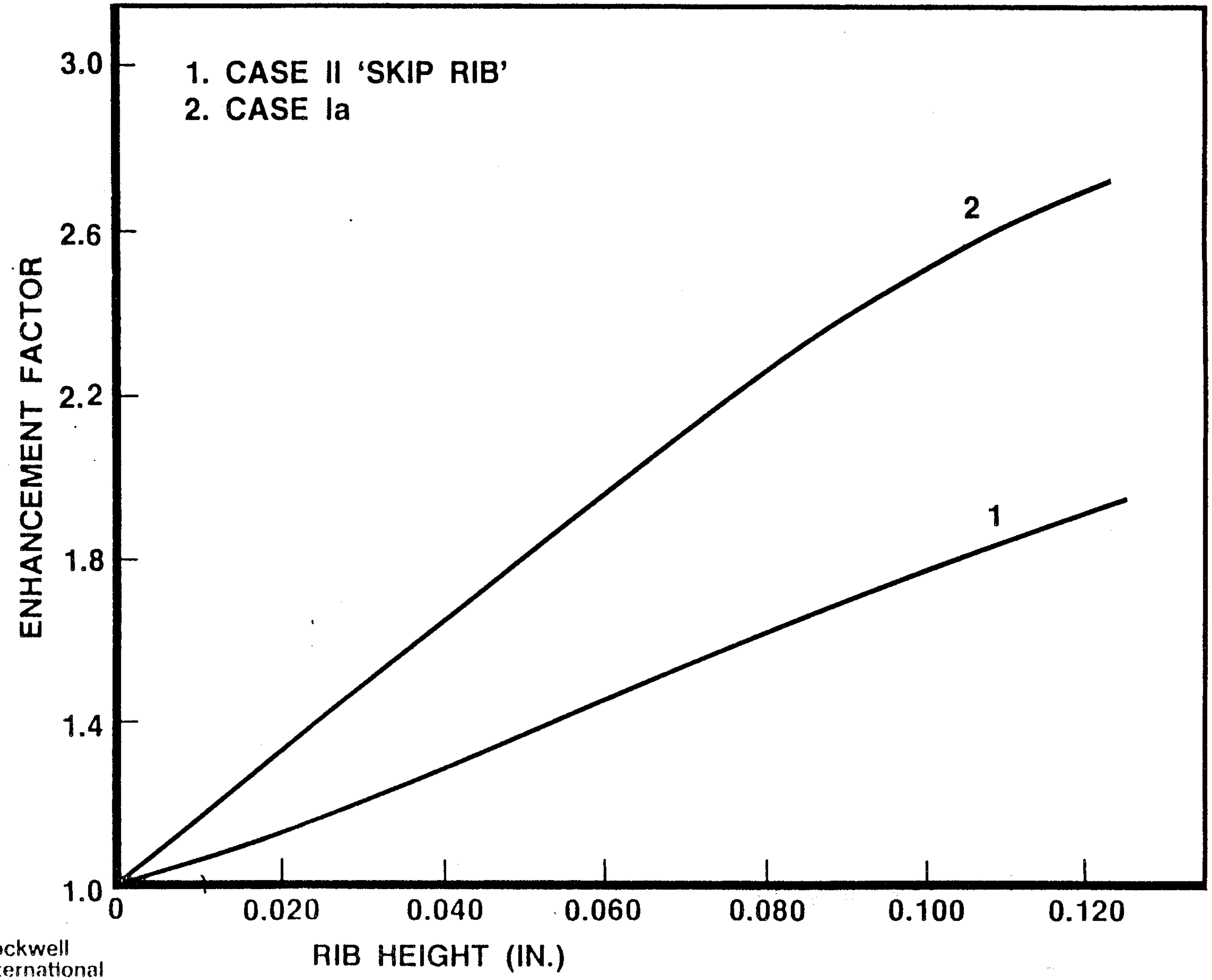
TYPE	HEIGHT	SHAPE	TYPE	HEIGHT	SHAPE
Ia. STANDARD RIB	0.040		**III. HALF PITCH RIB**	0.040	
RIB OVER LAND 0.040 BASE WIDTH 0.0785 PITCH 0.020 TIP	0.060		0.020 BASE WIDTH 0.0385 PITCH 0.010 TIP	0.0785	
	0.080				
	0.120				
Ib. STANDARD RIB	0.040		**IV. RADIUS 0.020**	0.040	
RIB OVER LAND 0.060 BASE WIDTH 0.0785 PITCH 0.020 TIP	0.060		0.0785 PITCH 0.020 TIP	0.060	
	0.080			0.080	
(RIB OVER CHANNEL FOR 0.060)	0.120			0.120	
II. SKIP RIB	0.060		**V. RADIUS 0.060**	0.060	
0.040 BASE WIDTH 0.1570 PITCH 0.020 TIP	0.080		0.1570 PITCH 0.020 TIP	0.080	
	0.120			0.120	

FIGURE 2-2

HEAT TRANSFER ENHANCEMENT



Boundary layer risk was evaluated based on a best estimate of boundary layer growth over combustor wall length, taking into account the insulating effect of a "filled" rib contour, and rib corner effects on boundary layer formation. Results, and subsequent ratings, reflect that the wider spacing of ribs is best, yielding the most effective boundary layer contour with minimized risk of heat flux degrading boundary layer build-up.

Producibility risk addressed the difficulty in machining complex liner geometries. Rib complexity is driven by aspect ratio, scale and multiple contours. As expected, the larger and simpler rib geometry types rated higher.

The structural and life considerations were based primarily on material property degradation with increased temperature. Comparison data was obtained from the DEAP steady state temperature profiles. These were relative temperature comparisons, since some rib tip temperatures went well beyond material limits (see Figure 2-3). Potential advances in material and cooling technology were considered in selecting cases to be tested. An .080 high rib was selected as a lab test configuration to acquire data for analysis of material survivability at its upper temperature limits. Evaluation of ribs in this category showed that the taller ribs rated lowest, due mainly to excessive material temperatures. Again, note that there is essentially no difference in the rib over land and rib over channel configurations.

A rib sensitivity study was conducted to evaluate how potential variations in hot-gas wall film coefficient (Hg) due to boundary layer effects would impact rib temperature and heat transfer enhancement. The results, depicted in Figure 2-4, show that Hg variations do affect heat transfer enhancement directly, but due to a parallel effect of lower material temperature, Figure 2-5, may allow the use of taller ribs. Additionally, a study was made to determine the effect on Hg of large temperature gradients from rib tip to trough. Results showed only a 12% change in Hg for a 1000F temperature gradient, which fell well into the Hg range covered in the sensitivity studies described above.

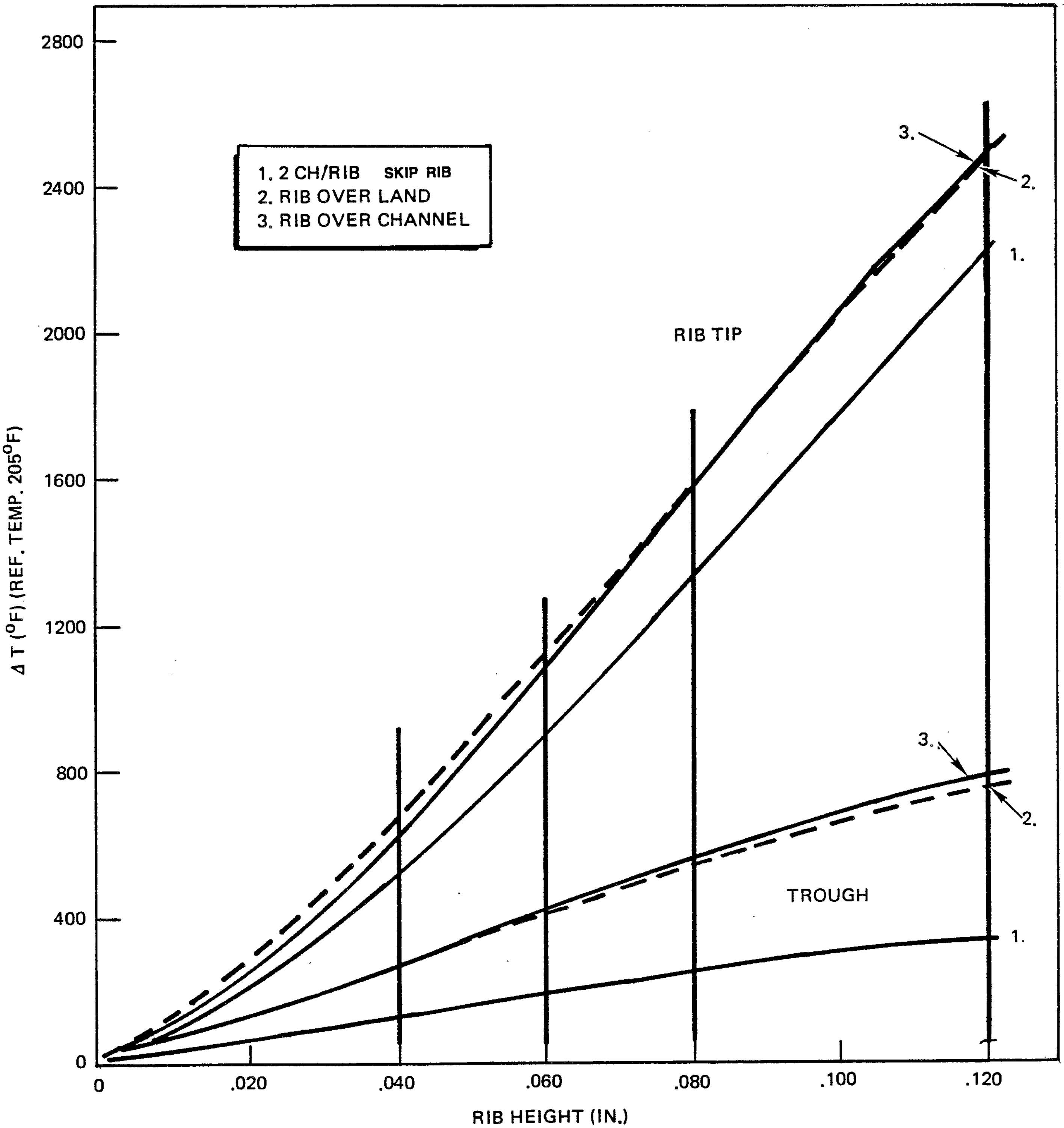


Figure 2-3. Structure/Life Considerations

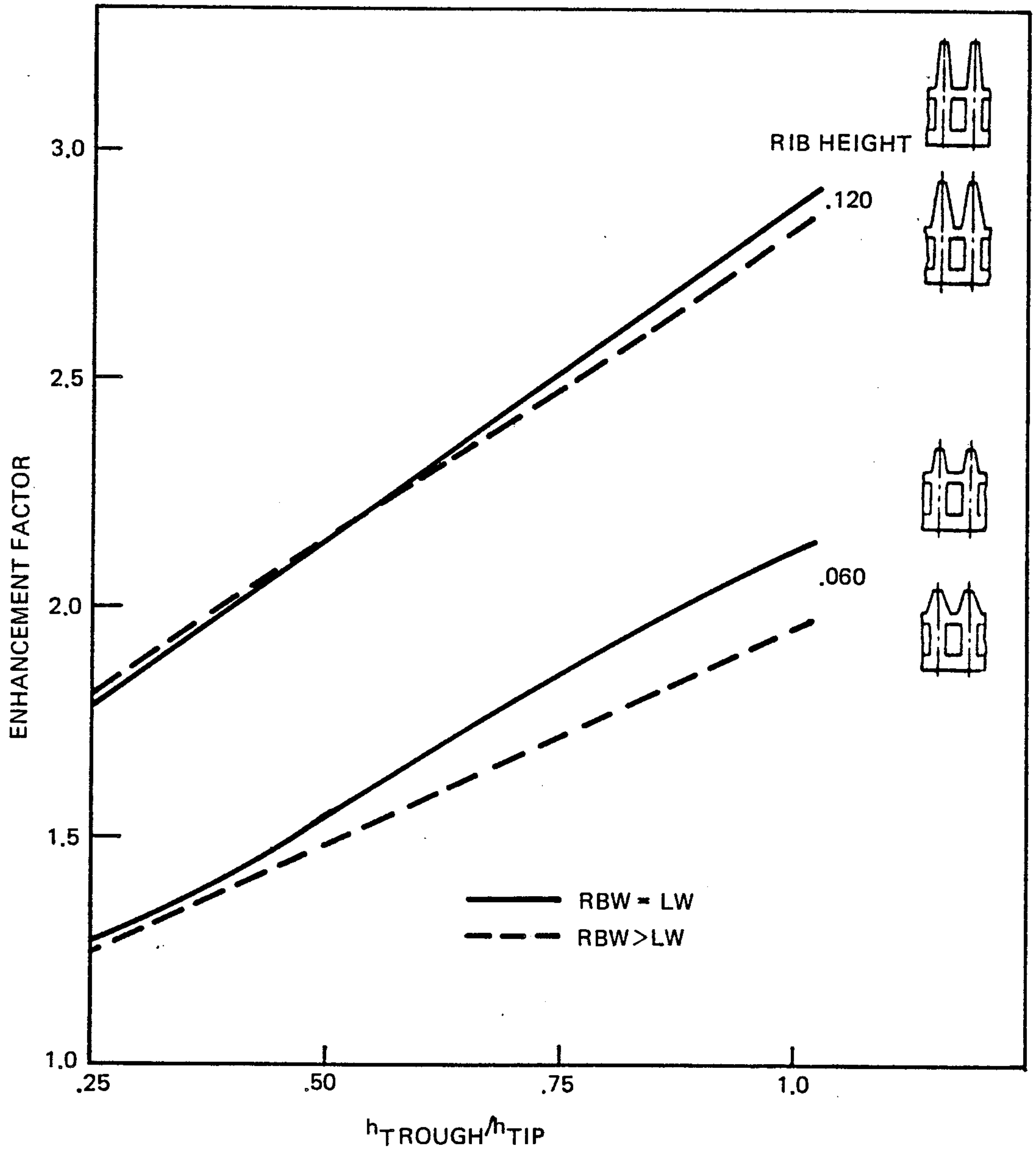


Figure 2-4. Enhancement Factor Sensitivity to Variations in Hot Gas Wall Film Coefficient (hg)

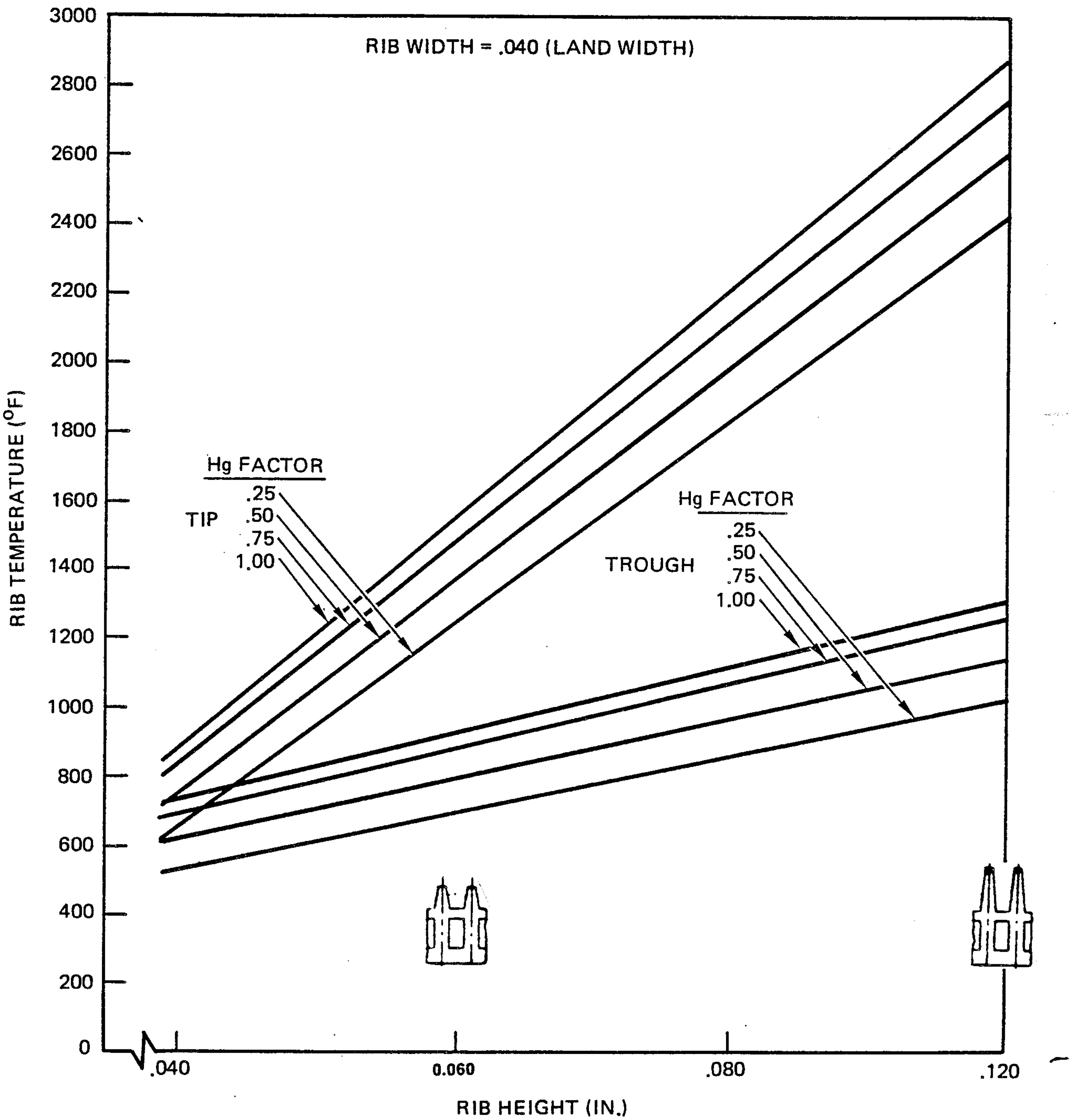


Figure 2-5. Rib Temperature Sensitivity to Variations in hg Factor

Final rib selection was based on total weighted scores for each rib type in the four categories, plus "other factors", such as duplication of data, and broadening of the data base. The concept scores and relative weighting of the selection criteria are shown in Table 2-1. Both boundary layer risk and heat transfer were weighted highest, due to their direct influence on rib effectiveness. Producibility was weighted low due to the relatively narrow range of influence it has, considering that all ribs analyzed are within the state-of-the-art for machining processes. Structure/life considerations, though important, will play a much larger role in structural analysis studies farther along in the program. The overall weighted rating score gives a priorized ranking of the candidates for the four quantified evaluation criteria.

The selected concepts are indicated in prioritized order on the right hand column of Table 2-1. Ribs of 0.040, 0.060, and 0.080 height were selected. Two base width values were selected for the 0.060 high rib to evaluate the impact of this parameter. A twice-nominal pitch configuration, the 'skip rib' case, was included based on its overall ranking and low boundary layer growth risk. Finally, a radius based design rated highly and was also selected for technical breadth.

Table 2-1. Hot Gas Side Rib Selection Matrix

RIB GEOMETRY	HEIGHT	HEAT TRANSFER .30 WEIGHTED		BOUNDARY LAYER .30 WEIGHTED		PRODUCIBILITY .15 WEIGHTED		STRUCTURE/ LIFE .25 WEIGHTED		WT'D SUMS	RANK	OTHER FACTORS	SEL RANK
		RAT'G	WT'D	RAT'G	WT'D	RAT'G	WT'D	RAT'G	WT'D				
IA. STANDARD RIB RIB OVER LAND .040 BASE WIDTH .0785 PITCH .020 TIP	.040	6	1.8	6	1.8	10	1.5	9	2.25	7.35	1		1
	.060	7	2.1	5.5	1.65	10	1.5	4	1.0	6.25	3		2
	.080	8.5	2.55	5	1.50	8	1.2	0	0	5.25	9	EXPAND DATA BASE FOR ADV MAT'L DEV	6
	.120	10	3.0	4	1.20	6	.9	0	0	5.10	11		
IB. STANDARD RIB RIB OVER LAND .060 BASE WIDTH .0785 PITCH .020 TIP	.040	5	1.5	5	1.5	10	1.5	9	2.25	6.75	2	DUPLICATION: CHANGE IN BASE WIDTH TO BE COMPARED AT .060 HT	–
	.060	6	1.8	4.5	1.35	10	1.5	4	1.0	5.65	7		4
	.080	7.5	2.25	4	1.2	9	1.35	0	0	4.80	13		
	.120	9	2.7	3	.9	7	1.05	0	0	4.65	14		
II. SKIP RIB .040 BASE WIDTH .1570 PITCH .020 TIP	.060	3	.9	8	2.4	8	1.2	5	1.25	5.75	6	TECHNICAL BREADTH	3
	.080	4.5	1.35	8	2.4	7	1.05	0	0	4.80	12		
	.120	6	1.8	9	2.7	5	.75	0	0	5.25	10		
III. HALF PITCH RIB .020 BASE WIDTH .0385 PITCH .010 TIP	.040	–	–	0	0	5	.75	–	–	.75	20	HEAT TRANSFER AND LIFE NOT ANALYZED DUE TO EXTREME BOUNDARY LAYER RISK	
	.0785	–	–	0	0	3	.45	–	–	.45	21		
IV. RIB/CHANNEL SH RIB OVER CHANNEL .040 BASE WIDTH .0785 PITCH	.060	7	2.1	5.5	1.65	10	1.5	4	1.0	6.25	4	DUPLICATION: HOT GAS WALL IDENTICAL TO IA./.060	–
V. RADIUS .020 .0785 PITCH .020 TIP	.040	5.5	1.65	4	1.2	7	1.05	9	2.25	6.15	5	DUPLICATION: CHANGE IN THROUGH GEOMETRY TO BE COMPARED AT .060 HEIGHT	–
	.060	6.5	1.95	4	1.2	7	1.05	5	1.25	5.45	8	TECHNICAL BREADTH	5
	.080	8	2.4	3	.9	6	.9	0	0	4.25	15		
	.120	9	2.7	2	.6	4	.6	0	0	3.90	17		
VI. RADIUS .060 .1570 PITCH .020 TIP	.060	2	.6	4	1.2	6	.9	5	1.25	3.95	16		
	.080	3.5	1.05	5	1.5	5	.75	0	0	3.30	18		–
	.120	5	1.5	4	1.2	3	.45	0	0	3.15	19		

AIR TEST PROGRAMS DEFINITION

Two air test programs were formulated for hot-gas wall rib flow evaluation. A hot-air test program was planned for obtaining a quantitative comparison of heat transfer enhancement. Detailed boundary layer velocity profile mapping was planned in the second test series. Analyses were conducted to define test conditions that would provide the best simulation of hot-fire conditions possible for each laboratory test. Fixtures were designed for each test program.

Analysis

Proper simulation of the hot-fire combustor boundary layer was of prime importance in the planned hot-air and cold flow tests. There are vast differences between the actual combustor boundary layer and that which can be produced in an air flow simulation. The most important difference is the high heat flux into the cooled combustor wall; this cannot be recreated in a cold flow test. The resultant temperature gradient at the wall greatly reduces the momentum and displacement thicknesses of the boundary layer (while having little effect on the velocity thickness). Therefore, the boundary layer cannot be entirely recreated in an air flow test, but certain characteristics can be. The problem was then to choose the proper characteristic to be matched or scaled to the hot-fire conditions.

The scaling characteristic chosen for the air flow simulation is the boundary layer momentum thickness (θ), since it is closely related to the heat transfer. The momentum thickness is defined as,

$$\theta = \int \frac{\overline{\rho u}}{\rho u} \left(1 - \frac{\overline{u}}{u} \right) dy \qquad (1)$$

where, ρu = freestream density and velocity

$\overline{\rho u}$ = turbulent (rms) density and velocity

The momentum thickness is calculated for hot-fire conditions by the Rocketdyne boundary layer computer program. The calculated value of the momentum thickness at the end of the cylindrical portion of the combustor (~13 inches from the injector) is,

$$\theta = 0.029 \text{ inches} \tag{2}$$

for the combustor conditions: Pc = 1650 (psia), Tc = 6571 (R). The momentum boundary layer thickness as a function of axial position on the combustor cylindrical section is plotted in Figure 2-6.

In the air flow tests, it is desirable to scale this value at the downstream end of the ribbed plate test section. The theoretical growth rate of a turbulent boundary layer on an adiabatic flat plate is written,

$$\theta = \frac{0.0142}{\sqrt[7]{Rex}} \; x \tag{3}$$

Where, x = distance from start of turbulent B.L.
$Rex = ux/\nu$ Reynolds no. based on x

In order to account for any physical geometry differences between the air flow test section and the actual ribbed combustor wall, a scale factor S is introduced as a multiplier to the momentum thickness (eq. 1). In the case of the cold flow study, an enlargement of the rib dimensions is desired in order to make detailed measurements of the correspondingly larger boundary layer.

By multiplying equation (1) by S and equating with equation (2), the following expression for the required air flow velocity is derived,

$$U = \nu \left[\frac{L}{(0.1267)\,(S)^{1.17}} \right]^{6} \tag{4}$$

where, U = the freestream velocity (ft/s)
ν = air kinematic viscosity (ft2/s)
L = length of the test section (ft)
S = geometric scale factor

PREDICTED COMBUSTOR MOMENTUM BOUNDARY LAYER THICKNESS

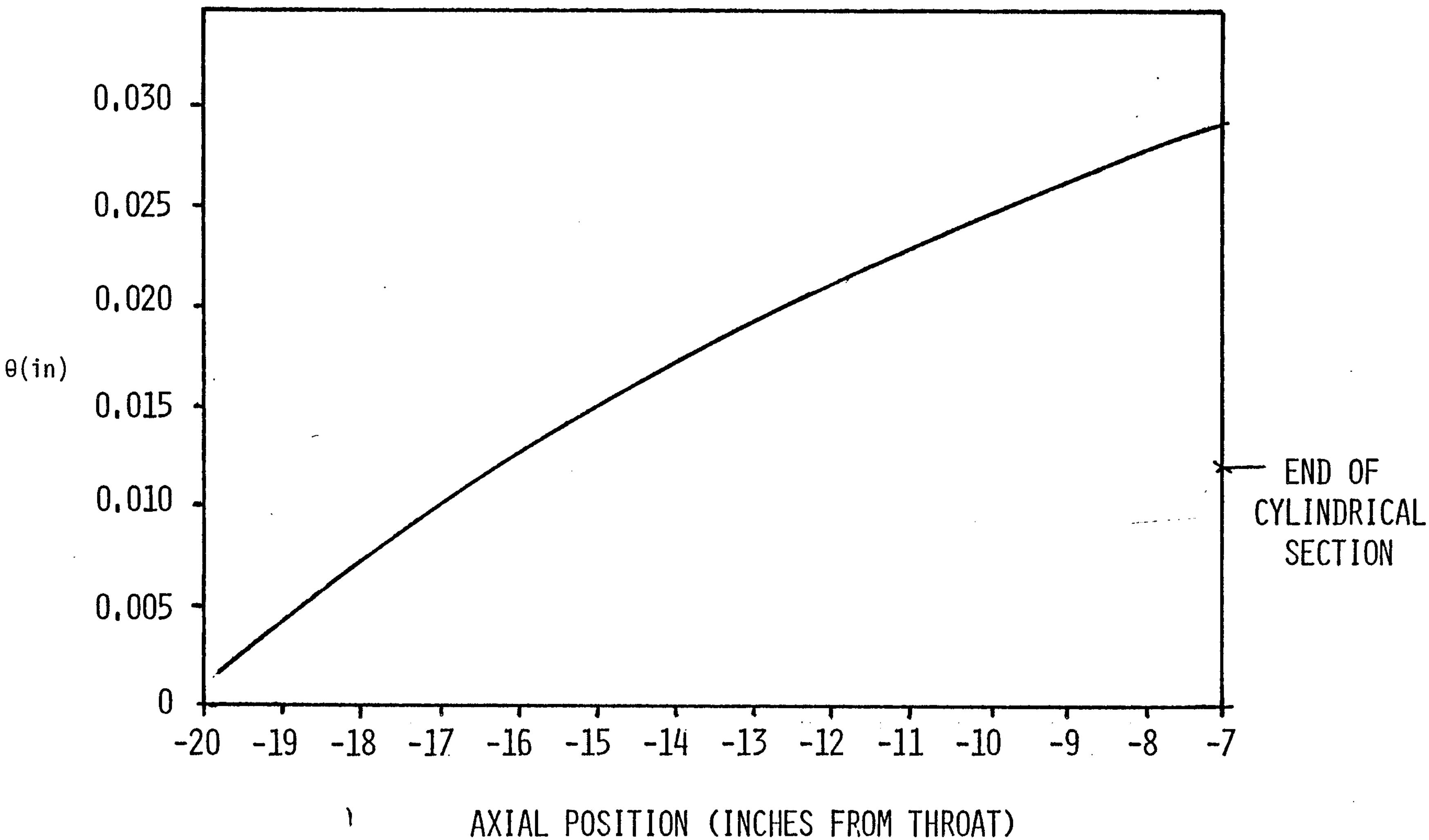


FIGURE 2-6

As an example, for a 2 ft test section which has ribs of twice the actual size (S=2), and for air flow conditions of P = 14.7 psia, and T = 80°F (ν = 1.69E-4), equation (4) gives the required air velocity as,

$$U = 21 \text{ ft/s}$$

This corresponds to a plate Reynolds number of 2.4E5 which is in the turbulent regime. This will result in a match of the momentum thickness of the air boundary layer to the hot-fire momentum thickness as desired.

In order to summarize the effects of plate length and air flow conditions in the momentum thickness, a rearrangement of the growth equation (3) was performed to give,

$$\theta/(x)^{6/7} = 0.0142/(U/\nu)^{1/7} \qquad (5)$$

Since the right hand side contains air flow properties only, a flow parameter was defined as,

$$\emptyset = (\nu/U)\ /c \qquad (6)$$

where c = constant of proportionality

For a known dependence of air kinematic viscosity on temperature and pressure. the air flow parameter was related to the basic thermodynamic variables. For air temperature above 0°F and pressures not exceeding 400 psi, the absolute viscosity can be expressed as a function of temperature only,

$$u/u. = (T/T.)^{0.7} \qquad (7)$$

Where the subscripted values are taken as a reference condition. The air density is found from the Perfect Gas law as,

$$p/p. = (P/T)\ /\ (P./T.) \qquad (8)$$

Combining (7) and (8) gives the kinematic viscosity as,

$$\nu/\nu. = (T/T.)^{1.7}\ (P./P) \qquad (9)$$

Assuming a reference of T. = 560 (R), P. = 14.7 (psia), and ν. = 17.9E-5 (ft2/s) gives the result,

$$\nu(ft^2/s) = C \frac{(T\ (R))^{1.7}}{P\ (psia)} \qquad (10)$$

where, C = 5.6E-8 for alr

By combining this with (6), and choosing the proportionality constant c as equal to the constant C derived above, then the flow parameter is shown to be,

$$\phi = \frac{T^{1.7}\ (R)}{P\ (psia)\ u\ (ft/s)} \qquad (11)$$

Then the momentum thickness growth equation (5) is written,

$$\theta / x^{6/7} = 0.0142\ (c\phi)^{1/7}$$

or,
$$\theta / x^{6/7} = 0.00131\phi^{1/7} \qquad (12)$$

The air flow parameter is governed by the limitations of the test facility. It is evident from equation (12) that in order to develop a thick layer, a large ϕ is required. By inspection of equation (11), this implies that the air temperature should be as high as possible, and the pressure and velocity as low as possible.

The lower limit on the velocity is governed by the Reynolds number requirement for the maintenance of a fully turbulent boundary layer. If the velocity were allowed to drop too low, the layer may become laminar. As a rule of thumb, it was determined that the Reynolds number should be above Re = 1,000,000 over most of the test section. The Reynolds number at any location increases for smaller air flow parameter values. This suggested that the maximum allowable value be,

$$\phi_{max} = 100$$

Given a value of the flow parameter (θ), the required test plate length was determined for a selected scale factor. This process is summarized in Figures 2-7 and 2-8. A graphical representation of equation 12 is presented in Figure 2-9.

For the hot-air tests, a one-to-one rib scale was used. Accordingly, a momentum boundary layer thickness matching the predicted 0.029-inch value at the end of the combustor cylindrical section was to be simulated. For test conditions of 900°F and 300 psi, a test panel length of 18 inches and a flow velocity of approximately 70 ft/sec produce an air-flow parameter of 10 giving the desired momentum boundary layer thickness.

For the ambient air-flow, boundary-layer mapping tests, an increased test panel scale was used to provide adequate space for flow mapping. For a rib scale of four-to-one, a 72-inch test panel length with a flow parameter of less than 50 results in a momentum boundary layer thickness four times the combustor value.

0515k

FIGURE 2-7

BOUNDARY LAYER RELATIONSHIP RELATES AIR FLOW TO HOT-FIRE CONDITIONS

- **COMBUSTOR MOMENTUM BOUNDARY LAYER (θ) BASED ON FLAT PLATE ANALYSIS**
  - $\theta = \dfrac{0.0142}{(u/\nu)^{1/7}} x^{6/7}$

    u = FREE STREAM VELOCITY
    ν = KINEMATIC VISCOSITY
    x = DISTANCE ALONG COMBUSTOR
  - EVALUATED BY ROCKETDYNE'S 9R-247 COMPUTER PROGRAM
  - AT END OF CYLINDRICAL SECTION $\theta = 0.029$ INCH
- **SIMILAR RELATIONSHIP USED FOR AIR FLOW TEST ANALYSIS**

$$\theta = 0.0142 \, (\phi/C)^{1/7} \, x^{6/7}$$

ϕ = AIR FLOW PARAMETER
C = AIR CONSTANT = 1.287×10^7
X = DISTANCE ALONG TEST PANEL

$$\phi = C_1 \, (\nu/u) = T^{1.7}/P \, u$$

T = AIR TEMPERATURE
P = AIR PRESSURE

0515k

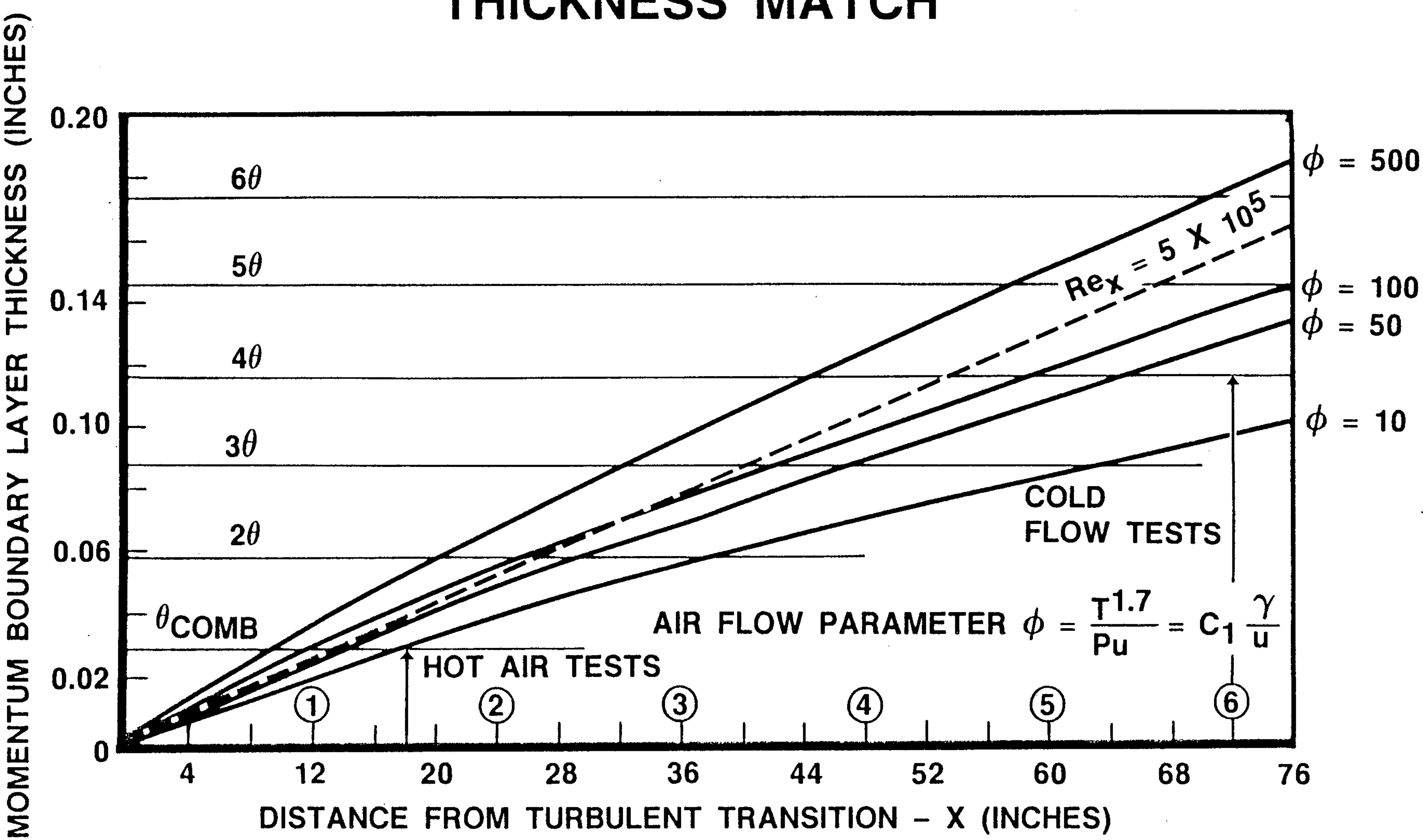
FIGURE 2-8

TEST FIXTURE DIMENSIONS SET BY COMBUSTOR CONDITIONS

- **REQUIRED LENGTH A FUNCTION OF SCALE FACTOR(S), θ, AND ϕ**
  - $L = (S\theta/0.0142)^{7/6} \ (C_1/\phi)^{1/6}$
- **FOR TURBULENT FLOW $\phi \leq 100$, AND WITH θ = 0.029 INCH**
  - $L = 0.9507 \ S^{7/6}$
- **S = 4 PROVIDES ADEQUATE SPATIAL SCALE AND ACCEPTABLE LENGTH**
  - L = 60 INCHES (5 FT)

FIGURE 2-9

FLOW PARAMETER VALUES FOR AIR TEST/ COMBUSTOR BOUNDARY LAYER MOMENTUM THICKNESS MATCH



0515k

RI/RD86-199
2-19

Test Fixtures Design

Hot-Air Test Chamber. The calorimeter test chamber was designed with segmented test panels to allow different rib configurations to be tested in the same set-up. A two-piece clamshell housing confines the four separable 90 degree test panel segments. The housing has attach flanges at both ends for facility interface. Spacer rings are used at both ends to house instrumentation and flow devices. Panel water feed lines and axial thermocouples are fed through ports in the housing. A chamber assembly layout is shown in Figure 2-10.

The test panels are identical in design with the exception of the hot-gas wall configuration which is varied to match a candidate design. One panel had a smooth wall for reference heat transfer values. The panel consists of an OFHC copper liner brazed into a CRES structural shell. The liner back has coolant channels machined axially between the integral manifolds at both ends. The manifolds are fed by a single water supply (drain) tube at each end. Bosses are provided for thermocouples that are inserted in coolant channels at five axial locations on each panel. The panel edges have a relief and a seal to minimize heat transfer between adjacent panels at the interface.

The forward spacer ring houses a flow plate that straightens and trips the air flow just upstream of the chamber. It also contains a port for a thermocouple rake to measure inlet radial air temperature distribution. The aft spacer ring also contains a boss for a thermocouple rake for measuring exit radial air temperature distribution. A replaceable exit nozzle, which partially controls the air flow rate, is bolted to the end of the discharge spacer.

The chamber is a bolted assembly with o-ring seals used between the mating parts and the facility flanges. Detail drawings for the chamber components are contained in Appendix B.

Cold Flow Test Fixture. The cold flow test fixture was designed as a long box-like passage for flowing the air past the rib geometries. The fixture was configured to use a structural beam as a support and assembly means. It consists of two side members, a replaceable test panel, a cover plate which

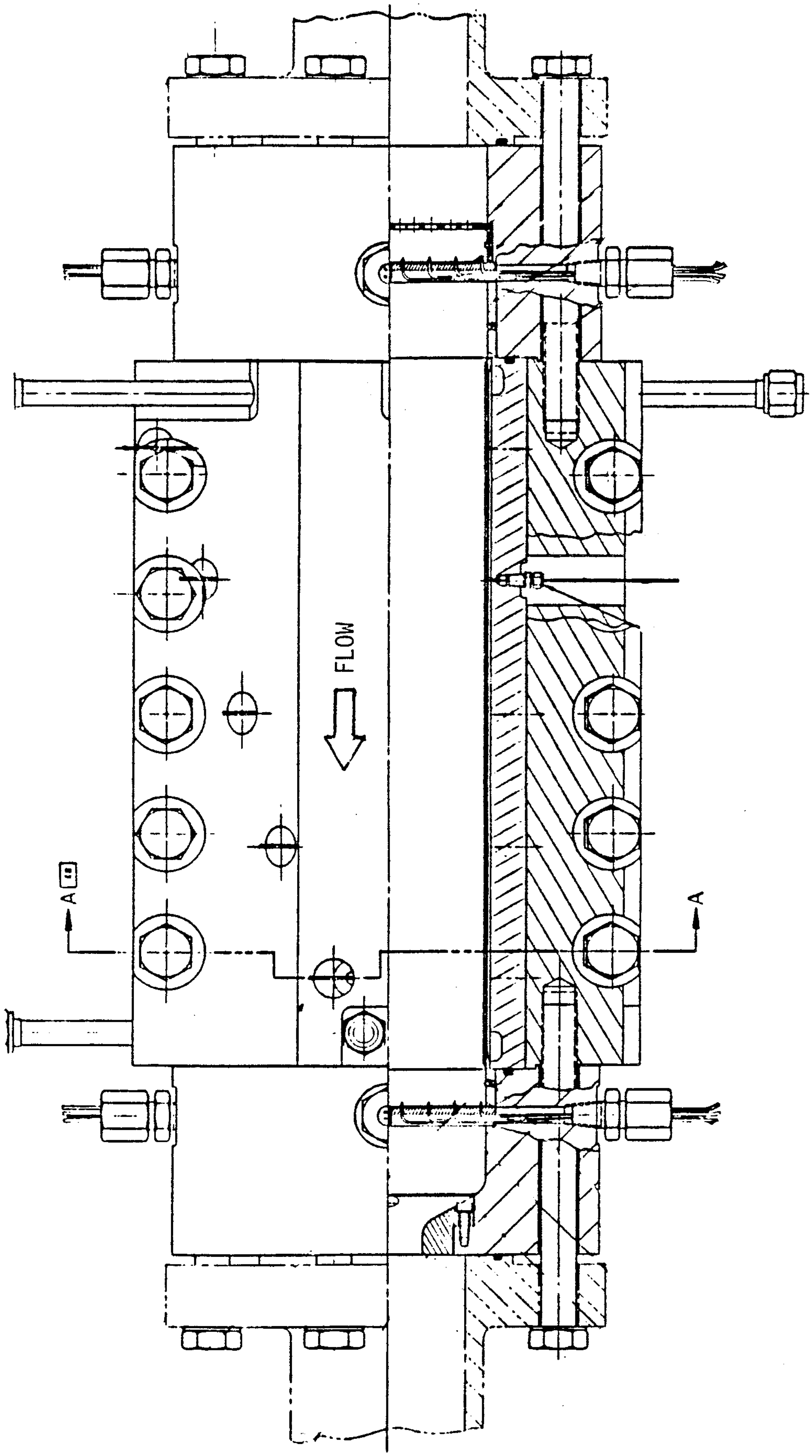


FIGURE 2-10 HOT AIR FLOW FIXTURE - CROSS SECTIONAL VIEW

includes three velocimeter access windows, and an inlet plenum. A design objective was to use this fixture for the Subtask 2 test effort, so a configuration that would allow easy modification to the channel test mode was formulated. Detail drawings for the assembly are given in Appendix C and a cross section layout is shown in Figure 2-11.

The side members are bolted directly to a structural beam with a matching bolt hole pattern. Spacing for the members is provided by the replaceable test panel which is bolted into lands on the side members. For the rib test configuration, the test panel is at the bottom of the fixture, away from the cover plate, to provide the proper undisturbed free stream boundary condition. The test panel and side members form the lower three sides of the flow box.

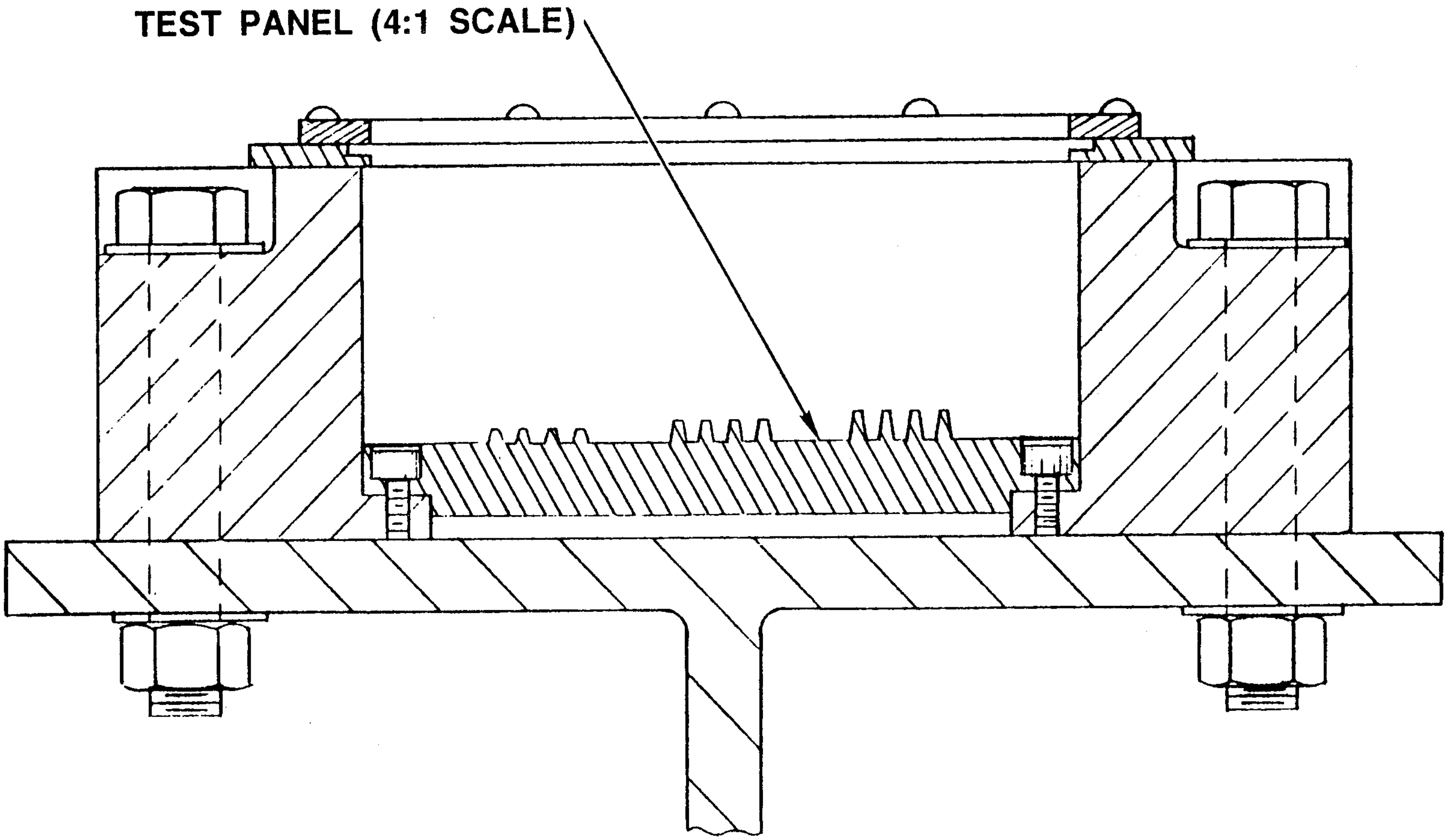
The test panels contained four-times scale ribs for each of the six selected configurations. Additionally, for one panel, half of the panel was left flat for reference flat plate measurements. Two to three rib types were included on a panel, but several ribs of each type were provided on each side of the measurement centerline to provide the proper boundary conditions. A black anodize surface treatment was selected to minimize plate reflectivity which could cloud velocimeter measurements and limit the ability to obtain measurements close to the surface.

The top closeout of the box is provided by the cover plate. It is a sheet metal panel that is bolted to the top of the side members. Three windows are included to provide access for the velocimeter laser beams. The windows are fused silica glass that are polished for flatness and have an antireflective surface coating. Extreme clarity, flatness, and antireflectivity are necessary to prevent distortion of the velocimeter laser beams that would reduce data accuracy. The windows are held in place with a cover plate and a thin cushioning film gasket.

An inlet plenum was designed to interface the test fixture with the facility. The plenum entrance adapted to facility ducting quick disconnect couplings. From the entrance, the air is turned 90 degrees and funneled to match the box dimensions. The air was exhausted to atmosphere, so no special fixture was designed for the exit.

FIGURE 2-11

COLD FLOW TEST FIXTURE – HOT-GAS RIB CONFIGURATION



0515k

Fabrication

The components fabricated include the entrance and exit sections, the two shell halves, and seven calorimeter panels (six with rib configurations and one smooth wall reference). The inlet and exit components are machined parts made from CRES material. The individual components, shown in Figure 2-12, include thermocouple support crossmembers at each end, an entrance flow turbulator, and a replaceable exit flow nozzle.

The calorimeter panels are brazed assemblies consisting of a CRES strongback, an OFHC copper liner, and CRES feed tubes. The fabrication sequence was:

1) machine the CRES strongback curvature and manifold sections, leaving extra stock on the ends for braze tooling;

2) machine coolant channels into the copper liner outside diameter (OD) leaving extra stock at the ends for braze tooling;

3) machine a curved inside diameter (ID) on the copper liner for interface with braze tooling, leaving extra stock for later machining of the hot-gas rib geometries;

4) check fit the components, Figure 2-13, and tack Nicoro braze alloy foil on the strong back in the channel areas;

5) assemble the liner to the strong back and insert positioning pins located in the extra stock area;

6) place the coated tooling bar, which matched the liner ID, on the liner and wrap the assembly with tungsten wire to apply a closing force during brazing, insert the feed tubes and braze alloy;

7) braze the assembly in an inert furnace, disassemble tooling when complete;

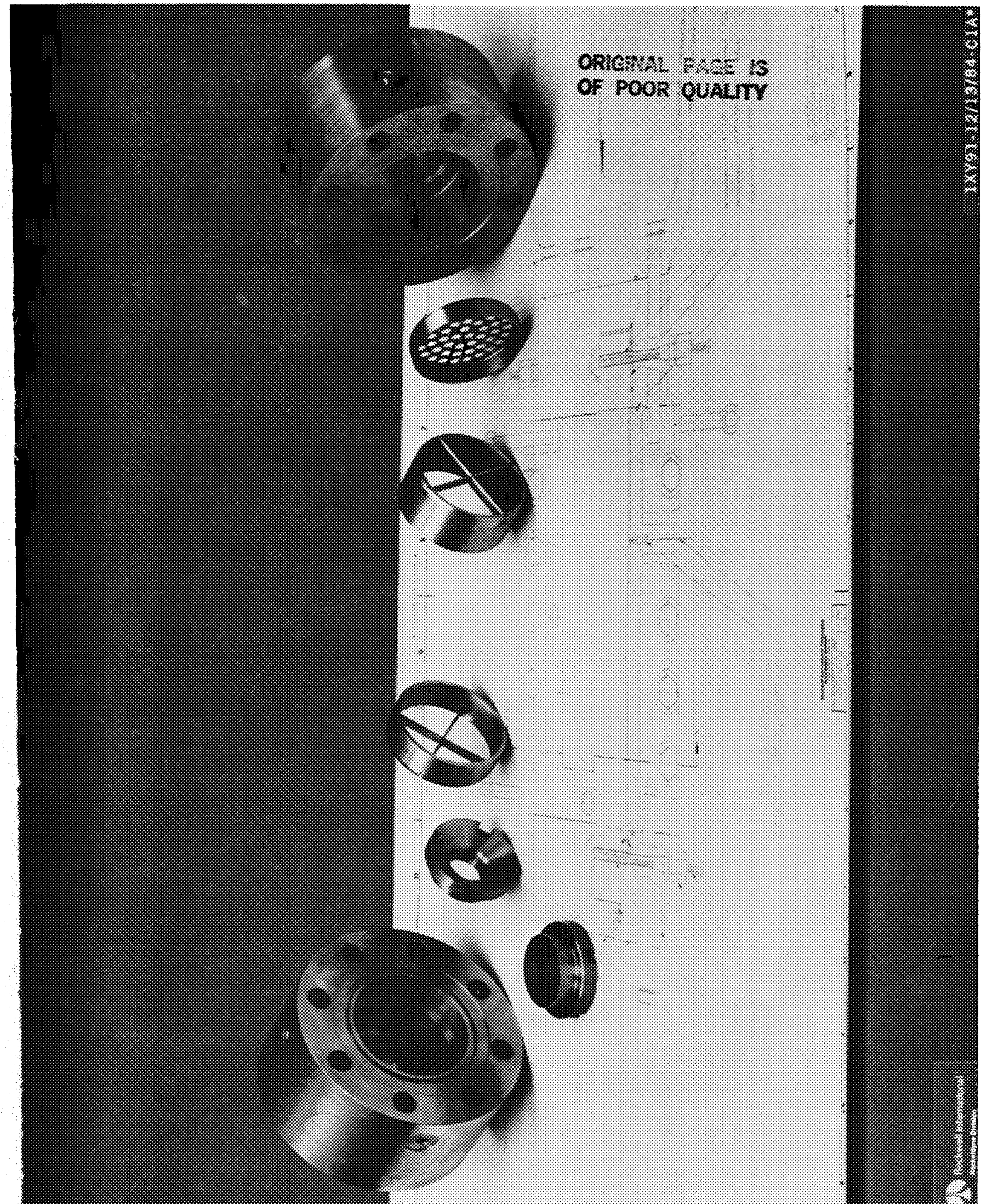


Figure 2-12. Hot-Air Test Chamber Entrance and Exit Components

0515k

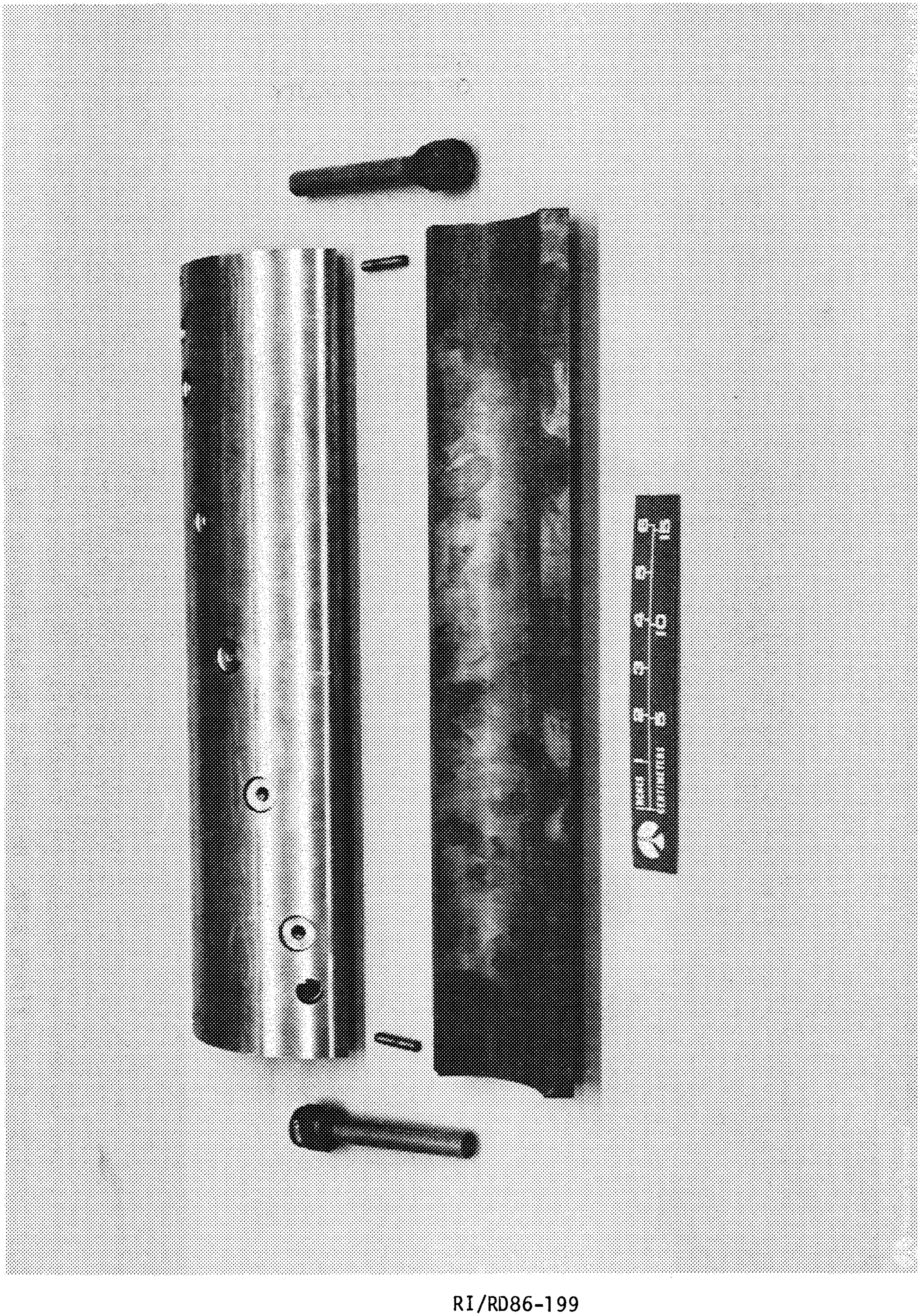


Figure 2-13. Hot-Air Test Panel Components

8) leak test the panel for overall leakages and x-ray to observe channel bonding;

9) final machine the panel hot-gas rib configuration, the thermocouple access bosses, and the end and side interfaces.

All seven panels were completed without significant problem. Some channel clogging appears to have occurred in the middle channels (lowest point channels during brazing) on several panels which reduced water flow area. The effect was localized, so it was concluded that the overall panel results would not be affected.

The two-piece clamshell housing was also machined from CRES material. It provides sealed interfaces for the entrance and exit sections, passages for the panel feed tubes and thermocouples, and bolted closure flanges to allow disassembly for panel replacement. The housing and a set of completed tests panels are pictured in Figure 2-14.

The chamber was assembled simply by placing the panels in the shell halves and bolting the halves together to encase and compress the panels. This formed a seal at the panel interfaces. A top and overall view of the assembly, prior to bolting together, are shown in Figure 2-15.

Testing

A test plan, contained in Appendix B, was prepared to define the hot-air test approach and requirements. In summary, it was planned to test each of two chamber builds (three ribbed panels and the smooth wall reference panel in each build) at two temperatures and varying cooling flowrates to determine the heat transfer characteristics. Water flowrates, water temperatures at the inlet and outlet and at several axial locations on the panel, and inlet and exit air properties were to be measured to provide the data for this characterization.

ORIGINAL PAGE IS
OF POOR QUALITY

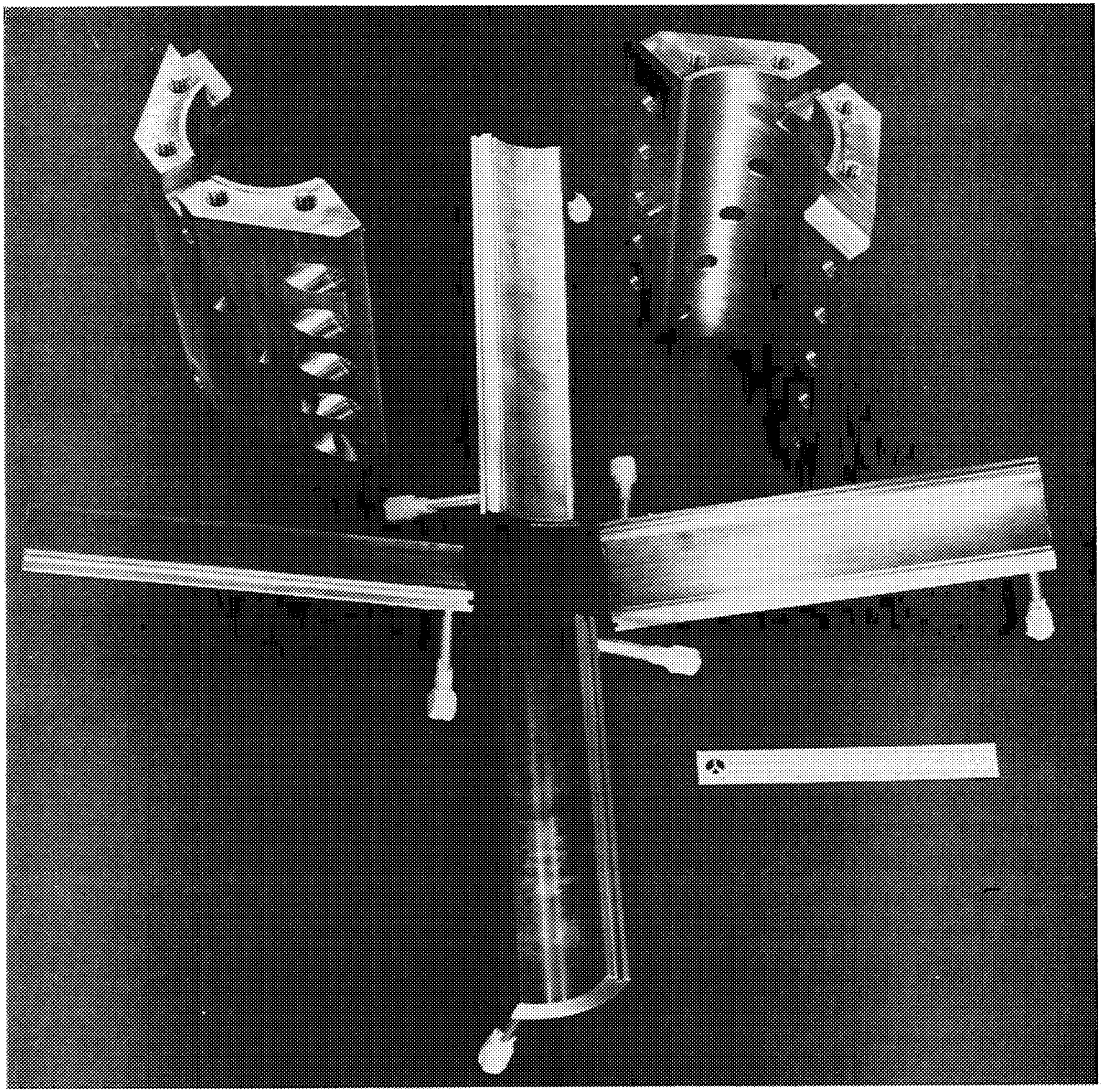


Figure 2-14. Hot-Air Test Chamber Components

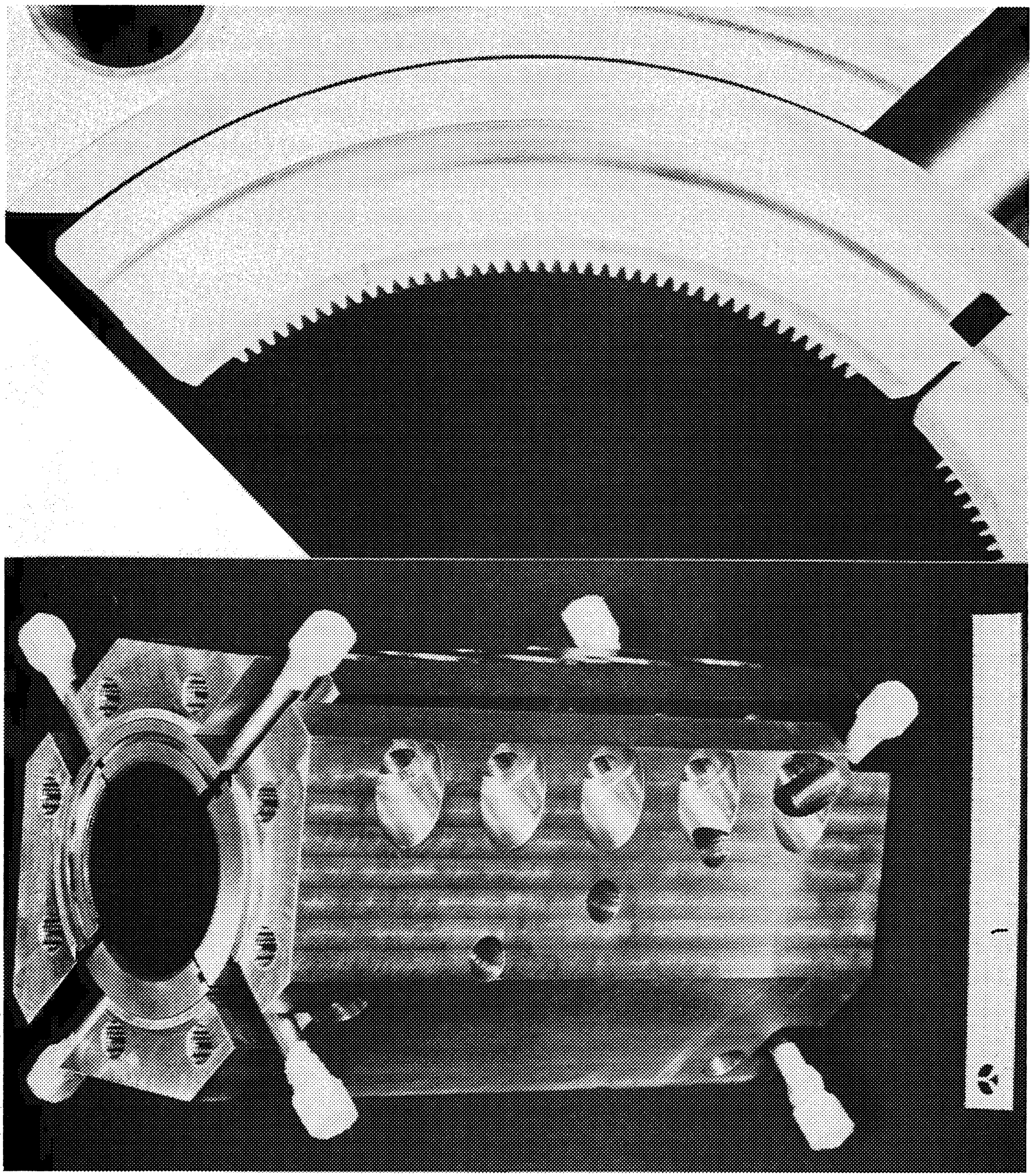


FIGURE 2-15. Hot-Air Test Chamber Assembly

0515k

Installation. A test position was established at Rockwell's North American Aircraft Operations (NAAO) Thermodynamics Laboratory to conduct the tests. The facility is illustrated schematically in Figure 2-16. An existing compressor and heater facility were used to supply air at the desired 700 -900 F, 300 psia conditions with a flowrate of up to 10 lb/sec. Hot air inlet conditions were available to regulate the flow. Individual water cooling circuits with flow, temperature, and pressure measurements were used for each test panel to obtain bulk heat input measurements. Crossbar thermocouple rakes were installed in the entrance and exit sections to evaluate air temperature uniformity.

An overview of the test position with the chamber and instrumentation installed is shown in Figure 2-17. A closer view is given in Figure 2-18, showing the entrance, test chamber, exit section, water feed lines, and the thermocouple junctions.

Data collection was provided by a high-speed Astrodata acquisition system available at NAAO.

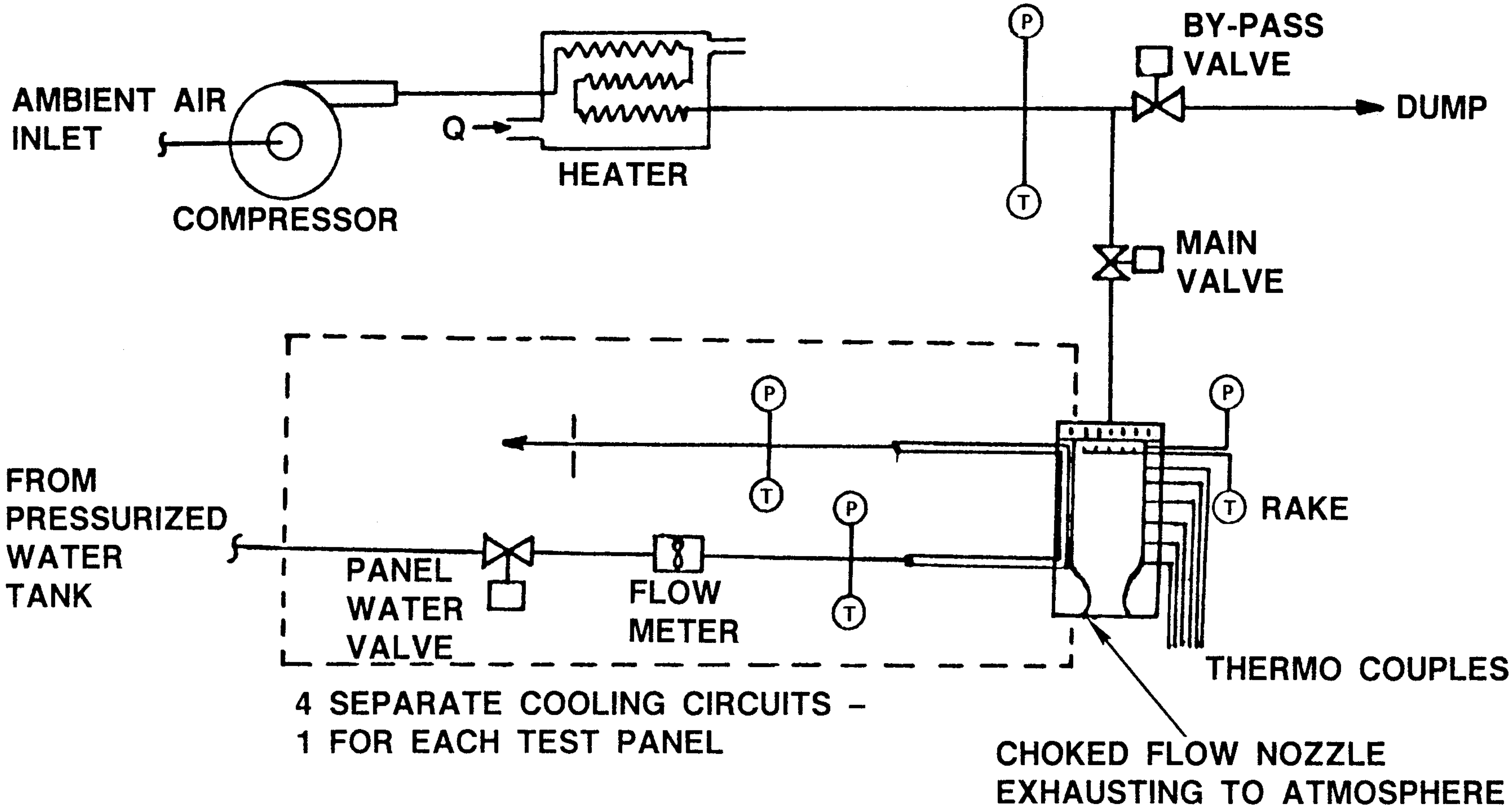
Tests. A large number of steady-state data slices were obtained for each chamber set-up. A summary of the test points and conditions is given in Figure 2-19. Varying hot-gas heating-to-water circuit cooling ratios were explored by running at extreme hot-air and water flowrates for the test temperatures of 700° and 900°F.

Summary tables for the tests conducted are contained in Appendix B. The tables list the pertinent conditions and the resulting water temperature rise as a function of axial position.

Representative axial thermocouple data are graphed in Figure 2-20. The curves show the higher temperature rise for the ribbed panel section compared to the smooth wall reference. A tendency for the ribbed panel to rise to near the final temperature rapidly and 'level off' towards the exit is notable. The smooth wall reference had a more linear temperature rise. This is evidence that the boundary layer build-up in the ribbed contour was limiting the heat transfer enhancement near the end of the panel section. Since the test panel length and conditions were selected to represent the boundary layer formation

FIGURE 2-16

HOT-AIR TEST SETUP SCHEMATIC



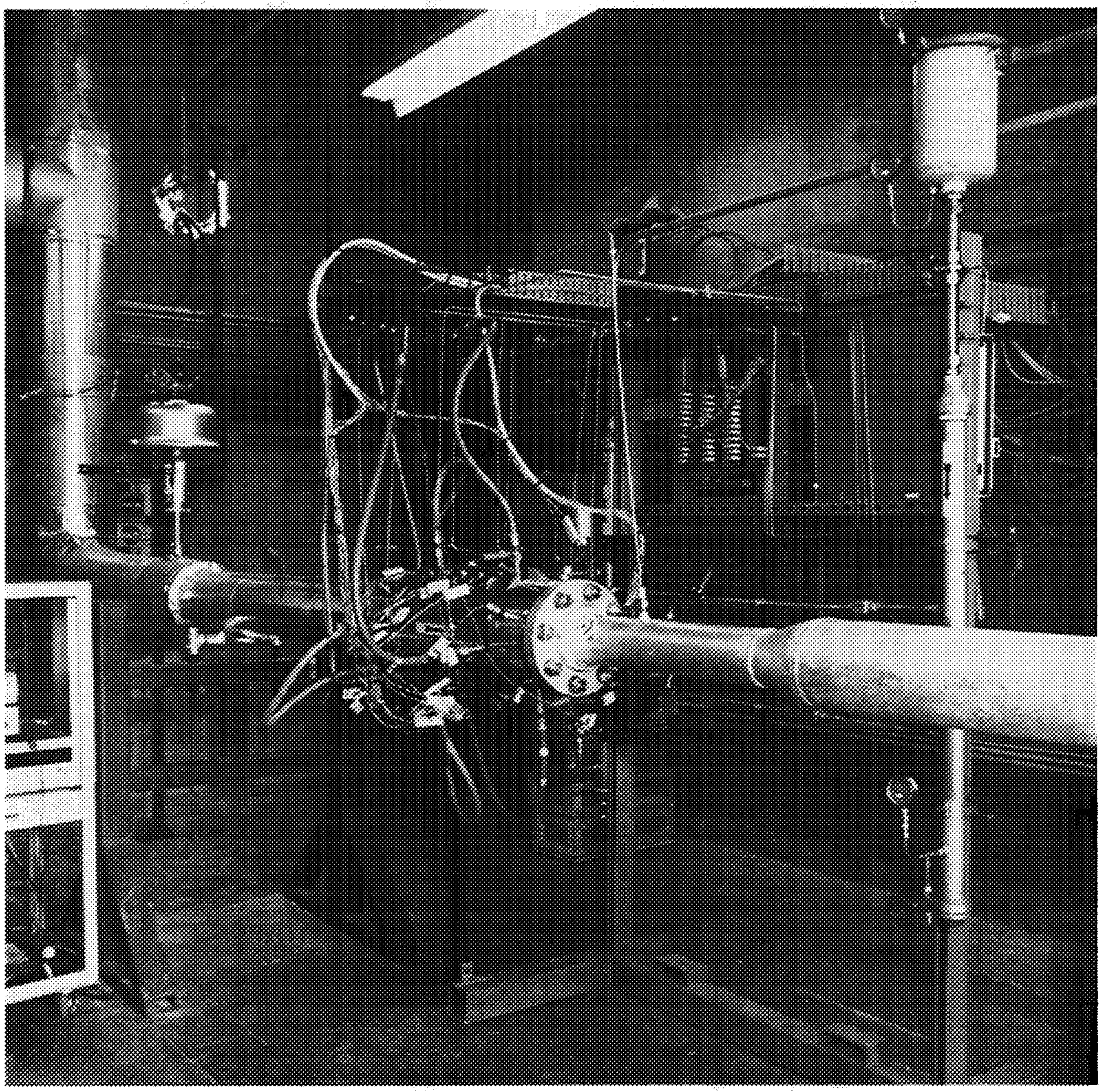


Figure 2-17. Hot-Air Test Installation

ORIGINAL PAGE IS
OF POOR QUALITY

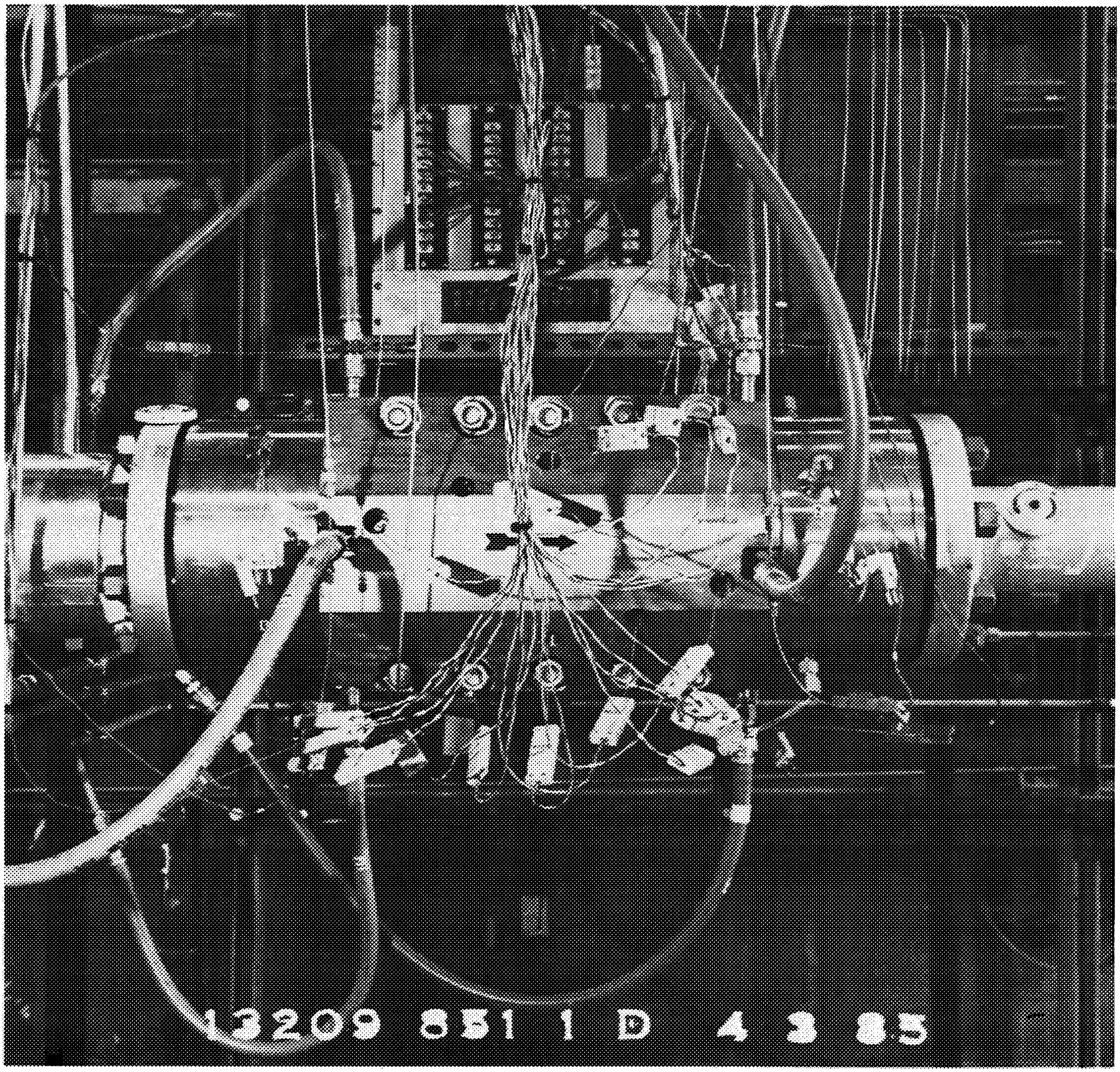
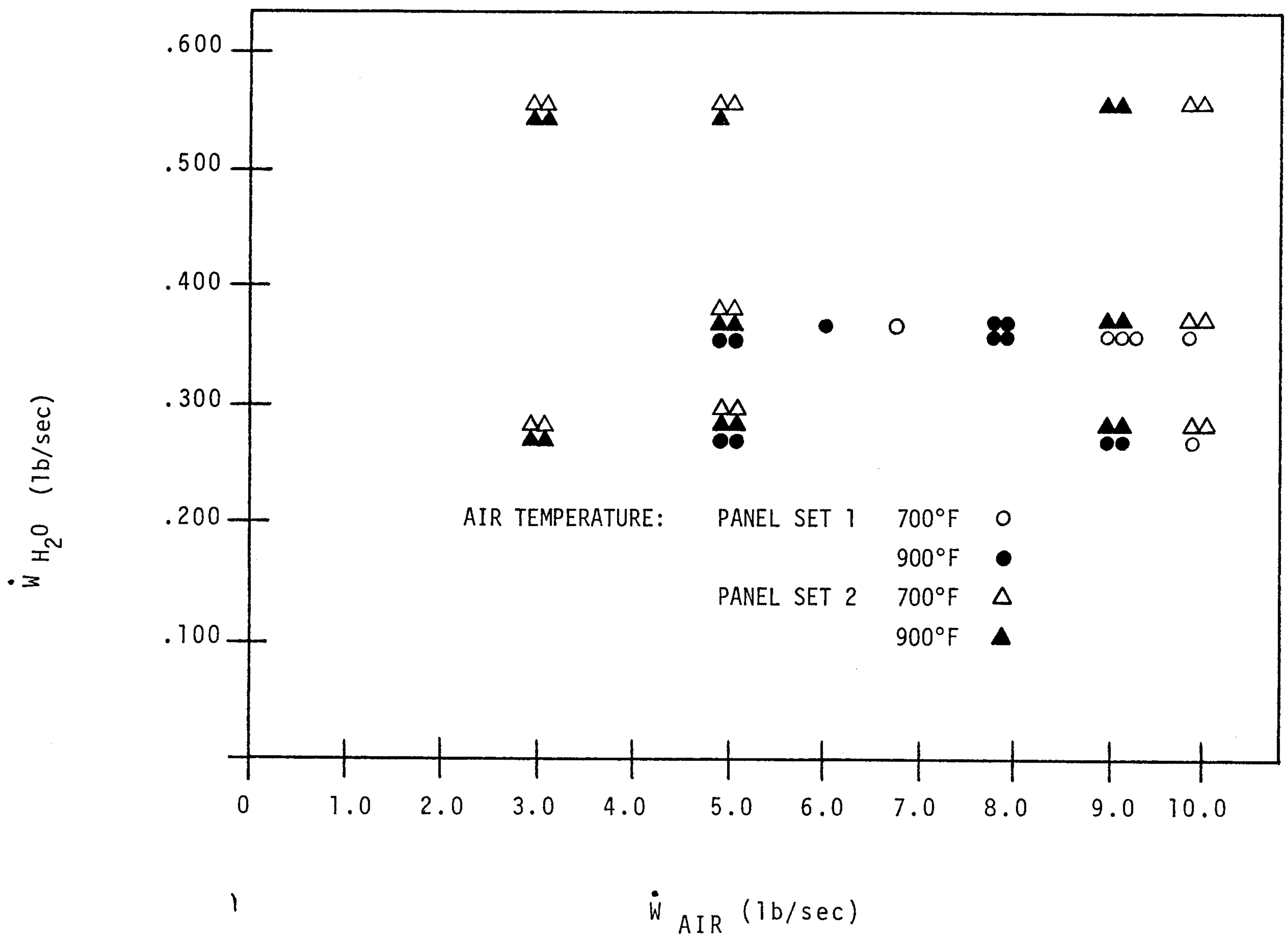


Figure 2-18. Hot-Air Chamber Test Setup

0515k

FIGURE 2-19

HOT AIR CALORIMETER PANEL TEST POINTS

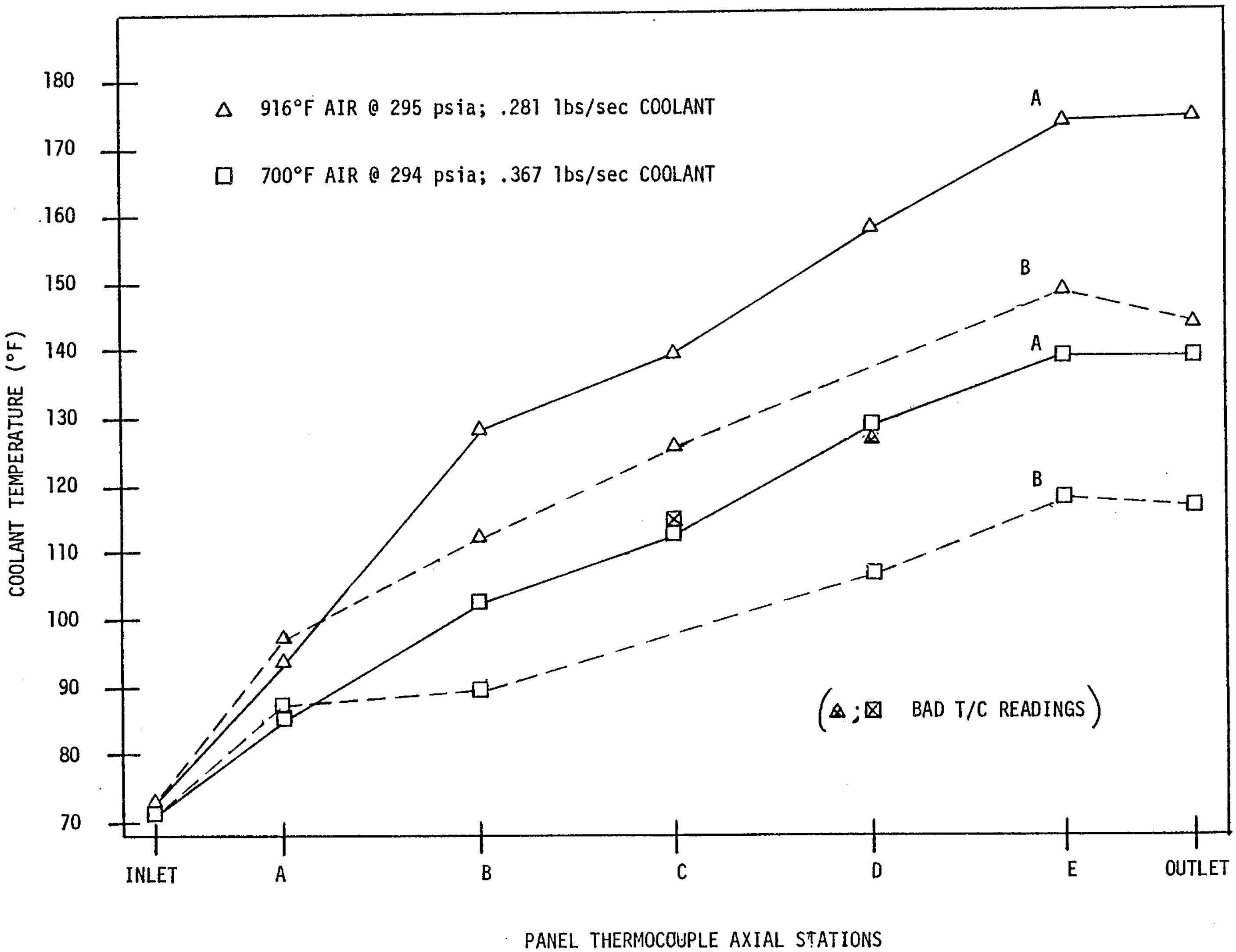


0515k

0515k

Figure 2-20

THERMAL PROFILES: PANEL A (.080 RIB) VS. PANEL B (BASELINE)



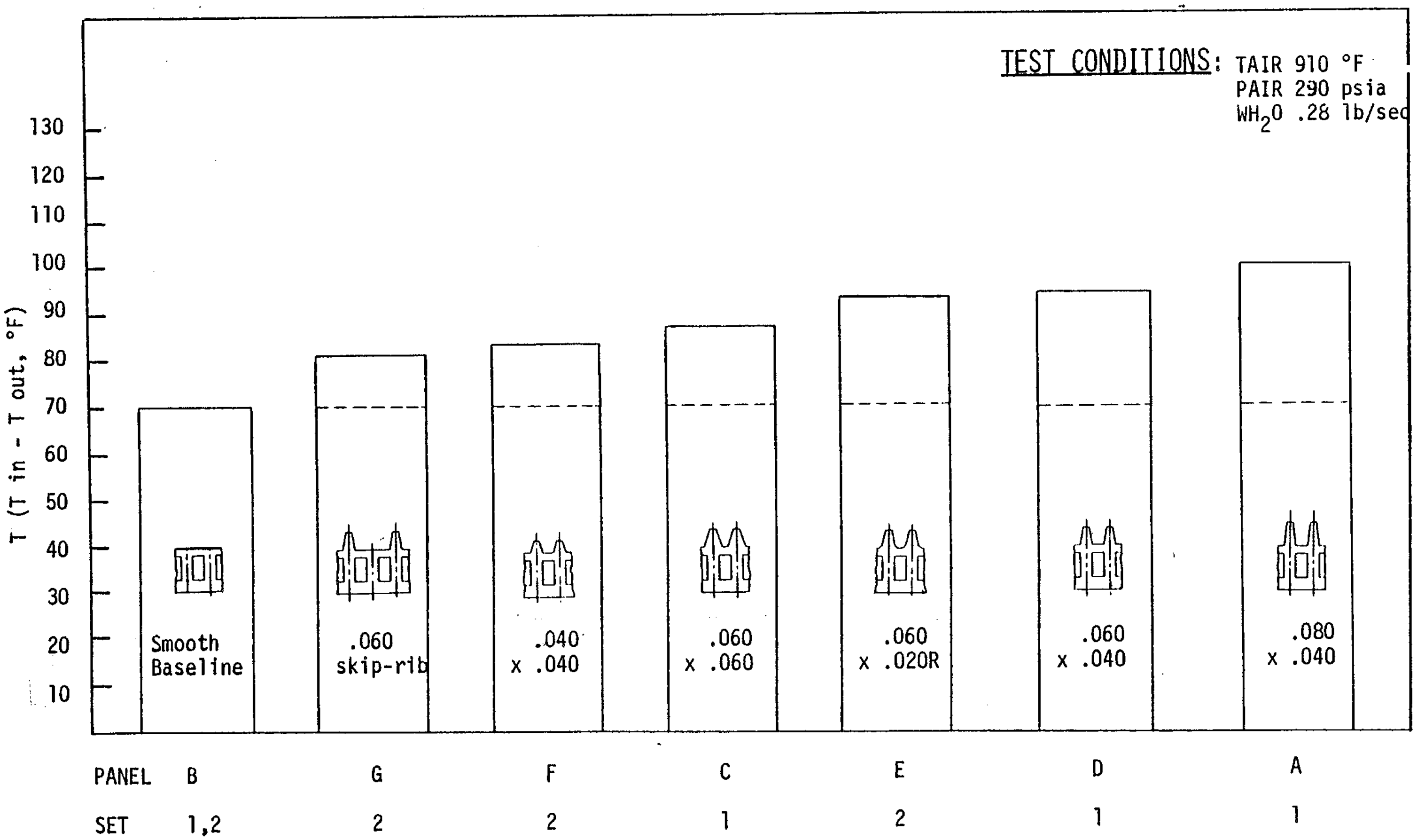
in the combustor at hot-fire conditions (see test program definition analysis), this information is representative of the axial enhancement profile for the combustor.

Representative bulk temperature rise results are presented in Figure 2-21. The taller ribs had a greater temperature rise, indicating a higher enhancement factor for the hot-air conditions. However, the difference between the taller and shorter ribs was not as large as expected based on the initial analysis at hot-fire conditions.

Results from the hot-air tests provided: 1) a direct measurement of the axial heat transfer enhancement development profile; and 2) a quantitative measure of the heat transfer enhancement at known conditions that could be used to anchor analytical methods for extrapolating results to hot-fire conditions.

Figure 2-21

TYPICAL MEASURED PANEL TEMPERATURE RISE



0515k

Fabrication

The ambient temperature and pressure conditions allowed the cold flow test fixture to be fabricated from aluminum stock. Bars and sheet stock in greater than six foot lengths were available in the sizes needed, so the large size of the fixture posed no difficulties. The components fabricated included the side members, a cover plate and windows, an inlet plenum, and three test panels.

The side members were simple rails with interfaces for the test panels and cover plate and a bolt hole pattern that matched the structural support beam. The members were machined with particular attention to the relative position of the various bolt hole patterns to ensure ease of assembly.

The cover is a 0.250 inch thick sheet that has three window openings. Fused silica windows were procured from a speciality glass supplier to meet the stringent needs for accurate velocimeter data acquisition. The windows were polished to one-quarter wavelength (coherent light) flatness and parallelism within 3 arc seconds. A broadband antireflective coating, encompassing the 514.5 nanometer laser wavelength, was applied to the outside surface to reduce reflection losses. Aluminum window 'blanks' were made to fill in for the windows not used during data collection at a particular axial station.

The test panels containing the four-times scale rib geometries were machined from plate stock. Parallelism was tightly controlled to ensure a uniform gap between the ribs. The panels were black anodized following machining to reduce reflectivity. A photograph of a test panel is presented in Figure 2-22. The panels were dimensionally inspected after completion to check acceptability and to provide exact dimensions for precise velocimeter focal volume positioning with respect to the ribs.

The inlet plenum was welded from sheet to form a funneled shape. A section of facility piping that had an existing coupling interface was welded into the plenum as the inlet piece. Prior to assembly to the test fixture, it was

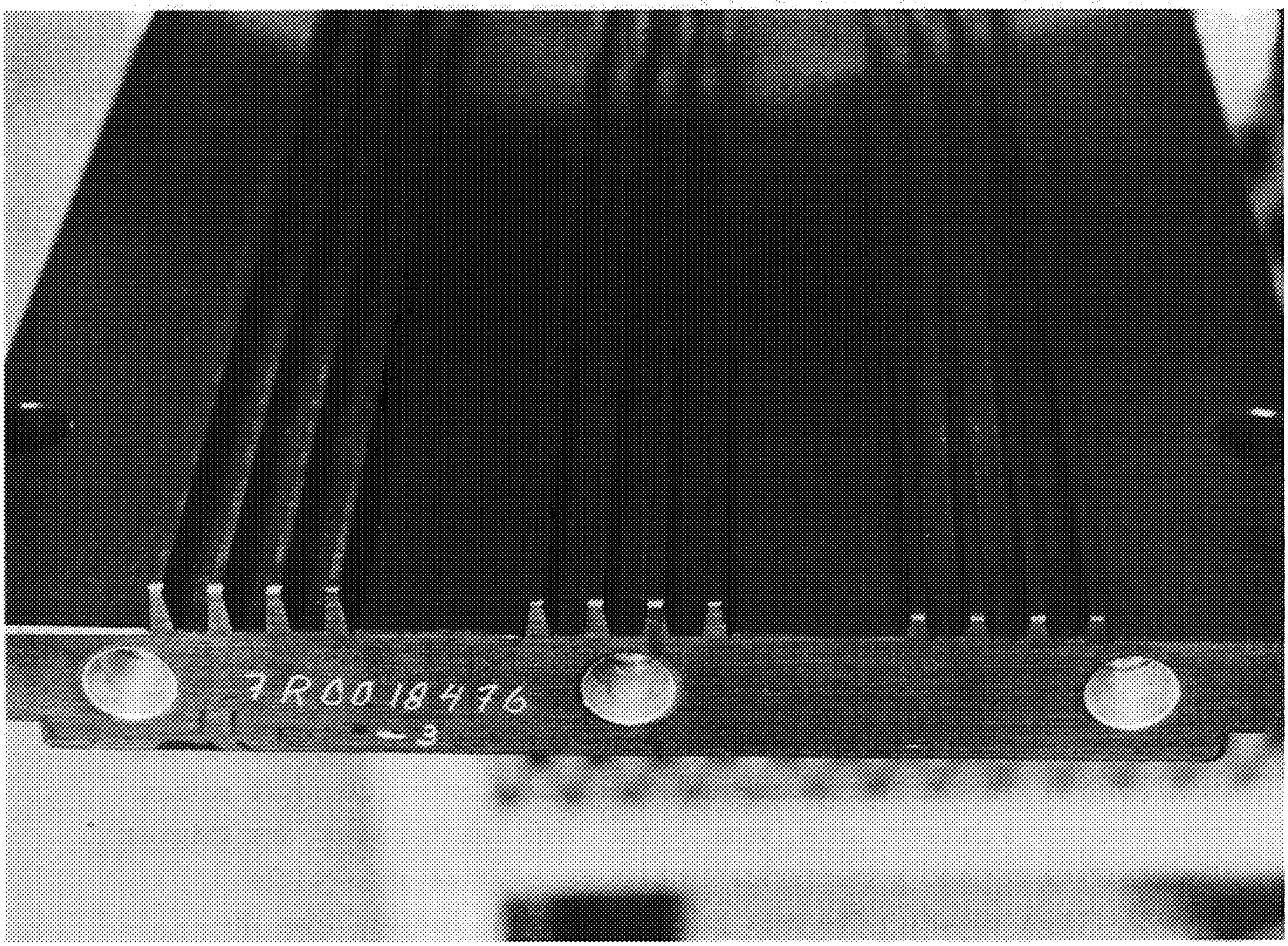


Figure 2-22. Rib Cold Flow Test Panel

decided to add a flow straighter tube bundle and flow trip screen to the straight section of the plenum that is just upstream of the fixture entrance. The bundle and screen were assembled and tacked into the plenum.

Testing

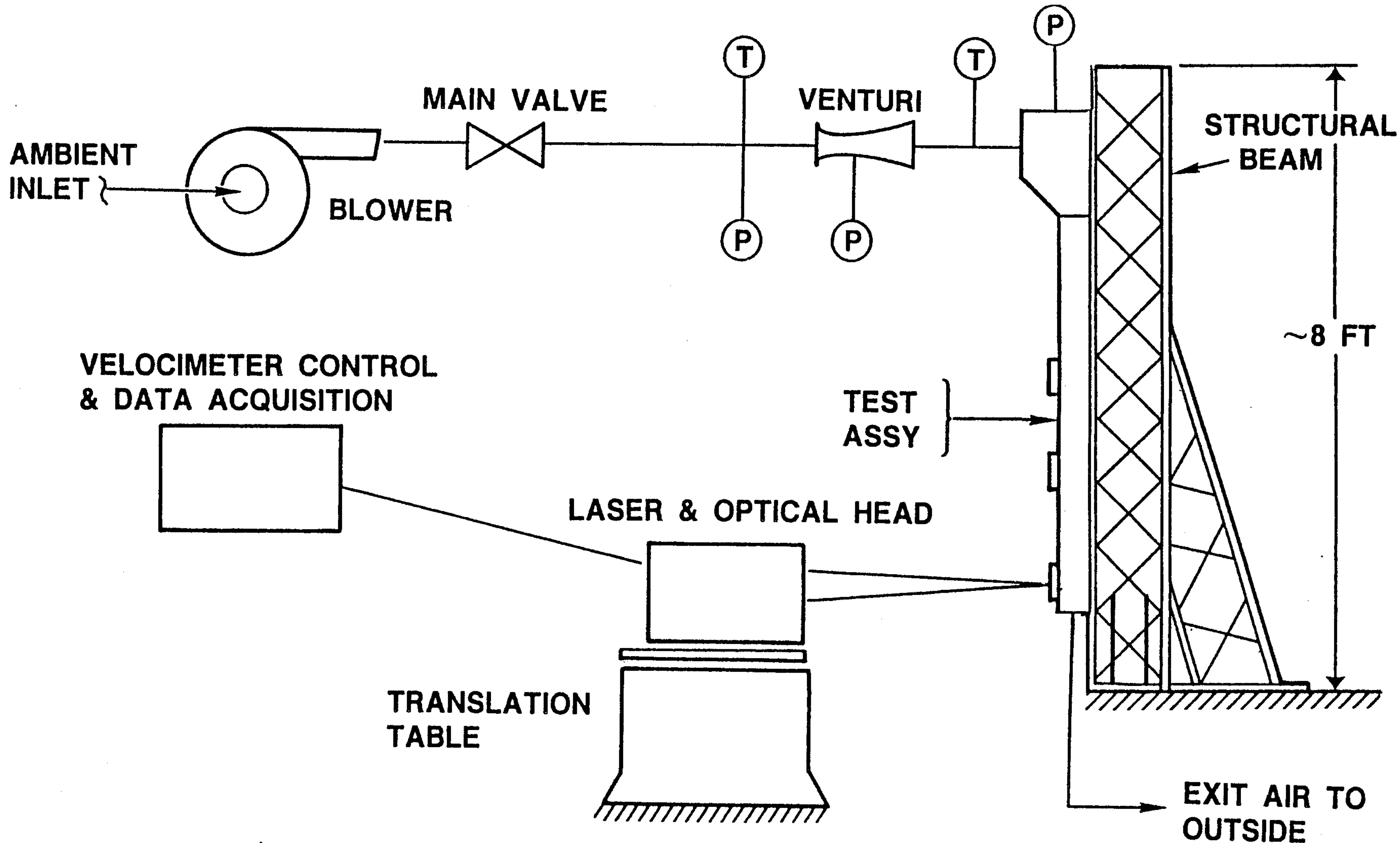
A test plan was developed to define and specify requirements for the cold flow tests (see Appendix C). The basic approach was to map the flow field around the ribs using the laser velocimeter at a single freestream flow velocity that met the conditions specified in the test planning analysis. Originally it was planned to do this at all three available axial positions, however, attainable data acquisition rates and the available test period and budget required that testing be limited to the end position.

Installation. The test position for the cold flow tests was established in Rocketdyne's Engineering Development Laboratory (EDL). The schematic for the facility is illustrated in Figure 2-23. The system used an existing low pressure air blower system with venturi measurement device to feed the test fixture. The primary measurement tool for the test set-up was the laser two-focus (L2F) velocimeter.

