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ROCKETDYNE

A DIVISION OF NORTH AMERICAN AVIATION INC
6633 CANOGA AVENUE CANOGA PARK CALIFORNIA

R-5615-9

6

(Unclassified Title)

HISTORY: PROJECT FIRST,
F-1 COMBUSTION STABILITY PROGRAM,
VOLUME 3, BOOK 1

FILE COPY

NASA-CR-178842

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Contract NASw-16
Scope of Work Para. VII-K of Mod. 71

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NO OF PAGES 126 & viii

REVISIONS

DATE 4 March 1966

DATE	REV. BY	PAGES AFFECTED	REMARKS

FOREWORD

This is Volume 3, Book 1 of the History: Project First, F-1 Combustion Stability Program Report, prepared in compliance with the provisions of Contract NASw-16, Scope of Work Para. VII-K of Mod. 71. The Rocketdyne F-1 Engine Development Program for the National Aeronautics and Space Administration.

ABSTRACT

A history of the F-1 Combustion Stability Program from October through December 1964 is presented. Results of studies, tests, and procedures are discussed and graphically presented, and problems encountered are described.

(Unclassified Abstract)

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ILLUSTRATIONS

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TABLES

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INTRODUCTION

Volume 3, Book 1 describes the Combustion Stability Program for the period of October through December 1964. By this time, the problem of engine self-triggering instabilities had been eliminated. The primary effort during the report period was directed toward the elimination of the resurge and buzz modes of instabilities and the attainment of high-performance injector configurations commensurate with stability. To this end, injector pattern modifications near the confining baffle surfaces were made and tested. Test results indicated significant importance of the injector pattern near the baffles.

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SUMMARY

The program was highlighted during this period by the damping of three bomb-induced disturbances within the maximum 100 milliseconds duration by the F-1 engine system, as part of the FRT demonstration.

Effort was expended on the attainment of improved dynamic stability and improved performance. To this end, injector modifications which evaluated the effects of oxidizer sprays near the radial baffles, various oxidizer splitter modifications, and flow distribution on combustion stability and performance were tested.

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ANALYTICAL AND THEORETICAL WORK

F-1 SURGE MODEL

During this period a sustained effort was made to understand and eliminate the resurging problem. Rocketdyne's previous work on a chug model was extended to include portions of the LOX feed system. This was done as a result of data analysis which revealed oscillation in the 120- to 140-cps region in the ducting during normal operation. The resurging was by no means periodic but had the majority of its spectral power in the 100- to 140-cps region. The ducting was described by classical water hammer equations.

The system was found to be marginally unstable at 130 cps with the FRT injector. Variation in the LOX impedance was found to stabilize the FRT system. In order not to disturb the spray pattern of this injector, which would introduce another variable, it was recommended that an increase in LOX impedance be made at the axial feed holes. Model results showed that orificing of the axial feed holes to increase the overall LOX differential pressure to 380 psi would result in a stable injector. This modification on injector 098 resulted in an oxidizer differential pressure of 350 psi. However, the resurging persisted.

DUAL CHAMBER MODEL

In performing the above analytical work it was noted that a response peak occurred at 500 cps. It was decided to construct a dual chamber model, which would combine the surge model with the 500 cps model. This was done by incorporating into the model a time lag of 1 millisecond across the combustion chamber.

DETERMINATION OF FLOW DISTRIBUTION

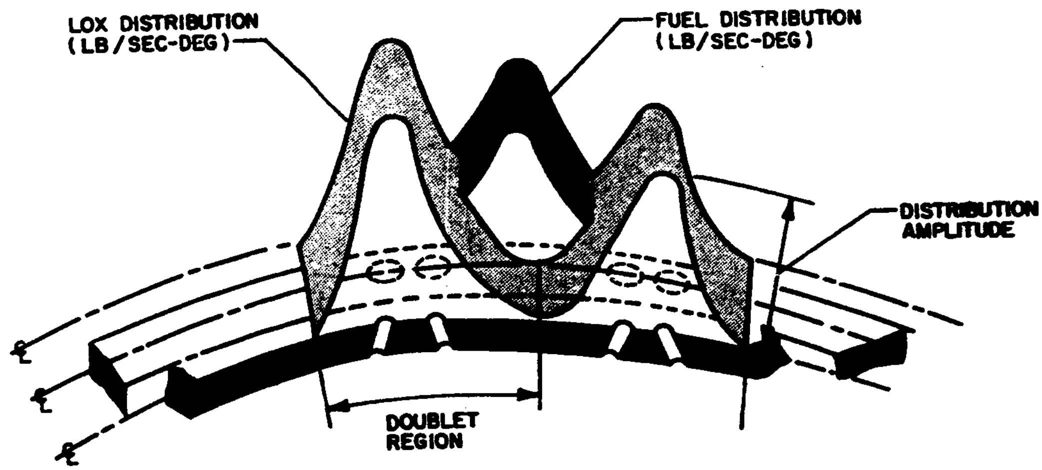
During this report period utilization of the flow distribution program, developed during the previous period, continued. Its results did not correlate well with Project First's flow bench results. It became evident that both flow bench and computor program methods required some refinement.

Current injector designs were analytically flowed and the results were reported. In addition, fan canting along the radial baffles was determined for the 084 series injectors on the basis of conservation of axial and transverse liquid momentum. The results showed that relative stability correlated with cant away from the radial baffles.

It was recommended that a short experimental water flow program be carried out to more accurately determine the various head loss coefficients utilized by the digital program.

INJECTOR DISTRIBUTION AND MIXTURE RATIO PROGRAM

An IBM program was written to calculate the propellant mixture ratio distribution in a polar coordinate system. The propellant distribution (injection density) resulting from an injector element was assumed to vary cosinusoidally in a circumferential direction, peaking directly above the element and dropping to zero midway between elements (Fig. 1). Elemental propellant distribution was assumed constant radially, and was limited by the circumferential center lines of the adjacent rings. The integral of the elemental distribution curve was calculated by the program to match the total elemental flow as obtained in the high-flow bench.



PROPELLANT DISTRIBUTION PROFILE

$$D = A(1 - \cos(\theta + \beta))$$

Figure 1. Propellant Distribution Profile

A spatially dependent c* was calculated by the program using an arithmetic curve for mixture ratios between 1.5 and 4.0. Outside of the range, a linear relationship was assumed. Chamber pressure was fixed at 1100 psi.

For baffled injectors, each compartment must be handled separately, with a separate printout for each.

The results of the program consist of:

1. Point values: oxidizer distribution, fuel distribution, mixture ratio
2. Ring values: total oxidizer flow, total fuel flow
3. Compartment values: total propellant flow, product of total propellant flow and c*, and average c*.

Figures 2 and 3 are cathode ray tube (CRT) plots of the data obtained from a portion of injector 050.

The results of the c* calculation program appeared to be of only qualitative use at this time rather than of quantitative use.