The velocimeter allows non-intrusive measurement of flow velocities and turbulence levels around the ribs shapes. The L2F type of velocimeter uses two sharply focused laser beams to form a 'gate' through which time-of-flight measurements can be made for small particles entrained in the flow stream. Backscattered light collected by the L2F indicates when a particle passes through either a 'start' or a 'stop' beam. When the two beams are aligned with the flow stream, a statistically high correlation of particle times-of-flight occurs. The most probable speed is derived from the statistically highest time-of-flight and the precisely known beam separation, Figure 2-24. The velocity vector is determined from the angulation of the line between the beams and a reference line. The turbulence level is determined from the breadth of the times-of-flight distribution around the most prominent value.

FIGURE 2-23

COLD-FLOW TEST SETUP SCHEMATIC



0515k

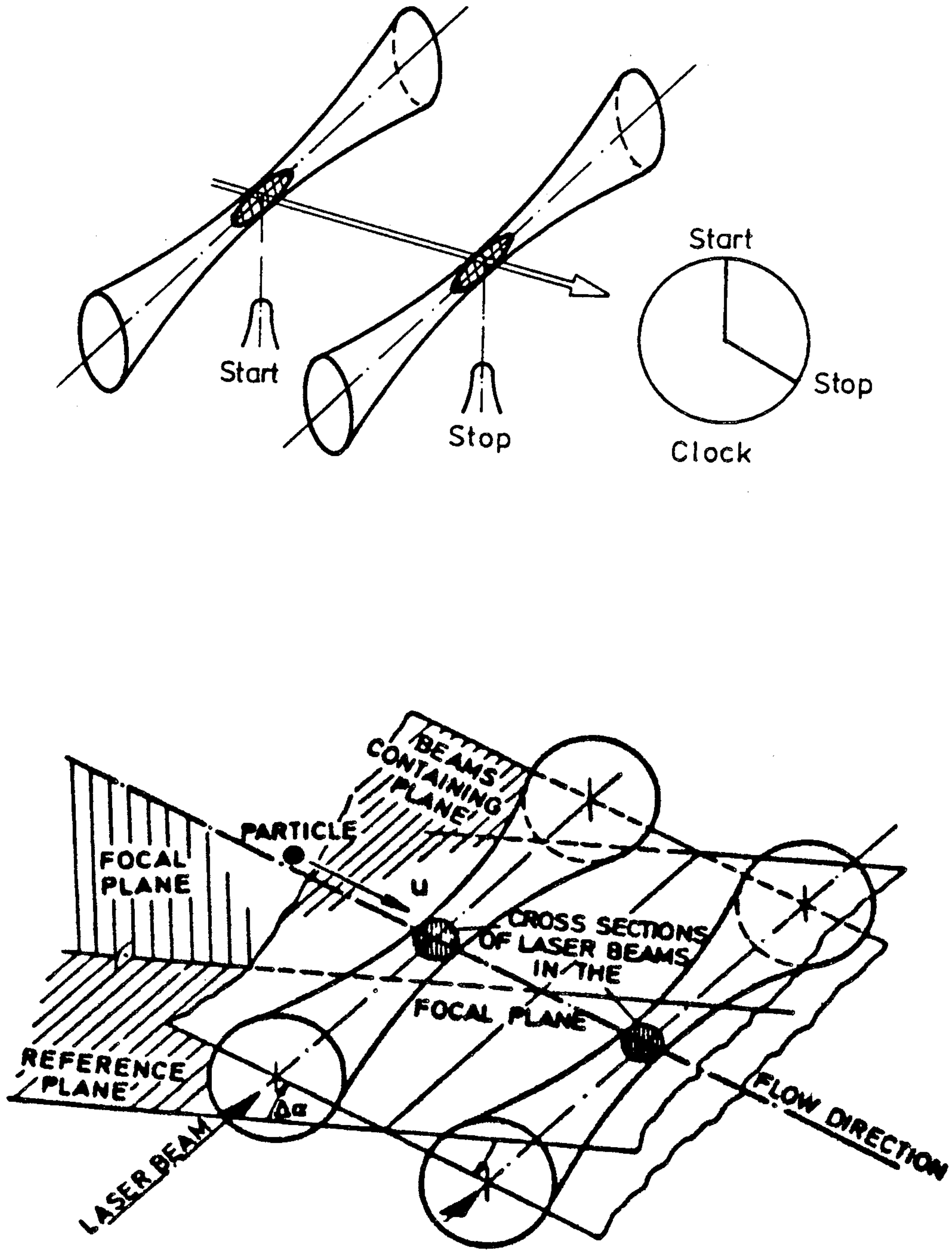


Figure 2-24. Velocimeter Time of Flight Measurement

0515k

The L2F system consists of the laser and optical head, a control processor, signal conditioning electronics, and a multichannel analyzer. Additionally, for this set-up, a remotely controlled translation system that provides precise optical head movement and positioning was used to allow a matrix of points to be collected efficiently.

The completed test set-up is shown in Figure 2-25. The fixture was positioned with the entrance at the top to eliminate the need for placing the translation table on a high platform. Fixture assembly was accomplished by: loosely bolting the side members to the structural beam, fitting the initial test panel in place and securing at the ends, check fitting the cover panel to verify alignment, final torquing the side member bolts with the panel in place, and final installation and sealing of the test panel and cover plate. The inlet plenum was secured to the beam and test fixture and the piping attached to the plenum with a coupling. Exposed interfaces were sealed with foil tape to prevent leakage.

The flow venturi and instrumentation, used to set the basic flow conditions, are visible in the left hand side of the figure. A 'bank' of insence sticks was positioned at the blower inlet to introduce small smoke particles into the flow to enhance the data collection rate.

The velocimeter optical head and translating table are shown in the test position in front of the last window. The microcomputers and processors for control of the velocimeter and translating table were in a remote clean room, Figure 2-26, and were connected to the velocimeter through data buses.

The exhaust air was collected in a large box at the fixture exit and was routed away from the test area through a flexible duct and discharged to the atmosphere.

<u>Tests</u>. Prior to conducting tests on each panel the velocimeter angular reference was established by alignment with the installed test panel. This was accomplished using a tool that referenced off the panels at the first and third windows (removed) and provided a 'line' for the velocimeter to use as a zero degree reference.

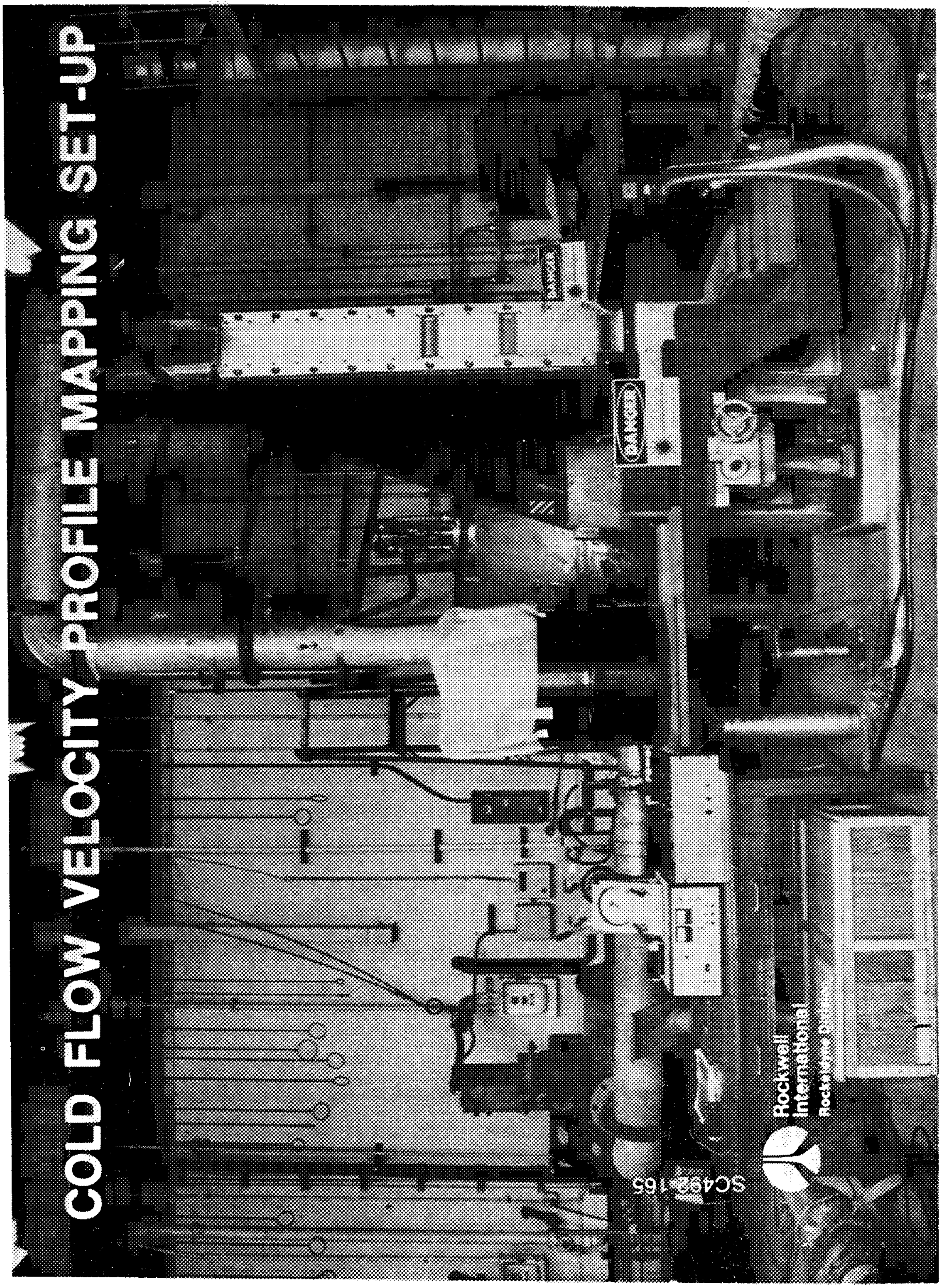


Figure 2-25

0515k

ORIGINAL PAGE IS
OF POOR QUALITY

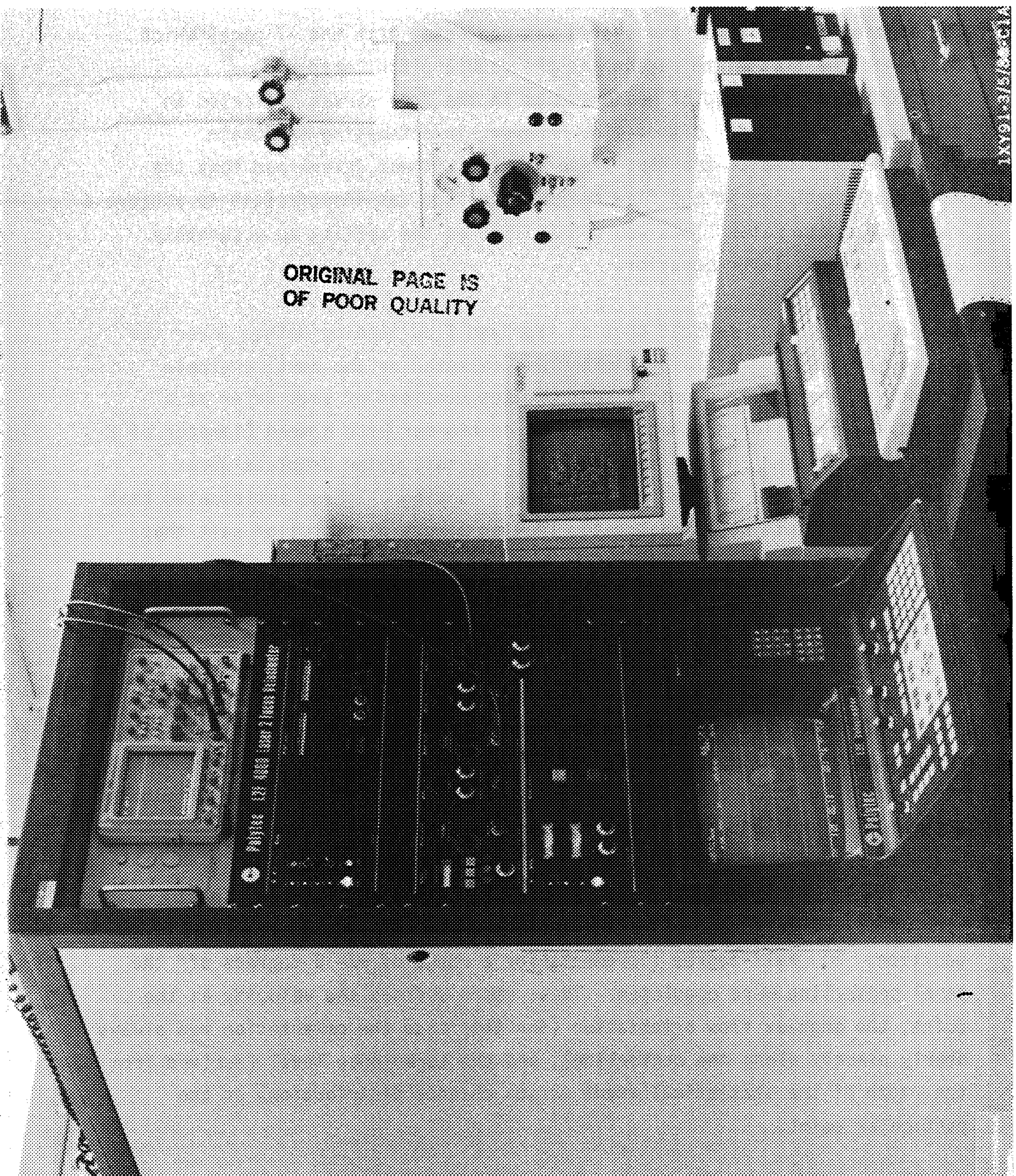


Figure 2-26. Velocimeter Data System

0515k

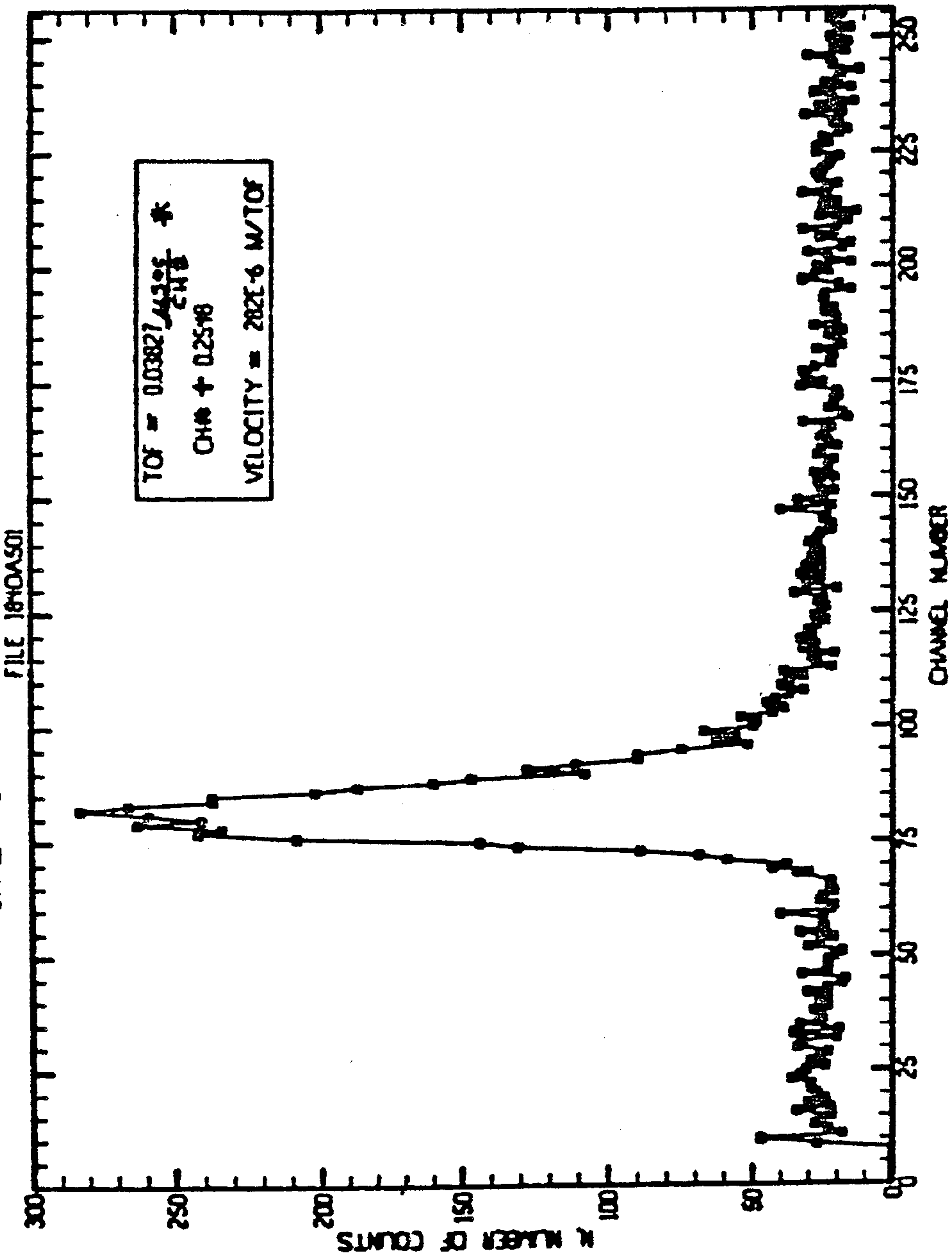
The initial checkout for the system was conducted with the -7 panel which contained the flat plate region and the double pitch 'skip rib' configuration. A sweep of measurements in the free stream indicated an acceptably uniform velocity field. However, in attempting to obtain measurements close to the flat plate surface, it was determined that the number of particles in the flow near the surface was insufficient to achieve a reasonable data rate. This would have limited the ability to accurately assess boundary layer behavior.

As a result, it was decided that an improved flow seeding method (over the smoke) was needed. A fluid atomizer was selected as the best candidate method. A jet baffle atomizer that creates droplets of salt water at a density of 6 million droplets per cubic centimeter with a mean diameter of 2 microns was leased for the test set-up. The salt water droplets were introduced into the system in the air feed ducting. It was anticipated that the water droplets would evaporate, leaving minute particles of salt that would seed the flow.

Initial tests with the revised system resulted in significantly increased data rates and measurements within 0.012 to 0.020 inch from the surface were achieved. The typical data collection process for a velocity point was: 1) the velocimeter focal volume was positioned at a specific location with respect to the ribs by computer control of the translating table; 2) times-of- flight measurements were collected at a discrete angular alignment between the fixed and moving laser beams and a histogram of occurances (events) versus time-of-flight values (listed as channels) obtained, Figure 2-27; 4) after a threshold number of events at the predominant time-of-flight had been collected, the angle was incremented to a new position; 5) half-degree increments for a range of +/- 5 degrees off the panel centerline were completed. These steps defined the velocity at the point, the angular flow orientation (for this case the orientation was always nearly exactly along the centerline), and the turbulence level (derived from the width of the statistical event versus channel distribution) at the particular point.

Figure 2-27

TIME OF FLIGHT DISTRIBUTION



0515k

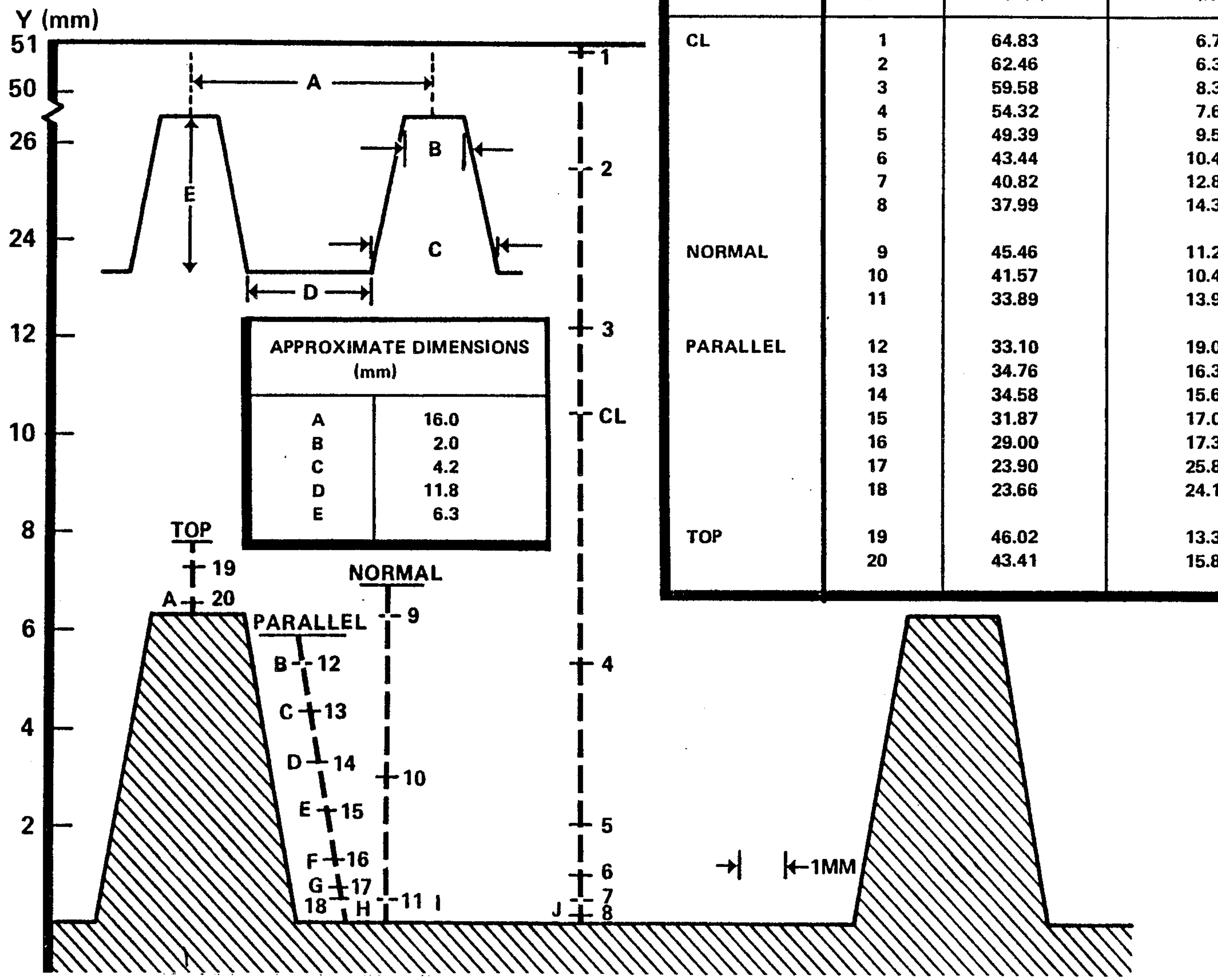
Velocity fields were mapped for the scaled up models of four rib geometries; the dual pitch 'skip' rib (0.060 high), the 0.040 tall rib, the 0.060 tall rib, and the 0.080 tall rib. In each case, the free stream velocity at the centerline of the measurement grid was measured to provide a reference velocity. A grid of points, as exemplified in Figure 2-28, was collected for each configuration to evaluate the velocity profile.

The velocity fields for each configuration are contained in Appendix C. Figure 2-29 is a graph of the normalized centerline velocity as a function of distance off the surface for the rib types. These curves illustrate the velocity degradation encountered with the taller ribs, indicating an increasing boundary layer thickness. This thickness is directly related to the heat transfer capability.

These tests provided quantified profiles of the velocity fields around the rib configurations for representative momentum boundary layer development conditions. This information was collected to provide a basis for adjusting hot-fire boundary layer predictions to obtain accurate hot-fire heat transfer calculations.

FIGURE 2-28

AIR FLOW VELOCITY MAPPING RESULTS FOR SKIP RIB CASE

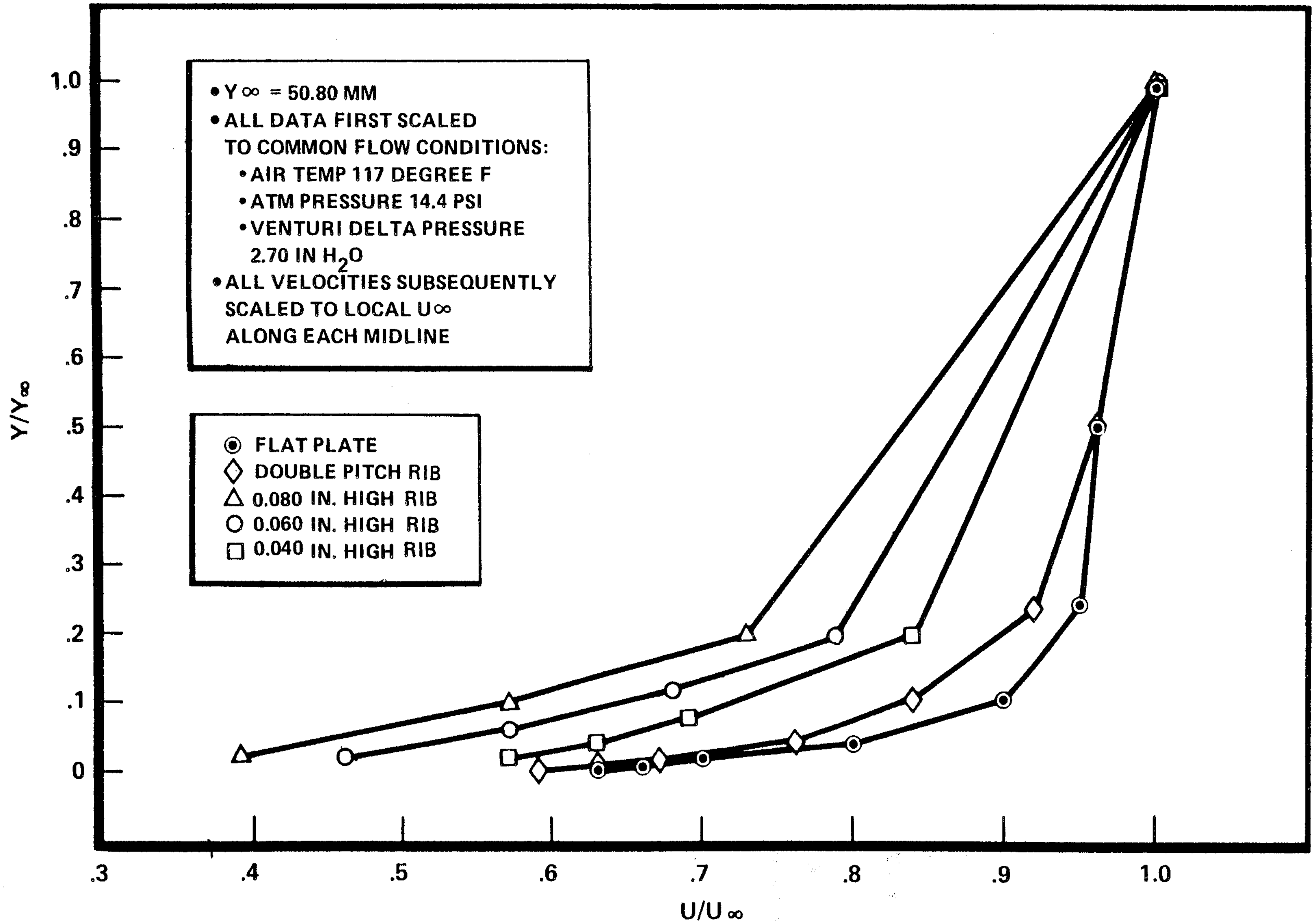


APPROXIMATE DIMENSIONS (mm)	
A	16.0
B	2.0
C	4.2
D	11.8
E	6.3

PLANE	POINT	VELOCITY (m/s)	TURBULENCE (%)
CL	1	64.83	6.77
	2	62.46	6.35
	3	59.58	8.30
	4	54.32	7.66
	5	49.39	9.51
	6	43.44	10.41
	7	40.82	12.83
	8	37.99	14.34
NORMAL	9	45.46	11.25
	10	41.57	10.48
	11	33.89	13.97
PARALLEL	12	33.10	19.04
	13	34.76	16.31
	14	34.58	15.64
	15	31.87	17.08
	16	29.00	17.37
	17	23.90	25.80
	18	23.66	24.15
TOP	19	46.02	13.36
	20	43.41	15.86

FIGURE 2-29

NONDIMENSIONALIZED SCALED VELOCITIES
ALONG MIDLINE BETWEEN RIBS



Scaling Procedure

The scaling procedure for the velocimeter data, which provides a comparison of heat transfer enhancement at hot-fire conditions, is summarized below. A flow diagram of the scaling process is presented in Figure 2-30 as an aid in following the summary. A numerical example of the rib scaling analysis is presented in Appendix D.

Velocity profile data were obtained as close as possible to the model wall to provide the best indication of the boundary layer behavior. A nondimensional heat transfer parameter, the Stanton number, was determined from the velocity profile. The Stanton number varies around the rib profile and directly reflects the influence of the boundary layer development on the heat transfer. The Stanton number is derived from a process in which the local skin friction is determined from a piecewise wall velocity evaluation.

The velocity profiles are fit to a universal profile in the logarithmic overlap region of the turbulent boundary layer, Figure 2-31. The universal velocity profile has a best fit equation for the logarithmic overlap region as,

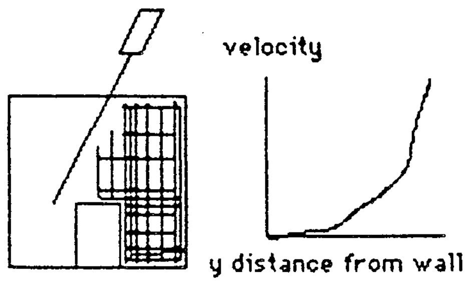
$$U^{+} = 2.43 \, \ell n \, (y+) + 4.9 \quad \text{Log overlap region velocity profile}$$

where,

$u^{+} = U/V^{*}$	Dimensionless velocity
$y^{+} = yV^{*}/V$	Dimensionless distance above the plate or rib

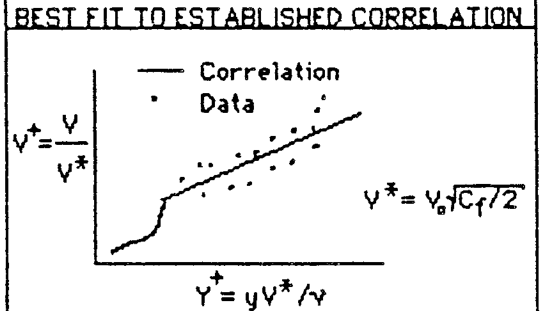
Figure 2-30. FLOWCHART OF THE DATA REDUCTION PROCEDURE FOR THE COLD FLOW TESTS.

LASER VELOCIMETER TESTS



VELOCITY PROFILES ARE MEASURED BY THE TWO-FOCUS LASER SYSTEM. THE MOST IMPORTANT MEASUREMENTS ARE THE VELOCITY PROFILES ALONG A NORMAL FROM THE SURFACE. EMPHASIS WAS ON THE TROUGH REGIONS WHERE THE FLOW IS SLOWED DUE TO MERGING BOUNDARY LAYERS.

BEST FIT TO ESTABLISHED CORRELATION



THE VELOCITIES WERE PLOTTED IN TERMS OF THE "INNER VARIABLES" AND FITTED TO THE ESTABLISHED EQUATION FOR FLAT PLATE TURBULENT BOUNDARY LAYERS:

$$V^+ = 2.43 \ln(Y^+) + 4.9 \quad \text{(LOGRITHMIC REGION)}$$

THE BEST FIT WAS MADE BY VARYING THE FRICTION VELOCITY V* . THIS DEFINED THE LOCAL SKIN FRICTION FACTOR. A V* WAS CHOSEN AT EACH WALL LOCATION.

CALCULATION OF HEAT AND MOMENTUM COEFFICIENTS

$Cf/2 = (V^*/Vo)^2$ Skin friction factor

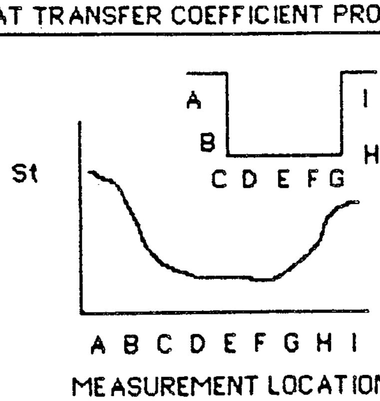
$St = Cf/2\ Pr^{2/3}$ by Reynolds Analogy the Stanton number

THE FRICTION FACTOR DIRECTLY DEFINES THE HEAT TRANSFER STANTON NUMBER BY THE REYNOLDS ANALOGY, WHICH IS SHOWN WITH A PRANDTL NUMBER CORRECTION, WHERE:

$$St = \frac{h}{\rho VoCp} \qquad \text{Stanton number}$$

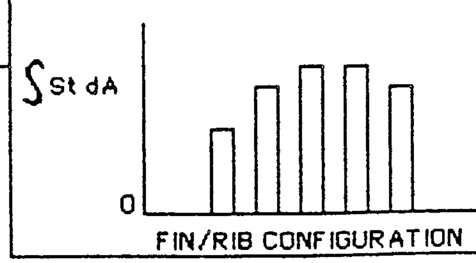
THE STANTON NUMBER WAS DETERMINED AT EACH WALL LOCATION. AN AREA INTEGRATION OF St ABOUT THE FIN/RIB GAVE A TOTAL HEAT TRANSFER WHICH WAS USED AS THE BASIS FOR COMPARISON FOR DIFFERENT CONFIGURATIONS.

HEAT TRANSFER COEFFICIENT PROFILE



REPEAT PROCESS FOR ANOTHER CONFIGURATION

TOTAL HEAT TRANSFER COMPARISON



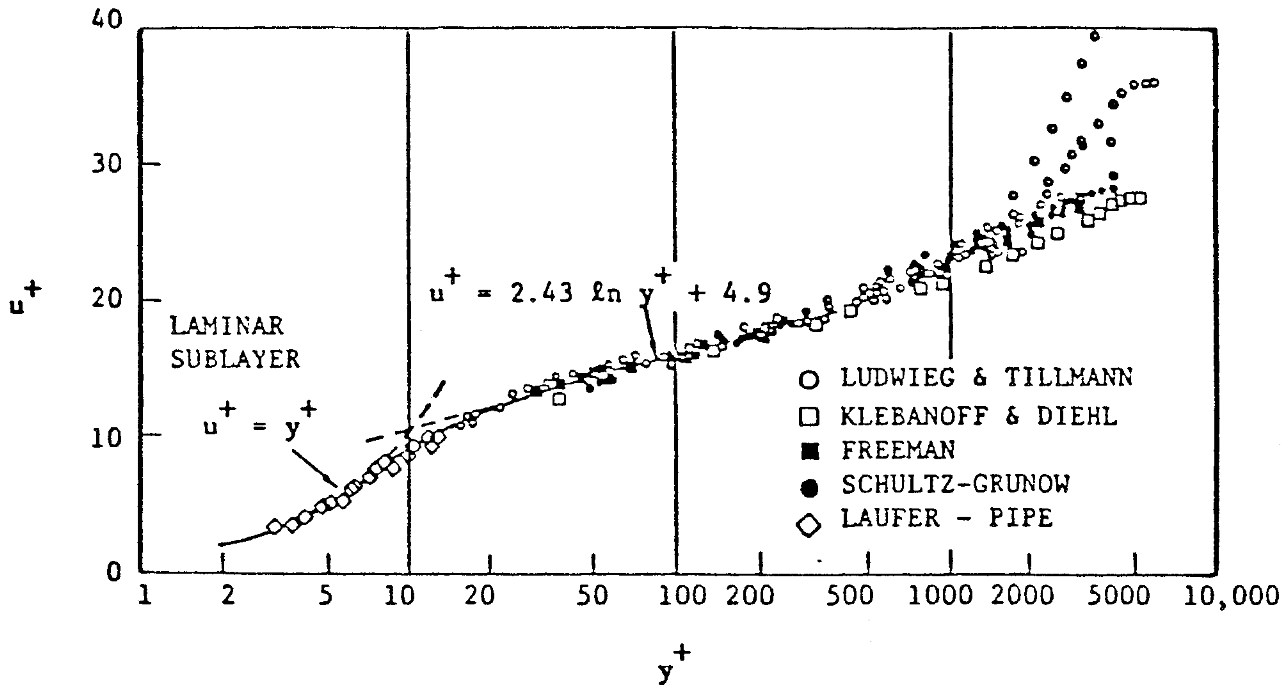


Figure 2-31. Turbulent Boundary Layer Universal Velocity Profile

U = local velocity [m/s]
y = distance from surface [m]

$v^* = \sqrt{Tw/\rho}$ $\qquad$ $Uo = \sqrt{Cf/2}$ $\qquad$ "Friction velocity"

Uo = Freestream velocity
Tw = Wall shear stress
ρ = fluid density
Cf = Skin friction coefficient

The basic premise for the data analysis method was that, at any location on a rib or fin, the boundary layer could be characterized by a flat plate boundary layer having the same near-wall region called the "logrithmic overlap region". Under these test conditions, the overlap region extends from about one-half millimeter to several millimeters from the wall.

As evidence of the applicability of the established correlation, it was compared to the measurements from the Cold Flow tests performed on a flat plate as shown in Figure 2-32. The agreement was very good except at large distances from the wall where the correlation is no longer valid. Therefore, it was shown that the cold flow velocimeter measurements could reproduce the results of past flat plate studies.

The data from the cold flow tests were fit to this universal profile by choosing an appropriate friction velocity V*. This defines the shear stress at the wall based upon the empirical results of past flat plat turbulent boundary layer studies. In effect, it is assumed that the boundary layer at each location around the rib is equivalent to a flat plate boundary layer of the same thickness.

The heat transfer Stanton number is derived from the wall shear stress or skin friction coefficient by the Reynold's analogy,

$$St = Pr^{2/3} \ Cf/2 \qquad (1)$$

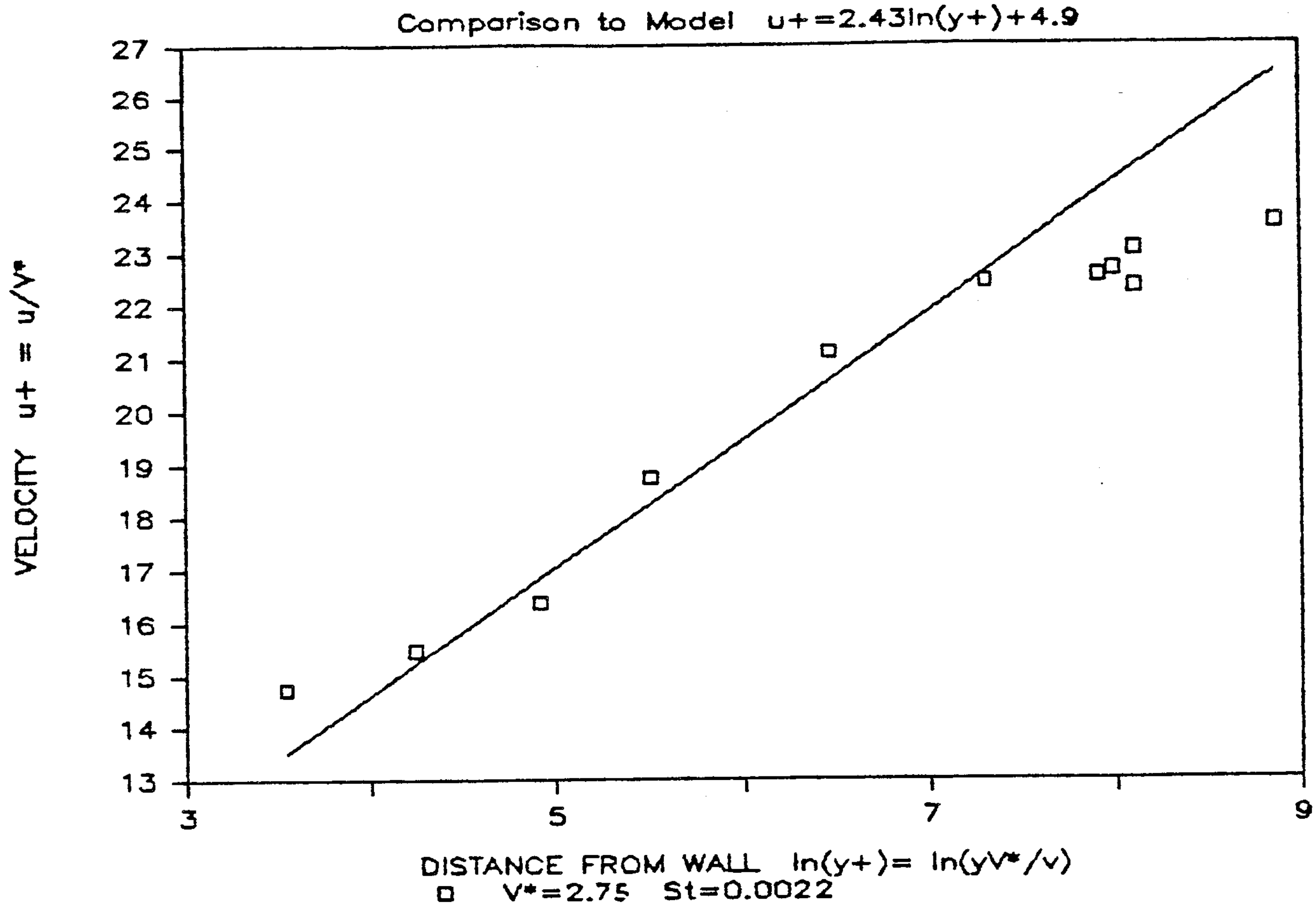
where,

$St = h/\rho \ (UoCp)$ $\qquad$ Stanton number $\qquad$ (2)

$Pr = 0.69$ $\qquad$ Prandtl number for air

h = local heat transfer coefficient

Figure 2-32. FLAT PLATE VELOCITY PROFILE



0515k

The Stanton number can be thought of as a dimensionless heat transfer coefficient. Specifically, it is the ratio of the heat transferred to the total heat (enthalpy) content of the flowing gases. The Stanton number profile for the 'skip-rib' case that was derived from the previously presented velocity profile is shown on Figure 2-33.

The heat transfer coefficient (h) values for hot-air calorimeter or hot-fire conditions are determined by scaling the density, freestream velocity, and gas heat capacity denominator in equation (2) above to the appropriate conditions. For the hot-air calorimeter test series this provides an accurate scaling since the conditions are not radically different than the cold flow tests. This is reflected in the typically close results for the scaled calorimeter and the actual test results.

For hot-fire test conditions, a further scaling or compensation must be made for the extreme conditions produced by the combustion process. Conditions not present in the cold flow testing, such as an extremely high freestream velocity, compressibility due to high pressures, and other properties that vary with temperature are accounted for in the scaling. The scaling factors were determined from hot-fire conditions analysis using Rocketdyne's boundary layer analysis program. This scaling results in a more realistic or 'best' treatment of the cold flow data by accounting for these factors that cannot be simulated in the laboratory.

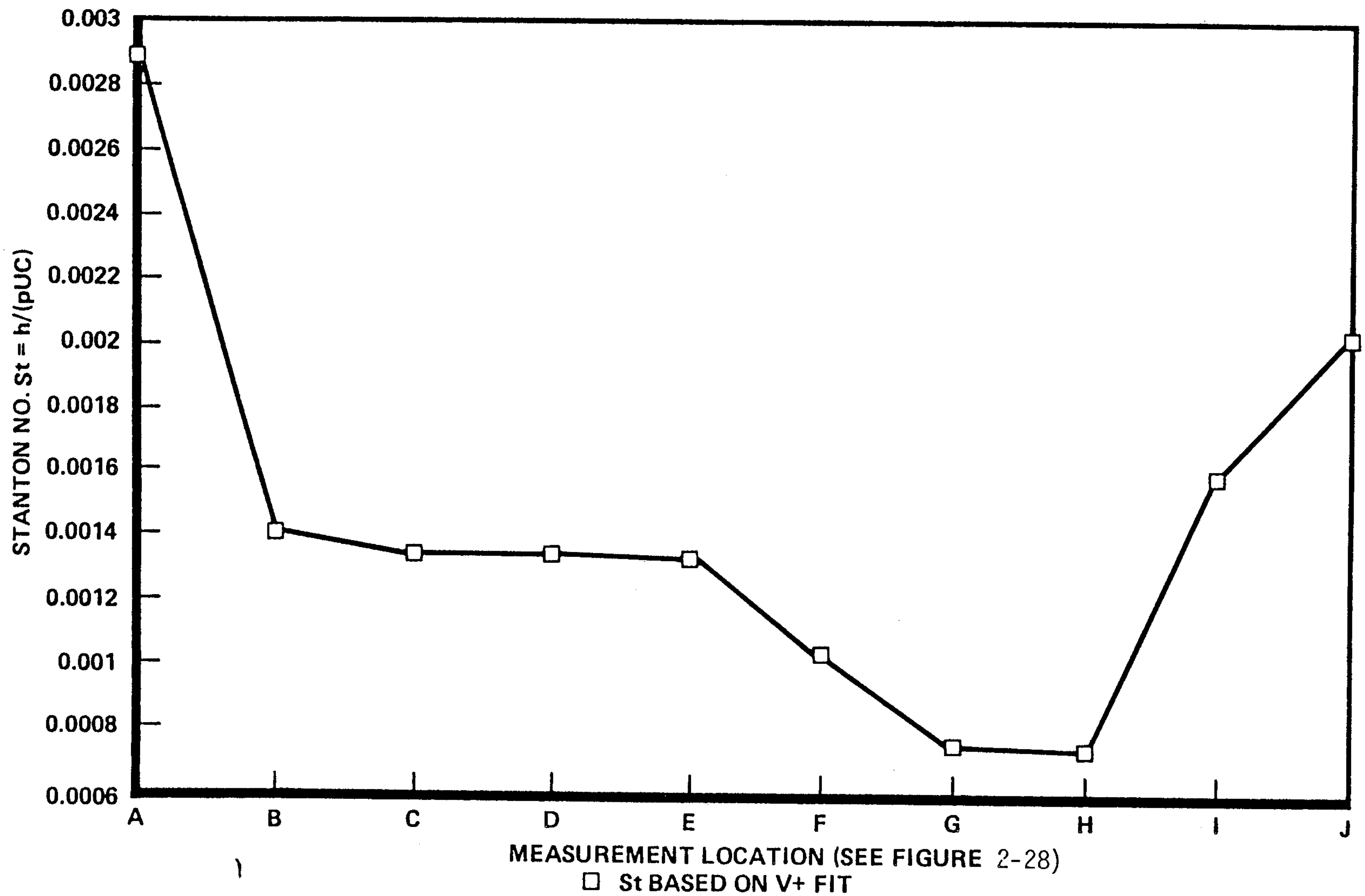
Results

Extrapolation of the cold flow test results to hot-fire conditions was performed in two ways. The difference lies in the scaling of the Stanton number. A conservative estimate of the cooling performance of a rib/fin configuration was afforded by direct usage of the cold flow test Stanton number profiles. A more realistic estimate was provided by the utilization of an appropriately scaled Stanton number profile. In both cases, the Stanton numbers were used to provide heat transfer coefficients to a DEAP thermal model of the combustor wall and channel.

FIGURE 2-33

RIB HEAT TRANSFER PROFILE

SKIP RIB CASE



Scaling the Stanton number required the utilization of thrust chamber aerodynamic and thermal computer models. A boundary layer computer model was required to provide a realistic hot-fire heat transfer coefficient between the combustion gases and the combustor wall. A regenerative cooling computer model named REGEN was used to determine a realistic heat transfer coefficient between the channel wall and the coolant.

The boundary layer computer model predicts a different heat transfer coefficient than a typical flat plate correlation because of the extreme environment existing in a combustor or nozzle. The influence of many effects such as high velocity, fluid compressibility, high pressure, high temperature and thermal gradients, and non-uniform fluid properties are modeled in this program. A scaling factor Sg was applied to the Stanton number profile on the ribs as defined by,

$$S_g = \frac{\text{St from BL model}}{\text{St from flat plate Cold Flow test}}$$

$$= 0.5 \qquad \text{(Gas side scaling factor)}$$

The REGEN computer model has been used extensively by Rocketdyne in the thermal design of regeneratively cooled thrust chambers. REGEN was used to determine the heat transfer coefficient on the liquid side. This was expected to differ from a typical internal flow correlation because of the differences in thermal properties between fluids such as air and a supercritical cryogenic coolant. A scaling factor S_l was applied to the channel Stanton number profile as defined by,

$$S_l = \frac{\text{St from REGEN}}{\text{St from open channel Cold Flow Test}}$$

$$= 1.2 \qquad \text{(Liquid side scaling factor)}$$

After these scaling factors were applied to the Stanton number profiles, the corresponding heat transfer coefficients were calculated based upon rocket engine conditions (by definition, h = St ρUoCp). These values provided the boundary conditions for DEAP thermal model of the combustor wall and channel. This model predicted the hot-fire wall temperatures and heat fluxes corresponding to the different rib and channel configurations.

The heat transfer enhancement predictions for hot-fire conditions are shown in Figure 2-34, which compares the heat transfer rates relative to a smooth wall. The percent of heat transfer enhancement is listed above each bar. The lower, conservative, estimate was based upon unscaled Stanton number profiles. The best estimate utilized the scaling factors S_g and S_l before inputting the Stanton number profiles into the DEAP model. These values provide a bracket on the enhancement that can be expected in an actual combustor.

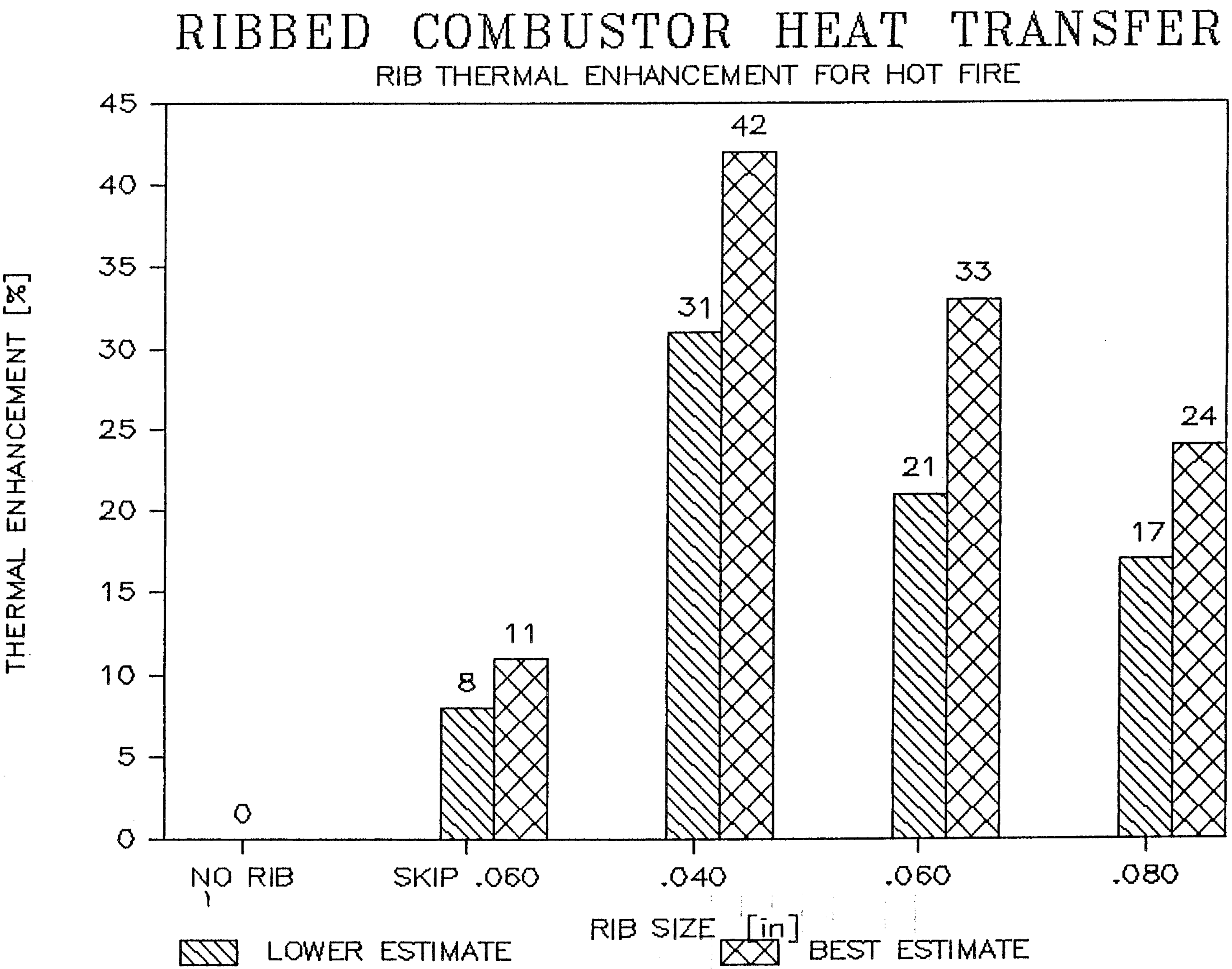
A summary of the rib flow test results and analyses is shown in the bar chart in Figure 2-35. Each rib configuration has four bars associated with it corresponding to the results of: unscaled Cold Flow tests, Hot Calorimeter tests, a DEAP thermal model for calorimeter conditions, a DEAP model for hot-fire conditions.

A comparison of the first two bars of each configuration demonstrates that the Cold Flow tests and the Calorimeter tests yield comparable results. These tests predict the heat transfer enhancement within 5% of each other. This lends support to the cold flow test data analysis procedure used in the transformation of velocity profiles to heat transfer rates.

The third bar of each configuration represents the result of a ribbed wall and channel DEAP thermal model which was run for the calorimeter test conditions. In this model, the Stanton number profiles predicted in the cold flow tests were used to determine the heat transfer coefficient about the rib. This represents the heat transfer prediction based upon cold flow results for a location near the end of the cylindrical combustor. Since this is the region of minimum enhancement due to boundary layer growth, it was expected that this predicted value would be less than the corresponding calorimeter result.

The fourth bar represents the DEAP model best estimate for hot-fire conditions. A substantial lowering of the rib effectiveness was expected due

FIGURE 2-34

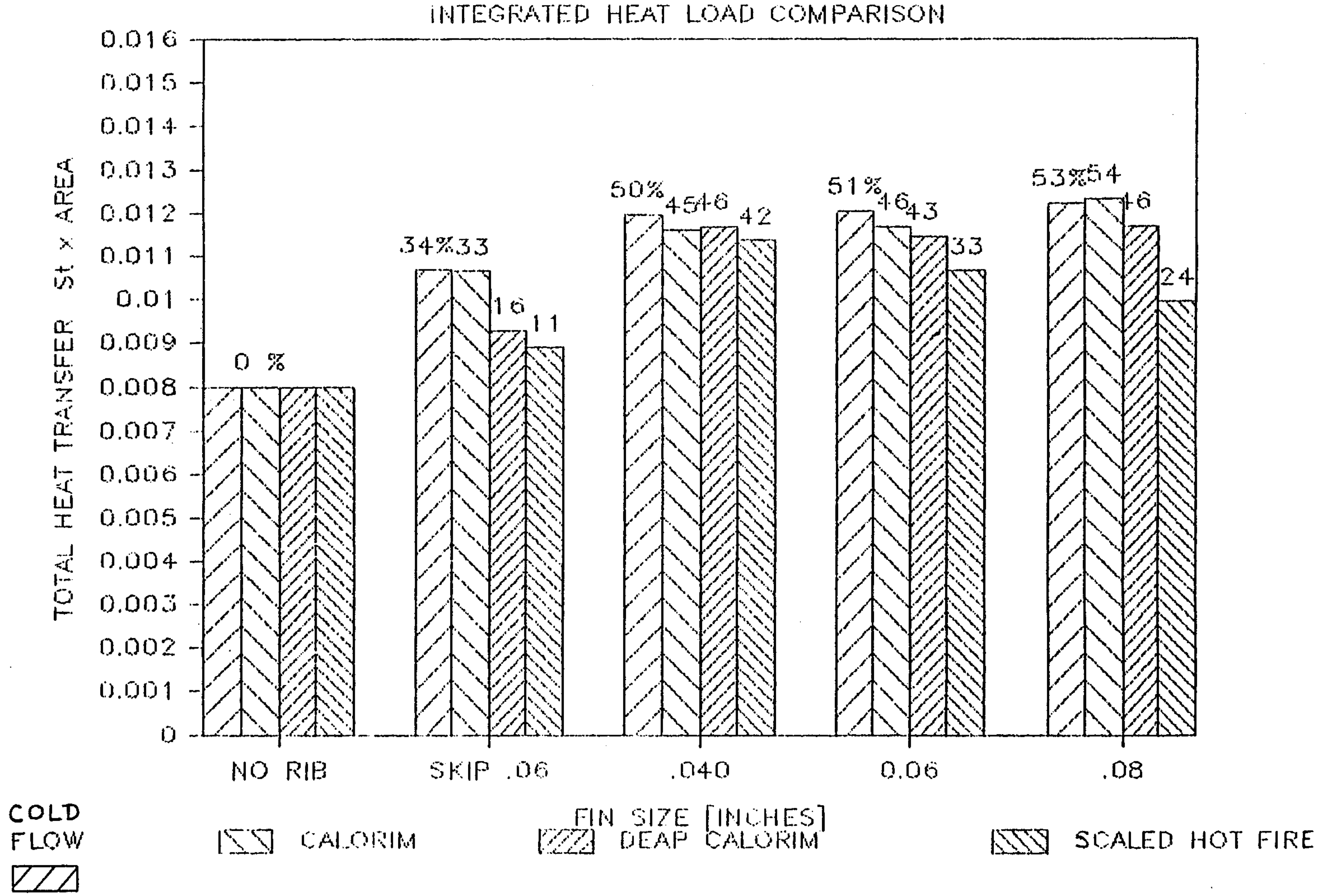


RI/RD86-199
2-60

0515k

FIGURE 2-35

RIBBED COMBUSTOR HEAT TRANSFER RESULTS



0515k

to the non-isothermal rib effect at high heat fluxes. Since the calorimeter tests were performed at relatively low heat fluxes, the ribs were isothermal. However, under hot-fire conditions the rib tip was predicted to be much hotter than the rib base, thus decreasing the effectiveness of the rib.

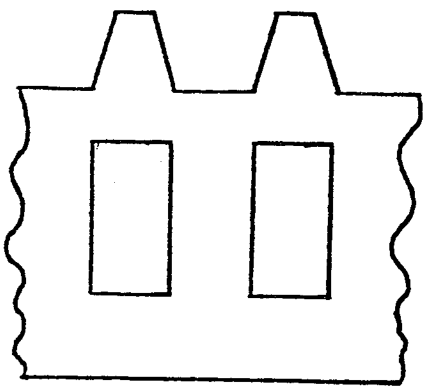
Selected Rib Configurations

Results of scaling analysis using the cold flow velocimeter data have indicated that a 0.040 high-0.040 base truncated triangular rib with a 0.020 tip width and a pitch of 0.0785 had the highest performance. Wall temperatures for this configuration are projected to be acceptable and fabricability was demonstrated during fabrication of the hot-air calorimeter test chamber. Accordingly, this design is the top recommended configuration.

The second recommended configuration is a 0.030 high-0.040 base truncated triangular rib with a 0.020 tip width and a 0.0785 pitch. This design was not directly tested in the air test programs, but is projected to be near the peak of the enhancement curve derived from test data. The design will also have a lower wall temperature than a taller option having the same enhancement so will have a longer life.

Taller rib configurations and those with greater pitches, such as the 'skip rib' design, are not favored due to lower enhancement at hot-fire conditions. The taller ribs are also predicted to have higher wall temperatures which reduce combustor life.

The selected configurations are depicted in Figure 2-36 with standard 0.040 x 0.080 coolant channels included as a reference.



0.040 tall - 0.040 base rib with
0.020 tip width - 0.0785 pitch

0.030 tall - 0.040 base rib with
0.020 tip width - 0.0785 pitch

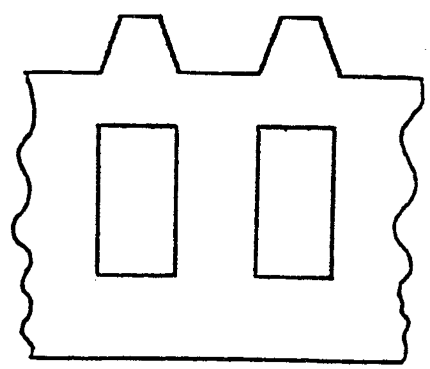


Figure 2-36. Selected Rib Configurations

3.0 SUBTASK II - INCREASED LIFE STUDY

OBJECTIVE

The objective of this study was to evaluate alternate combustor coolant channel geometries that will enhance the combustor liner service life. Design objectives are to maintain an acceptable wall temperature with the increased heat extraction due to hot-gas wall ribs without excessive coolant circuit pressure drop or adverse structural efficiency. Supporting task objectives were to: screen appropriate channel candidate configurations; evaluate the flow characteristics in the channels; compare the designs at hot-fire conditions; and select the best designs for hot-fire test evaluations.

APPROACH

The approach followed for this subtask is summarized in the right hand side of Figure 1-2. A matrix of candidate channel configurations was developed based on previous design studies at Rocketdyne. The matrix featured channels with base fins, high aspect ratio rectangular channels, rounded corner channels, and channels with interrupted flow fins. The base fins were of varying width, aspect ratio, shape, and number (one or two).

These candidates were screened by relative rating for temperature reduction capability (life), pressure drop, boundary layer build-up risk, producibility, and heat transfer enhancement. Heat transfer analyses were conducted using a two-dimensional computer model using fully developed flow characteristics in the channels. Results of the thermal analyses and evaluations in the other categories were used to select eight configurations for laboratory testing.

A cold flow velocity profile mapping test series, using the same fixture as in the hot-gas rib series, was conducted for the various channel configurations. The air flow velocity data were analytically scaled to hot-fire conditions to evaluate channel performance.

Three enhanced channel configurations were selected for hot-fire evaluation in the next program phase.

SCREENING ANALYSIS

A matrix of enhanced coolant channel concepts was formulated to provide a number of options for enhancing cooling efficiently. Five categories of channel enhancement methods were included:

I. Standard rectangular shape - varied aspect ratio
   - Variations on present channel design - no change in fabrication methods.

II. Finned base - varied aspect ratio, number of fins, and the fin taper
   - Preliminary analysis shows promise in reducing hot-gas rib temperature.

III. Varied corner radii for cases I and II
   - To evaluate effects of varied radii on boundary layer and ΔP.

IV. Alternating channels, of Case I and II or I and III
   - Using alternate channel types may allow specific cooling of hot spots (ribs) without a great sacrifice in coolant ΔP.

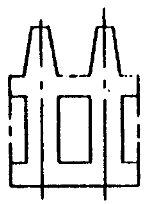
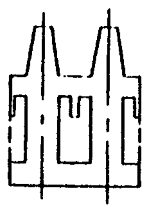
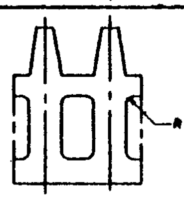
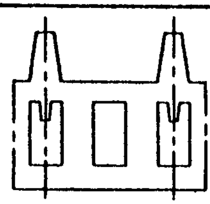
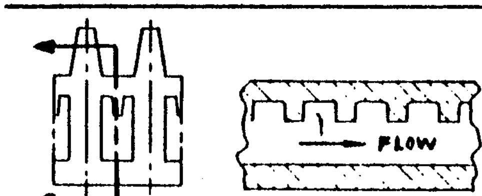
V. Interrupted fins - intermittent fin or channel base posts
   - To investigate advantages of boundary layer break-up and evaluate effect on ΔP.

The channel geometries are depicted in Figure 3-1 along with the feature dimensions.

Heat transfer and other data for all geometries originally proposed were analyzed, and each geometry rated in five categories: Structure & Life Considerations; Coolant Pressure Drop; Boundary Layer Risk; Producibility and Heat Transfer. A scale of 0 to 10 was used for each rating category, with zero indicating an unacceptable risk or benefit and ten being an optimum condition within that category.

A category weighting system was employed to rate each category with respect to its importance in determining selection rank. Structural considerations and

FIGURE 3-1 PRELIMINARY MATRIX OF ENHANCED COOLANT CHANNEL CONFIGURATIONS

CHANNEL GEOMETRY		CONSTANTS	VARIABLES
	I		CHANNEL ASPECT RATIO: 1.5 - 4 HEIGHT .08 TO .12 WIDTH .020 TO .060 CHANNEL PITCH .0397 - .100 RIB PITCH (W/CHANNELS) .0785 - 100
	II	CHANNEL HEIGHT .080 " WIDTH .040 CHANNEL PITCH .0785	FIN HEIGHT .015 TO .024 FIN BASE WIDTH .010 TO 020 FIN TIP WIDTH .010 TO 015 FIN NUMBER/CHANNEL 1,2,3
	III		CORNER RADII .001 TO .020 ° BOTH CHANNEL AND FIN WALLS INTERSECTIONS
	IV	CHANNEL HEIGHTS .080 CHANNEL WIDTHS .040 CHANNEL PITCH .0785 RIB PITCH .1570 (RIB OVER CHANNEL)	COMBINATIONS OF "BEST" CHANNEL CASES: ° TYPES I AND II ° TYPES I AND III
	V	CHANNEL HEIGHT .080 CHANNEL WIDTH .040 CHANNEL PITCH .0785	° FIN GEOMETRY ° INTERNAL OF INTERUPTION

0526k

coolant pressure drop were considered to be most important in determining selection ranking, together representing 60% of the weighted sums. Criteria for determining ratings within each category are included in Appendix E.

As mentioned previously, several cases were evaluated with the channel positioned under the hot-gas rib and under the land for comparison of heat transfer capability. No significant difference was noted, so from a heat transfer standpoint the location of the channel is not crucial. Further evaluation of structural considerations will be made following Subtask 3 of the task.

The final selection ranking, and the recommended channel candidates were based mainly on the weighted score rank. Another factor affecting selection was avoidance of duplication in flow analysis effort.

The dual-finned channel geometries were the highest ranked of the 27 configurations rated in this study. This is the result of the increased heat transfer provided by the two coolant side fins, resulting in a much lower maximum material temperature. The additional channel width aids in offsetting the increased pressure drop associated with the addition of fins to a channel. Both dual-fin geometries are recommended to study the effect of differing fin aspect ratio on coolant flow in the channel.

Single-finned channels were the most consistent in their beneficial enhancement effects, and four were selected for this flow study. The .015 x .015 finned channel showed the highest score in rating and is the lowest in fin aspect ratio. The .024 x .015 finned channel was selected for its higher aspect ratio, and to study flow effects of the higher, wider fin (as it differs from the .010 wide fins in the dual-fin channels). The two tapered fin geometries were also selected, and will allow comparison with the standard rectangular fin.

The increased corner radii selection was selected for testing in order to gain additional insight in coolant channel flow/boundary layer characteristics.

High aspect ratio rectangular channels were analyzed for widths between 0.020 and the 0.040 reference. The number of channels was increased in accordance with the width, but the land width was held at 0.040. Initial results indicated increased wall temperature and pressure drop for these configurations compared to the reference case (0.040 x 0.080 rectangle). Therefore, these configurations were not selected for test.

Subsequent review of computer outputs showed that a program override feature was mistakenly increasing the heat flux when the channel width was reduced. The cases were, therefore, invalid since they could not be directly compared to the other configurations. Later analysis indicated that high aspect ratio channels could provide a cooling benefit if both channels and land widths were reduced simultaneously.

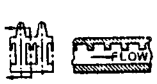
The combination geometries (category IV) resulted in a very good compromise between rib temperature reduction and channel pressure drop. Such channel geometry combinations show promise, but were not selected for this test since cold flow study of the individual channels shown would be duplicated by selection in categories I & IIa.

Specific heat transfer models of interrupted-flow (category V) type configurations were not made due to the time and complexity involved in such a task. Other analysis of this type of channel geometry have concluded that any advantage gained in utilizing an "interrupted fin" geometry would be more than off-set by the cost and complexity of fabricating it. The concept of breaking up the boundary layer along the coolant channel fin may be worthy of additional study, but is outside the scope of this task.

The ratings and ranking of the channel geometries considered in the study are presented on Table 3-1. The coolant geometries recommended for testing were:

1. & 2.	Dual fin geometries; fin aspect ratios 1.5 and 2.4.
3, 4, 6 & 7	Single fin geometries; fin aspect ratios 1.0 and 2.4, and taper fin.
5.	Finned channel with large corner radii (flow study)
8.	Baseline .040 x .080 standard channel.

TABLE 3-1 COOLANT SIDE CHANNEL GEOMETRY SELECTION MATRIX

CATEGORY	CHANNEL GEOMETRY	AR	STRUCTURE/ LIFE .35 WEIGHTED RAT'G	WT'D	COOLANT ΔP .25 WEIGHTED RAT'G	WT'D	BOUNDARY LAYER .20 WEIGHTED RAT'G	WT'D	PRODUCIBILITY .10 WEIGHTED RAT'G	WT'D	HEAT TRANSFER .10 WEIGHTED RAT'G	WT'D	WEIGHTED SUMS	WEIGHTED RANK	SELECTION RATIONALE	SELECTION RANK
I. ASPECT RATIO		AR														
.080 HEIGHT	x.040	2.0	0	0	9	2.25	8	1.60	10	1.00	0	0	4.85	18	BASELINE CHANNEL, FOR COMPARISONS	8
	x.030	2.67	2	.70	3	.75	7	1.40	10	1.00	6	.60	4.45	22		
	x.025	3.2	2	.70	0	0	6	1.20	8	.80	8	.80	3.50	24		
	x.020	4.0	0	0	0	0	5	1.00	8	.80	8	.80	2.60	28		
.120 HEIGHT	x.040	3.0	0	0	10	2.50	8	1.60	10	1.00	0	0	5.10	14		
	x.030	4.0	0	0	9	2.25	7	1.40	8	.80	4	.40	4.85	19		
	x.025	4.8	0	0	6	1.50	6	1.20	8	.80	6	.60	4.10	23		
	x.020	6.0	0	0	0	0	5	1.00	8	.80	8	.80	2.60	27		
.150 HEIGHT	x.040	3.75	0	0	10	2.50	8	1.60	10	1.00	0	0	5.10	15		
	x.030	5.0	0	0	10	2.50	7	1.40	8	.80	4	.40	5.10	16		
	x.025	6.0	0	0	8	2.00	6	1.20	8	.80	6	.60	4.60	21		
	x.020	7.5	0	0	3	.75	5	1.00	6	.60	8	.80	3.15	25		
IIA. SINGLE FIN	FIN GEOM.	AR														
• STANDARD .080x.040 CHANNEL	.016x.010	1.6	7	2.45	7	1.75	4	.80	7	.70	4	.40	6.10	7	NARROW FINS ALSO IN DUAL FIN GEOM'S (CAT. IIB)	
	.024x.010	2.4	8	2.80	6	1.50	3	.60	8	.80	4	.40	6.00	9		
	.016x.016	1.0	8	2.80	7	1.75	3	.60	7	.70	4	.40	6.25	5	BEST OF SINGLE FIN	3
	.024x.016	1.5	8	2.80	5	1.25	2	.40	6	.60	4	.40	5.45	13	WIDE FIN STUDY	7
TAPERED FIN	.024x.016/ .010 TIP	1.92	8	2.80	6	1.50	4	.80	5	.50	4	.40	6.00	8	TAPERED FIN STUDY	4
	.024x.020/ .015 TIP	1.37	8	2.80	5	1.25	3	.60	5	.50	4	.40	5.50	12		6
IIB. DUAL FIN .080x.060 CHANNEL	.016x.010	1.6	10	3.50	9	2.25	3	.60	4	.40	6	.60	7.35	1	BEST OVERALL	1
	.024x.010	2.4	10	3.50	9	2.25	2	.40	4	.40	6	.60	7.15	2		2
III. CORNER RADII	.080x.040 .020R		0	0	9	2.25	8	1.60	8	.80	0	0	4.65	20		
	.016x.010 FIN .005-.010R		7	2.45	7	1.75	4	.80	4	.40	4	.40	5.80	11	FLOW STUDY	5
IV. COMBINATION	FIN GEOM.															
• STANDARD .080x.040 CHANNEL. • 2 CHANNELS/RIB. • FIN UNDER RIB ONLY	.016x.010		7	2.45	8	2.00	4	.80	7	.70	4	.40	6.35	4	FLOW EFFECTS CHARACTERIZED IN CATEGORY I, IIA & IIB SELECTIONS	
	.024x.010		8	2.80	7	1.75	3	.60	6	.60	4	.40	6.15	6		
	.016x.016		8	2.80	8	2.00	3	.60	7	.70	4	.40	6.50	3		
	.016x.024		8	2.80	7	1.75	2	.40	6	.60	4	.40	5.95	10		
IV. INTERRUPTED "SAWTOOTH" (VARIATION OF SINGLE FIN)	 FLOW		8	2.80	4	1.00	4	.80	0	0	4	.40	5.00	17	PRODUCIBILITY	

0526k

AIR TEST PROGRAM DEFINITION

The cold flow velocity mapping test method was selected as the evaluation means for the coolant channel designs. An analysis was conducted to select the channel scale and flow conditions for testing. A design for modifying the existing fixture design was completed.

Analysis

The channel flow conditions required for accurate simulation were less stringent than those required by the external rib flow tests. Whereas for external flow tests a growing boundary layer must be correctly scaled, no such scaling problem arises in channel flows. The only requirement is that the channel flow be both hydrodynamically and thermally fully developed, and be fully turbulent as is the case for combustor channel flow.

The requirement for fully developed turbulence was satisfied by the Reynold's number capability of the Cold Flow test bed. A typical channel air flow velocity of 72 meters/sec corresponds to a Re = 50,000 which is far above the transition Re = 2500. This is based upon an eight times scale channel hydraulic diameter of Dh = 0.424 inches. Thus, the channel flow was assured to be fully turbulent. Although this is still an order of magnitude below the Reynold's number of an actual combustor channel, hydrodynamic similarity affords the extrapolation of the cold flow test results to these conditions.

The requirement of a hydrodynamically and thermally developed flow was based upon a conservative estimate of an entrance length of one hundred hydraulic diameters L = 100Dh. This corresponds to a length of L = 42.4 inches. Therefore, velocimeter measurements were taken at a distance of 72 inches downstream of the channel inlet. This insured that the internal flow in the channel was fully developed.

Test Fixture Design

The channel test panels were designed to fit into the existing test fixture with minimal changes. The main requirement for the test fixture was to properly create the correct channel flow conditions by providing a fixed boundary at the channel 'outside' wall to simulate the channel closeout. This was accomplished by positioning the test panel flush against the cover plate, using the cover as the closeout with the channel shape in the test panel itself.

Spacers were designed to raise the test panel from the lower (rib) test position to the upper (channel) test position. Exact measurements of the fabricated side panels were made to precisely size the spacers to provide a minimum gap between the test panels and the cover.

Two test panels were designed with four of the selected channel configurations in each panel. The channels were eight times scale as specified by the test analysis. A black anodize surface treatment was selected to reduce reflectivity.

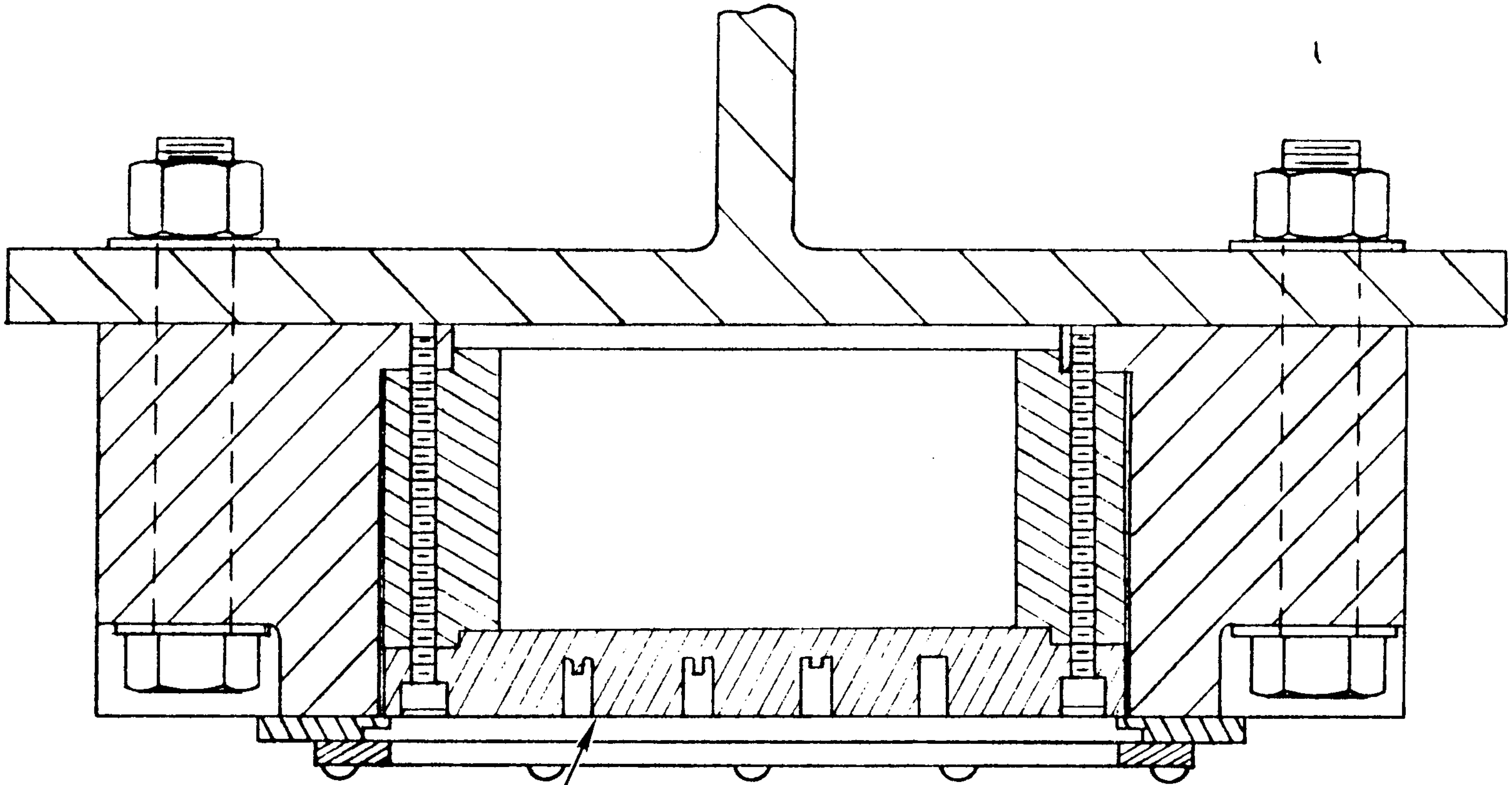
A cross section of the channel cold flow test fixture configuration is presented in Figure 3-2. The detail drawings for the spacers and panels are contained in Appendix F.

COLD FLOW TEST PROGRAM (CHANNELS)

Fabrication

The spacers and test panels were fabricated per the drawing requirements. The aluminum spacers were machined to match the test fixture bolt hole patterns.

The test panels were machined from aluminum plate. Special attention was given to maintaining smooth machine cuts in the channel shapes to prevent flow disturbances. The panels were black anodized after machining to provide a non-reflective surface. Photographs of the completed test panels are given in Figure 3-3. The channel configurations were dimensionally inspected at completion to ensure acceptability and to provide exact dimensions for use in formulating grid points for the velocity measurement matrix.

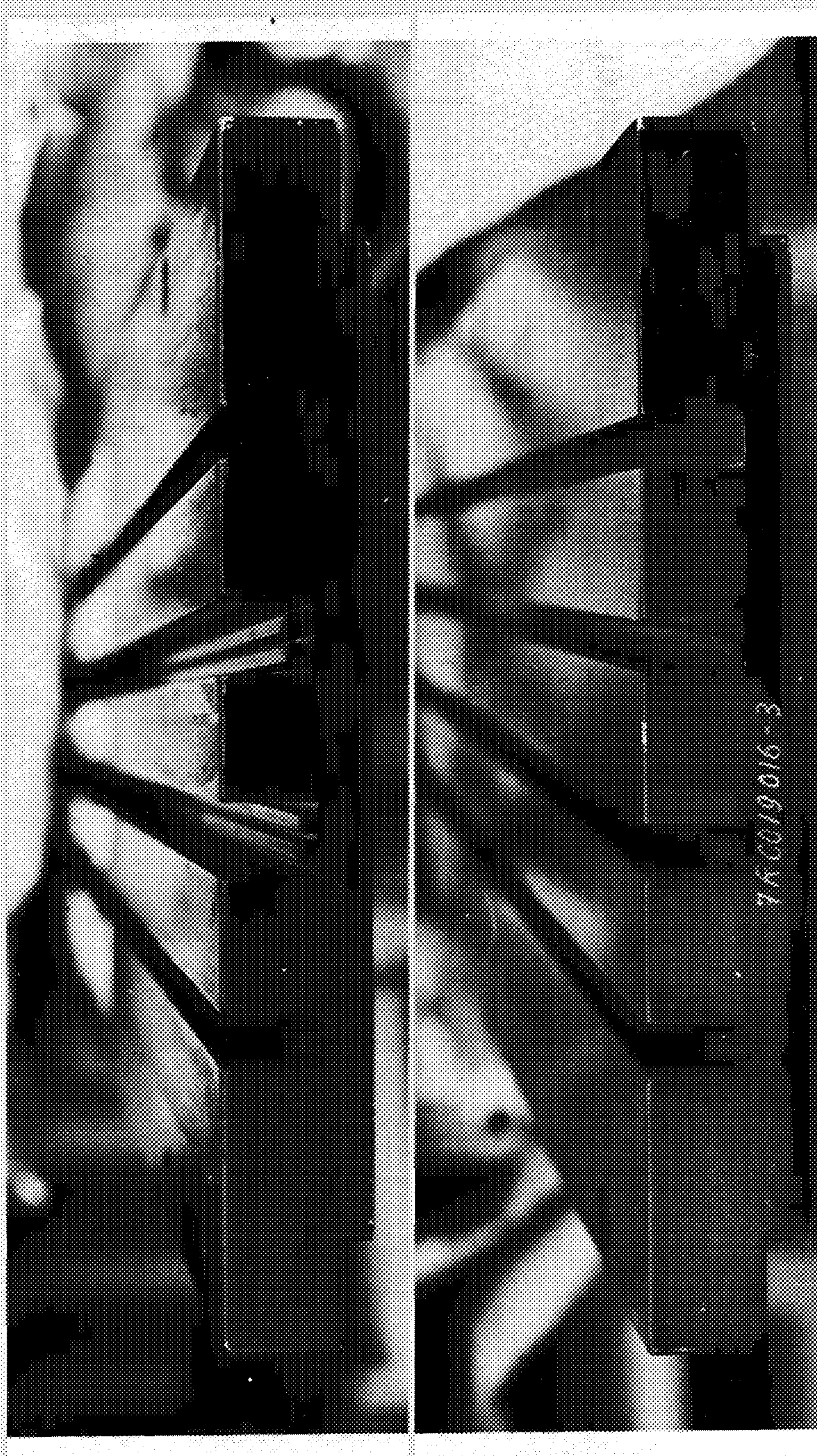

TEST PANEL (8:1 SCALE)

COLD FLOW TEST FIXTURE -
COOLANT CHANNEL CONFIGURATION

FIGURE 3-2

0526k

FIGURE 3-3. ENHANCED COOLANT CHANNEL TEST CONFIGURATIONS



Rockwell International
Rocketdyne Division

Testing

The same basic test approach as used for the rib flow evaluation was followed for the channel tests. A test matrix, Appendix F, similar to that used for the rib tests was initially planned, however, it was decided to observe the channel results only at the end window station as was done with the ribs.

Installation. The change-over to the channel test set-up was made without significant alteration to the overall test system. The channel panels were installed using the spacers without need to adjust the fixture side panels. An endplate was made for the fixture to cover the open area under the channel test panel and force the air to go only through the channel passages. The flow tubes and screens were removed from the plenum and the end section carefully sealed.

Just prior to installing the cover, a very thin coating of RTV elastomer was applied to the areas between the channels to provide a gap filler and a seal to preclude cross flow. The cover was installed and tightened down prior to RTV curing.

Tests. Initially, channel center velocities were measured to ensure that the required test conditions were met. Velocities of approximately 70 m/sec were obtained, resulting in a Reynolds number much greater than the 10,000 minimum. The seeding system was used for these tests and high data rates were obtained due to the particle concentration in the flow.

The data collection process was the same as for the rib tests. The reference channel and five enhanced channel geometries were mapped. Results are exemplified by the velocity field for the single tall fin configuration, Figure 3-4. As many as eighty data points were collected within the channels. Velocity maps for all of the tested channels are contained in Appendix F.

The results from these tests provide the first detailed flow velocity information in enhanced and rectangular coolant channels. The quantified velocity profiles were obtained to allow analytical assessments to be adjusted for heat transfer degradation due to velocity decreases in the corner and fin valley sections.

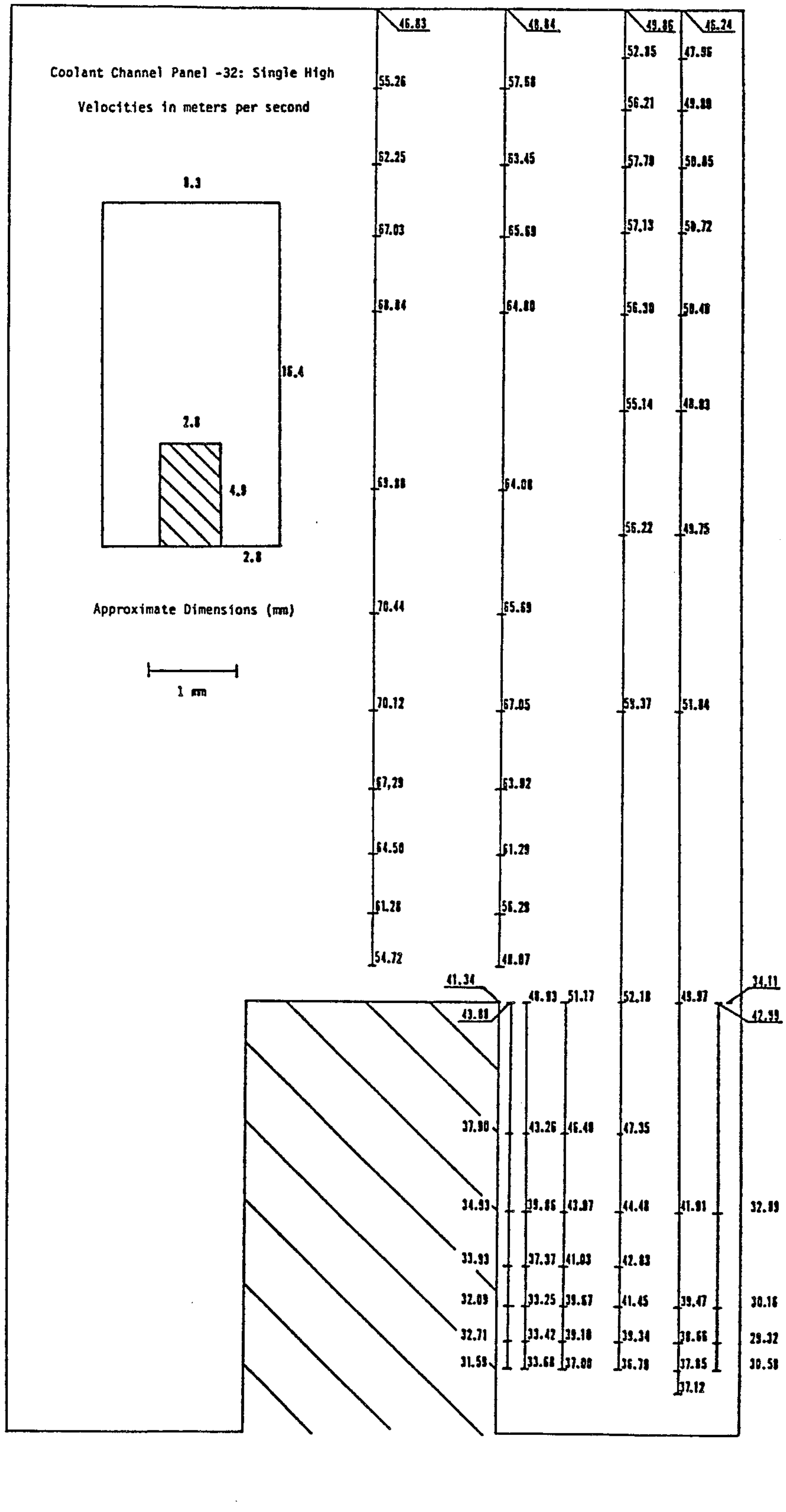


Figure 3-4. Velocity Profile for Single High Fin Configuration

0526k

Scaling Results (Channels)

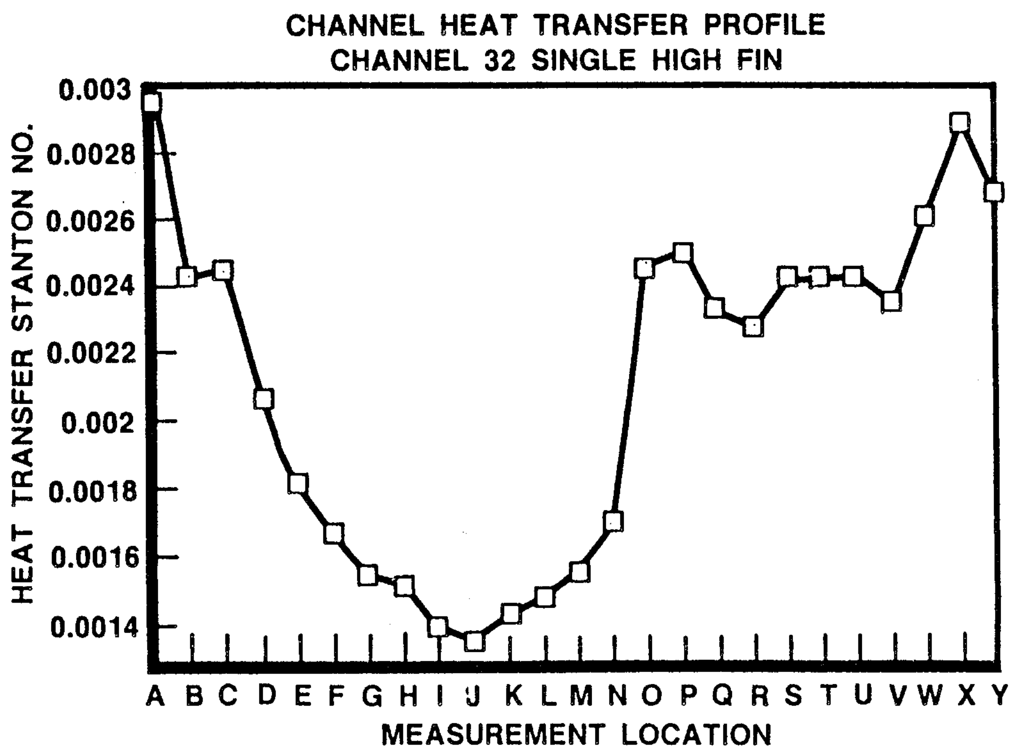
The scaling analysis for the coolant side conditions follows the same procedure as for the ribs. The coolant properties are scaled for hydrogen at the proper conditions at the end of the combustor cylindrical section. In the final scaling, corrections are made for the supercritical fluid properties, large bulk wall temperature gradients, and high heat flux effects. Again, these could not be simulated in the laboratory and a more realistic assessment of channel performance is obtained by this scaling. An example Stanton number profile for tall fin configuration is shown in Figure 3-5. The integrated cooling benefit (transfer coefficient x area) for the candidate channels is shown in Figure 3-6.

In addition to these configurations, high aspect ratio channels were considered in the analysis. No cold flow data were obtained for a rectangular channel other than the 2:1 aspect ratio reference channel. Analysis conducted compared a case where double the number of channels were evaluated. This configuration, with two 0.020 wide channels with 0.0204 land widths per channel, was evaluated at various channel heights (flow areas). A slight temperature increase occurred compared to the reference case, but the combustor pressure drop was lower. The pressure drop decreased further with increased channel height, but the wall temperature also increased. Reducing the channel height would be expected to increase velocities and decrease the wall temperature although the pressure drop would increase correspondingly.

Maintaining a wall temperature commensurate with long life at the higher heat fluxes is the primary goal for the enhanced channel designs. Accordingly, the temperature reduction compared to the reference channel is an appropriate means for comparing the configurations. (The heat flux enhancement is not affected appreciably by the channel design.) A graph of the temperature benefit for the tested enhanced geometries compared to the reference channel is presented in Figure 3-7. It can be noted in comparing figures 3-6 and 3-7 that only small differences in the cooling enhancement are sufficient to produce the temperature differences.

FIGURE 3-5.

TYPICAL COOLANT CHANNEL TEST RESULTS



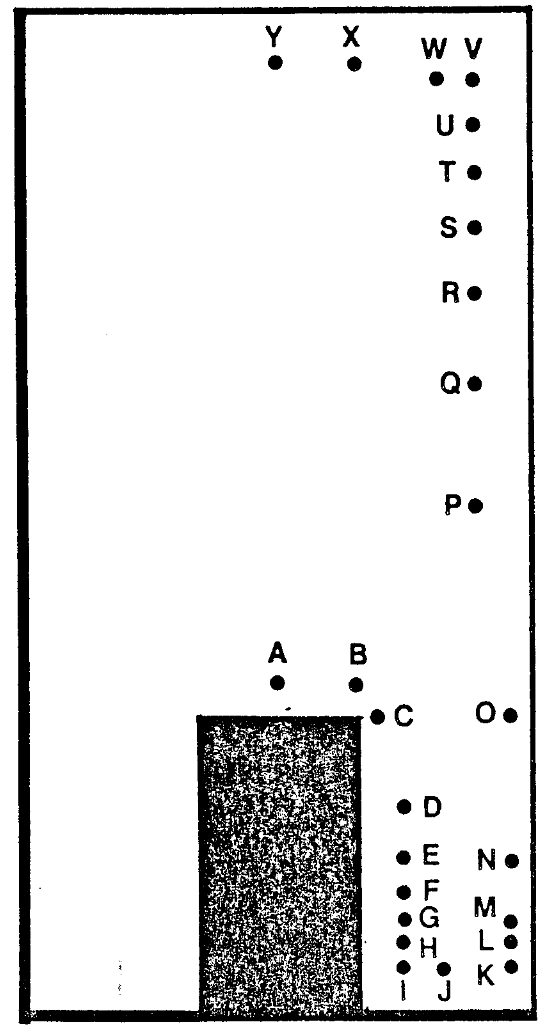
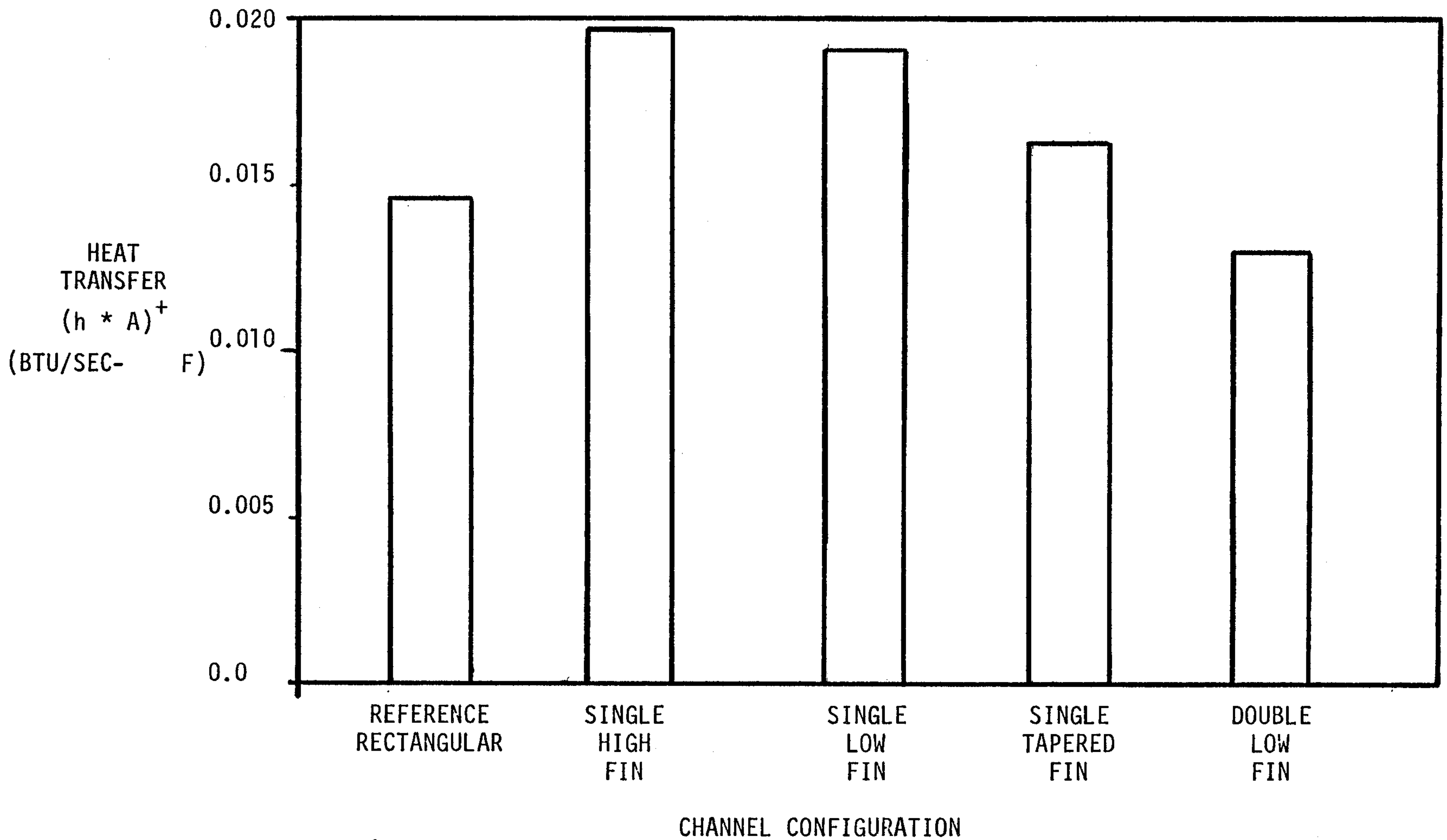


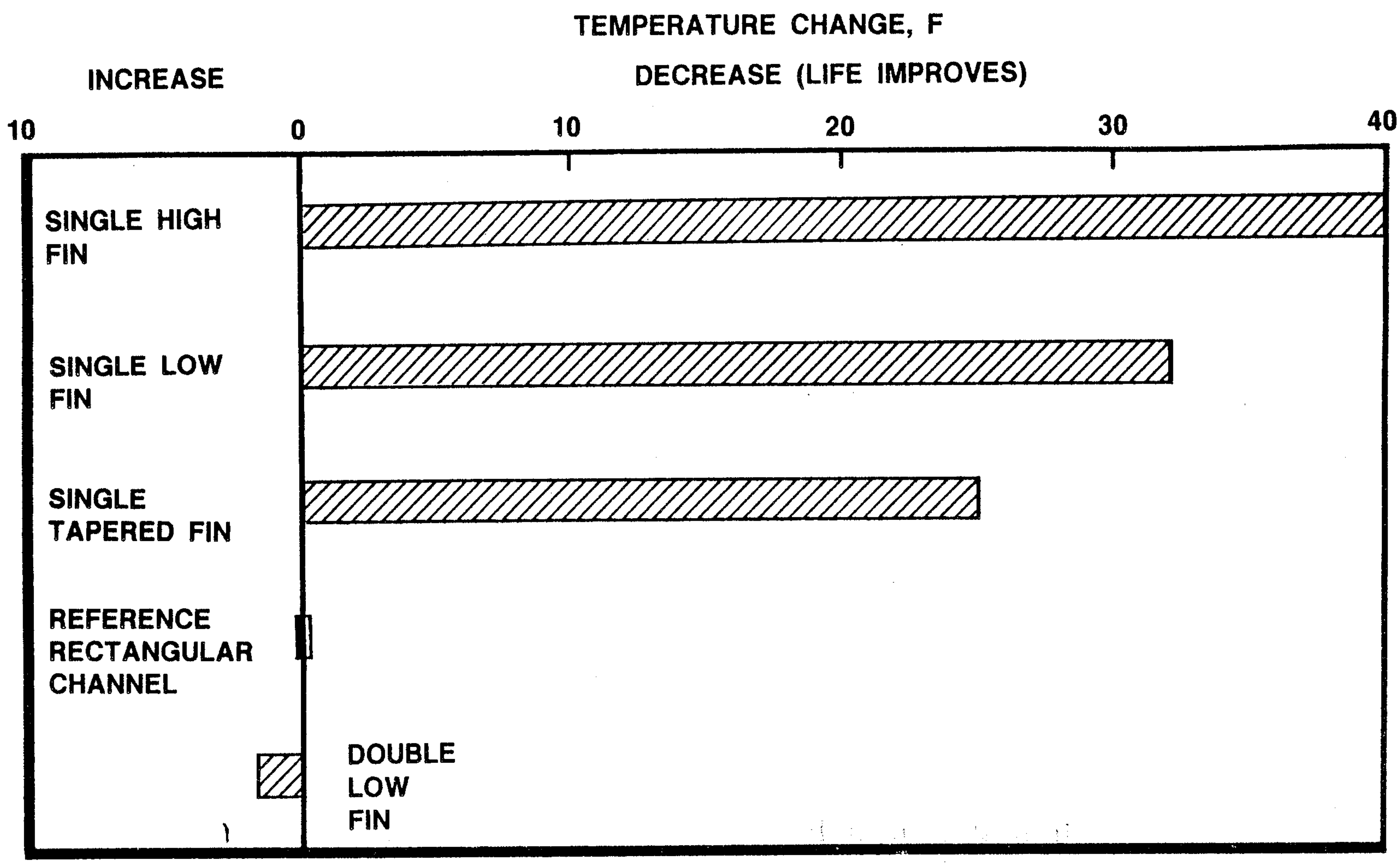
Figure 3-6. Cooling Enhancement For Candidate Channels



+ $h * A = N_{st} \left(\frac{\dot{M}C_p}{A_f}\right) * A$

FIGURE 3-7

LINER TEMPERATURE CHANGE WITH ENHANCED CHANNELS

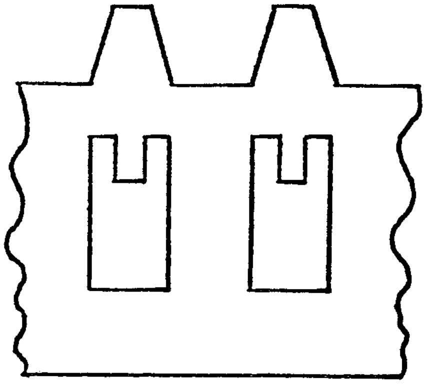


Selected Enhanced Channel Configurations

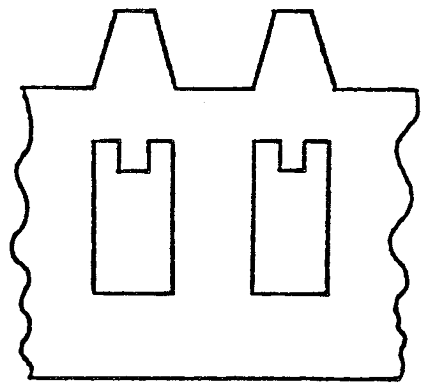
The two recommended channel configurations tested in the cold flow velocity mapping program are the single fin designs with a high and low aspect ratio fin. The 'tall fin' is a 0.024 tall-0.015 wide rectangular fin placed in the center of a 0.040 wide-0.080 tall rectangular channel. The land width is slightly more than the 0.040 channel width. The second design is similar to the first except that the fin height is reduced to 0.015.

High aspect ratio channels (AR>2.0) were investigated by analysis, but were not flow tested. Evaluation of a configuration with double the number of channels in the ribbed section (a 0.020 wide-0.080 tall rectangular channel with a land of approximately 0.020) was made using unadjusted flow conditions. A lower pressure drop resulted, although the trough wall temperature was higher than the reference case. A lower wall temperature could be achieved by reducing the channel height although the pressure drop would increase accordingly. Without specific flow data to support a refined analysis, this design cannot be completely evaluated and compared to the other designs. Because of the potential benefits, it is recommended that this configuration be included in the channel test calorimeter to complete the evaluation. This would require the test sections in the calorimeter to be quarter sections rather than one-thirds arcs. This is not expected to impact the design or quality of the results significantly.

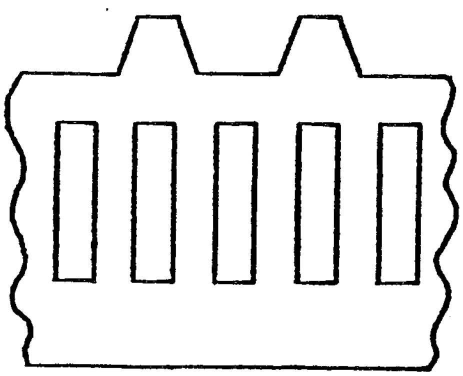
The configurations are depicted in Figure 3-8 with sample hot-gas wall ribs included as a reference to indicate channel orientation.



0.040 wide - 0.080 tall channel with
0.015 wide - 0.024 tall fin



0.040 wide - 0.080 tall channel with
0.015 wide - 0.015 tall fin



0.020 wide - 0.080 tall high aspect
ratio channel

Figure 3-8. Selected Channel Configurations

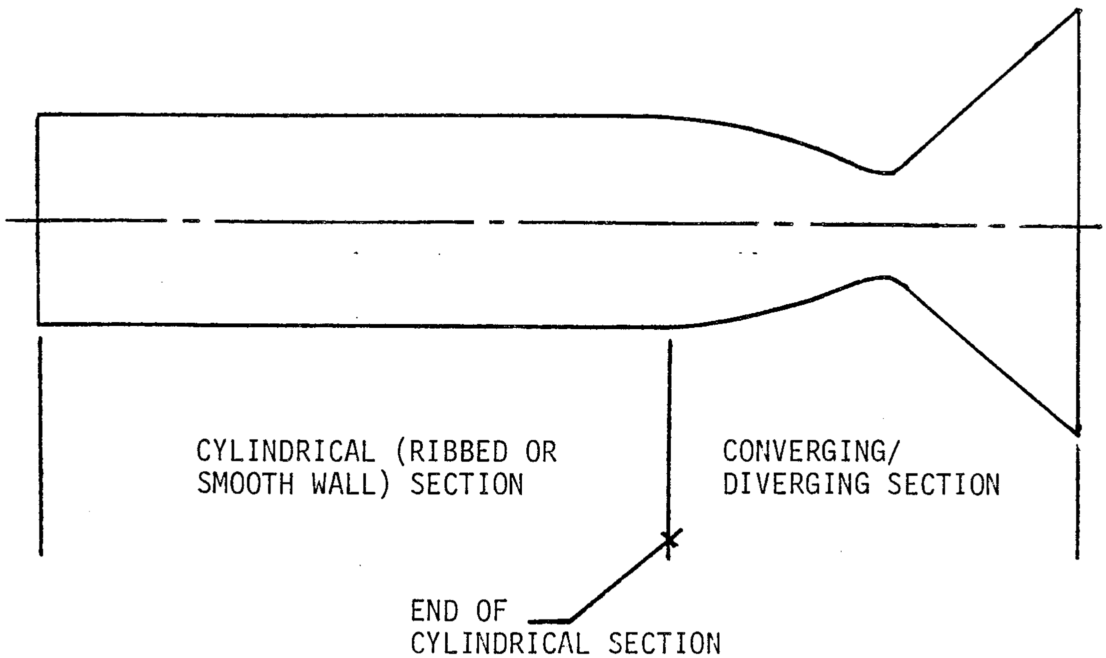
4.0 CONCLUSION

A structured selection analysis process has been completed to determine the best hot gas rib and enhanced coolant channel candidates for hot-fire evaluation. The process included analytical screening using available computer models with an assumption that ideal boundary layer behavior occured. Laboratory test programs were conducted to further screen the candidates and to evaluate the flow assumption. The test results provided a base for directly comparing the designs. Quantative flow field data, previously not available for the enhanced combustor geometries and conditions, were obtained in the laboratory tests to anchor flow behavior representation.

The results lead to the selection of the 0.040 high - 0.040 base rib and the single high fin channel configurations as the top candidates. Other configurations selected were a 0.030 high - 0.040 base rib, a single low fin channel and high aspect ratio (0.020 wide - 0.080 tall) rectangular channels. Reference designs are a smooth hot gas wall and a 0.040 wide - 0.080 tall rectangular coolant channel.

The laboratory test results were crucial in arriving at this selection. The flow mapping tests showed that the flow field did not match the 'ideal' case and that several designs that appeared 'better' in the analytical screening could be expected to perform poorly under actual conditions. The designs selected provided the best blend of thermal enhancement and temperature and pressure drop control.

The integrated enhancement for the ribbed combustor section with the top candidate 0.040 high rib is 60% above the comparative smooth wall design. Laboratory flow test results showed that the design suffered a minimal amount of heat transfer degradation compared to an 'ideal' case where the boundary layer was uniform. Although the enhancement at the end of the combustor cylindrical section was somewhat lower than the optimum value, the integrated heat load enhancement (following an exponential build-up) for the ribbed section was only 6% less. Further, in terms of the overall combustor heat load, including the converging throat section and the diverging nozzle portion, the difference compared to optimal was only 4%. These results are summarized in Figure 4-1.



COMBUSTOR SECTION	ENHANCEMENT	
	IDEAL BOUNDARY LAYER CONDITIONS	ACTUAL BASED ON TEST RESULTS
END OF CYLINDRICAL SECTION	66%	42%
OVERALL CYLINDRICAL SECTION	66%	60%
OVERALL COMBUSTOR (WITH CONVERGING/DIVERGING SECTION)	45.7%	41.6%

Figure 4-1. Heat Load Enhancement for Ribbed Combustor

0526k

C-2

Incorporating the enhancements into an OTV engine combustor can have several significant impacts. An overall increased heat load of 41.6% provides additional energy to drive the propellant pump turbines, thereby increasing engine chamber pressure capability. A comparison of the attainable chamber pressure for the smooth wall cylindrical contour, 'best estimate' for the 0.040 rib, and 'ideal' case (uniform heat transfer coefficient) for the 0.040 rib are indicated in Figure 4-2. The smooth wall tapered combustor contour used in the Integrated Component Evaluator (ICE) is also included as a reference for an enhanced combustor.

Hot-fire tests are planned to perform a final screening and verification of the candidate enhancements. These tests will be conducted at the design conditions to obtain accurate heat flux and hot gas flow conditions.

The test program will be conducted using the Integrated Components Evaluator (ICE) expander cycle test system. The enhanced combustor designs will be tested using a replaceable water cooled calorimeter spool section that is incorporated in the ICE thrust chamber. The spool fits between the injector and existing smooth wall tapered combustor as shown in Figure 4-3.

Tests will be conducted on the two rib designs and the smooth wall reference with circumferentially cooled spools. The three candidate enhanced channels and the reference channel will be tested using a single axially cooled, smooth walled spool.

These tests will provide the quantitative comparison of the candidates at hot-fire conditions needed to selecte the final designs to be incorporated in the enhanced combustor design. Additionally, the hot-fire results will be used to further anchor analytical tools so that a more accurate analysis of the detail combustor design can be made.

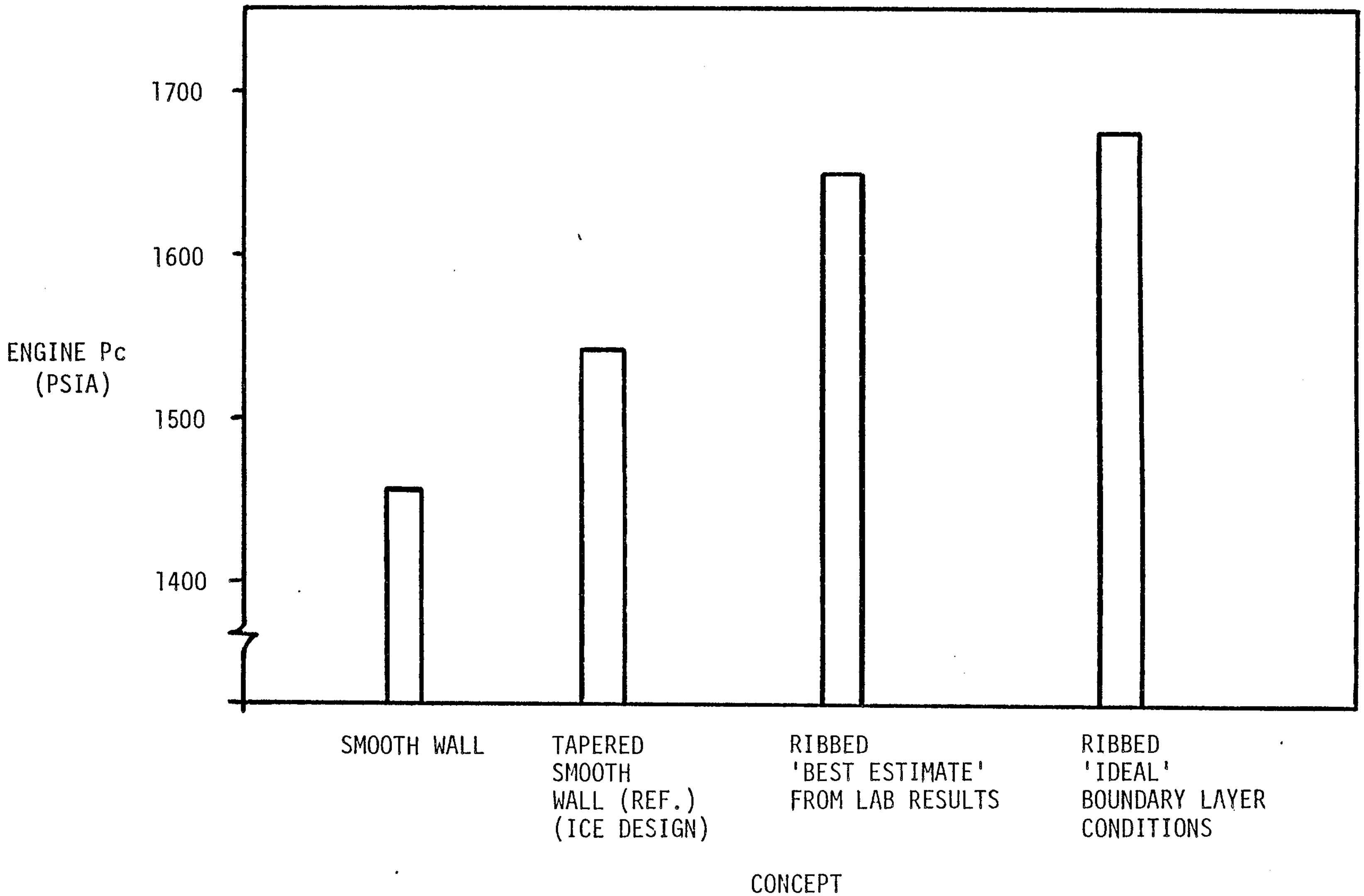
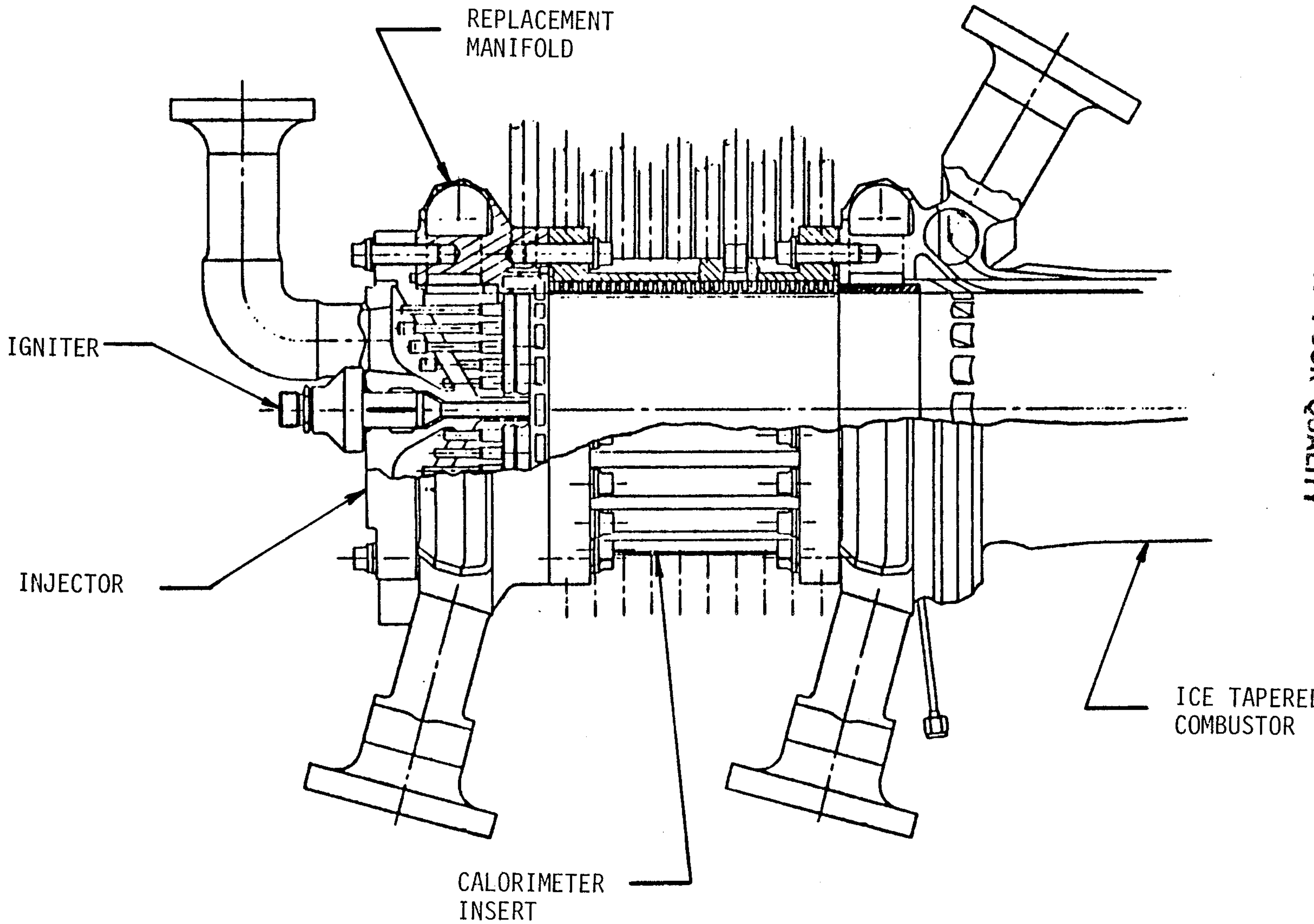


FIGURE 4-2. Attainable Chamber Pressure Comparison For Enhanced Combustor Concepts*

*Common S-O-A Turbomachinery Characteristics, 2000 Btu/Sec Regenerator in System

FIGURE 4-3

HOT FIRE VERIFICATION



APPENDIX A

RIB ANALYSIS COMPUTER OUTPUTS

RIB EVALUATION CRITERIA RATING SCALES

LOC. NUMBER	ADMITTANCES (Y)									
1	4.746E-03	7.548E-03	6.274E-03	5.376E-03	4.316E-03	2.006E-03	2.010E-03	1.007E-03	4.744E-03	7.544E-03
11	6.270E-03	5.372E-03	4.314E-03	2.946E-03	2.954E-03	3.258E-03	3.564E-03	3.572E-03	3.578E-03	3.583E-03
21	3.586E-03	3.588E-03	3.589E-03	1.569E-03	1.994E-03	9.129E+08	9.944E-04	2.946E-03	2.954E-03	3.258E-03
31	3.563E-03	3.571E-03	3.577E-03	3.582E-03	3.585E-03	3.587E-03	3.588E-03	1.560E-03	2.011E-03	9.469E-04
41	9.952E-04	2.949E-03	2.955E-03	3.258E-03	3.564E-03	3.572E-03	3.578E-03	3.583E-03	3.586E-03	3.588E-03
51	3.590E-03	1.582E-03	2.048E-03	9.979E-04	9.955E-04	2.008E-03	2.011E-03	1.007E-03	7.157E-04	1.370E-03
61	6.491E-04	7.352E-04	1.417E-03	6.965E-04	1.343E-03	1.657E-03	1.974E-03	2.293E-03	5.773E-03	5.783E-03
71	5.792E-03	2.685E-03	3.312E-03	3.946E-03	4.586E-03	1.253E-02	9.720E-03	9.743E-03	3.297E-03	3.307E-03
81	3.313E-03	3.318E-03	3.322E-03	3.324E-03	3.325E-03	3.326E-03	1.174E-03	1.093E-03	1.341E-03	1.655E-03
91	1.971E-03	2.291E-03	1.448E-02	4.048E-03	4.061E-03	6.594E-03	6.609E-03	6.622E-03	6.632E-03	6.639E-03
101	6.644E-03	6.647E-03	6.648E-03	9.427E-04	8.849E-04	1.360E-02	7.875E-03	7.894E-03	6.593E-03	6.609E-03
111	6.621E-03	6.632E-03	6.639E-03	6.644E-03	6.648E-03	6.649E-03	9.528E-04	9.245E-04	1.164E-02	9.727E-03
121	9.747E-03	3.297E-03	3.307E-03	3.313E-03	3.318E-03	3.322E-03	3.324E-03	3.326E-03	3.327E-03	1.202E-03
131	1.172E-03	5.779E-03	5.787E-03	5.796E-03	-2.826E-03	-6.631E-03	-5.731E-03	-1.966E-03	4.045E-05	2.442E-03
141	2.439E-03	7.285E-04	7.078E-04	8.950E-06	1.790E-05	2.745E-05	3.699E-05	3.699E-05	3.699E-05	5.455E-05
151	7.210E-05	7.210E-05	3.605E-05	4.427E-04	6.824E-04	4.932E-04	5.244E-04	5.508E-04	5.727E-04	5.899E-04
161	6.019E-04	6.086E-04	9.154E-04	6.047E-04	4.485E-04	6.867E-04	4.940E-04	5.246E-04	5.509E-04	5.730E-04
171	5.907E-04	6.039E-04	6.133E-04	9.323E-04	6.443E-04	0.	0.	0.	0.	0.

LOCATIONS 181 THROUGH 2999 EQUAL 0.

LOC. NUMBER	TEMPERATURES (T) Two channels/RIB									
1	6.859E+02	6.918E+02	7.089E+02	0.	0.	0.	0.	0.	0.	0.
11	6.280E+02	6.349E+02	6.557E+02	0.	0.	0.	0.	0.	0.	0.
21	5.494E+02	5.573E+02	5.819E+02	0.	0.	0.	0.	0.	0.	0.
31	4.582E+02	4.658E+02	4.915E+02	0.	0.	0.	0.	0.	0.	0.
41	3.621E+02	3.658E+02	3.809E+02	3.519E+02	3.393E+02	3.357E+02	0.	0.	0.	0.
51	3.211E+02	3.252E+02	3.477E+02	3.193E+02	3.018E+02	2.984E+02	0.	0.	6.259E+03	-1.820E+02
61	2.788E+02	2.670E+02	2.662E+02	2.591E+02	2.523E+02	2.599E+02	0.	0.	0.	0.
71	2.406E+02	2.067E+02	1.895E+02	1.990E+02	1.992E+02	2.241E+02	0.	0.	0.	0.
81	0.	1.167E+02	1.290E+02	1.316E+02	1.141E+02	0.	0.	0.	0.	0.
91	0.	6.502E+01	7.441E+01	7.510E+01	5.469E+01	0.	0.	0.	0.	0.
101	0.	1.108E+01	3.004E+01	3.015E+01	1.087E+01	0.	0.	0.	0.	0.
111	0.	-2.120E+01	-4.098E+00	-4.280E+00	-2.165E+01	0.	0.	0.	0.	0.
121	0.	-4.417E+01	-2.887E+01	-2.939E+01	-4.522E+01	0.	0.	0.	0.	0.
131	0.	-6.915E+01	-4.609E+01	-4.622E+01	-6.154E+01	0.	0.	0.	0.	0.
141	0.	-6.707E+01	-5.311E+01	-5.539E+01	-7.252E+01	0.	0.	0.	0.	0.
151	-6.253E+01	-6.903E+01	-5.235E+01	-5.653E+01	-8.179E+01	-1.057E+02	0.	0.	0.	0.
161	-3.104E+01	-1.273E+01	-1.234E+01	-2.942E+01	-4.832E+01	-6.248E+01	0.	0.	0.	0.
171	-9.806E+00	7.000E+01	7.000E+01	3.231E+00	-2.988E+01	-4.631E+01	0.	0.	0.	0.

LOCATIONS 181 THROUGH 999 EQUAL 0.

LOC.
NUMBER CAPACITANCES (C)

LOCATIONS 1 THROUGH 999 EQUAL 0.

STA 54

RBW = LW

RH = .04

LOC.
NUMBER GEN. RATES (Q)

LOCATIONS 1 THROUGH 999 EQUAL 0.

LOC. NUMBER	ADMITTANCES (Y)									
1	7.010E-03	1.116E-02	9.305E-03	7.999E-03	5.469E-03	1.998E-03	2.003E-03	1.004E-03	7.007E-03	1.116E-02
11	9.299E-03	7.994E-03	5.468E-03	2.935E-03	2.944E-03	3.249E-03	3.557E-03	3.566E-03	3.573E-03	3.579E-03
21	3.583E-03	3.585E-03	3.587E-03	1.547E-03	1.978E-03	9.129E+08	9.910E-04	2.936E-03	2.946E-03	3.250E-03
31	3.556E-03	3.565E-03	3.572E-03	3.577E-03	3.582E-03	3.584E-03	3.586E-03	1.534E-03	1.992E-03	9.436E-04
41	9.925E-04	2.941E-03	2.948E-03	3.250E-03	3.557E-03	3.566E-03	3.573E-03	3.579E-03	3.583E-03	3.586E-03
51	3.587E-03	1.559E-03	2.027E-03	9.900E-04	9.931E-04	2.003E-03	2.007E-03	1.005E-03	7.089E-04	1.361E-03
61	6.474E-04	7.274E-04	1.403E-03	6.901E-04	8.821E-04	1.091E-03	1.303E-03	1.519E-03	5.749E-03	5.761E-03
71	5.772E-03	1.764E-03	2.181E-03	2.605E-03	3.038E-03	1.248E-02	9.685E-03	9.712E-03	3.289E-03	3.300E-03
81	3.308E-03	3.314E-03	3.318E-03	3.321E-03	3.323E-03	3.324E-03	1.162E-03	1.088E-03	8.813E-04	1.089E-03
91	1.301E-03	1.518E-03	1.443E-02	4.035E-03	4.050E-03	6.579E-03	6.596E-03	6.611E-03	6.623E-03	6.632E-03
101	6.638E-03	6.642E-03	6.644E-03	9.307E-04	8.807E-04	1.356E-02	7.854E-03	7.874E-03	6.579E-03	6.596E-03
111	6.611E-03	6.623E-03	6.632E-03	6.638E-03	6.643E-03	6.645E-03	9.399E-04	9.165E-04	1.161E-02	9.704E-03
121	9.725E-03	3.291E-03	3.301E-03	3.309E-03	3.314E-03	3.318E-03	3.321E-03	3.324E-03	3.326E-03	1.188E-03
131	1.160E-03	5.766E-03	5.774E-03	5.783E-03	-2.814E-03	-6.604E-03	-5.712E-03	-1.961E-03	4.035E-05	2.441E-03
141	2.439E-03	7.219E-04	7.011E-04	8.950E-06	1.790E-05	3.620E-05	5.450E-05	5.450E-05	5.450E-05	6.330E-05
151	7.210E-05	7.210E-05	3.605E-05	4.177E-04	6.477E-04	4.716E-04	5.044E-04	5.325E-04	5.563E-04	5.755E-04
161	5.897E-04	5.986E-04	9.049E-04	6.025E-04	4.324E-04	6.604E-04	4.755E-04	5.062E-04	5.335E-04	5.570E-04
171	5.764E-04	5.916E-04	6.028E-04	9.199E-04	6.392E-04	0.	0.	0.	0.	0.

LOCATIONS 181 THROUGH 2999 EQUAL 0.

LOC. NUMBER	TEMPERATURES (T) 2 channels/Rib									
1	1.075E+03	1.080E+03	1.095E+03	0.	0.	0.	0.	0.	0.	0.
11	9.803E+02	9.868E+02	1.006E+03	0.	0.	0.	0.	0.	0.	0.
21	8.378E+02	8.456E+02	8.691E+02	0.	0.	0.	0.	0.	0.	0.
31	6.635E+02	6.711E+02	6.965E+02	0.	0.	0.	0.	0.	0.	0.
41	4.738E+02	4.747E+02	4.827E+02	4.258E+02	4.025E+02	3.953E+02	0.	0.	6.259E+03	-1.790E+02
51	4.228E+02	4.238E+02	4.418E+02	3.924E+02	3.648E+02	3.576E+02	0.	0.	0.	0.
61	3.716E+02	3.529E+02	3.444E+02	3.265E+02	3.126E+02	3.174E+02	0.	0.	0.	0.
71	3.270E+02	2.809E+02	2.544E+02	2.593E+02	2.553E+02	2.791E+02	0.	0.	0.	0.
81	0.	1.712E+02	1.834E+02	1.832E+02	1.619E+02	0.	0.	0.	0.	0.
91	0.	9.865E+01	1.194E+02	1.186E+02	9.493E+01	0.	0.	0.	0.	0.
101	0.	4.623E+01	6.716E+01	6.654E+01	4.451E+01	0.	0.	0.	0.	0.
111	0.	7.530E+00	2.662E+01	2.611E+01	6.417E+00	0.	0.	0.	0.	0.
121	0.	-2.044E+01	-3.280E+00	-3.927E+00	-2.174E+01	0.	0.	0.	0.	0.
131	0.	-3.943E+01	-2.354E+01	-2.467E+01	-4.180E+01	0.	0.	0.	0.	0.
141	0.	-5.077E+01	-3.461E+01	-3.676E+01	-5.590E+01	0.	0.	0.	0.	0.
151	-5.557E+01	-5.646E+01	-3.579E+01	-3.967E+01	-6.834E+01	-9.676E+01	0.	0.	0.	0.
161	-2.485E+01	-5.397E+00	-3.493E+00	-1.901E+01	-3.769E+01	-5.268E+01	0.	0.	0.	0.
171	-4.953E+00	7.000E+01	7.000E+01	9.786E+00	-2.095E+01	-3.689E+01	0.	0.	0.	0.

LOCATIONS 181 THROUGH 999 EQUAL 0.

LOC.
NUMBER CAPACITANCES (C)

LOCATIONS 1 THROUGH 999 EQUAL 0.

STA 54

REW = LW

LOC.
NUMBER GEN. RATES (Q)

RH = .06

LOCATIONS 1 THROUGH 999 EQUAL 0.

LOC. NUMBER	ADMITTANCES (Y)									
1	9.187E-03	1.465E-02	1.225E-02	1.058E-02	6.616E-03	1.991E-03	1.997E-03	1.001E-03	9.183E-03	1.465E-02
11	1.224E-02	1.067E-02	6.616E-03	2.026E-03	2.936E-03	3.241E-03	3.550E-03	3.561E-03	3.569E-03	3.575E-03
21	3.580E-03	3.583E-03	3.605E-03	1.526E-03	1.962E-03	9.129E+08	9.079E-04	2.928E-03	2.938E-03	3.243E-03
31	3.549E-03	3.559E-03	3.567E-03	3.574E-03	3.578E-03	3.582E-03	3.584E-03	1.511E-03	1.973E-03	9.405E-04
41	9.901E-04	2.934E-03	2.941E-03	3.244E-03	3.551E-03	3.561E-03	3.569E-03	3.575E-03	3.580E-03	3.583E-03
51	3.585E-03	1.638E-03	2.007E-03	9.827E-04	9.910E-04	1.999E-03	2.003E-03	1.003E-03	7.026E-04	1.352E-03
61	6.458E-04	7.201E-04	1.389E-03	6.842E-04	6.508E-04	8.064E-04	9.670E-04	1.133E-03	5.728E-03	5.742E-03
71	5.754E-03	1.301E-03	1.612E-03	1.933E-03	2.265E-03	1.243E-02	9.654E-03	9.685E-03	3.281E-03	3.295E-03
81	3.304E-03	3.310E-03	3.315E-03	3.319E-03	3.321E-03	3.323E-03	1.151E-03	1.084E-03	6.502E-04	8.056E-04
91	9.658E-04	1.132E-03	1.438E-02	4.023E-03	4.040E-03	6.665E-03	6.585E-03	6.602E-03	6.616E-03	6.625E-03
101	6.633E-03	6.638E-03	6.640E-03	9.196E-04	8.768E-04	1.352E-02	7.835E-03	7.857E-03	6.566E-03	6.585E-03
111	6.602E-03	6.615E-03	6.626E-03	6.633E-03	6.638E-03	6.640E-03	9.279E-04	9.091E-04	1.158E-02	9.683E-03
121	9.705E-03	3.285E-03	3.296E-03	3.304E-03	3.311E-03	3.315E-03	3.319E-03	3.321E-03	3.324E-03	1.175E-03
131	1.150E-03	5.753E-03	5.762E-03	5.772E-03	-2.804E-03	-6.681E-03	-5.694E-03	-1.956E-03	4.027E-05	2.441E-03
141	2.438E-03	7.158E-04	6.949E-04	8.950E-06	1.790E-05	4.505E-05	7.220E-05	7.220E-05	7.220E-05	7.215E-05
151	7.210E-05	7.210E-05	3.605E-05	3.991E-04	6.213E-04	4.548E-04	4.885E-04	5.177E-04	5.429E-04	5.636E-04
161	5.794E-04	5.902E-04	8.959E-04	6.007E-04	4.196E-04	6.396E-04	4.608E-04	4.915E-04	5.194E-04	5.439E-04
171	5.646E-04	5.811E-04	5.939E-04	9.093E-04	6.349E-04	0.	0.	0.	0.	0.

LOCATIONS 181 THROUGH 2999 EQUAL 0.

LOC. NUMBER	~~TEMPERATURES (T)~~ 2 channels/Rib									
1	1.504E+03	1.509E+03	1.523E+03	0.	0.	0.	0.	0.	0.	0.
11	1.371E+03	1.377E+03	1.395E+03	0.	0.	0.	0.	0.	0.	0.
21	1.154E+03	1.161E+03	1.184E+03	0.	0.	0.	0.	0.	0.	0.
31	8.791E+02	8.869E+02	9.121E+02	0.	0.	0.	0.	0.	0.	0.
41	5.723E+02	5.711E+02	5.743E+02	4.925E+02	4.596E+02	4.491E+02	0.	0.	6.259E+03	-1.760E+02
51	5.129E+02	5.114E+02	5.262E+02	4.582E+02	4.216E+02	4.111E+02	0.	0.	0.	0.
61	4.541E+02	4.296E+02	4.147E+02	3.872E+02	3.671E+02	3.695E+02	0.	0.	0.	0.
71	4.041E+02	3.475E+02	3.128E+02	3.137E+02	3.061E+02	3.289E+02	0.	0.	0.	0.
81	0.	2.213E+02	2.326E+02	2.299E+02	2.053E+02	0.	0.	0.	0.	0.
91	0.	1.383E+02	1.602E+02	1.581E+02	1.316E+02	0.	0.	0.	0.	0.
101	0.	7.835E+01	1.010E+02	9.972E+01	7.530E+01	0.	0.	0.	0.	0.
111	0.	3.390E+01	5.473E+01	5.392E+01	3.221E+01	0.	0.	0.	0.	0.
121	0.	1.421E+00	2.023E+01	1.947E+01	-8.744E-02	0.	0.	0.	0.	0.
131	0.	-2.118E+01	-3.668E+00	-4.786E+00	-2.352E+01	0.	0.	0.	0.	0.
141	0.	-3.565E+01	-1.750E+01	-1.952E+01	-4.047E+01	0.	0.	0.	0.	0.
151	-4.909E+01	-4.477E+01	-2.043E+01	-2.402E+01	-5.581E+01	-8.836E+01	0.	0.	0.	0.
161	-1.910E+01	1.390E+00	4.681E+00	-9.367E+00	-2.783E+01	-4.338E+01	0.	0.	0.	0.
171	-4.417E-01	7.000E+01	7.000E+01	1.584E+01	-1.267E+01	-2.814E+01	0.	0.	0.	0.

LOCATIONS 181 THROUGH 999 EQUAL 0.

LOC.
NUMBER CAPACITANCES (C)

LOCATIONS 1 THROUGH 999 EQUAL 0.

LOC.
NUMBER GEN. RATES (Q)

LOCATIONS 1 THROUGH 999 EQUAL 0.

STA 54

RBW = LW

RH = .08

4

LOC. NUMBER ADMITTANCES (Y)

LOC. NUMBER										
1	1.328E-02	2.125E-02	1.789E-02	1.559E-02	8.898E-03	1.981E-03	1.987E-03	9.965E-04	1.328E-02	2.125E-02
11	1.788E-02	1.558E-02	8.899E-03	2.909E-03	2.923E-03	3.229E-03	3.539E-03	3.552E-03	3.561E-03	3.569E-03
21	3.575E-03	3.579E-03	3.581E-03	1.493E-03	1.938E-03	9.129E+08	9.830E-04	2.914E-03	2.926E-03	3.232E-03
31	3.539E-03	3.550E-03	3.560E-03	3.567E-03	3.573E-03	3.577E-03	3.580E-03	1.472E-03	1.945E-03	9.356E-04
41	9.863E-04	2.923E-03	2.931E-03	3.233E-03	3.541E-03	3.553E-03	3.562E-03	3.569E-03	3.575E-03	3.579E-03
51	3.582E-03	1.503E-03	1.975E-03	9.711E-04	9.876E-04	1.992E-03	1.996E-03	1.000E-03	6.926E-04	1.339E-03
61	6.434E-04	7.086E-04	1.368E-03	6.748E-04	4.188E-04	5.217E-04	6.307E-04	7.463E-04	5.695E-03	5.711E-03
71	5.726E-03	8.374E-04	1.043E-03	1.261E-03	1.493E-03	1.236E-02	9.606E-03	9.643E-03	3.269E-03	3.285E-03
81	3.296E-03	3.304E-03	3.310E-03	3.315E-03	3.318E-03	3.320E-03	1.134E-03	1.078E-03	4.185E-04	5.211E-04
91	6.299E-04	7.459E-04	1.430E-02	4.003E-03	4.023E-03	6.544E-03	6.567E-03	6.586E-03	6.602E-03	6.615E-03
101	6.624E-03	6.630E-03	6.633E-03	9.017E-04	8.707E-04	1.347E-02	7.804E-03	7.829E-03	6.545E-03	6.568E-03
111	6.587E-03	6.603E-03	6.615E-03	6.624E-03	6.630E-03	6.634E-03	9.088E-04	8.973E-04	1.154E-02	9.650E-03
121	9.673E-03	3.275E-03	3.288E-03	3.297E-03	3.305E-03	3.311E-03	3.315E-03	3.318E-03	3.321E-03	1.154E-03
131	1.133E-03	5.734E-03	5.743E-03	5.753E-03	-2.788E-03	-6.544E-03	-5.666E-03	-1.949E-03	4.013E-05	2.440E-03
141	2.438E-03	7.062E-04	6.850E-04	8.950E-06	1.790E-05	6.285E-05	1.078E-04	1.078E-04	1.078E-04	8.995E-05
151	7.210E-05	7.210E-05	3.605E-05	3.740E-04	5.852E-04	4.311E-04	4.657E-04	4.961E-04	5.228E-04	5.454E-04
161	5.634E-04	5.768E-04	8.812E-04	5.973E-04	4.009E-04	6.096E-04	4.396E-04	4.701E-04	4.985E-04	5.242E-04
171	5.465E-04	5.649E-04	5.799E-04	8.922E-04	6.276E-04	0.	0.	0.	0.	0.

LOCATIONS 181 THROUGH 2999 EQUAL 0.

LOC. NUMBER TEMPERATURES (T) z channels/Rib

LOC. NUMBER										
1	2.397E+03	2.400E+03	2.412E+03	0.	0.	0.	0.	0.	0.	0.
11	2.188E+03	2.194E+03	2.209E+03	0.	0.	0.	0.	0.	0.	0.
21	1.811E+03	1.818E+03	1.838E+03	0.	0.	0.	0.	0.	0.	0.
31	1.310E+03	1.318E+03	1.342E+03	0.	0.	0.	0.	0.	0.	0.
41	7.253E+02	7.221E+02	7.205E+02	5.988E+02	5.509E+02	5.354E+02	0.	0.	0.	0.
51	6.536E+02	6.490E+02	6.607E+02	5.631E+02	5.125E+02	4.969E+02	0.	0.	6.259E+03	-1.720E+02
61	5.837E+02	5.505E+02	5.263E+02	4.840E+02	4.543E+02	4.530E+02	0.	0.	0.	0.
71	5.255E+02	4.529E+02	4.058E+02	4.005E+02	3.875E+02	4.089E+02	0.	0.	0.	0.
81	0.	3.012E+02	3.111E+02	3.046E+02	2.749E+02	0.	0.	0.	0.	0.
91	0.	2.018E+02	2.265E+02	2.214E+02	1.905E+02	0.	0.	0.	0.	0.
101	0.	1.299E+02	1.551E+02	1.529E+02	1.248E+02	0.	0.	0.	0.	0.
111	0.	7.626E+01	9.982E+01	9.856E+01	7.368E+01	0.	0.	0.	0.	0.
121	0.	3.656E+01	5.797E+01	5.705E+01	3.473E+01	0.	0.	0.	0.	0.
131	0.	8.123E+00	2.824E+01	2.715E+01	5.836E+00	0.	0.	0.	0.	0.
141	0.	-1.140E+01	8.996E+00	8.182E+00	-1.574E+01	0.	0.	0.	0.	0.
151	-3.899E+01	-2.609E+01	4.286E+00	1.161E+00	-3.580E+01	-7.524E+01	0.	0.	0.	0.
161	-1.008E+01	1.214E+01	1.768E+01	5.981E+00	-1.215E+01	-2.883E+01	0.	0.	0.	0.
171	8.638E+00	7.000E+01	7.000E+01	2.543E+01	4.612E-01	-1.429E+01	0.	0.	0.	0.

LOCATIONS 181 THROUGH 999 EQUAL 0.

LOC. NUMBER CAPACITANCES (C)

LOCATIONS 1 THROUGH 999 EQUAL 0.

LOC. NUMBER GEN. RATES (Q)

LOCATIONS 1 THROUGH 999 EQUAL 0.

STA 54

RBW = LW

RH = .12

5

LOC. NUMBER	ADMITTANCES (Y)									
1	4.699E-03	7.472E-03	6.210E-03	5.319E-03	4.269E-03	1.984E-03	1.988E-03	9.955E-04	4.697E-03	7.468E-03
11	6.206E-03	5.316E-03	4.268E-03	2.914E-03	2.921E-03	3.221E-03	3.523E-03	3.530E-03	3.536E-03	3.541E-03
21	3.544E-03	3.547E-03	3.550E-03	1.154E-03	1.672E-03	9.129E+08	9.836E-04	2.914E-03	2.921E-03	3.221E-03
31	3.522E-03	3.529E-03	3.535E-03	3.540E-03	3.543E-03	3.546E-03	3.549E-03	1.133E-03	1.645E-03	8.828E-04
41	9.844E-04	2.916E-03	2.922E-03	3.221E-03	3.523E-03	3.530E-03	3.536E-03	3.541E-03	3.544E-03	3.547E-03
51	3.549E-03	1.144E-03	1.620E-03	8.390E-04	9.847E-04	1.986E-03	1.989E-03	9.959E-04	5.469E-04	1.144E-03
61	6.016E-04	5.333E-04	1.097E-03	5.584E-04	1.329E-03	1.640E-03	1.953E-03	2.269E-03	5.711E-03	5.719E-03
71	5.728E-03	2.658E-03	3.279E-03	3.905E-03	4.537E-03	1.239E-02	9.613E-03	9.634E-03	3.259E-03	3.268E-03
81	3.274E-03	3.279E-03	3.282E-03	3.285E-03	3.288E-03	3.291E-03	9.278E-04	1.003E-03	1.328E-03	1.638E-03
91	1.951E-03	2.267E-03	1.432E-02	4.004E-03	4.015E-03	6.519E-03	6.532E-03	6.544E-03	6.554E-03	6.562E-03
101	6.568E-03	6.573E-03	6.577E-03	7.359E-04	8.081E-04	1.345E-02	7.788E-03	7.805E-03	6.518E-03	6.532E-03
111	6.544E-03	6.554E-03	6.562E-03	6.568E-03	6.573E-03	6.576E-03	7.266E-04	7.724E-04	1.161E-02	9.620E-03
121	9.637E-03	3.260E-03	3.268E-03	3.274E-03	3.279E-03	3.282E-03	3.285E-03	3.288E-03	3.290E-03	9.021E-04
131	9.330E-04	5.716E-03	5.723E-03	5.731E-03	-2.795E-03	-6.559E-03	-5.669E-03	-1.944E-03	4.001E-05	2.424E-03
141	2.425E-03	5.462E-04	5.518E-04	8.500E-06	1.700E-05	2.607E-05	3.513E-05	3.513E-05	3.513E-05	5.181E-05
151	6.848E-05	6.848E-05	3.424E-05	4.862E-04	7.417E-04	5.194E-04	5.383E-04	5.537E-04	5.666E-04	5.776E-04
161	5.871E-04	5.962E-04	9.113E-04	6.310E-04	4.902E-04	7.445E-04	5.198E-04	5.384E-04	5.537E-04	5.665E-04
171	5.772E-04	5.862E-04	5.942E-04	9.040E-04	6.151E-04	0.	0.	0.	0.	0.

LOCATIONS 181 THROUGH 2999 EQUAL 0.

LOC. NUMBER	TEMPERATURES (T) z channels/Rib									
1	9.369E+02	9.423E+02	9.580E+02	0.	0.	0.	0.	0.	0.	0.
11	8.839E+02	8.902E+02	9.092E+02	0.	0.	0.	0.	0.	0.	0.
21	8.119E+02	8.192E+02	8.417E+02	0.	0.	0.	0.	0.	0.	0.
31	7.284E+02	7.353E+02	7.589E+02	0.	0.	0.	0.	0.	0.	0.
41	6.402E+02	6.437E+02	6.676E+02	6.312E+02	6.196E+02	6.161E+02	0.	0.	6.259E+03	1.720E+02
51	6.026E+02	6.066E+02	6.273E+02	6.014E+02	5.853E+02	5.819E+02	0.	0.	0.	0.
61	5.636E+02	5.534E+02	5.528E+02	5.464E+02	5.401E+02	5.466E+02	0.	0.	0.	0.
71	5.281E+02	4.983E+02	4.827E+02	4.914E+02	4.916E+02	5.135E+02	0.	0.	0.	0.
81	0.	4.162E+02	4.274E+02	4.299E+02	4.149E+02	0.	0.	0.	0.	0.
91	0.	3.611E+02	3.770E+02	3.778E+02	3.610E+02	0.	0.	0.	0.	0.
101	0.	3.201E+02	3.349E+02	3.352E+02	3.203E+02	0.	0.	0.	0.	0.
111	0.	2.881E+02	3.007E+02	3.010E+02	2.885E+02	0.	0.	0.	0.	0.
121	0.	2.625E+02	2.732E+02	2.736E+02	2.634E+02	0.	0.	0.	0.	0.
131	0.	2.414E+02	2.512E+02	2.521E+02	2.433E+02	0.	0.	0.	0.	0.
141	0.	2.221E+02	2.341E+02	2.359E+02	2.263E+02	0.	0.	0.	0.	0.
151	1.552E+02	1.990E+02	2.224E+02	2.258E+02	2.088E+02	1.845E+02	0.	0.	0.	0.
161	1.409E+02	1.405E+02	1.500E+02	1.665E+02	1.747E+02	1.748E+02	0.	0.	0.	0.
171	1.268E+02	7.000E+01	7.000E+01	1.288E+02	1.559E+02	1.653E+02	0.	0.	0.	0.

LOCATIONS 181 THROUGH 999 EQUAL 0.

LOC.
NUMBER CAPACITANCES (C)

LOCATIONS 1 THROUGH 999 EQUAL 0.

STA 63

RBW = LW

RH = .04

LOC.
NUMBER GEN. RATES (Q)

LOCATIONS 1 THROUGH 999 EQUAL 0.

LOC. NUMBER	ADMITTANCES (Y)									
1	6.934E-03	1.104E-02	9.196E-03	7.902E-03	5.399E-03	1.973E-03	1.977E-03	9.904E-04	6.931E-03	1.103E-02
11	9.191E-03	7.897E-03	5.398E-03	2.897E-03	2.905E-03	3.205E-03	3.508E-03	3.516E-03	3.523E-03	3.528E-03
21	3.532E-03	3.536E-03	3.539E-03	1.041E-03	1.594E-03	9.129E+08	9.782E-04	2.898E-03	2.907E-03	3.206E-03
31	3.507E-03	3.515E-03	3.522E-03	3.527E-03	3.531E-03	3.535E-03	3.538E-03	1.015E-03	1.555E-03	8.680E-04
41	9.796E-04	2.902E-03	2.908E-03	3.206E-03	3.508E-03	3.516E-03	3.523E-03	3.528E-03	3.532E-03	3.536E-03
51	3.538E-03	1.026E-03	1.514E-03	8.013E-04	9.802E-04	1.977E-03	1.980E-03	9.916E-04	5.039E-04	1.089E-03
61	5.897E-04	4.820E-04	1.018E-03	5.250E-04	8.724E-04	1.078E-03	1.287E-03	1.500E-03	5.676E-03	5.686E-03
71	5.696E-03	1.744E-03	2.156E-03	2.574E-03	3.000E-03	1.232E-02	9.559E-03	9.583E-03	3.244E-03	3.254E-03
81	3.261E-03	3.267E-03	3.271E-03	3.275E-03	3.278E-03	3.281E-03	8.646E-04	9.815E-04	8.716E-04	1.077E-03
91	1.286E-03	1.499E-03	1.424E-02	3.982E-03	3.986E-03	6.490E-03	6.505E-03	6.519E-03	6.530E-03	6.539E-03
101	6.546E-03	6.552E-03	6.557E-03	6.811E-04	7.893E-04	1.338E-02	7.751E-03	7.769E-03	6.489E-03	6.505E-03
111	6.519E-03	6.530E-03	6.539E-03	6.546E-03	6.552E-03	6.556E-03	6.666E-04	7.356E-04	1.146E-02	9.576E-03
121	9.595E-03	3.246E-03	3.255E-03	3.262E-03	3.267E-03	3.271E-03	3.274E-03	3.277E-03	3.280E-03	8.252E-04
131	8.745E-04	5.690E-03	5.698E-03	5.706E-03	-2.778E-03	-6.520E-03	-5.638E-03	-1.935E-03	3.983E-05	2.419E-03
141	2.421E-03	5.000E-04	5.137E-04	8.500E-06	1.700E-05	3.438E-05	5.176E-05	5.176E-05	5.176E-05	6.012E-05
151	6.848E-05	6.848E-05	3.424E-05	4.803E-04	7.347E-04	5.158E-04	5.352E-04	5.511E-04	5.644E-04	5.758E-04
161	5.859E-04	5.960E-04	9.140E-04	6.400E-04	4.904E-04	7.432E-04	5.181E-04	5.362E-04	5.514E-04	5.644E-04
171	5.754E-04	5.848E-04	5.933E-04	9.039E-04	6.159E-04	0.	0.	0.	0.	0.

LOCATIONS 181 THROUGH 2999 EQUAL 0.

LOC. NUMBER	TEMPERATURES (T) z channels/Rib									
1	1.348E+03	1.353E+03	1.367E+03	0.	0.	0.	0.	0.	0.	0.
11	1.262E+03	1.268E+03	1.286E+03	0.	0.	0.	0.	0.	0.	0.
21	1.133E+03	1.140E+03	1.161E+03	0.	0.	0.	0.	0.	0.	0.
31	9.738E+02	9.808E+02	1.004E+03	0.	0.	0.	0.	0.	0.	0.
41	8.010E+02	8.021E+02	8.095E+02	7.581E+02	7.368E+02	7.298E+02	0.	0.	0.	0.
51	7.542E+02	7.558E+02	7.724E+02	7.278E+02	7.026E+02	6.955E+02	0.	0.	6.259E+03	2.520E+02
61	7.070E+02	6.914E+02	6.842E+02	6.682E+02	6.553E+02	6.588E+02	0.	0.	0.	0.
71	6.653E+02	6.260E+02	6.029E+02	6.075E+02	6.035E+02	6.234E+02	0.	0.	0.	0.
81	0.	5.287E+02	5.391E+02	5.390E+02	5.207E+02	0.	0.	0.	0.	0.
91	0.	4.642E+02	4.811E+02	4.806E+02	4.613E+02	0.	0.	0.	0.	0.
101	0.	4.166E+02	4.327E+02	4.324E+02	4.156E+02	0.	0.	0.	0.	0.
111	0.	3.794E+02	3.931E+02	3.932E+02	3.794E+02	0.	0.	0.	0.	0.
121	0.	3.494E+02	3.610E+02	3.615E+02	3.504E+02	0.	0.	0.	0.	0.
131	0.	3.241E+02	3.348E+02	3.361E+02	3.268E+02	0.	0.	0.	0.	0.
141	0.	3.001E+02	3.138E+02	3.165E+02	3.064E+02	0.	0.	0.	0.	0.
151	2.078E+02	2.701E+02	2.987E+02	3.030E+02	2.851E+02	2.561E+02	0.	0.	0.	0.
161	1.831E+02	1.776E+02	1.897E+02	2.152E+02	2.301E+02	2.331E+02	0.	0.	0.	0.
171	1.610E+02	7.000E+01	7.000E+01	1.679E+02	2.006E+02	2.167E+02	0.	0.	0.	0.

LOCATIONS 181 THROUGH 999 EQUAL 0.

ORIGINAL PAGE IS OF POOR QUALITY

LOC. NUMBER CAPACITANCES (C)

LOCATIONS 1 THROUGH 999 EQUAL 0.

STA 63

RBW = LW

RH = .06

LOC. NUMBER GEN. RATES (Q)

LOCATIONS 1 THROUGH 999 EQUAL 0.

LOC. NUMBER ADMITTANCES (Y)

1	9.084E-03	1.448E-02	1.210E-02	1.043E-02	6.522E-03	1.963E-03	1.968E-03	9.860E-04	9.080E-03	1.448E-02
11	1.209E-02	1.043E-02	6.521E-03	2.883E-03	2.892E-03	3.192E-03	3.495E-03	3.504E-03	3.512E-03	3.517E-03
21	3.522E-03	3.526E-03	3.530E-03	9.449E-04	1.530E-03	9.129E+08	9.737E-04	2.885E-03	2.895E-03	3.194E-03
31	3.494E-03	3.503E-03	3.510E-03	3.516E-03	3.521E-03	3.525E-03	3.528E-03	9.147E-04	1.482E-03	8.562E-04
41	9.757E-04	2.891E-03	2.897E-03	3.194E-03	3.496E-03	3.505E-03	3.512E-03	3.517E-03	3.522E-03	3.526E-03
51	3.529E-03	9.254E-04	1.427E-03	7.711E-04	9.764E-04	1.969E-03	1.973E-03	9.880E-04	4.677E-04	1.044E-03
61	5.798E-04	4.386E-04	9.532E-04	4.979E-04	6.433E-04	7.967E-04	9.546E-04	1.117E-03	5.646E-03	5.658E-03
71	5.670E-03	1.286E-03	1.593E-03	1.909E-03	2.234E-03	1.225E-02	9.513E-03	9.541E-03	3.231E-03	3.243E-03
81	3.251E-03	3.257E-03	3.262E-03	3.265E-03	3.269E-03	3.273E-03	8.118E-04	9.639E-04	6.428E-04	7.959E-04
91	9.535E-04	1.116E-03	1.417E-02	3.964E-03	3.979E-03	6.465E-03	6.482E-03	6.497E-03	6.509E-03	6.520E-03
101	6.528E-03	6.535E-03	6.540E-03	6.352E-04	7.741E-04	1.332E-02	7.719E-03	7.738E-03	6.465E-03	6.482E-03
111	6.497E-03	6.510E-03	6.520E-03	6.528E-03	6.534E-03	6.539E-03	6.166E-04	7.061E-04	1.141E-02	9.539E-03
121	9.559E-03	3.234E-03	3.244E-03	3.251E-03	3.257E-03	3.261E-03	3.265E-03	3.268E-03	3.271E-03	7.610E-04
131	8.270E-04	5.669E-03	5.677E-03	5.685E-03	-2.764E-03	-6.487E-03	-5.612E-03	-1.927E-03	3.967E-05	2.416E-03
141	2.418E-03	4.624E-04	4.825E-04	8.600E-06	1.700E-05	4.279E-05	6.857E-05	6.857E-05	6.857E-05	6.853E-05
151	6.848E-05	6.848E-05	3.424E-05	4.782E-04	7.327E-04	5.152E-04	5.352E-04	5.513E-04	5.649E-04	5.767E-04
161	5.872E-04	5.980E-04	9.189E-04	6.491E-04	4.925E-04	7.451E-04	5.188E-04	5.368E-04	5.520E-04	5.650E-04
171	5.763E-04	5.860E-04	5.948E-04	9.069E-04	6.188E-04	0.	0.	0.	0.	0.

LOCATIONS 181 THROUGH 2999 EQUAL 0.

LOC. NUMBER TEMPERATURES (T) z channels/R.'L

1	1.780E+03	1.784E+03	1.797E+03	0.	0.	0.	0.	0.	0.	0.
11	1.659E+03	1.665E+03	1.681E+03	0.	0.	0.	0.	0.	0.	0.
21	1.463E+03	1.470E+03	1.490E+03	0.	0.	0.	0.	0.	0.	0.
31	1.214E+03	1.221E+03	1.244E+03	0.	0.	0.	0.	0.	0.	0.
41	9.360E+02	9.354E+02	9.386E+02	8.652E+02	8.353E+02	8.252E+02	0.	0.	0.	0.
51	8.816E+02	8.813E+02	8.953E+02	8.343E+02	8.010E+02	7.908E+02	0.	0.	6.259E+03	3.190E+02
61	8.274E+02	8.074E+02	7.950E+02	7.706E+02	7.520E+02	7.529E+02	0.	0.	0.	0.
71	7.803E+02	7.332E+02	7.039E+02	7.049E+02	6.972E+02	7.154E+02	0.	0.	0.	0.
81	0.	6.229E+02	6.328E+02	6.306E+02	6.093E+02	0.	0.	0.	0.	0.
91	0.	6.506E+02	5.684E+02	5.668E+02	5.452E+02	0.	0.	0.	0.	0.
101	0.	4.974E+02	5.146E+02	5.139E+02	4.954E+02	0.	0.	0.	0.	0.
111	0.	4.650E+02	4.707E+02	4.706E+02	4.567E+02	0.	0.	0.	0.	0.
121	0.	4.224E+02	4.348E+02	4.354E+02	4.236E+02	0.	0.	0.	0.	0.
131	0.	3.937E+02	4.053E+02	4.069E+02	3.971E+02	0.	0.	0.	0.	0.
141	0.	3.660E+02	3.813E+02	3.847E+02	3.741E+02	0.	0.	0.	0.	0.
151	2.517E+02	3.306E+02	3.636E+02	3.700E+02	3.496E+02	3.163E+02	0.	0.	0.	0.
161	2.183E+02	2.076E+02	2.217E+02	2.546E+02	2.755E+02	2.811E+02	0.	0.	0.	0.
171	1.896E+02	7.000E+01	7.000E+01	1.810E+02	2.367E+02	2.585E+02	0.	0.	0.	0.

LOCATIONS 181 THROUGH 999 EQUAL 0.

LOC. NUMBER CAPACITANCES (C)

SZ4 63

LOCATIONS 1 THROUGH 999 EQUAL 0.

RBW = LW

LOC. NUMBER GEN. RATES (Q)

RH = .08

LOCATIONS 1 THROUGH 999 EQUAL 0.

LOC.
NUMBER ADMITTANCES (Y)

LOC. NUMBER										
1	1.314E-02	2.102E-02	1.767E-02	1.637E-02	8.753E-03	1.948E-03	1.954E-03	9.796E-04	1.314E-02	2.101E-02
11	1.766E-02	1.536E-02	8.754E-03	2.861E-03	2.873E-03	3.173E-03	3.476E-03	3.487E-03	3.495E-03	3.502E-03
21	3.507E-03	3.512E-03	3.516E-03	8.014E-04	1.442E-03	9.129E+08	9.668E-04	2.866E-03	2.876E-03	3.175E-03
31	3.475E-03	3.485E-03	3.494E-03	3.501E-03	3.506E-03	3.511E-03	3.515E-03	7.645E-04	1.381E-03	8.403E-04
41	9.698E-04	2.873E-03	2.880E-03	3.177E-03	3.478E-03	3.487E-03	3.495E-03	3.502E-03	3.507E-03	3.511E-03
51	3.515E-03	7.761E-04	1.306E-03	7.297E-04	9.709E-04	1.958E-03	1.962E-03	9.827E-04	4.141E-04	9.791E-04
61	5.651E-04	3.744E-04	8.610E-04	4.601E-04	4.143E-04	5.155E-04	6.222E-04	7.350E-04	5.602E-03	5.617E-03
71	5.631E-03	8.285E-04	1.031E-03	1.244E-03	1.470E-03	1.216E-02	9.446E-03	9.479E-03	3.212E-03	3.226E-03
81	3.235E-03	3.242E-03	3.248E-03	3.252E-03	3.256E-03	3.261E-03	7.345E-04	9.394E-04	4.140E-04	5.150E-04
91	6.216E-04	7.346E-04	1.406E-02	3.936E-03	3.954E-03	6.428E-03	6.448E-03	6.465E-03	6.479E-03	6.491E-03
101	6.501E-03	6.509E-03	6.515E-03	5.683E-04	7.532E-04	1.324E-02	7.671E-03	7.693E-03	6.429E-03	6.449E-03
111	6.466E-03	6.480E-03	6.491E-03	6.500E-03	6.508E-03	6.513E-03	5.437E-04	6.652E-04	1.135E-02	9.485E-03
121	9.506E-03	3.217E-03	3.228E-03	3.236E-03	3.242E-03	3.247E-03	3.252E-03	3.255E-03	3.259E-03	6.675E-04
131	7.603E-04	5.637E-03	5.645E-03	5.654E-03	-2.743E-03	-6.437E-03	-5.572E-03	-1.916E-03	3.945E-05	2.410E-03
141	2.414E-03	4.078E-04	4.383E-04	8.500E-06	1.700E-05	5.969E-05	1.024E-04	1.024E-04	1.024E-04	8.543E-05
151	6.848E-05	6.848E-05	3.424E-05	4.783E-04	7.344E-04	5.176E-04	5.383E-04	5.550E-04	5.690E-04	5.811E-04
161	5.921E-04	6.036E-04	9.296E-04	6.646E-04	4.979E-04	7.517E-04	5.220E-04	5.406E-04	5.560E-04	5.692E-04
171	5.807E-04	5.907E-04	5.999E-04	9.165E-04	8.259E-04	0.	0.	0.	0.	0.

LOCATIONS 181 THROUGH 2999 EQUAL 0.

LOC.
NUMBER TEMPERATURES (T) z channels/Rib

LOC. NUMBER										
1	2.640E+03	2.644E+03	2.654E+03	0.	0.	0.	0.	0.	0.	0.
11	2.453E+03	2.458E+03	2.471E+03	0.	0.	0.	0.	0.	0.	0.
21	2.114E+03	2.119E+03	2.137E+03	0.	0.	0.	0.	0.	0.	0.
31	1.663E+03	1.670E+03	1.691E+03	0.	0.	0.	0.	0.	0.	0.
41	1.136E+03	1.134E+03	1.133E+03	1.025E+03	9.812E+02	9.663E+02	0.	0.	6.259E+03	4.170E+02
51	1.070E+03	1.068E+03	1.079E+03	9.928E+02	9.469E+02	9.317E+02	0.	0.	0.	0.
61	1.006E+03	9.795E+02	9.598E+02	9.227E+02	8.951E+02	8.919E+02	0.	0.	0.	0.
71	9.602E+02	8.919E+02	8.535E+02	8.492E+02	8.357E+02	8.510E+02	0.	0.	0.	0.
81	0.	7.619E+02	7.713E+02	7.659E+02	7.400E+02	0.	0.	0.	0.	0.
91	0.	6.778E+02	6.972E+02	6.940E+02	6.689E+02	0.	0.	0.	0.	0.
101	0.	6.165E+02	6.366E+02	6.341E+02	6.129E+02	0.	0.	0.	0.	0.
111	0.	5.688E+02	5.852E+02	5.848E+02	5.680E+02	0.	0.	0.	0.	0.
121	0.	5.301E+02	5.439E+02	5.446E+02	5.314E+02	0.	0.	0.	0.	0.
131	0.	4.968E+02	5.098E+02	5.118E+02	5.010E+02	0.	0.	0.	0.	0.
141	0.	4.640E+02	4.817E+02	4.861E+02	4.743E+02	0.	0.	0.	0.	0.
151	3.156E+02	4.208E+02	4.607E+02	4.690E+02	4.455E+02	4.050E+02	0.	0.	0.	0.
161	2.696E+02	2.497E+02	2.660E+02	3.098E+02	3.396E+02	3.495E+02	0.	0.	0.	0.
171	2.317E+02	7.000E+01	7.000E+01	2.121E+02	2.866E+02	3.173E+02	0.	0.	0.	0.

LOCATIONS 181 THROUGH 999 EQUAL 0.

LOC.
NUMBER CAPACITANCES (C)

SZA 65

LOCATIONS 1 THROUGH 999 EQUAL 0.

RBW = LW

LOC.
NUMBER GEN. RATES (Q)

RH = .12

LOCATIONS 1 THROUGH 999 EQUAL 0.

10

DYTCQ DUMP

LOC. NUMBER	ADMITTANCES (Y)									
1	4.761E-03	6.317E-03	4.734E-03	3.790E-03	2.899E-03	2.008E-03	2.012E-03	1.008E-03	4.758E-03	6.313E-03
11	4.730E-03	3.787E-03	2.898E-03	2.948E-03	2.956E-03	3.260E-03	3.567E-03	3.574E-03	3.580E-03	3.584E-03
21	3.587E-03	3.589E-03	3.590E-03	1.577E-03	2.000E-03	9.129E+08	1.193E-03	2.950E-03	2.957E-03	3.261E-03
31	3.566E-03	3.573E-03	3.570E-03	3.583E-03	3.586E-03	3.588E-03	3.589E-03	1.560E-03	2.018E-03	9.480E-04
41	1.194E-03	2.963E-03	2.959E-03	3.261E-03	3.567E-03	3.574E-03	3.580E-03	3.584E-03	3.587E-03	3.589E-03
51	3.591E-03	1.590E-03	2.055E-03	1.000E-03	1.195E-03	2.011E-03	2.014E-03	1.008E-03	7.178E-04	1.373E-03
61	6.496E-04	7.376E-04	1.422E-03	6.985E-04	1.496E-03	2.109E-03	2.726E-03	3.347E-03	5.777E-03	5.787E-03
71	5.796E-03	2.991E-03	4.217E-03	5.451E-03	6.692E-03	1.109E-02	9.728E-03	9.750E-03	3.299E-03	3.309E-03
81	3.315E-03	3.319E-03	3.323E-03	3.325E-03	3.326E-03	3.327E-03	1.178E-03	1.094E-03	1.494E-03	2.106E-03
91	2.722E-03	3.343E-03	1.016E-02	4.053E-03	4.065E-03	6.599E-03	6.613E-03	6.625E-03	6.635E-03	6.642E-03
101	6.646E-03	6.649E-03	6.650E-03	9.467E-04	8.862E-04	8.795E-03	7.886E-03	7.903E-03	6.599E-03	6.613E-03
111	6.626E-03	6.635E-03	6.642E-03	6.647E-03	6.650E-03	6.651E-03	9.571E-04	9.272E-04	9.724E-03	9.740E-03
121	9.758E-03	3.301E-03	3.309E-03	3.316E-03	3.320E-03	3.323E-03	3.325E-03	3.327E-03	3.328E-03	1.207E-03
131	1.175E-03	5.788E-03	5.795E-03	5.803E-03	-1.384E-03	-2.305E-03	-9.224E-04	9.235E-04	-9.240E-04	2.442E-03
141	2.440E-03	7.304E-04	7.099E-04	8.950E-06	1.790E-05	2.905E-05	4.020E-05	4.020E-05	4.020E-05	5.018E-05
151	6.017E-05	6.017E-05	3.008E-05	4.490E-04	6.937E-04	5.014E-04	5.326E-04	5.586E-04	5.799E-04	5.963E-04
161	6.075E-04	6.132E-04	9.206E-04	6.065E-04	4.605E-04	7.032E-04	5.041E-04	5.338E-04	5.593E-04	5.805E-04
171	5.973E-04	6.096E-04	6.181E-04	9.382E-04	6.469E-04	0.	0.	0.	0.	0.

LOCATIONS 181 THROUGH 2999 EQUAL 0.

LOC. NUMBER	TEMPERATURES (T)									
1	6.067E+02	6.137E+02	6.335E+02	0.	0.	0.	0.	0.	0.	0.
11	5.505E+02	5.596E+02	5.870E+02	0.	0.	0.	0.	0.	0.	0.
21	4.834E+02	4.939E+02	5.280E+02	0.	0.	0.	0.	0.	0.	0.
31	4.131E+02	4.228E+02	4.569E+02	0.	0.	0.	0.	0.	0.	0.
41	3.451E+02	3.506E+02	3.680E+02	3.202E+02	3.039E+02	2.937E+02	0.	0.	0.	0.
51	3.029E+02	3.040E+02	3.203E+02	2.810E+02	2.663E+02	2.606E+02	0.	0.	6.259E+03	-1.820E+02
61	2.603E+02	2.482E+02	2.410E+02	2.280E+02	2.204E+02	2.265E+02	0.	0.	0.	0.
71	2.228E+02	1.871E+02	1.676E+02	1.730E+02	1.713E+02	1.921E+02	0.	0.	0.	0.
81	0.	9.867E+01	1.101E+02	1.107E+02	9.329E+01	0.	0.	0.	0.	0.
91	0.	4.084E+01	5.068E+01	5.836E+01	3.057E+01	0.	0.	0.	0.	0.
101	0.	-8.700E-01	1.693E+01	1.661E+01	-1.879E+00	0.	0.	0.	0.	0.
111	0.	-3.104E+01	-1.489E+01	-1.528E+01	-3.186E+01	0.	0.	0.	0.	0.
121	0.	-5.224E+01	-3.777E+01	-3.839E+01	-5.349E+01	0.	0.	0.	0.	0.
131	0.	-6.578E+01	-5.248E+01	-5.367E+01	-6.830E+01	0.	0.	0.	0.	0.
141	0.	-7.245E+01	-5.935E+01	-6.170E+01	-7.804E+01	0.	0.	0.	0.	0.
151	-6.458E+01	-7.306E+01	-5.789E+01	-6.219E+01	-8.611E+01	-1.084E+02	0.	0.	0.	0.
161	-3.292E+01	-1.608E+01	-1.624E+01	-3.283E+01	-5.173E+01	-6.668E+01	0.	0.	0.	0.
171	-1.128E+01	7.000E+01	7.000E+01	1.097E+00	-3.276E+01	-4.930E+01	0.	0.	0.	0.

LOCATIONS 181 THROUGH 999 EQUAL 0.

LOC.
NUMBER CAPACITANCES (C)

LOCATIONS 1 THROUGH 999 EQUAL 0.

SZA 54
RBW > LW
RH = .04

LOC.
NUMBER GEN. RATES (Q)

DYTCQ DUMP

LOC.
NUMBER ADMITTANCES (Y)

LOC. NUMBER										
1	7.051E-03	9.369E-03	7.035E-03	5.646E-03	3.674E-03	2.000E-03	2.005E-03	1.005E-03	7.048E-03	9.363E-03
11	7.029E-03	5.641E-03	3.673E-03	2.938E-03	2.947E-03	3.252E-03	3.559E-03	3.568E-03	3.575E-03	3.580E-03
21	3.584E-03	3.586E-03	3.588E-03	1.555E-03	1.984E-03	9.129E+08	1.189E-03	2.941E-03	2.949E-03	3.254E-03
31	3.559E-03	3.567E-03	3.574E-03	3.579E-03	3.583E-03	3.586E-03	3.587E-03	1.544E-03	1.999E-03	9.448E-04
41	1.191E-03	2.945E-03	2.951E-03	3.254E-03	3.560E-03	3.569E-03	3.575E-03	3.580E-03	3.584E-03	3.587E-03
51	3.588E-03	1.568E-03	2.034E-03	9.929E-04	1.192E-03	2.006E-03	2.010E-03	1.006E-03	7.113E-04	1.364E-03
61	6.480E-04	7.301E-04	1.408E-03	6.924E-04	9.853E-04	1.392E-03	1.803E-03	2.219E-03	5.754E-03	5.766E-03
71	5.776E-03	1.970E-03	2.782E-03	3.605E-03	4.437E-03	1.105E-02	9.695E-03	9.721E-03	3.291E-03	3.303E-03
81	3.310E-03	3.316E-03	3.320E-03	3.322E-03	3.324E-03	3.325E-03	1.166E-03	1.090E-03	9.042E-04	1.390E-03
91	1.800E-03	2.217E-03	1.013E-02	4.040E-03	4.054E-03	6.585E-03	6.601E-03	6.615E-03	6.626E-03	6.635E-03
101	6.641E-03	6.644E-03	6.646E-03	9.353E-04	8.822E-04	8.771E-03	7.865E-03	7.884E-03	6.585E-03	6.602E-03
111	6.616E-03	6.627E-03	6.635E-03	6.641E-03	6.645E-03	6.646E-03	9.448E-04	9.195E-04	9.701E-03	9.717E-03
121	9.737E-03	3.294E-03	3.304E-03	3.311E-03	3.316E-03	3.320E-03	3.323E-03	3.325E-03	3.326E-03	1.193E-03
131	1.164E-03	5.775E-03	5.783E-03	5.791E-03	-1.378E-03	-2.296E-03	-9.194E-04	9.212E-04	-9.219E-04	2.441E-03
141	2.439E-03	7.241E-04	7.035E-04	8.950E-06	1.790E-05	3.731E-05	5.672E-05	5.672E-05	5.672E-05	5.045E-05
151	6.017E-05	6.017E-05	3.008E-05	4.237E-04	6.586E-04	4.797E-04	5.126E-04	5.404E-04	5.637E-04	5.822E-04
161	5.955E-04	6.036E-04	9.106E-04	6.044E-04	4.436E-04	6.759E-04	4.853E-04	5.154E-04	5.419E-04	5.647E-04
171	5.833E-04	5.975E-04	6.080E-04	9.263E-04	6.421E-04	0.	0.	0.	0.	0.

LOCATIONS 181 THROUGH 2999 EQUAL 0.

LOC.
NUMBER TEMPERATURES (T)

LOC. NUMBER										
1	9.302E+02	9.361E+02	9.530E+02	0.	0.	0.	0.	0.	0.	0.
11	8.309E+02	8.482E+02	8.729E+02	0.	0.	0.	0.	0.	0.	0.
21	7.202E+02	7.306E+02	7.629E+02	0.	0.	0.	0.	0.	0.	0.
31	5.874E+02	5.970E+02	6.311E+02	0.	0.	0.	0.	0.	0.	0.
41	4.549E+02	4.574E+02	4.666E+02	3.913E+02	3.659E+02	3.521E+02	0.	0.	6.259E+03	-1.790E+02
51	4.022E+02	3.992E+02	4.094E+02	3.510E+02	3.280E+02	3.185E+02	0.	0.	0.	0.
61	3.506E+02	3.290E+02	3.159E+02	2.927E+02	2.791E+02	2.816E+02	0.	0.	0.	0.
71	3.066E+02	2.586E+02	2.300E+02	2.310E+02	2.256E+02	2.456E+02	0.	0.	0.	0.
81	0.	1.519E+02	1.624E+02	1.603E+02	1.393E+02	0.	0.	0.	0.	0.
91	0.	8.243E+01	1.017E+02	1.001E+02	7.715E+01	0.	0.	0.	0.	0.
101	0.	3.277E+01	5.249E+01	5.148E+01	3.033E+01	0.	0.	0.	0.	0.
111	0.	-3.572E+00	1.451E+01	1.381E+01	-5.024E+00	0.	0.	0.	0.	0.
121	0.	-2.968E+01	-1.329E+01	-1.404E+01	-3.105E+01	0.	0.	0.	0.	0.
131	0.	-4.694E+01	-3.188E+01	-3.307E+01	-4.943E+01	0.	0.	0.	0.	0.
141	0.	-5.688E+01	-4.168E+01	-4.391E+01	-6.217E+01	0.	0.	0.	0.	0.
151	-5.788E+01	-6.104E+01	-4.208E+01	-4.609E+01	-7.326E+01	-9.872E+01	0.	0.	0.	0.
161	-2.697E+01	-8.056E+00	-6.775E+00	-2.287E+01	-4.157E+01	-5.610E+01	0.	0.	0.	0.
171	-6.618E+00	7.000E+01	7.000E+01	7.380E+00	-2.420E+01	-4.027E+01	0.	0.	0.	0.

LOCATIONS 181 THROUGH 999 EQUAL 0.

LOC.
NUMBER CAPACITANCES (C)

LOCATIONS 1 THROUGH 999 EQUAL 0.

LOC.
NUMBER GEN. RATES (Q)

LOCATIONS 1 THROUGH 999 EQUAL 0.

S24 S4

RBW > LW

RH = .06

11

ORIGINAL PAGE IS
OF POOR QUALITY

LOC. NUMBER	ADMITTANCES (Y)									
1	9.268E-03	1.233E-02	9.283E-03	7.473E-03	4.444E-03	1.983E-03	1.998E-03	1.002E-03	9.262E-03	1.232E-02
11	9.275E-03	7.467E-03	4.443E-03	2.928E-03	2.939E-03	3.244E-03	3.552E-03	3.563E-03	3.571E-03	3.576E-03
21	3.581E-03	3.584E-03	3.586E-03	1.535E-03	1.968E-03	9.129E+08	1.185E-03	2.932E-03	2.942E-03	3.246E-03
31	3.552E-03	3.562E-03	3.569E-03	3.575E-03	3.580E-03	3.583E-03	3.585E-03	1.520E-03	1.980E-03	9.417E-04
41	1.180E-03	2.938E-03	2.946E-03	3.247E-03	3.554E-03	3.564E-03	3.571E-03	3.577E-03	3.581E-03	3.584E-03
51	3.586E-03	1.546E-03	2.014E-03	9.855E-04	1.189E-03	2.002E-03	2.005E-03	1.004E-03	7.049E-04	1.356E-03
61	6.464E-04	7.228E-04	1.394E-03	6.864E-04	7.289E-04	1.032E-03	1.340E-03	1.655E-03	5.732E-03	5.745E-03
71	5.750E-03	1.457E-03	2.063E-03	2.680E-03	3.309E-03	1.101E-02	9.683E-03	9.693E-03	3.284E-03	3.297E-03
81	3.305E-03	3.312E-03	3.316E-03	3.320E-03	3.322E-03	3.323E-03	1.156E-03	1.086E-03	7.281E-04	1.030E-03
91	1.338E-03	1.653E-03	1.009E-02	4.027E-03	4.044E-03	6.571E-03	6.590E-03	6.606E-03	6.618E-03	6.628E-03
101	6.635E-03	6.639E-03	6.641E-03	9.240E-04	8.783E-04	8.748E-03	7.846E-03	7.866E-03	6.572E-03	6.590E-03
111	6.606E-03	6.619E-03	6.628E-03	6.635E-03	6.640E-03	6.642E-03	9.327E-04	9.119E-04	9.679E-03	9.696E-03
121	9.716E-03	3.288E-03	3.298E-03	3.306E-03	3.312E-03	3.317E-03	3.320E-03	3.322E-03	3.324E-03	1.180E-03
131	1.154E-03	5.762E-03	5.770E-03	5.779E-03	-1.373E-03	-2.288E-03	-9.165E-04	9.189E-04	-9.198E-04	-2.441E-03
141	2.439E-03	7.180E-04	6.972E-04	8.950E-06	1.790E-05	4.590E-05	7.390E-05	7.390E-05	7.390E-05	6.703E-05
151	6.017E-05	6.017E-05	3.008E-05	4.037E-04	6.303E-04	4.616E-04	4.956E-04	5.247E-04	5.495E-04	5.696E-04
161	5.847E-04	5.948E-04	9.012E-04	6.025E-04	4.291E-04	6.529E-04	4.692E-04	4.995E-04	5.268E-04	5.507E-04
171	5.708E-04	5.866E-04	5.987E-04	9.153E-04	6.376E-04	0.	0.	0.	0.	0.

LOCATIONS 181 THROUGH 2999 EQUAL 0.

LOC. NUMBER	TEMPERATURES (T)									
1	1.292E+03	1.287E+03	1.313E+03	0.	0.	0.	0.	0.	0.	0.
11	1.165E+03	1.173E+03	1.195E+03	0.	0.	0.	0.	0.	0.	0.
21	9.829E+02	9.930E+02	1.024E+03	0.	0.	0.	0.	0.	0.	0.
31	7.729E+02	7.829E+02	8.171E+02	0.	0.	0.	0.	0.	0.	0.
41	5.570E+02	5.570E+02	5.610E+02	4.695E+02	4.265E+02	4.083E+02	0.	0.	6.259E+03	-1.760E+02
51	4.957E+02	4.891E+02	4.945E+02	4.100E+02	3.872E+02	3.742E+02	0.	0.	0.	0.
61	4.360E+02	4.076E+02	3.873E+02	3.548E+02	3.355E+02	3.356E+02	0.	0.	0.	0.
71	3.862E+02	3.268E+02	2.898E+02	2.867E+02	2.780E+02	2.971E+02	0.	0.	0.	0.
81	0.	2.031E+02	2.126E+02	2.081E+02	1.837E+02	0.	0.	0.	0.	0.
91	0.	1.228E+02	1.434E+02	1.404E+02	1.146E+02	0.	0.	0.	0.	0.
101	0.	6.542E+01	8.692E+01	8.528E+01	6.165E+01	0.	0.	0.	0.	0.
111	0.	2.320E+01	4.309E+01	4.209E+01	2.117E+01	0.	0.	0.	0.	0.
121	0.	-7.409E+00	1.058E+01	9.724E+00	-9.094E+00	0.	0.	0.	0.	0.
131	0.	-2.846E+01	-1.173E+01	-1.291E+01	-3.093E+01	0.	0.	0.	0.	0.
141	0.	-4.158E+01	-2.435E+01	-2.645E+01	-4.657E+01	0.	0.	0.	0.	0.
151	-5.132E+01	-4.923E+01	-2.654E+01	-3.026E+01	-6.060E+01	-9.123E+01	0.	0.	0.	0.
161	-2.115E+01	-1.180E+00	1.510E+00	-1.310E+01	-3.159E+01	-4.679E+01	0.	0.	0.	0.
171	-2.052E+00	7.000E+01	7.000E+01	1.352E+01	-1.581E+01	-3.142E+01	0.	0.	0.	0.

LOCATIONS 181 THROUGH 999 EQUAL 0.

LOC.
NUMBER CAPACITANCES (C)

LOCATIONS 1 THROUGH 999 EQUAL 0.

LOC.
NUMBER GEN. RATES (Q)

LOCATIONS 1 THROUGH 999 EQUAL 0.

SZA 54

RBW > LW

RH = .08

LOC.
NUMBER ADMITTANCES (Y)

LOC. NUMBER										
1	1.346E-02	1.798E-02	1.362E-02	1.104E-02	5.972E-03	1.981E-03	1.988E-03	9.968E-04	1.346E-02	1.797E-02
11	1.360E-02	1.103E-02	5.973E-03	2.911E-03	2.924E-03	3.230E-03	3.541E-03	3.553E-03	3.563E-03	3.570E-03
21	3.575E-03	3.579E-03	3.582E-03	1.499E-03	1.942E-03	9.129E+08	1.178E-03	2.917E-03	2.929E-03	3.234E-03
31	3.541E-03	3.552E-03	3.561E-03	3.568E-03	3.574E-03	3.578E-03	3.580E-03	1.479E-03	1.949E-03	9.364E-04
41	1.183E-03	2.926E-03	2.933E-03	3.235E-03	3.543E-03	3.554E-03	3.563E-03	3.570E-03	3.576E-03	3.579E-03
51	3.582E-03	1.509E-03	1.980E-03	9.730E-04	1.185E-03	1.994E-03	1.998E-03	1.001E-03	6.942E-04	1.341E-03
61	6.437E-04	7.104E-04	1.372E-03	6.763E-04	4.715E-04	6.705E-04	8.770E-04	1.091E-03	5.695E-03	5.712E-03
71	5.727E-03	9.428E-04	1.341E-03	1.753E-03	2.182E-03	1.094E-02	9.609E-03	9.646E-03	3.271E-03	3.287E-03
81	3.297E-03	3.305E-03	3.311E-03	3.315E-03	3.318E-03	3.320E-03	1.137E-03	1.079E-03	4.711E-04	6.696E-04
91	8.756E-04	1.091E-03	1.003E-02	4.006E-03	4.026E-03	6.547E-03	6.570E-03	6.589E-03	6.605E-03	6.617E-03
101	6.625E-03	6.631E-03	6.634E-03	9.047E-04	8.716E-04	8.709E-03	7.812E-03	7.835E-03	6.549E-03	6.571E-03
111	6.590E-03	6.605E-03	6.617E-03	6.626E-03	6.632E-03	6.635E-03	9.119E-04	8.992E-04	9.640E-03	9.658E-03
121	9.681E-03	3.277E-03	3.289E-03	3.299E-03	3.306E-03	3.311E-03	3.316E-03	3.319E-03	3.321E-03	1.157E-03
131	1.136E-03	5.741E-03	5.749E-03	5.759E-03	-1.364E-03	-2.274E-03	-9.116E-04	9.150E-04	-9.163E-04	2.440E-03
141	2.438E-03	7.076E-04	6.865E-04	8.950E-06	1.790E-05	6.342E-05	1.080E-04	1.089E-04	1.089E-04	8.456E-05
151	6.017E-05	6.017E-05	3.008E-05	3.750E-04	5.888E-04	4.345E-04	4.694E-04	4.999E-04	5.266E-04	5.489E-04
161	5.666E-04	5.796E-04	8.845E-04	5.984E-04	4.068E-04	6.175E-04	4.445E-04	4.747E-04	5.028E-04	5.282E-04
171	5.502E-04	5.682E-04	5.828E-04	8.959E-04	6.293E-04	0.	0.	0.	0.	0.

LOCATIONS 181 THROUGH 2999 EQUAL 0.

LOC.
NUMBER TEMPERATURES (T)

LOC. NUMBER										
1	2.068E+03	2.071E+03	2.083E+03	0.	0.	0.	0.	0.	0.	0.
11	1.863E+03	1.869E+03	1.889E+03	0.	0.	0.	0.	0.	0.	0.
21	1.540E+03	1.550E+03	1.578E+03	0.	0.	0.	0.	0.	0.	0.
31	1.149E+03	1.159E+03	1.193E+03	0.	0.	0.	0.	0.	0.	0.
41	7.297E+02	7.266E+02	7.226E+02	5.761E+02	5.277E+02	5.048E+02	0.	0.	8.259E+03	-1.720E+02
51	6.526E+02	6.406E+02	6.387E+02	5.327E+02	4.888E+02	4.699E+02	0.	0.	0.	0.
61	5.798E+02	5.407E+02	5.092E+02	4.609E+02	4.322E+02	4.286E+02	0.	0.	0.	0.
71	5.208E+02	4.426E+02	3.915E+02	3.820E+02	3.878E+02	3.860E+02	0.	0.	0.	0.
81	0.	2.907E+02	2.985E+02	2.900E+02	2.601E+02	0.	0.	0.	0.	0.
91	0.	1.922E+02	2.147E+02	2.097E+02	1.790E+02	0.	0.	0.	0.	0.
101	0.	1.217E+02	1.461E+02	1.434E+02	1.157E+02	0.	0.	0.	0.	0.
111	0.	6.933E+01	9.224E+01	8.076E+01	6.633E+01	0.	0.	0.	0.	0.
121	0.	3.077E+01	5.165E+01	5.061E+01	2.873E+01	0.	0.	0.	0.	0.
131	0.	3.313E+00	2.283E+01	2.176E+01	8.994E-01	0.	0.	0.	0.	0.
141	0.	-1.534E+01	5.449E+00	3.571E+00	-1.981E+01	0.	0.	0.	0.	0.
151	-4.046E+01	-2.906E+01	2.149E-01	-3.003E+00	-3.900E+01	-7.715E+01	0.	0.	0.	0.
161	-1.144E+01	1.044E+01	1.558E+01	3.505E+00	-1.465E+01	-3.109E+01	0.	0.	0.	0.
171	5.576E+00	7.000E+01	7.000E+01	2.390E+01	-1.623E+00	-1.647E+01	0.	0.	0.	0.

LOCATIONS 181 THROUGH 999 EQUAL 0.

STA 54

LOC.
NUMBER CAPACITANCES (C)

LOCATIONS 1 THROUGH 999 EQUAL 0.

RBW >LW

LOC.
NUMBER GEN. RATES (Q)

RH = .12

LOCATIONS 1 THROUGH 999 EQUAL 0.

DYTCQ DUMP

LOC. NUMBER — ADMITTANCES (Y)

1	4.712E-03	6.252E-03	4.684E-03	3.749E-03	2.867E-03	1.985E-03	1.989E-03	9.961E-04	4.710E-03	6.248E-03
11	4.680E-03	3.746E-03	2.866E-03	2.916E-03	2.923E-03	3.223E-03	3.525E-03	3.532E-03	3.537E-03	3.542E-03
21	3.545E-03	3.548E-03	3.550E-03	1.169E-03	1.676E-03	9.129E+00	1.180E-03	2.917E-03	2.924E-03	3.224E-03
31	3.524E-03	3.531E-03	3.536E-03	3.541E-03	3.544E-03	3.547E-03	3.549E-03	1.140E-03	1.650E-03	8.835E-04
41	1.181E-03	2.920E-03	2.925E-03	3.223E-03	3.525E-03	3.532E-03	3.537E-03	3.542E-03	3.545E-03	3.548E-03
51	3.550E-03	1.150E-03	1.625E-03	8.406E-04	1.181E-03	1.988E-03	1.991E-03	9.969E-04	5.484E-04	1.146E-03
61	6.019E-04	5.351E-04	1.100E-03	5.597E-04	1.480E-03	2.007E-03	2.697E-03	3.311E-03	5.714E-03	5.722E-03
71	5.731E-03	2.960E-03	4.173E-03	5.393E-03	6.619E-03	1.097E-02	9.619E-03	9.640E-03	3.261E-03	3.269E-03
81	3.275E-03	3.280E-03	3.283E-03	3.286E-03	3.289E-03	3.291E-03	9.304E-04	1.004E-03	1.479E-03	2.084E-03
91	2.693E-03	3.307E-03	1.005E-02	4.007E-03	4.018E-03	6.523E-03	6.530E-03	6.547E-03	6.556E-03	6.564E-03
101	6.570E-03	6.574E-03	6.578E-03	7.389E-04	8.090E-04	8.697E-03	7.797E-03	7.812E-03	6.522E-03	6.536E-03
111	6.547E-03	6.556E-03	6.564E-03	6.570E-03	6.574E-03	6.577E-03	7.298E-04	7.742E-04	9.616E-03	9.630E-03
121	9.647E-03	3.262E-03	3.270E-03	3.275E-03	3.280E-03	3.283E-03	3.286E-03	3.288E-03	3.290E-03	9.054E-04
131	9.355E-04	5.723E-03	5.730E-03	5.737E-03	-1.368E-03	-2.280E-03	-9.122E-04	9.133E-04	-9.137E-04	2.424E-03
141	2.425E-03	5.465E-04	5.533E-04	8.500E-06	1.700E-05	2.759E-05	3.817E-05	3.817E-05	3.817E-05	4.766E-05
151	5.714E-05	5.714E-05	2.857E-05	4.899E-04	7.482E-04	5.238E-04	5.423E-04	5.573E-04	5.698E-04	5.803E-04
161	5.894E-04	5.981E-04	9.137E-04	6.317E-04	4.975E-04	7.544E-04	5.253E-04	5.429E-04	5.575E-04	5.697E-04
171	5.800E-04	5.886E-04	5.962E-04	9.064E-04	6.160E-04	0.	0.	0.	0.	0.

LOCATIONS 181 THROUGH 2999 EQUAL 0.

LOC. NUMBER — TEMPERATURES (T)

1	8.671E+02	8.735E+02	8.916E+02	0.	0.	0.	0.	0.	0.	0.
11	8.157E+02	8.240E+02	8.491E+02	0.	0.	0.	0.	0.	0.	0.
21	7.542E+02	7.638E+02	7.950E+02	0.	0.	0.	0.	0.	0.	0.
31	6.898E+02	6.986E+02	7.299E+02	0.	0.	0.	0.	0.	0.	0.
41	6.274E+02	6.326E+02	6.486E+02	6.050E+02	5.901E+02	5.807E+02	0.	0.	0.	0.
51	5.887E+02	5.900E+02	6.050E+02	5.691E+02	5.558E+02	5.504E+02	0.	0.	6.259E+03	1.720E+02
61	5.495E+02	5.371E+02	6.324E+02	6.206E+02	6.139E+02	5.182E+02	0.	0.	0.	0.
71	5.147E+02	4.832E+02	4.653E+02	4.704E+02	4.691E+02	4.876E+02	0.	0.	0.	0.
81	0.	4.031E+02	4.126E+02	4.133E+02	3.985E+02	0.	0.	0.	0.	0.
91	0.	3.601E+02	3.647E+02	3.646E+02	3.485E+02	0.	0.	0.	0.	0.
101	0.	3.110E+02	3.248E+02	3.247E+02	3.105E+02	0.	0.	0.	0.	0.
111	0.	2.806E+02	2.924E+02	2.925E+02	2.807E+02	0.	0.	0.	0.	0.
121	0.	2.564E+02	2.684E+02	2.668E+02	2.571E+02	0.	0.	0.	0.	0.
131	0.	2.364E+02	2.456E+02	2.464E+02	2.381E+02	0.	0.	0.	0.	0.
141	0.	2.181E+02	2.293E+02	2.310E+02	2.221E+02	0.	0.	0.	0.	0.
151	1.539E+02	1.960E+02	2.181E+02	2.213E+02	2.055E+02	1.828E+02	0.	0.	0.	0.
161	1.397E+02	1.389E+02	1.480E+02	1.641E+02	1.723E+02	1.726E+02	0.	0.	0.	0.
171	1.258E+02	7.000E+01	7.000E+01	1.274E+02	1.640E+02	1.633E+02	0.	0.	0.	0.

LOCATIONS 181 THROUGH 999 EQUAL 0.

LOC. NUMBER — CAPACITANCES (C)

LOCATIONS 1 THROUGH 999 EQUAL 0.

STA 63

REW > LW

RH = .04

LOC. NUMBER — GEN. RATES (Q)

LOCATIONS 1 THROUGH 999 EQUAL 0.

DYTCQ DUMP

LOC. NUMBER ADMITTANCES (Y)

LOC. NUMBER										
1	6.970E-03	9.259E-03	8.950E-03	5.675E-03	3.626E-03	1.974E-03	1.978E-03	9.910E-04	6.967E-03	9.253E-03
11	6.944E-03	5.571E-03	3.626E-03	2.899E-03	2.908E-03	3.208E-03	3.510E-03	3.518E-03	3.524E-03	3.529E-03
21	3.533E-03	3.537E-03	3.540E-03	1.047E-03	1.597E-03	9.129E+00	1.173E-03	2.902E-03	2.910E-03	3.209E-03
31	3.509E-03	3.517E-03	3.523E-03	3.528E-03	3.532E-03	3.536E-03	3.538E-03	1.023E-03	1.560E-03	8.687E-04
41	1.175E-03	2.906E-03	2.912E-03	3.209E-03	3.511E-03	3.518E-03	3.524E-03	3.529E-03	3.533E-03	3.536E-03
51	3.539E-03	1.032E-03	1.519E-03	8.030E-04	1.176E-03	1.979E-03	1.982E-03	9.926E-04	5.055E-04	1.091E-03
61	5.901E-04	4.838E-04	1.021E-03	5.264E-04	9.738E-04	1.375E-03	1.781E-03	2.191E-03	5.679E-03	5.690E-03
71	5.700E-03	1.947E-03	2.749E-03	3.560E-03	4.380E-03	1.090E-02	9.566E-03	9.590E-03	3.246E-03	3.256E-03
81	3.263E-03	3.268E-03	3.272E-03	3.275E-03	3.278E-03	3.282E-03	8.675E-04	9.824E-04	9.728E-04	1.373E-03
91	1.778E-03	2.188E-03	9.994E-03	3.906E-03	3.999E-03	6.494E-03	6.509E-03	6.522E-03	6.532E-03	6.541E-03
101	6.548E-03	6.554E-03	6.558E-03	6.844E-04	7.903E-04	8.655E-03	7.760E-03	7.777E-03	6.494E-03	6.509E-03
111	6.522E-03	6.532E-03	6.541E-03	6.548E-03	6.553E-03	6.557E-03	6.702E-04	7.375E-04	9.572E-03	9.587E-03
121	9.604E-03	3.249E-03	3.257E-03	3.263E-03	3.268E-03	3.272E-03	3.275E-03	3.278E-03	3.280E-03	8.288E-04
131	8.772E-04	5.698E-03	5.705E-03	5.712E-03	-1.360E-03	-2.266E-03	-9.073E-04	9.089E-04	-9.096E-04	2.419E-03
141	2.422E-03	5.014E-04	5.152E-04	8.500E-06	1.700E-05	3.544E-05	5.387E-05	5.387E-05	5.387E-05	5.551E-05
151	5.714E-05	5.714E-05	2.857E-05	4.839E-04	7.412E-04	5.200E-04	5.392E-04	5.546E-04	5.674E-04	5.784E-04
161	5.882E-04	5.000E-04	9.164E-04	8.407E-04	4.972E-04	7.524E-04	5.232E-04	5.406E-04	5.551E-04	5.675E-04
171	5.781E-04	5.871E-04	5.953E-04	9.063E-04	6.168E-04	0.	0.	0.	0.	0.

LOCATIONS 181 THROUGH 2999 EQUAL 0.

LOC. NUMBER TEMPERATURES (T)

LOC. NUMBER										
1	1.219E+03	1.224E+03	1.240E+03	0.	0.	0.	0.	0.	0.	0.
11	1.137E+03	1.144E+03	1.167E+03	0.	0.	0.	0.	0.	0.	0.
21	1.028E+03	1.037E+03	1.067E+03	0.	0.	0.	0.	0.	0.	0.
31	9.073E+02	9.161E+02	9.471E+02	0.	0.	0.	0.	0.	0.	0.
41	7.866E+02	7.893E+02	7.979E+02	7.298E+02	7.068E+02	6.941E+02	0.	0.	6.259E+03	2.520E+02
51	7.384E+02	7.363E+02	7.460E+02	6.933E+02	6.724E+02	6.635E+02	0.	0.	0.	0.
61	6.910E+02	6.727E+02	6.613E+02	6.406E+02	6.282E+02	6.299E+02	0.	0.	0.	0.
71	6.500E+02	6.088E+02	5.836E+02	5.848E+02	5.799E+02	5.969E+02	0.	0.	0.	0.
81	0.	5.141E+02	5.227E+02	5.211E+02	5.032E+02	0.	0.	0.	0.	0.
91	0.	4.621E+02	4.676E+02	4.663E+02	4.478E+02	0.	0.	0.	0.	0.
101	0.	4.065E+02	4.215E+02	4.200E+02	4.050E+02	0.	0.	0.	0.	0.
111	0.	3.712E+02	3.840E+02	3.839E+02	3.709E+02	0.	0.	0.	0.	0.
121	0.	3.427E+02	3.535E+02	3.539E+02	3.435E+02	0.	0.	0.	0.	0.
131	0.	3.186E+02	3.286E+02	3.298E+02	3.211E+02	0.	0.	0.	0.	0.
141	0.	2.966E+02	3.084E+02	3.111E+02	3.018E+02	0.	0.	0.	0.	0.
151	2.065E+02	2.668E+02	2.938E+02	2.988E+02	2.815E+02	2.543E+02	0.	0.	0.	0.
161	1.819E+02	1.759E+02	1.876E+02	2.126E+02	2.275E+02	2.308E+02	0.	0.	0.	0.
171	1.600E+02	7.000E+01	7.000E+01	1.565E+02	1.986E+02	2.145E+02	0.	0.	0.	0.

LOCATIONS 181 THROUGH 999 EQUAL 0.

LOC. NUMBER CAPACITANCES (C)

STA 63

LOCATIONS 1 THROUGH 999 EQUAL 0.

¢BW > LW

LOC. NUMBER GEN. RATES (Q)

RH = .06

LOCATIONS 1 THROUGH 999 EQUAL 0.

LOC. NUMBER	ADMITTANCES (Y)									
1	9.154E-03	1.218E-02	9.182E-03	7.370E-03	4.370E-03	1.984E-03	1.989E-03	9.866E-04	9.151E-03	1.217E-02
11	9.155E-03	7.364E-03	4.379E-03	2.885E-03	2.895E-03	3.194E-03	3.497E-03	3.506E-03	3.513E-03	3.518E-03
21	3.523E-03	3.527E-03	3.530E-03	9.507E-04	1.534E-03	9.129E+08	1.160E-03	2.889E-03	2.897E-03	3.196E-03
31	3.496E-03	3.505E-03	3.512E-03	3.518E-03	3.522E-03	3.526E-03	3.529E-03	9.217E-04	1.486E-03	8.568E-04
41	1.170E-03	2.894E-03	2.900E-03	3.197E-03	3.498E-03	3.506E-03	3.513E-03	3.519E-03	3.523E-03	3.527E-03
51	3.530E-03	9.315E-04	1.432E-03	7.726E-04	1.171E-03	1.972E-03	1.975E-03	9.889E-04	4.891E-04	1.046E-03
61	5.801E-04	4.403E-04	9.561E-04	4.992E-04	7.199E-04	1.019E-03	1.322E-03	1.631E-03	5.649E-03	5.661E-03
71	5.672E-03	1.440E-03	2.036E-03	2.644E-03	3.262E-03	1.085E-02	9.520E-03	9.547E-03	3.233E-03	3.244E-03
81	3.252E-03	3.268E-03	3.262E-03	3.266E-03	3.270E-03	3.274E-03	0.144E-04	9.648E-04	7.193E-04	1.017E-03
91	1.320E-03	1.630E-03	9.943E-03	3.968E-03	3.982E-03	6.469E-03	6.485E-03	6.500E-03	6.512E-03	6.522E-03
101	6.530E-03	6.536E-03	6.541E-03	6.382E-04	7.750E-04	8.618E-03	7.728E-03	7.746E-03	6.470E-03	6.486E-03
111	6.500E-03	6.512E-03	6.522E-03	6.529E-03	6.535E-03	6.540E-03	6.199E-04	7.077E-04	9.534E-03	9.549E-03
121	9.567E-03	3.237E-03	3.246E-03	3.253E-03	3.258E-03	3.262E-03	3.266E-03	3.269E-03	3.272E-03	-7.642E-04
131	8.293E-04	5.676E-03	5.683E-03	5.691E-03	-1.353E-03	-2.255E-03	-9.030E-04	9.052E-04	-9.060E-04	2.416E-03
141	2.419E-03	4.636E-04	4.838E-04	8.500E-06	1.700E-05	4.359E-05	7.018E-05	7.018E-05	7.018E-05	6.366E-05
151	5.714E-05	5.714E-05	2.857E-05	4.808E-04	7.379E-04	5.187E-04	5.384E-04	5.542E-04	5.675E-04	5.789E-04
161	5.891E-04	5.996E-04	9.209E-04	6.496E-04	4.982E-04	7.529E-04	5.231E-04	5.404E-04	5.561E-04	5.677E-04
171	5.785E-04	5.879E-04	5.965E-04	9.090E-04	6.194E-04	0.	0.	0.	0.	0.