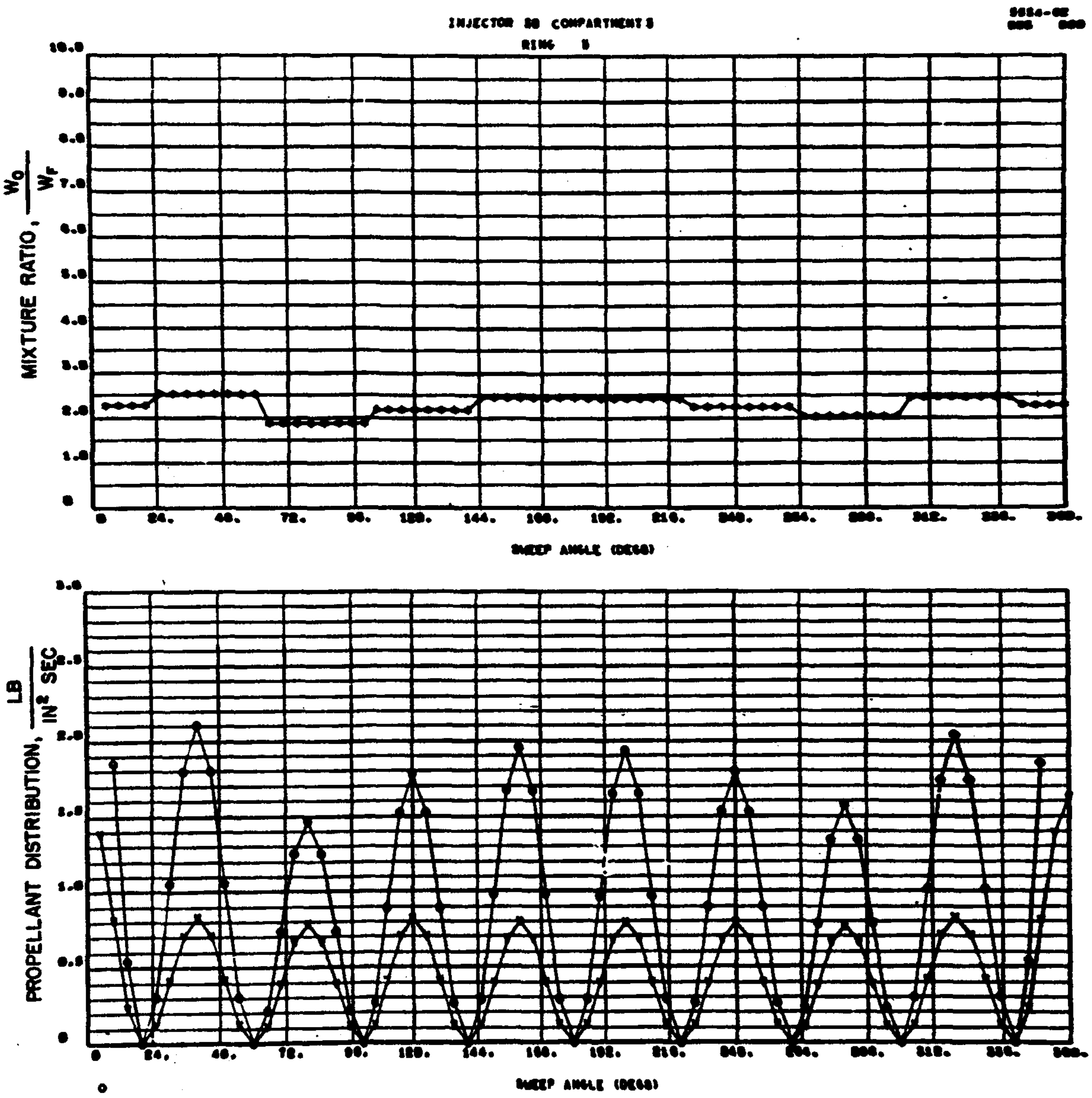


Figure 2. Cathode Ray Tube Plot (003), Injector 050
o = oxidizer distribution
v = fuel distribution

[redacted]

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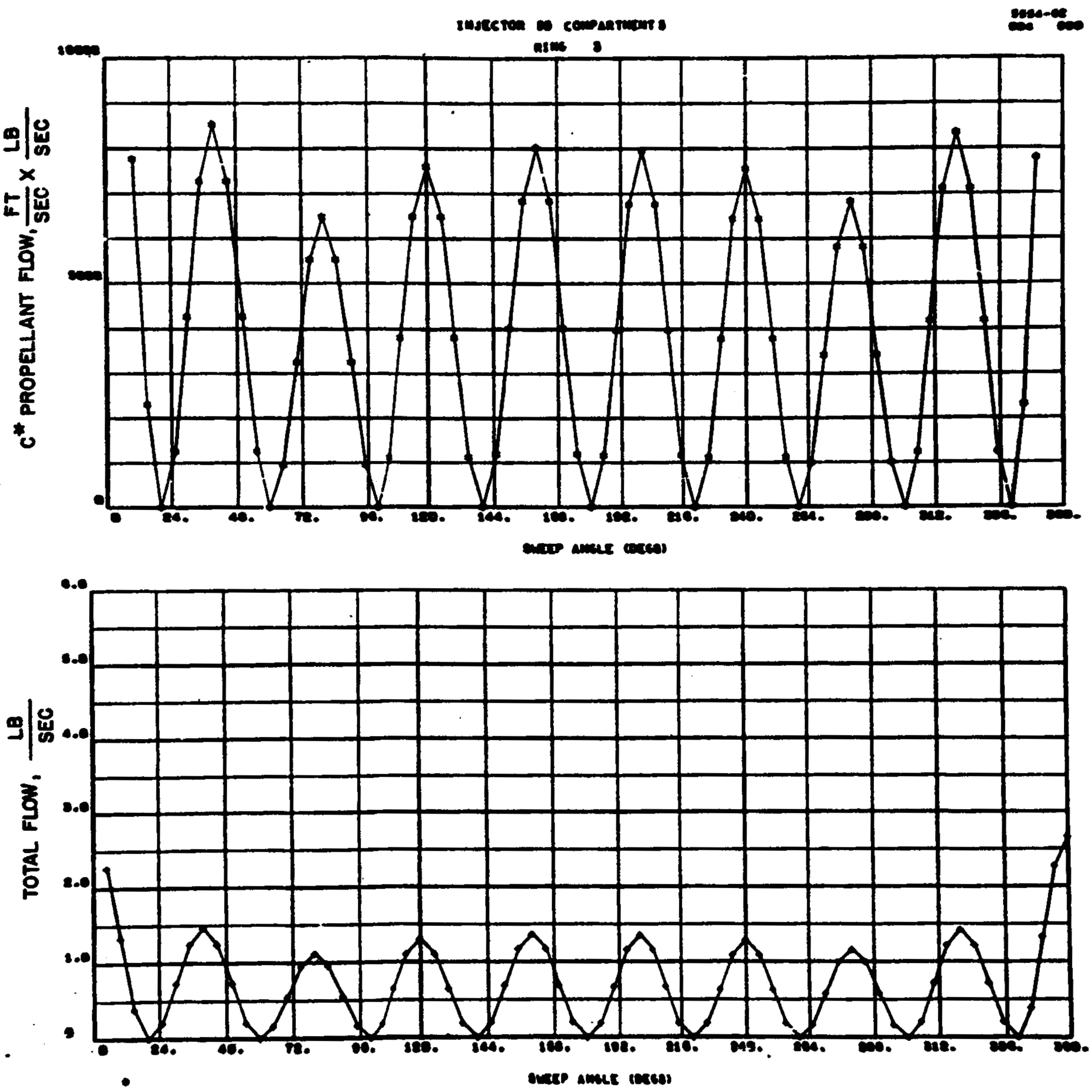

Figure 3. Cathode Ray Tube Plot (004), Injector 050

[redacted]

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DESIGN

MODIFICATIONS

Injectors X051, X052, X053, X056, and 086 were modified to incorporate the fuel-cooled GSE throat plug boss. Injectors X051, X052, and X053 were also modified by the addition of a redesigned outer fuel ring to replace part of the outer fuel ring on the injector body (Fig. 4). This change was made to improve the heat transfer and minimize the thermal stresses responsible for separation of the stainless steel ring and the outer fuel ring at the tips of the radial baffles. This modification was discarded on subsequent injectors because it caused a new separation on the next inboard ring-to-land joint.

Many other modifications were made on existing injectors for the purpose of improving stability and performance. These modifications and the results of testing are discussed under "Analysis".

NEW INJECTORS

Flat-face injector 077 was a complete rebuild from an existing injector body. The major design concepts incorporated in this unit were: enlarged oxidizer feed passages, multistep drilled radial fuel feed ports, and programmed injection density. Figure 5 shows the fuel port geometry and representative plots of the desired injection density and mixture ratio as a function of the injector radius. This unit performed approximately 1 second higher than the FRT injector.

Injector 097 was a rotated baffle, F-1 injector, with an FRT ring set (Fig. 6 and 7).