LOCATIONS 181 THROUGH 2999 EQUAL 0.

LOC. NUMBER	TEMPERATURES (T)									
1	1.591E+03	1.595E+03	1.609E+03	0.	0.	0.	0.	0.	0.	0.
11	1.475E+03	1.482E+03	1.503E+03	0.	0.	0.	0.	0.	0.	0.
21	1.311E+03	1.320E+03	1.348E+03	0.	0.	0.	0.	0.	0.	0.
31	1.121E+03	1.130E+03	1.161E+03	0.	0.	0.	0.	0.	0.	0.
41	9.261E+02	9.267E+02	9.298E+02	8.389E+02	8.082E+02	7.923E+02	0.	0.	6.259E+03	3.190E+02
51	8.694E+02	8.645E+02	8.700E+02	8.016E+02	7.738E+02	7.615E+02	0.	0.	0.	0.
61	8.144E+02	7.910E+02	7.737E+02	7.448E+02	7.273E+02	7.264E+02	0.	0.	0.	0.
71	7.677E+02	7.180E+02	6.863E+02	6.840E+02	6.757E+02	6.912E+02	0.	0.	0.	0.
81	0.	6.097E+02	6.179E+02	6.142E+02	5.933E+02	0.	0.	0.	0.	0.
91	0.	5.396E+02	5.561E+02	5.537E+02	5.329E+02	0.	0.	0.	0.	0.
101	0.	4.883E+02	5.045E+02	5.034E+02	4.857E+02	0.	0.	0.	0.	0.
111	0.	4.485E+02	4.624E+02	4.621E+02	4.479E+02	0.	0.	0.	0.	0.
121	0.	4.163E+02	4.280E+02	4.285E+02	4.173E+02	0.	0.	0.	0.	0.
131	0.	3.887E+02	3.996E+02	4.012E+02	3.918E+02	0.	0.	0.	0.	0.
141	0.	3.619E+02	3.764E+02	3.797E+02	3.698E+02	0.	0.	0.	0.	0.
151	2.506E+02	3.275E+02	3.591E+02	3.654E+02	3.463E+02	3.148E+02	0.	0.	0.	0.
161	2.173E+02	2.062E+02	2.199E+02	2.624E+02	2.732E+02	2.791E+02	0.	0.	0.	0.
171	1.888E+02	7.000E+01	7.000E+01	1.798E+02	2.349E+02	2.567E+02	0.	0.	0.	0.

LOCATIONS 181 THROUGH 999 EQUAL 0.

LOC.
NUMBER CAPACITANCES (C)

LOCATIONS 1 THROUGH 999 EQUAL 0.

SZA 63

KBW > LW

RH = .08

LOC.
NUMBER GEN. RATES (Q)

LOCATIONS 1 THROUGH 999 EQUAL 0.

LOC. NUMBER — ADMITTANCES (Y)

LOC. NUMBER										
1	1.331E-02	1.776E-02	1.343E-02	1.088E-02	5.875E-03	1.948E-03	1.954E-03	9.798E-04	1.331E-02	1.775E-02
11	1.342E-02	1.087E-02	5.875E-03	2.863E-03	2.874E-03	3.174E-03	3.477E-03	3.488E-03	3.496E-03	3.502E-03
21	3.508E-03	3.512E-03	3.516E-03	8.052E-04	1.444E-03	9.129E+00	1.159E-03	2.868E-03	2.878E-03	3.177E-03
31	3.477E-03	3.487E-03	3.495E-03	3.501E-03	3.507E-03	3.511E-03	3.515E-03	7.691E-04	1.383E-03	8.407E-04
41	1.163E-03	2.876E-03	2.882E-03	3.178E-03	3.479E-03	3.489E-03	3.496E-03	3.503E-03	3.508E-03	3.512E-03
51	3.515E-03	7.801E-04	1.308E-03	7.306E-04	1.164E-03	1.960E-03	1.963E-03	9.833E-04	4.150E-04	9.801E-04
61	5.853E-04	3.755E-04	8.628E-04	4.608E-04	4.659E-04	6.619E-04	8.646E-04	1.074E-03	5.602E-03	5.617E-03
71	5.631E-03	9.316E-04	1.323E-03	1.729E-03	2.148E-03	1.076E-02	9.448E-03	9.482E-03	3.213E-03	3.227E-03
81	3.236E-03	3.243E-03	3.248E-03	3.253E-03	3.257E-03	3.261E-03	7.361E-04	9.398E-04	4.655E-04	6.611E-04
91	8.633E-04	1.074E-03	9.865E-03	3.939E-03	3.956E-03	6.431E-03	6.450E-03	6.467E-03	6.481E-03	6.492E-03
101	6.502E-03	6.510E-03	6.516E-03	5.702E-04	7.537E-04	8.561E-03	7.678E-03	7.690E-03	6.433E-03	6.452E-03
111	6.468E-03	6.481E-03	6.492E-03	6.501E-03	6.509E-03	6.514E-03	5.457E-04	6.662E-04	9.475E-03	9.491E-03
121	9.512E-03	3.219E-03	3.229E-03	3.237E-03	3.243E-03	3.248E-03	3.252E-03	3.256E-03	3.259E-03	6.695E-04
131	7.617E-04	5.642E-03	5.650E-03	5.659E-03	-1.342E-03	-2.237E-03	-8.963E-04	8.994E-04	-9.005E-04	2.410E-03
141	2.414E-03	4.085E-04	4.390E-04	8.500E-06	1.700E-05	6.023E-05	1.035E-04	1.035E-04	1.035E-04	8.031E-05
151	5.714E-05	5.714E-05	2.057E-05	4.788E-04	7.365E-04	5.193E-04	5.400E-04	5.565E-04	5.704E-04	5.823E-04
161	5.932E-04	6.046E-04	9.307E-04	8.649E-04	5.016E-04	7.565E-04	5.254E-04	5.428E-04	5.578E-04	5.707E-04
171	5.820E-04	5.918E-04	6.009E-04	9.167E-04	6.263E-04	0.	0.	0.	0.	0.

LOCATIONS 181 THROUGH 2999 EQUAL 0.

LOC. NUMBER — TEMPERATURES (T)

LOC. NUMBER										
1	2.342E+03	2.346E+03	2.358E+03	0.	0.	0.	0.	0.	0.	0.
11	2.159E+03	2.165E+03	2.183E+03	0.	0.	0.	0.	0.	0.	0.
21	1.870E+03	1.878E+03	1.903E+03	0.	0.	0.	0.	0.	0.	0.
31	1.519E+03	1.528E+03	1.559E+03	0.	0.	0.	0.	0.	0.	0.
41	1.141E+03	1.139E+03	1.137E+03	1.008E+03	9.630E+02	9.417E+02	0.	0.	6.259E+03	4.170E+02
51	1.071E+03	1.062E+03	1.063E+03	9.679E+02	9.283E+02	9.104E+02	0.	0.	0.	0.
61	1.004E+03	9.728E+02	9.466E+02	9.043E+02	8.780E+02	8.729E+02	0.	0.	0.	0.
71	9.478E+02	8.847E+02	8.428E+02	8.350E+02	8.209E+02	8.338E+02	0.	0.	0.	0.
81	0.	7.546E+02	7.621E+02	7.551E+02	7.292E+02	0.	0.	0.	0.	0.
91	0.	6.713E+02	6.896E+02	6.855E+02	6.608E+02	0.	0.	0.	0.	0.
101	0.	6.109E+02	6.292E+02	6.273E+02	6.067E+02	0.	0.	0.	0.	0.
111	0.	5.641E+02	5.800E+02	5.794E+02	5.630E+02	0.	0.	0.	0.	0.
121	0.	5.262E+02	5.396E+02	5.402E+02	5.274E+02	0.	0.	0.	0.	0.
131	0.	4.936E+02	5.062E+02	5.081E+02	4.977E+02	0.	0.	0.	0.	0.
141	0.	4.613E+02	4.785E+02	4.828E+02	4.716E+02	0.	0.	0.	0.	0.
151	3.150E+02	4.188E+02	4.578E+02	4.660E+02	4.434E+02	4.042E+02	0.	0.	0.	0.
161	2.690E+02	2.489E+02	2.650E+02	3.085E+02	3.383E+02	3.404E+02	0.	0.	0.	0.
171	2.312E+02	7.000E+01	7.000E+01	2.114E+02	2.856E+02	3.162E+02	0.	0.	0.	0.

LOCATIONS 181 THROUGH 999 EQUAL 0.

LOC. NUMBER — CAPACITANCES (C)

LOCATIONS 1 THROUGH 999 EQUAL 0.

LOC. NUMBER — GEN. RATES (Q)

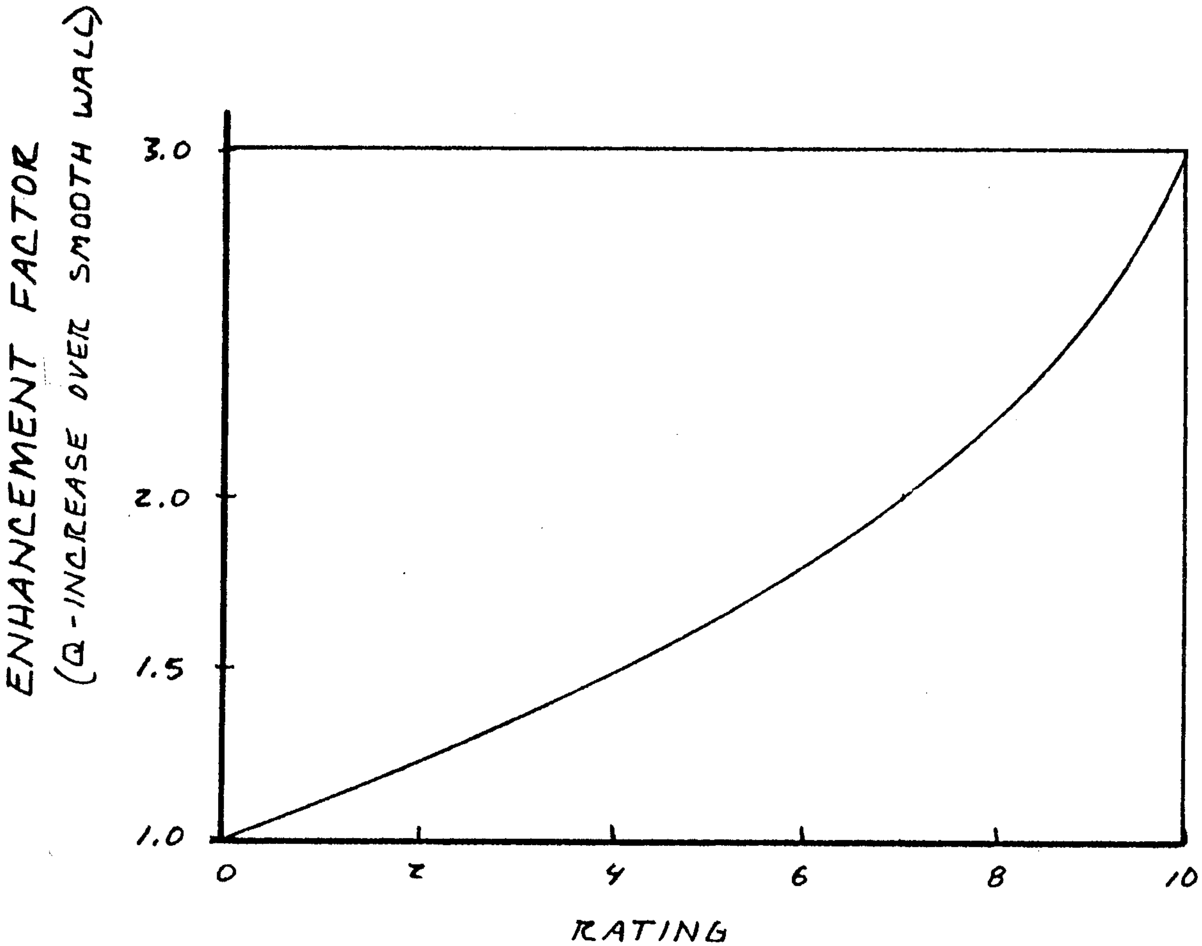
LOCATIONS 1 THROUGH 999 EQUAL 0.

STA 63

RBW > LO

RH = .12

RIB EVALUATION CRITERIA RATING SCALES



HEAT TRANSFER RATING

BOUNDARY LAYER RATING:

Based on Estimated Boundary Layer Growth

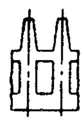
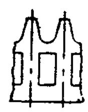
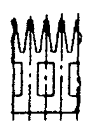
Over Ribbed Combustor Wall Length

RATING	DESCRIPTION
10	Optimum boundry layer growth on rib contour. No Q losses.
8	Well defined boundry layer to end of panel. Some Q losses.
6	Boundry layer blends to fill contour by end of panel.
4	Boundry layer blends to fill contour prior to end of panel. Significant Q Loss.
2	Contour filled prior to 50% length.
0	Contour fills quickly - negligible Q enhancement from ribbed wall contour.

Boundry Layer Rating

1774/d

PRODUCIBILITY RISK RATING:
Based on Scale, Aspect Ratio and Contour Complexity

RATING	EXAMPLE	DESCRIPTION
10		Simple in shape; moderate feature size (Approx. .040)
8		Basic Shape; higher aspect ratio (i.e. deeper cut)
6	 	Very high aspect ratio or contour complexity
5		Smaller feature sizes and/or complex contours
4-1		Combinations of small scale, high aspect ratio and complex contours
0		Size and complexity requirements make fabrication prohibitively difficult and expensive

PRODUCIBILITY RATING

1774/d

STRUCTURAL/LIFE CONSIDERATIONS:
Based Primarily on Material Property Degradation
With Temperature (NARloy -Z)

RATING	DESCRIPTION
10	No life limit in application
9	Life well exceeds design requirements
8	Life meets design requirements
6	Occasional material roughening at rib tips (1400°F)
4	Material roughening on ribs over large areas
2	Material may survive in optimal conditions
0	Material will not survive in application

Structural/Life Rating ___

1774/d

APPENDIX B
HOT AIR TESTS

HOT AIR TEST FIXTURE DRAWINGS

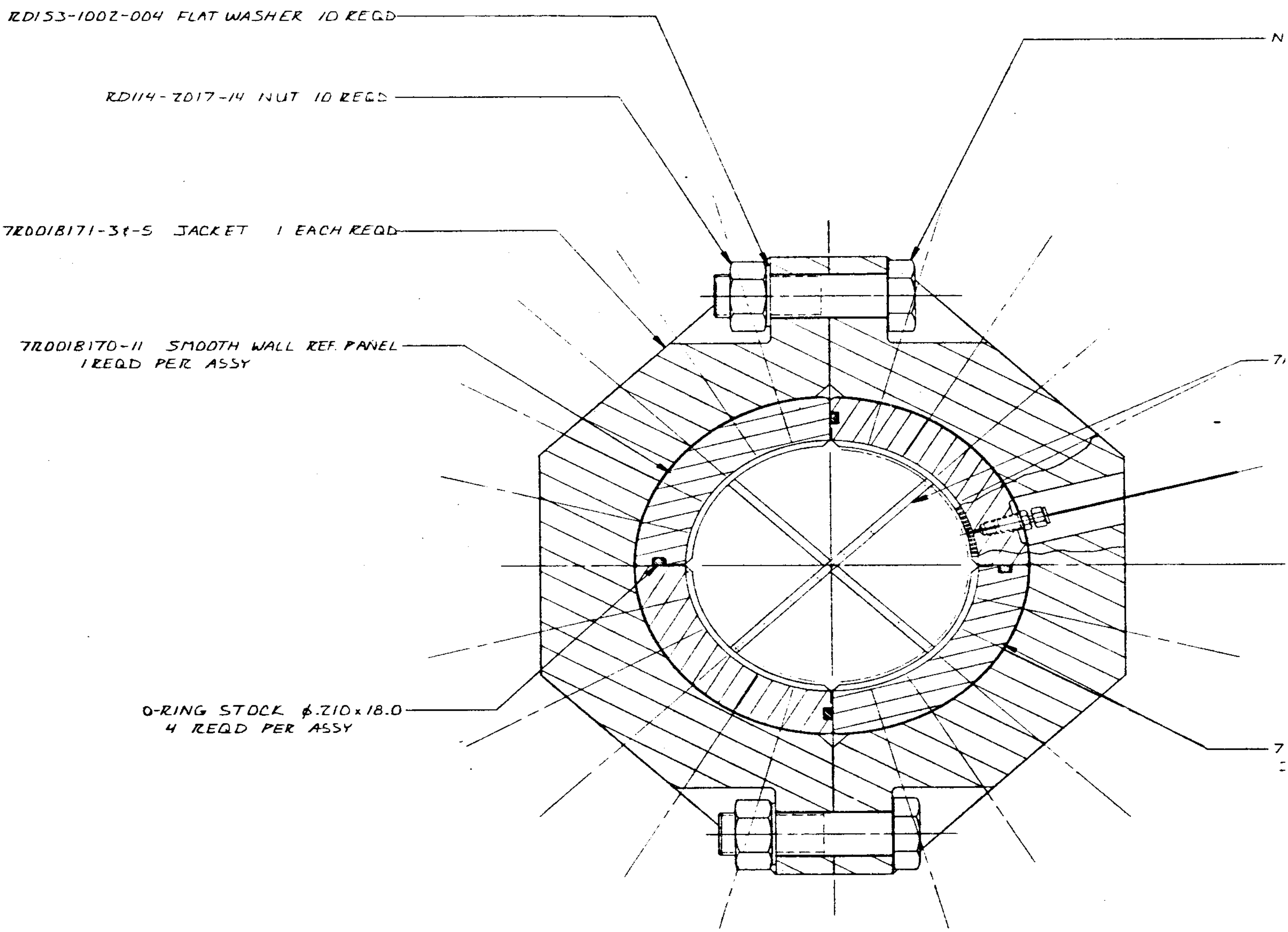
TITLE	DWG #
HOT AIR TEST ASSEMBLY	7R0018169
TEST PANELS	7R0018170
JACKET	7R0018171
ENTRANCE SECTION	7R0018172
EXIT SECTION	7R0018168
REPLACEABLE NOZZLE	7R0018483
RETAINER RING	7R0018484
SUPPORT BAR (INSTRUMENTATION)	7R0018485
TURBULATOR	7R0018491

TEST PLAN

TEST DATA

ORIGINAL PAGE IS
OF POOR QUALITY

FOLDOUT FRAME



SECTION A-A 4G

2 FOLDOUT FRAME

• MICROFILM OVERLAP AREA •

16 | 15 | 14 | 13

D14-3D BOLT (140K) 10 REQD

TEST FAC

NAS1081-3-
12

1B485-3, -5 T/C SUPPORT BARS (REF)

7R0018483-5 REPLACABLE

)1B170-XX TEST PANELS (1)
EQD PER ASSY (-XX TBD)

NAS1351-4-10 CA
MS35338-139 LOCK W

7R0018485-34-5 T/C SUPPORT

7R0018168-3 EXIT

7R0018484-3 RETAIN

MHC-040-A4-V

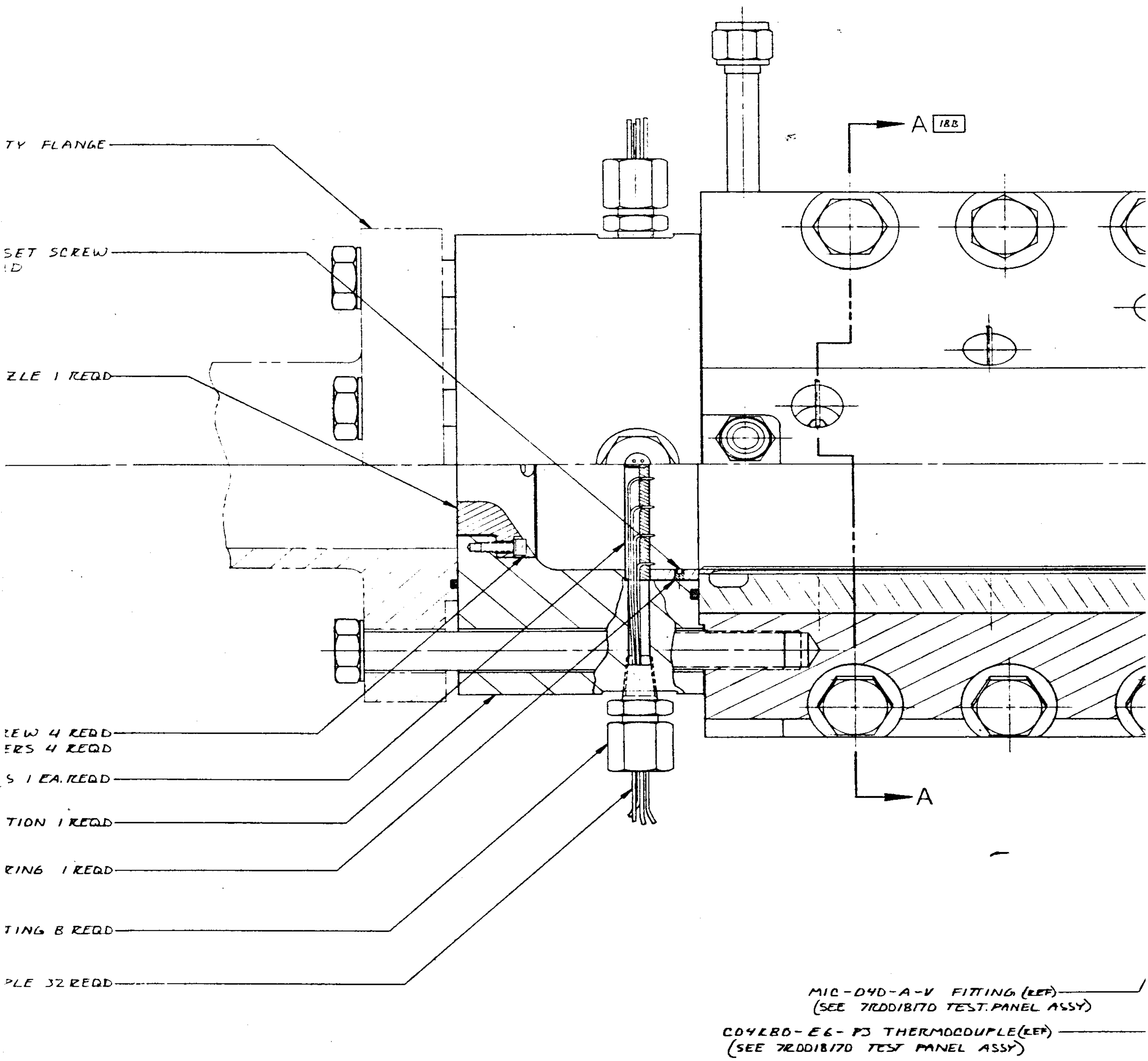
C04280-E12-PJ THERMC

nal Corporation
Division

FRAME 1
SH | REV

16 | 15 | 14 | 13

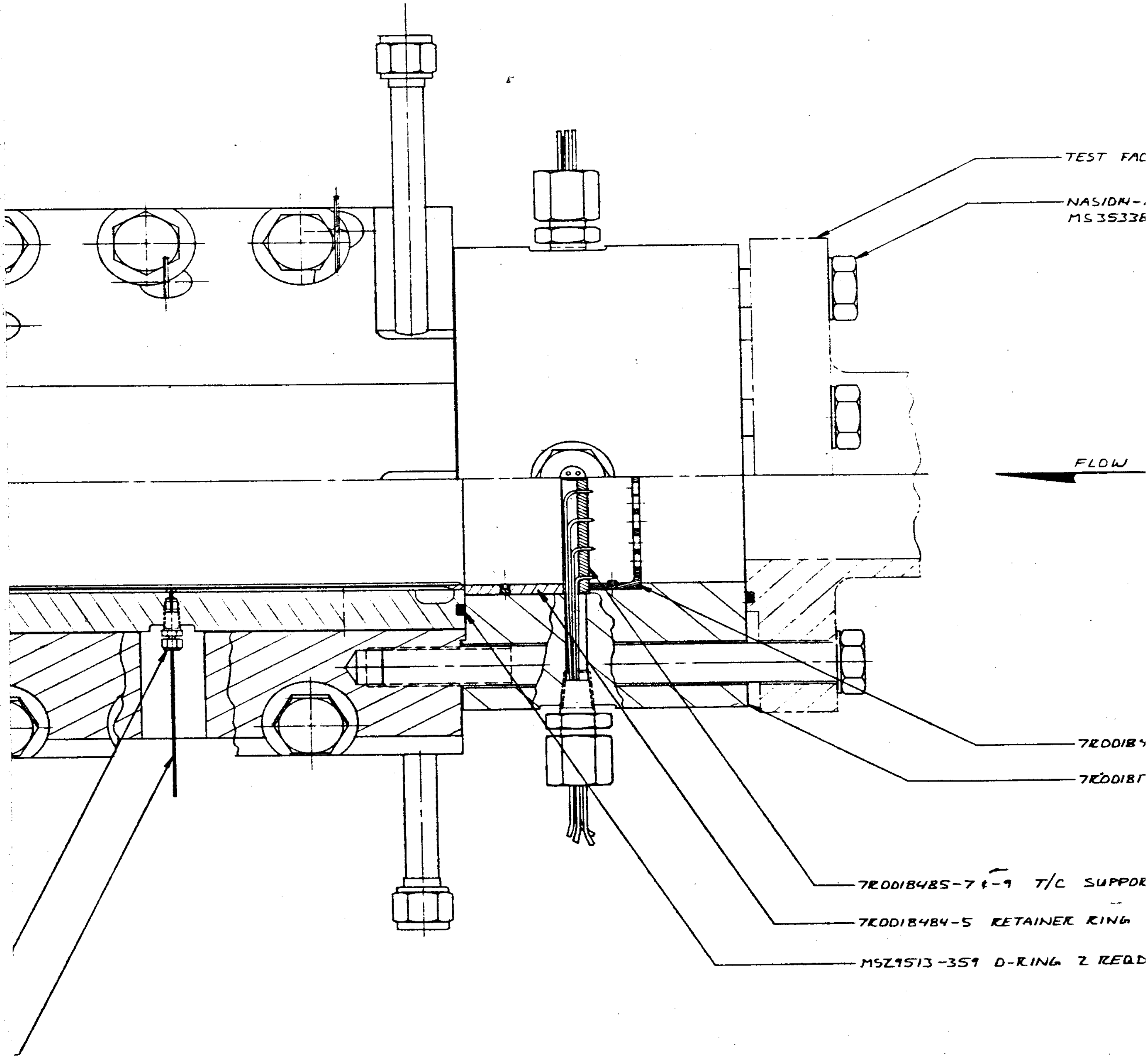
• MICROFILM OVERLAP AREA •



3 FOLDOUT FRAME

Rockwell International Corp
Rocketdyne Division
Canoga Park, California

FSCM NO 02602	FRAME
7RD018169	



4 FOLDOUT FRAME

5 INSTALL THREADE
(4) INSTRUMENT LABO
3. INSTALL THREADED
(2) CALIFORNIA ALLOY
(1) SPECIFIC PANELS

32	CD4KBO-E12-PJ		THERMOCOUPLE ASSY		⟨2⟩		13B
5	CD4KBO-E6-PJ		THERMOCOUPLE ASSY		(PER PANEL) ⟨2⟩		10B
8	MHC-040-A4-V		CONAX FITTING		⟨4⟩		13B
5	MIC-040-A-V		CONAX FITTING		(PER PANEL) ⟨4⟩		10B
4			CORD STOCK	VITON	ϕ.210 × 18.0 PER ASSY		21D
2	TBD		O-RING		(TO FACILITY)		5C
2	M83248/1-359		O-RING				6B
4	MS35338-139		WASHER, LOCK				13C
4	NAS1351-4-10		CAPSCREW ϕ.250-28				13C
16	MS35338-147		WASHER, LOCK				5F
10	RD153-1002-0014		WASHER, FLAT				21G
10	RD114-2017-14		NUT ϕ.875-14				20G
16	NAS1014-118		BOLT ϕ.875-14		140L ; EXTRA LONG		5F
10	NAS1014-30		BOLT ϕ.875-14		140L		17G
12	NAS1081-3-4		SETSCREW 0.190-32		.250 LONG		13F
1	7R0018491-3		TURBULATOR				5C
1	7R0018485-9		SUPPORT BAR				6B
1	7R0018485-7		"				6B
1	7R0018485-5		"				14C
1	7R0018485-3		"				14C
1	7R0018484-5		RETAINER RING				6B
1	7R0018484-3		RETAINER RING				13C
1	7R0018483-3		REPLACABLE NOZZLE				14E
1	7R0018168-3		EXIT SECTION				13C
1	7R0018172-3		ENTRANCE SECTION				5C
1	7R0018171-5		JACKET HALF				21F
1	7R0018171-3		JACKET HALF				21F
4	7R0018170-XX		TEST PANELS		⟨1⟩		17D
REQD	PART NUMBER	FSCM	NOMENCLATURE	MATERIAL	SPECS ; NOTES	SH	ZONE

·Y FLANGE

BOLT (140L EXTRA LONG) 16 REQD
7 LOCK WASHERS 16 REQD

ORIGINAL PAGE IS
OF POOR QUALITY

5 FOLDOUT FRAME

FOR INFORMATION

TURBULATOR RING 1 REQD

ENTRANCE SECTION 1 REQD

ARS 1 EA. REQD

QD

STENERS PER RA0101-002.
·Y, 1323 W. 130TH ST., GARDENA, CA 90247
·ENERS PER RA0101-002
1475 POTRERO AVE., EL MONTE, CA 91733
BE USED IN ASSY TBD AT TIME OF TEST.

NOTE: UNLESS OTHERWISE SPECIFIED

HEAT TREAT | FINISH | MATL

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES AND APPLY PRIOR TO FINISH.
125/ MACH. SURF. ROUGHNESS
TOLERANCES ON: ANGLES ± 0° 30' DECIMALS XX ± .03 XXX ± .010
HOLES NOTED "DRILL"

OVER	THRU	TOLERANCE
.0000	.0400	+ .0015 — .0010
.0400	.1300	+ .0030 — .0010
.1300	.2250	+ .0040 — .0010
.2250	.5000	+ .0050 — .0010
.5000	.7500	+ .0070 — .0010
.7500	1.0000	+ .0080 — .0010
1.0000	2.0000	+ .0130 — .0010

DO NOT SCALE PRINT

CONTR
DWN G DEFEVER DATE 5-4-84
CHK DATE
DSGN
MATL
STRUCT
DESIGN ACTIVITY APVD DATE

Rockwell International Corporation
Rocketdyne Division
Canoga Park, California

HDT AIR PANEL TEST ASSEMBLY

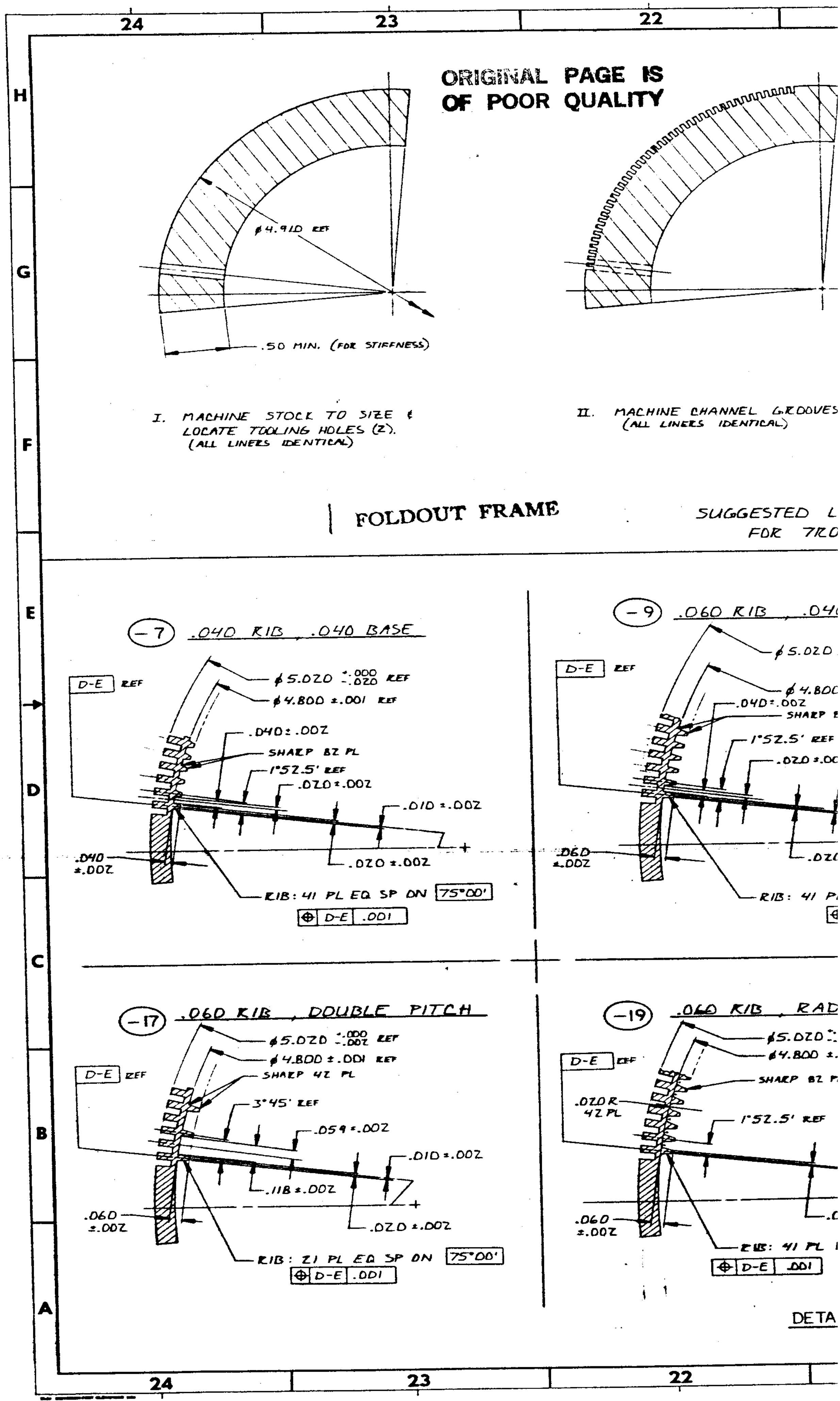
SIZE J FSCM NO 02602 DWG NO 7R0018169

SCALE FULL SHEET

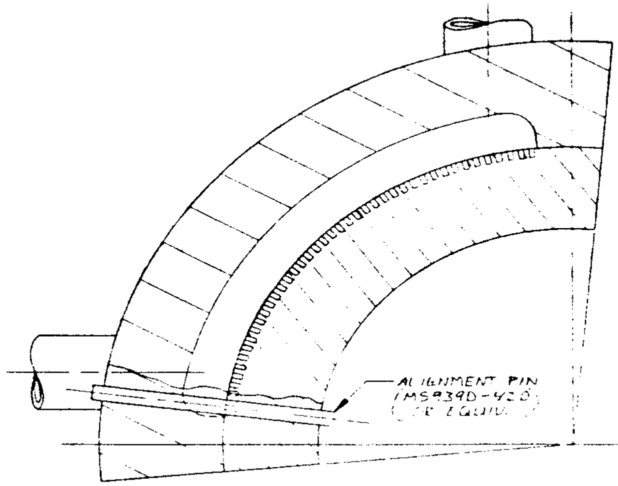
FRAME 2

FORM NO. R1110-H-5 REV

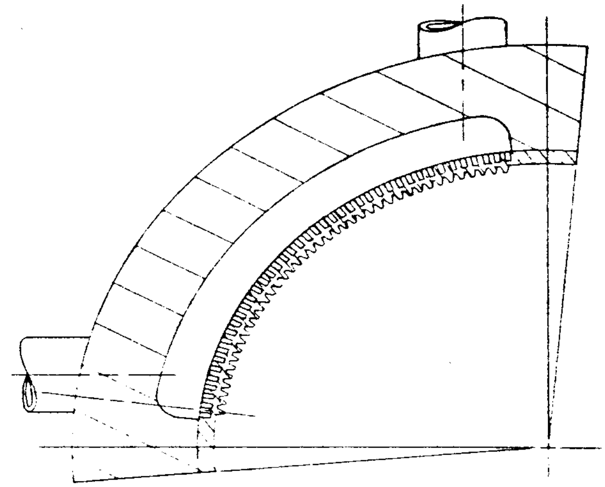
ORIGINAL PAGE IS
OF POOR QUALITY



FOLDOUT FRAME



III. BRAZE TO -3 MANIFOLD (ALONG WITH -5 TUBES) USING PIN FOR PROPER ALIGNMENT. ⟨4⟩

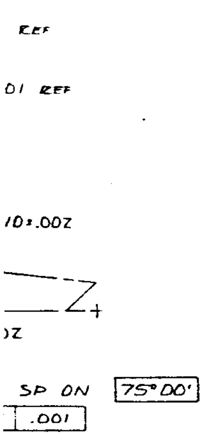


IV. MACHINE RIBS IN LINER, PER INDIVIDUAL LINER DETAILS.

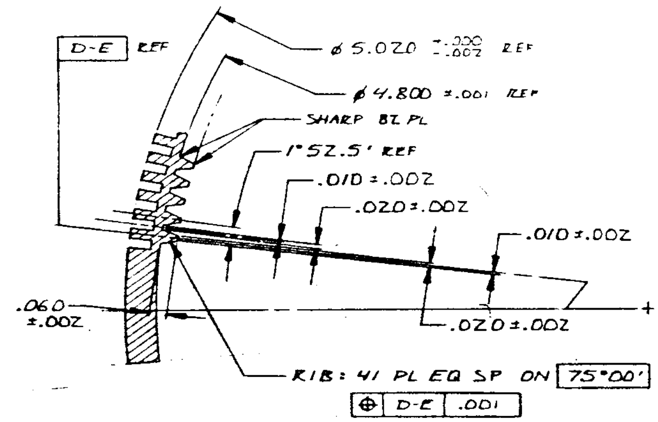
V. MACHINE ASSY TO FINISHED DIMENSIONS. (SEE SHEET 1, ZONE 8A)

ER FABRICATION SEQUENCE
170-11 THRU -81 ASSY'S

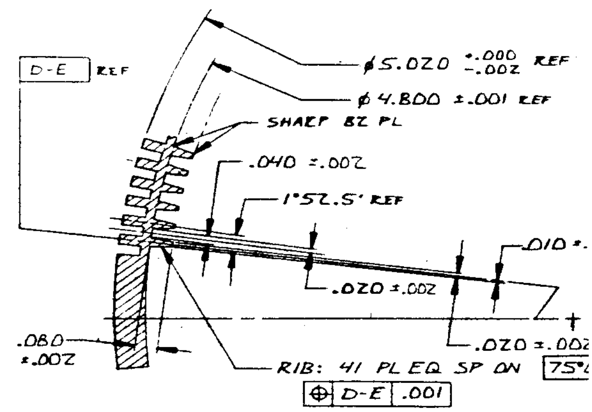
ASE



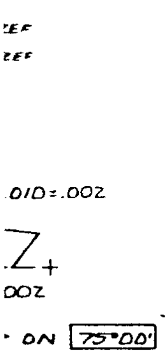
(-13) .060 RIB, .060 BASE



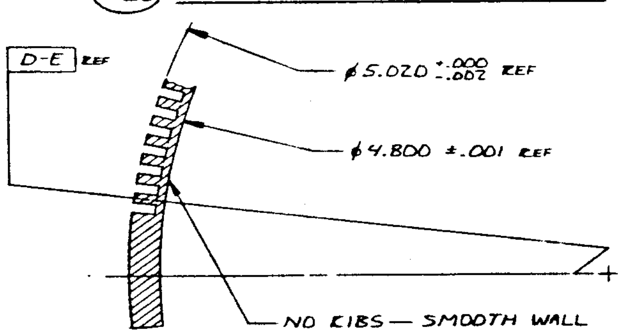
(-15) .080 RIB, .040 BASE



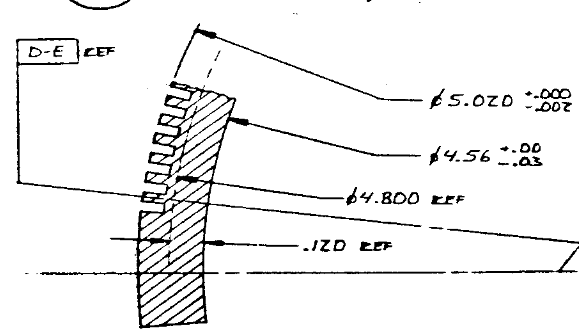
TROUGH



(-23) SMOOTH WALL BASELINE



(-25) BLANK

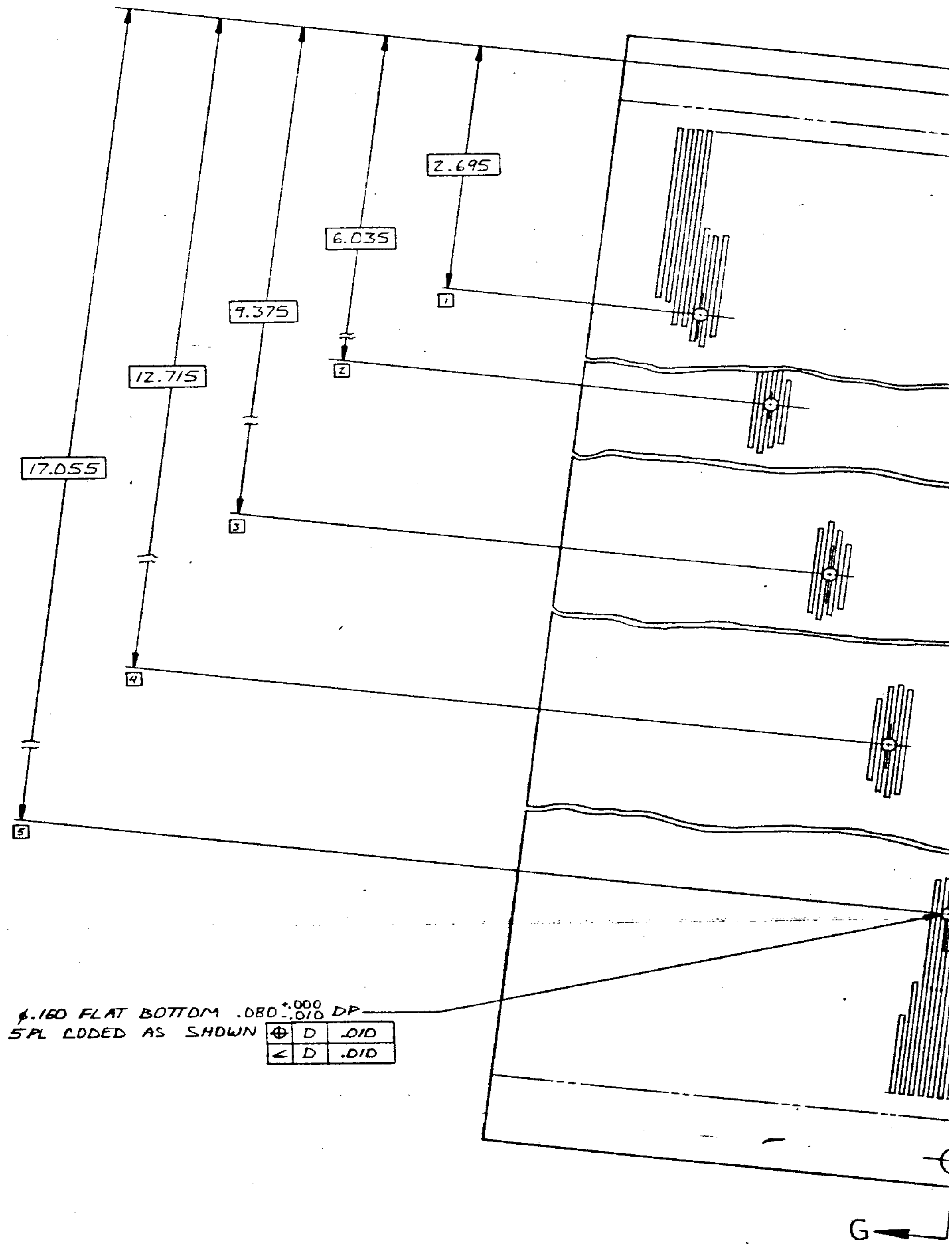


2 FOLDOUT FRAME

7C SELECTED LINER RIB CONFIGURATIONS
SCALE 4/1

• MICROFILM OVERLAP AREA •

17 | 16 | 15 | 14

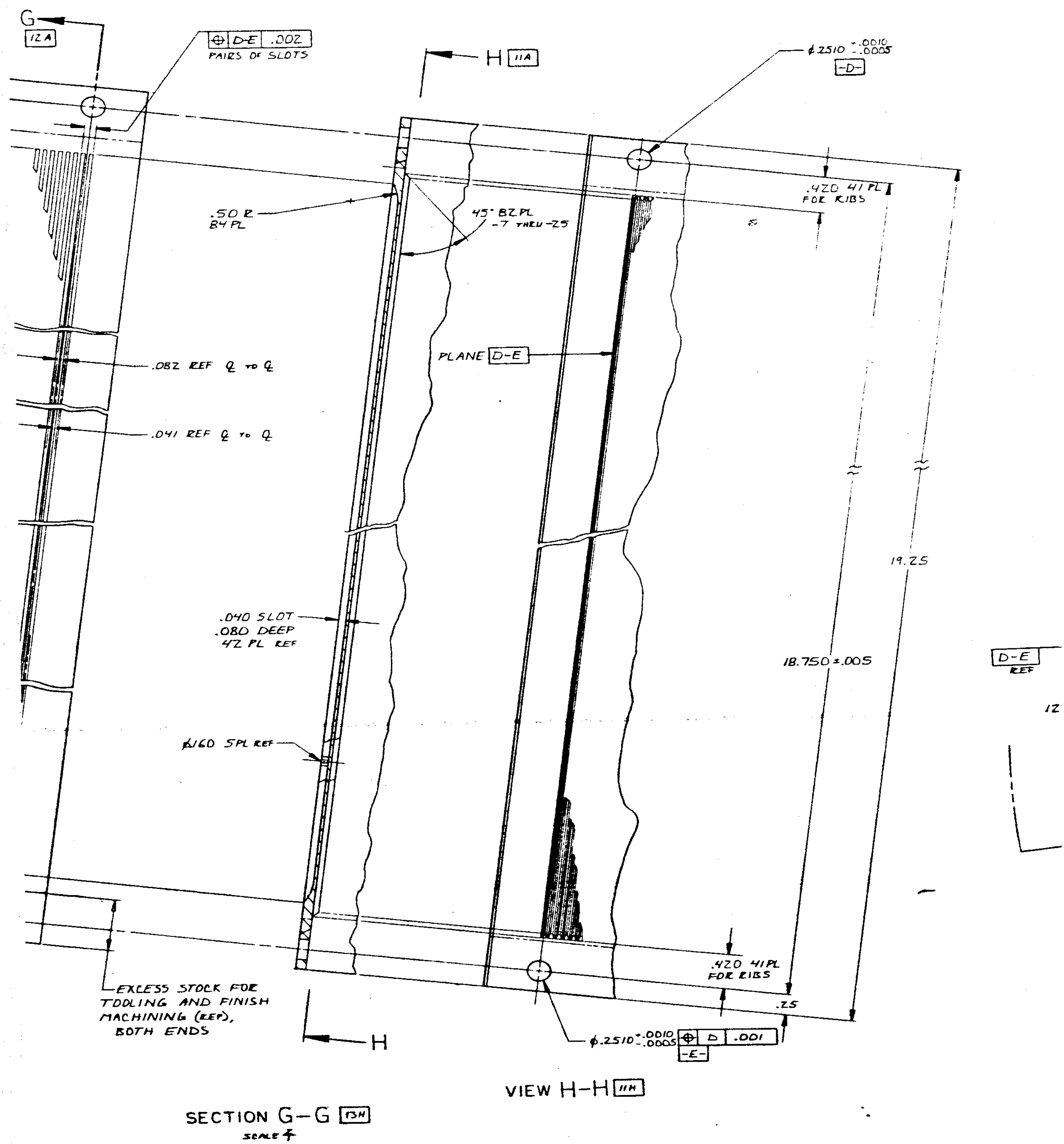


VIEW F-F 5H

)18170 | SH Z | REV

17 | 16 | 15 | 14

• MICROFILM OVERLAP AREA •

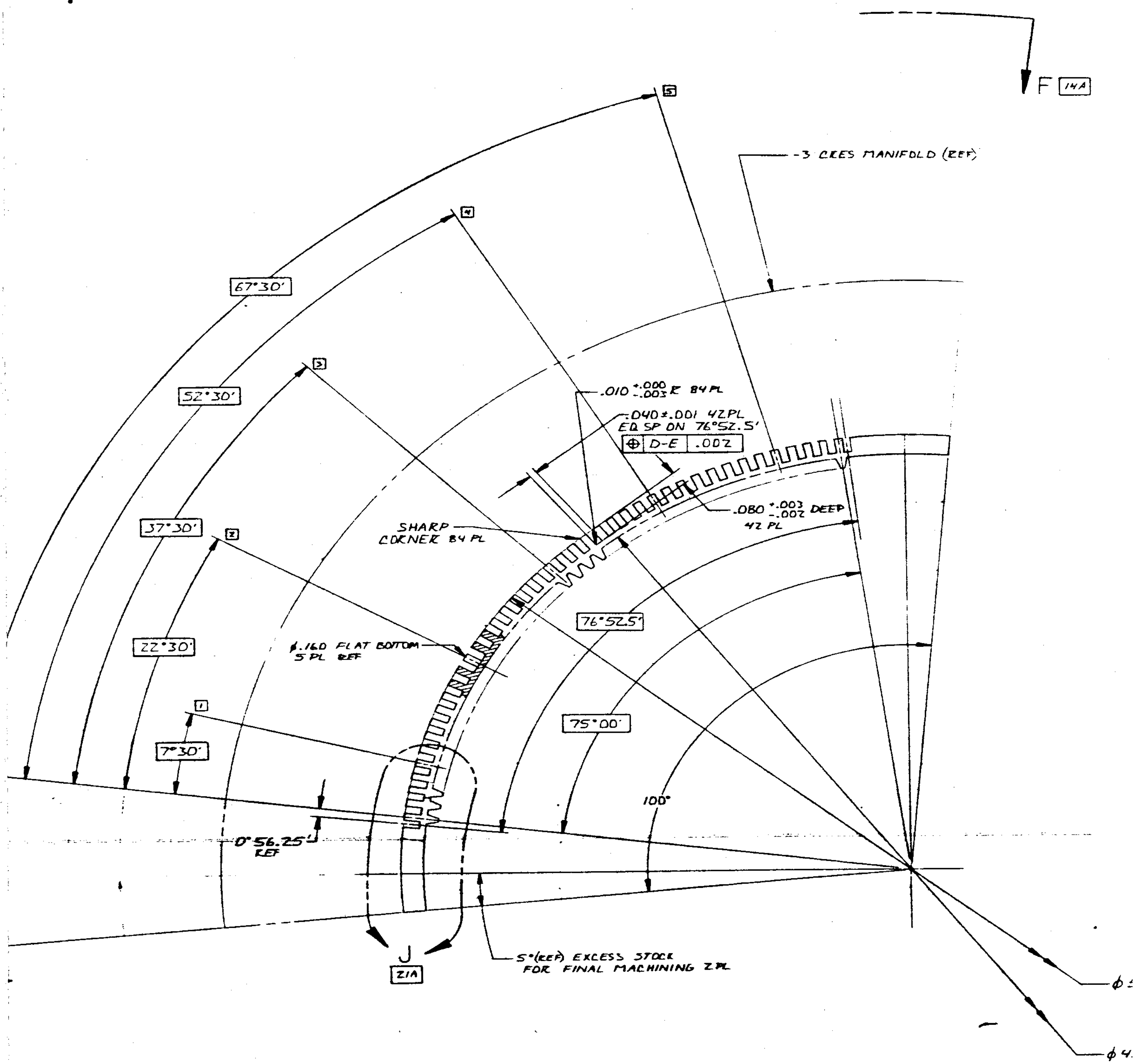


3 FOLDOUT FRAME

7K00181

MICROFILM OVERLAP AREA

8 7 6 5



(-7) LINER (END VIEW) SCALE 4

- ALL DIMENSIONS EXCEPT RIB GEOMETRIES TYPICAL FOR -7 THRU -25 LINERS.
- INCLUDES EXCESS STOCK FOR TOOLING AND FINISH MACHINING.
- SEE SUGGESTED FABRICATION SEQUENCE Z1F

4 FOLDOUT FRAME

Z

8 7 6 5

MICROFILM OVERLAP AREA

ZONE	REV	DESCRIPTION	DISPN	DATE	APPROVED
		1. MAY BE REWORKED 3. RECORD CHANGE 2. CANNOT BE REWORKED 4. NOW SHOP PRACTICE 5. PARTS MADE OK			

REVISIONS

ORIGINAL PAGE IS
OF POOR QUALITY

$\Delta\ ^{+.000}_{-.002}$

$\pm .001$ $\boxed{\oplus}\boxed{B}\boxed{\phi .003}$ (3)

5 FOLDOUT FRAME

FOR INFORMATION

NOTE: UNLESS OTHERWISE SPECIFIED

HEAT TREAT	
FINISH	
MAT'L	

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES AND APPLY PRIOR TO FINISH.
125/ MACH. SURF. ROUGHNESS
TOLERANCES ON: ANGLES ± 0° 30'
DECIMALS .XX ± .03 .XXX ± .010
HOLES NOTED "DRILL"

OVER	THRU	TOLERANCE
.0000	.0400	+ [illegible] — [illegible]
.0400	.1250	+ [illegible] — [illegible]
.1250	.2500	+ [illegible] — [illegible]
.2500	.5000	+ [illegible] — [illegible]
.5000	.7500	+ [illegible] — [illegible]
.7500	1.0000	+ [illegible] — [illegible]
1.0000	2.0000	+ [illegible] — [illegible]

DO NOT SCALE PRINT

CONTR	
DWN G DEFEVER	DATE 4-4-85
CHK	DATE
DSGN	
MAT'L	
STRUCT	
DESIGN ACTIVITY APVD	DATE

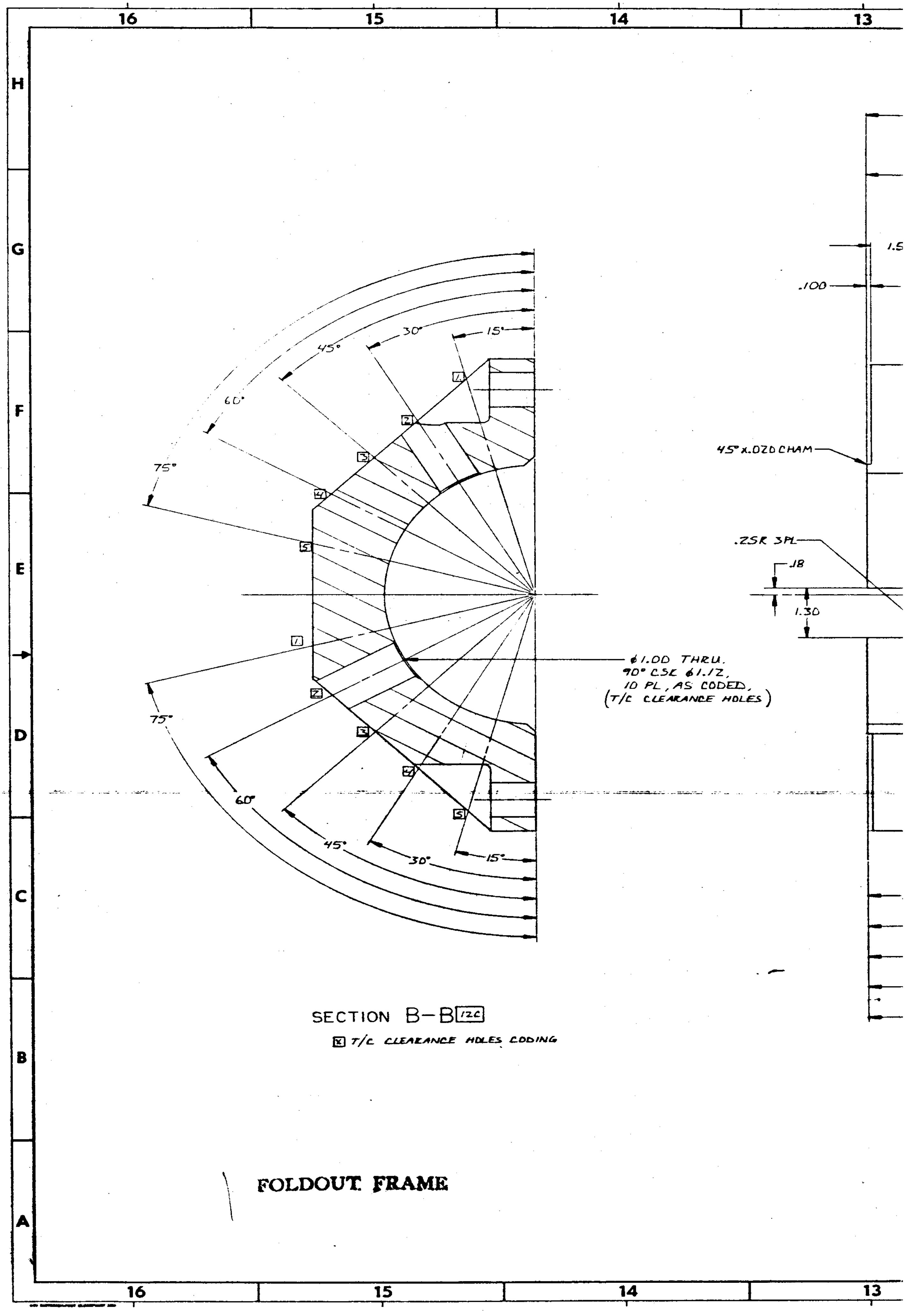
Rockwell International Corporation
Rocketdyne Division
Canoga Park, California

SIZE	FSCM NO	DWG NO
J	02602	7R0018170

SCALE 2/1 SHEET 2

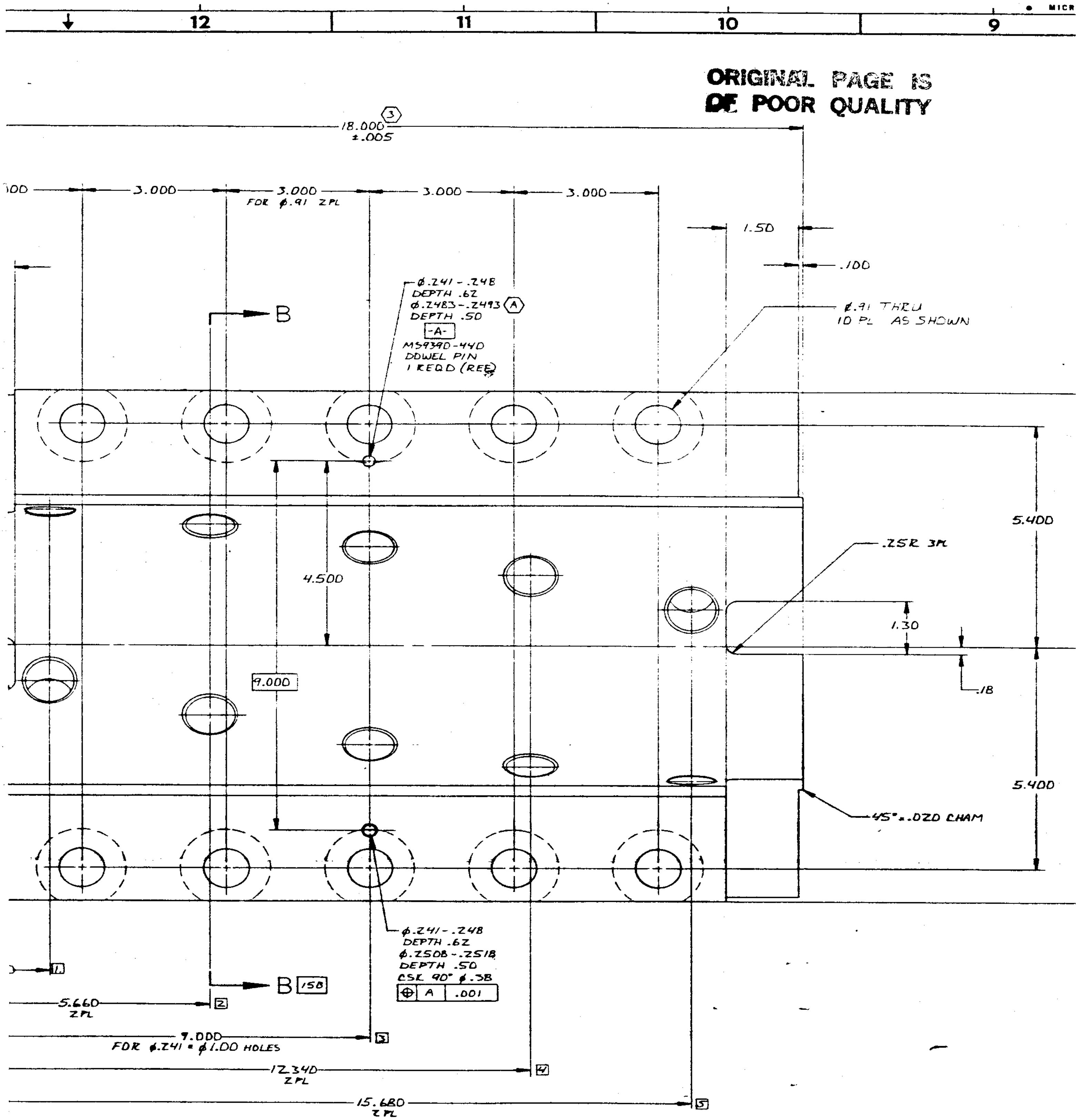
FRAME 3

FORM NO. R13-



FOLDOUT FRAME

ORIGINAL PAGE IS OF POOR QUALITY



VIEW A-A 5B

2 FOLDOUT FRAME

Rockwell International Corporation
Rocketdyne Division
Canoga Park, California

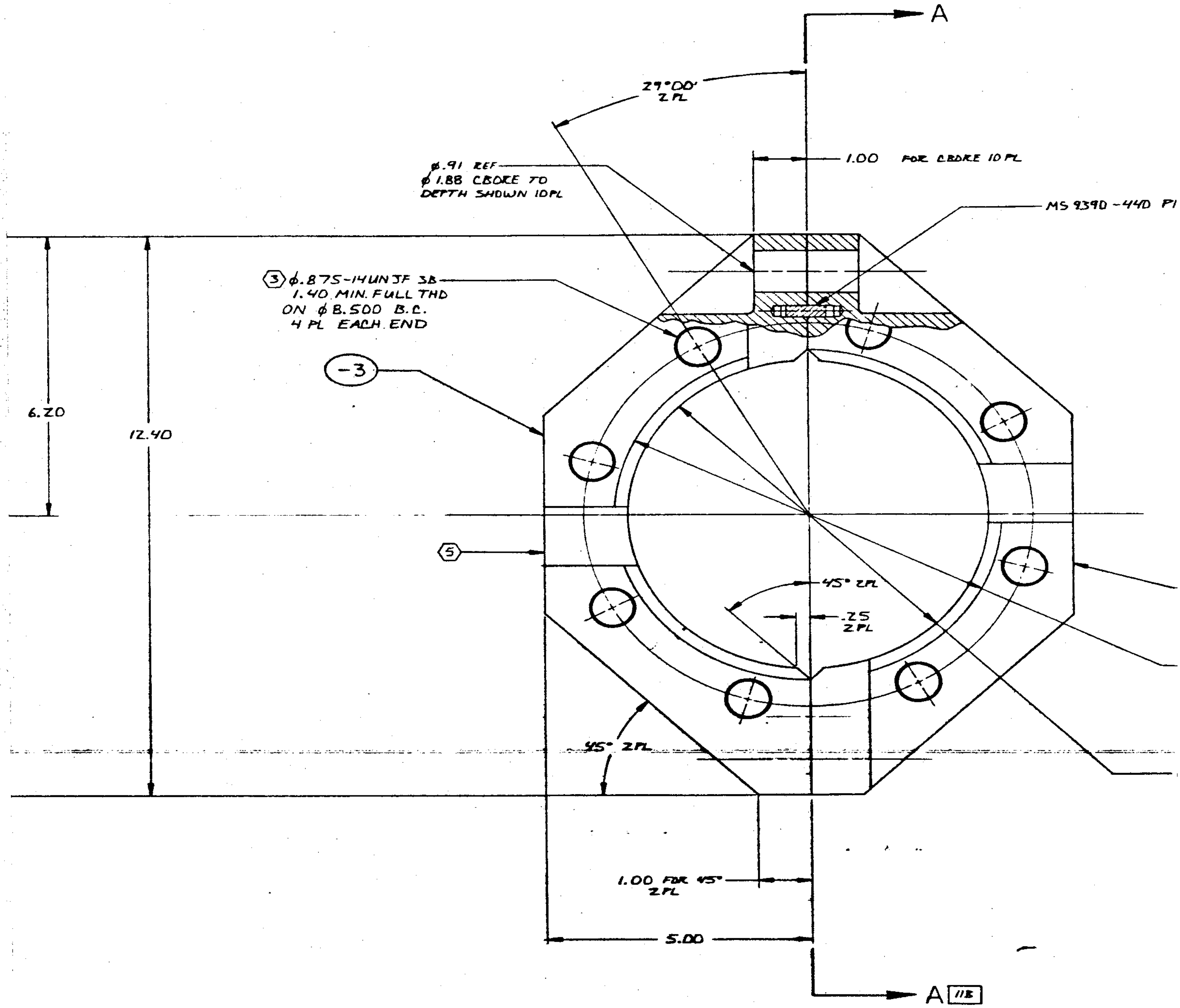
FSCM NO 02602 | FRAME 1

7R0018171

12 11 10 9

OVERLAP AREA

8 | 7 | 6 | 5



3 FOLDOUT FRAME

(5) IDENTIFY
(4) PRESS FIT
(3) MATCH MA
ALIGNING
(2) -5 IDENT.
INDICATE
1. MACHINE

8 | 7 | 6 | 5

OVERLAP AREA

REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED
		1. MAY BE REWORKED 3. RECORD CHANGE 2. CANNOT BE REWORKED 4. NOW SHOP PRACTICE 5. PARTS MADE OK		

Z READ ⟨A⟩

-5

ϕ7.300 ⟨3⟩

00 ⟨3⟩

ORIGINAL PAGE IS
OF POOR QUALITY

4 FOLDOUT FRAME

FOR
INFORMATION

⟨2⟩	-5	300 SERIES CRES		COMMERCIAL	4D
-1	-3	300 SERIES CRES		COMMERCIAL	7F
ASSY	NO.	MATERIAL	SIZE	SPECIFICATION	ZONE

AND -5 PER RAD104-008, IMPRESSION STAMP
N INTO EACH HOLE CODED ⟨A⟩.
E -3 & -5 AS INDICATED, AFTER
TS WITH -7 DOWEL PINS ⟨4⟩.
TO -3 IN ALL DIMENSIONS EXCEPT AS
Y ⟨5⟩
RAD103-016
UNLESS OTHERWISE SPECIFIED

HEAT TREAT: NONE
FINISH: NONE
MATL: NOTED

DO NOT SCALE PRINT

DWN: G DEFEVER
DSGN: DEFEVER

Rockwell International Corporation
Rocketdyne Division
Canoga Park, California

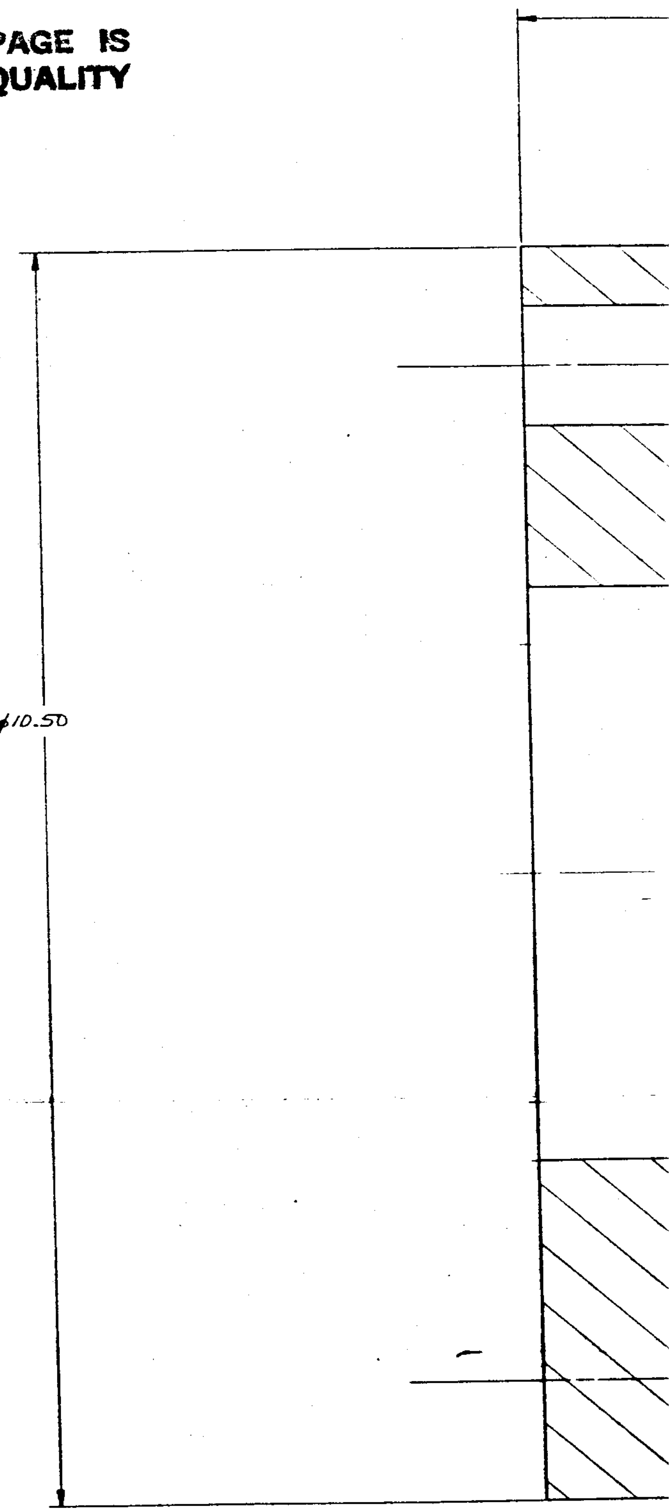
JACKET, HOT AIR
FLOW TEST FIXTURE

SIZE: J | FSCM NO: 02602 | DWG NO: 7R0018171

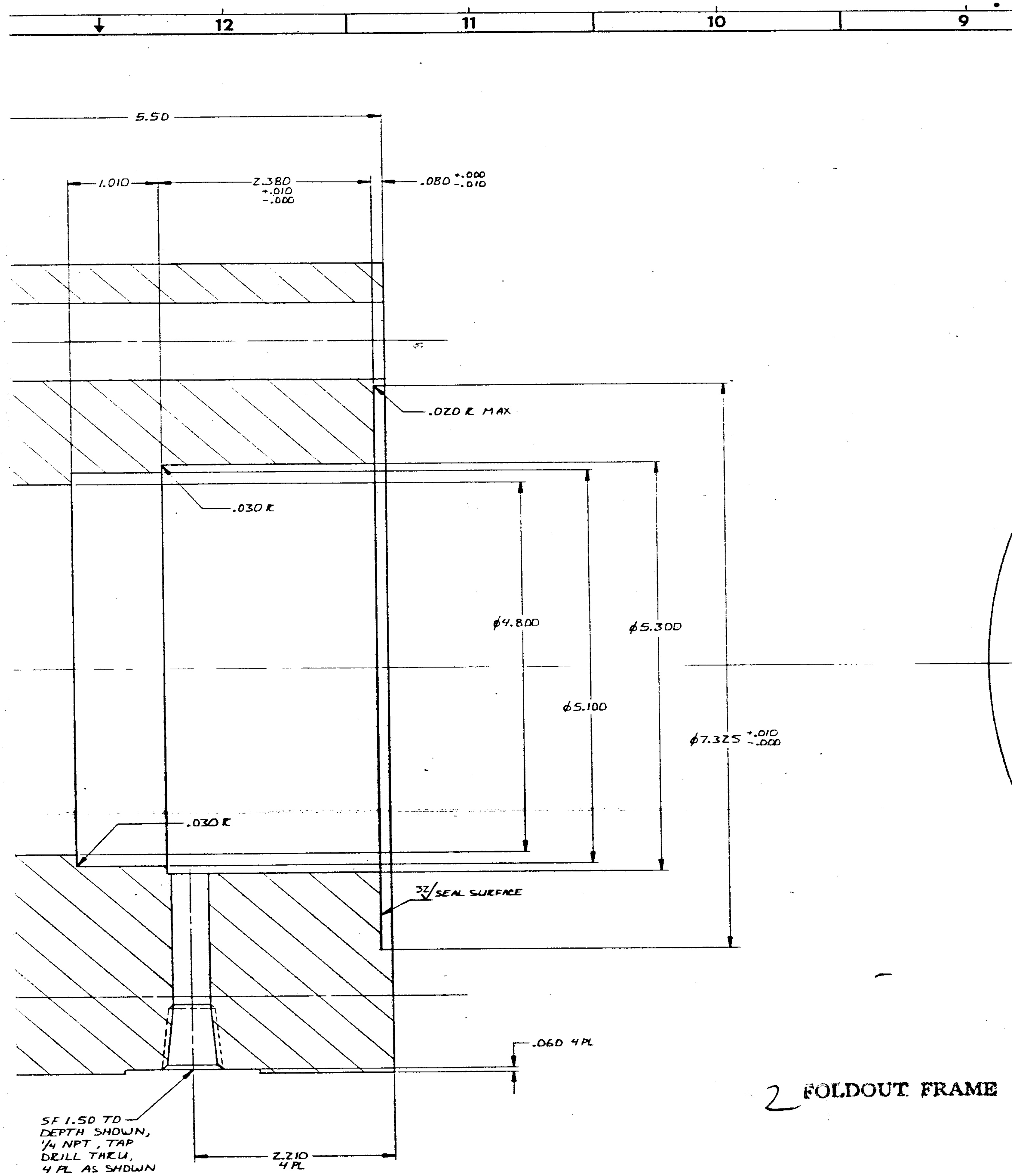
SCALE: FULL

DWG NO 7R0018171

FRAME 2



FOLDOUT FRAME



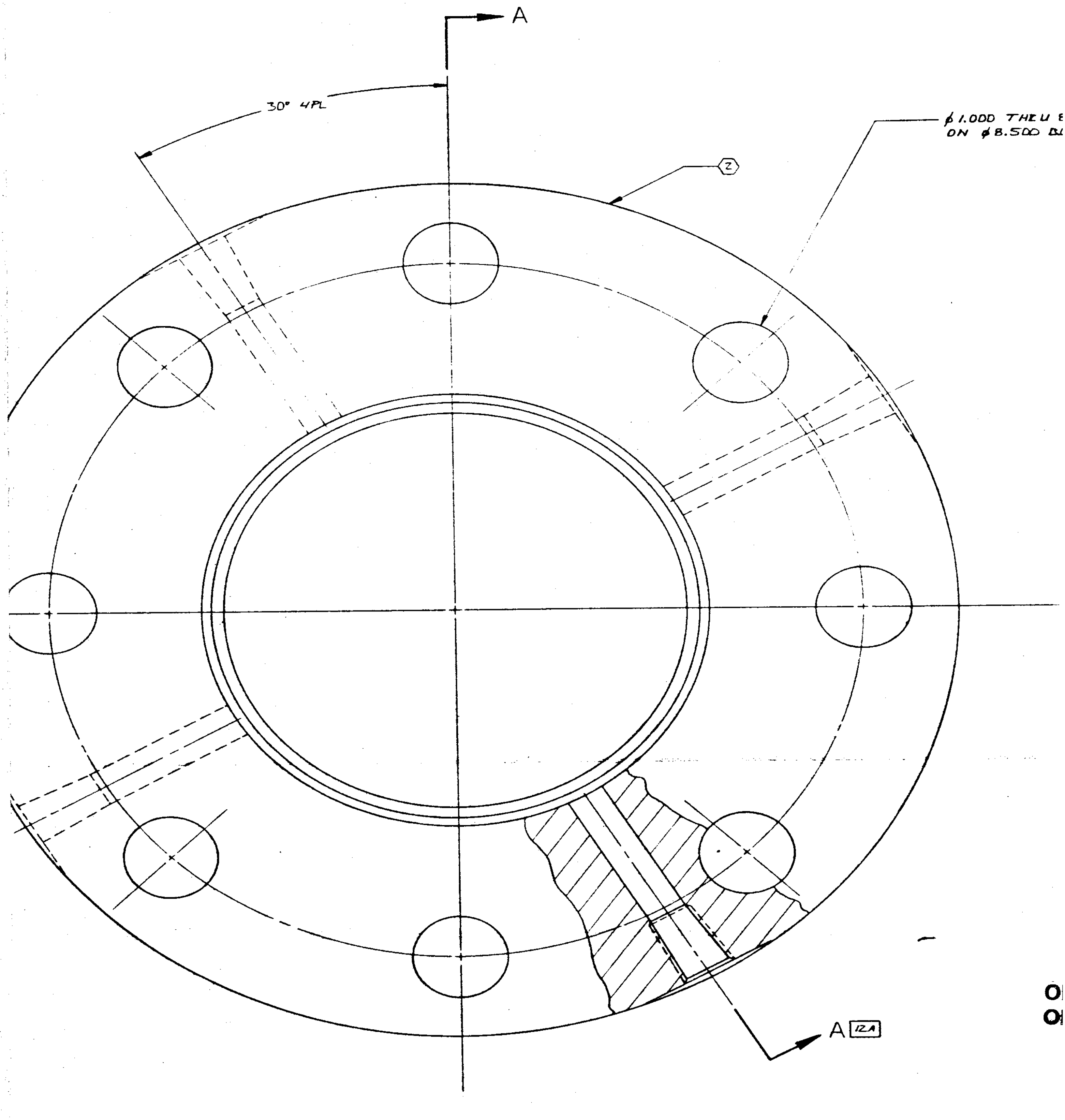
SECTION A-A 6B

2 FOLDOUT FRAME

Rockwell International
Rocketdyne Di
Canoga Park, Cali

7RD01817Z

12 11 10 9



O
O

4 3 2 1

REVISIONS					
ZONE	REV	DESCRIPTION	DISPN	DATE	APPROVED
		1. MAY BE REWORKED 3. RECORD CHANGE 2. CANNOT BE REWORKED 4. NOW SHOP PRACTICE 5. PARTS MADE OK			

EQ SP

3 FOLDOUT FRAME

4 FOLDOUT FRAME

INAL PAGE IS
OOR QUALITY

FOR
INFORMATION

-3	300 SERIES CRES		COMMERCIAL
NO.	MATERIAL	SIZE	SPECIFICATION

ETCH IDENTIFY PER RAD104-008
MACHINE PER RAD103-016
NOTE: UNLESS OTHERWISE SPECIFIED

HEAT TREAT: NONE
FINISH: NONE
MATL: NOTED

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES AND APPLY PRIOR TO FINISH.
125/ MACH. SURF. ROUGHNESS
TOLERANCES ON: ANGLES ± 0° 30' DECIMALS .XX ± .03 .XXX ± .010
HOLES NOTED "DRILL"
OVER THRU TOLERANCE
DO NOT SCALE PRINT

CONTR
DWN G. DEFEVER DATE 5-7-81
CHK DATE
DSGN G. Defever
MATL
STRUCT
DESIGN ACTIVITY APVD DATE

Rockwell International Corporation
Rocketdyne Division
Canoga Park, California

TEST CHAMBER
ENTRANCE SECTIO

SIZE J FSCM NO 02602 DWG NO 7R0018172
SCALE 2/1 SHEET
FRAME 2

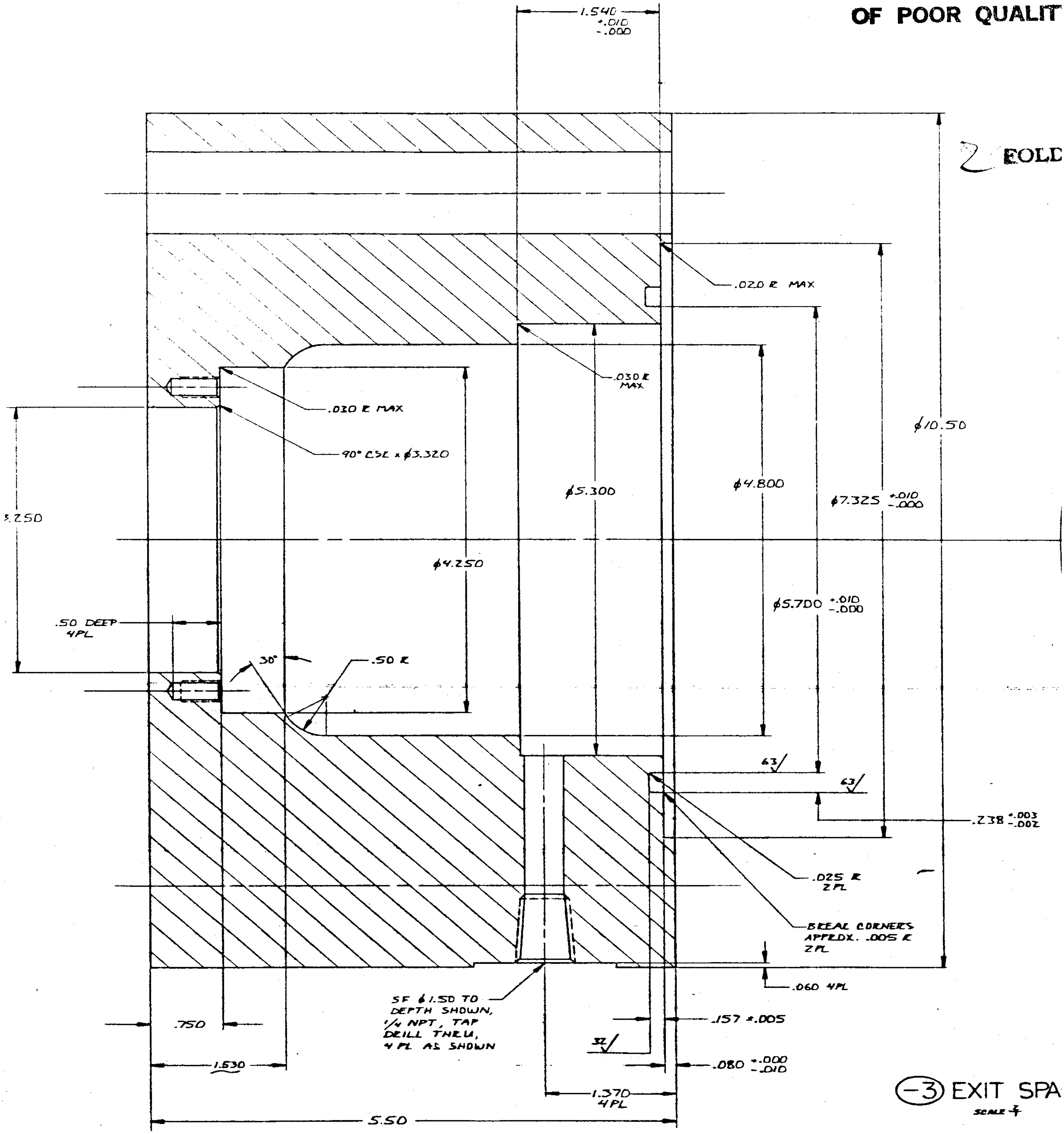
4 3 2 1

FORM NO. R130-H

ORIGINAL PAGE IS
OF POOR QUALITY

FOLDOUT FRAME

ORIGINAL PAGE I
OF POOR QUALIT



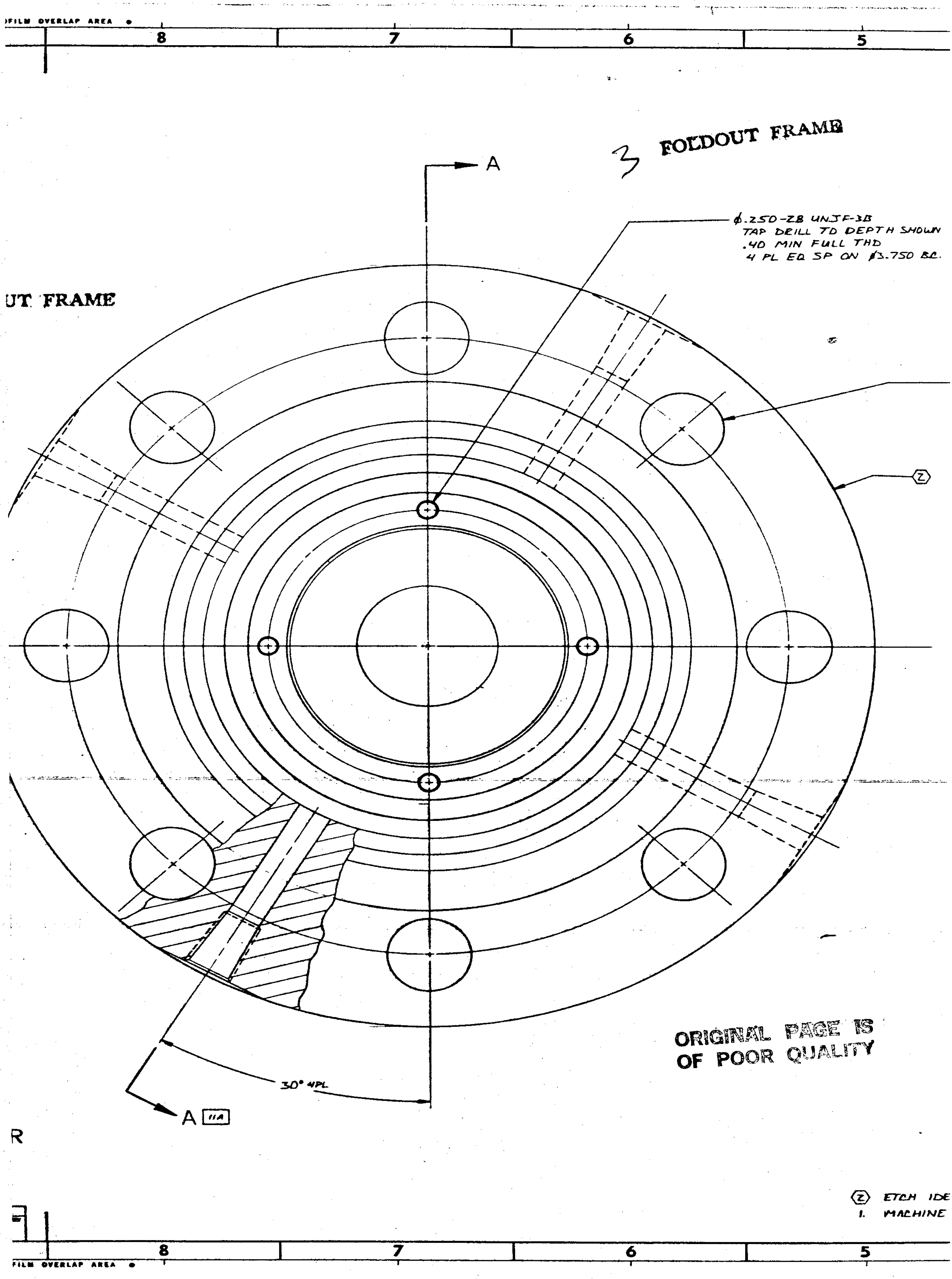
-3 EXIT SPA
SCALE 1/2

SECTION A-A 8A

Rockwell International Corpo
Rocketdyne Division
Canoga Park, California

FSCM NO 02602 | FRAME 1
7R0018168

3 FOLDOUT FRAME



ORIGINAL PAGE IS
OF POOR QUALITY

Z ETCH IDE
1. MACHINE

REVISIONS					
ZONE	REV	DESCRIPTION	DISPN	DATE	APPROVED
		1. MAY BE REWORKED 2. CANNOT BE REWORKED 3. RECORD CHANGE 4. NOW SHOP PRACTICE 5. PARTS MADE OK			

ϕ1.00 THRU 8PL EQ SP
ON ϕ8.500 B.C.

4 FOLDOUT FRAME

FOR
INFORMATION

-3	300 SERIES CRES		COMMERCIAL	
NO.	MATERIAL	SIZE	SPECIFICATION	

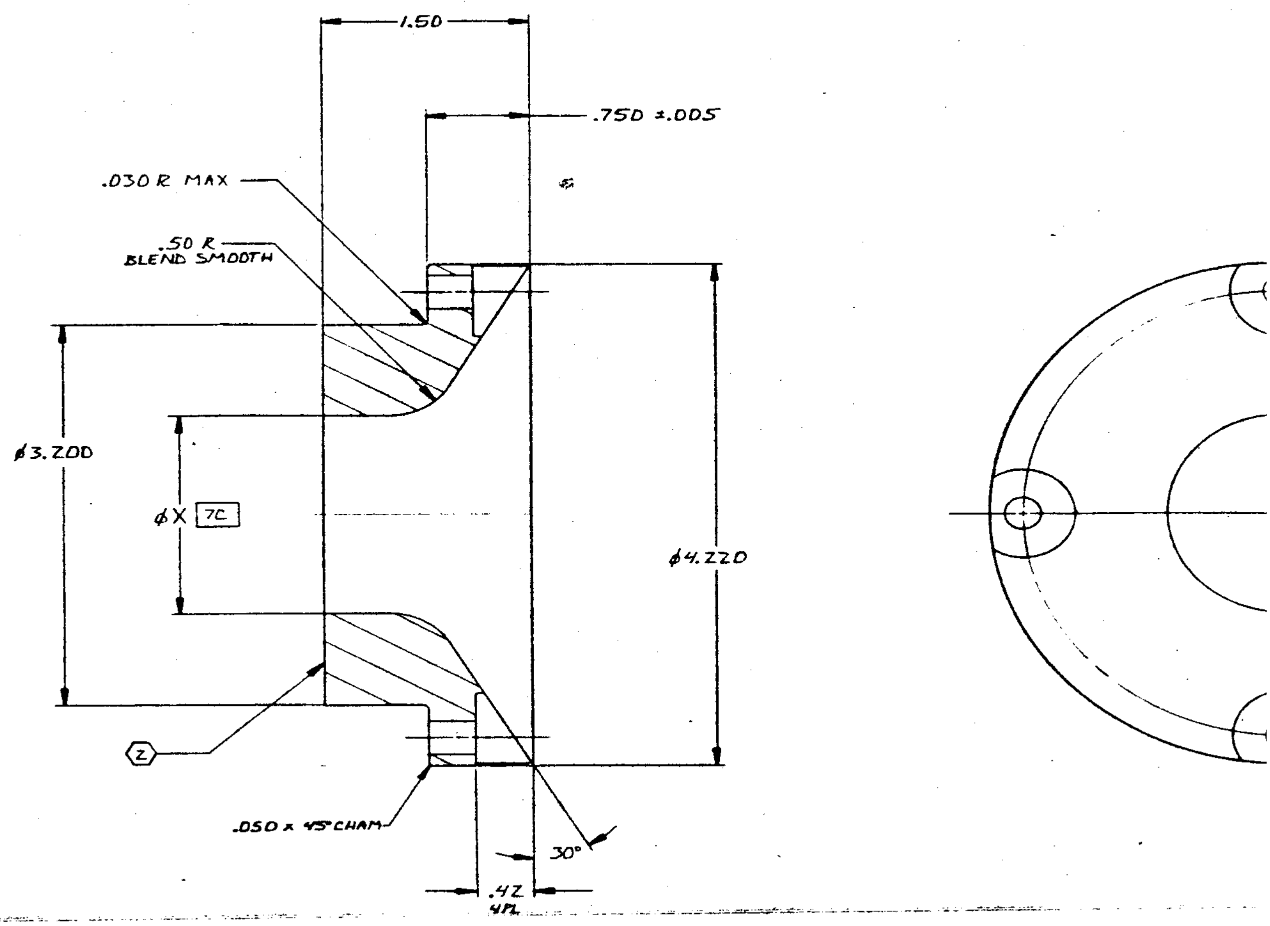
FY PER RA0104-008 AS INDICATED.
: RA0103-016
PER UNLESS OTHERWISE SPECIFIED

HEAT TREAT: NONE	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES AND APPLY PRIOR TO FINISH. 125/ MACH. SURF. ROUGHNESS	CONTR DWN G.DEFEVER DATE 4-12-84 CHK DATE	Rockwell International Corporation Rocketdyne Division Canoga Park, California
FINISH: NONE	TOLERANCES ON: ANGLES ± 0° 30' DECIMALS .XX ± .03 .XXX ± .010	DSGN G.Defever MATL STRUCT	TEST CHAMBER EXIT SECTION
MATL: NOTED	HOLES NOTED "DRILL"	DESIGN ACTIVITY APVD DATE	SIZE J FSCM NO 02602 DWG NO 7R0018168
	DO NOT SCALE PRINT		SCALE SHEET

DWG NO 7R0018168

FRAME 2

FORM NO. R130-N-5 REV. 7-77



NO.	ϕX 7E
-3	ϕ0.0 (BLANK)
-5	ϕ1.666

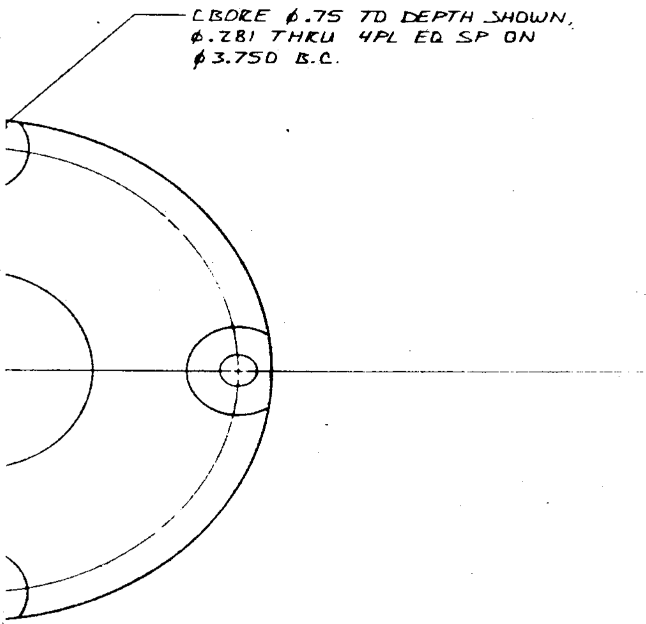
(SHOWN ABOVE)

FOLDOUT FRAME

Z ELECTROCHEM ETC

1. MACHINE PER RAD

ZONE	REV	REVISIONS DESCRIPTION	DATE	APPROVED
		1. MAY BE REWORKED 3. RECORD CHANGE 2. CANNOT BE REWORKED 4. NOW SHOP PRACTICE 5. PARTS MADE OK		



ORIGINAL PAGE IS OF POOR QUALITY

FOLDOUT FRAME

FOR INFORMATION

-5	300 SERIES CRES		COMMERCIAL	BC
-3	300 SERIES CRES		COMMERCIAL	BC
NO.	MATERIAL	SIZE	SPECIFICATION	

...NTIFY PER RA0104-008
...16

HEAT TREAT: NONE
FINISH: NOTED
MATL: NOTED

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND APPLY PRIOR TO FINISH.
DO NOT SCALE PRINT

DRN G. DEFEVER DATE 4-14-81

Rockwell International Corporation
Rocketdyne Division
Canoga Park, California

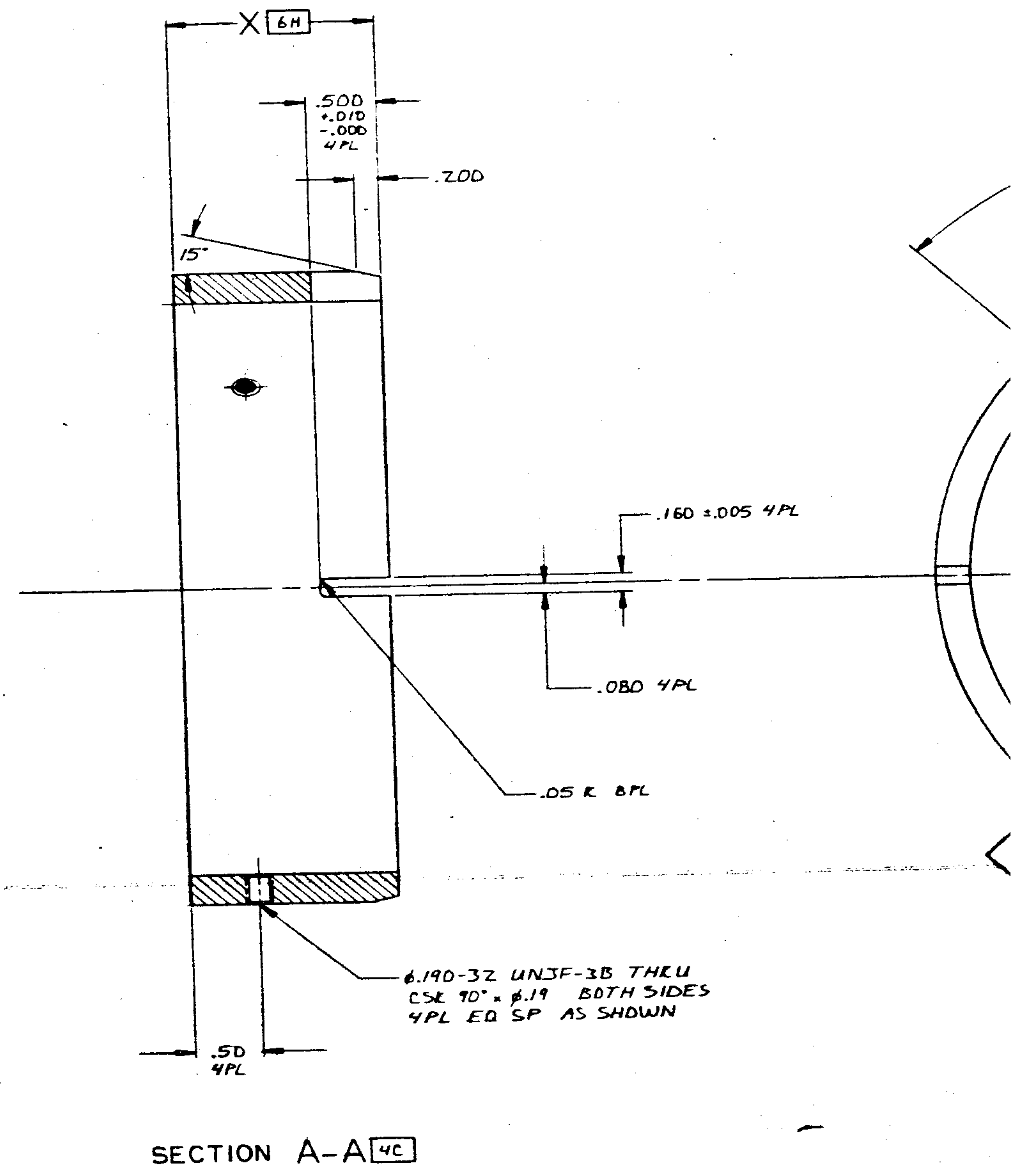
NOZZLE, REPLACABLE

SIZE E | FSCM NO 02602 | DWG NO 7R0018483

DWG NO 7R0018483

X 7G	
1.540 $^{+.000}_{-.010}$	FOR − 3
2.380 $^{+.000}_{-.010}$	FOR − 5

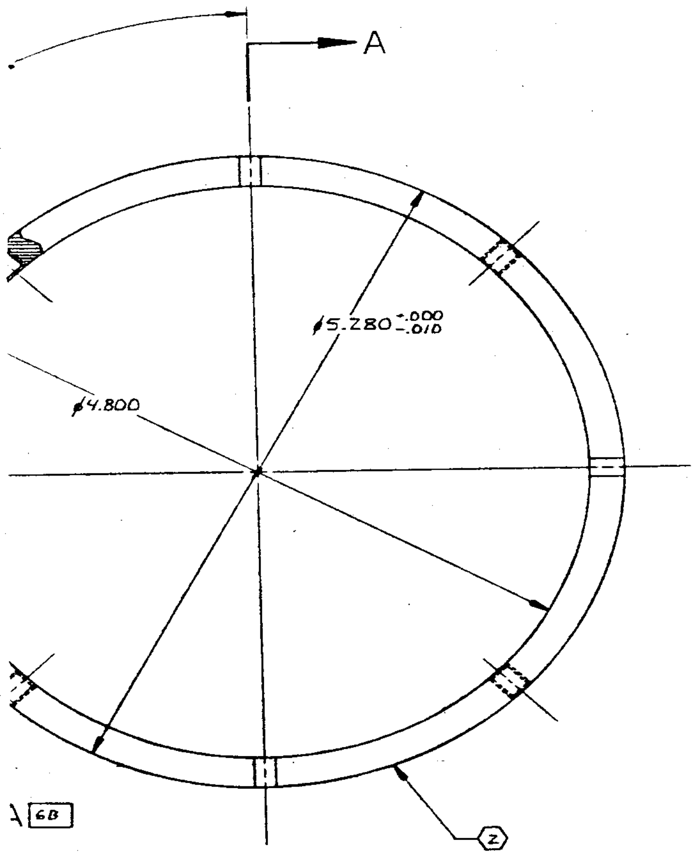
FOLDOUT FRAME



SECTION A–A 4C

ORIGINAL PAGE IS
OF POOR QUALITY

REVISIONS					
ZONE	REV	DESCRIPTION	DISPN	DATE	APPROVED
		1. MAY BE REWORKED 3. RECORD CHANGE 2. CANNOT BE REWORKED 4. NOW SHOP PRACTICE 5. PARTS MADE OK			



2 FOLDOUT FRAME

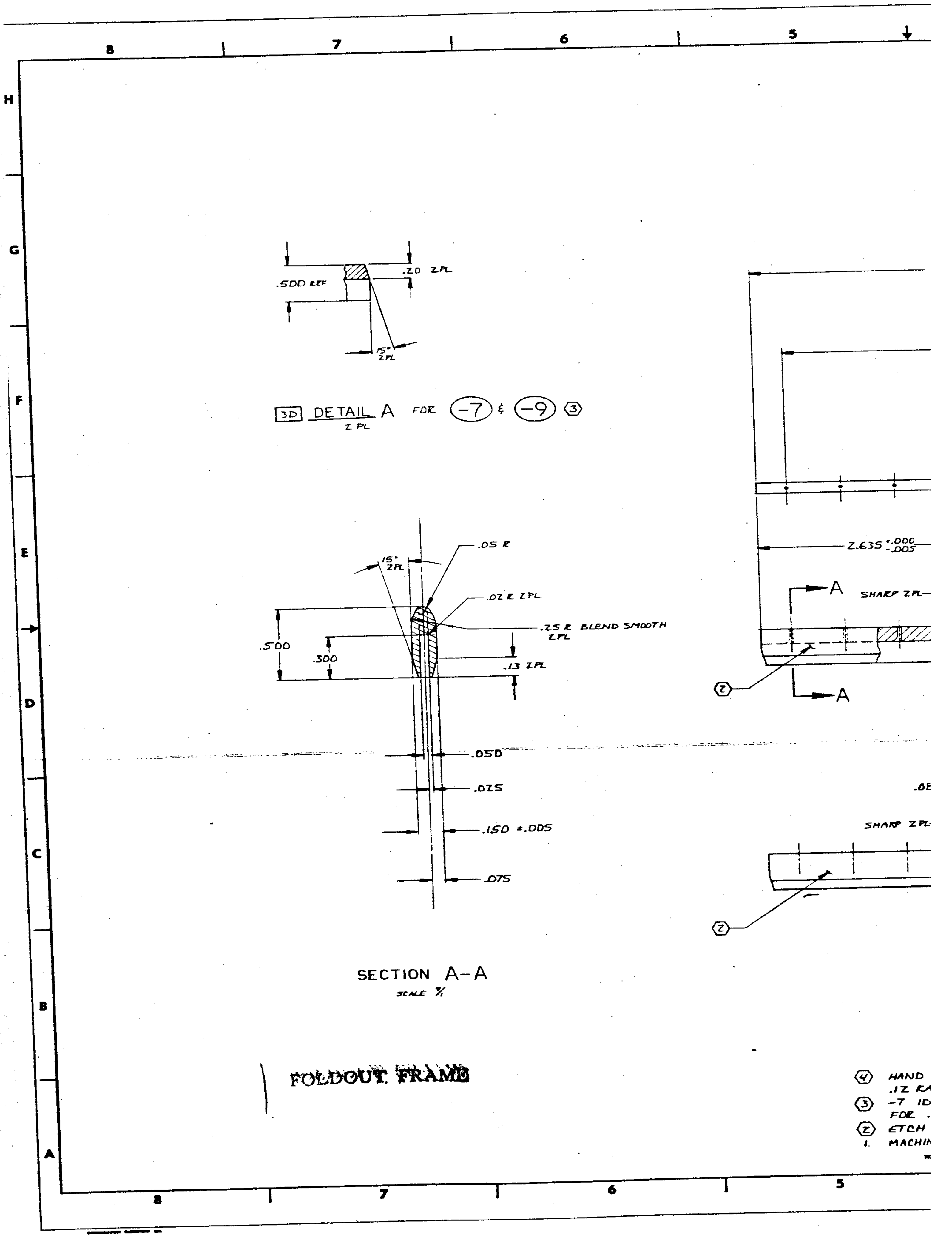
FOR INFORMATION

3 -5	300 SERIES CRES		COMMERCIAL	
-3	300 SERIES CRES		COMMERCIAL	
NO.	MATERIAL	SIZE	SPECIFICATION	

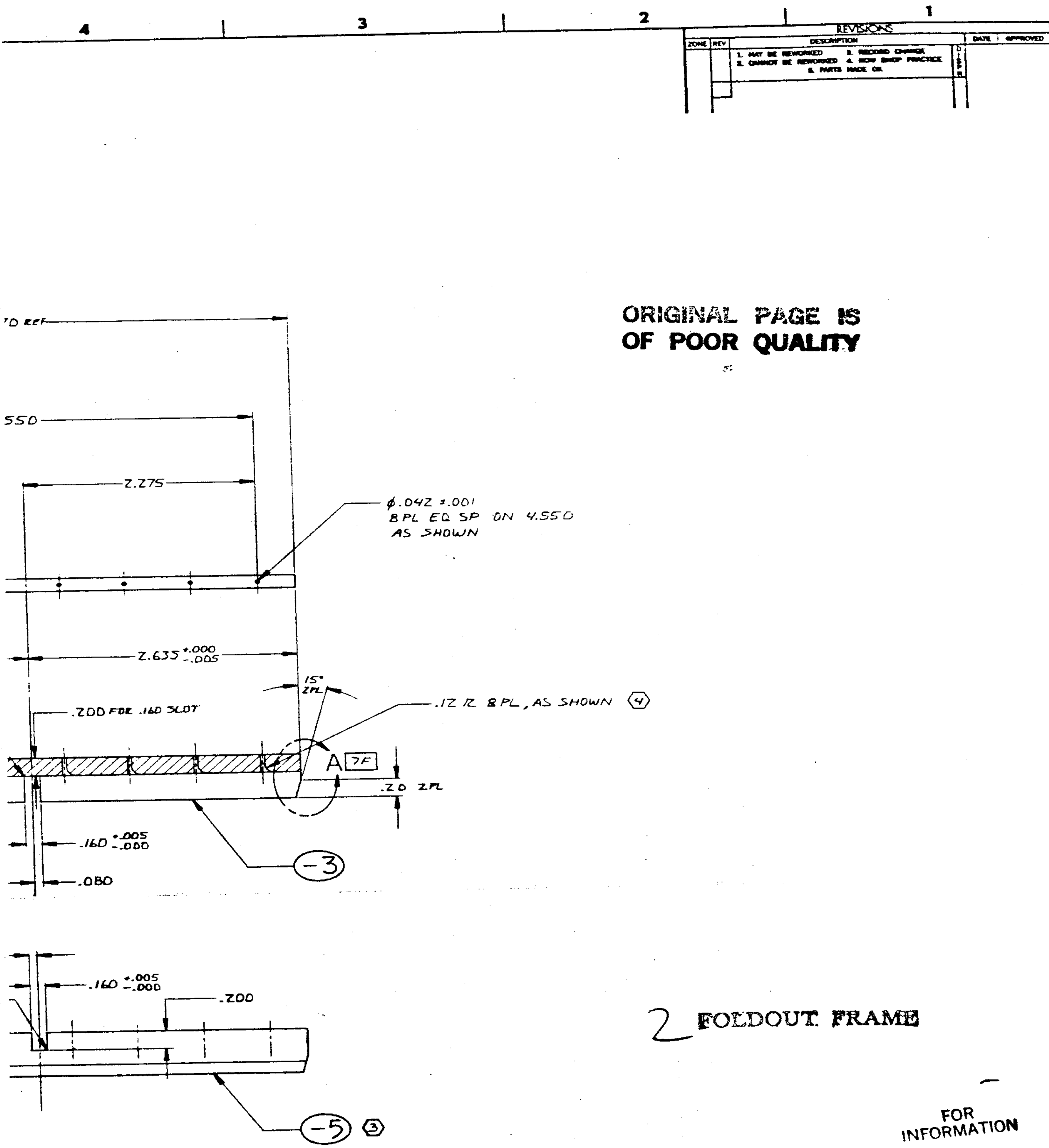
DENTICAL TO -3 EXCEPT IN "X" DIM. INDICATED
H IDENTIFY PER RADIO4-008 AS INDICATED.
HINE PER RADIO3-016
S: UNLESS OTHERWISE SPECIFIED

HEAT TREAT NONE	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES AND APPLY PRIOR TO FINISH. 125/ MACH. SURF. ROUGHNESS	CONTR DWN G DEFEVER DATE 7-18-84 CHK DATE	Rockwell International Corporation Rocketdyne Division Canoga Park, California
FINISH NONE	TOLERANCES ON: ANGLES ± 0° 30' DECIMALS .XX ± .03 .XXX ± .010 HOLES NOTED "DRILL" OVER THRU TOLERANCE [illegible]	DESIGN G Defever MATL STRUCT	RETAINER RING, T/C SUPPORT
MATL NOTED	DO NOT SCALE PRINT	DESIGN ACTIVITY APVD DATE	SIZE E FSCM NO 02602 DWG NO 7R0018484 SCALE 2/1 SHEET

DWG NO 7R0018484



FOLDOUT FRAME



ORIGINAL PAGE IS
OF POOR QUALITY

2 FOLDOUT FRAME

FOR INFORMATION

No.	MATERIAL	SIZE	SPECIFICATION	
−9	300 SERIES CRES		COMMERCIAL	6F
−7				6F
−5				3B
−3	300 SERIES CRES		COMMERCIAL	3D

D OR OTHERWISE PROVIDE APPROXIMATELY
AS SHOWN FOR T/C BEND CLEARANCE.
AL TO −3 AND −9 IDENTICAL TO −5, EXCEPT
SLOT, AS INDICATED ON −5 VIEW
TIFY PER RA0104-008 AS INDICATED.
R RA0103-016.
OTHERWISE SPECIFIED

HEAT TREAT: NONE	UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES AND APPLY PRIOR TO FINISH. MACH. SURF. ROUGHNESS	CONTR / DRN GDEFEVER DATE 7-27 / CHK DATE / ENGR G. Defever / MATL / STRUCT / DESIGN ACTIVITY APVD DATE
FINISH: NONE	TOLERANCES ON: ANGLES ± ; DECIMALS .XX ± .XXX ± ; HOLES NOTED "DRILL"	
MATL: NOTED	DO NOT SCALE PRINT	

Rockwell International Corporation
Rocketdyne Division
Canoga Park, California

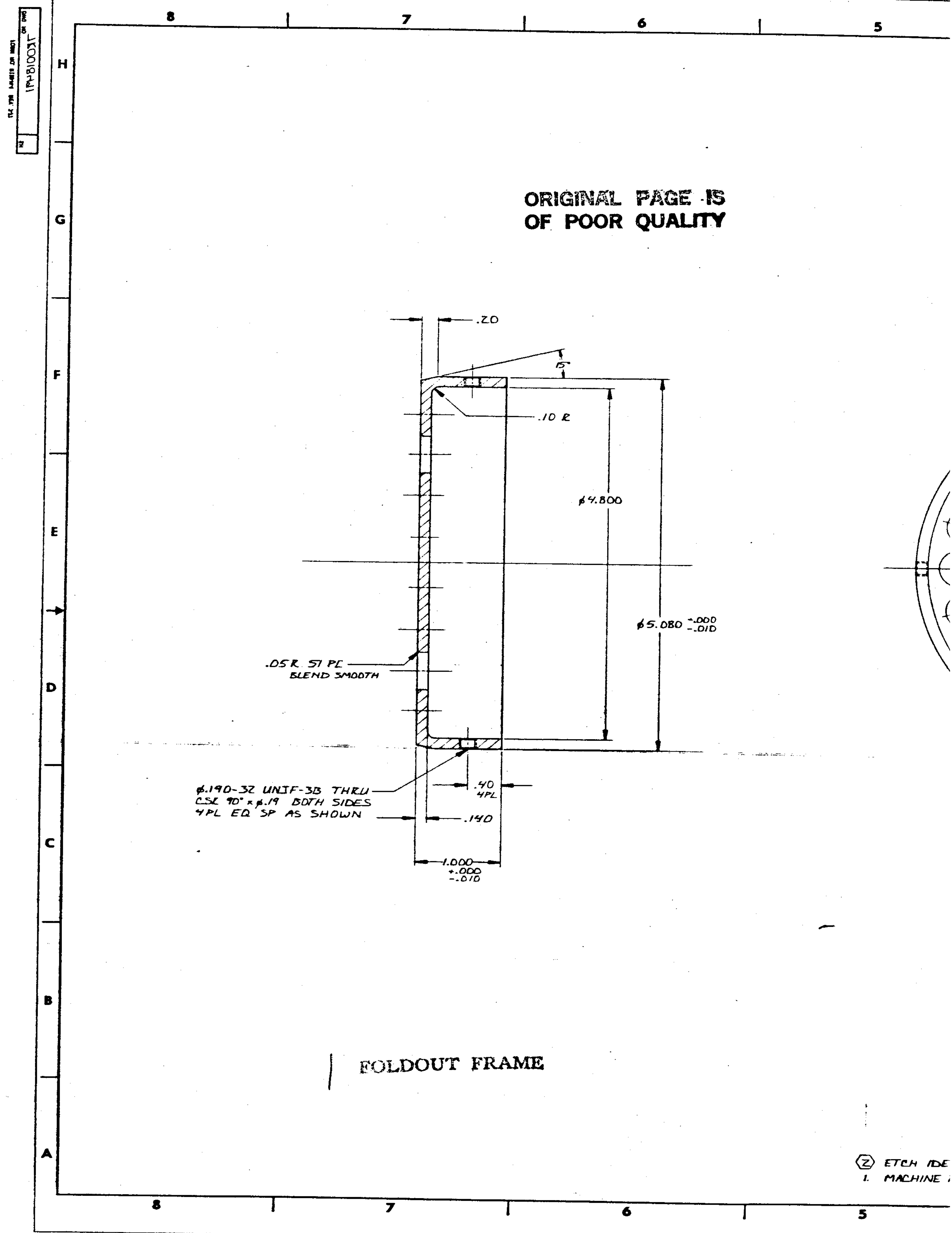
SUPPORT BAR,
THERMOCOUPLE

SIZE E | FSCM NO 02602 | DWG NO 7R0018485

SCALE 2/1 | SHEET

7R0018485

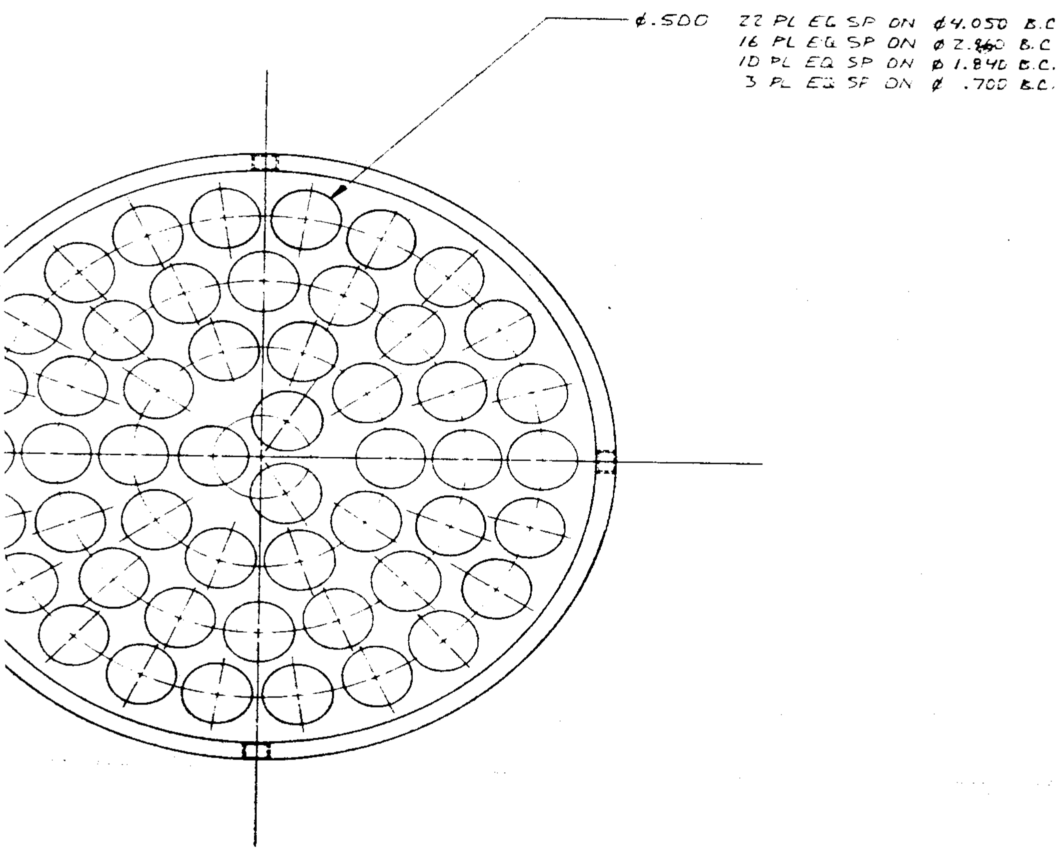
ORIGINAL PAGE IS
OF POOR QUALITY



FOLDOUT FRAME

ZONE	REV	DESCRIPTION	DATE	APPROVED
		1. MAY BE REWORKED 3. RECORD CHANGE 2. CANNOT BE REWORKED 4. NEW SHOP PRACTICE 5. PARTS MADE OK		

REVISIONS



2 FOLDOUT FRAME

FOR INFORMATION

-3	300 SERIES CRES		COMMERCIAL	
NO.	MATERIAL	SIZE	SPECIFICATION	

Y PER RA0104-008
RA0103-016
UNLESS OTHERWISE SPECIFIED

HEAT TREAT	NONE
FINISH	NONE
MATL	NOTED

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES AND APPLY PRIOR TO FINISH. MACH. SURF. ROUGHNESS. TOLERANCES ON: ANGLES ± 0° 30' DECIMALS .XX ± .03 .XXX ± .010 HOLES NOTED "DRILL". DO NOT SCALE PRINT

DWN DEFEVER DATE
DESIGN ACTIVITY APVD

Rockwell International Corporation
Rocketdyne Division
Canoga Park, California

TURBULANCE BAFFLE

SIZE	FSCM NO	DWG NO
E	02602	7R0018491

SCALE 2/1 SHEET

DWG NO 7R0018491

TEST PLAN FOR HOT AIR FLOW OF ADVANCED COMBUSTOR RIB GEOMETRIES

The following describes planned testing to be conducted at the Rockwell International NAAO Thermodynamics Laboratory. The testing will be done under Contract NAS3-23773, Enhanced Heat Transfer Combustor Technology with NASA Lewis Research Center.

SUMMARY

A 4.8 inch diameter calorimeter chamber will be built and supplied to the NAAO division for hot air flow testing. The chamber assembly will contain four 18-inch test panels, each assembled as a 90° segment of the cylindrical chamber (see assy dwg 7R0018169). Coolant (water) will be supplied to each panel and thermocouples used to monitor coolant temperature to derive heat transfer efficiency data on each test panel. A schematic of the test setup is shown in Figure 1. The apparatus will include a total of six test panels and one baseline reference panel.

TEST PLAN

Two separate test series are planned, since the segmented chamber will only accept three test panels at a time along with the one reference panel. These test series are outlined in Table 1. One test fixture tear-down and build-up will be required to change out the test panels between test series A and B. The testing will be accomplished per the schedule shown in Figure 2.

As shown in Figure 1, each of the four sectors of the calorimeter test chamber will have its own coolant water supply. The inlet and outlet temperatures and pressures will be recorded along with the water flowrates. Five wall temperature measurements will be made axially along the flow path on each of the test panels.

In addition to the water flow parameters, the chamber pressure and temperature profile will be recorded. A thermocouple rake at the injector end will give the actual hot air temperatures.

The targeted test conditions are given in Table 2.

The required instrumentation is listed in table 3. Parameters required to run the facility will be displayed on digital readout for monitoring purposes. Only those parameters required for data are shown in the table. Additional measurements will be required to monitor the test facility, and will be determined during facility set-up. Data will be collected using the Astrodata system at NAAO, where it is stored on magnetic type. Hard copy data will be obtained from the system.

G.J. Defever
Member of the Technical Staff
Advanced Combustion Devices

GJD:kw
2165/d

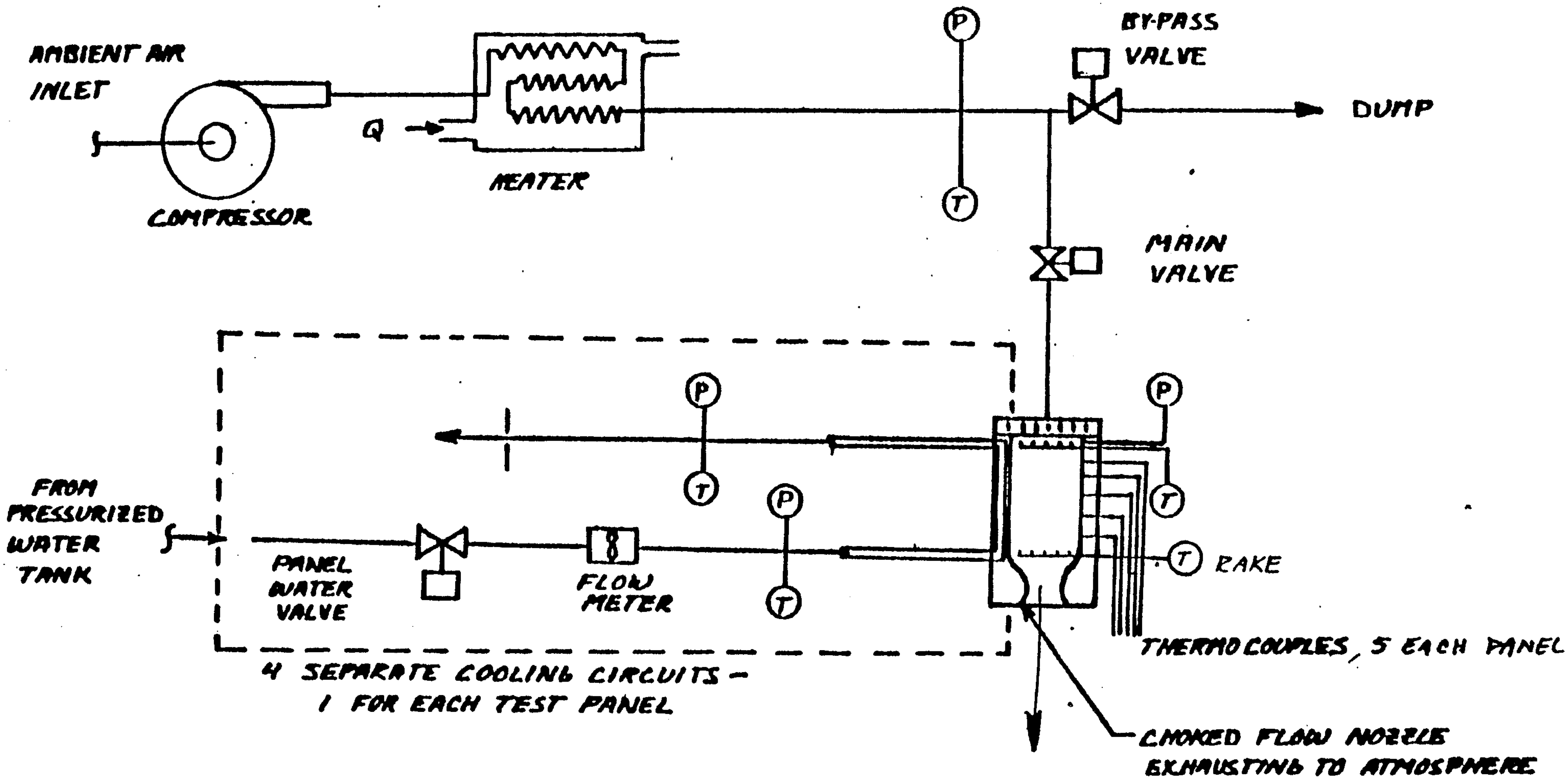

AMBIENT AIR
INLET
COMPRESSOR
Q
HEATER
BY-PASS
VALVE
DUMP
MAIN
VALVE
FROM
PRESSURIZED
WATER
TANK
PANEL
WATER
VALVE
FLOW
METER
RAKE
THERMOCOUPLES, 5 EACH PANEL
4 SEPARATE COOLING CIRCUITS -
1 FOR EACH TEST PANEL
CHOKED FLOW NOZZLE
EXHAUSTING TO ATMOSPHERE

TABLE 1

TEST MATRIX

	Hardware	Description
Series A		
Test 1	Panels A,B,C and Baseline	Short Duration Facility/Data Acquisition Checkout
Test 2	Panels A,B,C and Baseline	Long Duration to Steady State. Collect 20 Data Samples 900F
Test 3	Panels A,B,C and Baseline	Long Duration to Steady State. Collect 20 Data Samples 900F
Test 4	Panels A,B,C and Baseline	Long Duration to Steady State. Collect 20 Data Samples 700F
Test 5	Panels A,B,C and Baseline	Long Duration to Steady State. Collect 20 Data Samples 700F
Series B		
Test 1	Panels D,E,F and Baseline	Short Duration Facility/Data Acquisition Checkout
Test 2	Panels D,E,F and Baseline	Long Duration to Steady State. Collect 20 Data Samples at 900F
Test 3	Panels D,E,F and Baseline	Long Duration to Steady State. Collect 20 Data Samples at 900F
Test 4	Panels D,E,F and Baseline	Long Duration to Steady State. Collect 20 Data Samples at 700F
Test 5	Panels D,E,F and Baseline	Long Duration to Steady State. Collect 20 Data Samples at 700F

TABLE 2

HOT AIR TEST CONDITIONS

HOT AIR TEMPERATURE AT INLET 700° - 900°F

CHAMBER PRESSURE - 300 PSIA

HOT AIR FLOWRATE - 8.3 to 9 LB/SEC

WATER FLOW PER PANEL - .37 LB/SEC

TABLE 3

INSTRUMENTATION LIST - HOT AIR TESTS

PARAMETER	NUMBER REQ'D	RANGE	TRANSDUCER	ASTRO - DATA	DIGITA DISPLA
BYPASS VALVE PRESS	1	0-500 PSIG	TABER	X	X
CHAMBER PRESS	1	0-500 PSIG	TABER	X	X
WATER TANK PRESS	1	0-500 PSIG	TABER	X	X
PANEL H_2O PR IN	4	0-500 PSIG	TABER	X	
PANEL H_2O PR OUT	4	0-500 PSIG	TABER	X	
PANEL H_2O FLOW	4	.5-2.5 GPM	TURBINE F/M	X	
BYPASS VALVE TEMP	1	0-1500°F	T/C	X	X
CHAMBER/C RAKE	32	0-1500°F	T/C	X (16)	
PANEL H_2O TEMP IN	4	0-200°F	T/C	X	
PANEL H_2O TEMP OUT	4	0-200°F	T/C	X	
PANEL H/G WALL TEMP	20	0-1500°F	T/C	X	

OTVW41Ø4
4-3Ø-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .Ø4
DATE : 4-Ø1-85
TIME : 16:46
dTIME : 2

T AIR (F) : 418
P AIR (psia): 163

W AIR (lb/sec): 6.2568Ø3
W H2O (lb/sec): Ø (4-PANEL AVERAGE)
W AIR/W H2O : ERROR (4-PANEL AVERAGE)

PANEL	T IN	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H2Ø
A	N/G	95.83	116.62	134.72	151.55	159.69	N/G	Ø	ERROR	N/G	ERROR
B	N/G	97.Ø1	1Ø4.Ø7	111.44	121	132.5	N/G	Ø	1	N/G	ERROR
C	N/G	99.37	13Ø.16	125.86	132.Ø7	146.61	N/G	Ø	ERROR	N/G	ERROR
D	N/G	1Ø7	119.83	127.17	136.11	148.62	N/G	Ø	ERROR	N/G	ERROR

OTVW4105
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .05
DATE : 4-01-85
TIME : 16:49
dTIME : 3

T AIR (F) : 499
P AIR (psia): 157

W AIR (lb/sec): 5.766370
W H2O (lb/sec): 0 (4-PANEL AVERAGE)
W AIR/W H2O : ERROR (4-PANEL AVERAGE)

PANEL	T IN*	AXIAL STATION 1	AXIAL STATION 2	AXIAL STATION 3	AXIAL STATION 4	AXIAL STATION 5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H20
A	N/G	98.47	127.34	140.58	159.16	166.75	N/G	0	ERROR	N/G	ERROR
B	N/G	95.54	103.65	116.82	126.76	134.2	N/G	0	1	N/G	ERROR
C	N/G	101.93	124.42	128.47	136.08	151.55	N/G	0	ERROR	N/G	ERROR
D	N/G	104.91	121.82	126.12	140.53	156.83	N/G	0	ERROR	N/G	ERROR

OTVW4303
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .03
DATE : 4-03-85
TIME : 14:15
dTIME : 0

T AIR (F) : 589
P AIR (psia): 159

W AIR (lb/sec): 5.583693
W H2O (lb/sec): .36675 (4-PANEL AVERAGE)
W AIR/W H2O : 15.22479 (4-PANEL AVERAGE)

PANEL	T IN*	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H2O
A	70	80	90.2	98.94	103.82	108.58	106.3	36.3	1.532292	.351	15.90795668
B	70	79.45	80.94	93.98	89.85	96.29	93.69	23.69	1	.366	15.25599124
C	69.45	86.45	93.71	91.49	94.29	104.35	99.72	30.27	1.277754	.374	14.92965988
D	70.52	82.71	87.29	89.73	96.85	104.09	101.89	31.37	1.324187	.376	14.85024679

* APPROX. VALUES, PANELS A, B.

OTVW4304
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .04
DATE : 4-03-85
TIME : 14:17
dTIME : 2

T AIR (F) : 694

P AIR (psia): 199

W AIR (lb/sec): 6.662885

W H2O (lb/sec): .36675 (4-PANEL AVERAGE)

W AIR/W H2O : 18.16738 (4-PANEL AVERAGE)

PANEL	T IN*	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H2O
A	70	83.03	96.74	105.73	115.93	122.35	120.85	50.85	1.483805	.351	18.98257792
B	70	82.87	85.22	103.88	97.59	106.36	104.27	34.27	1	.366	18.20460342
C	69.22	91.86	102.63	99.66	103.63	117.47	112.06	42.84	1.250073	.374	17.81520014
D	70.33	86.63	93.27	97.22	106.78	117.04	114.65	44.32	1.293259	.376	17.72043843

* APPROX. VALUES, PANELS A, B.

OTVW4305
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .05
DATE : 4-03-85
TIME : 14:21
dTIME : 4

T AIR (F) : 746
P AIR (psia): 202

W AIR (lb/sec): 6.615914
W H2O (lb/sec): .366 (4-PANEL AVERAGE)
W AIR/W H2O : 18.07627 (4-PANEL AVERAGE)

PANEL	T IN*	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H20
A	70	84.06	98.93	108.35	120.34	127.71	126.03	56.03	1.479145	.351	18.84875784
B	70	84.15	86.71	107.19	100.22	109.9	107.88	37.88	1	.366	18.07626777
C	70	93.91	106.39	102.62	107.17	122.37	116.7	46.7	1.232841	.371	17.83265230
D	70.36	87.67	95.62	100.09	110.64	121.96	119.72	49.36	1.303062	.376	17.59551596

* APPROX. VALUES, PANELS A, B, C.

OTVW4306
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .06
DATE : 4-03-85
TIME : 14:24
dTIME : 3

T AIR (F) : 786
P AIR (psia): 249

W AIR (lb/sec): 8.023289
W H2O (lb/sec): .365 (4-PANEL AVERAGE)
W AIR/W H2O : 21.98162 (4-PANEL AVERAGE)

PANEL	T IN*	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H20
A	72	86.02	103.11	113.8	128.77	138.06	136.84	64.84	1.468297	.349	22.98936813
B	72	86.48	89.74	114.17	106.87	118.27	116.16	44.16	1	.364	22.04200406
C	71.51	97.43	112.16	108.02	113.32	131.25	127.48	55.97	1.267437	.373	21.51015946
D	72.41	90.43	100.05	105.73	117.94	131.38	131.21	58.8	1.331522	.374	21.45264567

* APPROX. VALUES, PANELS A, B.

OTVW4307
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .07
DATE : 4-03-85
TIME : 14:42
dTIME : 17

T AIR (F) : 792
P AIR (psia): 242

W AIR (lb/sec): 7.779028
W H2O (lb/sec): .365 (4-PANEL AVERAGE)
W AIR/W H2O : 21.31241 (4-PANEL AVERAGE)

PANEL	T IN*	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H2O
A	72.5	87.72	105.98	117.21	133.34	143.9	141.83	69.33	1.476049	.349	22.28947865
B	72.5	88.72	91.65	116.96	109.38	120.97	119.47	46.97	1	.364	21.37095618
C	72.24	99.43	115.94	111.1	116.82	135.66	131.94	59.7	1.271024	.373	20.85530308
D	72.84	92.22	101.73	108.28	121.48	135.48	135.83	62.99	1.341069	.374	20.79954023

* APPROX. VALUES, PANELS A, B.

OTVW4308
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: >08
DATE : 4-03-85
TIME : 14:47
dTIME : 6

T AIR (F) : 799

P AIR (psia): 294

W AIR (lb/sec): 9.424246

W H2O (lb/sec): .3645 (4-PANEL AVERAGE)

W AIR/W H2O : 25.85527 (4-PANEL AVERAGE)

PANEL	T IN*	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H2O
A	73	87.42	105.86	117.63	135.11	144.8	145.36	72.36	1.457989	.349	27.00356941
B	73	88.81	92.24	119.84	111.38	124.36	122.63	49.63	1	.364	25.89078495
C	73	99.51	116.49	111.71	117.73	137.43	134.16	61.16	1.232319	.371	25.40227958
D	72.83	91.07	102.86	109.89	123.6	138.44	138.74	65.91	1.328027	.374	25.19851798

* APPROX. VALUES, PANELS A, B, C.

OTVW43Ø9
4-3Ø-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .Ø9
DATE : 4-Ø3-85
TIME : 15:Ø4
dTIME : 17

T AIR (F) : 7ØØ
P AIR (psia): 294

W AIR (lb/sec): 9.818168
W H2O (lb/sec): .36725 (4-PANEL AVERAGE)
W AIR/W H2O : 26.73429 (4-PANEL AVERAGE)

PANEL	T IN*	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H2Ø
A	72	85.59	1Ø2.7	112.96	128.39	136.61	136.56	64.56	1.453727	.351	27.97198941
B	72	86.75	89.94	114.58	1Ø6.32	118.Ø3	116.41	44.41	1	.367	26.7525Ø213
C	71.93	96.67	113.38	1Ø7.76	113.2	13Ø.56	126.24	54.31	1.222923	.374	26.25178685
D	71.Ø6	88.64	99.55	1Ø5.43	118.15	13Ø.89	129.98	58.92	1.326728	.377	26.Ø4288669

* APPROX. VALUES, PANELS A, B.

OTVW4310
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .10
DATE : 4-03-85
TIME : 15:18
dTIME : 14

T AIR (F) : 705

P AIR (psia): 294

W AIR (lb/sec): 9.797077

W H2O (lb/sec): .36525 (4-PANEL AVERAGE)

W AIR/W H2O : 26.82293 (4-PANEL AVERAGE)

PANEL	T IN*	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H20 (lb/sec)	W AIR/W H20
A	72	85.56	102.84	113	128.64	136.72	136.13	64.13	1.445346	.349	28.07185272
B	72	86.86	90	114.76	106.6	118.13	116.37	44.37	1	.366	26.76796885
C	72	96.21	113.14	107.6	113.14	130.51	126.6	54.6	1.230561	.37	26.47858540
D	71.67	88.46	99.55	105.43	118.13	131.44	130.4	58.73	1.323642	.376	26.05605478

* APPROX. VALUES, PANELS A, B, C.

OTVW4403
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .03
DATE : 4-04-85
TIME : 14:45
dTIME : 0

T AIR (F) : 598

P AIR (psia): 292

W AIR (lb/sec): 10.21062

W H2O (lb/sec): .373075 (4-PANEL AVERAGE)

W AIR/W H2O : 27.36882 (4-PANEL AVERAGE)

PANEL	T IN	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H20
A	74.29	84.38	95.75	104.77	117.13	123.07	123.53	49.24	1.374267	.3755	27.19206640
B	73.67	86.15	87.92	99.38	101.69	112.27	109.5	35.83	1	.3658	27.91312448
C	71.99	59.03 N/G	97.86	102.19	106.53	120.63	116.38	44.39	1.238906	.3755	27.19206640
D	72.92	86.73	95.51	99.72	109.84	120.68	119.2	46.28	1.291655	.3755	27.19206640

OTVW4404
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .04
DATE : 4-04-85
TIME : 14:50
dTIME : 5

T AIR (F) : 594

P AIR (psia): 292

W AIR (lb/sec): 10.22998

W H2O (lb/sec): .372725 (4-PANEL AVERAGE)

W AIR/W H2O : 27.44645 (4-PANEL AVERAGE)

PANEL	T IN	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H20
A	74.24	84.28	95.65	104.76	117.05	123.44	123.68	49.44	1.381006	.3741	27.34556958
B	73.64	86	87.81	99	101.37	112.03	109.44	35.8	1	.3658	27.96604040
C	72.03	60.58 N/G	98.18	102.02	106.4	120.41	116.56	44.53	1.243855	.3755	27.24361539
D	72.91	86.69	95.41	99.65	109.95	120.62	119.51	46.6	1.301676	.3755	27.24361539

OTVW4405
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .05
DATE : 4-04-85
TIME : 14:55
dTIME : 5

T AIR (F) : 592
P AIR (psia): 292

W AIR (lb/sec): 10.23970
W H2O (lb/sec): .3717 (4-PANEL AVERAGE)
W AIR/W H2O : 27.54828 (4-PANEL AVERAGE)

PANEL	T IN	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H20
A	74.16	84.28	95.74	104.99	117.3	123.41	123.92	49.76	1.381455	.3741	27.37155112
B	73.63	85.96	87.86	99.22	101.67	112.19	109.65	36.02	1	.3658	27.99261147
C	72.26	60.98 N/G	98.98	102.42	106.96	120.83	117.29	45.03	1.250139	.3728	27.46699913
D	73.24	86.8	95.88	100.1	110.64	121.11	120.33	47.09	1.307329	.3741	27.37155112

OTVW4406
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .06
DATE : 4-04-85
TIME : 15:00
dTIME : 5

T AIR (F) : 608
P AIR (psia): 292

W AIR (lb/sec): 10.16271
W H2O (lb/sec): .372025 (4-PANEL AVERAGE)
W AIR/W H2O : 27.31727 (4-PANEL AVERAGE)

PANEL	T IN	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H20
A	73.85	84.24	96.09	105.49	118.37	124.81	125.31	51.46	1.400653	.3741	27.16574706
B	73.47	86.22	87.92	99.52	102.07	112.86	110.21	36.74	1	.3658	27.78213772
C	72.19	61.79 N/G	99.14	102.64	107.17	121.53	118.02	45.83	1.247414	.3741	27.16574706
D	73.19	86.86	95.97	100.16	110.82	121.63	121.07	47.88	1.303212	.3741	27.16574706

OTVW44Ø7
4-3Ø-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .Ø7
DATE : 4-Ø4-85
TIME : 15:Ø5
dTIME : 5

T AIR (F) : 627

P AIR (psia): 292

W AIR (lb/sec): 1Ø.Ø735Ø

W H2O (lb/sec): .372375 (4-PANEL AVERAGE)

W AIR/W H2O : 27.Ø52Ø2 (4-PANEL AVERAGE)

PANEL	T IN	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H2Ø
A	73.5	84.32	96.55	1Ø6.25	119.54	126.17	126.75	53.25	1.396538	.3741	26.92728128
B	73.Ø9	86.23	88.22	1ØØ.12	1Ø2.63	113.88	111.22	38.13	1	.3658	27.53826115
C	71.27	62.1 N/G	1ØØ.Ø2	1Ø3.31	1Ø8.Ø1	123.Ø9	118.79	47.52	1.246263	.3741	26.92728128
D	72.29	86.91	96.64	1Ø1.Ø4	112.Ø3	123.27	122.29	5Ø	1.311303	.3755	26.82688663

OTVW4408
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .08
DATE : 4-04-85
TIME : 15:10
dTIME : 5

T AIR (F) : 621
P AIR (psia): 289

W AIR (lb/sec): 9.997632
W H2O (lb/sec): .3717 (4-PANEL AVERAGE)
W AIR/W H2O : 26.89705 (4-PANEL AVERAGE)

PANEL	T IN	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H20
A	73.75	84.43	96.33	105.93	119.04	125.77	126.41	52.66	1.391281	.3741	26.72448984
B	73.34	86.35	88.19	100.09	102.91	113.88	111.19	37.85	1	.3658	27.33086837
C	72.6	63 N/G	100.25	103.2	108.06	122.71	119.6	47	1.241744	.3728	26.81768146
D	73.37	86.84	96.2	100.65	111.56	122.87	122.76	49.39	1.304888	.3741	26.72448984

OTVW4409
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .09
DATE : 4-04-85
TIME : 15:15
dTIME : 5

T AIR (F) : 620
P AIR (psia): 292

W AIR (lb/sec): 10.10609
W H2O (lb/sec): .368225 (4-PANEL AVERAGE)
W AIR/W H2O : 27.44542 (4-PANEL AVERAGE)

PANEL	T IN	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H2O
A	74.08	84.95	96.91	106.56	119.66	126.46	126.68	52.6	1.389696	.3755	26.91368519
B	73.67	86.88	88.56	100.62	103.03	114.15	111.52	37.85	1	.3672	27.52202829
C	71.51	63.7 N/G	99.96	103.82	108.58	123.28	118.61	47.1	1.244386	.3547	28.49193344
D	72.3	87.5	96.85	101.37	112.33	123.47	121.96	49.66	1.312021	.3755	26.91368519

OTVW4410
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .10
DATE : 4-04-85
TIME : 15:21
dTIME : 6

T AIR (F) : 657
P AIR (psia): 292

W AIR (lb/sec): 9.937300
W H2O (lb/sec): .3724 (4-PANEL AVERAGE)
W AIR/W H2O : 26.68448 (4-PANEL AVERAGE)

PANEL	T IN	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H20
A	74.27	85.63	98.61	109.1	123.17	130.39	131.58	57.31	1.395083	.3755	26.46418107
B	73.86	87.9	89.8	102.72	105.64	117.47	114.94	41.08	1	.3672	27.06236381
C	72.81	64.54 N/G	102.07	106.26	111.4	127.35	123.79	50.98	1.240993	.3714	26.75632739
D	73.48	88.37	98.49	103.83	115.42	127.64	127.45	53.97	1.313778	.3755	26.46418107

OTVW4411
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .11
DATE : 4-04-85
TIME : 15:29
dTIME : 8

T AIR (F) : 734
P AIR (psia): 293

W AIR (lb/sec): 9.644453
W H2O (lb/sec): .373075 (4-PANEL AVERAGE)
W AIR/W H2O : 25.85124 (4-PANEL AVERAGE)

PANEL	T IN	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H20
A	73.83	86.08	100.29	111.74	127.15	135.19	136.32	62.49	1.408702	.3755	25.68429512
B	73.49	88.75	90.69	104.74	106.95	120.04	117.85	44.36	1	.3672	26.26484972
C	71.16	64.7 N/G	103.2	108.71	114.42	131.83	126.07	54.91	1.237827	.3741	25.78041384
D	71.37	89.29	100.3	106.14	119.06	132.35	130.33	58.96	1.329125	.3755	25.68429512

OTVW4412
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .12
DATE : 4-04-85
TIME : 15:38
dTIME : 9

T AIR (F) : 768
P AIR (psia): 293

W AIR (lb/sec): 9.510001
W H2O (lb/sec): .373425 (4-PANEL AVERAGE)
W AIR/W H2O : 25.46696 (4-PANEL AVERAGE)

PANEL	T IN*	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H2O
A	73.82	86.57	101.42	113.28	129.44	138.04	139.47	65.65	1.417008	.3755	25.32623495
B	73.41	89.22	91.17	105.92	108.77	122.34	119.74	46.33	1	.3672	25.89869614
C	72	65.6 N/G	104.25	110.4	116.39	134.66	130.06	58.06	1.253184	.3755	25.32623495
D	72.22	89.81	101.24	107.34	120.54	134.56	133.55	61.33	1.323764	.3755	25.32623495

* APPROX. VALUE, PANEL C.

OTVW4413
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .13
DATE : 4-04-85
TIME : 15:41
dTIME : 3

T AIR (F) : 775
P AIR (psia): 293

W AIR (lb/sec): 9.483012
W H2O (lb/sec): .372025 (4-PANEL AVERAGE)
W AIR/W H2O : 25.49025 (4-PANEL AVERAGE)

		AXIAL STATION									
PANEL	T IN*	1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H20
A	74.04	86.96	102.05	113.94	130.33	138.98	140.9	66.86	1.417126	.3741	25.34886796
B	73.81	89.49	91.92	106.8	109.98	123.66	120.99	47.18	1	.3658	25.92403363
C	74	66.21 N/G	105.14	110.79	116.97	135.32	131.6	57.6	1.220856	.3741	25.34886796
D	73.28	90.08	101.67	107.93	121.7	135.96	135.8	62.52	1.325138	.3741	25.34886796

* APPROX. VALUE, PANEL C.

OTVW4414
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .14
DATE : 4-04-85
TIME : 15:48
dTIME : 7

T AIR (F) : 813

P AIR (psia): 249

W AIR (lb/sec): 7.937748

W H2O (lb/sec): .372725 (4-PANEL AVERAGE)

W AIR/W H2O : 21.29653 (4-PANEL AVERAGE)

PANEL	T IN*	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H2O
A	73.94	87.45	103.33	114.98	131.4	140.06	141.94	68	1.451131	.3741	21.21825053
B	73.6	90.46	92.04	107.16	109.25	122.18	120.46	46.86	1	.3658	21.69969252
C	74	66.17 N/G	106.64	112.78	118.86	137.13	133.38	59.38	1.267179	.3769	21.06061959
D	73.1	91.4	102.85	109.66	123.7	137.99	137.74	64.64	1.379428	.3741	21.21825053

* APPROX. VALUE, PANEL C.

OTVW4415
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .15
DATE : 4-04-85
TIME :15:53
dTIME : 5

T AIR (F) : 843
P AIR (psia): 252

W AIR (lb/sec): 7.940365
W H2O (lb/sec): .373775 (4-PANEL AVERAGE)
W AIR/W H2O : 21.24370 (4-PANEL AVERAGE)

PANEL	T IN*	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H20
A	74.01	87.6	103.9	116.23	133.16	142.26	144.27	70.26	1.453455	.3755	21.14611197
B	73.67	90.87	92.56	108.12	109.55	123.03	122.01	48.34	1	.3672	21.62408781
C	73	66.79 N/G	107.73	114.13	120.44	139.48	134.94	61.94	1.281341	.3769	21.06756446
D	72.23	91.88	103.88	111.09	125.69	140.79	139.48	67.25	1.391187	.3755	21.14611197

* APPROX. VALUE, PANEL C.

OTVW4416
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .16
DATE : 4-04-85
TIME : 15:58
dTIME : 5

T AIR (F) : 863
P AIR (psia): 251

W AIR (lb/sec): 7.848848
W H2O (lb/sec): .373425 (4-PANEL AVERAGE)
W AIR/W H2O : 21.01854 (4-PANEL AVERAGE)

PANEL	T IN*	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H2O
A	73.62	88.04	104.76	117.23	134.65	143.73	145.79	72.17	1.452113	.3755	20.90239227
B	73.29	91.28	92.94	109	110.66	124.4	122.99	49.7	1	.3658	21.45666566
C	73	67.04 N/G	108.72	115.14	121.64	141.12	135.47	62.47	1.256942	.3769	20.82475006
D	71.95	92.15	104.7	112.13	127.05	142.6	141.15	69.2	1.392354	.3755	20.90239227

* APPROX. VALUE, PANEL C.

OTVW4417
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .17
DATE : 4-04-85
TIME :16:01
dTIME : 3

T AIR (F) : 873
P AIR (psia): 252

W AIR (lb/sec): 7.850505
W H2O (lb/sec): .372375 (4-PANEL AVERAGE)
W AIR/W H2O : 21.08226 (4-PANEL AVERAGE)

PANEL	T IN*	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H2O
A	73.54	87.91	104.88	117.59	135.28	144.8	147.27	73.73	1.455676	.3741	20.98504446
B	73.2	91.14	92.92	109.31	111.53	125.42	123.85	50.65	1	.3658	21.46119501
C	73	67.85 N/G	109.6	115.31	122.06	141.76	138.14	65.14	1.286081	.3755	20.90680462
D	72.85	91.9	104.92	112.16	127.17	142.97	142.76	69.91	1.380257	.3741	20.98504446

* APPROX. VALUE, PANEL C.

OTVW4418
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .18
DATE : 4-04-85
TIME : 16:06
dTIME : 5

T AIR (F) : 887
P AIR (psia): 251

W AIR (lb/sec): 7.778611
W H2O (lb/sec): .372375 (4-PANEL AVERAGE)
W AIR/W H2O : 20.88919 (4-PANEL AVERAGE)

PANEL	T IN*	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H20
A	73.5	88.12	105.49	118.51	136.63	145.91	148.89	75.39	1.458503	.3741	20.79286583
B	73.13	91.29	93.24	109.55	112.42	126.52	124.82	51.69	1	.3658	21.26465584
C	73.5	68.61 N/G	109.1	116.06	122.79	142.9	140.07	66.57	1.287870	.3755	20.71534250
D	73.52	91.85	105.27	112.86	128.21	144.09	144.82	71.3	1.379377	.3741	20.79286583

* APPROX. VALUE, PANEL C.

OTVW4419
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .19
DATE : 4-04-85
TIME :16:08
dTIME : 2

T AIR (F) : 893
P AIR (psia): 252

W AIR (lb/sec): 7.792266
W H2O (lb/sec): .372025 (4-PANEL AVERAGE)
W AIR/W H2O : 20.94554 (4-PANEL AVERAGE)

PANEL	T IN*	AXIAL STATION 1	AXIAL STATION 2	AXIAL STATION 3	AXIAL STATION 4	AXIAL STATION 5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H20
A	73.55	88.17	105.66	118.67	136.65	146.25	149.04	75.49	1.457055	.3741	20.82936691
B	73.2	91.74	93.39	110.3	112.33	126.52	125.01	51.81	1	.3658	21.30198513
C	73	68.64 N/G	109.53	116.48	123.14	143.52	139.55	66.55	1.284501	.3741	20.82936691
D	72.79	91.9	105.32	113.04	128.64	144.46	144.28	71.49	1.379849	.3741	20.82936691

* APPROX. VALUE, PANEL C

OTVW4420
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .20.
DATE : 4-04-85
TIME : 16:09
dTIME : 1

T AIR (F) : 893
P AIR (psia): 252

W AIR (lb/sec): 7.792266
W H2O (lb/sec): .372375 (4-PANEL AVERAGE)
W AIR/W H2O : 20.92586 (4-PANEL AVERAGE)

PANEL	T IN*	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H20
A	73.6	88.27	105.69	118.8	136.73	146.41	149.37	75.77	1.459642	.3741	20.82936691
B	73.22	91.76	93.4	110.2	112.41	126.66	125.13	51.91	1	.3658	21.30198513
C	73	68.64 N/G	109.47	116.63	123.42	143.6	140.12	67.12	1.293007	.3755	20.75170748
D	72.98	92.09	105.61	113.37	129	145.21	144.92	71.94	1.385860	.3741	20.82936691

* APPROX. VALUE, PANEL C.

OTVW4421
4-30-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .21
DATE : 4-04-85
TIME : 16:15
dTIME : 7

T AIR (F) : 625
P AIR (psia): 251

W AIR (lb/sec): 8.667044
W H2O (lb/sec): .37205 (4-PANEL AVERAGE)
W AIR/W H2O : 23.29537 (4-PANEL AVERAGE)

PANEL	T IN*	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O (lb/sec)	W AIR/W H20
A	73.65	84.78	97.56	106.82	119.96	126.83	127.56	53.91	1.417565	.3728	23.24850788
B	73.36	87.54	88.46	100.46	102.77	113.74	111.39	38.03	1	.3658	23.69339458
C	73.5	73.9 N/G	101.04	104.88	109.68	124.19	121.81	48.31	1.270313	.3755	23.08134151
D	73.91	87.36	97.13	101.96	113.34	124.85	125.25	51.34	1.349987	.3741	23.16771916

* APPROX. VALUE, PANEL C.

OTVW4805
4-29-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .05
DATE :4-08-85
TIME : 12:06
dTIME :

T AIR (F) : 903

P AIR (psia): 198

W AIR (lb/sec): 6.099994

W H2O (lb/sec): .3679 (4-PANEL AVERAGE)

W AIR/W H2O : 16.58058 (4-PANEL AVERAGE)

PANEL	T IN	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O	W AIR/W H2O
A	73.13	85.35	99.89	110.43	125.41	133.74	135.92	62.79	1.508650	.3686	16.54908807
B	72.86	87.46	89.02	102.46	104.7	116.87	114.48	41.62	1	.3672	16.61218373
C	72.35	86.98	106.45	109.01	114.86	133.23	128.08	55.73	1.339020	.3672	16.61218373
D	72.44	88.21	100.46	107.19	119.63	133.31	131.94	59.5	1.429601	.3686	16.54908807

OTVW4806
4-29-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .06
DATE : 4-08-85
TIME : 12:16
dTIME : 10

T AIR (F) : 912
P AIR (psia): 166

W AIR (lb/sec): 5.097335
W H2O (lb/sec): .3672 (4-PANEL AVERAGE)
W AIR/W H2O : 13.88163 (4-PANEL AVERAGE)

		AXIAL STATION									
PANEL	T IN	1	2	3	4	5	T OUT	dT	E.F.	W H2O	W AIR/W H20
A	73.26	84.41	97.49	107.03	120.34	127.21	129.53	56.27	1.544606	.3686	13.82890640
B	72.99	85.37	87.41	99.2	101.5	112.06	109.42	36.43	1	.3658	13.93475916
C	72.51	85.88	102.41	105.44	110.71	126.94	122.13	49.62	1.362064	.3658	13.93475916
D	73.15	86.51	97.79	103.66	114.91	127.03	126.05	52.9	1.452100	.3686	13.82890640

OTVW4807
4-29-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .07
DATE : 4-08-85
TIME : 12:21
dTIME : 5

T AIR (F) : 913
P AIR (psia): 165

W AIR (lb/sec): 5.064783
W H2O (lb/sec): .3693 (4-PANEL AVERAGE)
W AIR/W H2O : 13.71455 (4-PANEL AVERAGE)

PANEL	T IN	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O	W AIR/W H20
A	73.24	84.39	97.45	107.02	120.39	127.46	129.51	56.27	1.544606	.37	13.68860171
B	72.98	85.87	87.48	99.28	101.27	111.87	109.41	36.43	1	.3672	13.79298103
C	72.51	85.84	102.71	105.39	110.71	126.95	121.24	48.73	1.337634	.37	13.68860171
D	72.18	86.51	97.75	103.64	114.83	127.18	125.23	53.05	1.456217	.37	13.68860171

C-3

OTVW48Ø8
4-29-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .Ø8
DATE : 4-Ø8-85
TIME : 12:31
dTIME : 1Ø

T AIR (F) : 915

P AIR (psia): 166

W AIR (lb/sec): 5.Ø91771

W H2O (lb/sec): .28Ø275 (4-PANEL AVERAGE)

W AIR/W H2O : 18.167Ø5 (4-PANEL AVERAGE)

PANEL	T IN	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O	W AIR/W H2Ø
A	73.Ø6	89.33	117.27	133.Ø6	135.49	146.4	145.34	72.28	1.539182	.2796	18.21Ø9125Ø
B	73.Ø8	91.Ø5	1Ø2.Ø1	11Ø.97	11Ø.9	125.29	12Ø.Ø4	46.96	1	.281	18.12Ø18198
C	72.7	92	131.74	133.89	123.93	145.37	135.74	63.Ø4	1.342419	.2782	18.3Ø25562Ø
D	72.15	92.45	119.37	125.45	129.55	145.54	14Ø.63	68.48	1.458262	.2823	18.Ø3673799

OTVW48Ø9
4-29-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .Ø9
DATE : 4-Ø8-85
TIME : 12:36
dTIME : 5

T AIR (F) : 916
P AIR (psia): 164

W AIR (lb/sec): 5.Ø28596
W H2O (lb/sec): .27785 (4-PANEL AVERAGE)
W AIR/W H2O : 18.Ø9824 (4-PANEL AVERAGE)

PANEL	T IN	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O	W AIR/W H2Ø
A	73.Ø4	88.82	116.55	133.68	134.64	146.Ø6	144.84	71.8	1.536815	.2768	18.16689396
B	73.1	91.15	1Ø1.73	11Ø.96	11Ø.91	125.28	119.82	46.72	1	.2782	18.Ø7547177
C	72.66	91.57	132.79	133.84	123.24	144.83	136.35	63.69	1.363228	.2754	18.25924563
D	73.18	92.8	119.61	126.71	129.Ø5	145.13	141.18	68	1.455479	.281	17.89536Ø31

OTVW481Ø
4-29-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .1Ø
DATE : 4-Ø8-85
TIME : 12:39
dTIME : 3

T AIR (F) : 916

P AIR (psia): 293

W AIR (lb/sec): 8.984Ø16

W H2O (lb/sec): .28Ø275 (4-PANEL AVERAGE)

W AIR/W H2O : 32.Ø5429 (4-PANEL AVERAGE)

PANEL	T IN	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O	W AIR/W H2Ø
A	72.8	93.92	128.2	139.35	158.Ø6	173.65	174.57	1Ø1.77	1.45Ø955	.2796	32.13167549
B	72.96	97.68	112.4	125.89	126.27	148.27	143.1	7Ø.14	1	.281	31.97158885
C	72.5	96.28	145.94	144.44	14Ø.36	169.38	16Ø.9	88.4	1.26Ø336	.2782	32.29337335
D	72.11	1ØØ.47	132	133.74	147.9	17Ø.29	167.61	95.5	1.361563	.2823	31.82435872

OTVW4811
4-29-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .11
DATE : 4-08-85
TIME : 12:43
dTIME : 4

T AIR (F) : 894
P AIR (psia): 293

W AIR (lb/sec): 9.056709
W H2O (lb/sec): .279575 (4-PANEL AVERAGE)
W AIR/W H2O : 32.39456 (4-PANEL AVERAGE)

PANEL	T IN	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O	W AIR/W H2O
A	72.79	93.51	127.65	138.82	156.26	171.74	172	99.21	1.441377	.2782	32.55467007
B	72.95	97.31	111.76	125.09	125.65	147.32	141.78	68.83	1	.2796	32.39166386
C	72.48	95.76	146.11	143.55	139.02	167.5	159.56	87.08	1.265146	.2782	32.55467007
D	72.77	100.01	130.62	132.97	146.54	168.45	166.02	93.25	1.354787	.2823	32.08186048

OTVW4812
4-29-85

HOT AIR RIBBED CALORIMETER TESTS

DATA SUMMARY: BULK COOLANT T AND PANEL COOLANT TEMPERATURE PROFILE

TEST NO.: .12
DATE : 4-Ø8-85
TIME : 12:48
dTIME : 5

T AIR (F) : 698
P AIR (psia): 29Ø

W AIR (lb/sec): 9.692947
W H2O (lb/sec): .27925 (4-PANEL AVERAGE)
W AIR/W H2O : 34.71Ø64 (4-PANEL AVERAGE)

PANEL	T IN	AXIAL STATION 1	2	3	4	5	T OUT	dT	E.F.	W H2O	W AIR/W H2Ø
A	73.Ø2	9Ø.Ø6	121.26	135.74	139.83	152.93	15Ø.61	77.59	1.414327	.2782	34.84165117
B	73.13	93.3	1Ø5.58	116.13	115.73	134	127.99	54.86	1	.2796	34.66719369
C	72.82	91.79	136.43	136.78	126.32	149.44	14Ø.57	67.75	1.234962	.2782	34.84165117
D	72.52	95.93	123.81	133.15	132.64	149.33	146.Ø3	73.51	1.339956	.281	34.49447458

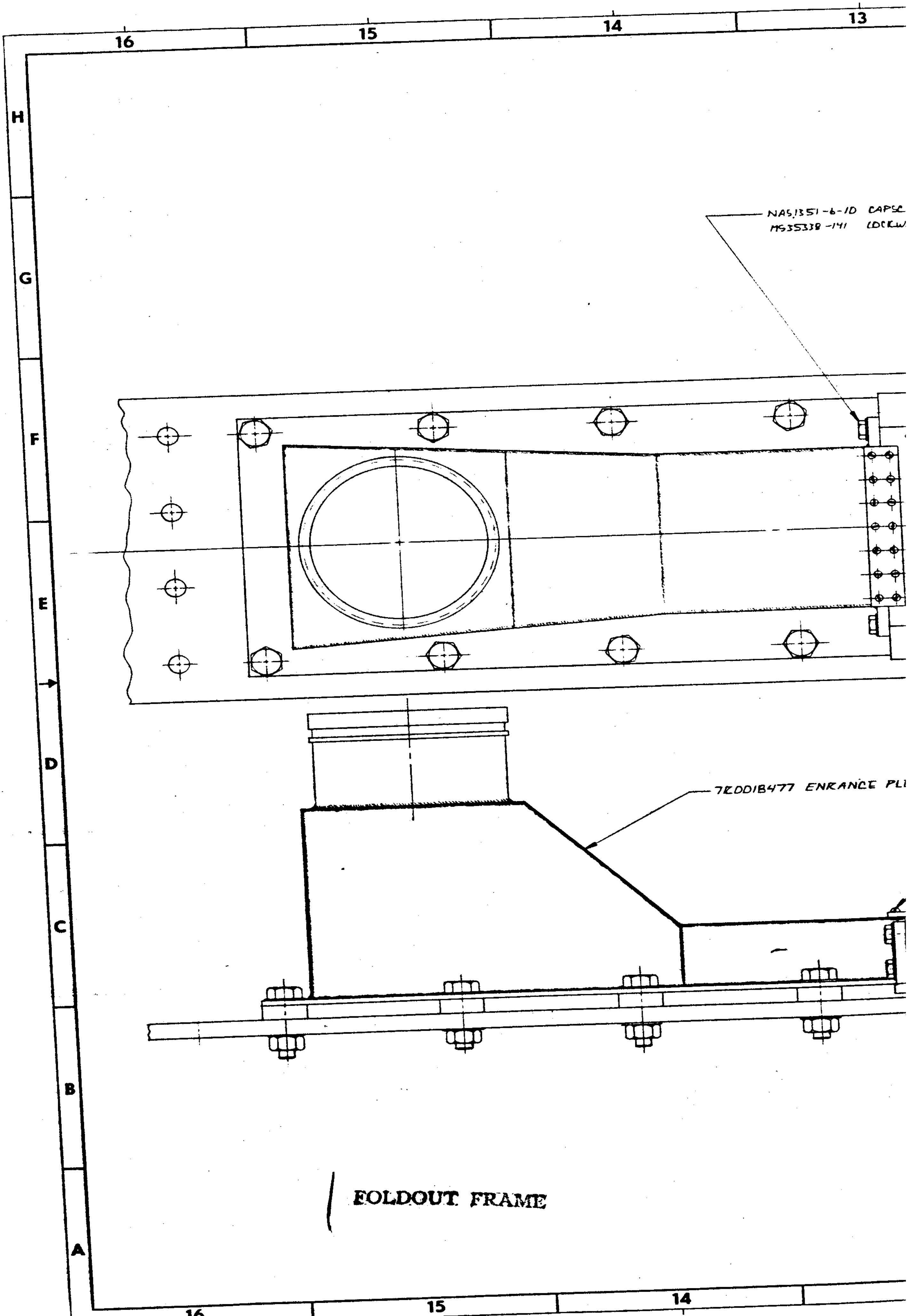
APPENDIX C
RIB COLD FLOW TESTS

RIB COLD FLOW FIXTURE DRAWINGS

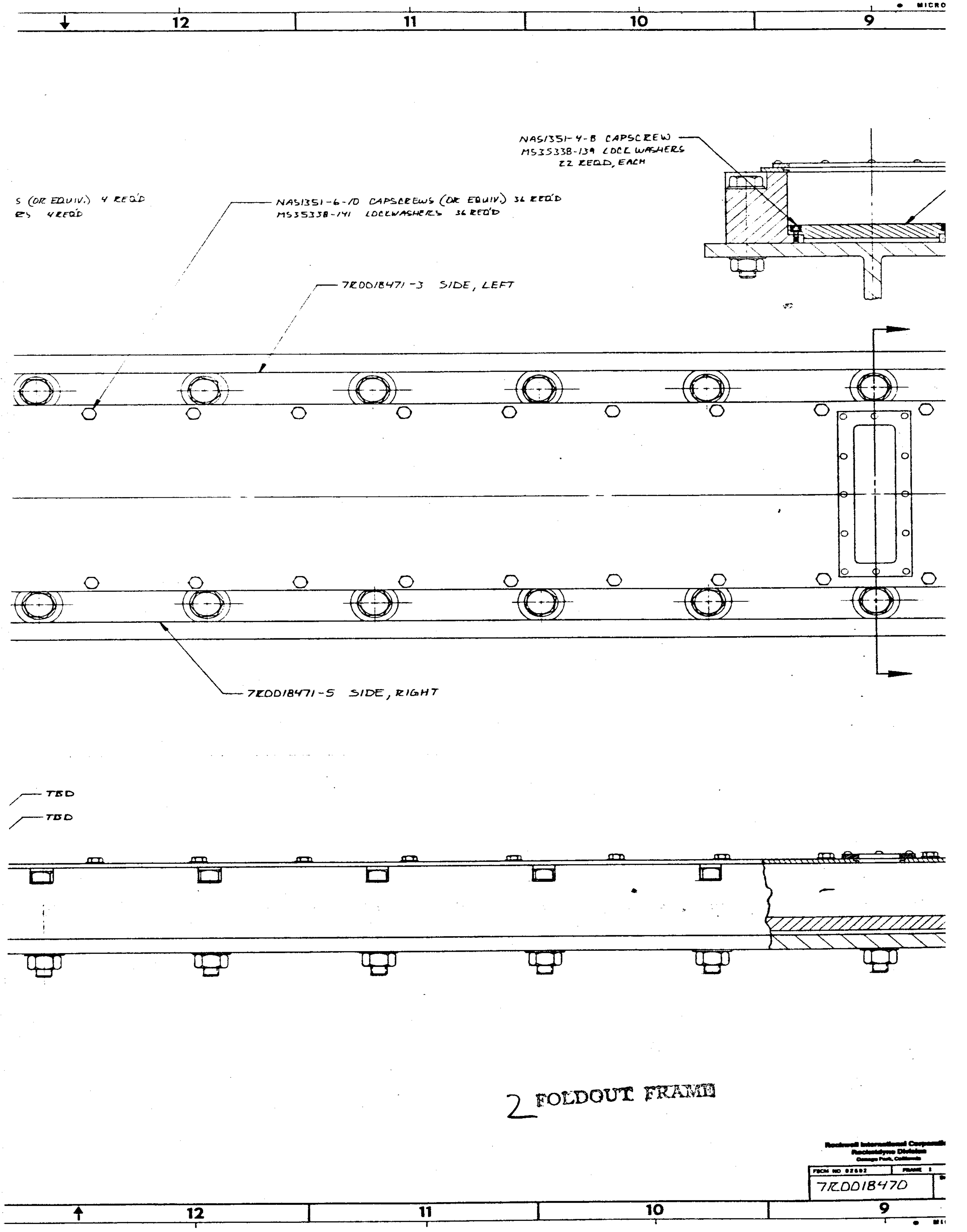
TITLE	DWG #
COLD FLOW TEST FIXTURE, ASSY	7R0018470
SIDE PANELS	7R0018471
COVER	7R0018472
WINDOW	7R0018473
WINDOW FLANGE	7R0018474
WINDOW COVER	7R0018475
TEST PANEL	7R0018476

TEST PLAN

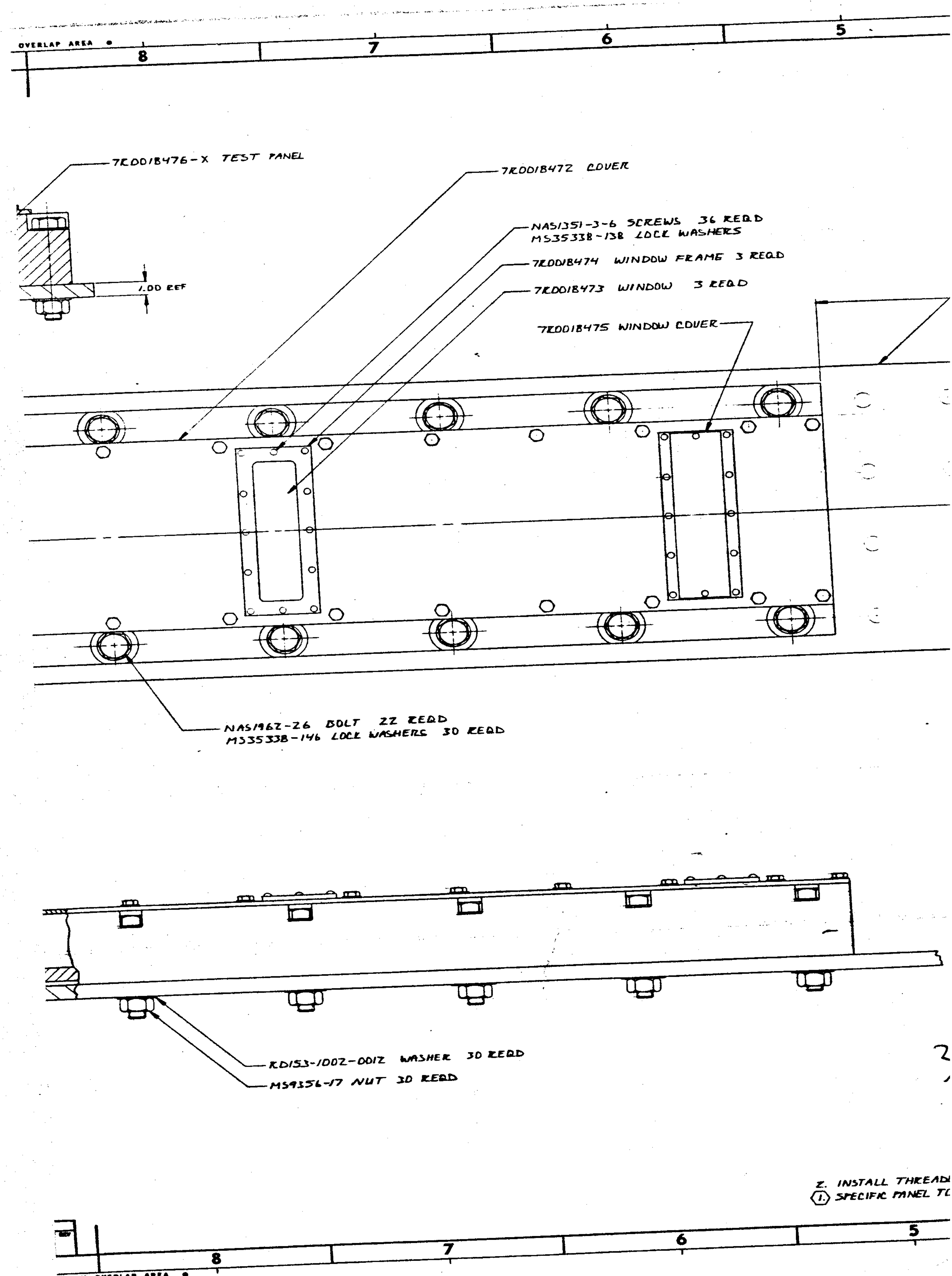
TEST DATA



FOLDOUT FRAME

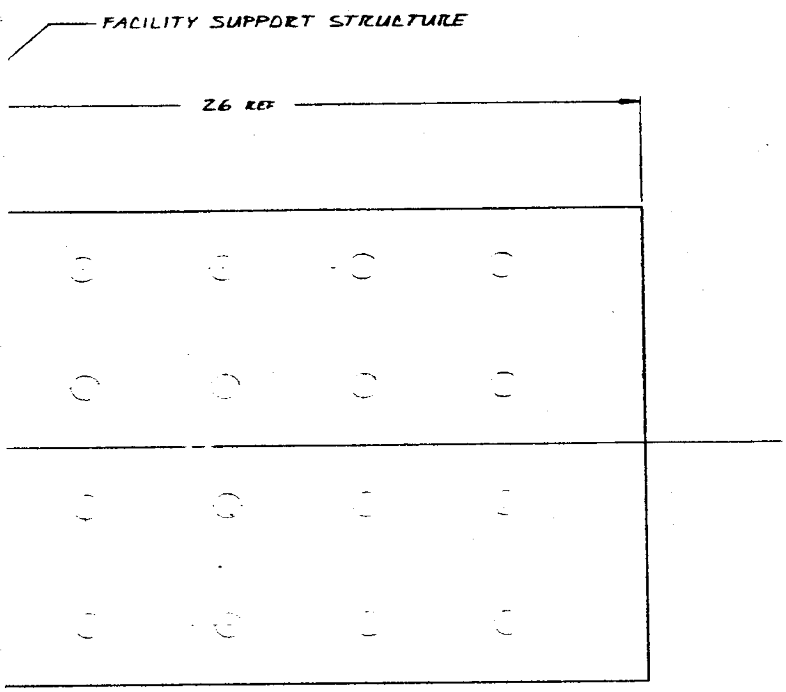


2 FOLDOUT FRAME


OVERLAP AREA
8
7
6
5
7RD018476-X TEST PANEL
7RD018472 COVER
NAS1351-3-6 SCREWS 36 REQD
MS35338-138 LOCK WASHERS
7RD018474 WINDOW FRAME 3 REQD
7RD018473 WINDOW 3 REQD
7RD018475 WINDOW COVER
1.00 REF
NAS1962-26 BOLT 22 REQD
MS35338-146 LOCK WASHERS 30 REQD
RD153-1002-0012 WASHER 30 REQD
MS9356-17 NUT 30 REQD
2. INSTALL THREAD
1. SPECIFIC PANEL TO
8
7
6
5
OVERLAP AREA

REVISIONS

ZONE	REV	DESCRIPTION	DATE	APPROVED
		1. MAY BE REWORKED 2. CANNOT BE REWORKED 3. RECORD CHANGE 4. NOW SHOP PRACTICE 5. PARTS MADE OK (DISPN)		
	A			
10H		ADDED NAS1351-4-8 22 REQ'D MS35338-139		
11G		ADDED NAS1351-6-10 36 REQ'D MS35338-141 36 REQ'D		
13G		ADDED NAS1351-6-10 4 REQ'D MS35338-141 4 REQ'D	1-9-85	
5C		ADDED ADD'L INFO. TO PARTS LIST.		



4 FOLDOUT FRAME

ORIGINAL PAGE IS
OF POOR QUALITY

FOR INFORMATION

REQD	PART NUMBER	FSCM	NOMENCLATURE	MATERIAL	SPECS / NOTES		ZONE
36	MS35338-138		WASHER LOCK				6G
22	MS35338-139		WASHER LOCK				10H
40	MS35338-141		WASHER LOCK				11G 13G
30	MS35338-146		WASHER LOCK				8D
30	RD153-1002-0012		WASHER FLAT				8D
30	MS9356-17		NUT				8D
36	NAS1351-3-6		SCREW				6G
22	NAS1351-4-8		SCREW				10H
40	NAS1351-6-10		SCREW				11G 13G
30	NAS1962-26		BOLT				8D
1	7R0018477		ENTRANCE PLENUM	STEEL	COMMERCIAL		13D
3	7R0018476		TEST PANEL	6061-T6 AL.	COMMERCIAL		8H
3	7R0018475		WINDOW COVER				6F
3	7R0018474		WINDOW FLANGE				6G
3	7R0018473		WINDOWS				6G
1	7R0018472		COVER				6H
1	7R0018471-5		SIDE, RIGHT, SUBASSY				12D
1	7R0018471-3		SIDE, LEFT, SUBASSY	6061-T6 AL.	COMMERCIAL		11G

DOUT FRAME

NERS PER RA0101-002.
IN ASSY TBD AT TIME OF TEST.

Rockwell International Corporation
Rocketdyne Division
Canoga Park, California

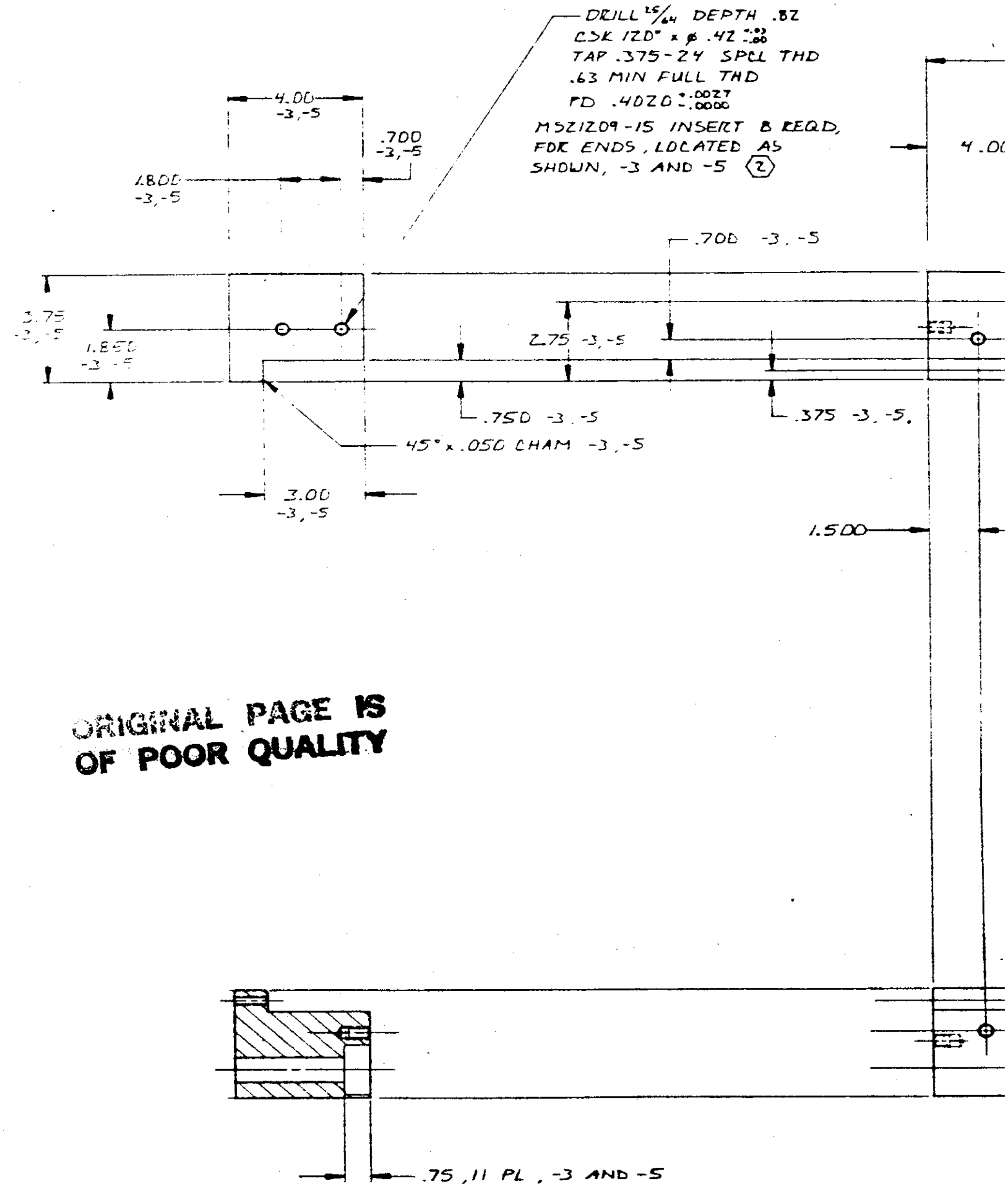
DRN G. Defever

COLD AIR FLOW TEST FIXTURE, ASSY

SIZE J FSCM NO 02602 DWG NO 7R0018470

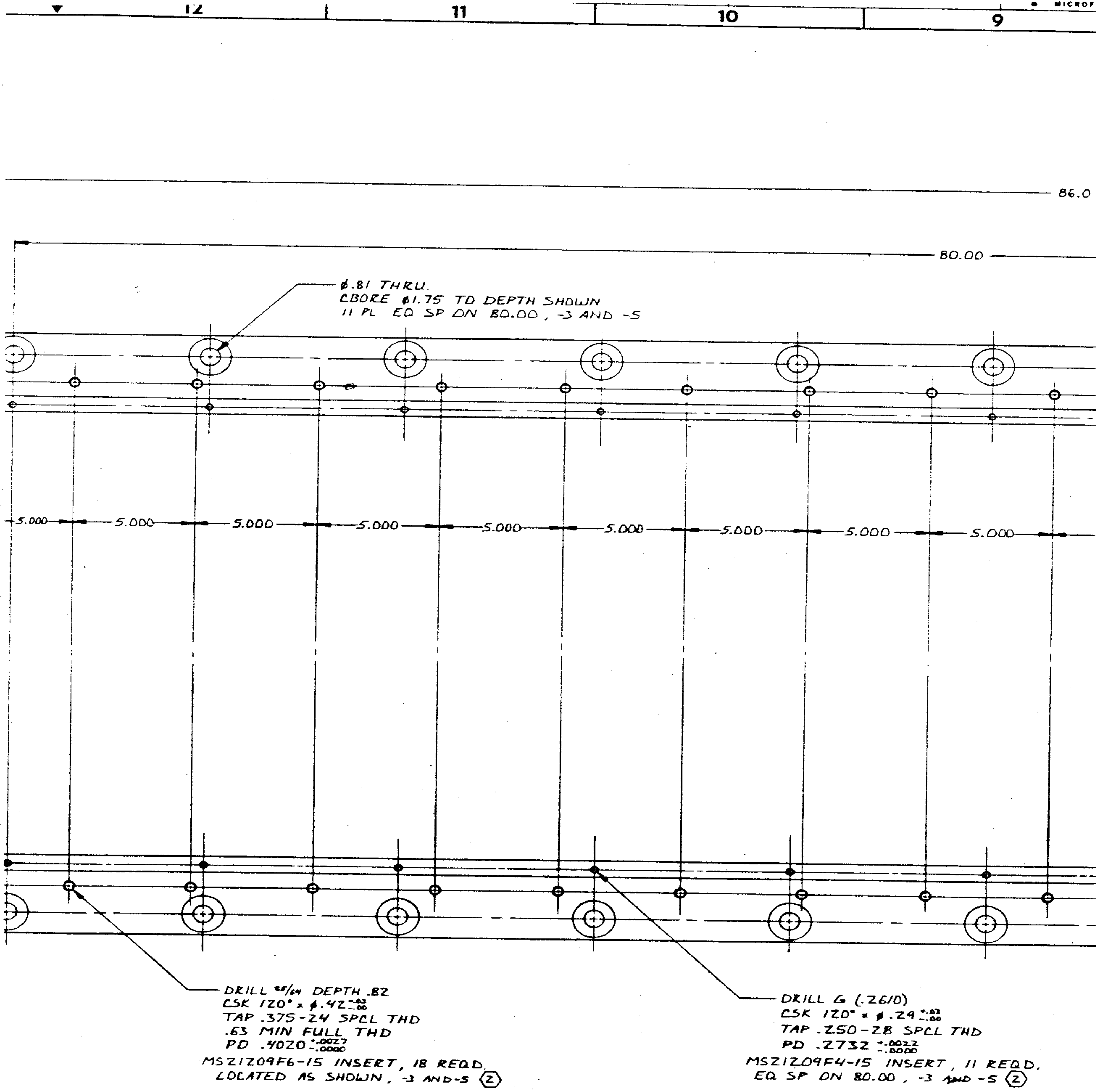
SCALE HALF

DWG NO 7R0018470



ORIGINAL PAGE IS
OF POOR QUALITY

FOLDOUT FRAME



2 FOLDOUT FRAME

Rockwell International Corporation
Rocketdyne Division
Canoga Park, California

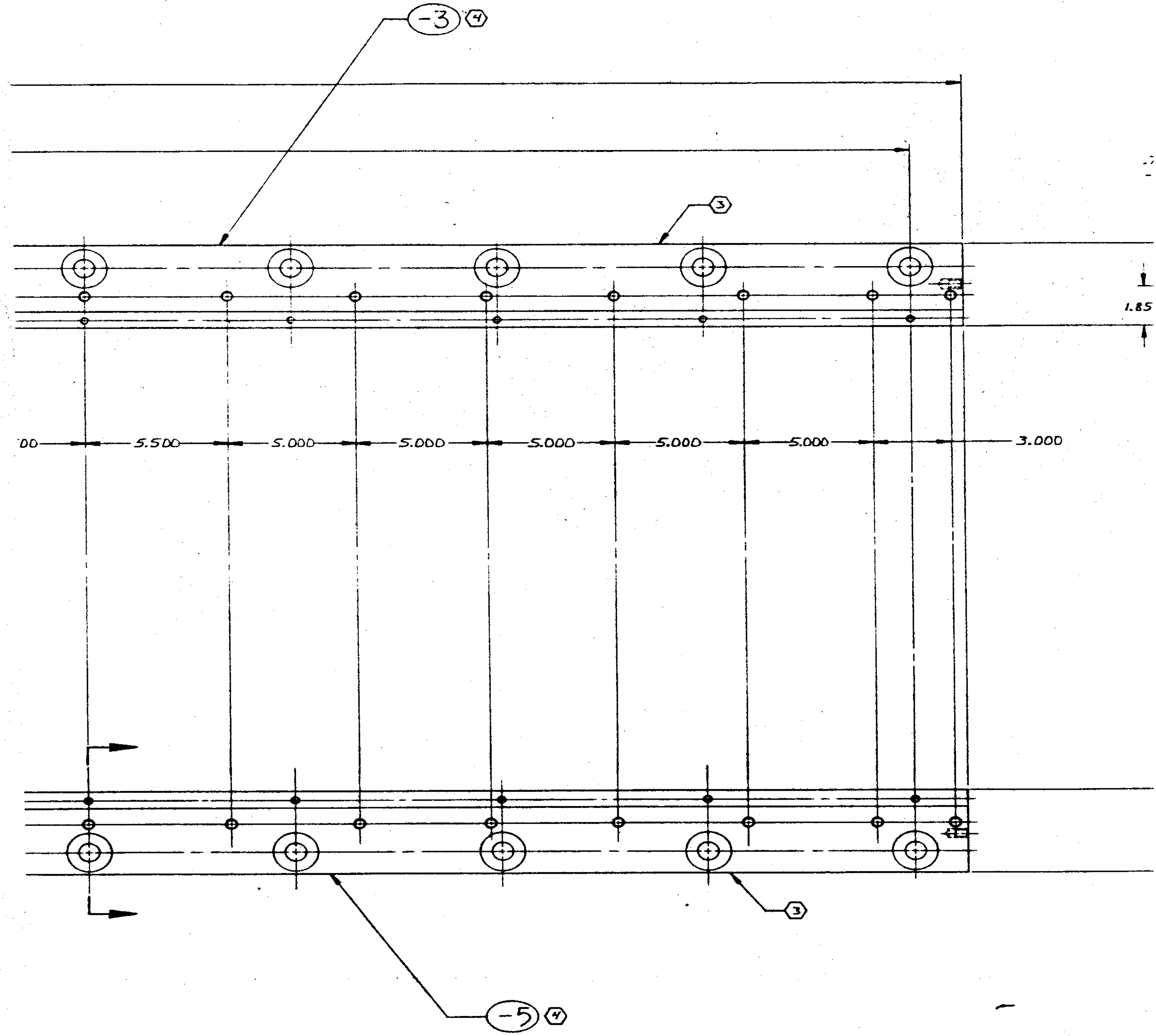
FSCM NO 02602	FRAME 1	
7RD018471	SH	REV

12 11 10 9

MICROFILM

OVERLAP AREA

8	7	6	5



3 FOLDOUT FRAM

4 -3 AND -5 AR
3 ETCH IDENTIFY
2 INSTALL WITH
PER RAD101-0
1. MACHINE PER

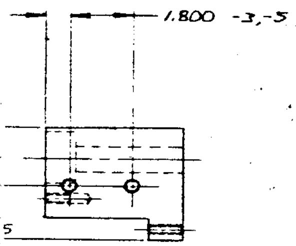
8	7	6	5

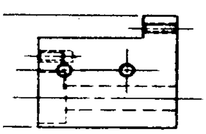
ERLAP AREA

ORIGINAL PAGE IS
OF POOR QUALITY

REVISIONS

ZONE	REV	DESCRIPTION	DATE	APPROVED
		1. MAY BE REWORKED 3. RECORD CHANGE 2. CANNOT BE REWORKED 4. NOW SHOP PRACTICE 5. PARTS MADE OK (DISPN)		
	A			
4F		1.850 WAS 2.000		
136		4.00 WAS 2.00		





4 FOLDOUT FRAME

FOR
INFORMATION

-5	SIDE PANEL, RIGHT	6061-T6 ALUM	COMMERCIAL	7B
-3	SIDE PANEL, LEFT	6061-T6 ALUM	COMMERCIAL	7H
NO.	DESCRIPTION	MATERIAL	SPECIFICATION	ZONE

T/RIGHT MIRROR IMAGE
RAD104-008 AS INDICATED
CHROMATE PRIMER TT-P-1757

-016
OTHERWISE SPECIFIED

HEAT TREAT: NONE
FINISH: NOTED
MATL: NOTED

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES AND APPLY PRIOR TO FINISH.
125 MACH. SURF. ROUGHNESS
TOLERANCES ON ANGLES ± 0° 30'
DO NOT SCALE PRINT

CONT'R
DRN G DeFever DATE 1-..-87
CHK DATE
DSGN G DeFever
MATL
STRUCT
DESIGN ACTIVITY APVD DATE

Rockwell International Corporation
Rocketdyne Division
Canoga Park, California

SIDE PANELS, COLD AIR FLOW TEST FIXTURE

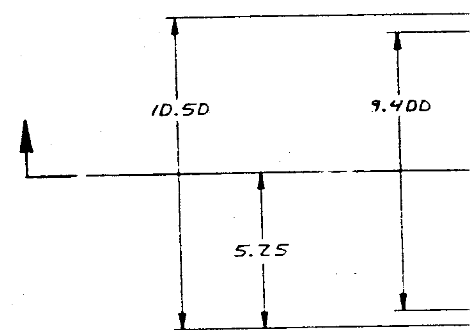
SIZE J | FSCM NO 02602 | DWG NO 7R0018471

SCALE HALF | SHEET

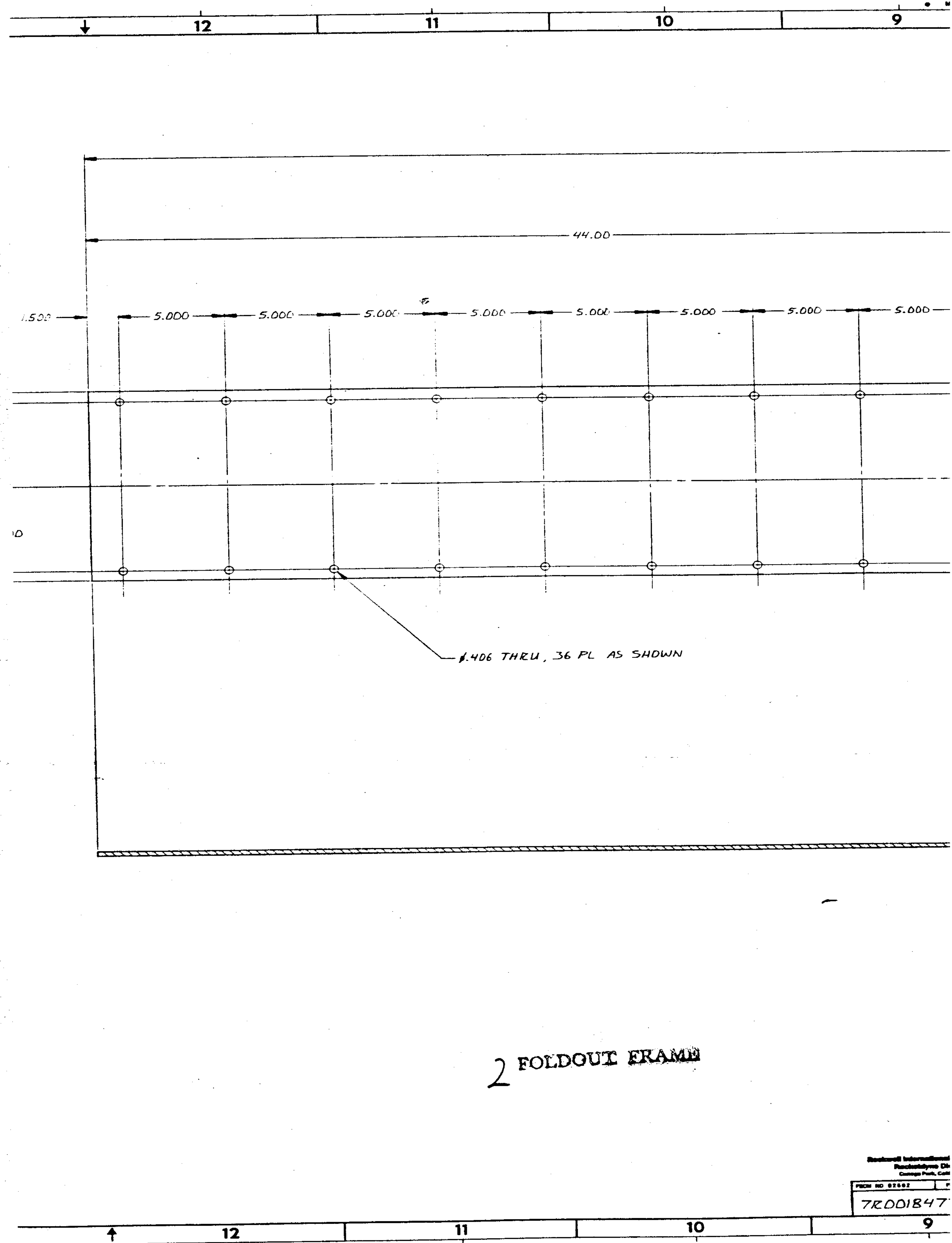
FRAME 2

DWG NO 7R0018471

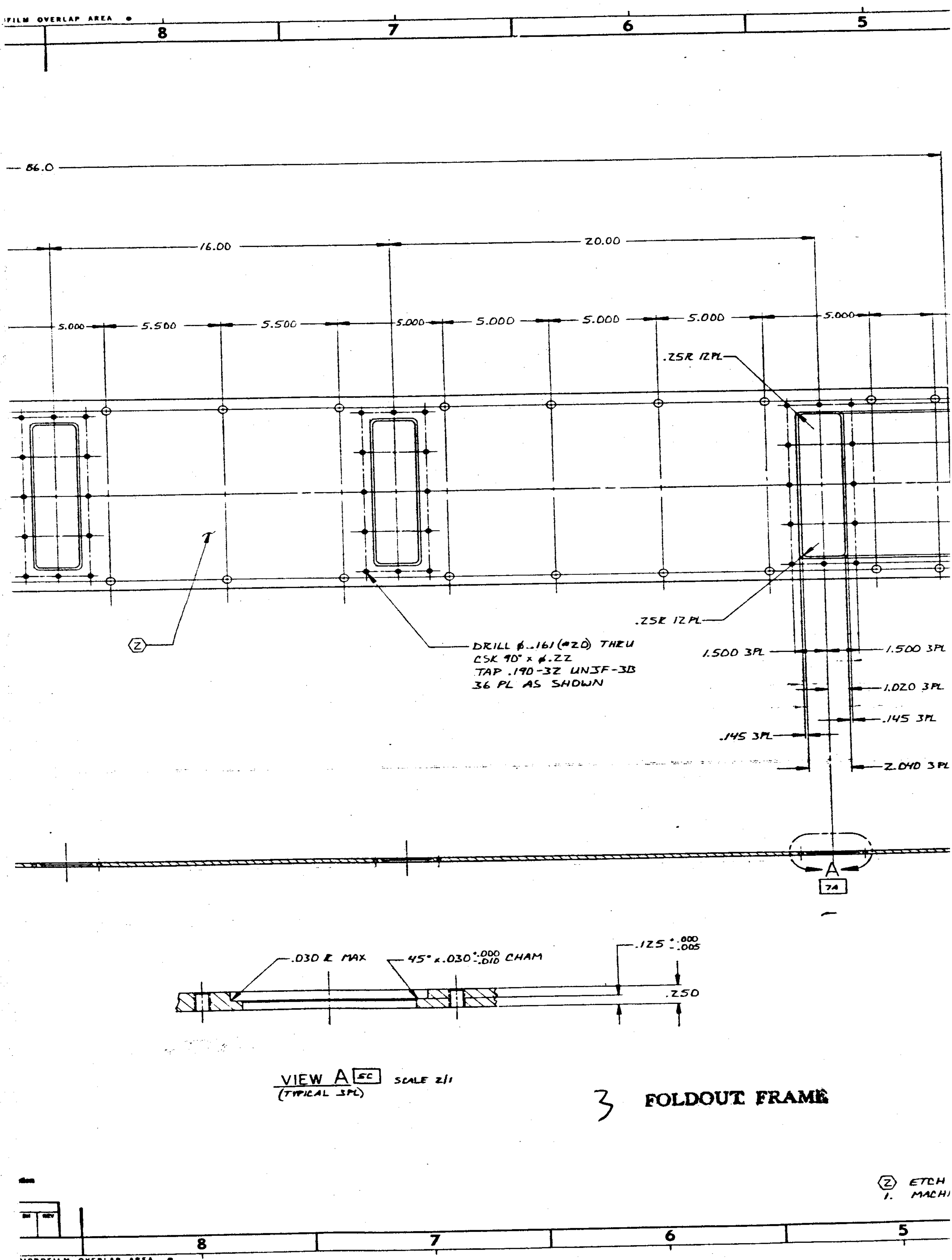
FORM NO. R130-H-8 REV. 7-7



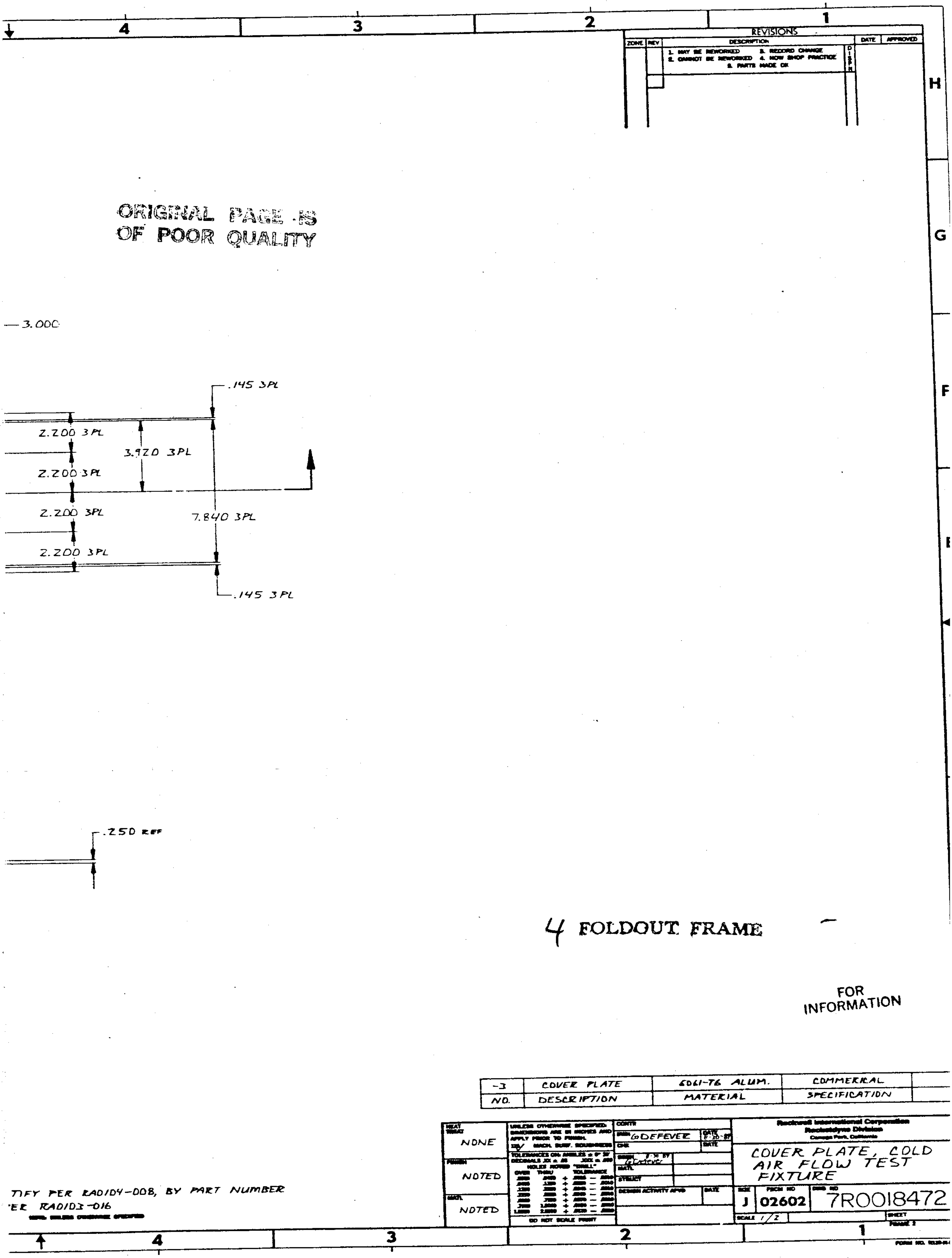
FOLDOUT FRAME

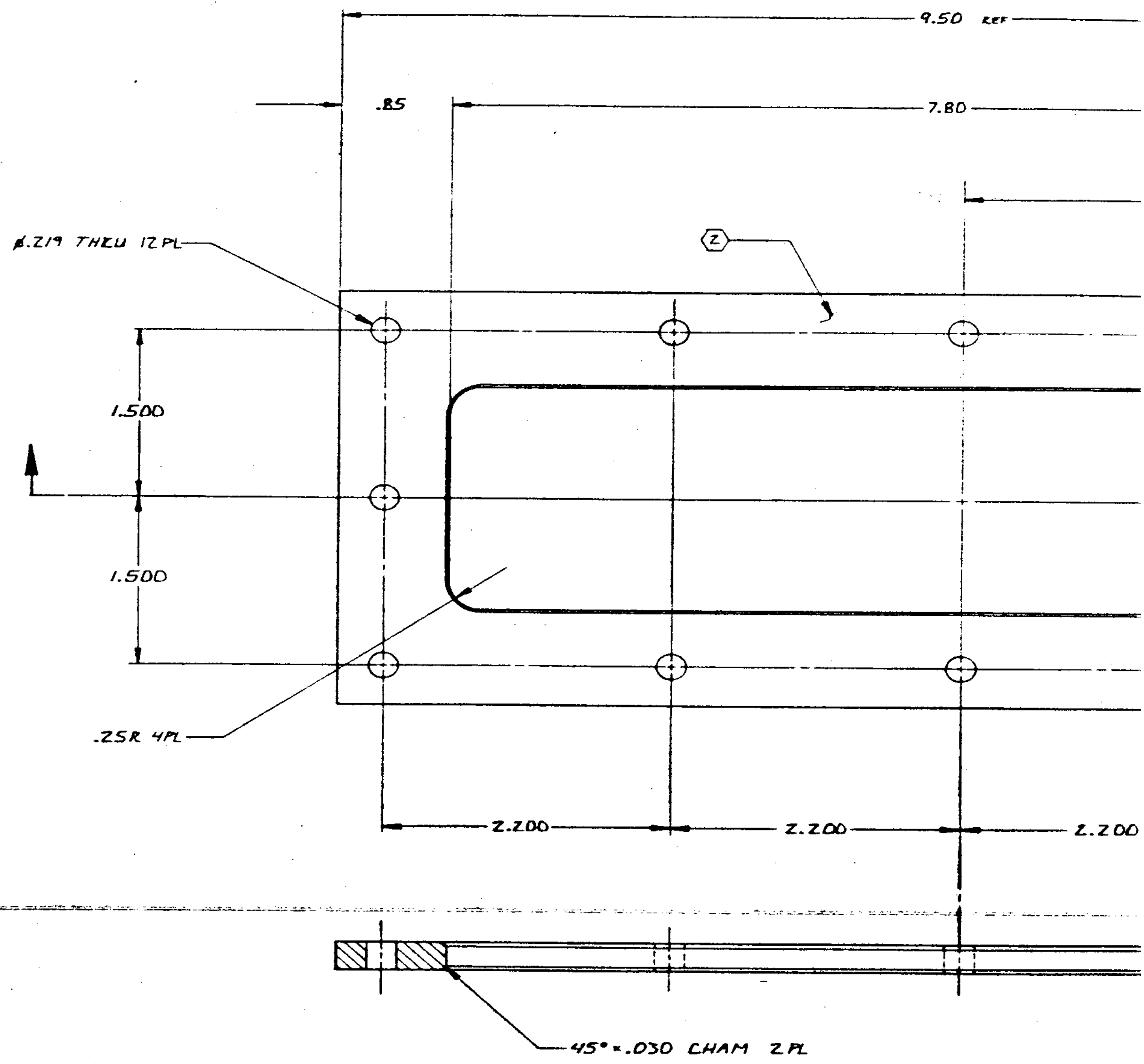


2 FOLDOUT FRAME



3 FOLDOUT FRAME

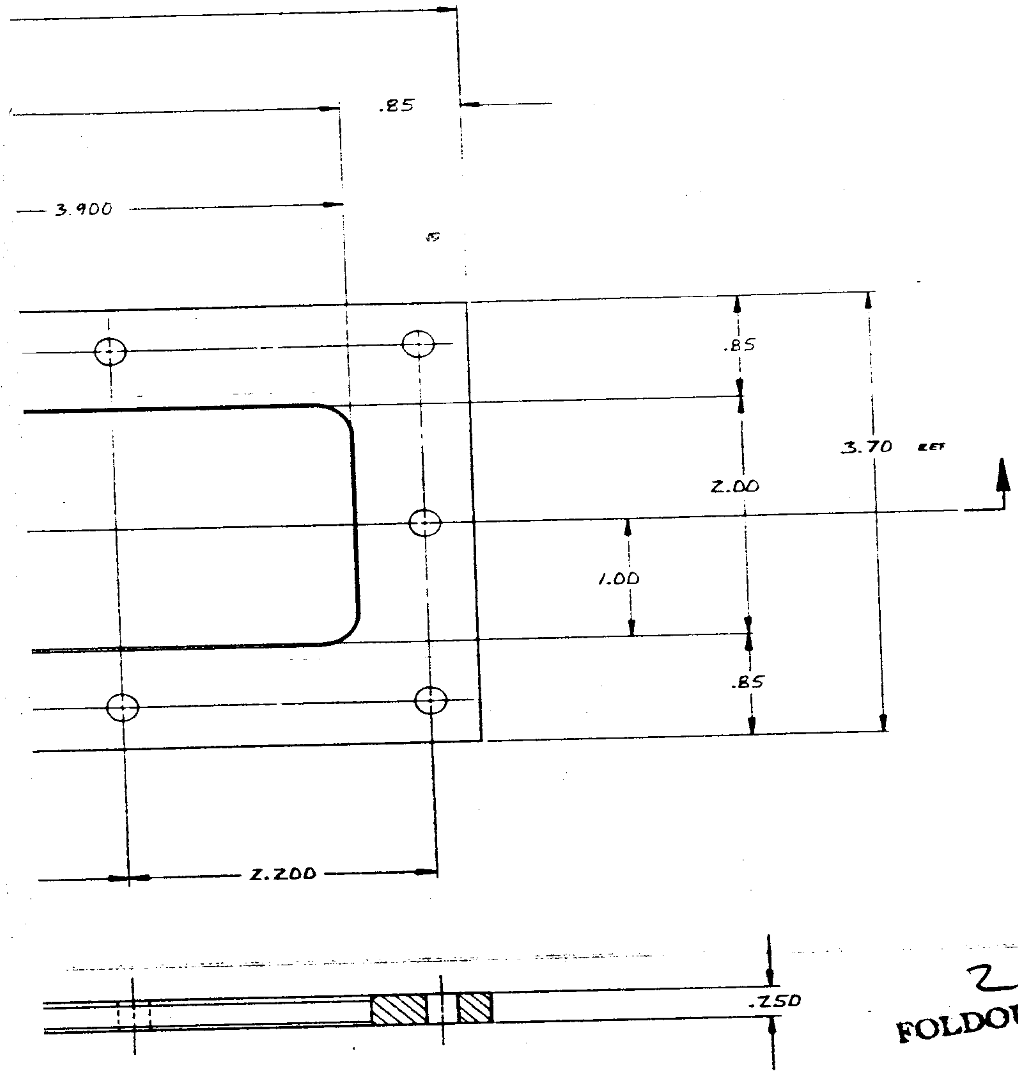

REVISIONS
ZONE
REV
DESCRIPTION
DATE
APPROVED
1. MAY BE REWORKED 3. RECORD CHANGE
2. CANNOT BE REWORKED 4. NOW SHOP PRACTICE
5. PARTS MADE OK
ORIGINAL PAGE IS OF POOR QUALITY
3.000
.145 3PL
2.200 3PL
3.920 3PL
2.200 3PL
2.200 3PL
7.840 3PL
2.200 3PL
.145 3PL
.250 REF
4 FOLDOUT FRAME
FOR INFORMATION
-3 COVER PLATE 6061-T6 ALUM. COMMERICAL
NO. DESCRIPTION MATERIAL SPECIFICATION
TIFY PER RA0104-008, BY PART NUMBER
ER RA0103-016
HEAT TREAT NONE
FINISH NOTED
MATL NOTED
DO NOT SCALE PRINT
G DEFEVER
Rockwell International Corporation
Rocketdyne Division
Canoga Park, California
COVER PLATE, COLD AIR FLOW TEST FIXTURE
SIZE J
FSCM NO 02602
DWG NO 7R0018472
SCALE 1/2