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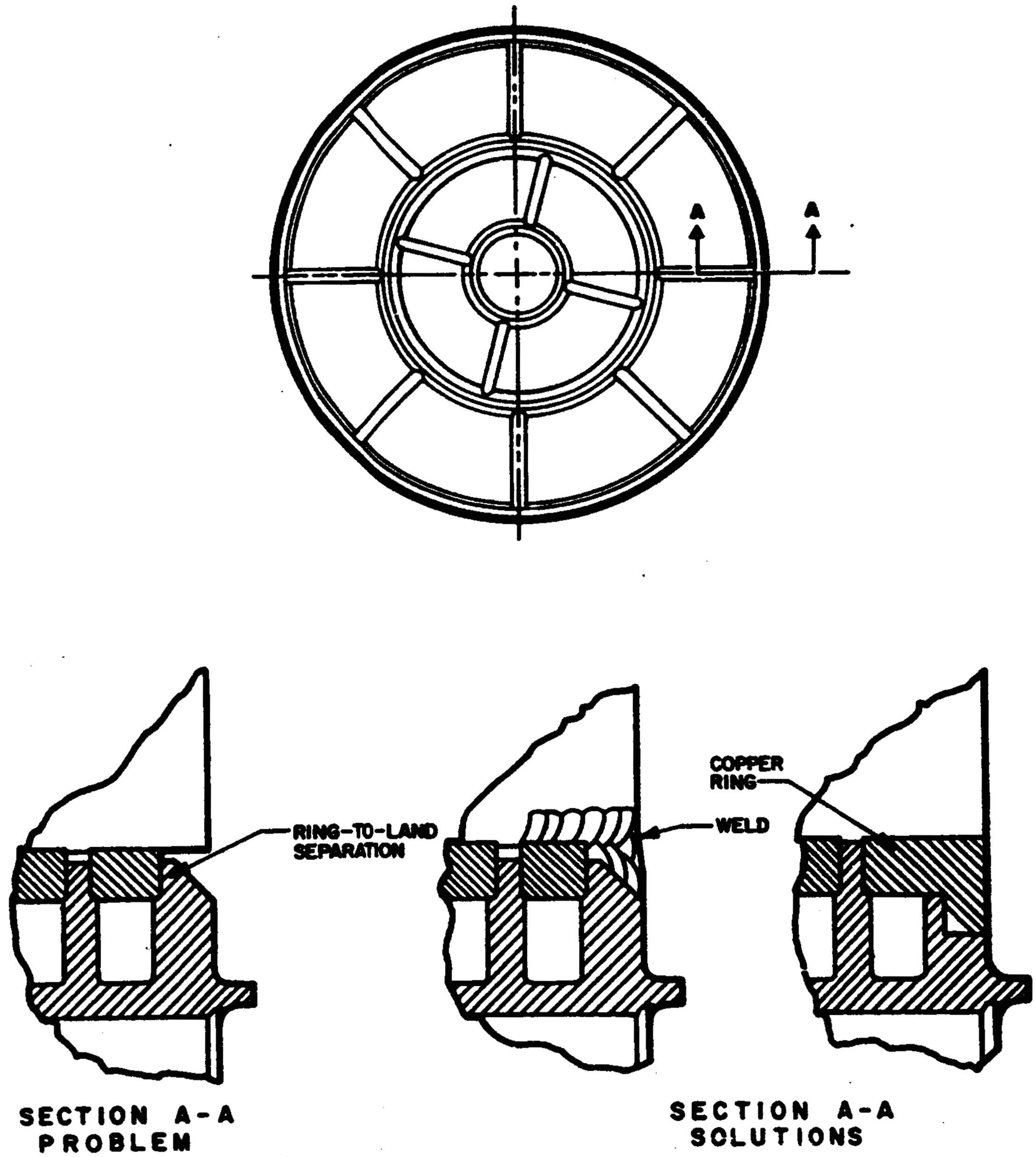

Figure 4. Ring-to-Land Separation Problem and Solutions

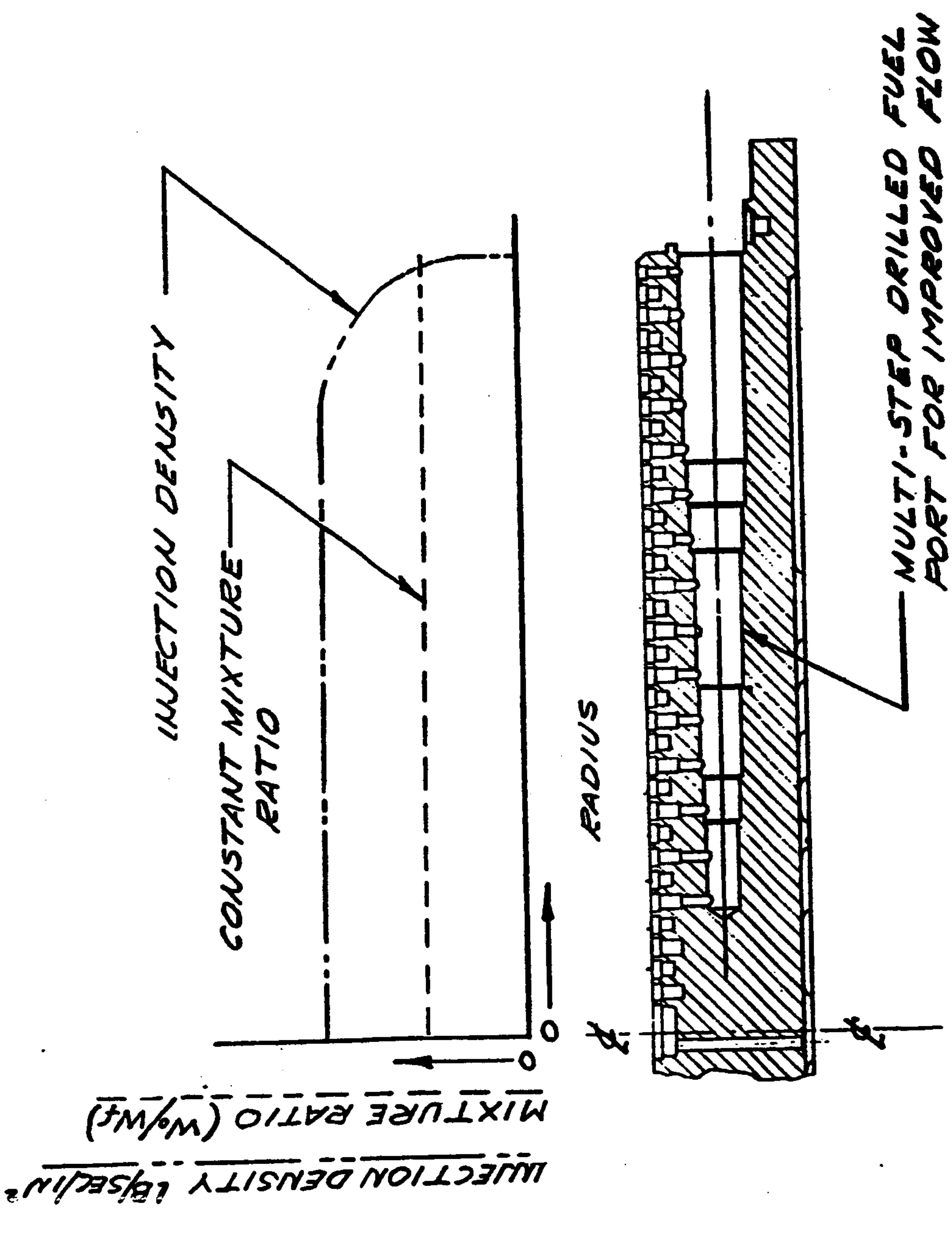

Figure 5. Injector 077

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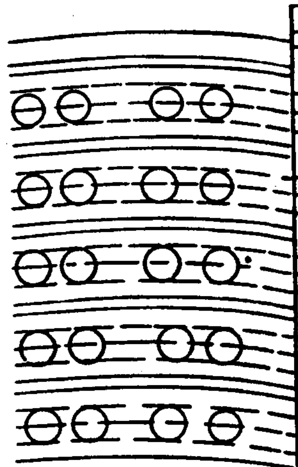
Assembly Dwg: XEOR 914605
Plate Dwg: XEOR 917780
Ring Set Dwg: XEOR 918332

INJECTOR DESCRIPTION

UNIT 097, TYPE 5885-G4, S/N

ORIFICE PATTERN

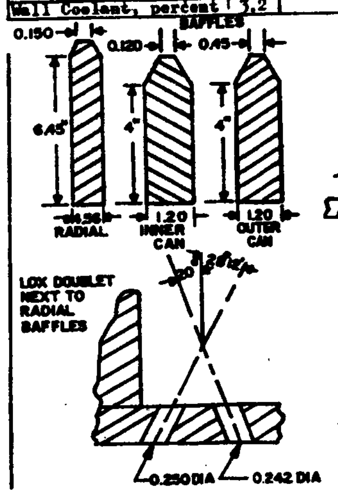


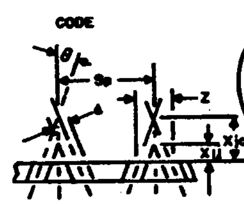
NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.776	0.228	96/104	0.416	20	1.14	0.571	0.258
-57	36.746	0.209	96/104	0.416	20	1.11	0.571	0.284
-55	35.626	0.281	88/96	0.428	15	1.17	0.799	0.274
-53	34.506	0.242	88/96	0.416	20	1.13	0.571	0.238
-51	33.386	0.281	80/88	0.428	15	1.19	0.799	0.274

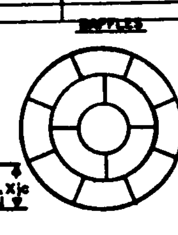
Pattern, General	Fuel	Oxid.
Orifice Area	85.0	61.8
Ring Groove Depth	.538	.538
Ring Material	CU	CU
Wall Gap (Fuel Ring)	.711	
Injection Vel. (1500K)	56 ·	132
Wall Coolant, percent	3.2	

Baffle Design	
Number of Compartments	13
Baffle Construction	Wide Base
Baffle Coolant	Fuel
Baffle Length	6 inches

Injector Mod's.
NONE







REMARKS: This injector has the basic FRT orifice pattern but has 6-inch baffles instead of the conventional 3-inch baffles. It has no LOX splitters or circumferential baffle dams, and the baffle gap is not sealed. The outer fuel ring is orificed for 70 percent flow and the two bomb bosses are located at the 225 and 135 degree locations in the fourth fuel ring. It has a GSE boss.