FOLDOUT FRAME

2 ETCH IDENTIFY
1. MACHINE PER

ZONE	REV	DESCRIPTION	DATE	APPROVED
		REVISIONS 1. MAY BE REWORKED 3. RECORD CHANGE 2. CANNOT BE REWORKED 4. NOW SHOP PRACTICE 5. PARTS MADE OK		



2
FOLDOUT FRAME

FOR INFORMATION

-3	WINDOW FRAME	6061-T6 ALUM	COMMERCIAL
NO.	DESCRIPTION	MATERIAL	SPECIFICATION

HEAT TREAT: NONE

FINISH: NONE

MKG.: NOTED

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES AND APPLY PRIOR TO FINISH. MACH. SURF. ROUGHNESS

DO NOT SCALE PRINT

DRN: G. DEFEVER

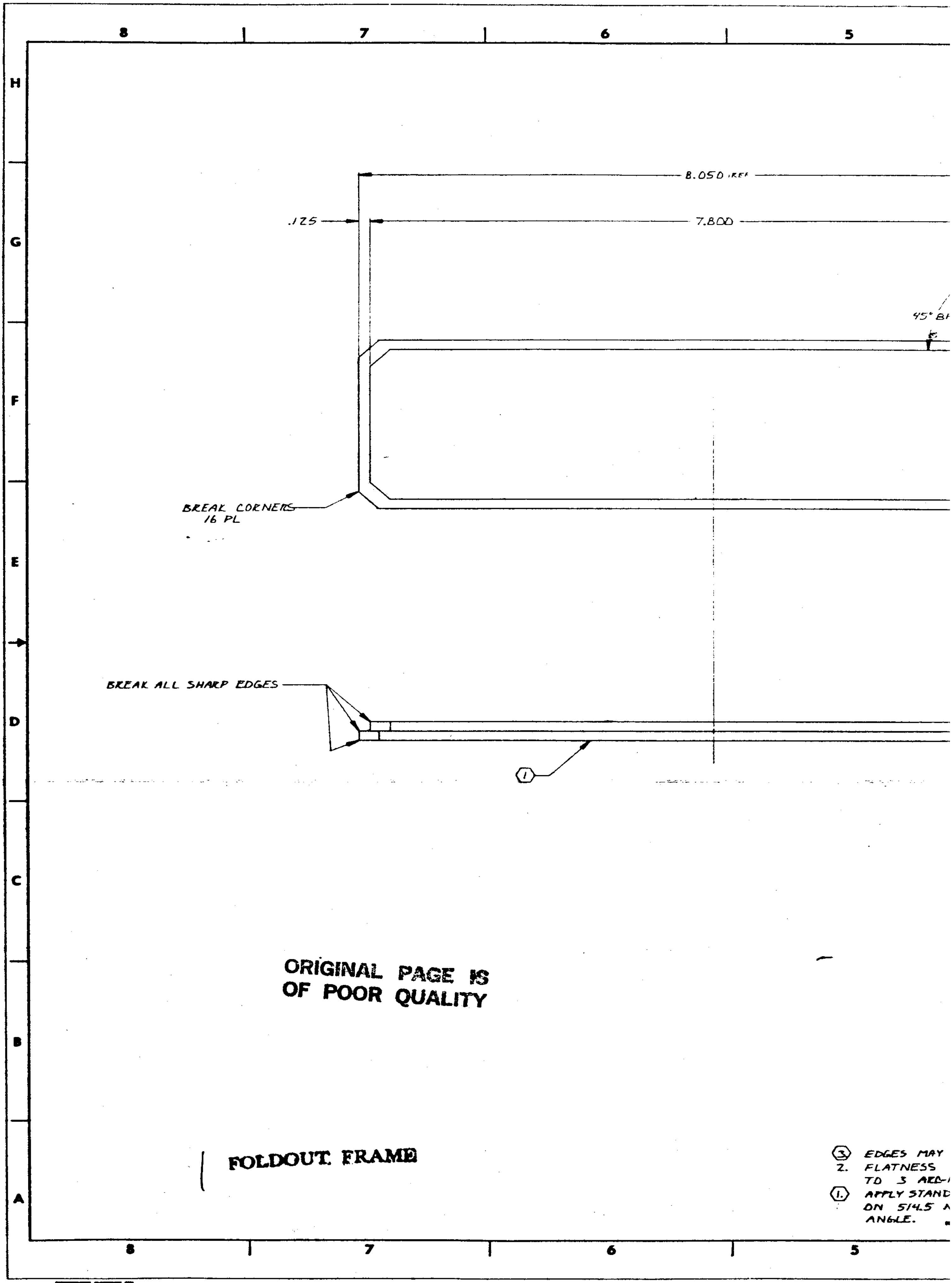
Rockwell International Corporation
Rocketdyne Division
Canoga Park, California

WINDOW FRAME, COLD AIR FLOW TEST FIXTURE

SIZE: E | FSCM NO: 02602 | DWG NO: 7R0018474

SCALE 2/1

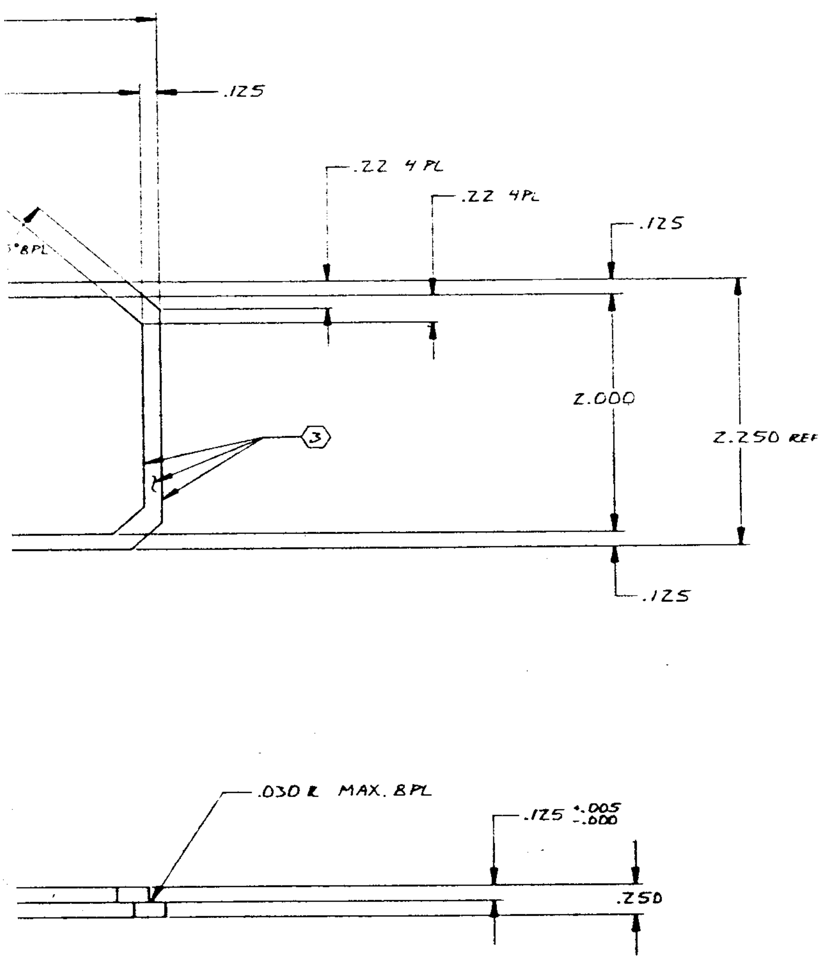
PER RA0104-008, BY PART NUMBER
RA0103-016
UNLESS OTHERWISE SPECIFIED



FOLDOUT FRAME

REVISIONS

ZONE	REV	DESCRIPTION	DATE	APPROVED
		1. MAY BE REWORKED 3. RECORD CHANGE 2. CANNOT BE REWORKED 4. NOW SHOP PRACTICE 5. PARTS MADE OK		



FOLDOUT FRAME

FOR INFORMATION

-3	WINDOW	STD. SILICON GLASS	——
NO.	DESCRIPTION	MATERIAL	SPECIFICATION

LEFT UNPOLISHED
1/4-WAVE PEAK TO PEAK; PARALLELISM
ATES (SINGLE SIDE, SHOWN)
BROADBAND ANTIREFLECTIVE COATING, CENTERED
METER WAVELENGTH (MULTILAYER); 0° INCIDENCE
LESS OTHERWISE SPECIFIED

HEAT TREAT: NONE
FINISH: NOTED
MATL: NOTED

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES AND APPLY PRIOR TO FINISH.
MACH. SURF. ROUGHNESS
TOLERANCES ON: ANGLES ± 0° 30' DECIMALS .XX ± .03 .XXX ± .010
DO NOT SCALE PRINT

DWN: G DEFEVER
DSGN: G DEFEVER

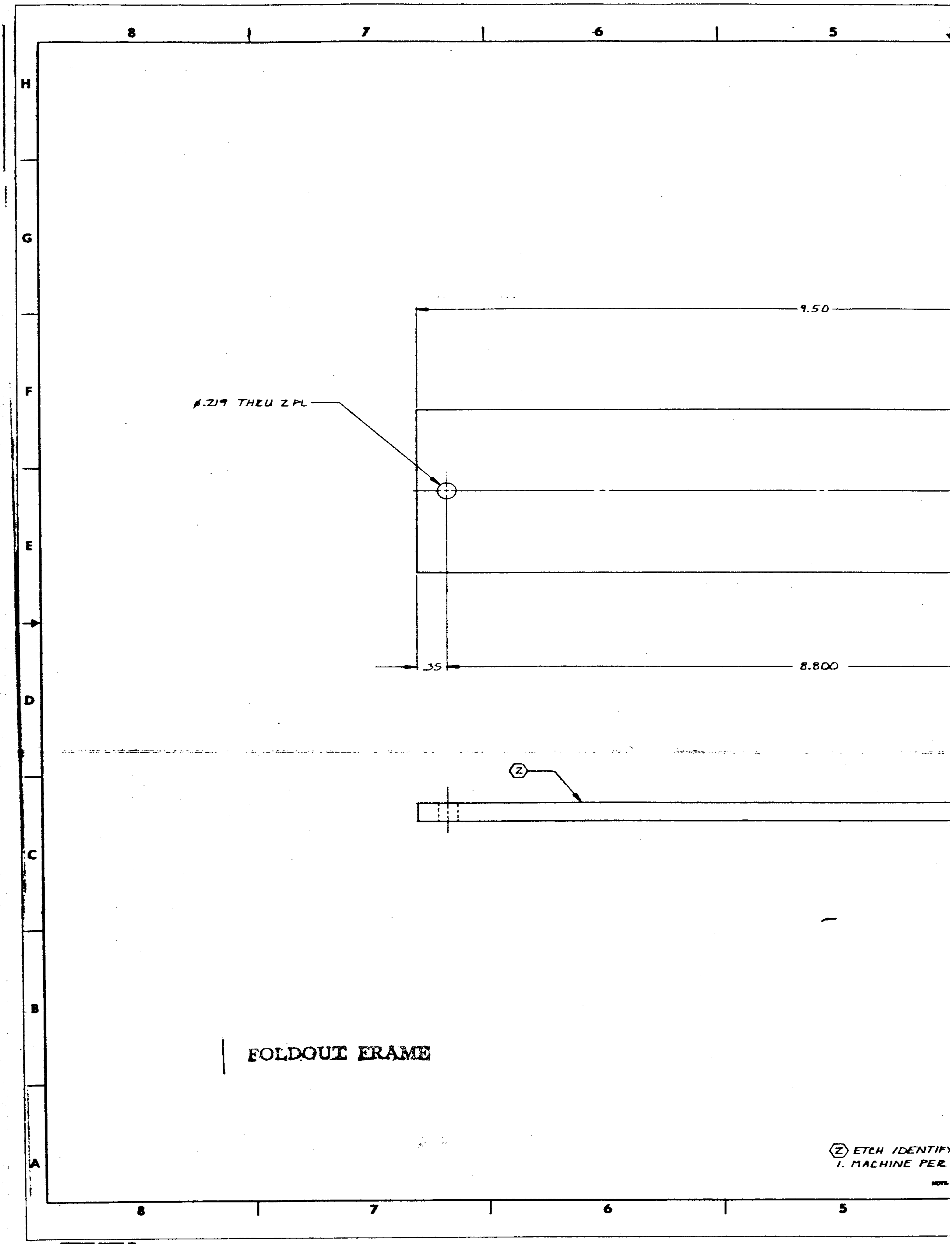
Rockwell International Corporation
Rocketdyne Division
Canoga Park, California

WINDOW, COLD AIR FLOW TEST FIXTURE

SIZE: E | FSCM NO: 02602 | DWG NO: 7R0018473

SCALE 2/1

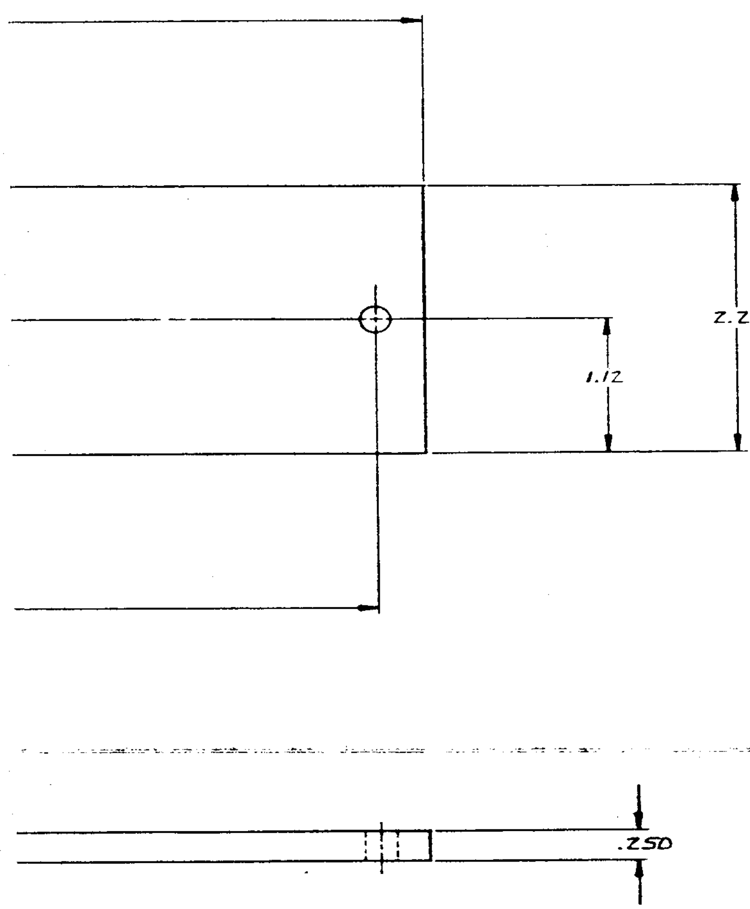
7R0018473



FOLDOUT FRAME

REVISIONS

ZONE	REV	DESCRIPTION	DISP	DATE	APPROVED
		1. MAY BE REWORKED 3. RECORD CHANGE 2. CANNOT BE REWORKED 4. NOW SHOP PRACTICE 5. PARTS MADE OK			



FOLDOUT FRAME 2

FOR INFORMATION

-3	WINDOW COVER	6061-T6 ALUM	COMMERCIAL	
NO.	DESCRIPTION	MATERIAL	SPECIFICATION	

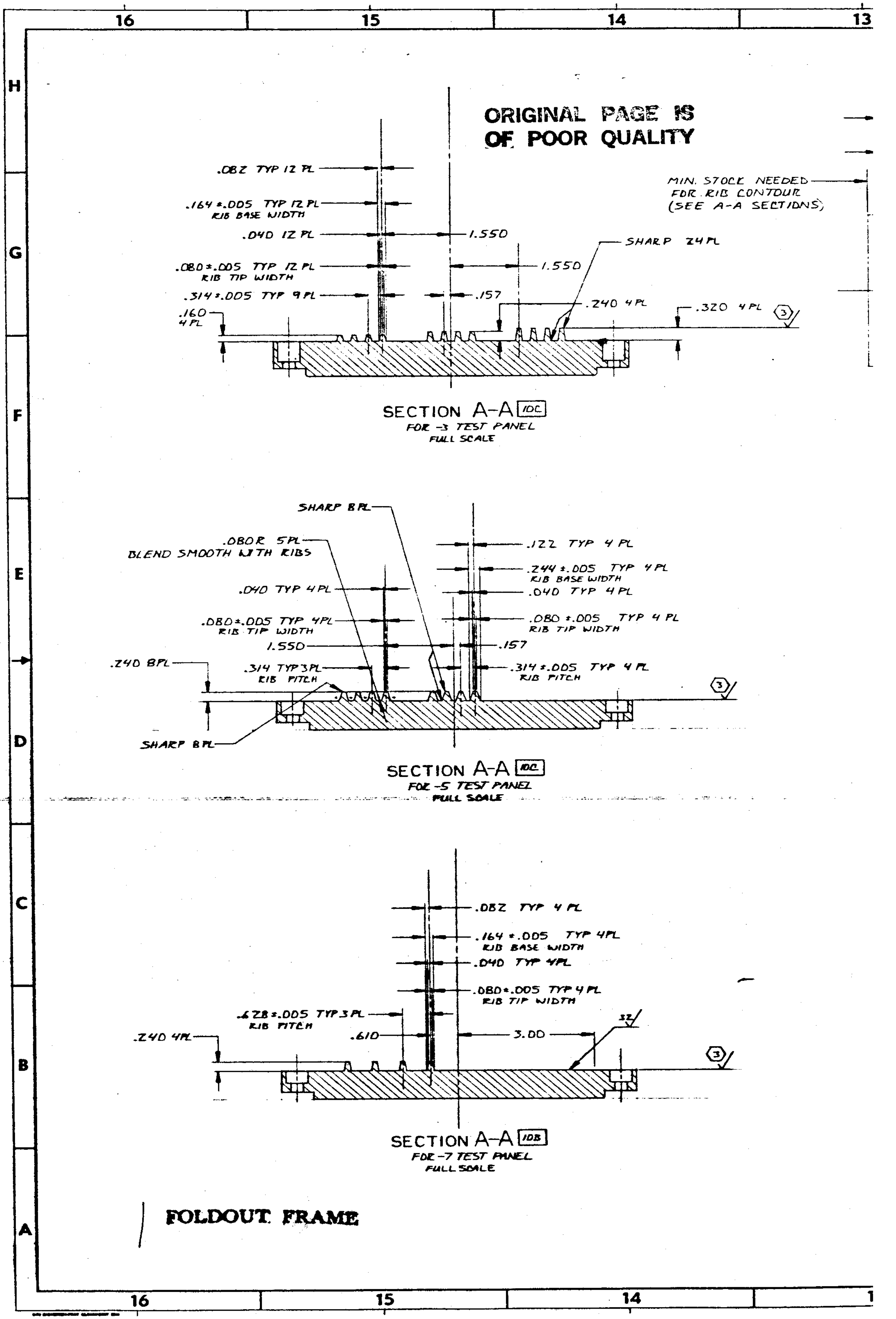
7R0018475

…E RA0104-008, BY PART NUMBER
…103-016

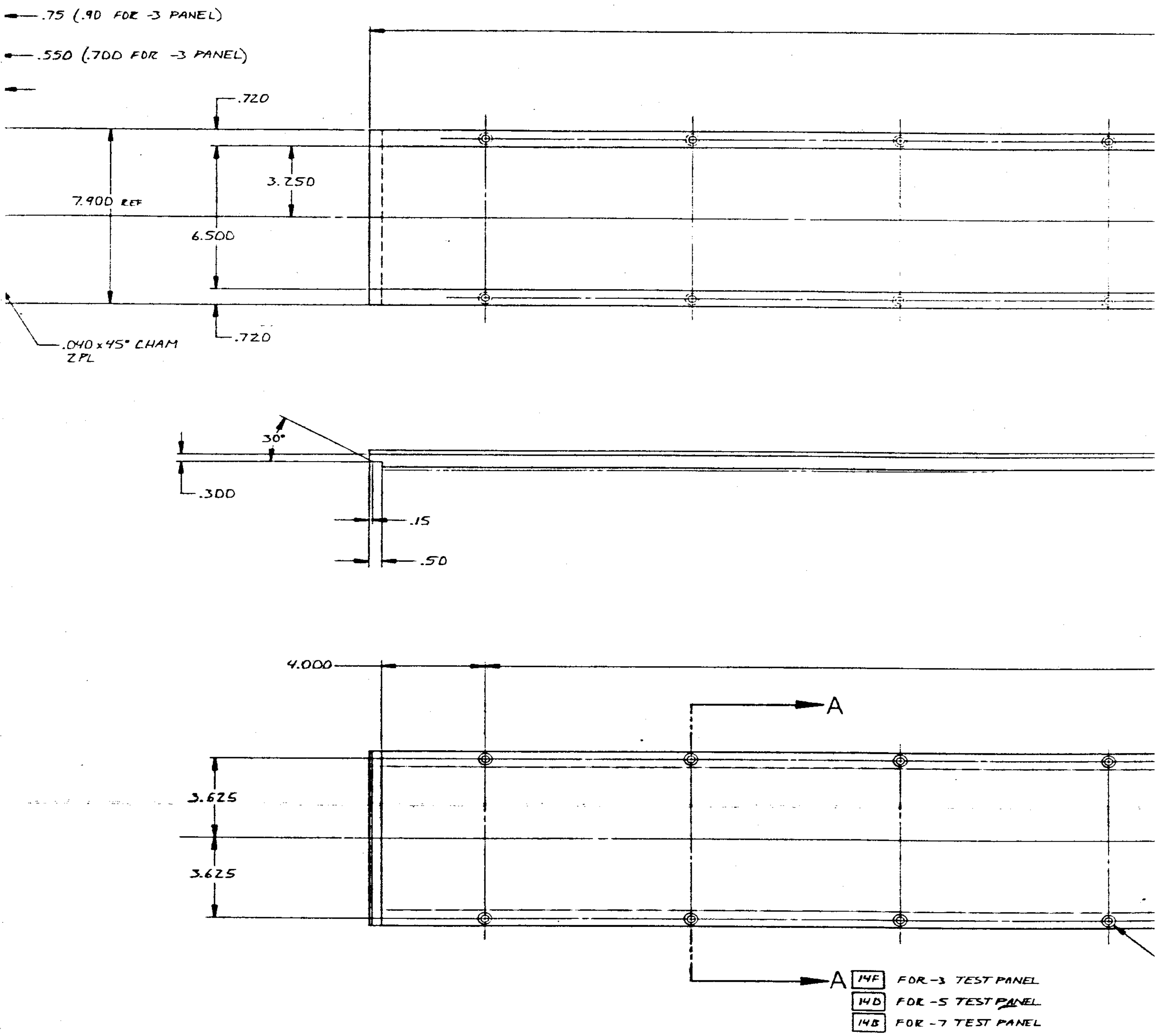
…OTHERWISE SPECIFIED

HEAT TREAT: NONE	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES AND APPLY PRIOR TO FINISH. MACH. SURF. ROUGHNESS	CONTR DWN GoDEFE VER DATE CHK DATE DSGN GoDEFE MATL STRUCT	Rockwell International Corporation Rocketdyne Division Canoga Park, California
FINISH: NONE	TOLERANCES ON: ANGLES ± DECIMALS .XX ± .XXX ± HOLES NOTED "DRILL"	DESIGN ACTIVITY APVD DATE	WINDOW COVER, COLD AIR FLOW TEST FIXTURE
MATL: NOTED	DO NOT SCALE PRINT		SIZE E FSCM NO 02602 DWG NO 7R0018475 SCALE SHEET

ORIGINAL PAGE IS OF POOR QUALITY



FOLDOUT FRAME

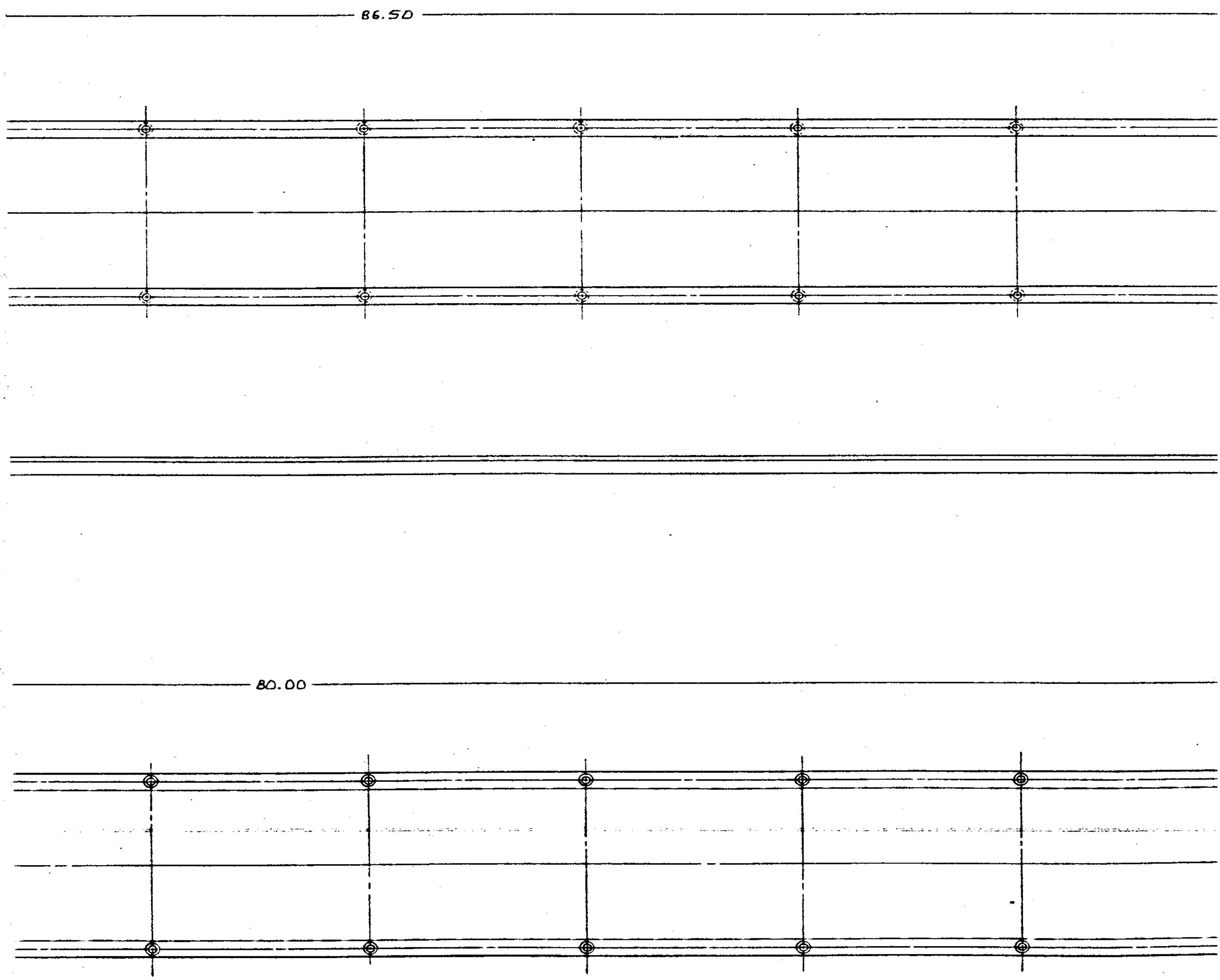


2 FOLDOUT FRAME

Rockwell International Cor
Rocketdyne Divisio
Canoga Park, California
FSCM NO 02602
7R0D1B476

ROFILM OVERLAP AREA

8 | 7 | 6 | 5



ϕ.281 THRU
CBORE ϕ .500 .32 DEEP (.47 DEEP FOR -3 PANEL)
22 PL (11 PL EQ SP ON
80.00, EACH SIDE)

-3
-5
-7
TEST PANELS
(1/2 SCALE)

3 FOLDOUT FRAME

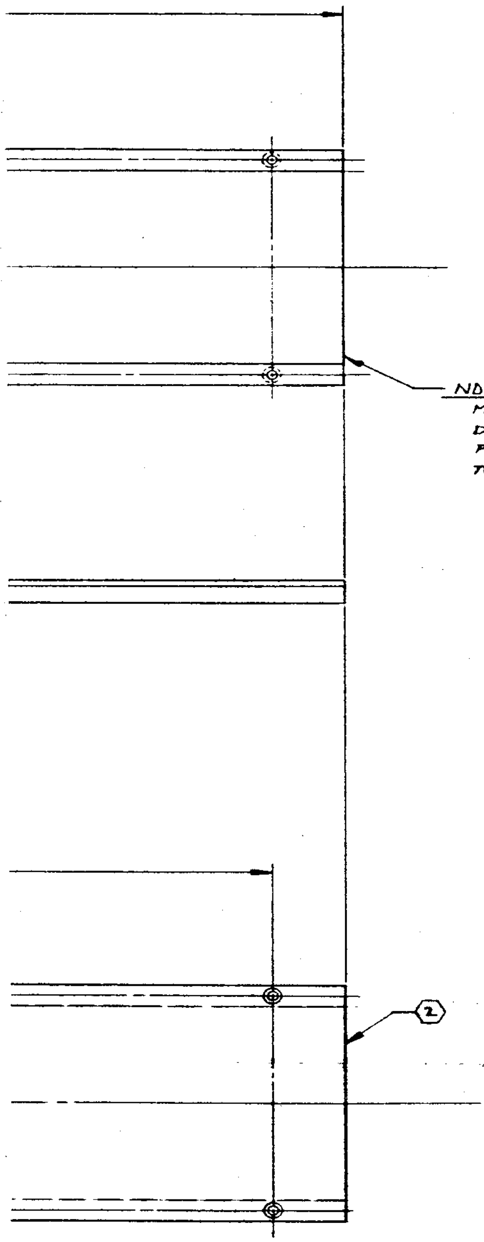
5 CH
TY
4. CA
EI
3 EN
FR
FO
2 ID
1. MA

REV

8 | 7 | 6 | 5

ROFILM OVERLAP AREA

ZONE	REV	DESCRIPTION	DATE	APPROVED
		1. MAY BE REWORKED 2. CANNOT BE REWORKED 3. RECORD CHANGE 4. NOW SHOP PRACTICE 5. PARTS MADE OK		
	A			
7H		86.50 WAS 84.50		
3F		ADDED NOTE ON FABRICATION		
12E		DELETE .250, ADDED .300		
13H		ADDED (.700 FOR -3 PANEL)		
13H		ADDED (.90 FOR -3 PANEL)		
12G		7.900 REF WAS 7.940 REF		
8B		ADDED (.47 DEEP FOR -3 PANEL)	1-8-85	



NOTE ON FABRICATION:
MFR. ADDED 2.00 (BOLTED) TO STOCK DUE TO SHORT RAW MATL. ORDERED PER BAD DIMENSION (84.50 CHANGED TO 86.50). ALL 3 PANELS.
— G. DeFever 1-8-85

ORIGINAL PAGE IS OF POOR QUALITY

4 FOLDOUT FRAME

FOR INFORMATION

-7	TEST PANEL	6061-T6 ALUM.	COMMERCIAL	9B
-5	TEST PANEL	6061-T6 ALUM.	COMMERCIAL	9B
-3	TEST PANEL	6061-T6 ALUM.	COMMERCIAL	9B
NO.	DESCRIPTION	MATERIAL	SPECIFICATION	ZN

K ACID ANODIZE (BLACK) PER RA0104-021,
I. COLOR AND FINISH ONLY PER PRZ-10.
N - CRITICAL TEST ITEM - PROTECT FINISHED
RFACES FROM DAMAGE.
RIBBED SURFACES FOR 84-INCH LENGTH TO BE
OF NICKS SCRATCHES OR IMPERFECTIONS - CRITICAL
OUNDRY LAYER FLOW TESTING.
FY PER RA0104-008, IMPRESSION STAMP
E PER RA0103-016
NOTE: UNLESS OTHERWISE SPECIFIED

HEAT TREAT: NONE
FINISH: NOTED
MATL: NOTED

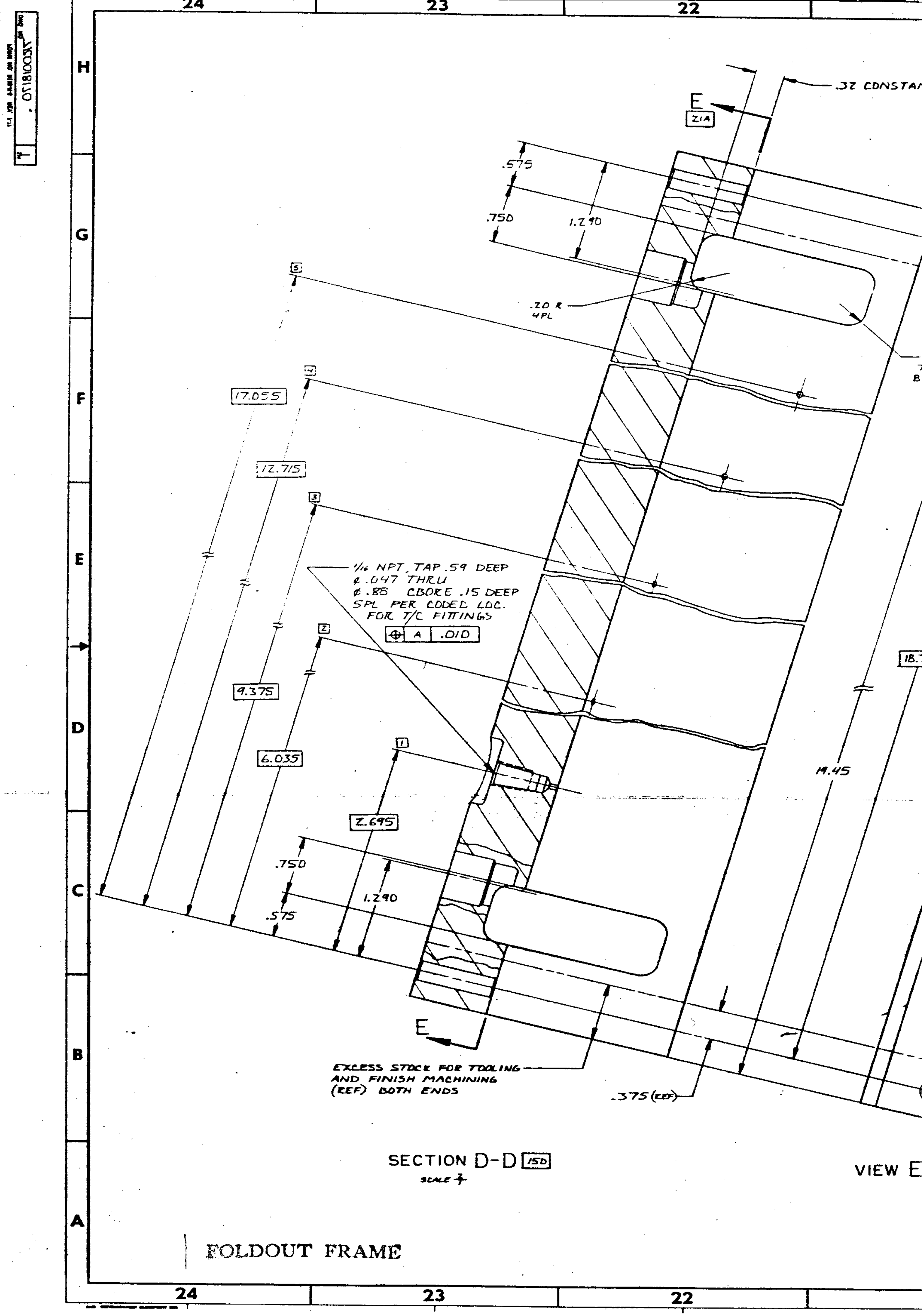
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES AND APPLY PRIOR TO FINISH. 125 MACH. SURF. ROUGHNESS
DO NOT SCALE PRINT

DWN G. DEFEVER DATE 8-?-84
DESIGN G. DeFever

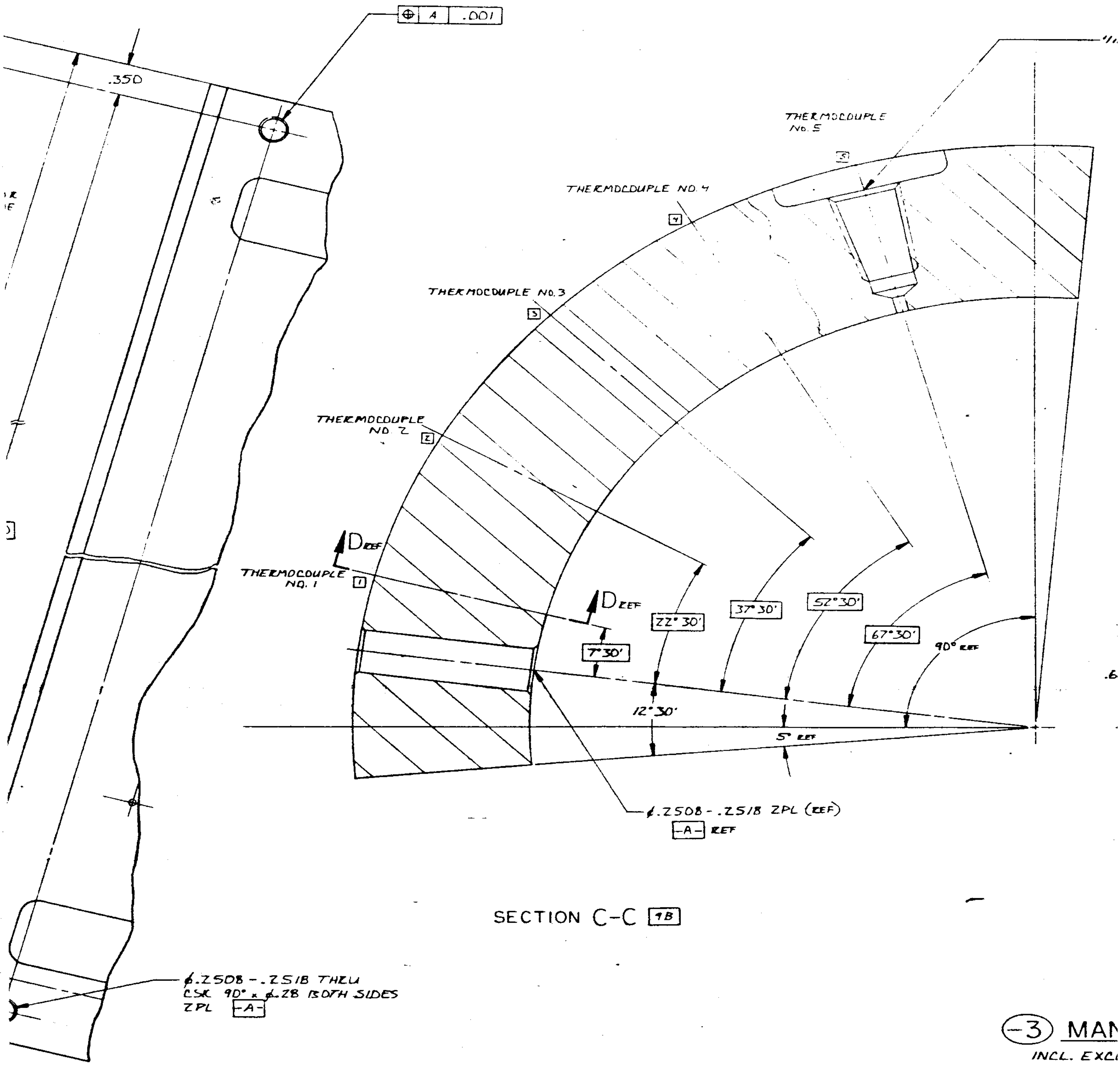
Rockwell International Corporation
Rocketdyne Division
Canoga Park, California

TEST PANELS, COLD AIR FLOW TEST FIXTURE

SIZE J | FSCM NO 02602 | DWG NO 7R0018476
SCALE 1/2
FRAME 2



24
23
22
H
G
F
E
D
C
B
A
.32 CONSTAN
E
21A
.575
.750
1.290
.20 R
4PL
5
4
3
2
1
17.055
12.715
9.375
6.035
2.695
1/16 NPT, TAP .59 DEEP
⌀ .047 THRU
⌀ .88 CBORE .15 DEEP
SPL PER CODED LOC.
FOR T/C FITTINGS
A .010
18.
19.45
.750
1.290
.575
E
EXCESS STOCK FOR TOOLING
AND FINISH MACHINING
(REF) BOTH ENDS
.375 (REF)
SECTION D-D 15D
VIEW E
FOLDOUT FRAME



SECTION C-C 1B

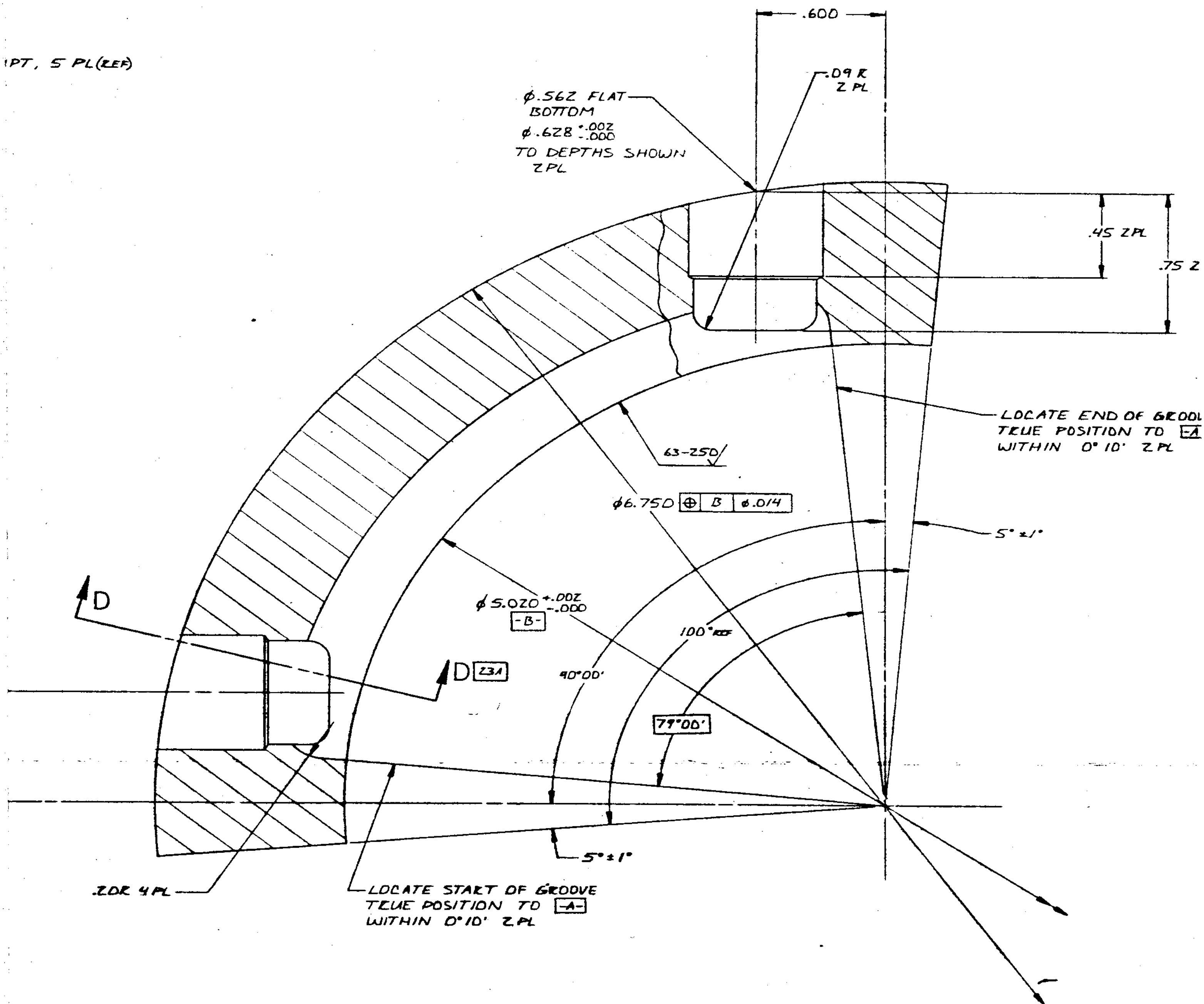
(-3) MAN
INCL. EXC
TOOLING

E 22H

FOLDOUT FRAME

7R001817

IPT, 5 PL(REF)



SECTION B-B 9F

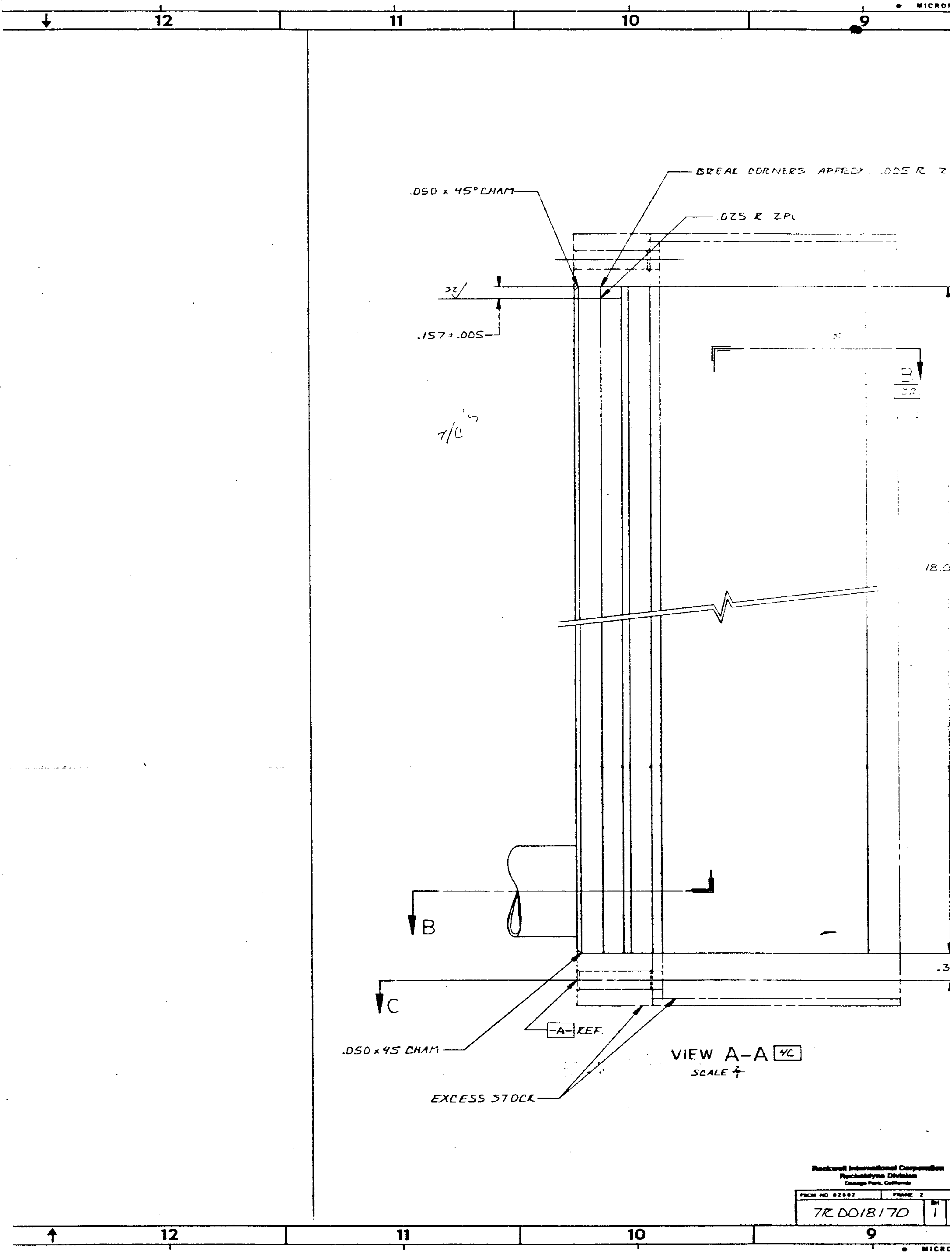
-3 PRE-ASSY DETAIL
FOR LINER DETAIL (-7 THRU -25) SEE SHEET 2

SCALE 4/1

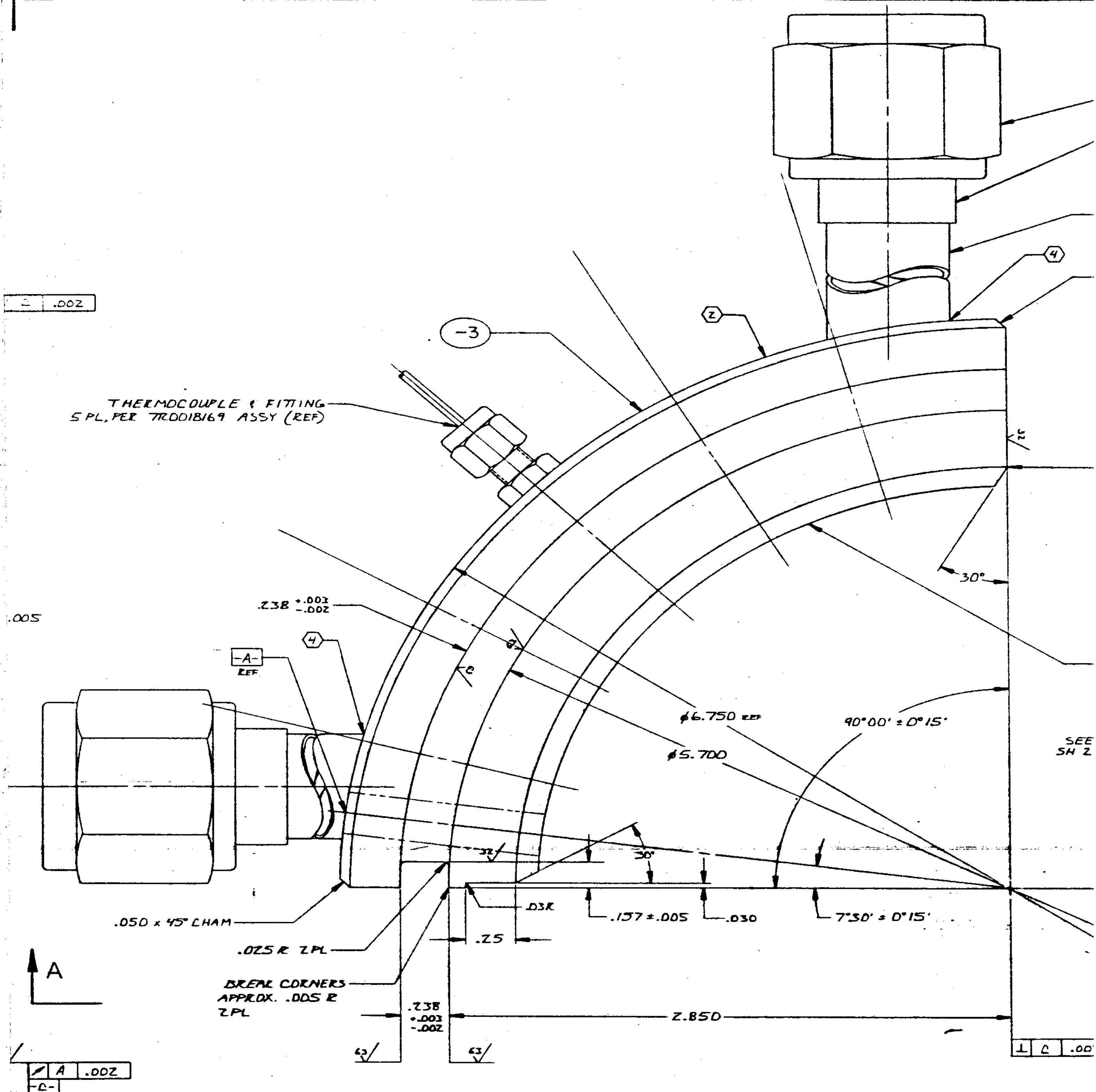
OLD

STOCK FOR
IISH MACHINING

FOLDOUT FRAME



12
11
10
9
BREAK CORNERS APPROX .005 R 2
.050 x 45° CHAM
.025 R 2PL
32
.157±.005
18.0
B
C
-A- REF.
.050 x 45 CHAM
VIEW A-A 4C
SCALE 2/1
EXCESS STOCK
Rockwell International Corporation
Rocketdyne Division
Canoga Park, California
FSCM NO 02602
FRAME 2
7R0018170
SH 1



TOP VIEW
SCALE 4

4 **FOLDOUT FRAME**

(-11) PANEL ASSY — FINISHED DIMENSIONS
TYPICAL FOR -11, -21, -31, -41, -51, -61, -71, -81 SUBASSY'S

6. ALLOWABLE ALTERNATE :
ASTM A632.
5. ø.625 x .035 W.T. x 6.5
4. BRAZE PER RADI07-DIC
3. DATUM FROM -3 TO B
2. ETCH IDENTIFY PER
1 MACHINE PER RADIO3

4	3	2	1

REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED
		1. MAY BE REWORKED 3. RECORD CHANGE 2. CANNOT BE REWORKED 4. NOW SHOP PRACTICE 5. PARTS MADE OK		

(-27) 2 REQD, PER ASSY 7R0018169

(-29) 2 REQD, PER ASSY 7R0018169

5) 2 REQD, PER ASSY 7R0018169 (5)
FLARE TUBE END
PER MS33584

)50 x 45° CHAM

ORIGINAL PAGE IS
OF POOR QUALITY

(-7) Cu LINER FOR -11 SUBASSY
(-9) Cu LINER FOR -21 SUBASSY
(-13) Cu LINER FOR -31 SUBASSY
(-15) Cu LINER FOR -41 SUBASSY
(-17) Cu LINER FOR -51 SUBASSY
(-19) Cu LINER FOR -61 SUBASSY
(-23) Cu LINER FOR -71 SUBASSY
(-25) CU LINER FOR -81 SUBASSY

L | C | .002

FOLDOUT FRAME

A [9B]

FOR
INFORMATION

SUB-ASSY
-81
-71
-61
-51
-41
-31
-21
-11

NO.	DESCRIPTION	MATERIAL	SPECIFICATION	ZONE
-29	SLEEVE	CRES	MS20819-10J	4H
-27	B-NUT	CRES	AN818-10J	4H
-25	Cu LINER	OFHC COPPER	QQ-C-576	21A SH 2
-23				
-19				
-17				
-15				
-13				
-9				
-7	Cu LINER	OFHC COPPER	QQ-C-576	21A SH 2
(6) -5	COOLANT TUBE	347 CRES (5)	MIL-T-8808 TYPE II	4G
(6) -3	MANIFOLD	347 CRES	QQ-S-763, COND A	17B

', 316 or 347 CRES PER
6
ID M&P INSTRUCTIONS.
ACHINED AFTER BRAZE ASSY.
)4-008 AS INDICATED.
.
...ESS OTHERWISE SPECIFIED

HEAT TREAT	NONE
FINISH	NONE
MATL	NOTED

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES AND APPLY PRIOR TO FINISH.
125/ MACH. SURF. ROUGHNESS
TOLERANCES ON: ANGLES ± 0° 30' DECIMALS .XX ± .03 .XXX ± .010
HOLES NOTED "DRILL" OVER THRU TOLERANCE
DO NOT SCALE PRINT

CONTR
DWN G DEFEVER DATE 4-6-84
CHK DATE
DSGN G DeFever 4-6-84
MATL
STRUCT
DESIGN ACTIVITY APVD DATE

Rockwell International Corporation
Rocketdyne Division
Canoga Park, California

HOT AIR TEST
PANELS, ASSY OF

SIZE J | FSCM NO 02602 | DWG NO 7R0018170
SCALE NOTED | SHEET 1 of 2
FRAME 3

DWG NO 7R0018170

4	3	2	1

FORM NO. R1310-H-6 REV. 7-77

TEST PLAN FOR COLD FLOW OF ADVANCED COMBUSTOR WALL GEOMETRIES

The following describes planned testing to be conducted in the Rocketdyne Experimental Development Laboratory (EDL). The testing is being conducted as part of Contract NAS3-23773 Enhanced Heat Transfer Combustor Technology, with NASA Lewis Research Center.

SUMMARY

An 80 inch long air-flow chamber will be fabricated and supplied to the EDL for testing. The chamber assembly will stand vertically, and be rigidly mounted to a structural beam to be supplied by the EDL. The chamber assembly will consist of 2 side pieces, a windowed cover plate, and 5 removable test panels (see drawing). Test data will be collected using Laser Velocimeter equipment, to be supplied by the Rocketdyne Turbomachinery Group. (ref. Tom Ferguson). Tests will be conducted in the "helium shack" area of the EDL, utilizing the large Spencer blower located there. Schematics of the test set-up are shown in Figure 1.

TEST PLAN

Two test series are planned in an effort to map the boundry layer flow field about 6 different rib shapes and 8 channel shapes, on five interchangable test panels. These test series are shown in Tables 1 and 2. Finalized testing matrix will be determined after flat plate calibration and analysis has been completed. Total number of test points and test velocity ranges will depend significantly on data aquisition rate and quality of data.

Test data aquisition will be accomplished utilizing the Laser Velocimeter. Facility preparation, calibration and testing will be conducted per the schedule presented in Figure 2. Instrumentation requirements are listed in Table 2. Some flow measurements may be acquired from instrumentation already a part of the Spencer blower assembly. This will be determined during facility preparation.

All test data in the test series will be acquired at steady-state flow conditions. Parameters required to monitor the facility test set-up during testing will be displayed on digital read-out and recorded periodically during data aquisition.

Actual testing will consist of relatively long steady state air flow runs for data collection. Length of individual test runs will depend on factors such as particle density and distribution within the boundary layer and will be better known after initial calibration tests.

Once the apparatus is assembled, calibrated and the running of matrix tests is initiated, the use of a lab technician full time may not be necessary. Start-up, shut-down, and test panel changes will be the only major lab tasks during the data collection phase.

TABLE 1
PRELIMINARY TEST MATRIX - COLD FLOW TESTS OF
HOT GAS WALL RIBS

TEST SERIES 1:

RIB PATTERN	WINDOW POSITION (IN)	VELOCITY (~~lb~~ ft/sec)	PRESSURE (psig)	TEMPERATURE (F)	COMMENTS
Smooth	80	300	Ambient	Ambient	Checkout & Baseline
			"	"	"
	60	"	"	"	"
	44	"	"	"	"
1	80	300	Ambient	Ambient on Pattern	Velocity Profile
	60	"	"	"	"
	44	"	"	"	"
2	80	300	Ambient	Ambient on Pattern	Velocity Profile
	60	"	"	"	"
	44	"	"	"	"
3	80	300	Ambient	Ambient on Pattern	Velocity Profile
	60	"	"	"	"
	44	"	"	"	"
4	80	300	Ambient	Ambient on Pattern	Velocity Profile
	60	"	"	"	"
	44	"			"
5	80	300	Ambient	Ambient on Pattern	Velocity Profile
	60	"	"	"	"
	44	"	"	"	"
6	80	300	Ambient	Ambient on Pattern	Velocity Profile
	60	"	"	"	"
	44	"	"	"	"

1943/d

1943/d

A typical test day would consist of the following:

1. Start-up of blower and velocimeter equipment.

2. Monitor flow conditions and manually adjust flow to set required flow velocity for test.

3. Record velocimeter data on boundary layer and flow conditions for as many points as time allows.

4. Shut-down of blower and velocimeter equipment.

5. Process data acquired-check content, quality; plan next tests.

Monitoring of test conditions and data collection will be accomplished by engineering personnel.

A drawing of the test fixture hardware assembly is included as figure 3. Assembly of the fixture will be directly to an upright beam secured firmly to the floor. Rigidity of the test assembly is important to the acquisition of accurate data with the velocimeter. Location of the test fixture with respect to the blower and test area will be such that in the event of a priority need for the blower facility during the course of these tests, the air flow piping can be readily moved. This would eliminate any need to disassemble or move the panel test fixture during the testing program, minimizing impact on test schedule should such a need arise.

G.J. Defever
Member of the Technical Staff
Advanced Combustion Devices

GJD:kw
2164/d

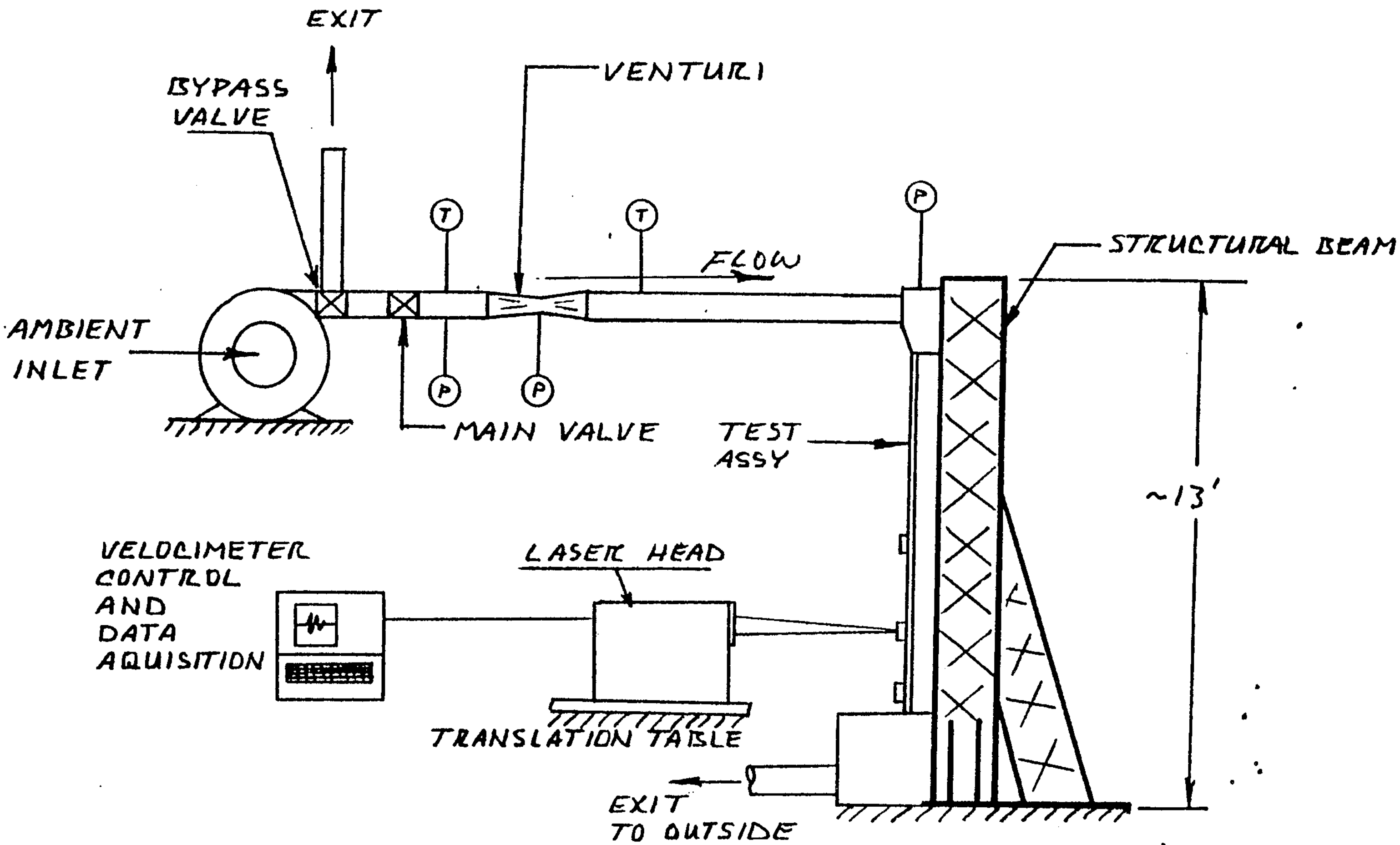


FIGURE 1. COLD FLOW TEST APPARATUS

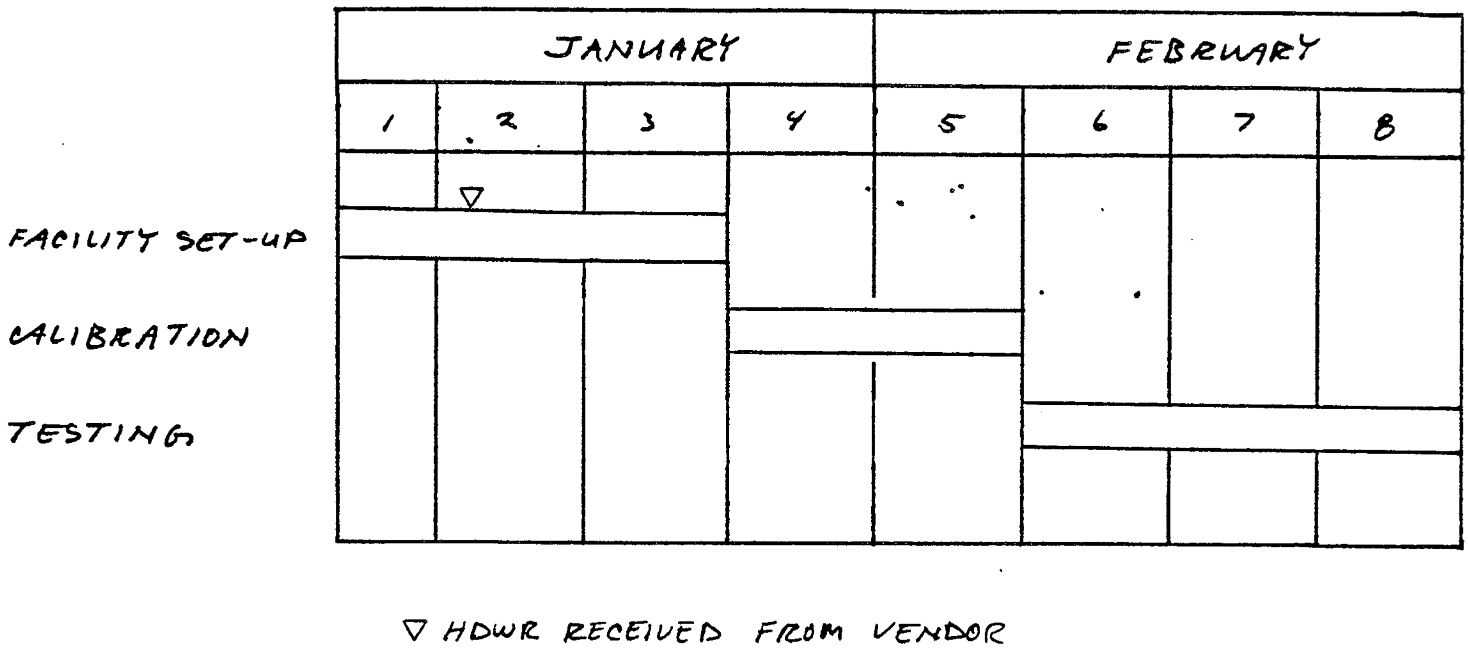


FIGURE 2.

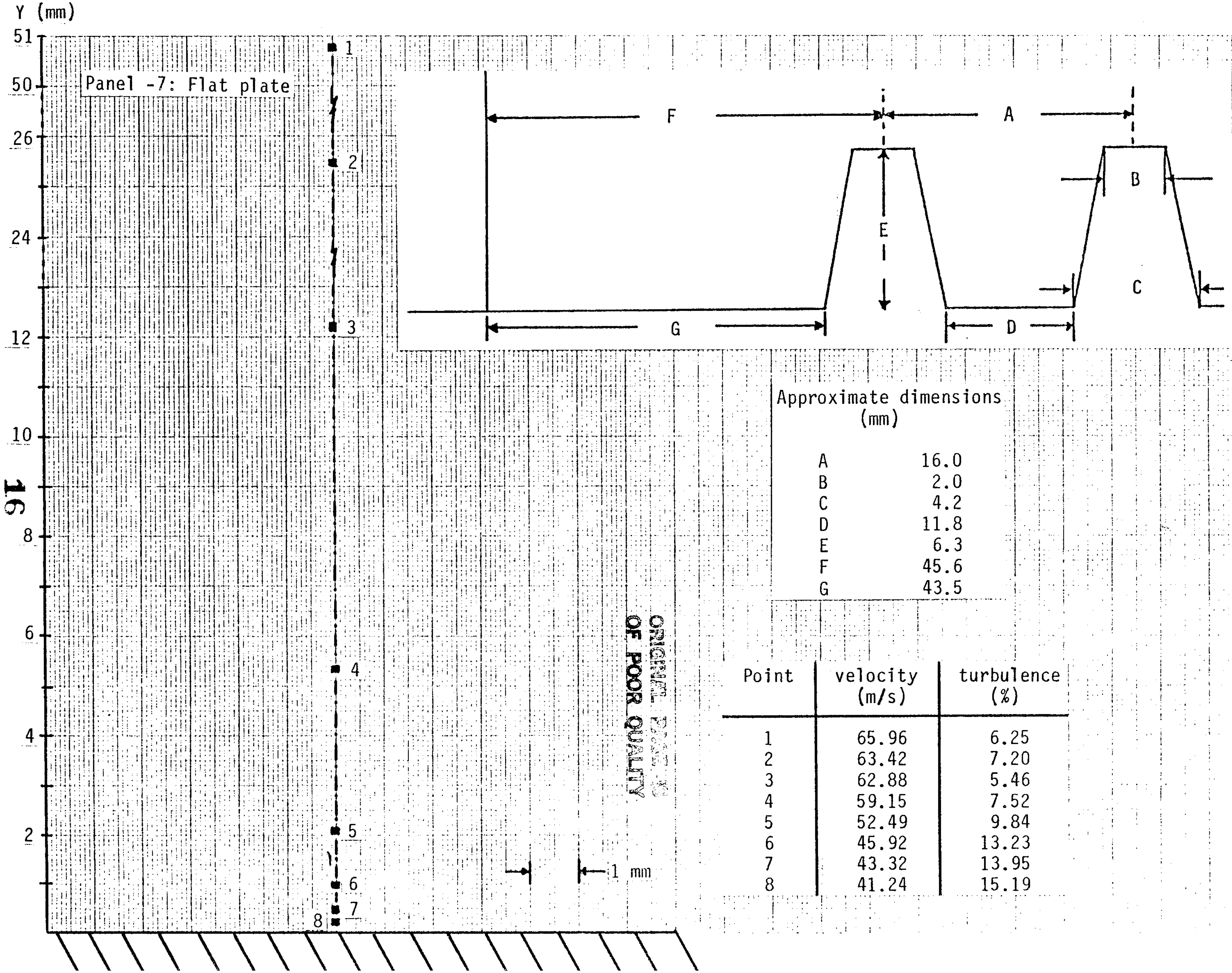
SCHEDULE, COLD AIR FLOW TESTING

TABLE 3

INSTRUMENTATION LIST - COLD FLOW TESTS

PARAMETER	NUMBER REQ'D	RANGE		DIGITAL DISPLAY
VALVE DISCH PRESS	1	0-50 PSIG		X
VENTURI THROAT PRESS	1	0-50 PSIG		X
MANIFOLD UPSTREAM PRESS	1	0-100 PSIG		X
MANIFOLD PRESS	1	0-100 PSIG		
VENTURI INLET TEMP	1	0-150 F	T/C	
MANIFOLD INLET TEMP	1	0-150 F	T/C	X

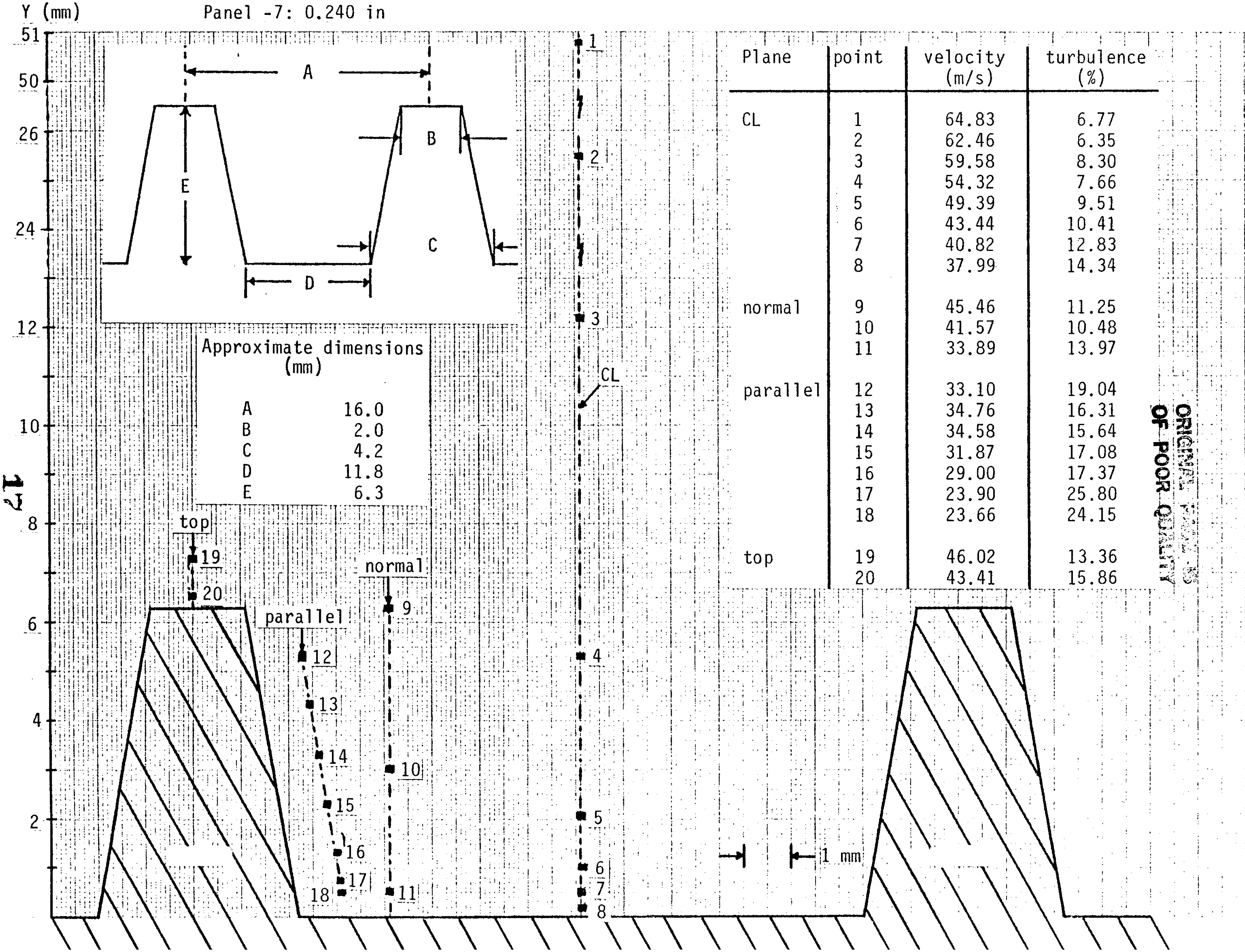
STANDARD INSTRUMENTATION FOR FACILITY OPERATION NOT LISTED.



Approximate dimensions (mm)

A	16.0
B	2.0
C	4.2
D	11.8
E	6.3
F	45.6
G	43.5

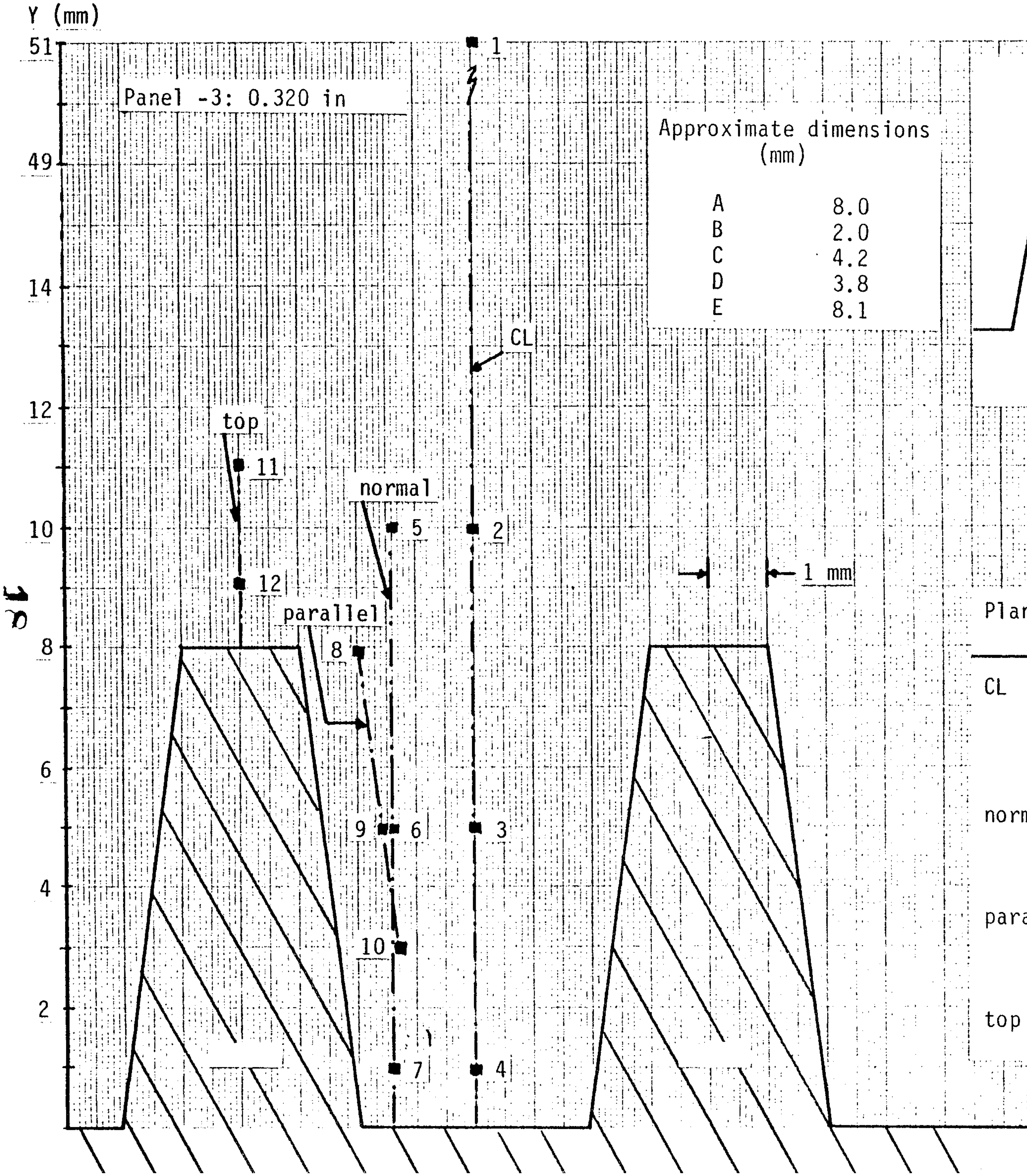
Point	velocity (m/s)	turbulence (%)
1	65.96	6.25
2	63.42	7.20
3	62.88	5.46
4	59.15	7.52
5	52.49	9.84
6	45.92	13.23
7	43.32	13.95
8	41.24	15.19



Approximate dimensions (mm)

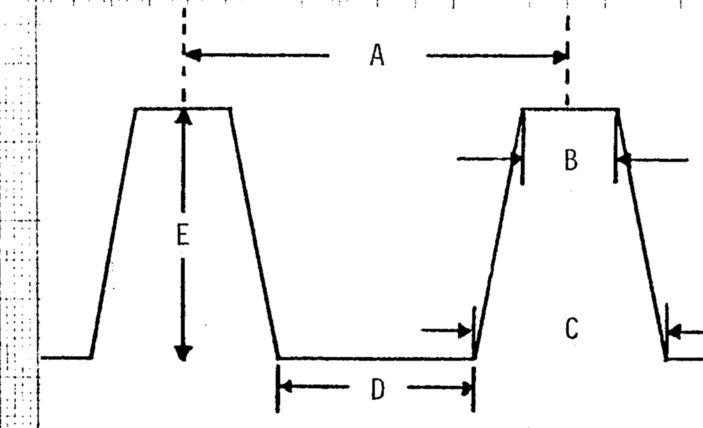
A	16.0
B	2.0
C	4.2
D	11.8
E	6.3

Plane	point	velocity (m/s)	turbulence (%)
CL	1	64.83	6.77
	2	62.46	6.35
	3	59.58	8.30
	4	54.32	7.66
	5	49.39	9.51
	6	43.44	10.41
	7	40.82	12.83
	8	37.99	14.34
normal	9	45.46	11.25
	10	41.57	10.48
	11	33.89	13.97
parallel	12	33.10	19.04
	13	34.76	16.31
	14	34.58	15.64
	15	31.87	17.08
	16	29.00	17.37
	17	23.90	25.80
	18	23.66	24.15
top	19	46.02	13.36
	20	43.41	15.86

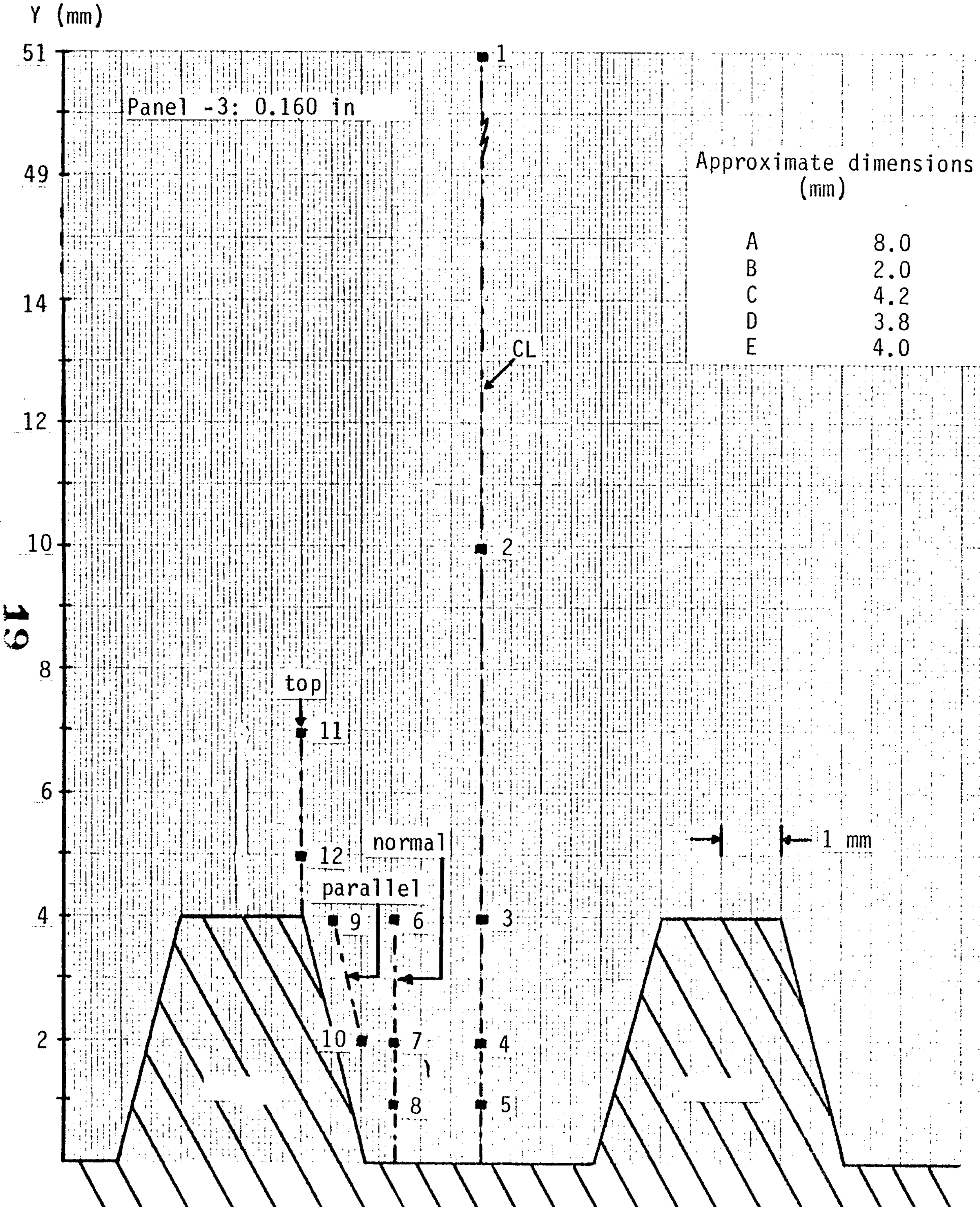


Approximate dimensions (mm)

A	8.0
B	2.0
C	4.2
D	3.8
E	8.1

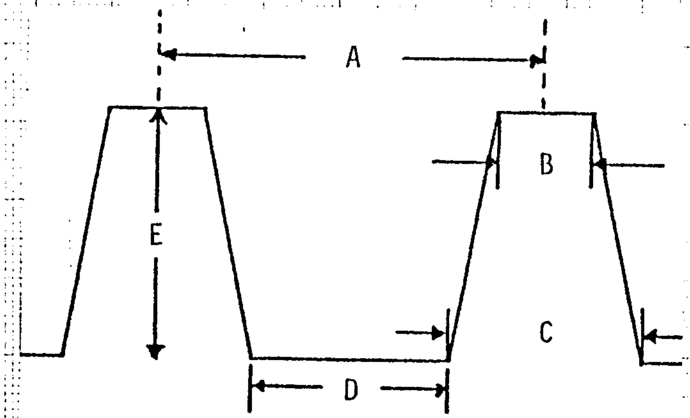


Plane	point	velocity (m/s)	turbulence (%)
CL	1	71.96	6.89
	2	52.39	11.05
	3	41.36	9.59
	4	27.96	14.03
normal	5	52.26	10.62
	6	38.69	11.75
	7	26.46	14.63
parallel	8	45.97	12.14
	9	37.11	12.95
	10	31.95	12.86
top	11	52.92	10.96
	12	46.79	13.30

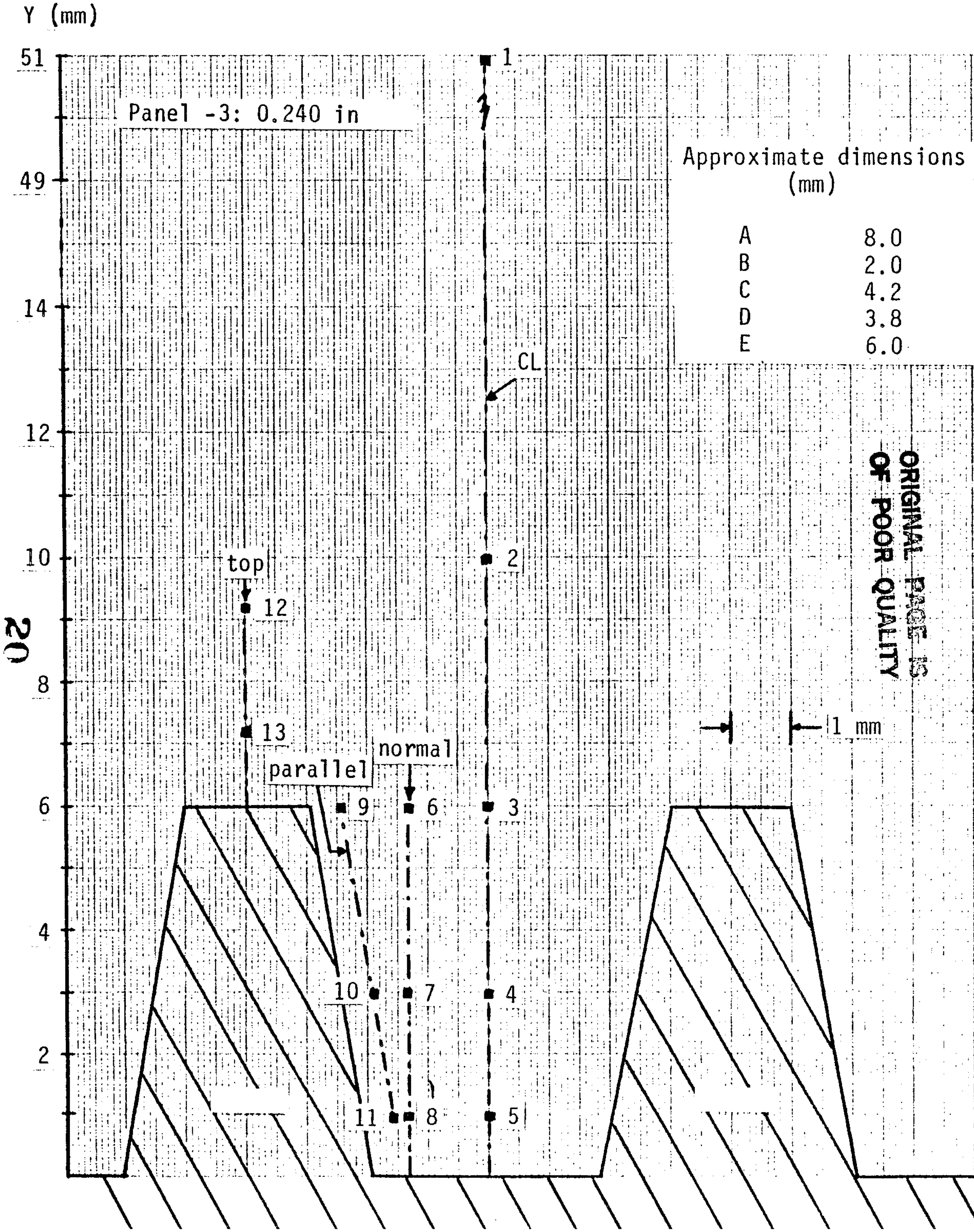


Approximate dimensions (mm)

A	8.0
B	2.0
C	4.2
D	3.8
E	4.0

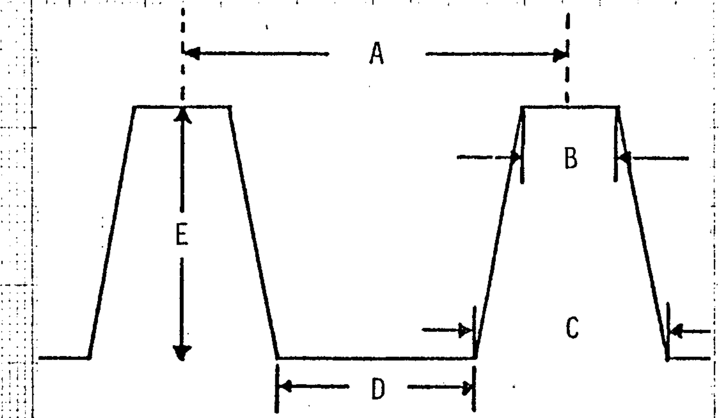


Plane	point	velocity (m/s)	turbulence (%)
CL	1	70.43	6.38
	2	59.09	8.49
	3	48.70	9.38
	4	44.72	8.46
	5	40.01	11.46
normal	6	47.08	12.10
	7	43.02	10.49
	8	41.52	13.06
parallel	9	46.35	15.91
	10	42.54	14.12
top	11	59.50	11.06
	12	52.21	14.57



Approximate dimensions (mm)

A	8.0
B	2.0
C	4.2
D	3.8
E	6.0



Plane	point	velocity (m/s)	turbulence (%)
CL	1	58.72	8.47
	2	56.43	9.05
	3	48.24	9.82
	4	40.63	9.96
	5	32.68	12.60
normal	6	46.91	10.59
	7	39.62	11.04
	8	32.74	11.94
parallel	9	43.16	14.01
	10	35.47	13.07
	11	30.56	13.39
top	12	55.54	10.62
	13	48.91	13.96

APPENDIX D

RIB SCALED ANALYSIS

EXAMPLE CALCULATION FOR 0.040 RIB

STANTON NUMBER PROFILES

APPENDIX D. SAMPLE CALCULATION FOR THE 0.040 RIB

The method used to derive the thermal performance of a rib configuration from the measured velocity profiles was based upon the well established characteristics of a flat plate boundary layer. The local shear stress at any location on the rib wall was derived by fitting the measured local velocity profile to the established flat plate profile. The heat transfer Stanton number defined by St = h/(pUoCp) was found directly by assuming Reynold's analogy. Figure D1. graphically illustrates these steps in the data reduction process. A numerical example of this method will be presented for the 0.040 rib configuration.

The measured velocity profile was fit to the established flat plate correlation by varying the friction velocity parameter defined as V* = Uo /(Cf/2). Figure D2. shows the measured velocity as a function of distance from the wall for the location midway between ribs. The solid line shown is the logrithmic overlap model corresponding to the best fit value of V* = 2.39. It is evident that this coincides with the measured velocity profile near the wall.

The fit of the data was actually performed by inspection of the velocity profile expressed in terms of inner variables u+ = U/V* (dimensionless velocity) and y+ = yV*/v (dimensionless distance). A semilog plot shown in Figure D3. presents the logrithmic overlap correlation as a straight line. The measured velocity data is shown for the best choice of V*. Since the V* parameter by definition is in the denominator of u+ and in the numerator of y+, variation of V* results in a change of position of the measured data. Therefore, V* is chosen such that the data points, particularly those closest to the wall, fall on the correlation line.

Based upon a freestream velocity of Uo = 70.5 meters/sec, the best fit value for V* corresponds to a friction factor of,

$$Cf/2 = (V^*/Uo)^2$$

$$= 0.00115$$

The Reynold's analogy with a Prandtl number correction (for air Pr = 0.69) provides the heat transfer Stanton number as,

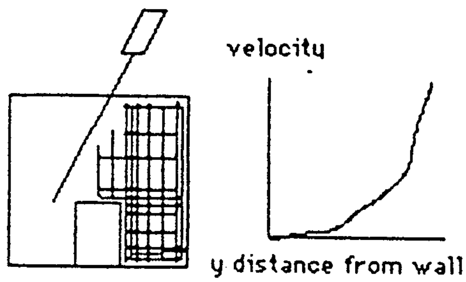
$$St = Pr^{-2/3} \; Cf/2$$

$$= 0.00146$$

The Stanton number defines the heat transfer coefficient for a given set of flow conditions. This procedure was repeated for every location about the rib where velocity profiles were measured. Thus a Stanton number profile about the rib was calculated as shown

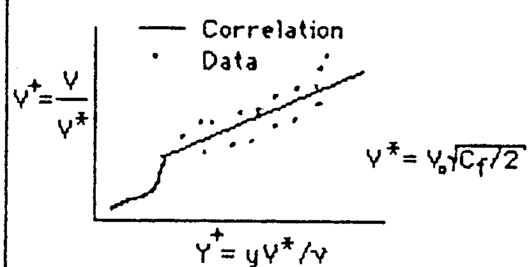
FIGURE D1. FLOWCHART OF THE DATA REDUCTION PROCEDURE FOR THE COLD FLOW TESTS.

LASER VELOCIMETER TESTS



VELOCITY PROFILES ARE MEASURED BY THE TWO-FOCUS LASER SYSTEM. THE MOST IMPORTANT MEASUREMENTS ARE THE VELOCITY PROFILES ALONG A NORMAL FROM THE SURFACE. EMPHASIS WAS ON THE TROUGH REGIONS WHERE THE FLOW IS SLOWED DUE TO MERGING BOUNDARY LAYERS.