Figure 6. Description, Injector 097

[redacted]

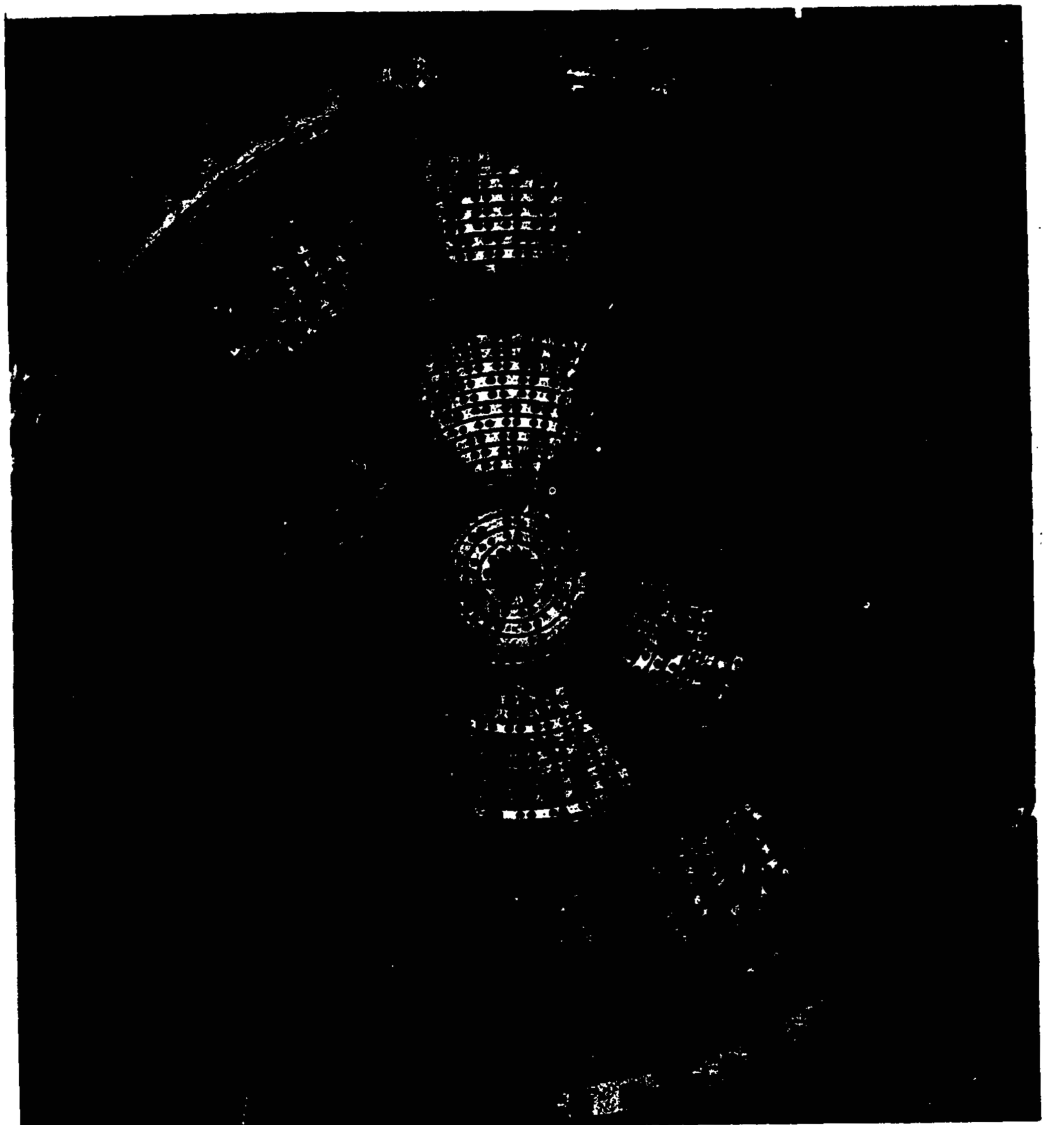


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Figure 7. Injector 097

The unique features of this injector were the 6-inch-high, fuel-cooled baffles. In this configuration, fuel flows into the outer can and into the 12 radial baffles. Inside the baffle the fuel flows in two paths, one path channels the flow along the face of the baffle and out of the orifices at the tip of the baffle. The other path directs the flow along can, where it is injected at the baffle tip. Six-inch baffles were used to determine the possible increase in efficiency and combustion stability.

Injector 089 was a rotated baffle, F-1 injector, with a modified FRT ring set. The modification consisted of canting the fuel orifices next to the radial baffles to match the canting of the LOX orifices on the FRT injector.

To improve the hydraulic characteristics of this injector the following changes were made (Fig. 8 and 9):

1. The fuel port hole entrances were rounded and the transition areas at changes in hole diameter were tapered.
2. For better fuel distribution from the radial feed ports to the orifice, a stainless steel ring was installed in the fuel groove upstream of the injecting orifice. The hole area in the secondary ring was proportioned to provide the flow required at the injector face.
3. The fuel groove was extended into the fuel radial feed ports to provide circumferential distribution of the propellant upstream of the secondary ring.
4. The oxidizer axial feed passage area was increased to reduce the velocity and thus minimize the ill effects of high dynamic head on the distribution of the propellant.

[redacted]

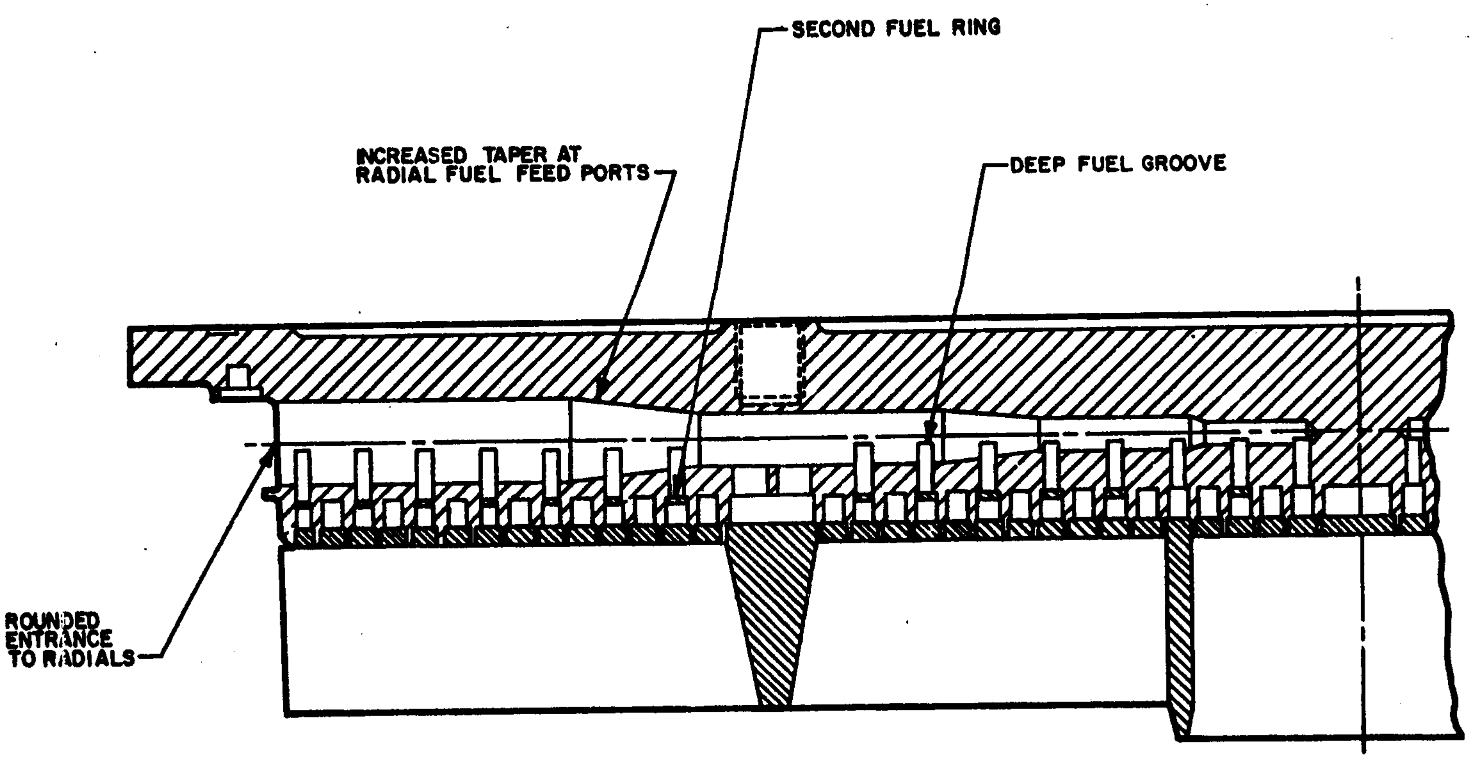

Figure 8. Hydraulic Improvement Configuration, Injector 089

[redacted]

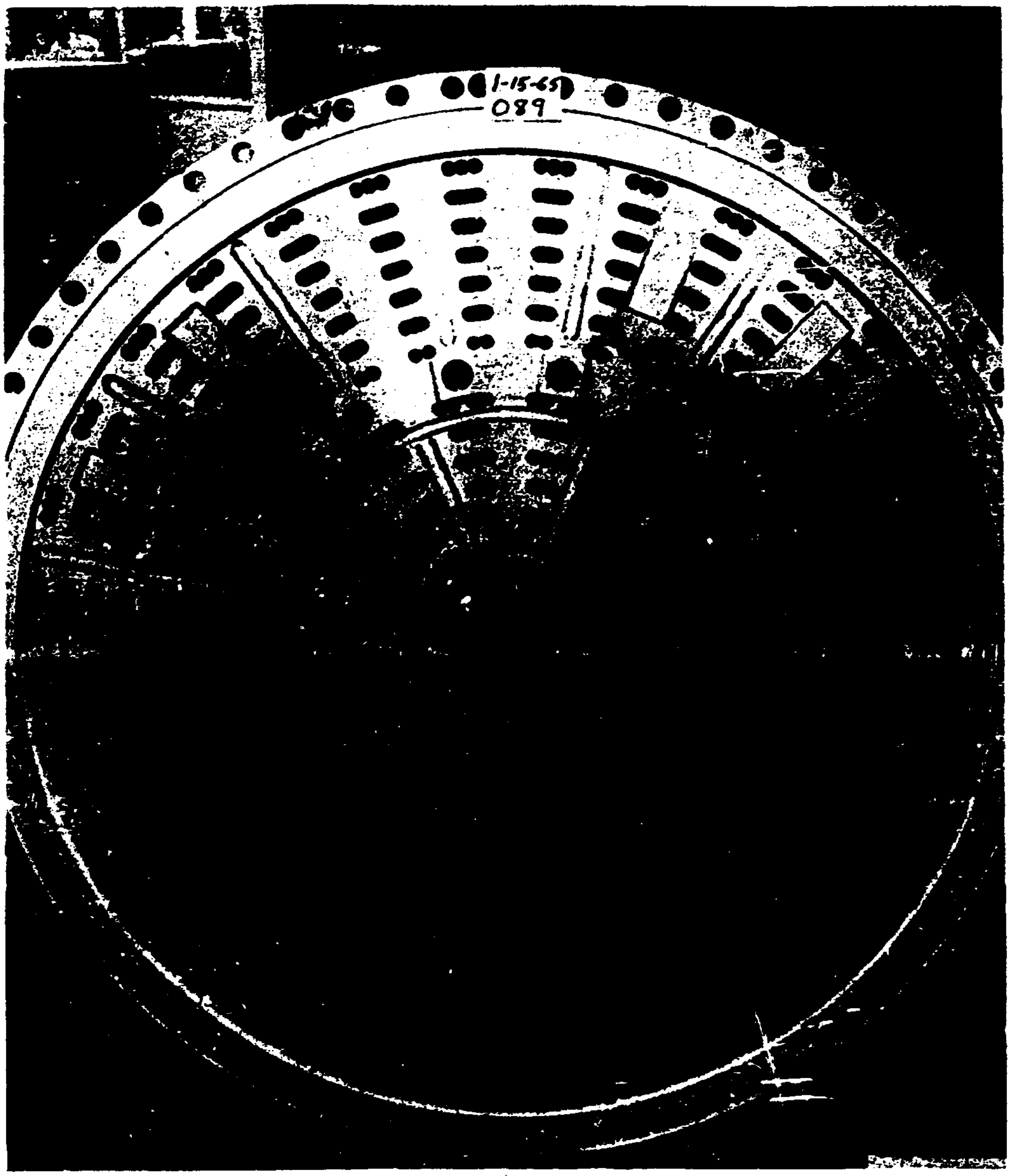

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Figure 9. Injector 089

Injector X033 was a rotated baffled injector with 13-compartment, 3-inch-high baffles (13 x 3). It had programmed orifices to give completely uniform mixture ratio and injection density. The orifices adjacent to the radial baffles were not canted. This injector performed approximately 1-1/2 seconds higher than the FRT injector.

Injector X058 was designed to scale up an H-1 injector, which had exhibited good performance and stability characteristics, to the F-1 size. This injector differed from the F-1 FRT injector in that it had higher propellant injection velocities, short fuel, and long LOX impingement distances (the reverse of F-1), and a much lower injection density.

Injector 099 was rebuilt into a 25-compartment, 3-inch high, baffled injector (Fig. 10 and 11). This injector had biplanar impingement, canted LOX fans along the radial baffles, and injection velocities similar to the FRT injector. Some differences in the spacing and number of orifice groups were necessary, however, because of the additional area occupied by the baffle system.

Injector X060 was designed similar to the FRT injector but with modifications to improve its performance. This unit had regeneratively cooled baffles (Fig. 12) and tapered radial fuel ports. The canted LOX doublets adjacent to the radial baffles were smaller than the FRT injector, and the matching fuel doublets were sized for nominal mixture ratio in this area.

Fabrication was started on injector X017 (Fig. 13). This unit had programmed orifices to ensure constant mixture ratio and injection density. The unique feature of this injector was the four bipropellant cooled baffles. Hydraulic modifications were the same as injector 089.

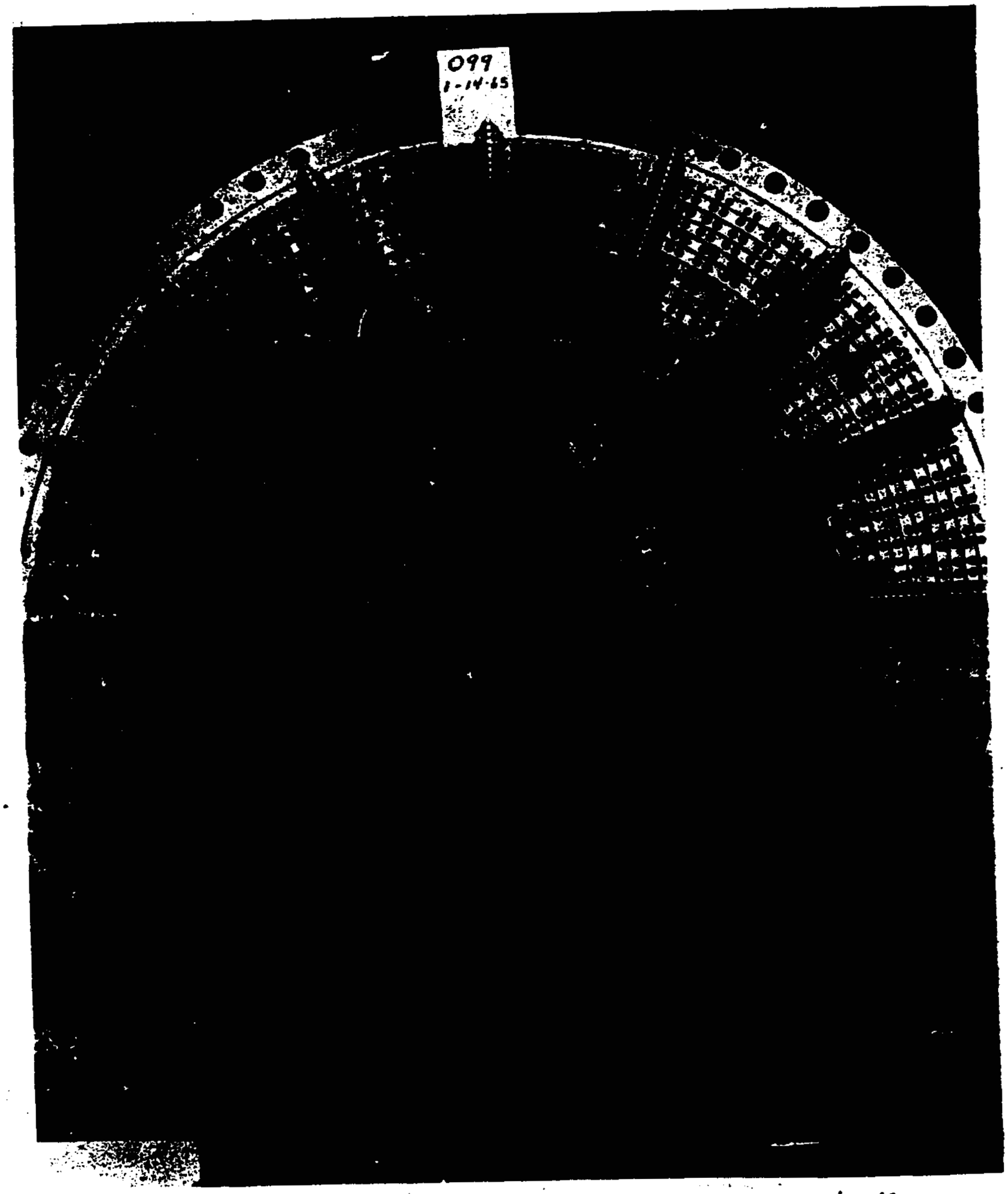

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Figure 10. Injector 099

[redacted]