BEST FIT TO ESTABLISHED CORRELATION



THE VELOCITIES WERE PLOTTED IN TERMS OF THE "INNER VARIABLES" AND FITTED TO THE ESTABLISHED EQUATION FOR FLAT PLATE TURBULENT BOUNDARY LAYERS:

$$V^+ = 2.43 \ln(Y^+) + 4.9 \quad \text{(LOGRITHMIC REGION)}$$

THE BEST FIT WAS MADE BY VARYING THE FRICTION VELOCITY V* . THIS DEFINED THE LOCAL SKIN FRICTION FACTOR. A V* WAS CHOSEN AT EACH WALL LOCATION.

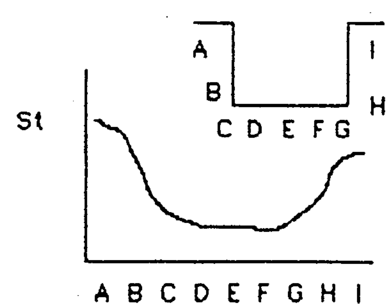
CALCULATION OF HEAT AND MOMENTUM COEFFICIENTS

$Cf/2 = (V*/Vo)^2$	Skin friction factor
$St = Cf/2\ Pr^{2/3}$	by Reynolds Analogy the Stanton number

THE FRICTION FACTOR DIRECTLY DEFINES THE HEAT TRANSFER STANTON NUMBER BY THE REYNOLDS ANALOGY, WHICH IS SHOWN WITH A PRANDTL NUMBER CORRECTION, WHERE:

$$St = \frac{h}{\rho VoCp} \quad \text{Stanton number}$$

HEAT TRANSFER COEFFICIENT PROFILE



REPEAT PROCESS FOR ANOTHER CONFIGURATION

THE STANTON NUMBER WAS DETERMINED AT EACH WALL LOCATION. AN AREA INTEGRATION OF St ABOUT THE FIN/RIB GAVE A TOTAL HEAT TRANSFER WHICH WAS USED AS THE BASIS FOR COMPARISON FOR DIFFERENT CONFIGURATIONS.

TOTAL HEAT TRANSFER COMPARISON

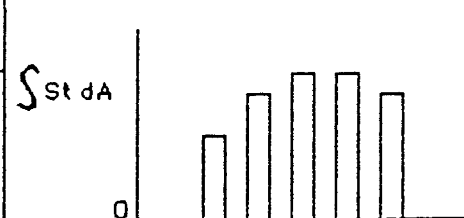


FIGURE D2

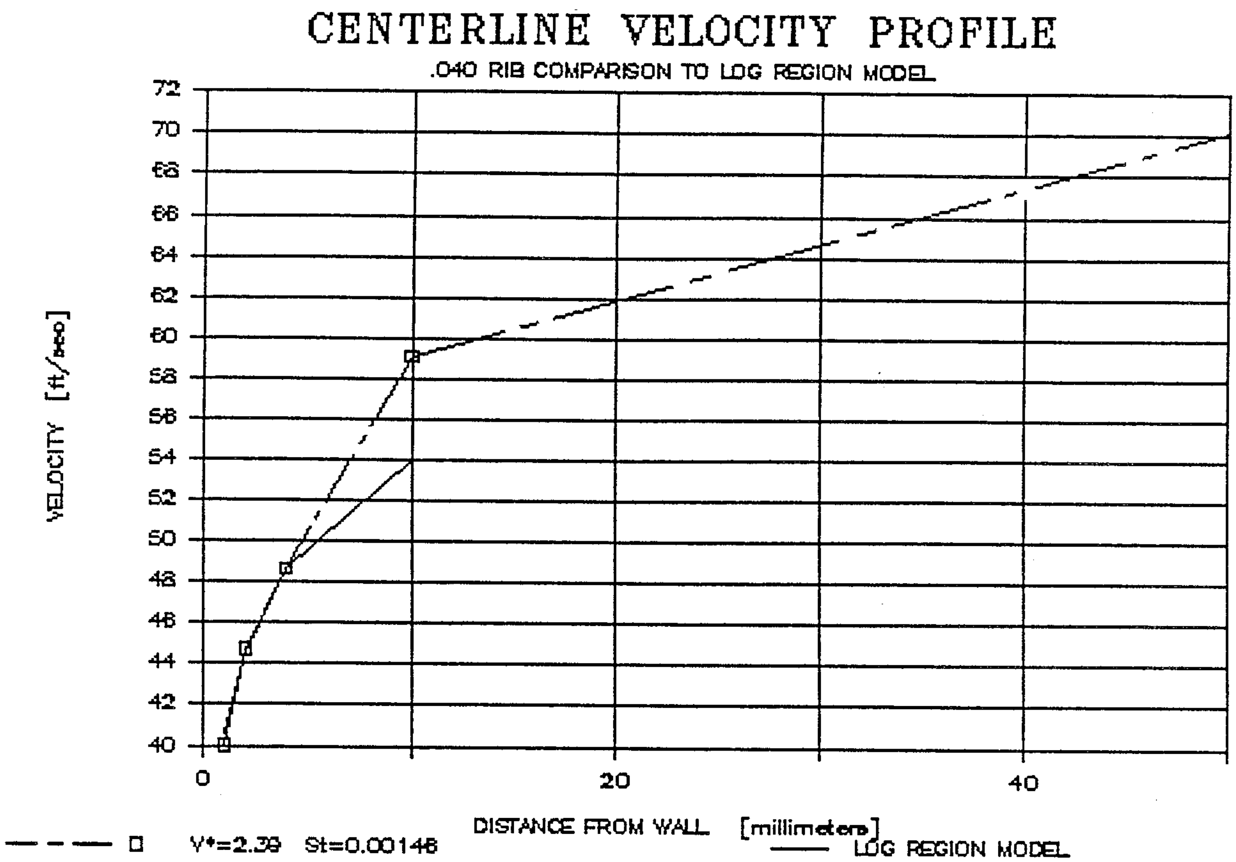
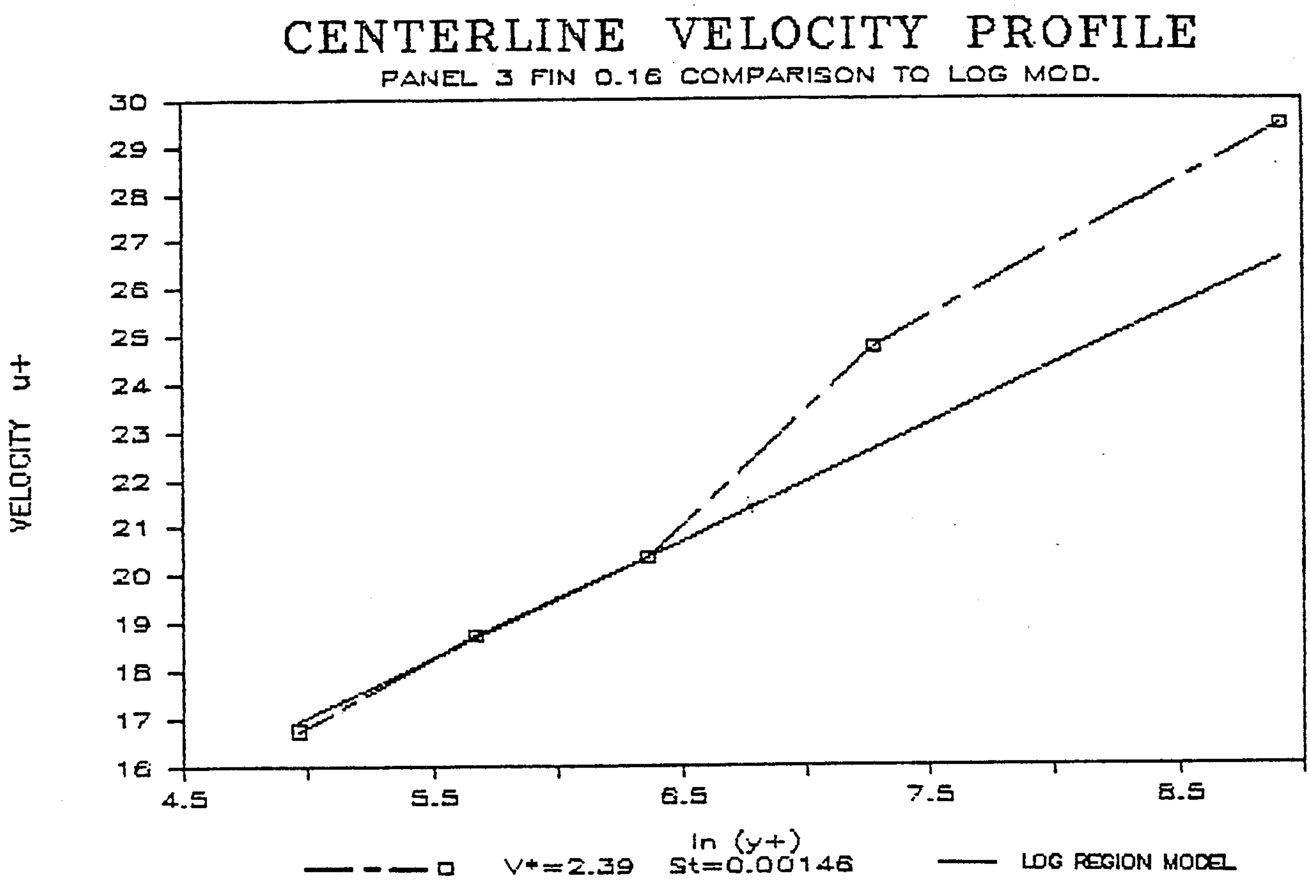

CENTERLINE VELOCITY PROFILE
.040 RIB COMPARISON TO LOG REGION MODEL
72
70
68
66
64
62
60
58
56
54
52
50
48
46
44
42
40
0
20
40
VELOCITY [ft/sec]
DISTANCE FROM WALL [millimeters]
V*=2.39 St=0.00146
LOG REGION MODEL

FIGURE D3


CENTERLINE VELOCITY PROFILE
PANEL 3 FIN 0.16 COMPARISON TO LOG MOD.
VELOCITY u+
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
4.5
5.5
6.5
7.5
8.5
ln (y+)
V+=2.39 St=0.00146
LOG REGION MODEL

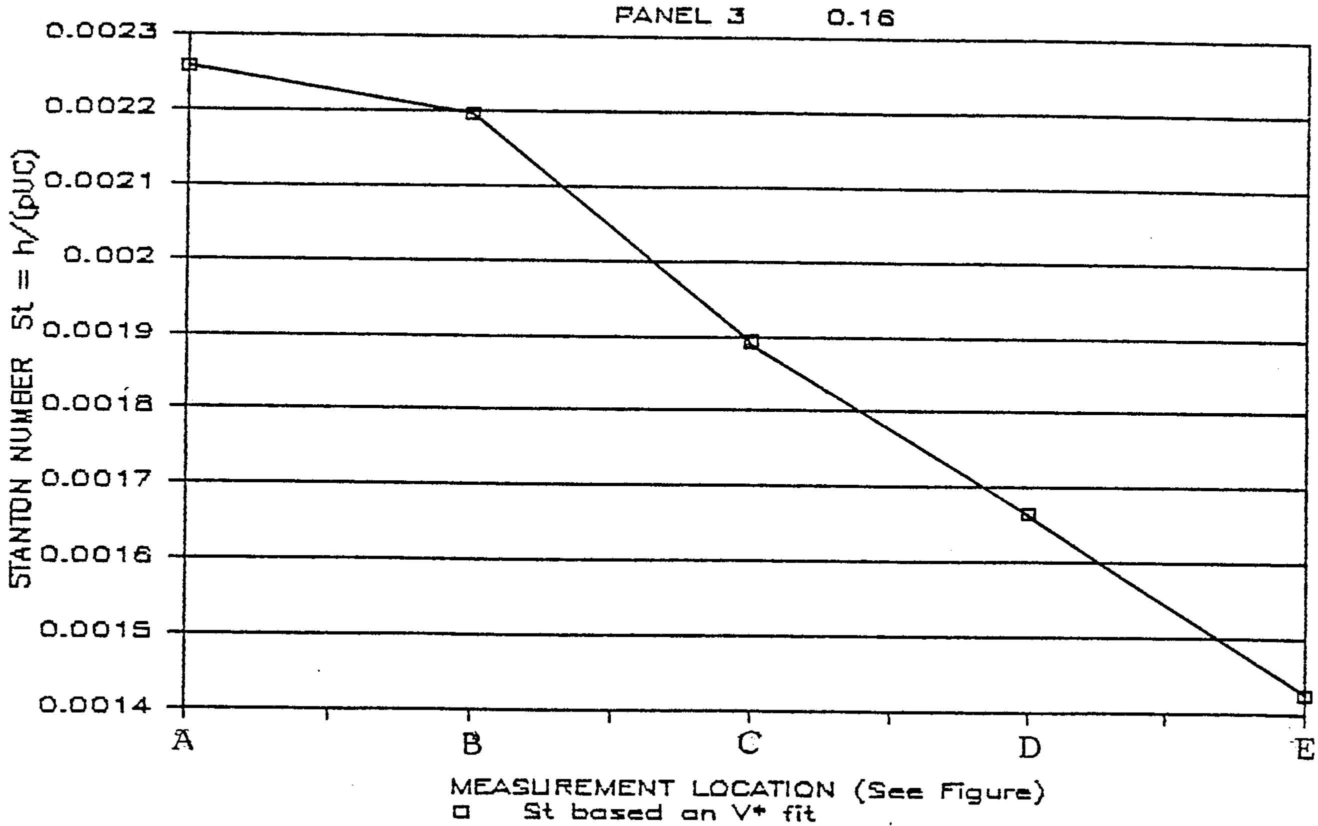
in Figure D4.

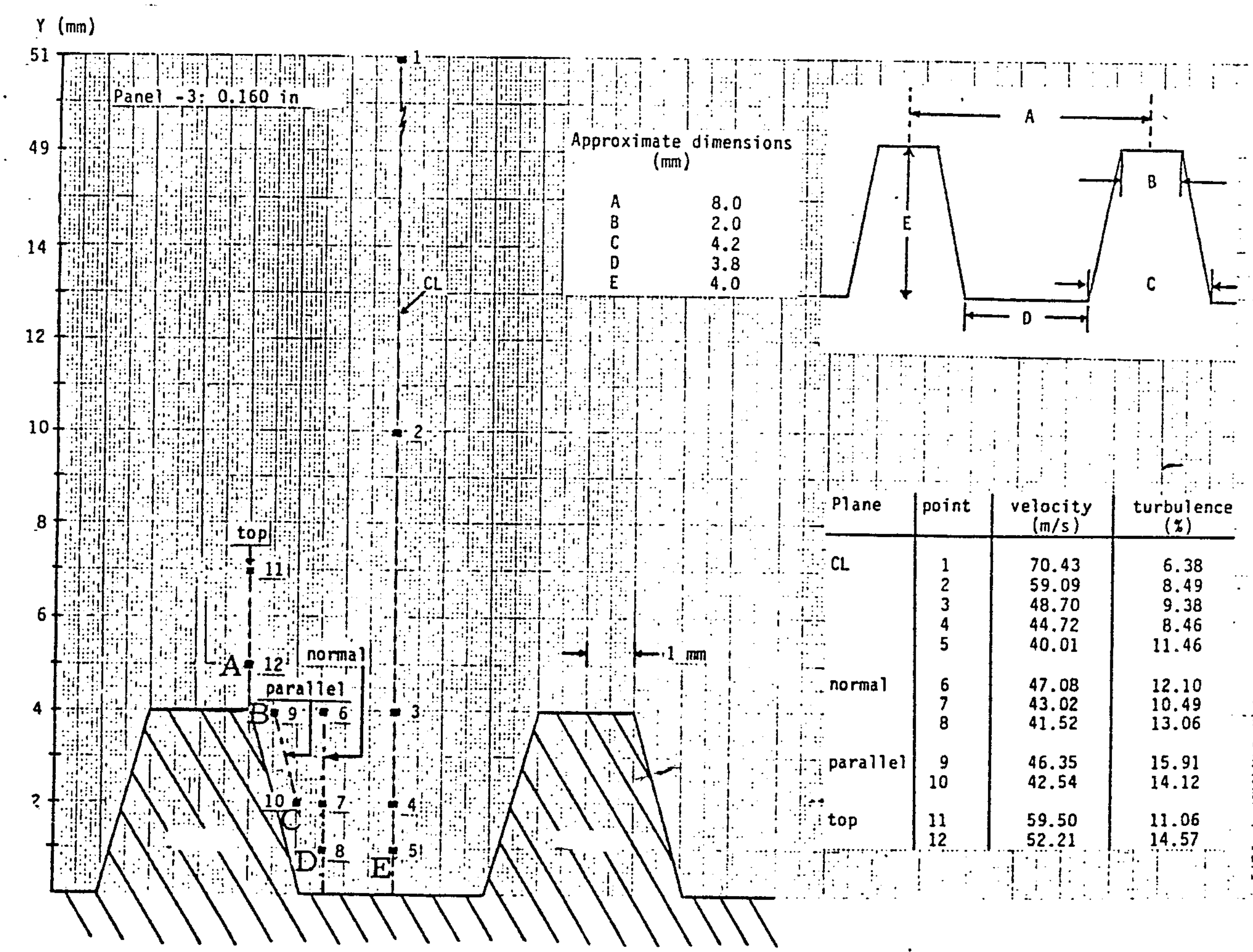
In order to compare the relative performances of different rib configurations, the Stanton number profiles were integrated with respect to surface area to provide a total heat transfer parameter. This parameter reflects the heat transferred per rib. Since the skipped rib configuration has a spacing twice that of the other configurations, one half of the calculated total heat transfer parameter was used for comparison.

Scaling the Cold Flow results to hot-fire conditions required a scaling factor for the gas-side Stanton number. This scaling factor, denoted as Sg, was defined as the ratio of the Stanton number for a hot-fired smooth walled combustor to the Stanton number for a Cold Flow test on a flat plate. The boundary layer computer model predicted the hot-fire combustor Stanton number. The scaling factor was found to be Sg = 0.5. This was used as a Stanton number multiplier for all rib configurations.

FIGURE D4

HEAT TRANSFER PROFILE

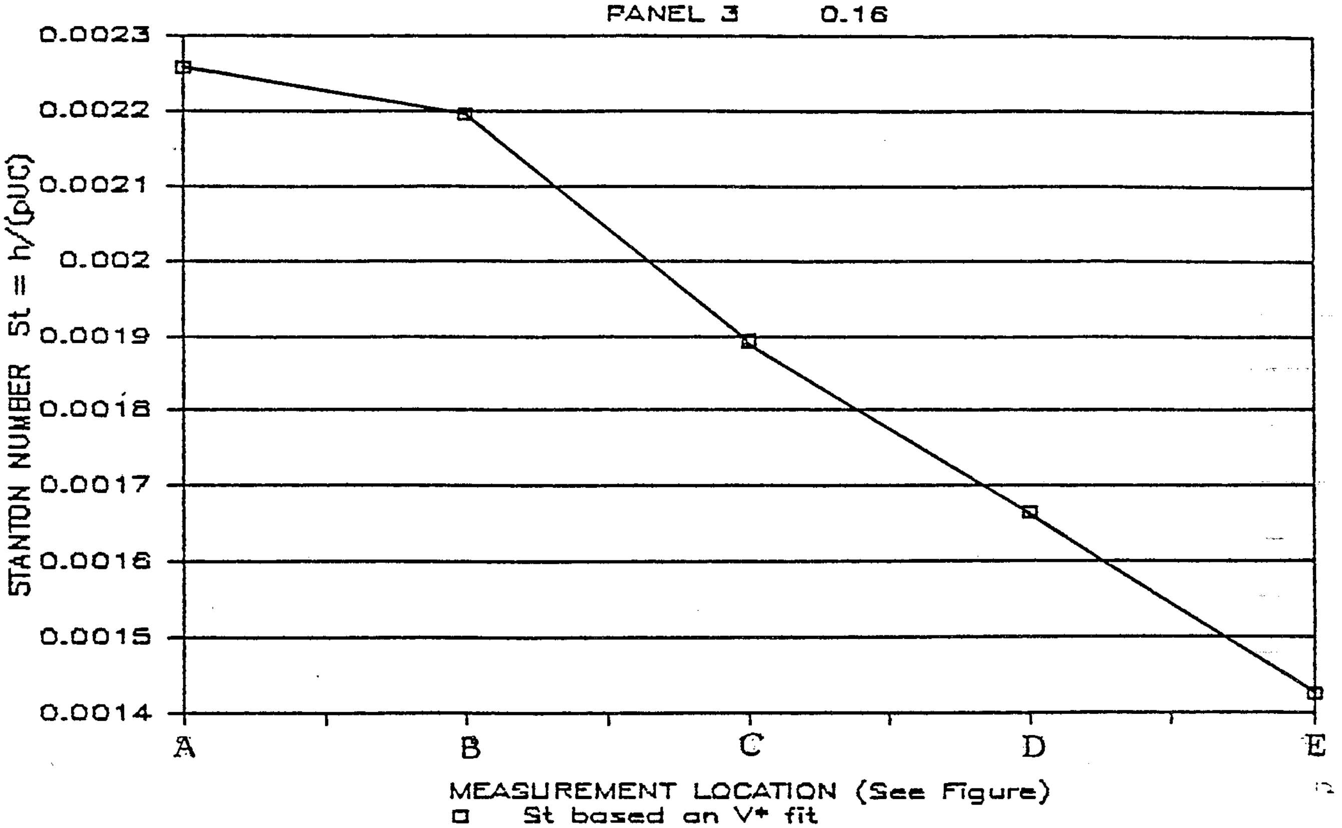


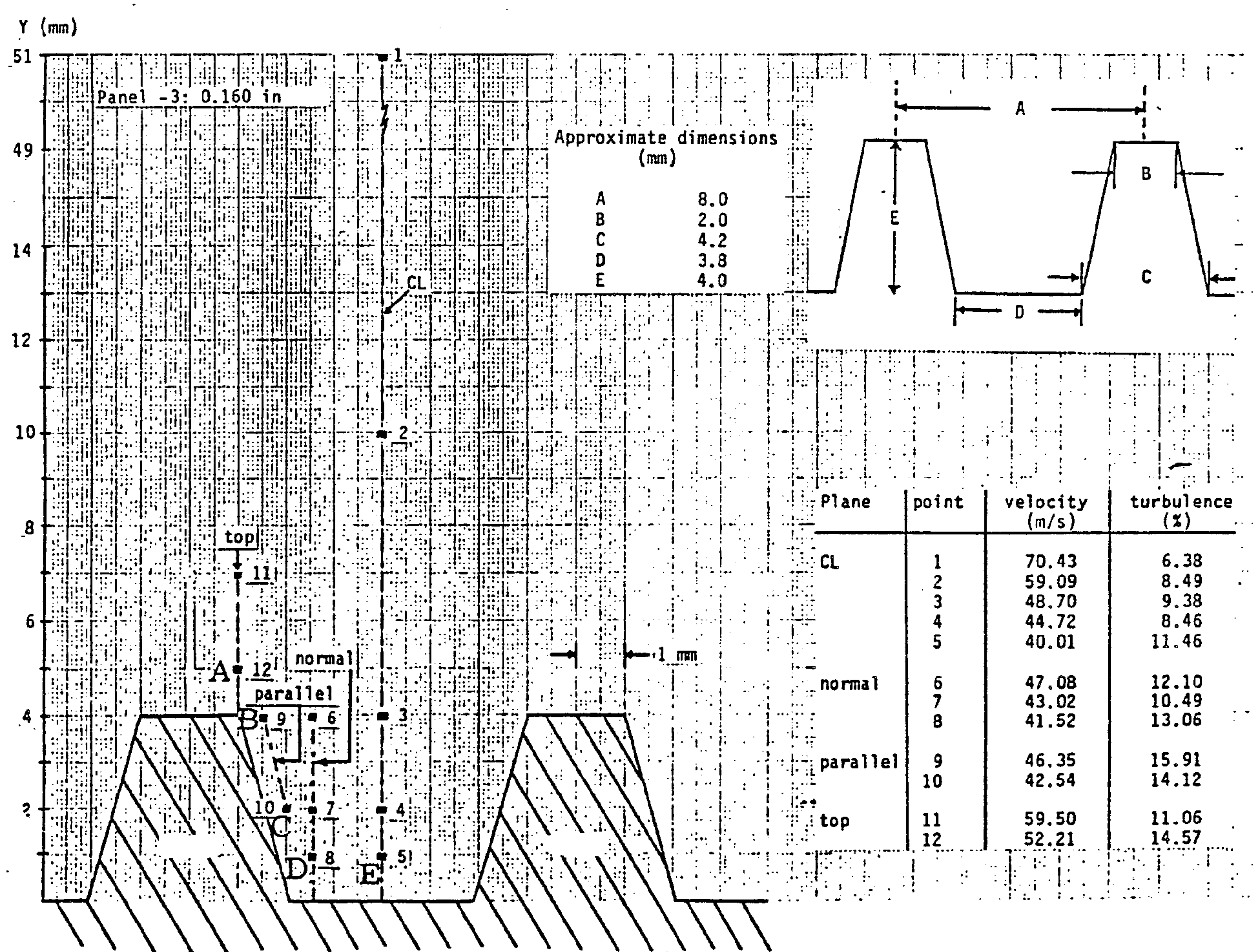


Approximate dimensions (mm)	
A	8.0
B	2.0
C	4.2
D	3.8
E	4.0

Plane	point	velocity (m/s)	turbulence (%)
CL	1	70.43	6.38
	2	59.09	8.49
	3	48.70	9.38
	4	44.72	8.46
	5	40.01	11.46
normal	6	47.08	12.10
	7	43.02	10.49
	8	41.52	13.06
parallel	9	46.35	15.91
	10	42.54	14.12
top	11	59.50	11.06
	12	52.21	14.57

HEAT TRANSFER PROFILE





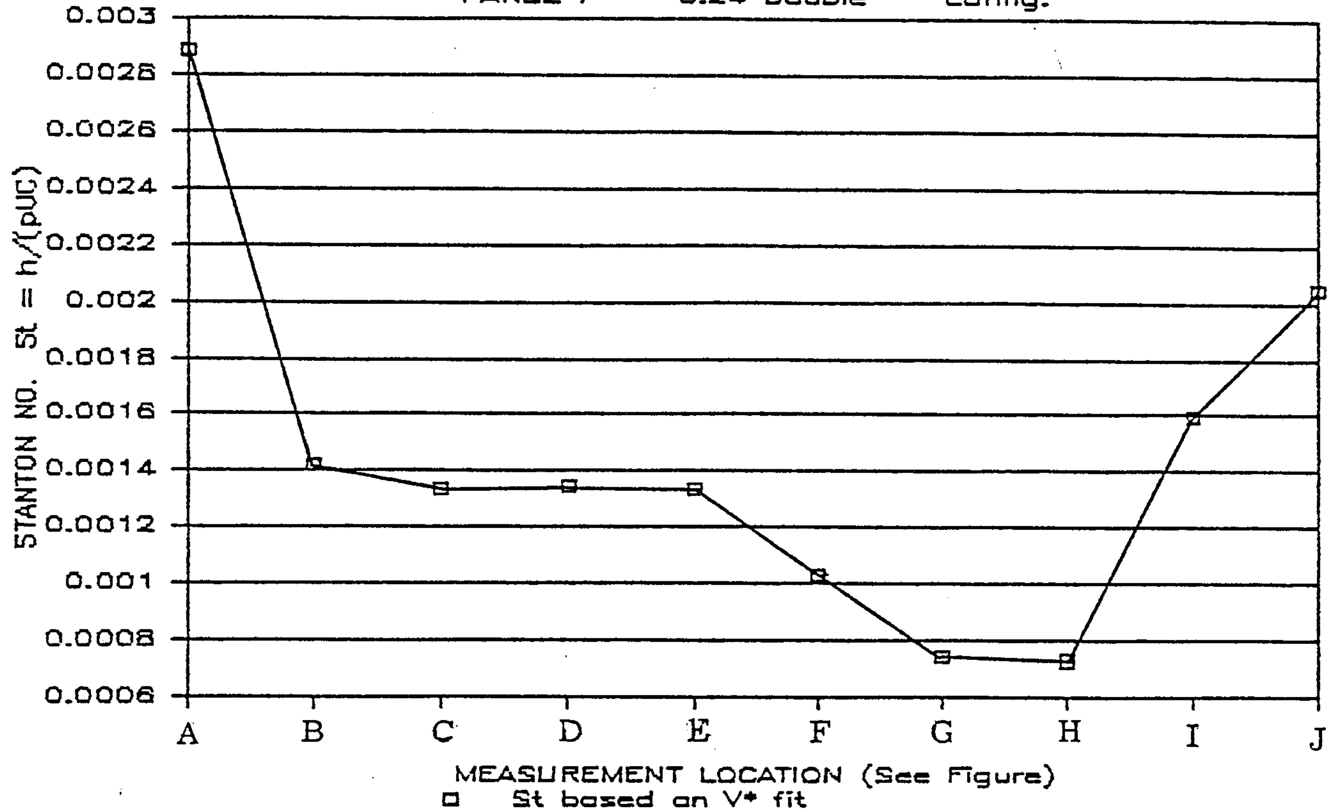
Approximate dimensions (mm)

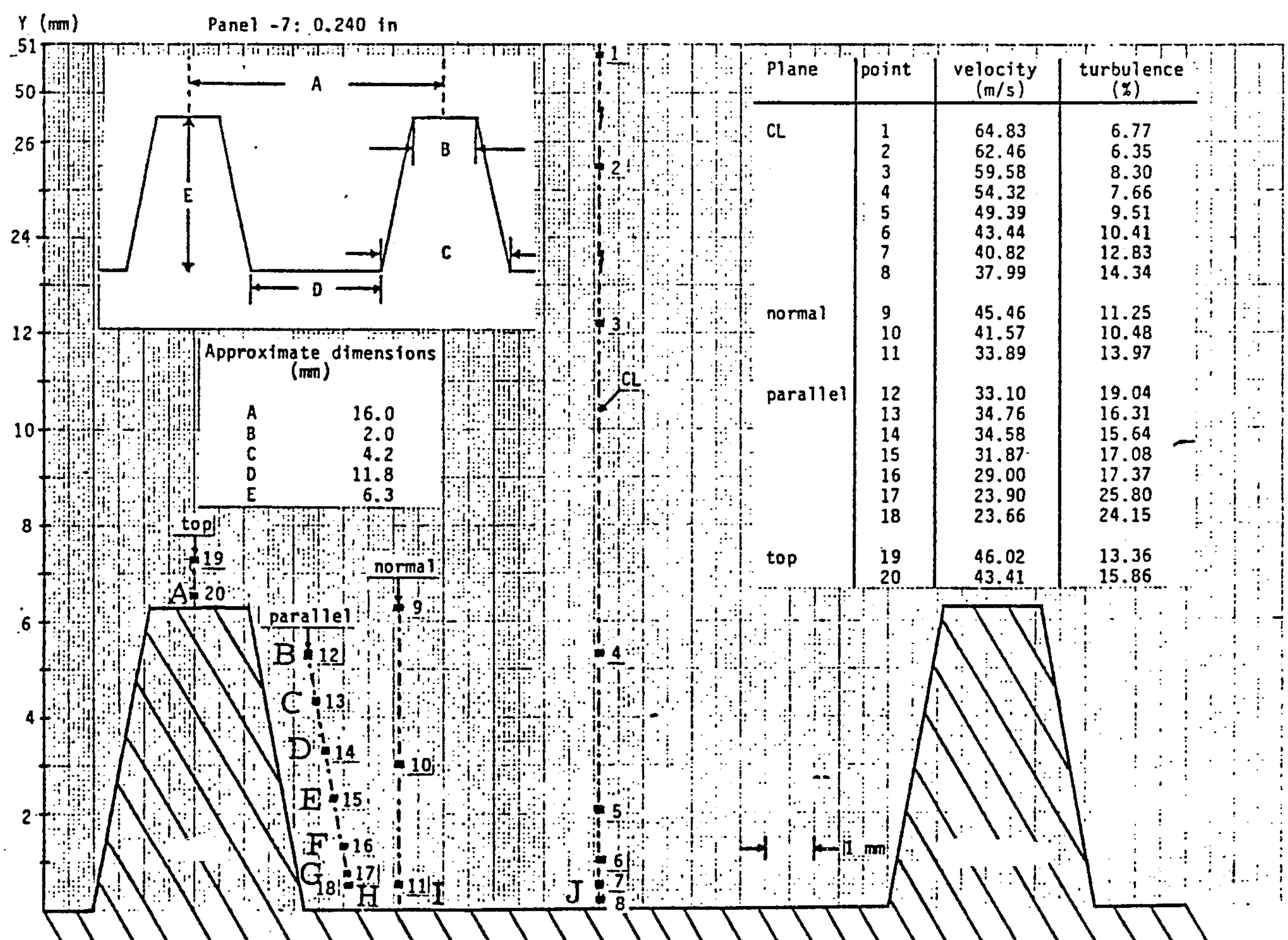
A	8.0
B	2.0
C	4.2
D	3.8
E	4.0

Plane	point	velocity (m/s)	turbulence (%)
CL	1	70.43	6.38
	2	59.09	8.49
	3	48.70	9.38
	4	44.72	8.46
	5	40.01	11.46
normal	6	47.08	12.10
	7	43.02	10.49
	8	41.52	13.06
parallel	9	46.35	15.91
	10	42.54	14.12
top	11	59.50	11.06
	12	52.21	14.57

HEAT TRANSFER PROFILE

PANEL 7 0.24 Double config.





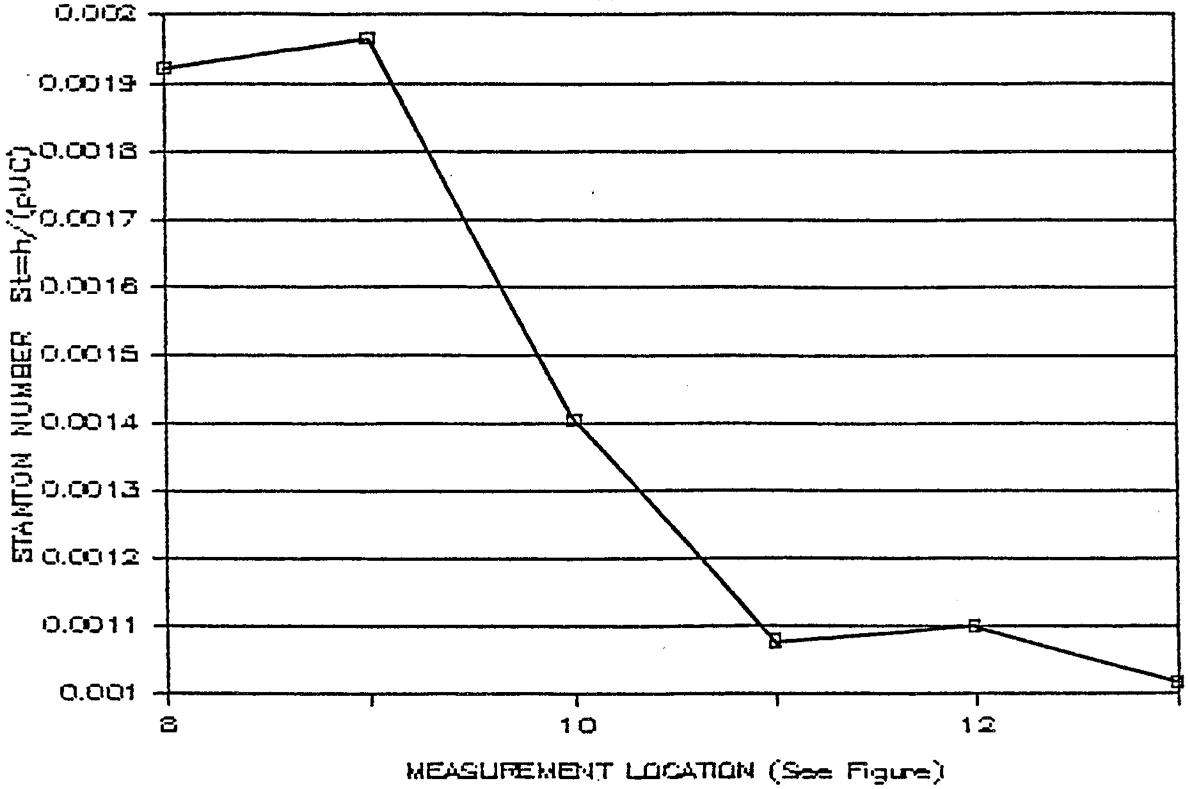
Plane	point	velocity (m/s)	turbulence (%)
CL	1	64.83	6.77
	2	62.46	6.35
	3	59.58	8.30
	4	54.32	7.66
	5	49.39	9.51
	6	43.44	10.41
	7	40.82	12.83
	8	37.99	14.34
normal	9	45.46	11.25
	10	41.57	10.48
	11	33.89	13.97
parallel	12	33.10	19.04
	13	34.76	16.31
	14	34.58	15.64
	15	31.87	17.08
	16	29.00	17.37
	17	23.90	25.80
	18	23.66	24.15
top	19	46.02	13.36
	20	43.41	15.86

Approximate dimensions (mm)

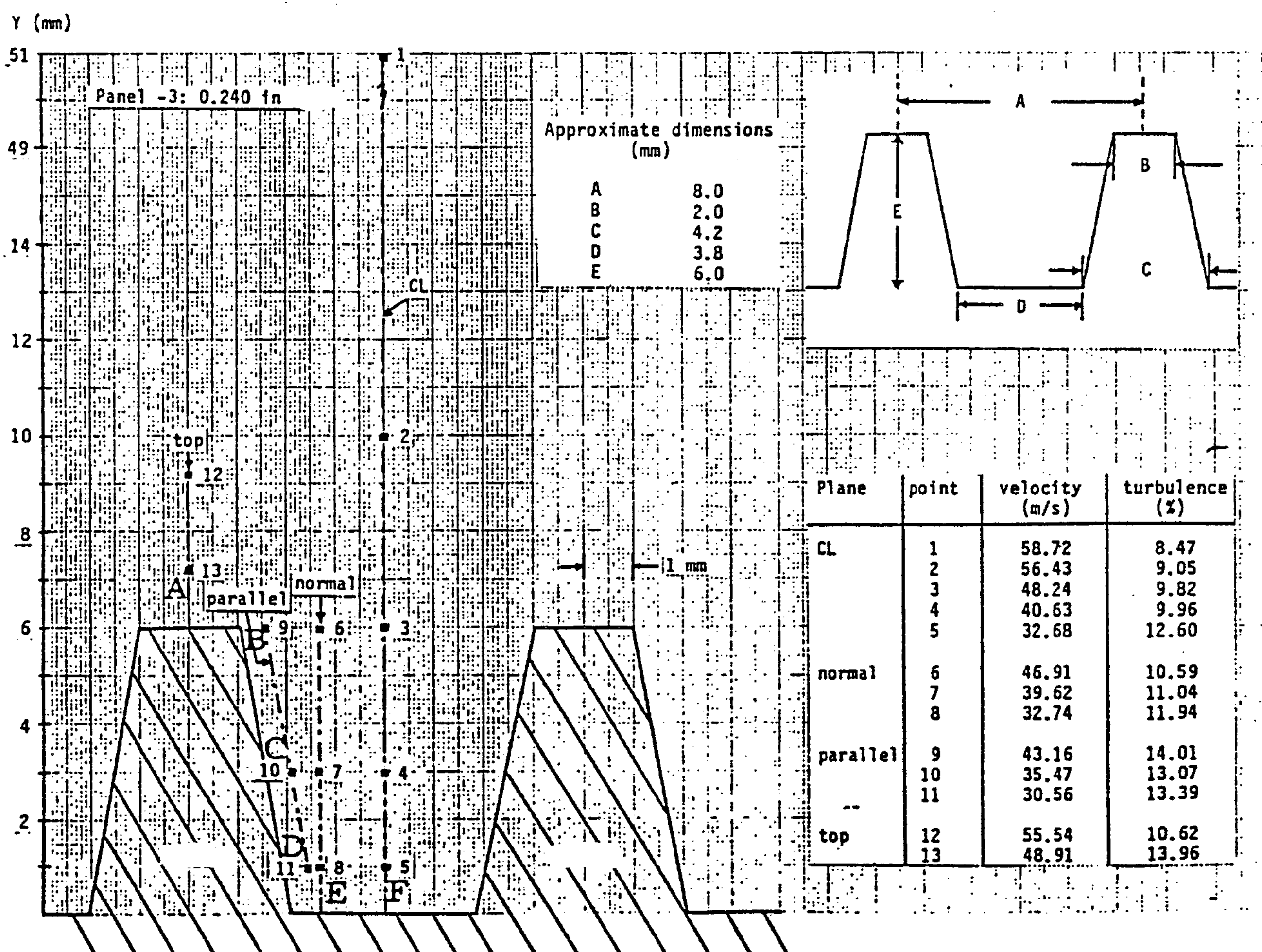
A	16.0
B	2.0
C	4.2
D	11.8
E	6.3

HEAT TRANSFER PROFILE *

PANEL 3 0.24 St based on V* fit



*(Specified Freestream U_∞ is 70.4 m/s)



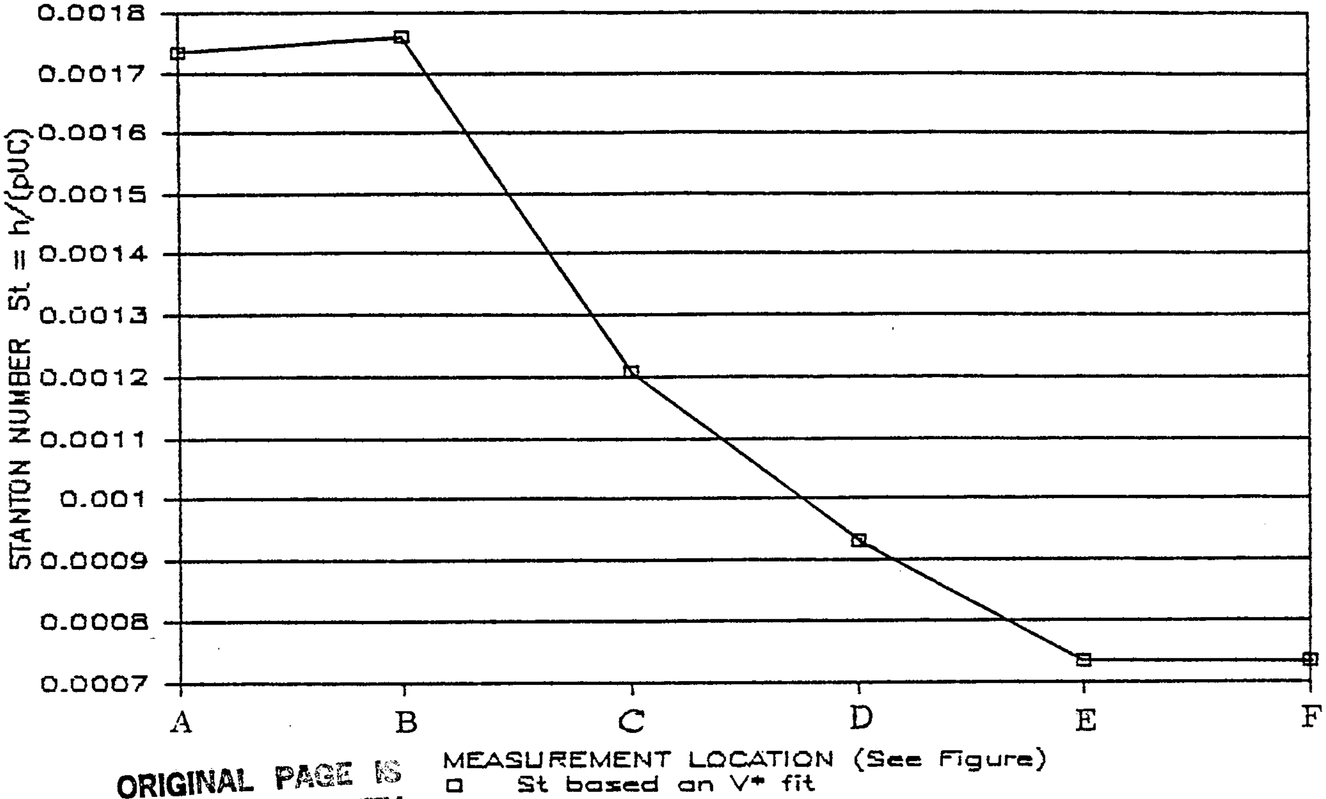
Approximate dimensions (mm)

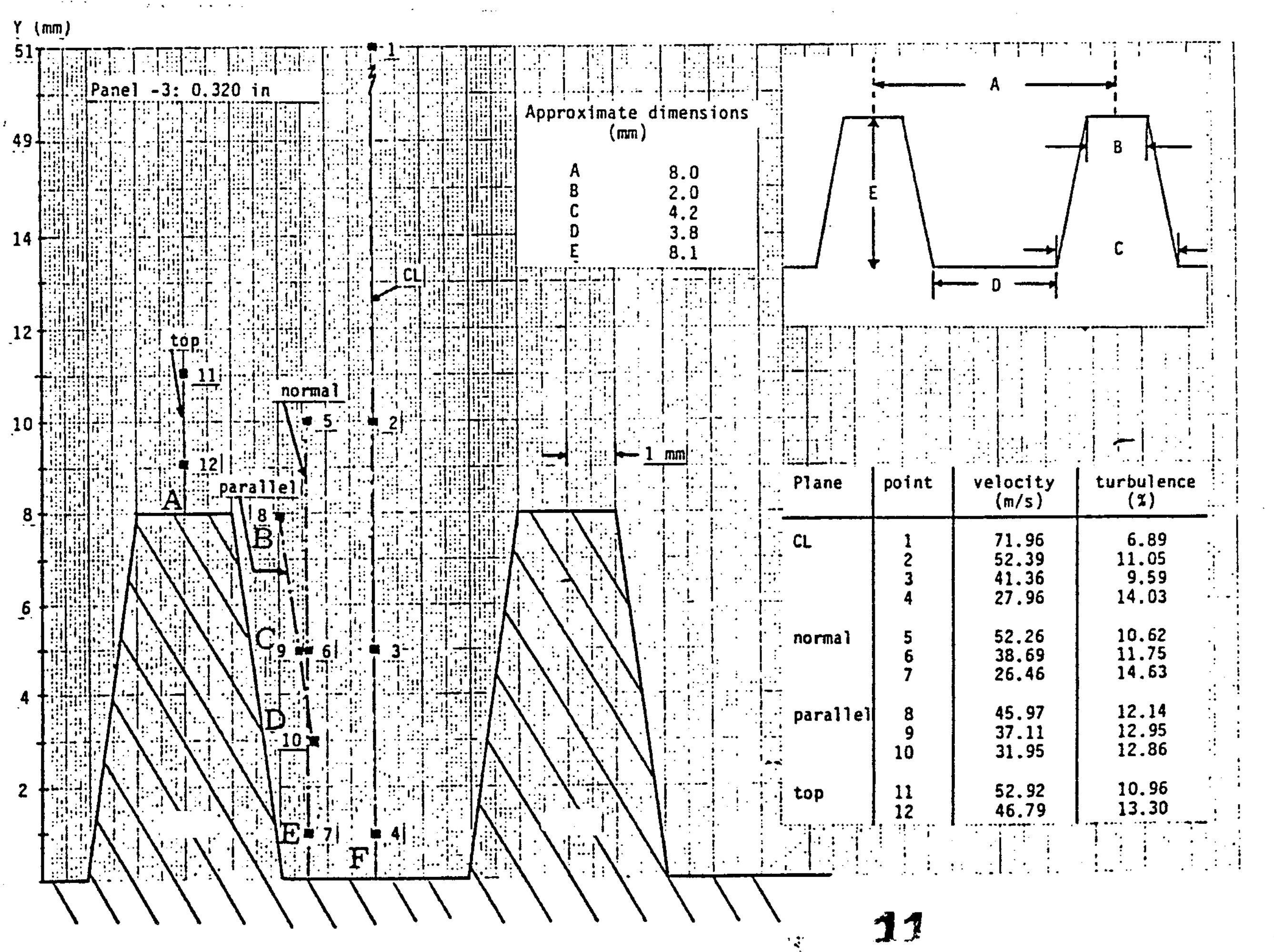
A	8.0
B	2.0
C	4.2
D	3.8
E	6.0

Plane	point	velocity (m/s)	turbulence (%)
CL	1	58.72	8.47
	2	56.43	9.05
	3	48.24	9.82
	4	40.63	9.96
	5	32.68	12.60
normal	6	46.91	10.59
	7	39.62	11.04
	8	32.74	11.94
parallel	9	43.16	14.01
	10	35.47	13.07
	11	30.56	13.39
top	12	55.54	10.62
	13	48.91	13.96

HEAT TRANSFER PROFILE

PANEL 3 0.32





Approximate dimensions (mm)	
A	8.0
B	2.0
C	4.2
D	3.8
E	8.1

Plane	point	velocity (m/s)	turbulence (%)
CL	1	71.96	6.89
	2	52.39	11.05
	3	41.36	9.59
	4	27.96	14.03
normal	5	52.26	10.62
	6	38.69	11.75
	7	26.46	14.63
parallel	8	45.97	12.14
	9	37.11	12.95
	10	31.95	12.86
top	11	52.92	10.96
	12	46.79	13.30

APPENDIX E

CHANNEL ANALYSIS COMPUTER OUTPUTS

CHANNEL EVALUATION CRITERIA RATING SCALES

STATION NO. 63   X = -16.400   X/RT = -13.813

NUMBER OF ITERATIONS = 76
DIFFERENCE BETWEEN HEAT IN AND HEAT OUT = .00560 PERCENT

HEAT INFLUX = 38.093

			1586	1573	1568
			1497	1480	1475
			1364	1344	1337
			1199	1178	1172
923	927	945	988	995	996
883	865	893	905	912	914
836	835	834	831	833	834
789	787	778	752	754	757
			638	661	667
			560	583	591
			500	521	528
			455	473	479
			420	436	441
			395	408	413
			376	389	394
306	310	325	360	379	385
338	339	343	349	356	359
344	344	346	349	352	354

A. RIB HEIGHT = .06000
B. RIB TOP WIDTH = .02000
1. LAND WIDTH = .04084
2. CHANNEL WIDTH = .04000 HG FACTOR = 1.00000
3. WALL THICKNESS = .02500
4. CHANNEL DEPTH = .08000
5. CLOSEOUT THICKNESS = .04000
6. TAW = 6259. DEG. F
7. HG = .0034000
8. TC = 252. DEG. F
9. REFERENCE HC = .0617861

CATAGORY I .080×.040 channel.

STATION NO. 63 X = -16.400 X/RT = -13.413

NUMBER OF ITERATIONS = 71
DIFFERENCE BETWEEN HEAT IN AND HEAT OUT = .00667 PERCENT

HEAT INFLUX = 44.960

			1640	1627	1622
			1552	1535	1530
			1419	1399	1392
			1252	1231	1225
1000	1004	1017	1041	1045	1046
944	945	948	953	959	961
873	873	872	872	876	878
806	804	797	784	795	799
			677	704	712
			608	634	642
			560	581	588
			526	542	548
			501	514	519
			484	495	499
			473	483	486
447	448	454	465	477	481
465	465	465	466	469	470
467	467	467	467	468	468

#16

CAT. I , .080 x .020 CHANNEL

A. RIB HEIGHT = .06000
B. RIB TOP WIDTH = .02000
1. LAND WIDTH = .03970
2. CHANNEL WIDTH = .02000 HG FACTOR = 1.00000
3. WALL THICKNESS = .02500
4. CHANNEL DEPTH = .08000
5. CLOSEOUT THICKNESS = .04000
6. TAW = 6259. DEG. F
7. HG = .0034000
8. TC = 416. DEG. F
9. REFERENCE HC = .0984649
10. HC FACTOR FOR UPPER WALL = 1.0000
11. HC FACTOR FOR LOWER WALL = 1.0000
12. EXPONENT = .5500
13-14. K OF REGION 1 = .004875 + (-.1870E-06) * T
15-16. K OF REGION 2 = .004875 + (-.1870E-06) * T
17-18. K OF REGION 3 = .001340 + (-.1390E-05) * T
19. CONVERGENCE CRITERION = .0100 DEG. F

3

Rockwell International

NUMBER OF ITERATIONS = 135
DIFFERENCE BETWEEN IN AND HEAT OUT = .01846 PERCENT

#12

HEAT INFLUX = 38.907

					1490	1480	1474	1471
					1399	1386	1379	1376
					1263	1248	1239	1236
					1095	1078	1069	1067
793	794	797	809	833	875	883	887	889
749	750	752	761	774	788	800	806	808
690	690	693	701	710	717	725	730	732
614	615	618	641	652	647	655	660	662
587	588	593			558	574	584	586
574	573	568			496	511	520	523
561	559	550			449	462	470	473
549	546	536			414	425	431	433
539	536	525			387	396	402	404
530	527	517			368	376	381	382
					354	362	366	368
307	308	314	317	326	342	353	359	361
329	329	330	332	334	336	340	342	343
333	333	334	334	335	336	338	339	339

CAT. IIa. .015 x .010 FIN

A. RIB HEIGHT = .06000 FIN HEIGHT = .01500
B. RIB TOP WIDTH = .02000 FIN BASE = .01000
1. LAND WIDTH = .04084 FIN TIP WIDTH = .01000
2. CHANNEL WIDTH = .04000 HG FACTOR = 1.00000
3. WALL THICKNESS = .02500
4. CHANNEL DEPTH = .08000
5. CLOSEOUT THICKNESS = .04000
6. TAW = 6259. DEG. F
7. HG = .0034000
8. TC = 264. DEG. F
9. REFERENCE HC = .06693
10. HC FACTOR FOR UPPER WALL = 1.00000
11. HC FACTOR LOWER WALL = 1.00000
12. EXPONENT = .55000
13-14. K OF REGION 1 = .004875 + (-.1870E-06) * T
15-16. K OF REGION 2 = .004875 + (-.1870E-06) * T
17-18. K OF REGION 3 = .001340 + (-.1390E-05) * T
19. CONVERGENCE CRITERION = .0100 DEG. F

4

Rockwell International

NUMBER OF ITERATIONS = 122
DIFFERENCE BETWEEN IN AND HEAT OUT = .01567 PERCENT

HEAT INFLUX = 39.084

#9

					1468	1458	1452	1450
					1377	1365	1357	1354
					1241	1226	1216	1213
					1072	1055	1046	1044
768	767	770	783	807	851	860	864	865
722	723	725	735	748	764	776	782	784
661	662	664	674	684	692	702	708	710
582	583	586	610	625	624	633	639	641
536	537	542			539	556	565	568
513	511	505			480	495	504	507
491	489	480			436	449	456	459
473	470	461			403	413	420	422
458	455	446			378	387	392	394
447	444	436			360	367	372	373
					347	354	359	360
304	305	310	313	322	336	346	352	353
324	324	325	327	329	331	334	336	337
328	328	328	329	330	331	332	333	334

CAT. IIa. .024x.010 FIN

A. RIB HEIGHT = .06000 FIN HEIGHT = .02400
B. RIB TOP WIDTH = .02000 FIN BASE = .01000
1. LAND WIDTH = .04084 FIN TIP WIDTH = .01000
2. CHANNEL WIDTH = .04000 HG FACTOR = 1.00000
3. WALL THICKNESS = .02500
4. CHANNEL DEPTH = .08000
5. CLOSEOUT THICKNESS = .04000
6. TAW = 6259. DEG. F
7. HG = .0034000
8. TC = 267. DEG. F
9. REFERENCE HC = .07022
10. HC FACTOR FOR UPPER WALL = 1.00000
11. HC FACTOR LOWER WALL = 1.00000
12. EXPONENT = .55000
13-14. K OF REGION 1 = .004875 + (-.1870E-06) * T
15-16. K OF REGION 2 = .004875 + (-.1870E-06) * T
17-18. K OF REGION 3 = .001340 + (-.1390E-05) * T
19. CONVERGENCE CRITERION = .0100 DEG. F

NUMBER OF ITERATIONS = 131
DIFFERENCE BETWEEN IN AND HEAT OUT = .01872 PERCENT

HEAT INFLUX = 39.017

					1476	1466	1460	1458
					1385	1373	1365	1363
					1249	1234	1225	1222
					1080	1064	1055	1052
777	779	786	800	822	860	869	873	874
734	735	740	749	760	773	785	791	793
674	676	680	687	695	701	710	716	718
603	603	606	625	634	632	640	646	649
580	579	581			545	562	571	574
569	567	560			486	501	510	513
558	555	544			441	454	461	464
548	544	531			407	417	424	426
539	535	521			381	390	396	397
530	526	512			363	370	375	377
					349	357	361	363
305	306	311	315	323	338	349	354	356
326	326	327	329	331	333	336	339	339
330	330	330	331	332	333	334	335	336

#11

CAT. IIa. .015 x .015 FIN

A. RIB HEIGHT = .06000 FIN HEIGHT = .01500
B. RIB TOP WIDTH = .02000 FIN BASE = .01500
1. LAND WIDTH = .04084 FIN TIP WIDTH = .01500
2. CHANNEL WIDTH = .04000 HG FACTOR = 1.00000
3. WALL THICKNESS = .02500
4. CHANNEL DEPTH = .08000
5. CLOSEOUT THICKNESS = .04000
6. TAW = 6259. DEG. F
7. HG = .0034000
8. TC = 266. DEG. F
9. REFERENCE HC = .06880
10. HC FACTOR FOR UPPER WALL = 1.00000
11. HC FACTOR LOWER WALL = 1.00000
12. EXPONENT = .55000
13-14. K OF REGION 1 = .004875 + (-.1870E-06) * T
15-16. K OF REGION 2 = .004875 + (-.1870E-06) * T
17-18. K OF REGION 3 = .001340 + (-.1390E-05) * T
19. CONVERGENCE CRITERION = .0100 DEG. F

NUMBER OF ITERATIONS = 116
DIFFERENCE BETWEEN IN AND HEAT OUT = .01311 PERCENT

HEAT INFLUX = 39.206

#10

					1453	1443	1437	1435
					1362	1349	1342	1339
					1225	1210	1201	1198
					1056	1039	1030	1028
749	751	758	772	796	834	843	847	849
705	707	712	721	733	746	759	766	768
644	646	650	658	667	674	685	691	693
570	571	574	593	606	606	617	623	626
531	530	531			525	541	551	554
512	509	501			468	483	492	495
494	491	478			426	438	446	448
478	474	461			394	404	410	412
465	461	448			370	379	384	386
454	450	437			353	360	365	366
					341	348	352	354
301	303	307	310	318	331	341	346	348
320	320	321	323	324	326	330	332	332
323	324	324	325	325	326	328	329	329

CAT. IIa. .024 x .015 FIN

A. RIB HEIGHT = .06000 FIN HEIGHT = .02400
B. RIB TOP WIDTH = .02000 FIN BASE = .01500
1. LAND WIDTH = .04084 FIN TIP WIDTH = .01500
2. CHANNEL WIDTH = .04000 HG FACTOR = 1.00000
3. WALL THICKNESS = .02500
4. CHANNEL DEPTH = .08000
5. CLOSEOUT THICKNESS = .04000
6. TAW = 6259. DEG. F
7. HG = .0034000
8. TC = 269. DEG. F
9. REFERENCE HC = .07351
10. HC FACTOR FOR UPPER WALL = 1.00000
11. HC FACTOR LOWER WALL = 1.00000
12. EXPONENT = .55000
13-14. K OF REGION 1 = .004875 + (-.1870E-06) * T
15-16. K OF REGION 2 = .004875 + (-.1870E-06) * T
17-18. K OF REGION 3 = .001340 + (-.1390E-05) * T
19. CONVERGENCE CRITERION = .0100 DEG. F

Rockwell International

STATION NO. 62   X = -15.201   X/RT = -12.432

NUMBER OF ITERATIONS = 119
DIFFERENCE BETWEEN IN AND HEAT OUT = .01387 PERCENT

HEAT INFLUX = 39.595

#13

					1435	1425	1419	1417
					1343	1330	1323	1320
					1205	1190	1180	1177
					1034	1017	1008	1006
727	729	736	750	773	811	820	824	825
683	685	689	698	710	722	735	741	743
623	625	628	636	643	650	659	665	667
551	552	555	571	582	580	589	595	597
515	514	515			492	510	519	522
487	485	477			432	448	457	460
463	460	450			387	400	408	411
442	439	429			353	364	371	373
426	423	413			328	337	342	344
414	411	402			309	317	322	323
					296	304	308	310
254	256	260	264	272	285	296	301	303
274	274	275	277	279	281	284	286	287
278	278	278	279	280	281	282	283	283

CAT. IIa.   .024 x .015 x .010 tip FIN.

A. RIB HEIGHT = .06000 FIN HEIGHT = .02400
B. RIB TOP WIDTH = .02000 FIN BASE = .01500
1. LAND WIDTH = .04084 FIN TIP WIDTH = .01000
2. CHANNEL WIDTH = .04000 HG FACTOR = 1.00000
3. WALL THICKNESS = .02500
4. CHANNEL DEPTH = .08000
5. CLOSEOUT THICKNESS = .04000
6. TAW = 6259. DEG. F
7. HG = .0034200
8. TC = 216. DEG. F
9. REFERENCE HC = .07172
10. HC FACTOR FOR UPPER WALL = 1.00000
11. HC FACTOR LOWER WALL = 1.00000
12. EXPONENT = .55000
13-14. K OF REGION 1 = .004875 + (-.1870E-06) * T
15-16. K OF REGION 2 = .004875 + (-.1870E-06) * T
17-18. K OF REGION 3 = .001340 + (-.1390E-05) * T
19. CONVERGENCE CRITERION = .0100 DEG. F

NUMBER OF ITERATIONS = 117
DIFFERENCE BETWEEN IN AND HEAT OUT = .01404 PERCENT

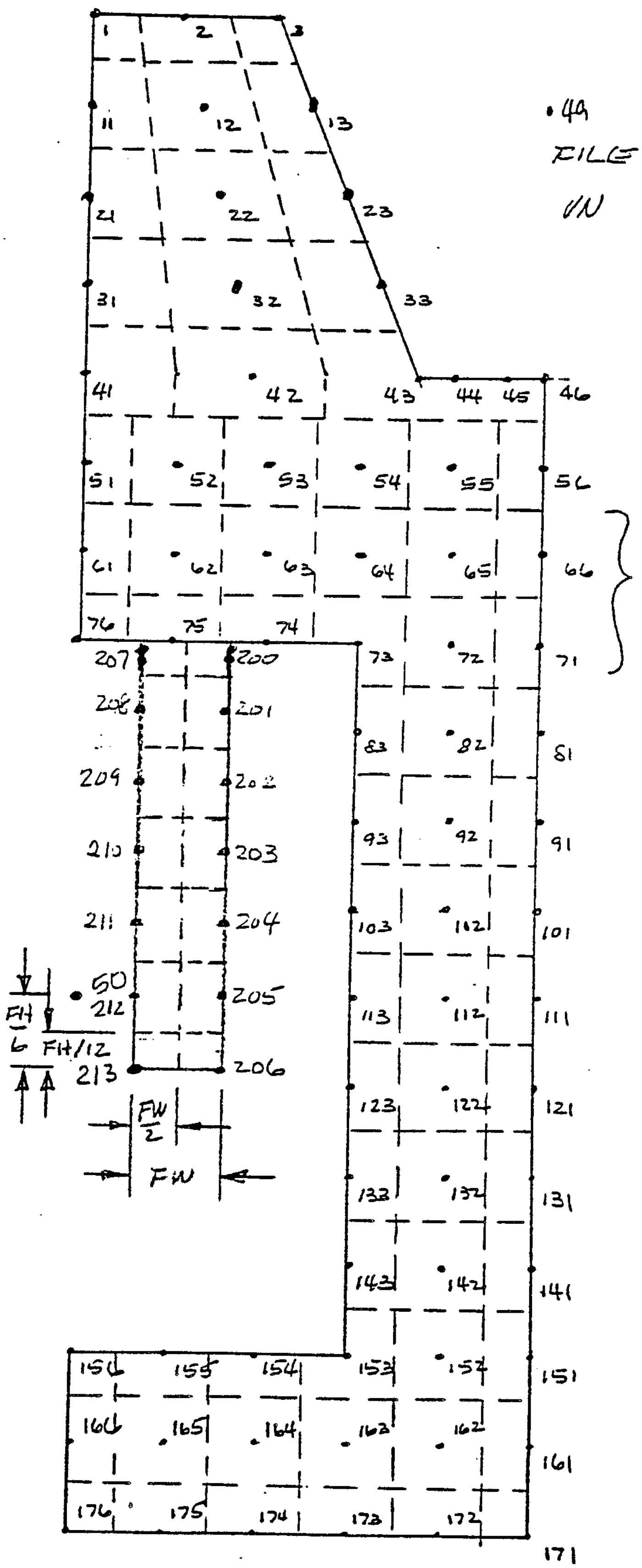
HEAT INFLUX = 39.197

#14

					1454	1444	1438	1436
					1363	1350	1342	1340
					1226	1211	1202	1199
					1057	1040	1031	1028
752	756	768	782	803	835	844	848	849
708	711	719	727	737	747	760	766	768
650	652	657	663	669	675	685	691	693
582	582	585	597	606	605	616	623	625
549	547	544			523	540	549	552
528	525	513			466	481	490	493
508	504	490			424	436	444	446
491	487	472			392	402	409	411
476	472	458			369	377	382	384
464	460	446			352	359	363	365
					340	346	351	352
300	302	306	309	316	330	339	344	346
319	319	320	321	323	325	328	330	331
322	322	323	323	324	325	326	327	328

CAT. IIa. .024 x .020 x .015 tip FIN

A. RIB HEIGHT = .06000 FIN HEIGHT = .02400
B. RIB TOP WIDTH = .02000 FIN BASE = .02000
1. LAND WIDTH = .04084 FIN TIP WIDTH = .01500
2. CHANNEL WIDTH = .04000 HG FACTOR = 1.00000
3. WALL THICKNESS = .02500
4. CHANNEL DEPTH = .08000
5. CLOSEOUT THICKNESS = .04000
6. TAW = 6259. DEG. F
7. HG = .0034000
8. TC = 268. DEG. F
9. REFERENCE HC = .07497
10. HC FACTOR FOR UPPER WALL = 1.00000
11. HC FACTOR LOWER WALL = 1.00000
12. EXPONENT = .55000
13-14. K OF REGION 1 = .004875 + (-.1870E-06) * T
15-16. K OF REGION 2 = .004875 + (-.1870E-06) * T
17-18. K OF REGION 3 = .001340 + (-.1390E-05) * T
19. CONVERGENCE CRITERION = .0100 DEG. F



• 49
FILE = RBOCH2F
IN = 4QA579

CHANGE CONNECTORS IN THIS REGION ONLY, ALL OTHERS REMAIN UNCHANGED

FH = FIN HEIGHT
FW = FIN WIDTH

NODAL GRID FOR CATAGORY II b.

521	0.	0.	5.655E-04	0.	0.	0.	0.	0.	0.	0.
531	0.	0.	5.730E-04	0.	0.	0.	0.	0.	0.	0.
541	0.	0.	5.791E-04	0.	0.	0.	0.	0.	0.	0.
551	0.	0.	5.864E-04	5.996E-04	6.047E-04	3.030E-04	0.	0.	0.	0.

LOCATIONS 561 THROUGH 600 EQUAL 0.

601	5.979E-05	1.793E-04	2.393E-04	1.796E-04	5.988E-05	0.	0.	0.	0.	0.

LOCATIONS 611 THROUGH 790 EQUAL 0.

791	0.	0.	0.	0.	0.	0.	0.	0.	0.	4.759E-03
801	4.759E-03	5.956E-04	1.192E-03	1.193E-03	1.194E-03	1.195E-03	1.196E-03	5.980E-04	9.534E-03	9.543E-03
811	9.551E-03	9.557E-03	9.562E-03	9.566E-03	9.534E-03	9.543E-03	9.551E-03	9.557E-03	9.562E-03	9.566E-03
821	6.235E-05	1.265E-04	1.280E-04	1.294E-04	1.305E-04	1.313E-04	3.299E-04	6.235E-05	1.265E-04	1.280E-04
831	1.294E-04	1.305E-04	1.313E-04	3.299E-04	0.	0.	0.	0.	0.	0.

LOCATIONS 841 THROUGH 2999 EQUAL 0.

ORIGINAL PAGE IS OF POOR QUALITY

#27

CAT. IIb

.015 x .010 FINS

LOC. NUMBER	TEMPERATURES (T)									
1	1.420E+03	1.424E+03	1.438E+03	0.	0.	0.	0.	0.	0.	0.
11	1.335E+03	1.341E+03	1.358E+03	0.	0.	0.	0.	0.	0.	0.
21	1.207E+03	1.214E+03	1.235E+03	0.	0.	0.	0.	0.	0.	0.
31	1.051E+03	1.057E+03	1.078E+03	0.	0.	0.	0.	0.	0.	0.
41	8.872E+02	8.840E+02	8.716E+02	8.023E+02	7.746E+02	7.668E+02	0.	0.	6.259E+03	2.520E+02
51	8.084E+02	8.029E+02	7.895E+02	7.553E+02	7.349E+02	7.285E+02	0.	0.	0.	0.
61	7.371E+02	7.274E+02	7.221E+02	6.988E+02	6.855E+02	6.814E+02	0.	0.	0.	0.
71	6.287E+02	6.300E+02	6.356E+02	6.686E+02	6.485E+02	6.796E+02	0.	0.	0.	0.
81	5.632E+02	5.592E+02	5.434E+02	0.	0.	0.	0.	0.	0.	0.
91	5.054E+02	5.001E+02	4.823E+02	0.	0.	0.	0.	0.	0.	0.
101	4.581E+02	4.529E+02	4.370E+02	0.	0.	0.	0.	0.	0.	0.
111	4.207E+02	4.161E+02	4.026E+02	0.	0.	0.	0.	0.	0.	0.
121	3.920E+02	3.880E+02	3.764E+02	0.	0.	0.	0.	0.	0.	0.
131	3.710E+02	3.672E+02	3.566E+02	0.	0.	0.	0.	0.	0.	0.
141	3.573E+02	3.530E+02	3.409E+02	0.	0.	0.	0.	0.	0.	0.
151	3.519E+02	3.462E+02	3.230E+02	2.920E+02	2.804E+02	2.774E+02	0.	0.	0.	0.
161	3.249E+02	3.222E+02	3.148E+02	3.059E+02	3.001E+02	2.981E+02	0.	0.	0.	0.
171	3.188E+02	3.173E+02	3.131E+02	3.083E+02	3.047E+02	3.033E+02	0.	0.	0.	0.

LOCATIONS 181 THROUGH 190 EQUAL 0.

FIN POINT VALUES (°F)

191	0.	0.	0.	0.	0.	0.	0.	0.	0.	5.905E+02
201	5.638E+02	5.413E+02	5.226E+02	5.076E+02	4.961E+02	4.880E+02	5.905E+02	5.638E+02	5.413E+02	5.226E+02
211	5.076E+02	4.961E+02	4.880E+02	0.	0.	0.	0.	0.	0.	0.

LOCATIONS 221 THROUGH 999 EQUAL 0.

LOC.
NUMBER CAPACITANCES (C)

LOCATIONS 1 THROUGH 999 EQUAL 0.

LOC.
NUMBER GEN. RATES (Q)

521	0.	0.	5.574E-04	0.	0.	0.	0.	0.	0.	0.
531	0.	0.	5.747E-04	0.	0.	0.	0.	0.	0.	0.
541	0.	0.	5.808E-04	0.	0.	0.	0.	0.	0.	0.
551	0.	0.	5.878E-04	6.003E-04	6.062E-04	3.032E-04	0.	0.	0.	0.

LOCATIONS 561 THROUGH 600 EQUAL 0.

601	5.866E-05	1.795E-04	2.395E-04	1.797E-04	5.991E-05	0.	0.	0.	0.	0.

LOCATIONS 611 THROUGH 790 EQUAL 0.

791	0.	0.	0.	0.	0.	0.	0.	0.	0.	4.785E-03
801	4.785E-03	8.542E-04	1.912E-03	1.915E-03	1.917E-03	1.918E-03	1.919E-03	9.801E-04	5.989E-03	5.979E-03
811	5.986E-03	5.992E-03	5.997E-03	6.000E-03	5.959E-03	5.979E-03	5.986E-03	5.992E-03	5.997E-03	6.000E-03
821	1.017E-04	2.085E-04	2.130E-04	2.166E-04	2.195E-04	2.218E-04	3.902E-04	1.017E-04	2.085E-04	2.130E-04
831	2.166E-04	2.195E-04	2.218E-04	3.902E-04	0.	0.	0.	0.	0.	0.

LOCATIONS 841 THROUGH 2999 EQUAL 0.

LOC. NUMBER — TEMPERATURES (T)

1	1.400E+03	1.404E+03	1.418E+03	0.	0.	0.	0.	0.	0.	0.
11	1.316E+03	1.320E+03	1.338E+03	0.	0.	0.	0.	0.	0.	0.
21	1.186E+03	1.193E+03	1.214E+03	0.	0.	0.	0.	0.	0.	0.
31	1.030E+03	1.036E+03	1.067E+03	0.	0.	0.	0.	0.	0.	0.
41	8.851E+02	8.821E+02	8.808E+02	7.834E+02	7.570E+02	7.486E+02	0.	0.	5.259E+03	2.520E+02
51	7.863E+02	7.801E+02	7.586E+02	7.366E+02	7.175E+02	7.118E+02	0.	0.	0.	0.
61	7.125E+02	7.028E+02	7.010E+02	6.808E+02	6.680E+02	6.653E+02	0.	0.	0.	0.
71	6.140E+02	6.150E+02	6.195E+02	5.476E+02	5.186E+02	5.540E+02	0.	0.	0.	0.
81	5.507E+02	5.468E+02	5.313E+02	0.	0.	0.	0.	0.	0.	0.
91	4.961E+02	4.898E+02	4.727E+02	0.	0.	0.	0.	0.	0.	0.
101	4.496E+02	4.446E+02	4.293E+02	0.	0.	0.	0.	0.	0.	0.
111	4.136E+02	4.093E+02	3.953E+02	0.	0.	0.	0.	0.	0.	0.
121	3.861E+02	3.823E+02	3.711E+02	0.	0.	0.	0.	0.	0.	0.
131	3.860E+02	3.623E+02	3.522E+02	0.	0.	0.	0.	0.	0.	0.
141	3.526E+02	3.487E+02	3.371E+02	0.	0.	0.	0.	0.	0.	0.
151	3.477E+02	3.422E+02	3.200E+02	2.803E+02	2.793E+02	2.784E+02	0.	0.	0.	0.
161	3.216E+02	3.182E+02	3.121E+02	3.037E+02	2.881E+02	2.862E+02	0.	0.	0.	0.
171	3.160E+02	3.146E+02	3.106E+02	3.059E+02	3.026E+02	3.012E+02	0.	0.	0.	0.

#28
CAT. IIb.
.024 x .010 FINS

LOCATIONS 181 THROUGH 190 EQUAL 0.

191	0.	0.	0.	0.	0.	0.	0.	0.	0.	5.553E+02
201	5.087E+02	4.733E+02	4.447E+02	4.231E+02	4.079E+02	3.883E+02	5.553E+02	5.087E+02	4.733E+02	4.447E+02
211	4.231E+02	4.079E+02	3.883E+02	0.	0.	0.	0.	0.	0.	0.

FIN VALUES

LOCATIONS 221 THROUGH 999 EQUAL 0.

LOC. NUMBER — CAPACITANCES (C)

LOCATIONS 1 THROUGH 999 EQUAL 0.

LOC. NUMBER — GEN. RATES (Q)

Rockwell International

LOCATIONS 1 THROUGH 999 EQUAL 0.

LOC. NUMBER — INDUCTANCES (L)

ORIGINAL PAGE IS OF POOR QUALITY

LOCATIONS 1 THROUGH 999 EQUAL 0.

LOC. NUMBER — *030 GAIN (G)

LOCATIONS 1 THROUGH 30 EQUAL 1.00000E+00

31	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	5.000E-01	2.500E-01	7.500E-01	1.000E+00
41	1.000E+00	5.000E-01	1.000E+00	7.500E-01	2.500E-01	1.000E+00	1.000E+00	3.000E+00	4.000E+00	1.000E+00
51	6.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.333E+00	2.000E+00	6.670E-01	2.500E-01	1.000E+00
61	1.000E+00	1.000E+00	5.000E-01	1.000E+00	1.000E+00	1.500E+00	2.000E+00	3.000E+00	7.000E+00	1.000E+00
71	1.500E+01	1.000E+00	3.000E+00	5.000E+00	1.000E+00	1.000E+00	5.000E+00	3.000E+00	1.000E+00	1.000E+00
81	7.000E+00	1.000E+00	1.000E+00	3.750E-01	1.000E+00	3.750E-01	3.000E+00	1.000E+00	3.750E-01	2.000E+00
91	1.000E+00	3.750E-01	3.000E+00	6.000E+00	1.000E+00	1.000E+00	1.250E-01	1.000E+00	1.000E+00	2.500E-01
101	5.000E-01	1.000E+00	2.500E-01	1.000E+00	5.000E-01	5.000E-01	1.000E+00	2.500E-01	8.333E-02	3.330E-01
111	5.000E-01	1.250E-01	1.250E-01	1.000E+00	8.333E-02	1.000E+00	8.333E-02	6.250E-02	1.000E+00	5.000E-01
121	8.330E-02	3.750E-01	1.000E+00	1.000E+00	3.000E+00	1.000E+00	1.000E+00	1.000E+00	3.000E+00	1.000E+00
131	5.000E-01	1.000E+00	2.778E-01	3.000E+00	3.000E+00	5.000E-01	1.000E+00	3.000E+00	-1.000E+00	1.000E+00
141	1.000E+00	6.000E+00	1.000E+00	1.000E+00	-1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	5.000E-01
151	1.000E+00	3.000E+00	1.000E+00	1.000E+00	1.250E-01	1.000E+00	6.000E+00	1.000E+00	1.000E+01	8.000E+00
161	1.000E+00	5.000E-01	1.250E-01	1.250E-01	1.250E-01	3.750E-01	5.000E-01	1.000E+00	1.000E+00	1.000E+00

LOCATIONS 171 THROUGH 180 EQUAL 1.00000E+00

181	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	5.000E-01	1.000E+00	1.000E+00	2.000E+00	1.000E+00
191	2.000E+00	1.000E+00	2.000E+00	1.000E+00	2.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00
201	1.000E+00	1.000E+00	1.000E+00	2.000E+00	1.000E+00	1.000E+00	5.000E-01	1.000E+00	1.000E+00	2.000E+00
211	1.000E+00	1.000E+00	2.000E+00	1.000E+00	1.000E+00	5.000E-01	1.000E+00	1.000E+00	1.000E+00	2.000E-01
221	4.000E-01	2.000E-01	1.250E+00	2.000E-03	4.000E-03	7.000E-03	2.000E-03	4.000E-03	7.000E-03	5.000E-01
231	1.000E+00	1.000E+00	2.000E+00	1.000E+00	2.000E+00	1.000E+00	1.000E+00	2.000E+00	1.000E+00	2.000E+00
241	1.000E+00	2.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00

LOCATIONS 251 THROUGH 260 EQUAL 1.00000E+00

261	1.000E+00	1.000E+00	1.000E+00	1.500E+00	6.000E+00	1.000E+00	5.000E+00	1.000E+00	1.000E+00	1.000E+00
271	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	0.	0.	0.	0.

LOCATIONS 281 THROUGH 999 EQUAL 0.

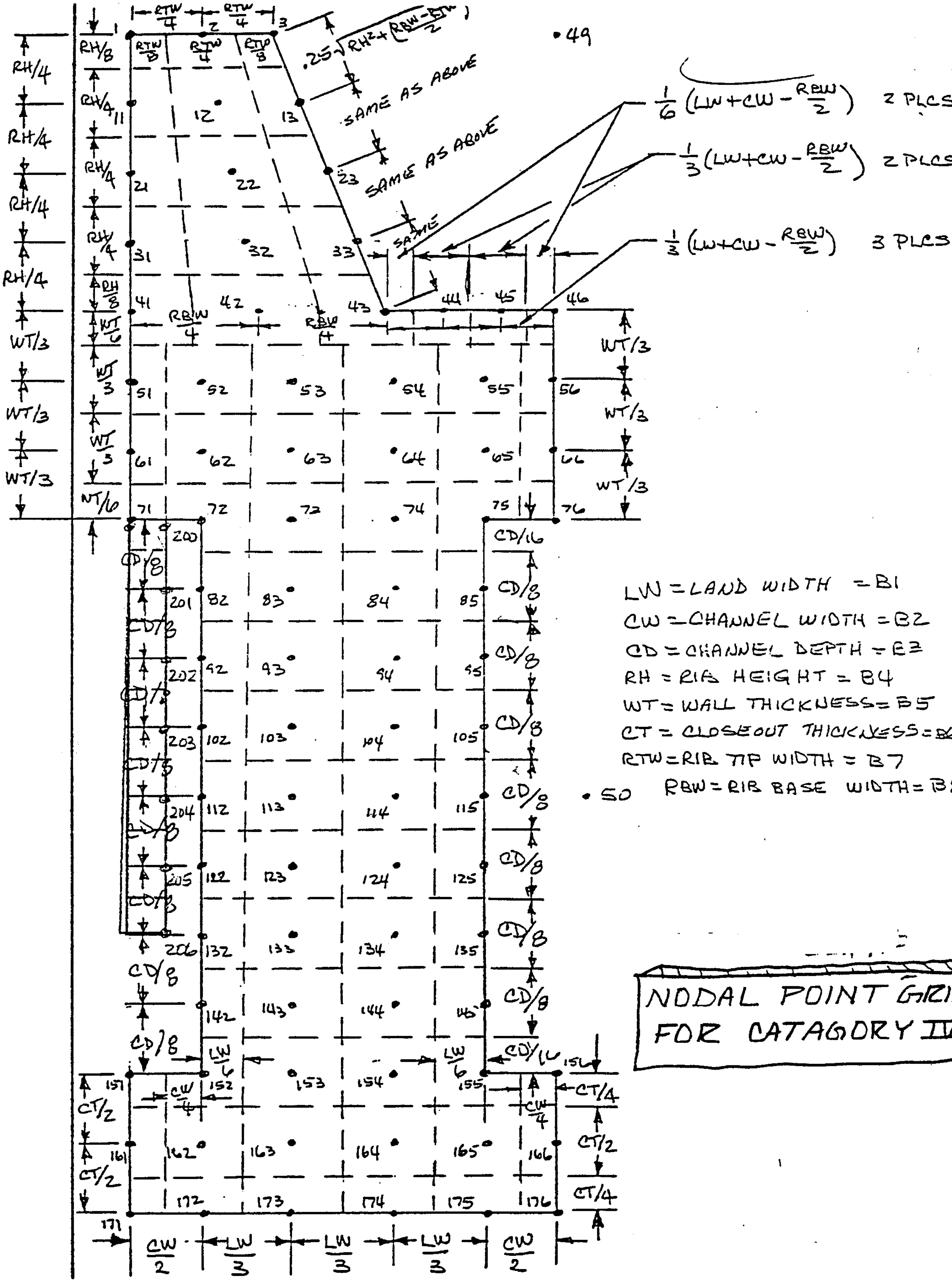
LOC. NUMBER — CONSTANTS (A)

1	-4.130E-02	-8.253E-02	-1.664E-01	-2.547E-01	-2.811E-01	-2.593E-01	-2.319E-01	-1.882E-01	-1.271E-01	-9.366E-02

LOCATIONS 11 THROUGH 40 EQUAL 0.

41	0.	0.	0.	0.	0.	0.	0.	0.	0.	-1.774E+00
51	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.532E-02

Rockwell International



LW = LAND WIDTH = B1
CW = CHANNEL WIDTH = B2
CD = CHANNEL DEPTH = B3
RH = RIB HEIGHT = B4
WT = WALL THICKNESS = B5
CT = CLOSEOUT THICKNESS = B6
RTW = RIB TIP WIDTH = B7
RBW = RIB BASE WIDTH = B8

NODAL POINT GRID
FOR CATAGORY IV

LOC. NUMBER	ADMITTANCES (Y)									
1	6.924E-03	1.102E-02	9.183E-03	7.890E-03	5.390E-03	1.972E-03	1.977E-03	9.909E-04	6.921E-03	1.102E-02
11	9.178E-03	7.886E-03	5.392E-03	2.899E-03	2.907E-03	3.206E-03	3.508E-03	3.516E-03	3.522E-03	3.527E-03
21	3.530E-03	3.533E-03	3.535E-03	9.727E-04	1.320E-03	6.625E-04	9.780E-04	2.902E-03	2.909E-03	3.208E-03
31	3.508E-03	3.515E-03	3.521E-03	3.526E-03	3.529E-03	3.532E-03	3.534E-03	9.551E-04	1.311E-03	6.595E-04
41	9.802E-04	2.906E-03	2.911E-03	3.208E-03	3.509E-03	3.517E-03	3.522E-03	3.527E-03	3.530E-03	3.533E-03
51	3.535E-03	9.729E-04	1.316E-03	6.600E-04	9.811E-04	1.979E-03	1.982E-03	9.923E-04	4.571E-04	9.121E-04
61	4.559E-04	4.594E-04	9.053E-04	4.514E-04	8.711E-04	1.077E-03	1.286E-03	1.498E-03	2.894E-03	5.684E-03
71	5.699E-03	1.742E-03	2.153E-03	2.570E-03	2.996E-03	3.014E-03	9.560E-03	9.586E-03	3.245E-03	3.255E-03
81	3.261E-03	3.266E-03	3.270E-03	3.272E-03	3.274E-03	3.276E-03	7.573E-04	7.600E-04	8.704E-04	1.075E-03
91	1.284E-03	1.498E-03	2.090E-03	3.987E-03	3.998E-03	6.492E-03	6.506E-03	6.518E-03	6.528E-03	6.536E-03
101	6.541E-03	6.545E-03	6.548E-03	5.989E-04	6.097E-04	5.807E-03	7.758E-03	7.775E-03	6.492E-03	6.506E-03
111	6.518E-03	6.528E-03	6.536E-03	6.541E-03	6.545E-03	6.548E-03	5.985E-04	6.088E-04	9.530E-03	9.585E-03
121	9.602E-03	3.248E-03	3.256E-03	3.262E-03	3.266E-03	3.270E-03	3.272E-03	3.274E-03	3.276E-03	7.558E-04
131	7.562E-04	5.695E-03	5.703E-03	5.711E-03	2.775E-03	6.518E-03	5.644E-03	1.937E-03	3.986E-05	2.410E-03
141	2.409E-03	4.624E-04	4.541E-04	8.500E-06	1.700E-05	3.438E-05	5.176E-05	5.176E-05	5.176E-05	6.012E-05
151	6.848E-05	6.848E-05	3.424E-05	2.427E-04	7.371E-04	5.170E-04	5.354E-04	5.496E-04	5.610E-04	5.700E-04
161	5.770E-04	5.827E-04	8.831E-04	5.982E-04	4.952E-04	7.499E-04	5.207E-04	5.370E-04	5.504E-04	5.613E-04
171	5.701E-04	5.771E-04	5.827E-04	8.832E-04	6.009E-04	1.937E-03	0.	0.	0.	0.

LOCATIONS 181 THROUGH 190 EQUAL 0.

191	4.759E-03	0.	0.	0.	0.	0.	0.	0.	0.	1.236E-01
201	1.236E-01	1.236E-01	1.236E-01	1.236E-01	1.236E-01	0.	0.	0.	0.	6.221E-05
211	1.245E-04	1.245E-04	1.245E-04	1.245E-04	1.245E-04	3.862E-04	0.	0.	0.	0.

LOCATIONS 221 THROUGH 2999 EQUAL 0.

LOC. NUMBER	TEMPERATURES (T)									
1	1.382E+03	1.387E+03	1.401E+03	0.	0.	0.	0.	0.	0.	0.
11	1.297E+03	1.303E+03	1.320E+03	0.	0.	0.	0.	0.	0.	0.
21	1.168E+03	1.175E+03	1.196E+03	0.	0.	0.	0.	0.	0.	0.
31	1.012E+03	1.018E+03	1.038E+03	0.	0.	0.	0.	0.	0.	0.
41	8.487E+02	8.440E+02	8.277E+02	7.516E+02	7.135E+02	7.075E+02	0.	0.	6.259E+03	2.520E+02
51	7.729E+02	7.576E+02	7.329E+02	6.984E+02	6.766E+02	6.733E+02	0.	0.	0.	0.
61	7.050E+02	6.869E+02	6.640E+02	6.462E+02	6.337E+02	6.381E+02	0.	0.	0.	0.
71	6.436E+02	6.196E+02	5.916E+02	5.922E+02	5.863E+02	6.044E+02	0.	0.	0.	0.
81	0.	5.245E+02	5.329E+02	5.307E+02	5.118E+02	0.	0.	0.	0.	0.
91	0.	4.638E+02	4.800E+02	4.784E+02	4.587E+02	0.	0.	0.	0.	0.
101	0.	4.207E+02	4.368E+02	4.359E+02	4.185E+02	0.	0.	0.	0.	0.
111	0.	3.886E+02	4.029E+02	4.025E+02	3.876E+02	0.	0.	0.	0.	0.
121	0.	3.644E+02	3.770E+02	3.768E+02	3.640E+02	0.	0.	0.	0.	0.
131	0.	3.463E+02	3.581E+02	3.580E+02	3.461E+02	0.	0.	0.	0.	0.
141	0.	3.320E+02	3.456E+02	3.455E+02	3.319E+02	0.	0.	0.	0.	0.
151	2.951E+02	3.174E+02	3.404E+02	3.404E+02	3.172E+02	2.889E+02	0.	0.	0.	0.
161	3.016E+02	3.141E+02	3.216E+02	3.225E+02	3.168E+02	3.087E+02	0.	0.	0.	0.
171	3.034E+02	3.127E+02	3.176E+02	3.187E+02	3.165E+02	3.126E+02	0.	0.	0.	0.

LOCATIONS 181 THROUGH 190 EQUAL 0.

191	0.	0.	0.	0.	0.	0.	0.	0.	0.	5.950E+02
201	5.933E+02	5.929E+02	5.929E+02	5.929E+02	5.929E+02	2.520E+02	0.	0.	0.	0.

35

CAT. IV:

.015 x .010 FIN

Rockwell International

DYTCQ DUMP

LOC. NUMBER	ADMITTANCES (Y)									
1	6.930E-03	1.103E-02	9.191E-03	7.897E-03	5.395E-03	1.974E-03	1.979E-03	9.921E-04	6.927E-03	1.103E-02
11	9.186E-03	7.892E-03	5.397E-03	2.901E-03	2.909E-03	3.208E-03	3.510E-03	3.517E-03	3.523E-03	3.528E-03
21	3.531E-03	3.533E-03	3.535E-03	9.777E-04	1.325E-03	6.652E-04	9.787E-04	2.904E-03	2.911E-03	3.210E-03
31	3.510E-03	3.516E-03	3.522E-03	3.527E-03	3.530E-03	3.532E-03	3.534E-03	9.608E-04	1.317E-03	6.623E-04
41	9.808E-04	2.907E-03	2.912E-03	3.210E-03	3.511E-03	3.518E-03	3.523E-03	3.528E-03	3.531E-03	3.533E-03
51	3.535E-03	9.778E-04	1.322E-03	6.628E-04	9.816E-04	1.980E-03	1.983E-03	9.928E-04	4.587E-04	9.153E-04
61	4.575E-04	4.609E-04	9.088E-04	4.532E-04	8.719E-04	1.077E-03	1.287E-03	1.499E-03	2.896E-03	5.691E-03
71	5.707E-03	1.743E-03	2.154E-03	2.573E-03	2.998E-03	3.016E-03	9.567E-03	9.593E-03	3.247E-03	3.256E-03
81	3.262E-03	3.267E-03	3.270E-03	3.273E-03	3.275E-03	3.276E-03	7.604E-04	7.629E-04	8.711E-04	1.076E-03
91	1.285E-03	1.499E-03	2.092E-03	3.990E-03	4.000E-03	6.495E-03	6.509E-03	6.520E-03	6.530E-03	6.537E-03
101	6.543E-03	6.546E-03	6.549E-03	6.021E-04	6.124E-04	5.810E-03	7.763E-03	7.779E-03	6.495E-03	6.509E-03
111	6.521E-03	6.530E-03	6.537E-03	6.543E-03	6.546E-03	6.549E-03	6.017E-04	6.115E-04	9.535E-03	9.590E-03
121	9.606E-03	3.249E-03	3.257E-03	3.263E-03	3.267E-03	3.270E-03	3.273E-03	3.275E-03	3.277E-03	7.589E-04
131	7.593E-04	5.698E-03	5.705E-03	5.713E-03	2.777E-03	6.523E-03	5.647E-03	1.938E-03	3.988E-05	2.410E-03
141	2.409E-03	4.637E-04	4.558E-04	8.500E-06	1.700E-05	3.438E-05	5.176E-05	5.176E-05	5.176E-05	6.012E-05
151	6.848E-05	6.848E-05	3.424E-05	2.479E-04	7.439E-04	5.205E-04	5.383E-04	5.521E-04	5.631E-04	5.718E-04
161	5.786E-04	5.841E-04	8.848E-04	5.990E-04	4.980E-04	7.543E-04	5.235E-04	5.396E-04	5.527E-04	5.634E-04
171	5.719E-04	5.786E-04	5.841E-04	8.849E-04	6.016E-04	1.938E-03	0.	0.	0.	0.

LOCATIONS 181 THROUGH 190 EQUAL 0.

191	4.789E-03	0.	0.	0.	0.	0.	0.	0.	0.	7.723E-02
201	7.723E-02	7.723E-02	7.723E-02	7.723E-02	7.723E-02	0.	0.	0.	0.	1.028E-04
211	2.059E-04	2.060E-04	2.060E-04	2.060E-04	2.060E-04	4.325E-04	0.	0.	0.	0.

LOCATIONS 221 THROUGH 2999 EQUAL 0.

ORIGINAL PAGE IS OF POOR QUALITY

15

LOC. NUMBER	TEMPERATURES (T)									
1	1.362E+03	1.367E+03	1.381E+03	0.	0.	0.	0.	0.	0.	0.
11	1.277E+03	1.282E+03	1.300E+03	0.	0.	0.	0.	0.	0.	0.
21	1.147E+03	1.154E+03	1.175E+03	0.	0.	0.	0.	0.	0.	0.
31	9.905E+02	9.963E+02	1.017E+03	0.	0.	0.	0.	0.	0.	0.
41	8.256E+02	8.220E+02	8.076E+02	7.360E+02	7.003E+02	6.955E+02	0.	0.	6.259E+03	2.520E+02
51	7.469E+02	7.373E+02	7.162E+02	6.841E+02	6.637E+02	6.614E+02	0.	0.	0.	0.
61	6.734E+02	6.672E+02	6.482E+02	6.328E+02	6.216E+02	6.267E+02	0.	0.	0.	0.
71	6.024E+02	6.018E+02	5.777E+02	5.800E+02	5.752E+02	5.937E+02	0.	0.	0.	0.
81	0.	5.123E+02	5.214E+02	5.202E+02	5.024E+02	0.	0.	0.	0.	0.
91	0.	4.547E+02	4.707E+02	4.696E+02	4.508E+02	0.	0.	0.	0.	0.
101	0.	4.136E+02	4.293E+02	4.286E+02	4.119E+02	0.	0.	0.	0.	0.
111	0.	3.828E+02	3.967E+02	3.964E+02	3.821E+02	0.	0.	0.	0.	0.
121	0.	3.597E+02	3.719E+02	3.717E+02	3.594E+02	0.	0.	0.	0.	0.
131	0.	3.423E+02	3.537E+02	3.536E+02	3.422E+02	0.	0.	0.	0.	0.
141	0.	3.287E+02	3.417E+02	3.416E+02	3.285E+02	0.	0.	0.	0.	0.
151	2.934E+02	3.146E+02	3.367E+02	3.367E+02	3.145E+02	2.874E+02	0.	0.	0.	0.
161	2.996E+02	3.115E+02	3.187E+02	3.195E+02	3.141E+02	3.063E+02	0.	0.	0.	0.
171	3.013E+02	3.102E+02	3.149E+02	3.160E+02	3.138E+02	3.101E+02	0.	0.	0.	0.

LOCATIONS 181 THROUGH 190 EQUAL 0.

191	0.	0.	0.	0.	0.	0.	0.	0.	0.	5.356E+02
201	5.319E+02	5.311E+02	5.311E+02	5.311E+02	5.311E+02	2.520E+02	0.	0.	0.	0.

36.

CAT. IV:
.024 x .010 FIN

Rockwell International

LOC. NUMBER	ADMITTANCES (Y)									
1	6.928E-03	1.103E-02	9.188E-03	7.894E-03	5.392E-03	1.973E-03	1.978E-03	9.915E-04	6.925E-03	1.102E-02
11	9.183E-03	7.890E-03	5.395E-03	2.900E-03	2.908E-03	3.207E-03	3.509E-03	3.517E-03	3.523E-03	3.527E-03
21	3.531E-03	3.533E-03	3.535E-03	9.757E-04	1.323E-03	6.642E-04	9.784E-04	2.903E-03	2.910E-03	3.209E-03
31	3.509E-03	3.516E-03	3.522E-03	3.526E-03	3.530E-03	3.532E-03	3.534E-03	9.585E-04	1.315E-03	6.612E-04
41	9.805E-04	2.906E-03	2.912E-03	3.209E-03	3.510E-03	3.517E-03	3.523E-03	3.527E-03	3.531E-03	3.533E-03
51	3.535E-03	9.759E-04	1.319E-03	6.617E-04	9.814E-04	1.979E-03	1.982E-03	9.926E-04	4.581E-04	9.141E-04
61	4.569E-04	4.603E-04	9.074E-04	4.525E-04	8.716E-04	1.077E-03	1.286E-03	1.499E-03	2.895E-03	5.688E-03
71	5.703E-03	1.743E-03	2.154E-03	2.572E-03	2.997E-03	3.015E-03	9.564E-03	9.589E-03	3.246E-03	3.255E-03
81	3.262E-03	3.266E-03	3.270E-03	3.273E-03	3.275E-03	3.276E-03	7.592E-04	7.618E-04	8.708E-04	1.076E-03
91	1.285E-03	1.498E-03	2.091E-03	3.988E-03	3.999E-03	6.494E-03	6.507E-03	6.519E-03	6.529E-03	6.536E-03
101	6.542E-03	6.546E-03	6.548E-03	6.008E-04	6.114E-04	5.809E-03	7.761E-03	7.777E-03	6.494E-03	6.508E-03
111	6.520E-03	6.529E-03	6.537E-03	6.542E-03	6.546E-03	6.548E-03	6.004E-04	6.105E-04	9.533E-03	9.588E-03
121	9.604E-03	3.248E-03	3.256E-03	3.262E-03	3.267E-03	3.270E-03	3.273E-03	3.275E-03	3.276E-03	7.577E-04
131	7.581E-04	5.697E-03	5.704E-03	5.712E-03	2.776E-03	6.521E-03	5.646E-03	1.938E-03	3.987E-05	2.410E-03
141	2.409E-03	4.632E-04	4.552E-04	8.500E-06	1.700E-05	3.438E-05	5.176E-05	5.176E-05	5.176E-05	6.012E-05
151	6.848E-05	6.848E-05	3.424E-05	1.226E-04	7.407E-04	5.189E-04	5.370E-04	5.511E-04	5.622E-04	5.710E-04
161	5.779E-04	5.835E-04	8.841E-04	5.987E-04	4.969E-04	7.525E-04	5.223E-04	5.385E-04	5.517E-04	5.625E-04
171	5.712E-04	5.780E-04	5.836E-04	8.842E-04	6.013E-04	1.938E-03	0.	0.	0.	0.

LOCATIONS 181 THROUGH 190 EQUAL 0.

191	4.765E-03	0.	0.	0.	0.	0.	0.	0.	0.	1.854E-01
201	1.854E-01	1.854E-01	1.854E-01	1.854E-01	1.854E-01	0.	0.	0.	0.	6.347E-05
211	1.270E-04	1.271E-04	1.271E-04	1.271E-04	1.271E-04	5.406E-04	0.	0.	0.	0.

LOCATIONS 221 THROUGH 2999 EQUAL 0.

16

LOC. NUMBER	TEMPERATURES (T)									
1	1.370E+03	1.375E+03	1.389E+03	0.	0.	0.	0.	0.	0.	0.
11	1.284E+03	1.290E+03	1.308E+03	0.	0.	0.	0.	0.	0.	0.
21	1.156E+03	1.163E+03	1.184E+03	0.	0.	0.	0.	0.	0.	0.
31	9.997E+02	1.005E+03	1.026E+03	0.	0.	0.	0.	0.	0.	0.
41	8.360E+02	8.318E+02	8.165E+02	7.427E+02	7.059E+02	7.005E+02	0.	0.	6.259E+03	2.520E+02
51	7.591E+02	7.464E+02	7.235E+02	6.902E+02	6.692E+02	6.664E+02	0.	0.	0.	0.
61	6.888E+02	6.762E+02	6.551E+02	6.385E+02	6.267E+02	6.314E+02	0.	0.	0.	0.
71	6.232E+02	6.099E+02	5.838E+02	5.852E+02	5.798E+02	5.981E+02	0.	0.	0.	0.
81	0.	5.177E+02	5.264E+02	5.247E+02	5.063E+02	0.	0.	0.	0.	0.
91	0.	4.587E+02	4.747E+02	4.733E+02	4.541E+02	0.	0.	0.	0.	0.
101	0.	4.166E+02	4.324E+02	4.317E+02	4.146E+02	0.	0.	0.	0.	0.
111	0.	3.852E+02	3.993E+02	3.989E+02	3.844E+02	0.	0.	0.	0.	0.
121	0.	3.616E+02	3.740E+02	3.738E+02	3.612E+02	0.	0.	0.	0.	0.
131	0.	3.439E+02	3.554E+02	3.554E+02	3.437E+02	0.	0.	0.	0.	0.
141	0.	3.300E+02	3.432E+02	3.432E+02	3.299E+02	0.	0.	0.	0.	0.
151	2.940E+02	3.157E+02	3.382E+02	3.382E+02	3.155E+02	2.879E+02	0.	0.	0.	0.
161	3.004E+02	3.125E+02	3.198E+02	3.207E+02	3.152E+02	3.072E+02	0.	0.	0.	0.
171	3.021E+02	3.112E+02	3.159E+02	3.170E+02	3.148E+02	3.110E+02	0.	0.	0.	0.