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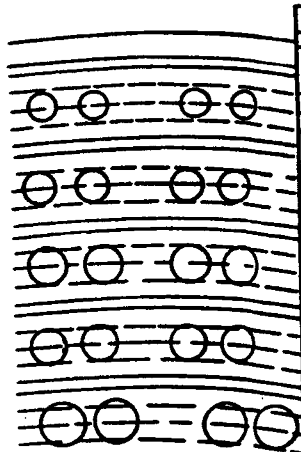
Assembly Dwg: XEO R918730
Plate Dwg. XEO R917600
Ring Set Dwg: XEO R918725

INJECTOR DESCRIPTION

UNIT 099, TYPE 6106-K4, S/N

ORIFICE PATTERN

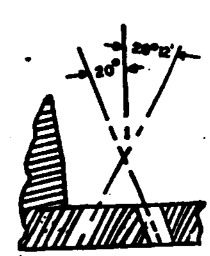


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.776	0.221	80/96	0.416	20	1.24	0.571	0.268
-57	36.746	0.257	80/96	0.416	20	1.20	0.571	0.218
-55	35.626	0.281	80/96	0.428	15	1.17	0.799	0.274
-53	34.506	0.250	80/96	0.416	20	1.13	0.571	0.228
-51	33.386	0.323	64/80	0.428	15	1.23	0.799	0.196

Pattern, General	Fuel	Oxid.
Orifice Area	81.9	59.9
Ring Groove Depth	.538	.538
Ring Material	CU	CU
Wall Gap (Fuel Ring)	.711	
Injection Vel. (1500K)	58	136
Wall Coolant, percent	3.0	

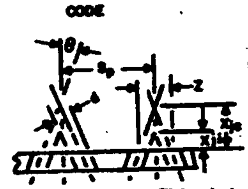
Baffle Design	
Number of Compartments	25
Baffle Construction	Wide Base
Baffle Coolant	FUEL
Baffle Length	3 inches
Baffle Area (in²)	3.56

Injector Mod's.
XEOR - Date
921055-(3-5-65)
921658-(4-19-65)

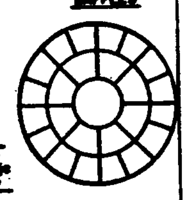


OXIDIZER DOUBLETS NEXT TO RADIAL BAFFLES EXCEPT AS NOTED.

CODE



BAFFLES



REMARKS: This injector has 25 baffle compartments and a radially aligned orifice pattern. The oxidizer doublets next to the radial baffles on all rings except the outer ring and rings next to circumferential baffles have canted fans (see sketch at left). The injector has a cooled GSE boss and the baffle-to-land gaps are not sealed. The injection orifice diameters are programmed for uniform propellant distribution. The outer fuel ring is orificed for 60- to 70-percent flow. There are no baffle dams, ring groove dams, or oxidizer splitters.

Figure 11. Description, Injector 099

[redacted]

[redacted]

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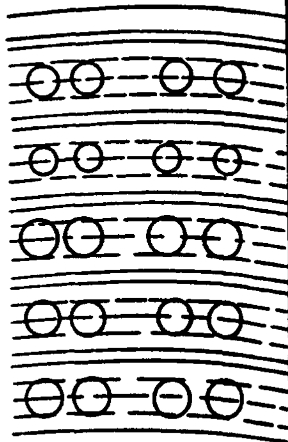
INJECTOR DESCRIPTION

Assembly Dwg: 99-208770
Plate Dwg: 99-208735-11
Ring Set Dwg: 99-208739

UNIT X060, TYPE 6115-V4, S/N

ORIFICE PATTERN



NO.	D	ø	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.776	0.228	96/104	0.416	20	1.14	0.571	0.258
-57	36.746	0.209	96/104	0.416	20	1.11	0.571	0.284
-55	35.626	0.281	72/96	0.428	15	1.17	0.799	0.274
		0.288	16	0.428	15		0.799	0.373
		(Next to Radial Baffle Except Outer Ring)						
-53	34.506	0.242	72/96	0.416	20	1.13	0.571	0.238
		0.209	16 holes		28.2			
		0.185	16 holes		20			
-51	33.386	0.281	64/88	0.428	15	1.19	0.799	0.274
		0.228	16					

Pattern, General

	Fuel	Oxid.
Orifice Area	80.7	57.7
Ring Groove Depth	.538	.538
Ring Material	CU	CU
Wall Gap (Fuel Ring)	.711	
Injection Vel. (1500K)	59	142
Wall Coolant, %	2.91	

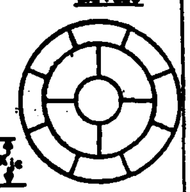
Baffle Design

Number of Compartments	13
Baffle Construction	Wide Base
Baffle Coolant	Fuel
Baffle Length	3 inches
Baffle Coolant Area	3.84

Injector Mod's.

XEOR 912685
XEOR 916120
XEOR 921020
XEOR 917794

BAFFLES



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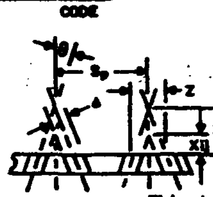
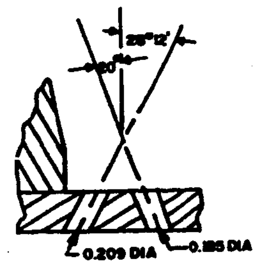




LOX DOUBLETS NEXT TO RADIAL BAFFLES (EXCEPT OUTER LOX RING)

REMARKS: This injector has regeneratively cooled radial baffles and dump cooled circumferential baffles. The fuel radial feed ports are tapered and the outer fuel ring is orificed for 60 percent flow. The oxidizer doublets next to the radial baffles (except outer LOX ring) are shown at the left. The oxidizer doublets next to the circumferential baffles are 0.209-inch diameter (20 degrees). The baffle-to-land gaps are sealed. The injector has a GSE buss.

Figure 12. Description, Injector X060

[redacted]

[redacted]

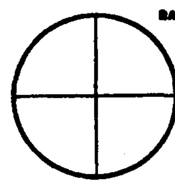
GENERAL INFORMATION	FUEL	OXID.
Orifice Area	87.805	60.478
Injection Vel.(1500K)	53.98	135.09
Ring Groove Depth	0.538	0.538
Ring Material	CU	CU
Wall Gap (Fuel Ring)		
Wall Gap (Outer Zone)		
Percent Film Coolant	4.27	
Excess Fuel on Wall	0.254 percent	

BAFFLE DESIGN	
Number of Compartments	4
Baffle Construction	Wide Base
Baffle Coolant	Bipropellant
Baffle Length	3 inches
Baffle Area	

UNIT X-017 TYPE 6111-P4 S/N

NO.	D	d	GROUPS	Z	θ	Sp	Xjc	Xji
Wall	39.188							
-69	37.414	0.234	84/89	0.430	15		0.800	0.365
-67	36.294	0.234	84/89	0.473	22.5		0.571	0.288
-65	35.174	0.277	84/89	0.430	15		0.800	0.285
-63	34.054	0.234	84/89	0.473	22.5		0.571	0.288
-61	32.934	0.266	84/89	0.430	15		0.800	0.306
-59	31.814	0.221	84/89	0.473	22.5		0.571	0.304
-57	30.694	0.257	84/89	0.430	15		0.800	0.322
-55	29.574	0.213	84/89	0.473	22.5		0.571	0.314
-53	28.454	0.302	56/63	0.430	15		0.800	0.238
-51	27.334	0.218	56/63	0.473	22.5		0.571	0.308
-49	26.214	0.290	56/63	0.430	15		0.800	0.261
-47	25.094	0.238	56/63	0.473	22.5		0.571	0.283
-45	23.974	0.277	56/63	0.430	15		0.800	0.285
-43	23.854	0.228	56/63	0.473	22.5		0.571	0.296
-41	21.734	0.261	56/63	0.430	15		0.800	0.315
-39	20.614	0.213	56/63	0.473	22.5		0.571	0.314
-37	19.494	0.236	36/43	0.430	15		0.800	0.250
-35	18.374	0.250	36/43	0.473	22.5		0.571	0.269
-33	17.254	0.290	36/43	0.430	15		0.800	0.261
-31	16.134	0.234	36/43	0.473	22.5		0.571	0.288
-29	15.014	0.261	36/43	0.430	15		0.800	0.315
-27	13.894	0.213	36/43	0.473	22.5		0.571	0.314
-25	12.774	0.290	24/30	0.430	15		0.800	0.261
-23	11.654	0.234	24/30	0.473	22.5		0.571	0.288
-21	10.534	0.261	24/30	0.430	15		0.800	0.315
-19	9.414	0.204	24/30	0.473	22.5		0.571	0.325
-17	8.294	0.234	24/30	0.430	15		0.800	0.365
-15	7.174	0.209	16/30	0.348	17		0.571	0.233
-13	6.054	0.250	16/30	0.282	10		0.800	0.091
-11	4.934	0.302	4	0.473	22.5		0.571	0.206
-9	3.814	0.272	4	0.430	15		0.800	0.294
-7	2.694		-					
-5	1.574		-					
-3			-					

BAFFLE DIAGRAM



REMARKS: The orifices are programmed for uniform injection density. There are secondary rings in all fuel grooves. The fuel feed ports are tapered at the diameter transition points to improve flow distribution. The oxidizer feed passages are enlarged. The baffles are bipropellant cooled.

Percent film coolant = 4.12.

Figure 13. Description, Injector X017

[redacted]

INJECTOR DURABILITY

An intensive study to determine the cause of ring cracking and braze joint failures on the FRT injector was begun. Four nonfireable test bodies were made to determine the best type of braze joint that could be used on the F-1 injector. These test bodies were made as follows:

1. Gold-plated rings and vapor-honed grooves
2. Gold-plated rings and nickel-plated grooves
3. Nickel-plated rings and nickel-plated grooves
4. Decorative chrome strike plus nickel plate on rings and nickel-plated grooves

These four bodies were then proof pressure tested until the braze joint failed. The average pressure required to cause failure was as follows:

1. 25,500 psi (Failed in joint)
2. 30,650 psi (Failed in parent metal)
3. 19,000 psi (Failed in joint)
4. 24,410 psi (Failed in joint)

The four bodies, along with four new ring sets, were remachined. Other methods and types of plating were planned for these assemblies for further evaluation.

In an attempt to determine the temperature of the injector rings during hot firing, three thermocouples were installed in injector 082B. The three thermocouples were mounted in a LOX ring, fuel ring, and the outer periphery of the injector. The initial hot-fire tests indicated the following temperatures: LOX ring, 850 F; fuel ring, 320 F; and the outer periphery, 200 F. Additional tests were planned for verification.

The investigation was scheduled to continue on a large scale using the FRT configuration injector, 085. This unit was to be modified to accept 11 thermocouples located between orifices, between doublets on the steel ring lands, on the outer baffle can, and on the outer periphery of the injector.

[redacted]

HYDRODYNAMICS

Work during this report period was devoted to obtaining injector flow distribution data, the design and fabrication of fixtures to facilitate gathering of these data, and the writing of an IBM program to reduce them

The effectiveness of various oxidizer splitter designs and spray devices was also investigated using flow fixtures.

A study was conducted to determine the time involved and relative igniter flows during the igniter priming sequence.

FLOW DISTRIBUTION STUDIES

Previous flow distribution studies of various injector elements had indicated discrepancies attributable to human error in the measurements of the times of flow when catch buckets were employed. Consequently, a flow collection system was designed and built (Fig. 14). In this design 24 tubes (with a potential of 40 tubes) were attached to a rotating fixt placed beneath the injector and covering one quadrant. Because the injector elements were too closely spaced to permit flow gathering of each the tubes were placed below alternate elements. The fixture was designe to index in increments of one octant; consequently, alternate elements not measured during one cycle would be measured during the next indexing cycle. The discharge ends of the tubes were attached to a pneumatically actuated, sliding table positioned over the catch buckets, normally plac so that the discharge would miss the buckets.

[redacted]

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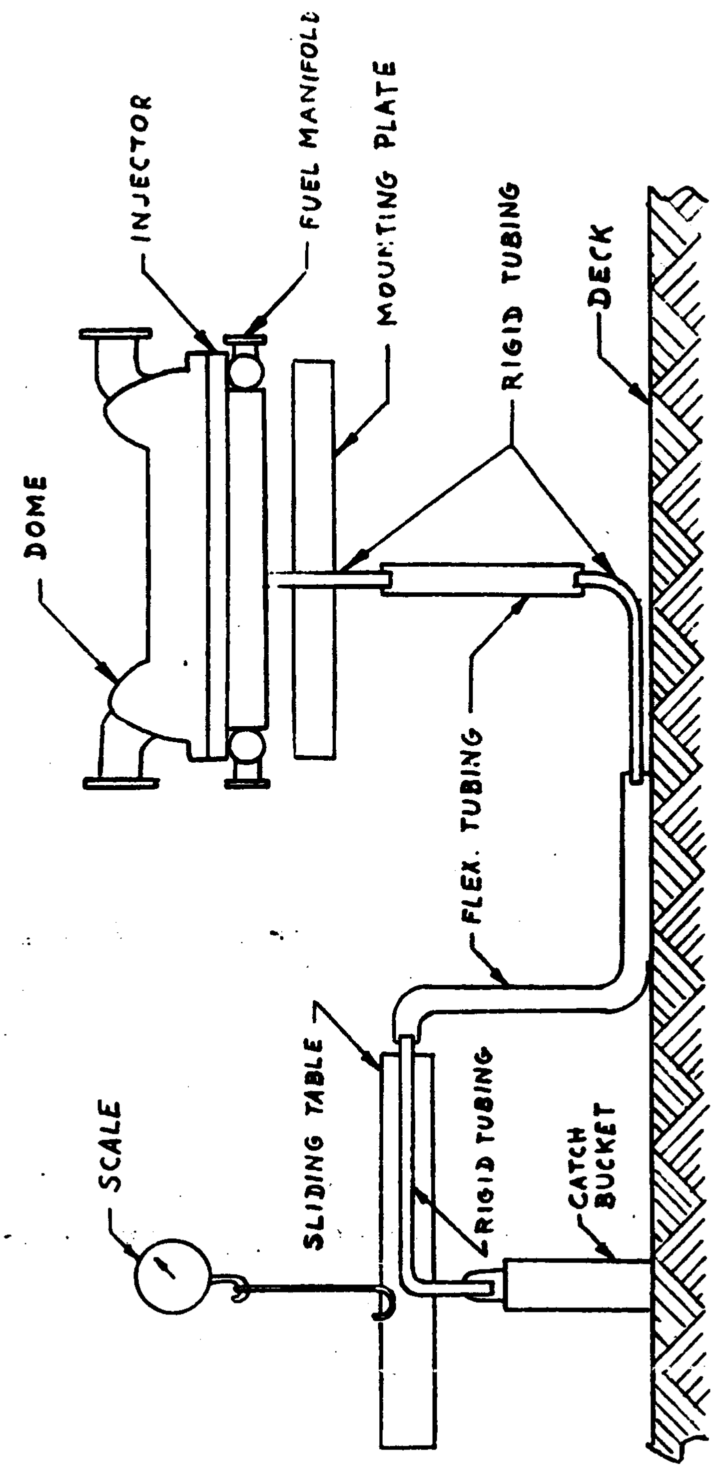

Figure 14. Flow Collection System

[redacted]

To measure the flow distribution, the injector was brought up to the desired flow and the sliding table was actuated. The movement of the table actuated a photo-electric cell that signalled the timer to start. The table was retracted at the discretion of the operator, which action stopped the timer. Individual catch buckets were weighed, the weight being divided by the elapsed time to yield elemental flowrates.

ELECTRONIC DATA PROCESSING OF FLOW DISTRIBUTION DATA

Because data could be gathered at a rate exceeding that possible for their reduction, a set of computer programs was written to expedite the data processing. Figure 15 is a work flow chart of this data processing network. By employing these programs, it was possible to obtain a printout and graphical (by means of a CRT printout) record of individual elemental flowrates for each ring broken down by baffle compartments. Total ring flows, as well as average elemental flowrates for similarly located elements, were also obtained.

Figure 16 is a representative sample of the CRT's of the oxidizer distribution of injector 084W, an FRT injector pattern with oxidizer splitters removed.

OXIDIZER SPLITTER FLOW STUDIES

Posttest inspection revealed that, in some instances, failures occurred in the weld joint binding the oxidizer splitters to the sides of the axial feed holes. Thus, there appeared the possibility of splitter vibration, perhaps triggering or enhancing combustion oscillations.