LOCATIONS 181 THROUGH 190 EQUAL 0.

191	0.	0.	0.	0.	0.	0.	0.	0.	0.	5.571E+02
201	5.556E+02	5.553E+02	5.553E+02	5.553E+02	5.553E+02	2.520E+02	0.	0.	0.	0.
	201	202	203	204	205	206				

#37

CAT. IV.

.015 x .015 FIN

Rockwell International

LOC. NUMBER	ADMITTANCES (Y)									
1	6.928E-03	1.103E-02	9.188E-03	7.894E-03	5.393E-03	1.973E-03	1.978E-03	9.917E-04	6.925E-03	1.102E-02
11	9.183E-03	7.890E-03	5.395E-03	2.900E-03	2.908E-03	3.208E-03	3.509E-03	3.517E-03	3.523E-03	3.527E-03
21	3.531E-03	3.533E-03	3.535E-03	9.759E-04	1.323E-03	6.642E-04	9.785E-04	2.903E-03	2.910E-03	3.209E-03
31	3.509E-03	3.516E-03	3.522E-03	3.526E-03	3.530E-03	3.532E-03	3.534E-03	9.587E-04	1.315E-03	6.613E-04
41	9.806E-04	2.907E-03	2.912E-03	3.209E-03	3.510E-03	3.517E-03	3.523E-03	3.527E-03	3.531E-03	3.533E-03
51	3.535E-03	9.761E-04	1.320E-03	6.618E-04	9.814E-04	1.979E-03	1.982E-03	9.926E-04	4.582E-04	9.141E-04
61	4.569E-04	4.603E-04	9.075E-04	4.526E-04	8.716E-04	1.077E-03	1.286E-03	1.499E-03	2.895E-03	5.688E-03
71	5.704E-03	1.743E-03	2.154E-03	2.572E-03	2.997E-03	3.015E-03	9.564E-03	9.590E-03	3.246E-03	3.255E-03
81	3.262E-03	3.266E-03	3.270E-03	3.273E-03	3.275E-03	3.276E-03	7.592E-04	7.619E-04	8.709E-04	1.076E-03
91	1.285E-03	1.499E-03	2.091E-03	3.989E-03	4.000E-03	6.494E-03	6.508E-03	6.520E-03	6.529E-03	6.537E-03
101	6.542E-03	6.546E-03	6.548E-03	6.009E-04	6.114E-04	5.809E-03	7.761E-03	7.777E-03	6.494E-03	6.508E-03
111	6.520E-03	6.529E-03	6.537E-03	6.542E-03	6.546E-03	6.548E-03	6.005E-04	6.105E-04	9.533E-03	9.588E-03
121	9.605E-03	3.248E-03	3.256E-03	3.262E-03	3.267E-03	3.270E-03	3.273E-03	3.275E-03	3.276E-03	7.578E-04
131	7.582E-04	5.697E-03	5.705E-03	5.712E-03	2.776E-03	6.522E-03	5.646E-03	1.938E-03	3.988E-05	2.410E-03
141	2.409E-03	4.632E-04	4.552E-04	8.500E-06	1.700E-05	3.438E-05	5.176E-05	5.176E-05	5.176E-05	6.012E-05
151	6.848E-05	6.848E-05	3.424E-05	1.230E-04	7.414E-04	5.192E-04	5.372E-04	5.512E-04	5.623E-04	5.711E-04
161	5.780E-04	5.836E-04	8.842E-04	5.987E-04	4.970E-04	7.527E-04	5.225E-04	5.386E-04	5.519E-04	5.626E-04
171	5.713E-04	5.781E-04	5.836E-04	8.843E-04	6.014E-04	1.938E-03	0.	0.	0.	0.
	LOCATIONS 181 THROUGH 190 EQUAL 0.									
191	4.766E-03	0.	0.	0.	0.	0.	0.	0.	0.	1.158E-01
201	1.158E-01	1.158E-01	1.158E-01	1.158E-01	1.158E-01	0.	0.	0.	0.	1.021E-04
211	2.044E-04	2.045E-04	2.045E-04	2.045E-04	2.045E-04	5.870E-04	0.	0.	0.	0.
	LOCATIONS 221 THROUGH 2999 EQUAL 0.									

17

LOC. NUMBER	TEMPERATURES (T)									
1	1.369E+03	1.374E+03	1.388E+03	0.	0.	0.	0.	0.	0.	0.
11	1.284E+03	1.290E+03	1.307E+03	0.	0.	0.	0.	0.	0.	0.
21	1.155E+03	1.162E+03	1.183E+03	0.	0.	0.	0.	0.	0.	0.
31	9.983E+02	1.004E+03	1.024E+03	0.	0.	0.	0.	0.	0.	0.
41	8.339E+02	8.299E+02	8.148E+02	7.416E+02	7.050E+02	6.998E+02	0.	0.	6.259E+03	2.520E+02
51	7.563E+02	7.446E+02	7.222E+02	6.892E+02	6.684E+02	6.657E+02	0.	0.	0.	0.
61	6.848E+02	6.743E+02	6.539E+02	6.376E+02	6.260E+02	6.308E+02	0.	0.	0.	0.
71	6.173E+02	6.082E+02	5.827E+02	5.844E+02	5.792E+02	5.975E+02	0.	0.	0.	0.
81	0.	5.166E+02	5.255E+02	5.240E+02	5.058E+02	0.	0.	0.	0.	0.
91	0.	4.580E+02	4.740E+02	4.728E+02	4.536E+02	0.	0.	0.	0.	0.
101	0.	4.161E+02	4.320E+02	4.313E+02	4.143E+02	0.	0.	0.	0.	0.
111	0.	3.849E+02	3.989E+02	3.986E+02	3.841E+02	0.	0.	0.	0.	0.
121	0.	3.614E+02	3.737E+02	3.735E+02	3.610E+02	0.	0.	0.	0.	0.
131	0.	3.438E+02	3.553E+02	3.552E+02	3.436E+02	0.	0.	0.	0.	0.
141	0.	3.299E+02	3.431E+02	3.430E+02	3.297E+02	0.	0.	0.	0.	0.
151	2.940E+02	3.156E+02	3.381E+02	3.381E+02	3.154E+02	2.879E+02	0.	0.	0.	0.
161	3.003E+02	3.124E+02	3.198E+02	3.206E+02	3.151E+02	3.072E+02	0.	0.	0.	0.
171	3.020E+02	3.111E+02	3.158E+02	3.170E+02	3.148E+02	3.110E+02	0.	0.	0.	0.
	LOCATIONS 181 THROUGH 190 EQUAL 0.									
191	0.	0.	0.	0.	0.	0.	0.	0.	0.	5.477E+02
201	5.451E+02	5.446E+02	5.446E+02	5.446E+02	5.446E+02	2.520E+02	0.	0.	0.	0.

#38

CAT. III.
.024 x .015 FIN

Rockwell International

CHANNEL EVALUATION CRITERIA RATING SCALES

DURABILITY (STRUCTURE/LIFE)

Based primarily on increased material durability resulting from a decrease in maximum material temperature (NARloy -Z) from enhanced coolant channel design, as compared with baseline channel.

RATING	DESCRIPTION
10	Major temperature reduction yeilding a large life enhancement. (greater than 150°F reduction).
8	Significant temperature reduction providing durability that exceeds design requirements. (100°F to 150°F reduction).
5	Durability improved, but occasional material roughening at rib tips (1400°F +) remains. (50°F to 100°F reduction)
2	Material temperature improved but still too high to provide reasonable life at normal operating conditions. (0°F to 50°F reduction).
0	Material temperature remains the same or increases, yielding no improvement or a decrease in material durability.

Durability Rating

COOLANT PRESSURE DROP

Ratings based on increase/decrease in coolant pressure drop (ΔP) through chamber, as compared with baseline .040 x .080 channel.

RATING	DESCRIPTION
10	Significant decrease in ΔP
9	No significant change in ΔP ($\pm$ 10% from baseline)
8	10 - 25% ΔP increase
7	25 - 50% ΔP increase
6	50 - 75% ΔP increase
5	75 - 100% ΔP increase
3	Large increase in ΔP (>100%), but remains within the bounds of consideration.
0	ΔP increase too high to justify further consideration.

Pressure ΔP Rating

BOUNDARY LAYER GROWTH

Based on estimated boundary layer (b.l.) growth over channel length.

RATING	DESCRIPTION
10	Optimal b.l. growth within channel/fin contour. No significant degradation in material cooling enhancement over length of channel due to b.l. effects.
8	Well defined b.l. through channel. Some degradation in channel cooling enhancement.
6	Boundary layer blends to fill narrow or finned contours prior to end of channel.
3	Boundary layer blends to fill narrow or finned contour over most of channel length. Channel cooling enhancement severly reduced.
0	Contour fills quickly - negligible cooling improvement derived from enhanced channel geometry.

Boundary Layer Risk Rating

PRODUCIBILITY RISK

Based on scale, aspect ratio and contour complexity.

RATING	DESCRIPTION
10	Simple in shape; moderate feature size (approximately .040)
8	Basic shape; higher aspect ratio (i.e. deeper cut).
6	Additional contour complexity: single fin.
4	Smaller feature size; double fin.
2	Combinations of fins and high aspect ratio channels.
0	Size and complexity requirements make fabrication prohibitively difficult and expensive.

Producibility Rating

HEAT TRANSFER ENHANCEMENT

Based on increase in total Q avilable from combustor (.060 Ribbed) as compared to baseline .040 x .080 channel.

RATING	DESCRIPTION
10	Reflects a great improvement in total energy extracted (20% increase).
8	Significant increase (10-20%).
6	Modest increase (5-10%).
3	Small increase (0-5%).
0	Negligible increase, or decrease, in total energy available.

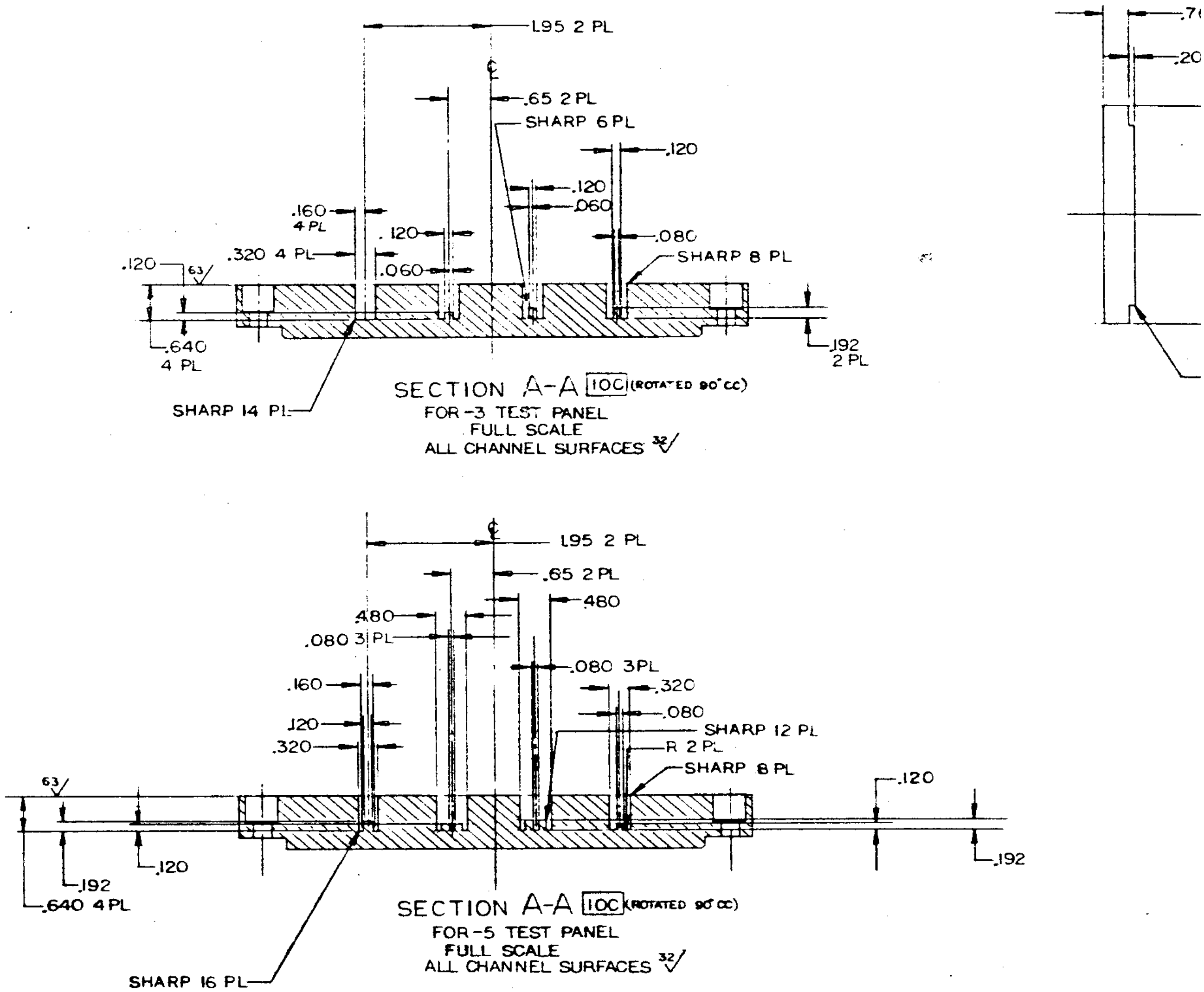
Heat Transfer Rating

APPENDIX F
CHANNEL COLD FLOW TESTS

CHANNEL COLD FLOW FIXTURE DRAWINGS

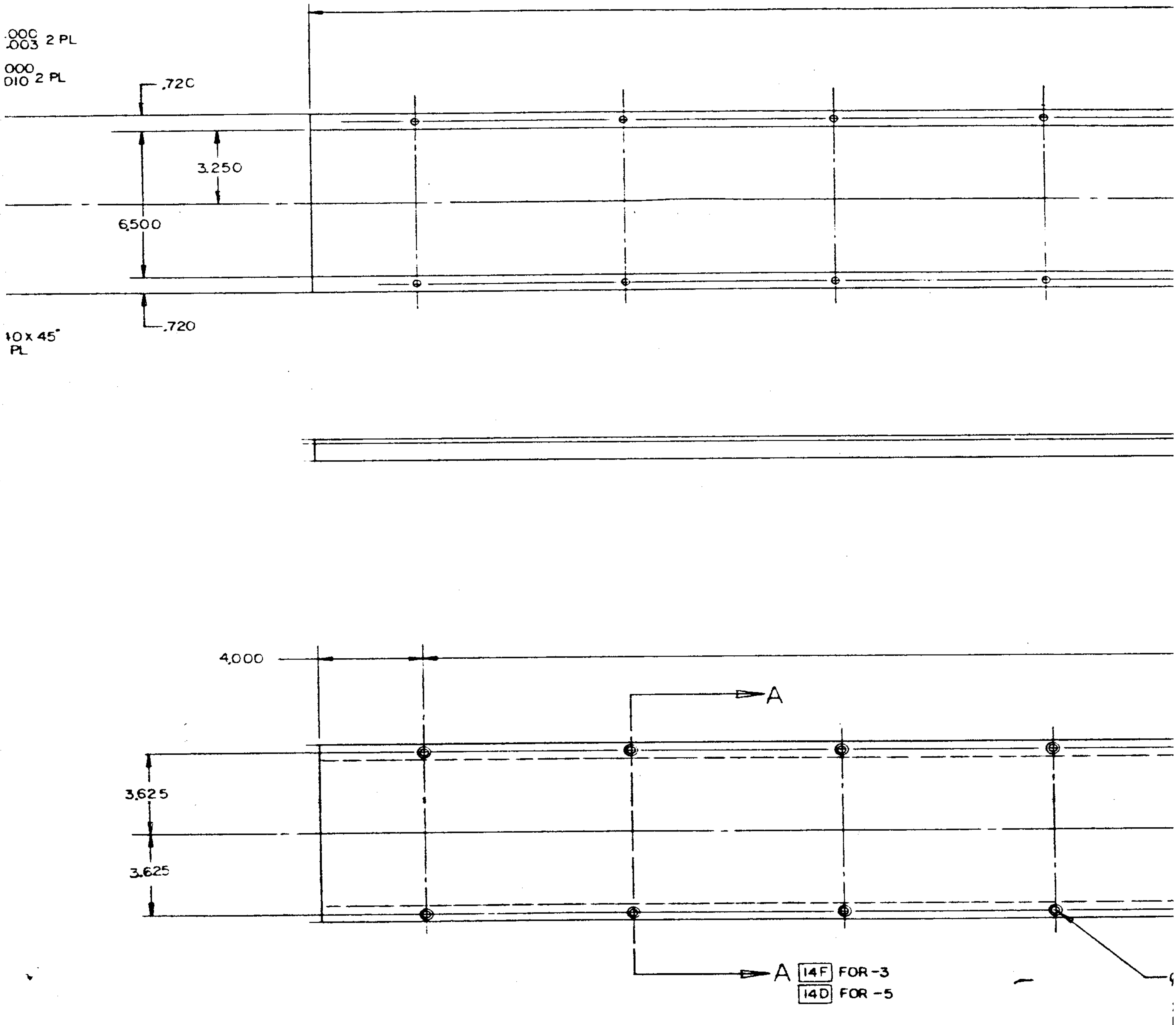
TITLE	DWG #
TEST PANELS	7R0019016
SPACERS	7R0019008

TEST DATA



ORIGINAL PAGE IS
OF POOR QUALITY

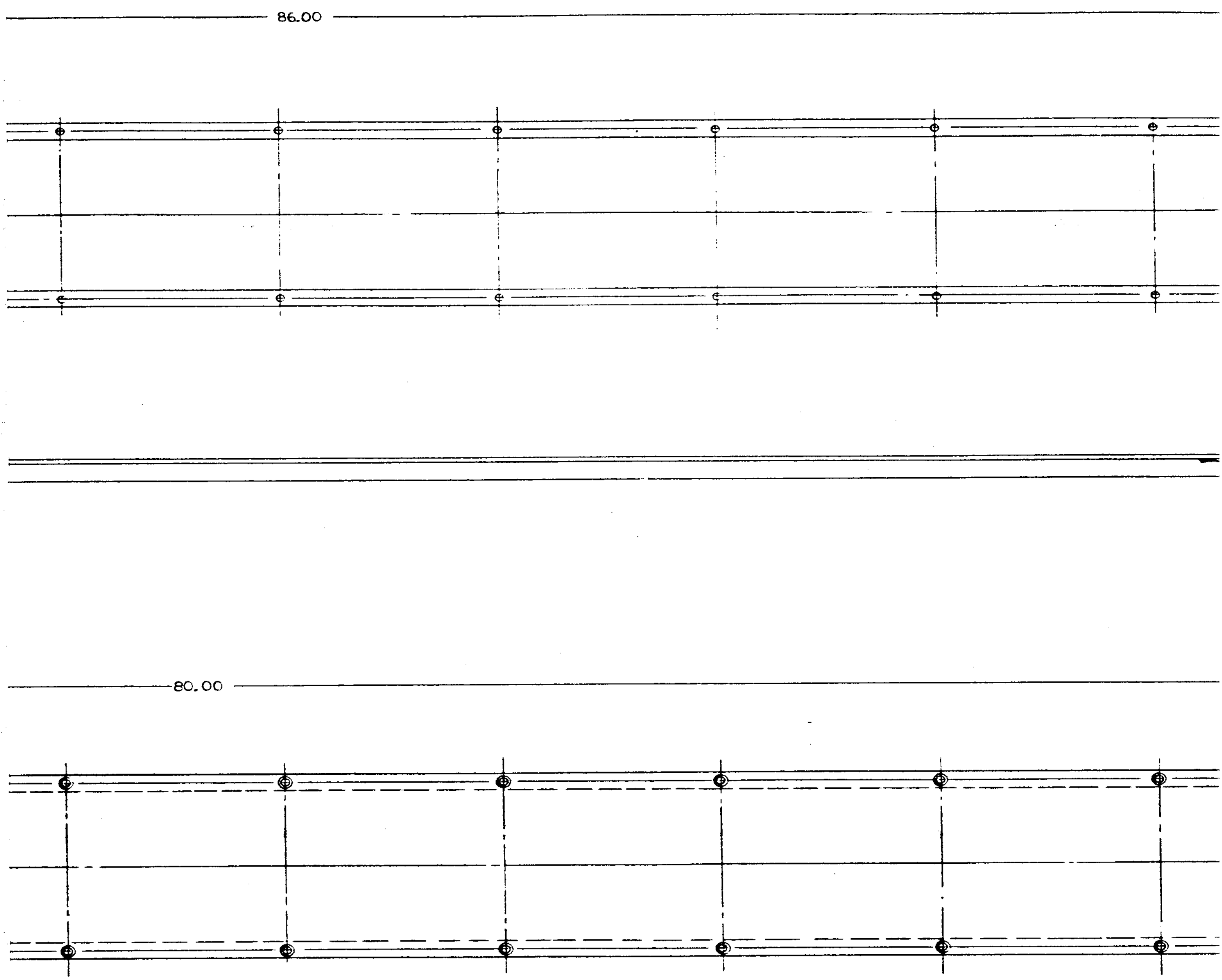
FOLDOUT FRAME



2 FOLDOUT FRAME

RLAP AREA ●

8 | 7 | 6 | 5



THRU
RE Ø .500 .47 DEEP
(11 PL EQ SP ON 80.00
SIDE)

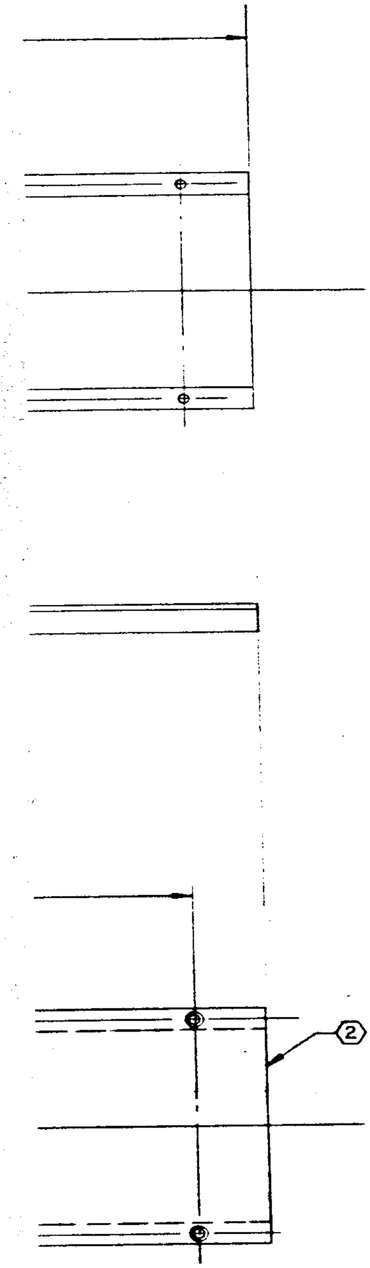
—TEST PANELS

3 FOLDOUT FRAME

(3) CHROMIC ACI
COLOR AND F
(2) IDENTIFY PE
1. MACHINE PER

8 | 7 | 6 | 5

ERLAP AREA ●



REVISIONS

ZONE	REV	DESCRIPTION	DATE	APPROVED
		1. MAY BE REWORKED 3. RECORD CHANGE 2. CANNOT BE REWORKED 4. NOW SHOP PRACTICE 5. PARTS MADE OK		

ORIGINAL PAGE IS
OF POOR QUALITY

4 FOLDOUT FRAME

FOR
INFORMATION

ODIZE(BLACK) PER RA0109-021, TYPE I
H ONLY PER PRZ-10.
0104-008 IMPRESSION STAMP
0103-016

	NO.	DESCRIPTION	MATERIAL	SPECIFICATION
3	-5	TEST PANEL	6061-T6 ALUM	COMMERCIAL
3	-3	TEST PANEL	6061-T6 ALUM	COMMERCIAL

HEAT TREAT
FINISH NOTED
MATL NOTED

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES AND APPLY PRIOR TO FINISH.
DO NOT SCALE PRINT

DRN F BEATMON DATE 1-23-85

Rockwell International Corporation
Rocketdyne Division
Canoga Park, California

TEST PANELS, COLD AIR FLOW TEST FIXTURE

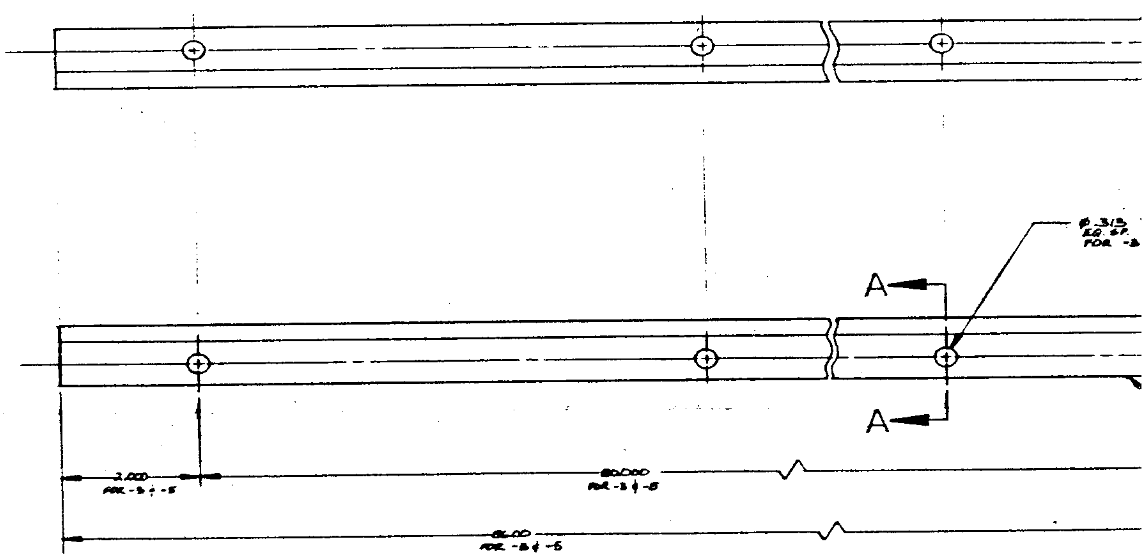
SIZE J | FSCM NO 02602 | DWG NO 7R0019016

SCALE 1/2

7R0019016

FOLDOUT FRAME

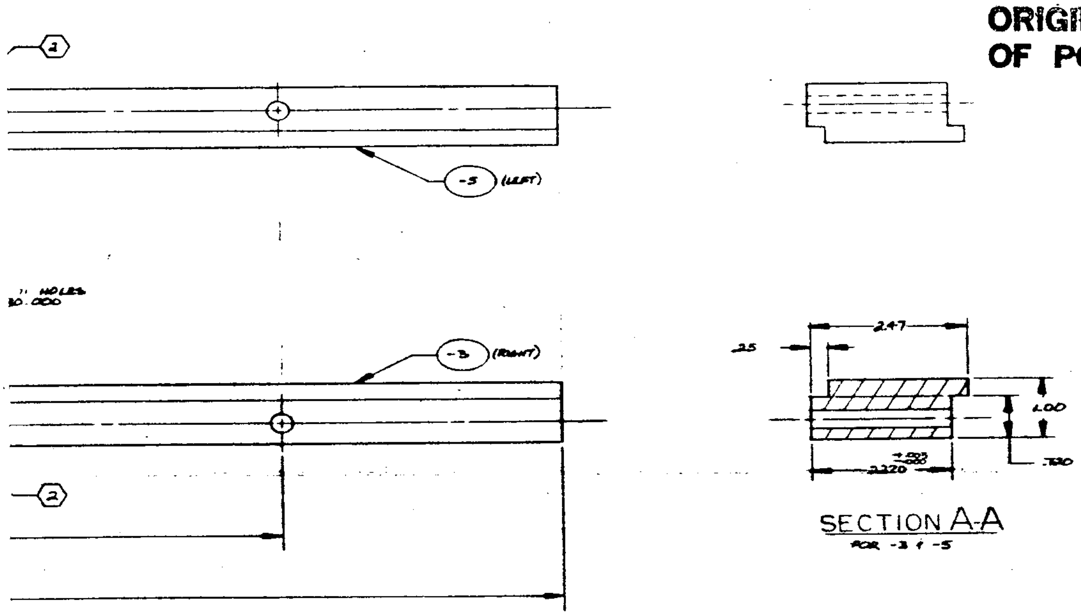
FOLDOUT FRAME



ORIGINAL PAGE IS
OF POOR QUALITY

2 FOLDOUT FRAME

ORIGINAL PAGE IS OF POOR QUALITY



FOR INFORMATION

-5	6061-T6 ALUMINUM		COMMERCIAL
-3	6061-T6 ALUMINUM		COMMERCIAL
DASH NO.	MATERIAL	SIZE	SPECIFICATION

T MIRROR IMAGES

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND APPLY PRIOR TO FINISH.

DO NOT SCALE PRINT

DRN D. J. BUCZA

Rockwell International Corporation
Rocketdyne Division
Canoga Park, California

SPACERS, COLD AIR FLOW TEST FIXTURE

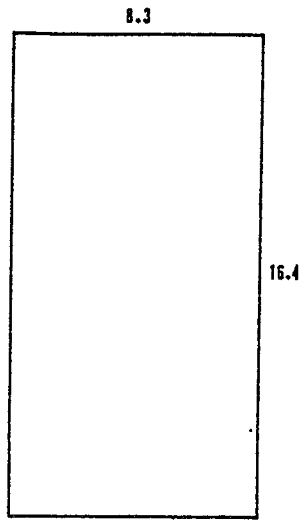
SIZE E | FSCM NO 02602 | DWG NO 7R0019008

SCALE FULL

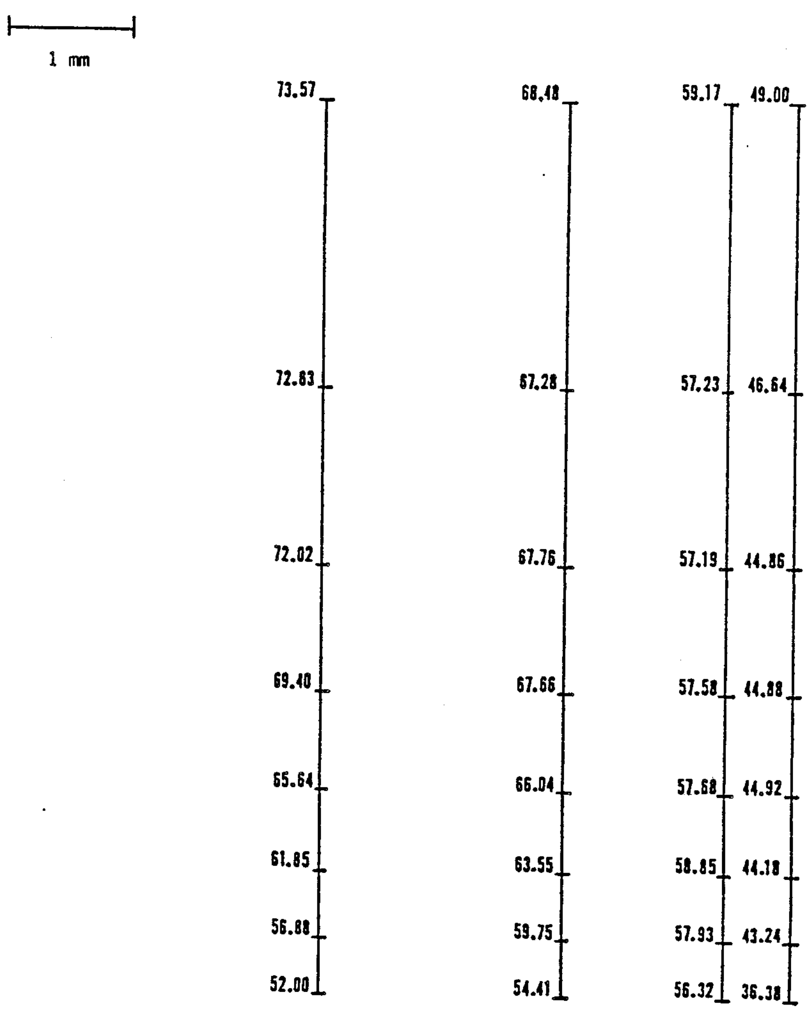
7R0019008

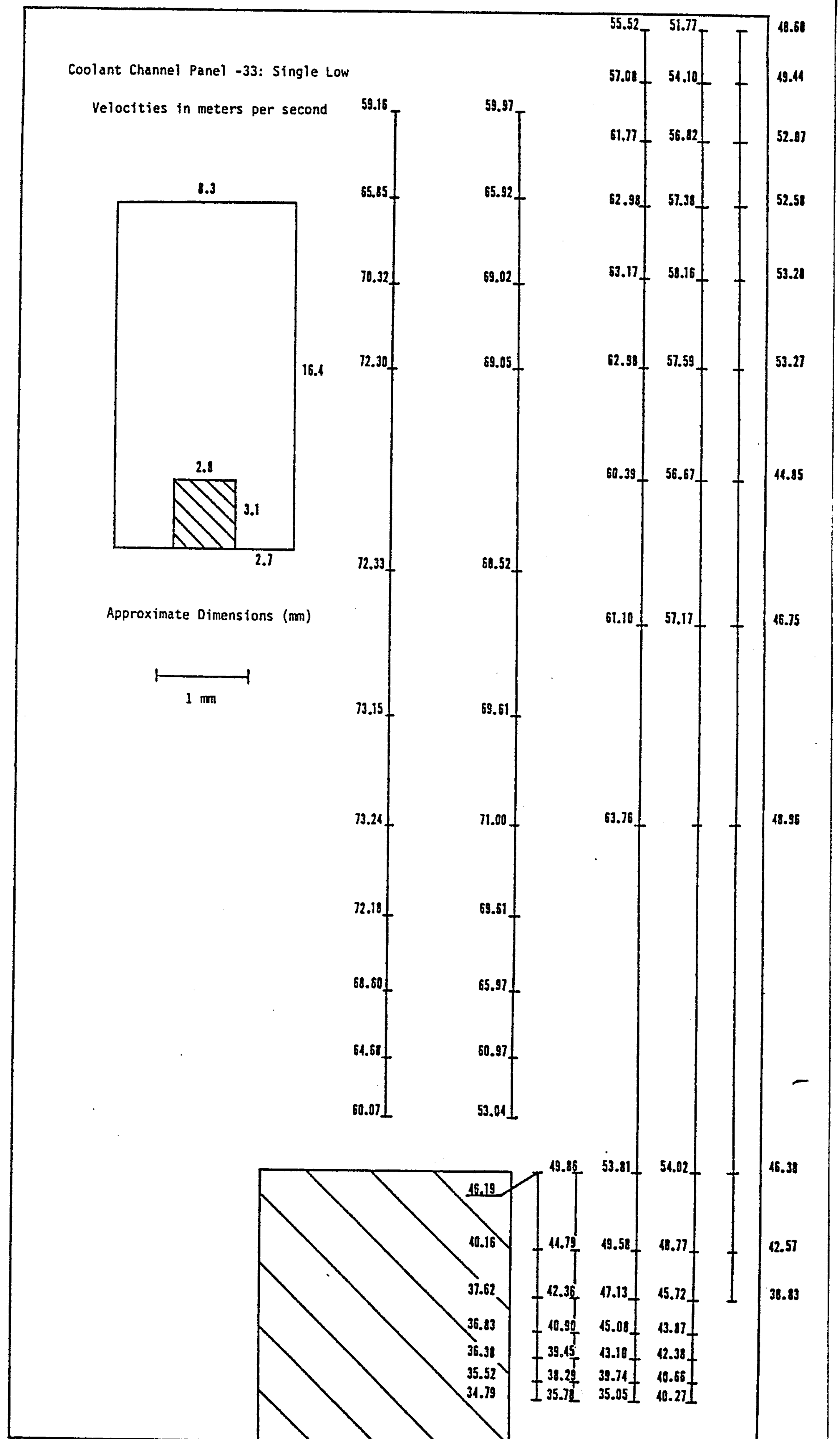
Coolant Channel Panel -34: Empty Baseline

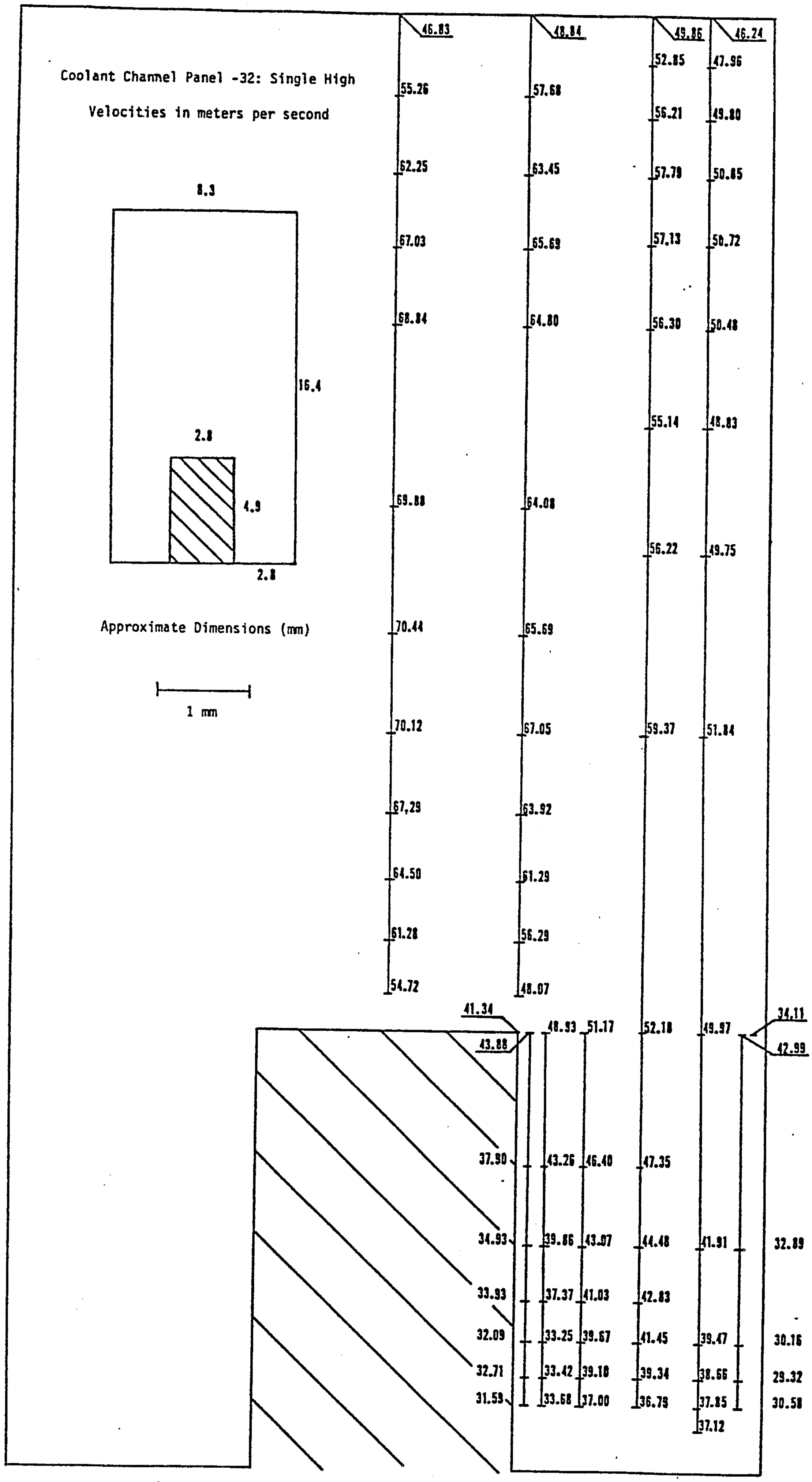
Velocities in meters per second



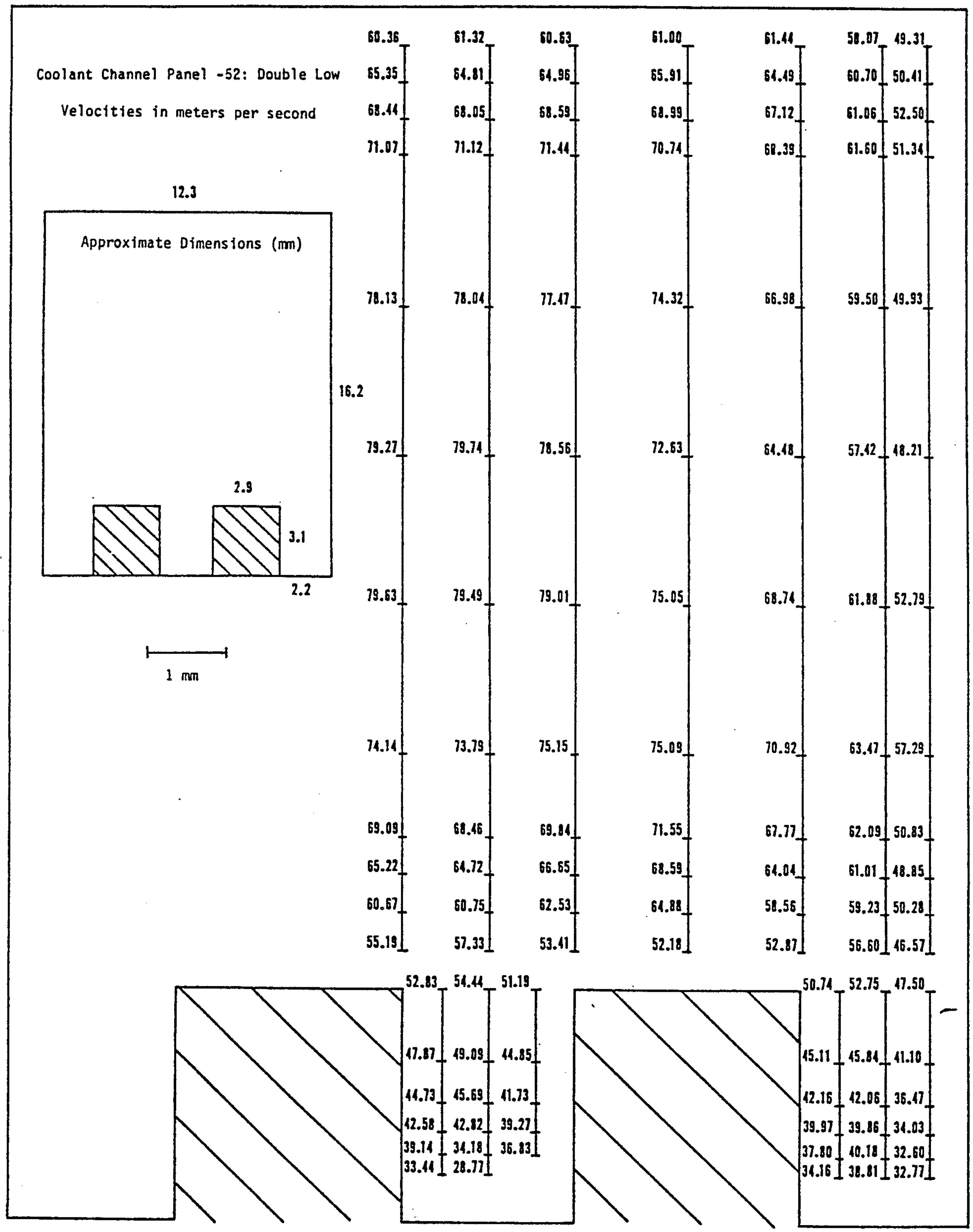
Approximate Dimensions (mm)

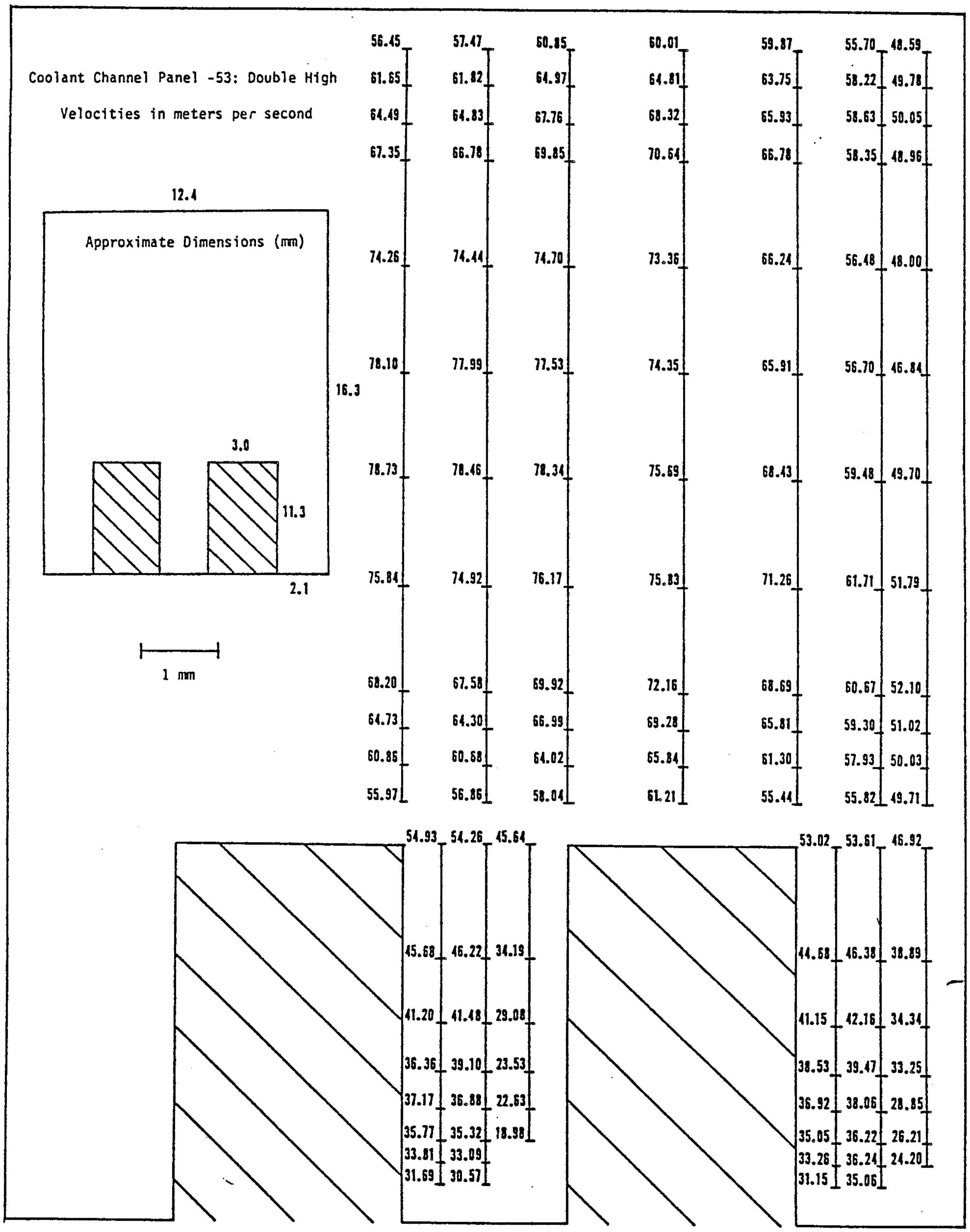



Coolant Channel Panel -33: Single Low
Velocities in meters per second
8.3
16.4
2.8
3.1
2.7
Approximate Dimensions (mm)
1 mm
59.16
65.85
70.32
72.30
72.33
73.15
73.24
72.18
68.60
64.68
60.07
59.97
65.92
69.02
69.05
68.52
69.61
71.00
69.61
65.97
60.97
53.04
55.52
57.08
61.77
62.98
63.17
62.98
60.39
61.10
63.76
53.81
49.58
47.13
45.08
43.18
39.74
35.05
51.77
54.10
56.82
57.38
58.16
57.59
56.67
57.17
54.02
48.77
45.72
43.87
42.38
40.66
40.27
48.68
49.44
52.87
52.58
53.28
53.27
44.85
46.75
48.96
46.38
42.57
38.83
49.86
44.79
42.36
40.90
39.45
38.29
35.78
46.19
40.16
37.62
36.83
36.38
35.52
34.79


Coolant Channel Panel -32: Single High
Velocities in meters per second
8.3
16.4
2.8
4.9
2.8
Approximate Dimensions (mm)
1 mm
46.83
55.26
62.25
67.03
68.84
69.88
70.44
70.12
67.29
64.50
61.28
54.72
48.84
57.68
63.45
65.69
64.80
64.08
65.69
67.05
63.92
61.29
56.29
48.07
49.86
52.85
56.21
57.79
57.13
56.30
55.14
56.22
59.37
52.18
47.35
44.48
42.83
41.45
39.34
36.79
46.24
47.96
49.80
50.85
50.72
50.48
48.83
49.75
51.84
49.97
41.91
39.47
38.66
37.85
37.12
41.34
43.88
37.90
34.93
33.93
32.09
32.71
31.59
48.93
43.26
39.86
37.37
33.25
33.42
33.68
51.17
46.40
43.07
41.03
39.67
39.18
37.00
34.11
42.99
32.89
30.16
29.32
30.58

6

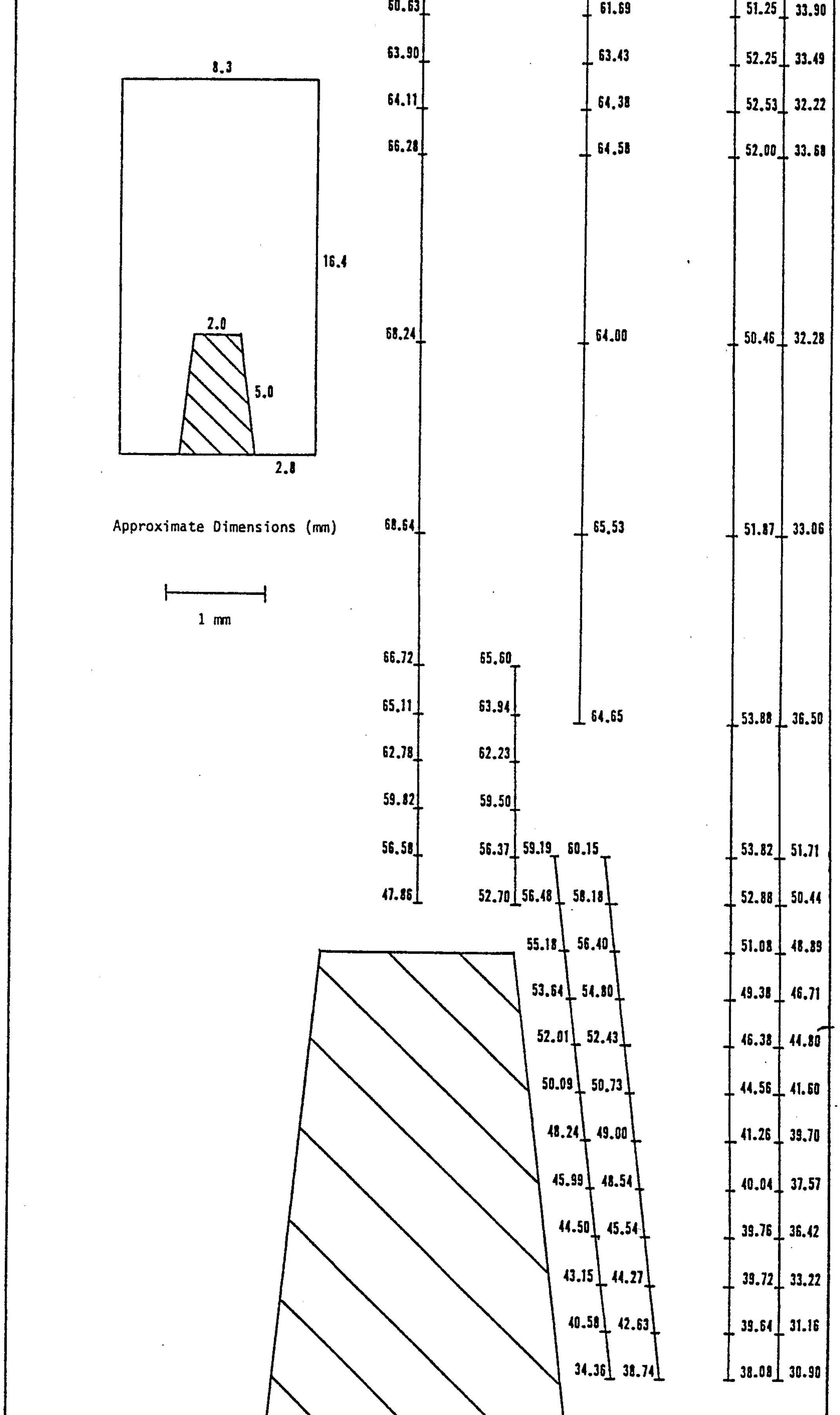

Coolant Channel Panel -52: Double Low
Velocities in meters per second
12.3
Approximate Dimensions (mm)
16.2
2.9
3.1
2.2
1 mm
60.36 65.35 68.44 71.07 78.13 79.27 79.63 74.14 69.09 65.22 60.67 55.19
61.32 64.81 68.05 71.12 78.04 79.74 79.49 73.79 68.46 64.72 60.75 57.33
60.63 64.96 68.59 71.44 77.47 78.56 79.01 75.15 69.84 66.65 62.53 53.41
61.00 65.91 68.99 70.74 74.32 72.63 75.05 75.09 71.55 68.59 64.88 52.18
61.44 64.49 67.12 68.39 66.98 64.48 68.74 70.92 67.77 64.04 58.56 52.87
58.07 60.70 61.06 61.60 59.50 57.42 61.88 63.47 62.09 61.01 59.23 56.60
49.31 50.41 52.50 51.34 49.93 48.21 52.79 57.29 50.83 48.85 50.28 46.57
52.83 47.87 44.73 42.58 39.14 33.44
54.44 49.09 45.69 42.82 34.18 28.77
51.19 44.85 41.73 39.27 36.83
50.74 45.11 42.16 39.97 37.80 34.16
52.75 45.84 42.06 39.86 40.18 38.81
47.50 41.10 36.47 34.03 32.60 32.77



Coolant Channel Panel -53: Double High
Velocities in meters per second
Approximate Dimensions (mm)
12.4
16.3
3.0
11.3
2.1
1 mm
56.45 61.65 64.49 67.35 74.26 78.10 78.73 75.84 68.20 64.73 60.86 55.97
57.47 61.82 64.83 66.78 74.44 77.99 78.46 74.92 67.58 64.30 60.68 56.86
60.85 64.97 67.76 69.85 74.70 77.53 78.34 76.17 69.92 66.99 64.02 58.04
60.01 64.81 68.32 70.64 73.36 74.35 75.69 75.83 72.16 69.28 65.84 61.21
59.87 63.75 65.93 66.78 66.24 65.91 68.43 71.26 68.69 65.81 61.30 55.44
55.70 58.22 58.63 58.35 56.48 56.70 59.48 61.71 60.67 59.30 57.93 55.82
48.59 49.78 50.05 48.96 48.00 46.84 49.70 51.79 52.10 51.02 50.03 49.71
54.93 45.68 41.20 36.36 37.17 35.77 33.81 31.69
54.26 46.22 41.48 39.10 36.88 35.32 33.09 30.57
45.64 34.19 29.08 23.53 22.63 18.98
53.02 44.68 41.15 38.53 36.92 35.05 33.26 31.15
53.61 46.38 42.16 39.47 38.06 36.22 36.24 35.06
46.92 38.89 34.34 33.25 28.85 26.21 24.20

Coolant Channel Panel -31: Single Tapered

Velocities in meters per second



APPENDIX G

CHANNEL SCALED ANALYSIS

EXAMPLE CALCULATION FOR SINGLE HIGH FIN CONFIGURATION

STANTON NUMBER PROFILES

APPENDIX G. SAMPLE CALCULATION FOR A SINGLE HIGH FINNED CHANNEL

The basic method of analysis for the finned channel was the same as that employed for the rib flow tests. This similarity was afforded by the results of past studies on internal (pipe) and external (flat plate) flows which demonstrated that the velocity profiles very close to the wall were described by a single relationship for both configurations, namely the logrithmic overlap correlation. One difference was that the freestream velocity Uo used in the rib tests was defined as the channel centerline velocity.

The method used to derive the thermal performance of a finned channel configuration from the measured velocity profiles was based upon the well established characteristics of internal flow as in a pipe. The local shear stress at any location on the rib wall was derived by fitting the measured local velocity profile to the established pipe flow profile. The heat transfer Stanton number defined by St = h/(pUoCp) was found directly by assuming Reynold's analogy. Figure D1. graphically illustrates these steps in the data reduction process. A numerical example of this method will be presented for the trough region of the single high fin configuration.

The measured velocity profile was fit to the established pipe flow correlation by varying the friction velocity parameter defined as V* = Uo /(Cf/2). The fit of the data was performed by inspection of the velocity profile expressed in terms of inner variables u+ = U/V* (dimensionless velocity) and y+ = yV*/v (dimensionless distance). Since the V* parameter by definition is in the denominator of u+ and in the numerator of y+, variation of V* results in a change of position of the measured data. Therefore, V* is chosen such that the data points, particularly those closest to the wall, fall on the correlation line.

The best fit friction velocity for the location in the trough region midway between the fin and the channel wall was V* = 2.3. Based upon a centerline velocity of Uo = 70.16 meters/sec, the best fit value for V* correspondes to a friction factor of,

$$Cf/2 = (V^*/Uo)^2$$

$$= 0.00107$$

The Reynold's analogy with a Prandtl number correction (for air Pr = 0.69) provides the heat transfer Stanton number as,

$$St = Pr^{-2/3}\ Cf/2$$

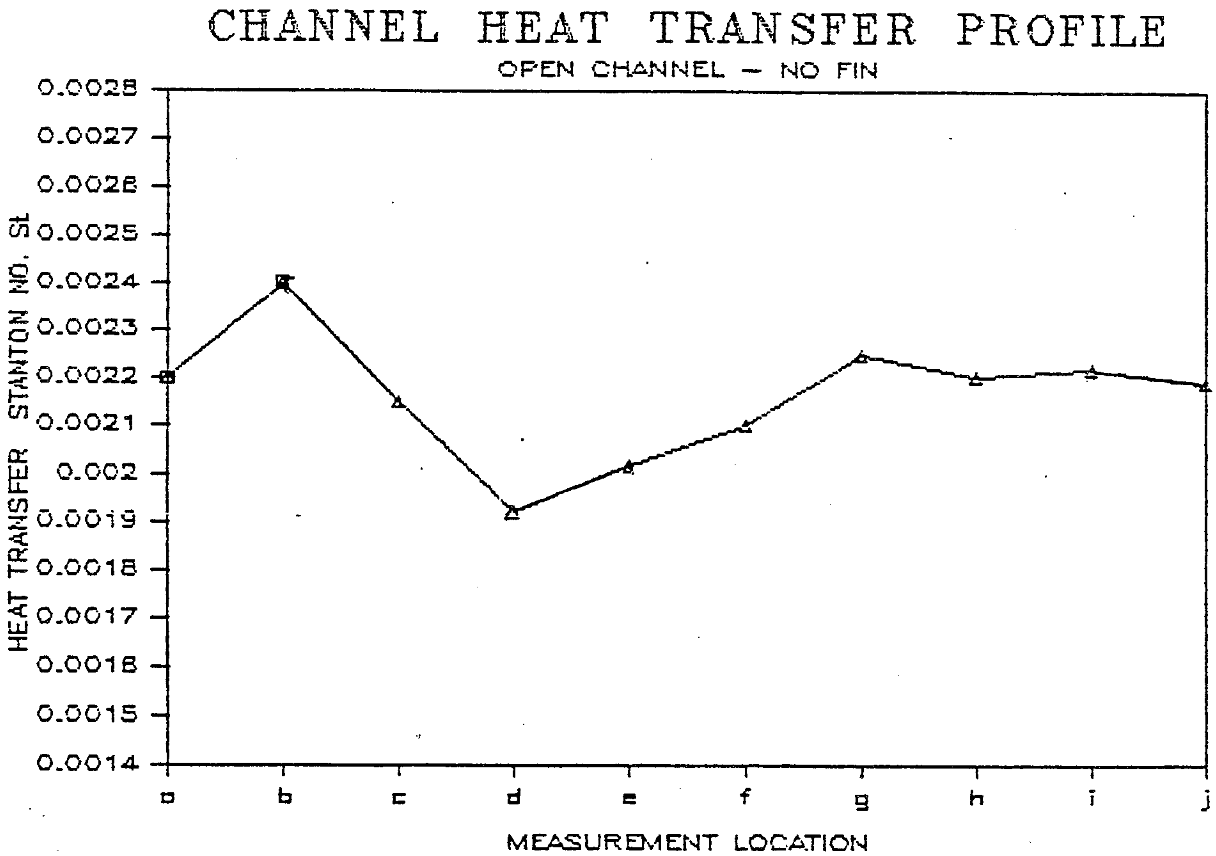
$$= 0.00136$$

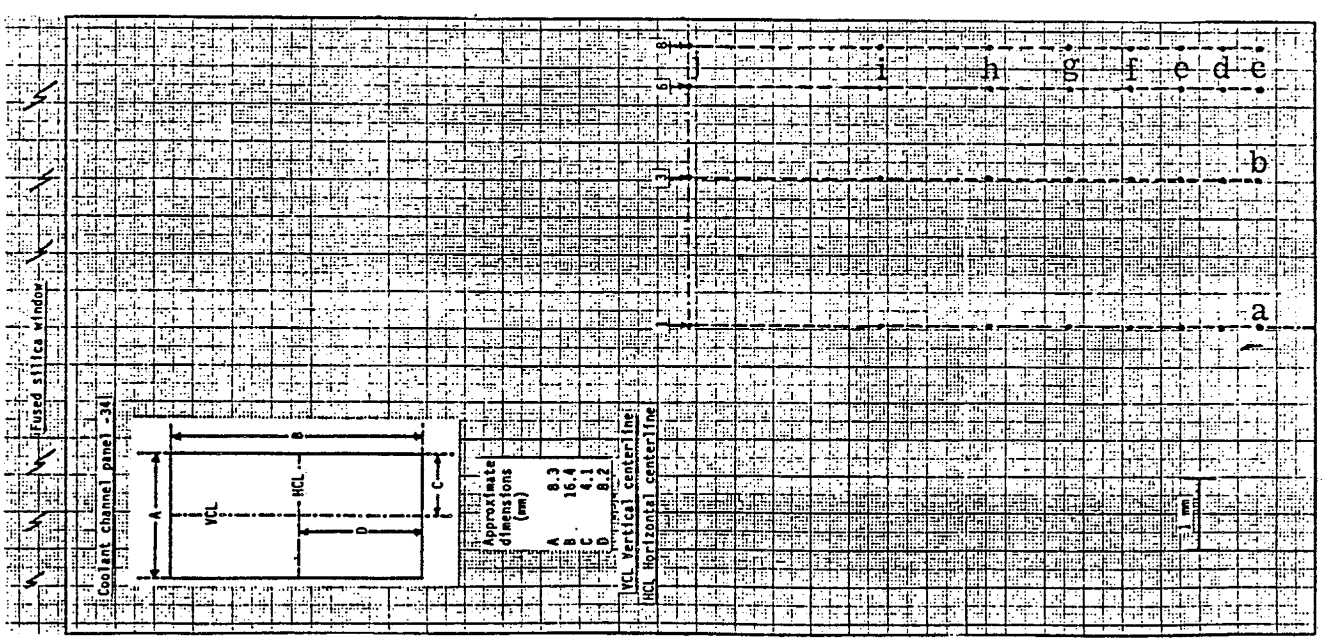
The Stanton number defines the heat transfer coefficient for a given set of flow conditions. This procedure was repeated for every location about the fin where velocity profiles were measured.

Thus a Stanton number profile about the fin was calculated as shown in Figure G1.

In order to compare the relative performances of different rib configurations, the Stanton number profiles were integrated with respect to surface area to provide a total heat transfer per channel parameter. This parameter was adjusted for the wider double finned channels on an equivalent flow area basis.

Scaling the Cold Flow results to hot-fire conditions required a scaling factor for the gas-side Stanton number. This scaling factor, denoted as S1, was defined as the ratio of the Stanton number for a open channel under hot-fire conditions to the Stanton number for a Cold Flow test on an open channel. The REGEN thermal program predicted the hot-fire channel Stanton number. The scaling factor was found to be S1 = 1.2. This was used as a Stanton number multiplier for all fin configurations.


CHANNEL HEAT TRANSFER PROFILE
OPEN CHANNEL — NO FIN
HEAT TRANSFER STANTON NO. St
0.0028
0.0027
0.0026
0.0025
0.0024
0.0023
0.0022
0.0021
0.002
0.0019
0.0018
0.0017
0.0016
0.0015
0.0014
a b c d e f g h i j
MEASUREMENT LOCATION


j i h g f e d c
b
a
Fused silica window
Coolant channel panel -34
VCL
HCL
Approximate dimensions (mm)
A 8.3
B 16.4
C 4.1
D 8.2
VCL Vertical centerline
HCL Horizontal centerline
1 mm

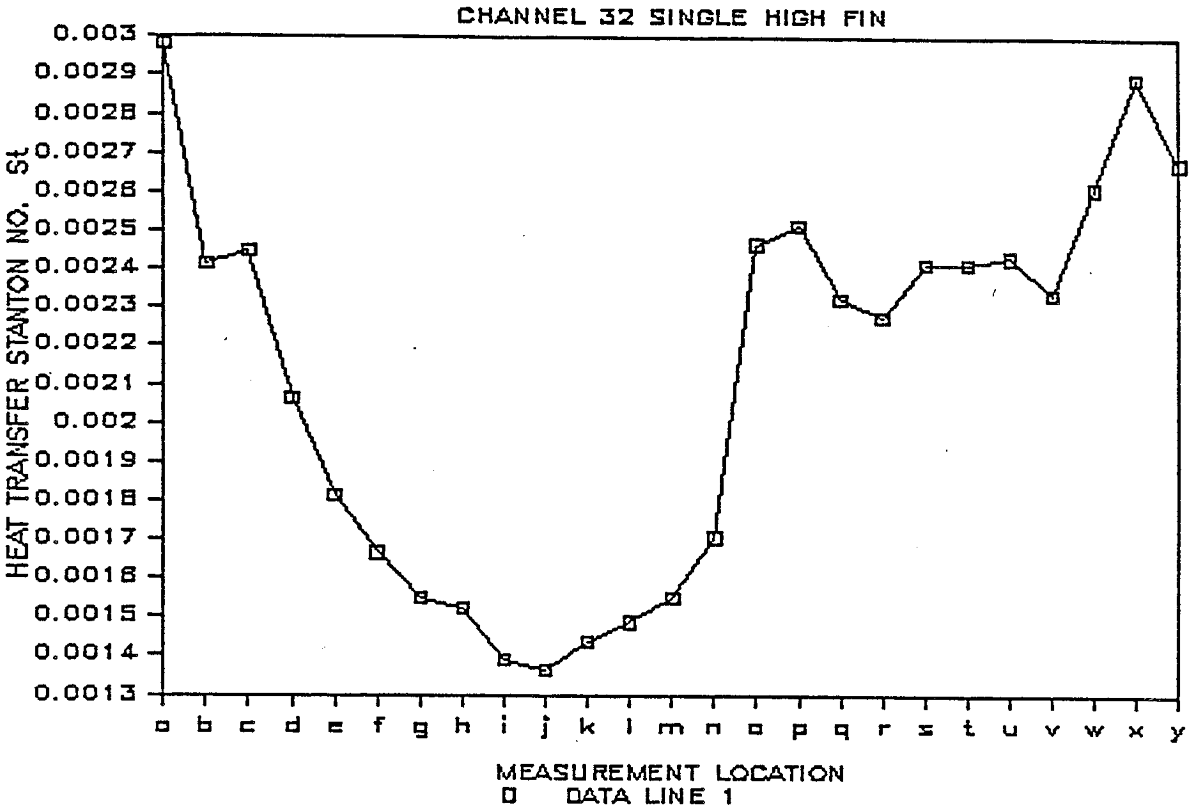
OPEN CHANNEL SCALED
(1/2 CHANNEL)

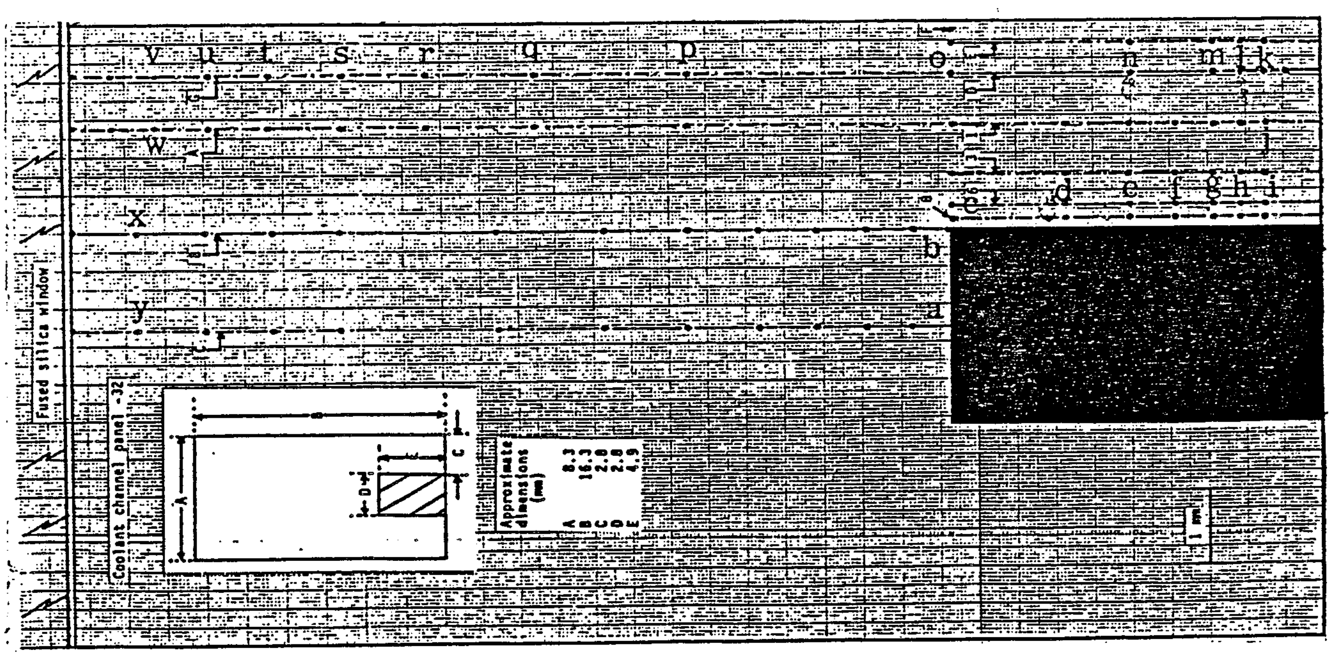
NODE	h	Area, in	h*Area
73	0.06015	0.008333	5.01E-04
74	0.06492	0.006666	4.33E-04
75	0.06549	0.006666	4.37E-04
76	0.06183	0.003333	2.06E-04
83	0.05790	0.010000	5.79E-04
93	0.06155	0.010000	6.16E-04
103	0.06127	0.010000	6.13E-04
113	0.06043	0.010000	6.04E-04
123	0.06127	0.010000	6.13E-04
133	0.06155	0.010000	6.16E-04
143	0.05790	0.010000	5.79E-04
153	0.06015	0.008333	5.01E-04
154	0.06492	0.006666	4.33E-04
155	0.06549	0.006666	4.37E-04
156	0.06183	0.003333	2.06E-04

(h*Area)total = 0.007371 IN

FULL CHANNEL SCALED = 0.014743 IN

CHANNEL HEAT TRANSFER PROFILE





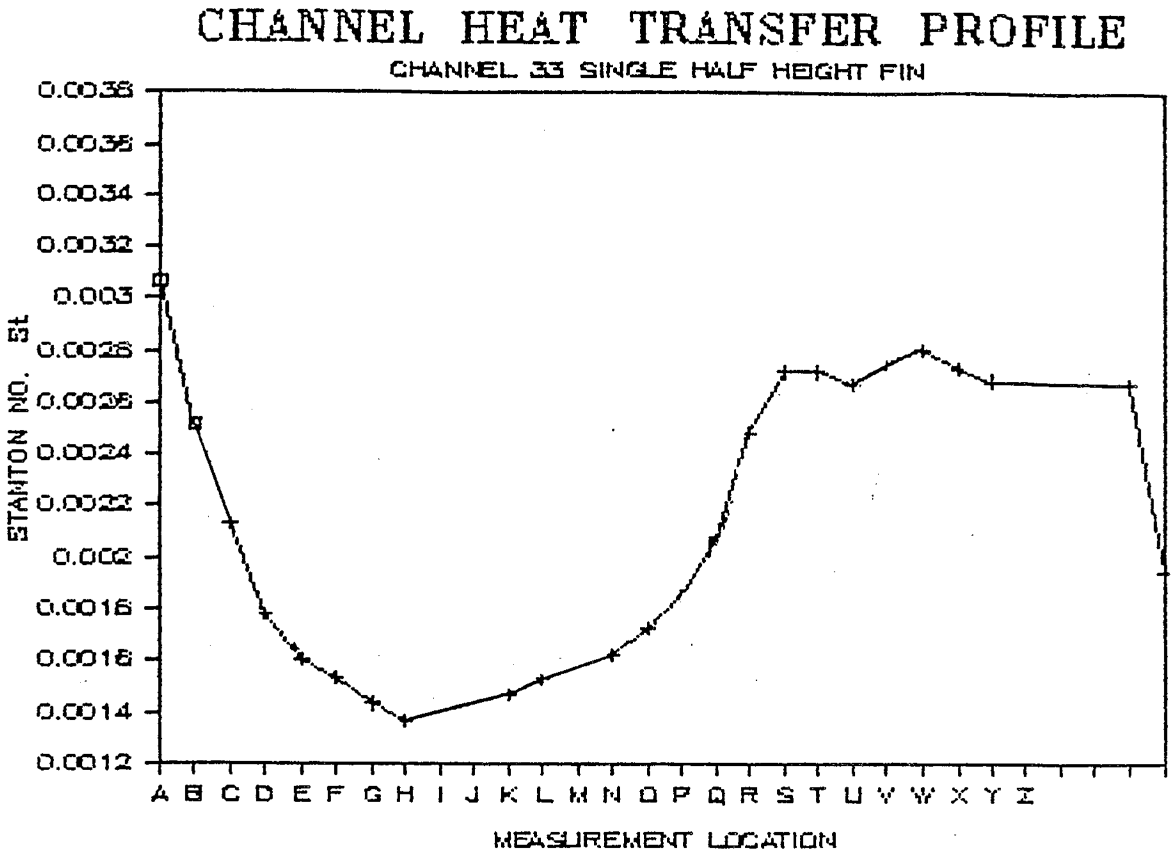
SINGLE HIGH FIN SCALED
(1/2 CHANNEL)

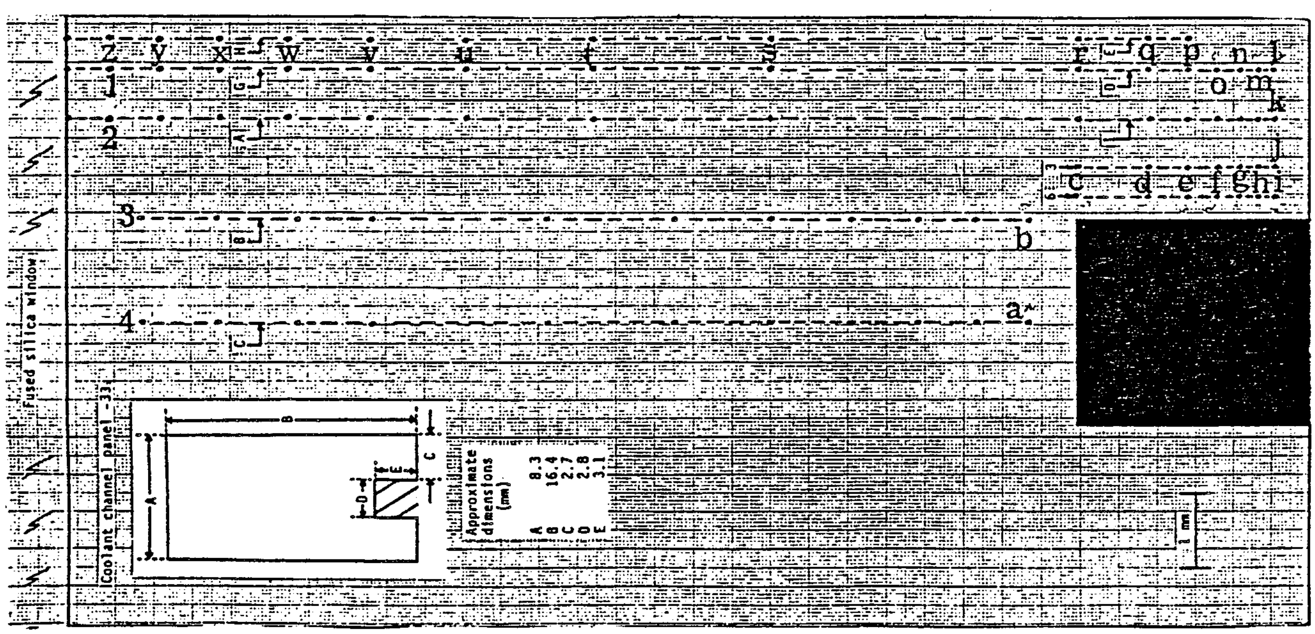
NODE	h	Area, in	h*Area
73	0.04550	0.008333	3.79E-04
74	0.04297	0.006666	2.86E-04
75	0.04408	0.002500	1.10E-04
83	0.05150	0.010000	5.15E-04
93	0.06951	0.010000	6.95E-04
103	0.07836	0.010000	7.84E-04
113	0.07931	0.010000	7.93E-04
123	0.07330	0.010000	7.33E-04
133	0.07349	0.010000	7.35E-04
143	0.07630	0.010000	7.63E-04
153	0.07362	0.008333	6.13E-04
154	0.08215	0.006666	5.48E-04
155	0.09163	0.006666	6.11E-04
156	0.08531	0.003333	2.84E-04
200	0.04487	0.002000	8.97E-05
201	0.04724	0.004001	1.89E-04
202	0.05027	0.004001	2.01E-04
203	0.05627	0.004001	2.25E-04
204	0.06392	0.004001	2.56E-04
205	0.07062	0.004001	2.83E-04
206	0.08247	0.009500	7.83E-04

(h*Area)total = 0.009876 IN

FULL CHANNEL SCALED = 0.019752 IN

NORMALIZED(hAsf/hAopen) = 1.339821 IN


CHANNEL HEAT TRANSFER PROFILE
CHANNEL 33 SINGLE HALF HEIGHT FIN
STANTON NO. St
0.0038
0.0036
0.0034
0.0032
0.003
0.0028
0.0026
0.0024
0.0022
0.002
0.0018
0.0016
0.0014
0.0012
A B C D E F G H I J K L M N O P Q R S T U V W X Y Z
MEASUREMENT LOCATION


Fused silica window
Coolant channel panel - 33
Approximate dimensions (mm)
A 8.3
B 16.4
C 2.7
D 2.8
E 3.1
1 mm

SINGLE LOW FIN SCALED
(1/2 CHANNEL)

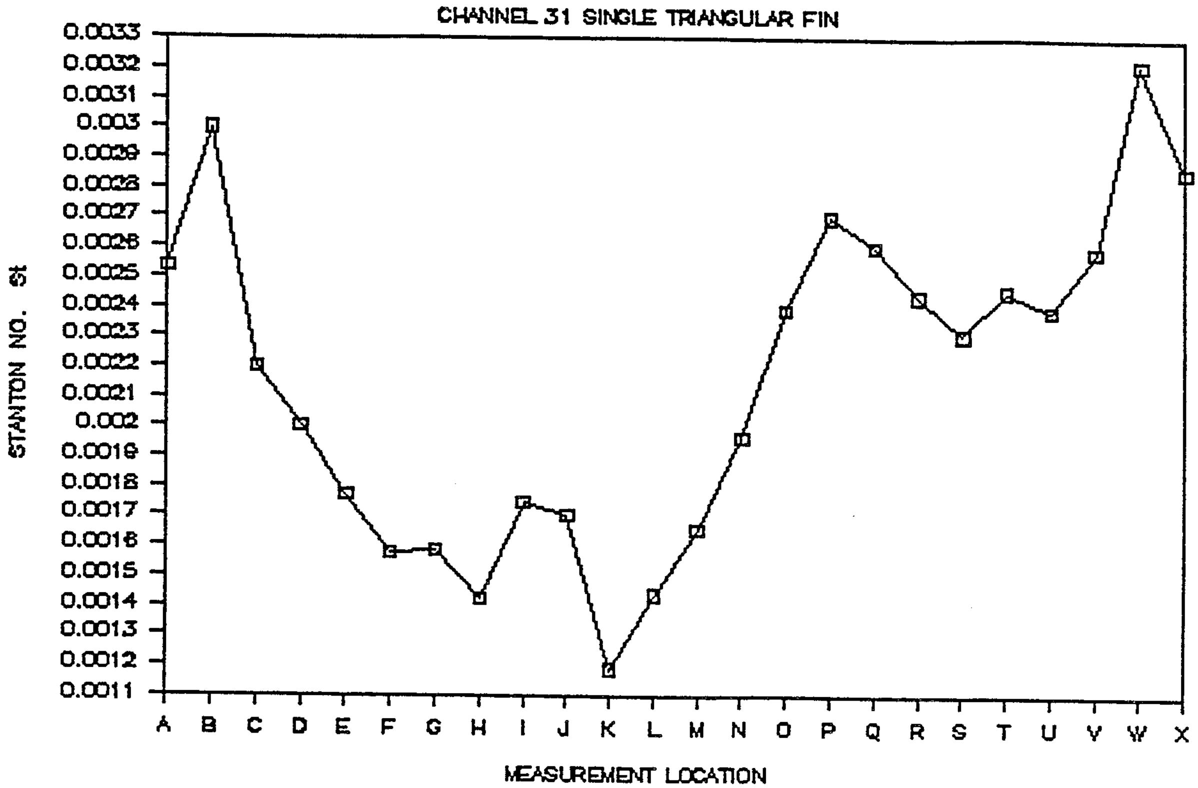
NODE	h	Area, in	h*Area
73	0.04648	0.008333	3.87E-04
74	0.04467	0.006666	2.98E-04
75	0.04225	0.002500	1.06E-04
83	0.06238	0.010000	6.24E-04
93	0.07641	0.010000	7.64E-04
103	0.08076	0.010000	8.08E-04
113	0.08269	0.010000	8.27E-04
123	0.08103	0.010000	8.10E-04
133	0.08330	0.010000	8.33E-04
143	0.08299	0.010000	8.30E-04
153	0.08058	0.008333	6.71E-04
154	0.08058	0.006666	5.37E-04
155	0.08058	0.006666	5.37E-04
156	0.05915	0.003333	1.97E-04
200	0.04213	0.001250	5.27E-05
201	0.04177	0.002501	1.04E-04
202	0.04506	0.002501	1.13E-04
203	0.04814	0.002501	1.20E-04
204	0.05339	0.002501	1.34E-04
205	0.05897	0.002501	1.47E-04
206	0.07777	0.008750	6.80E-04

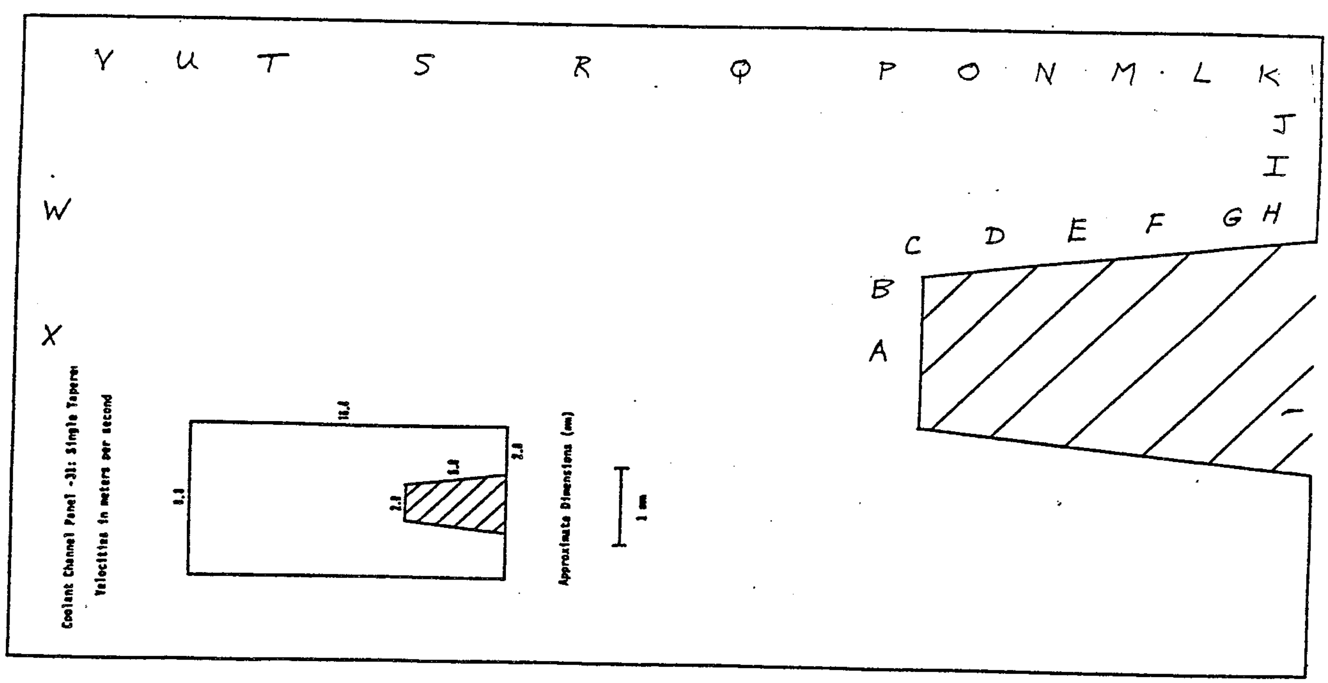
(h*Area)total = 0.009580 IN

FULL CHANNEL SCALED = 0.019161 IN

NORMALIZED(hAsf/hAopen) = 1.299728 IN

CHANNEL HEAT TRANSFER PROFILE





SINGLE TRIANGULAR FIN SCALED
(1/2 CHANNEL)

NODE	h	Area, in	h*Area
73	0.03668	0.008333	3.06E-04
74	0.06221	0.006667	4.15E-04
75	0.02928	0.002500	7.32E-05
83	0.04875	0.010000	4.88E-04
93	0.06983	0.010000	6.98E-04
103	0.08416	0.010000	8.42E-04
113	0.04593	0.010000	4.59E-04
123	0.04058	0.010000	4.06E-04
133	0.04104	0.010000	4.10E-04
143	0.04188	0.010000	4.19E-04
153	0.04671	0.008333	3.89E-04
154	0.08453	0.006666	5.63E-04
155	0.09815	0.006666	6.54E-04
156	0.08840	0.003333	2.95E-04
200	0.04095	0.002095	8.58E-05
201	0.04729	0.004191	1.98E-04
202	0.05079	0.004191	2.13E-04
203	0.05054	0.004191	2.12E-04
204	0.05686	0.004191	2.38E-04
205	0.06255	0.004191	2.62E-04
206	0.07973	0.007095	5.66E-04

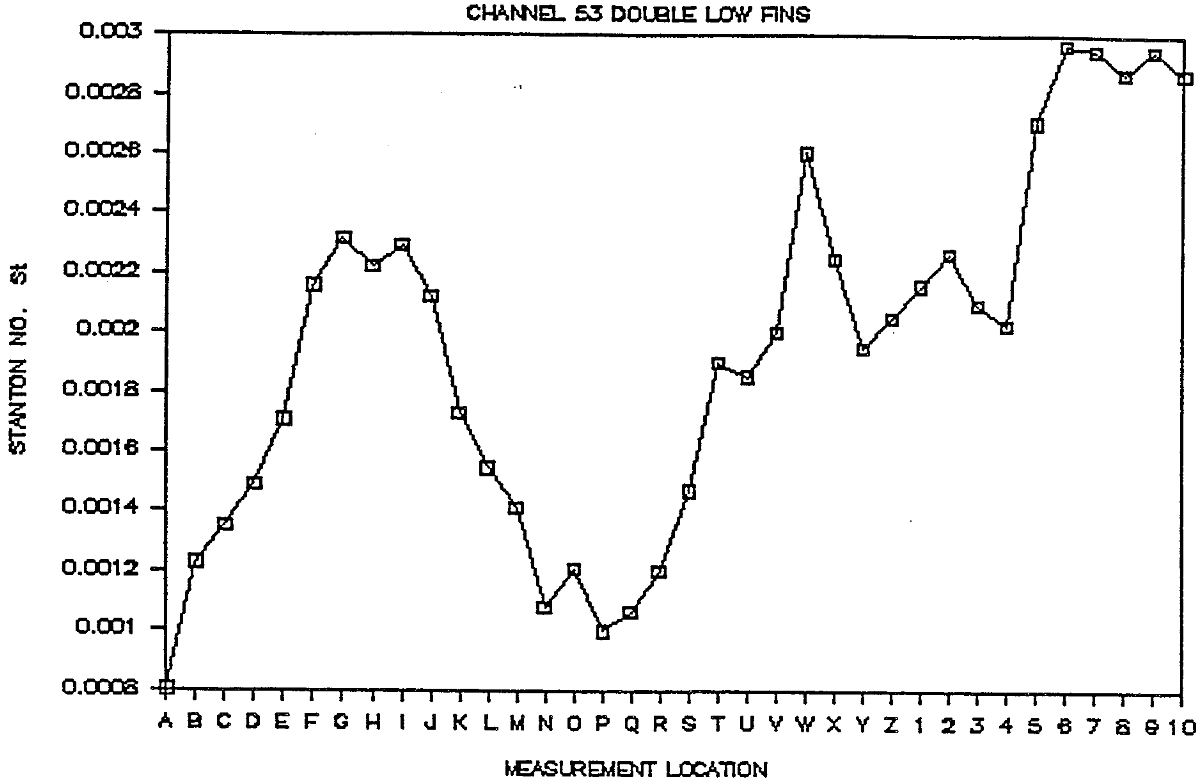
(h*Area)total = 0.008191 IN

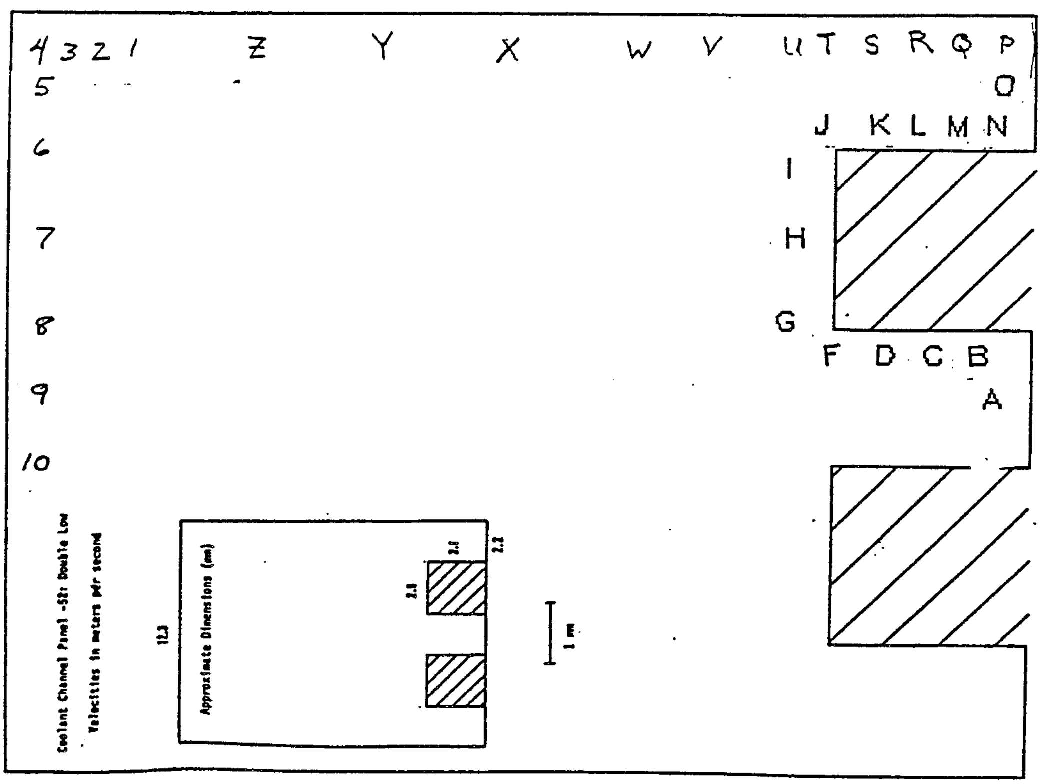
FULL CHANNEL SCALED = 0.016383 IN

NORMALIZED(hAtf/hAopen) = 1.111268 IN

C-4

CHANNEL HEAT TRANSFER PROFILE





DOUBLE LOW FIN SCALED
(1/2 CHANNEL)

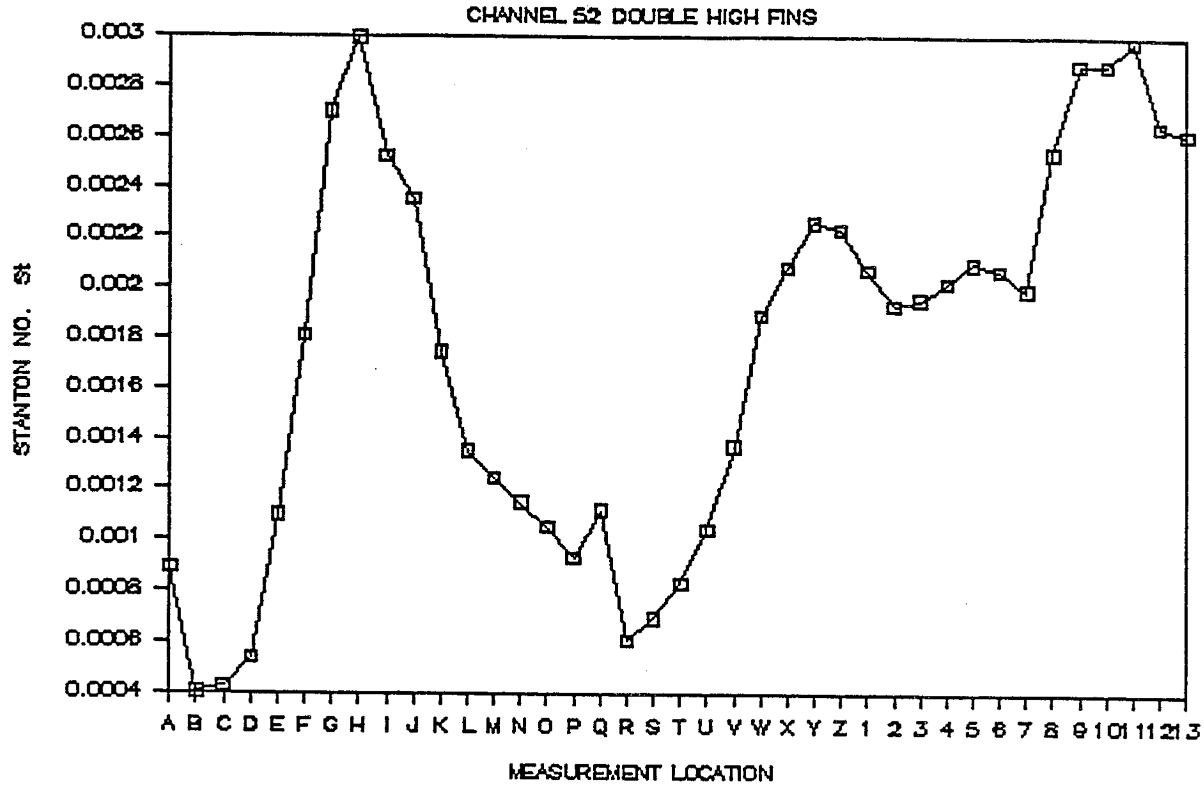
NODE	h	Area, in	h*Area
73	0.02519	0.010000	2.52E-04
74	0.02888	0.010000	2.89E-04
76	0.02022	0.005000	1.01E-04
83	0.03441	0.010000	3.44E-04
93	0.05092	0.010000	5.09E-04
103	0.06443	0.010000	6.44E-04
113	0.05726	0.010000	5.73E-04
123	0.04948	0.010000	4.95E-04
133	0.05180	0.010000	5.18E-04
143	0.05448	0.010000	5.45E-04
153	0.05120	0.010000	5.12E-04
154	0.07013	0.010000	7.01E-04
155	0.07475	0.010000	7.48E-04
156	0.07452	0.005000	3.73E-04
200	0.01540	0.001250	1.93E-05
201	0.02363	0.002500	5.91E-05
202	0.03380	0.002500	8.45E-05
203	0.03840	0.002500	9.60E-05
204	0.04248	0.002500	1.06E-04
205	0.04807	0.002500	1.20E-04
206	0.05791	0.006250	3.62E-04
207	0.02252	0.001250	2.82E-05
208	0.02658	0.002500	6.65E-05
209	0.03201	0.002500	8.00E-05
210	0.03709	0.002500	9.27E-05
211	0.04211	0.002500	1.05E-04
212	0.04819	0.002500	1.20E-04
213	0.05859	0.006250	3.66E-04

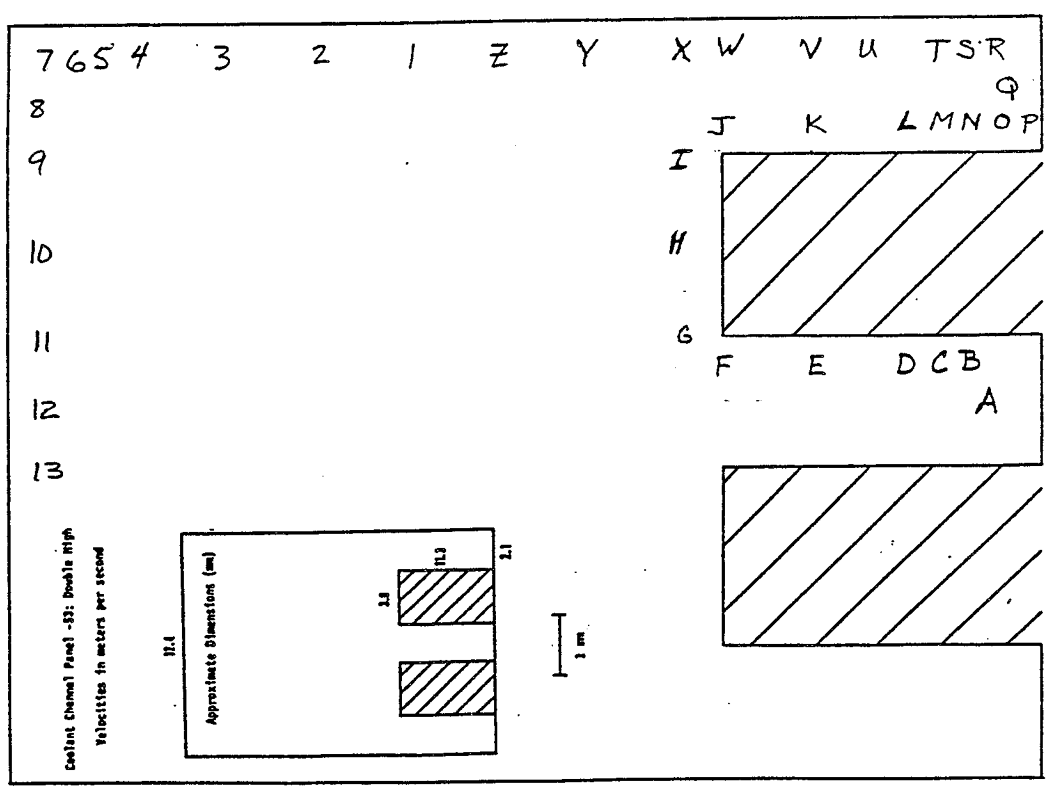
(h*Area)total = 0.006578 IN

FULL CHANNEL SCALED = 0.013156 IN

NORMALIZED(hAdf/hAopen) = 0.892395 IN

CHANNEL HEAT TRANSFER PROFILE





ORIGINAL PAGE IS
OF POOR QUALITY

DOUBLE HIGH FIN SCALED
(1/2 CHANNEL)

NODE	h	Area, in	h*Area
73	0.01057	0.010000	1.06E-04
74	0.02177	0.010000	2.18E-04
76	0.02340	0.005000	1.17E-04
83	0.02743	0.010000	2.74E-04
93	0.04073	0.010000	4.07E-04
103	0.05538	0.010000	5.54E-04
113	0.05893	0.010000	5.89E-04
123	0.05304	0.010000	5.30E-04
133	0.05078	0.010000	5.08E-04
143	0.05315	0.010000	5.32E-04
153	0.05249	0.010000	5.25E-04
154	0.07482	0.010000	7.48E-04
155	0.07681	0.010000	7.68E-04
156	0.07021	0.005000	3.51E-04
200	0.02064	0.001999	4.13E-05
201	0.02827	0.003980	1.13E-04
202	0.03366	0.003980	1.34E-04
203	0.03900	0.003980	1.55E-04
204	0.04481	0.003980	1.78E-04
205	0.05281	0.003980	2.10E-04
206	0.06653	0.006999	4.66E-04
207	0.00249	0.001999	4.98E-06
208	0.00810	0.003980	3.22E-05
209	0.01444	0.003980	5.75E-05
210	0.02056	0.003980	8.18E-05
211	0.02761	0.003980	1.10E-04
212	0.03721	0.003980	1.48E-04
213	0.07119	0.006999	4.98E-04

(h*Area)total = 0.006695 IN

FULL CHANNEL SCALED = 0.013390 IN

NORMALIZED(hAdf/hAopen) = 0.908238 IN