[redacted]

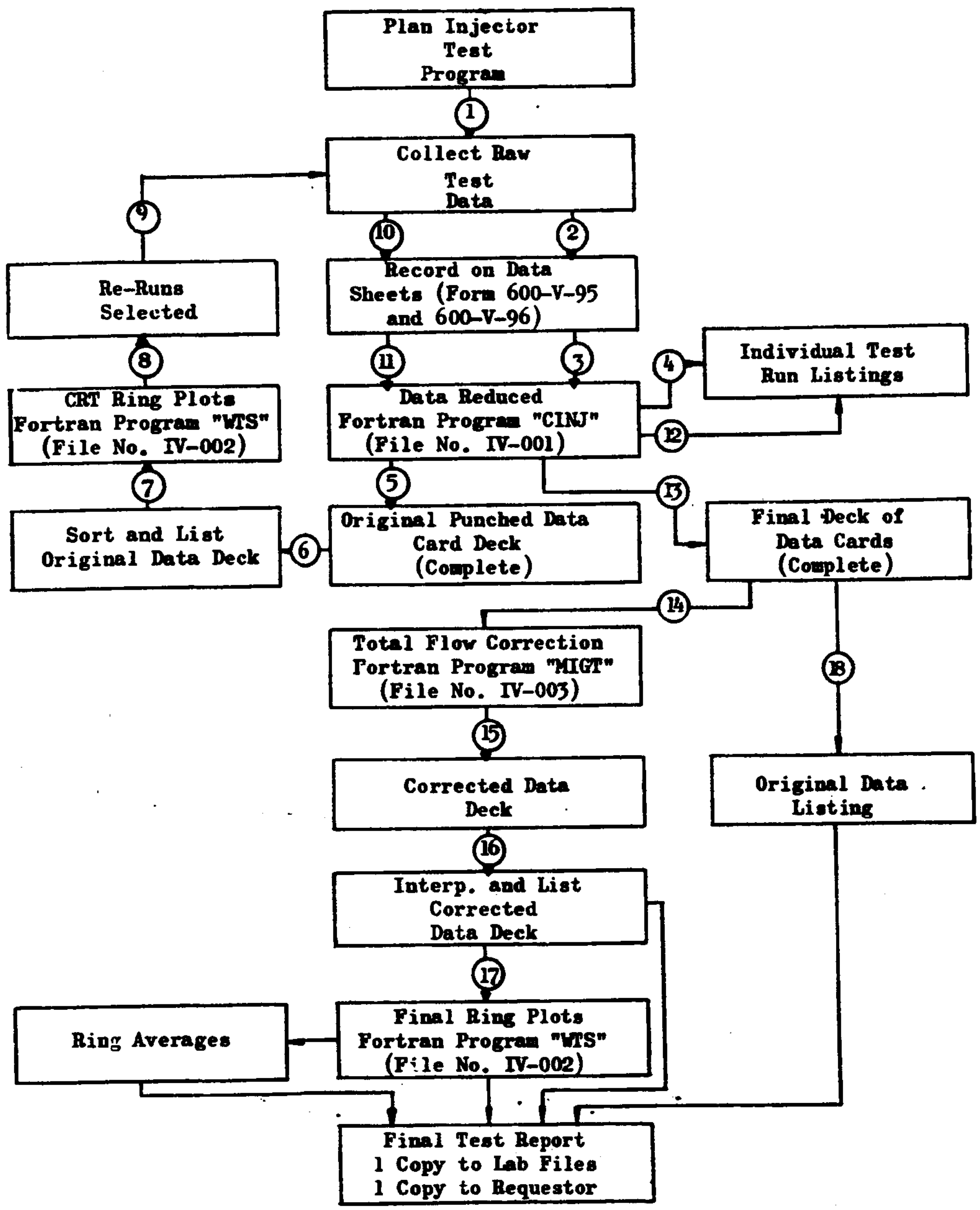

Figure 15. Work Flow Chart of Data Processing Network

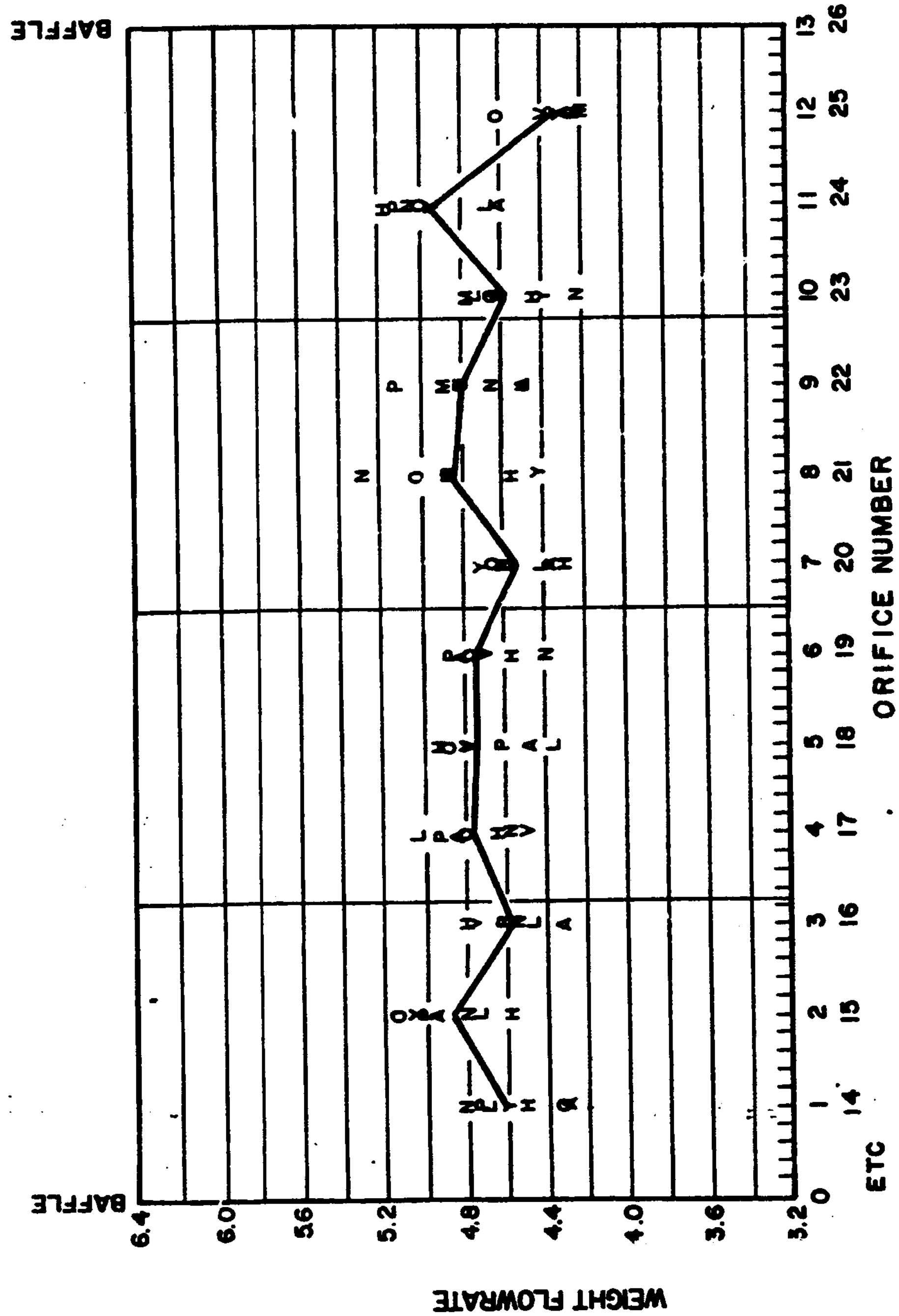

Figure 16. Cathode Ray Tube Plot, Injector 084W-57-Oxidizer Ring

Figure 17 is a drawing of a flow fixture built to investigate this possibility. The device simulated a portion of the ninth oxidizer groove adjacent to a radial baffle. The installation of loose splitters produced no discernible oscillation in the fans. As a result of the flow testing of this device, however, it was found that the physical configuration of the splitter was of secondary importance in canting a fan. The critical factor was the presence of a splitter of any of the designs investigated (crimped and spoon splitters). Likewise, bending of the splitter tip had little effect on fan canting. It was found that canted fans could be produced by the proper placement of oxidizer splitters, without modifying the drill angle of the orifices.

FLOW TESTING OF INJECTION DEVICES

Figure 18 is a drawing of a flow test fixture employing a swirl device to produce atomization. The principle was being considered for incorporation on an F-1 injector. Visual examination disclosed an excellent spray, but at the expense of an excessive pressure drop (850 psi at 13 gal/min, corresponding to the rated flowrate of a single oxidizer triplet orifice).

The device was modified, with no apparent vitiation of the spray, by enlarging the central restricting hole. The pressure drop, for the same flowrate, was lowered to 425 psi.

Future plans called for the enlargement of the tangentially drilled orifices.

A flow test was also conducted of a coaxial stream injection device of a size commensurate with F-1 ring dimensions. It contained an internal oxidizer swirler. Photographic analysis indicated adequate mixing.

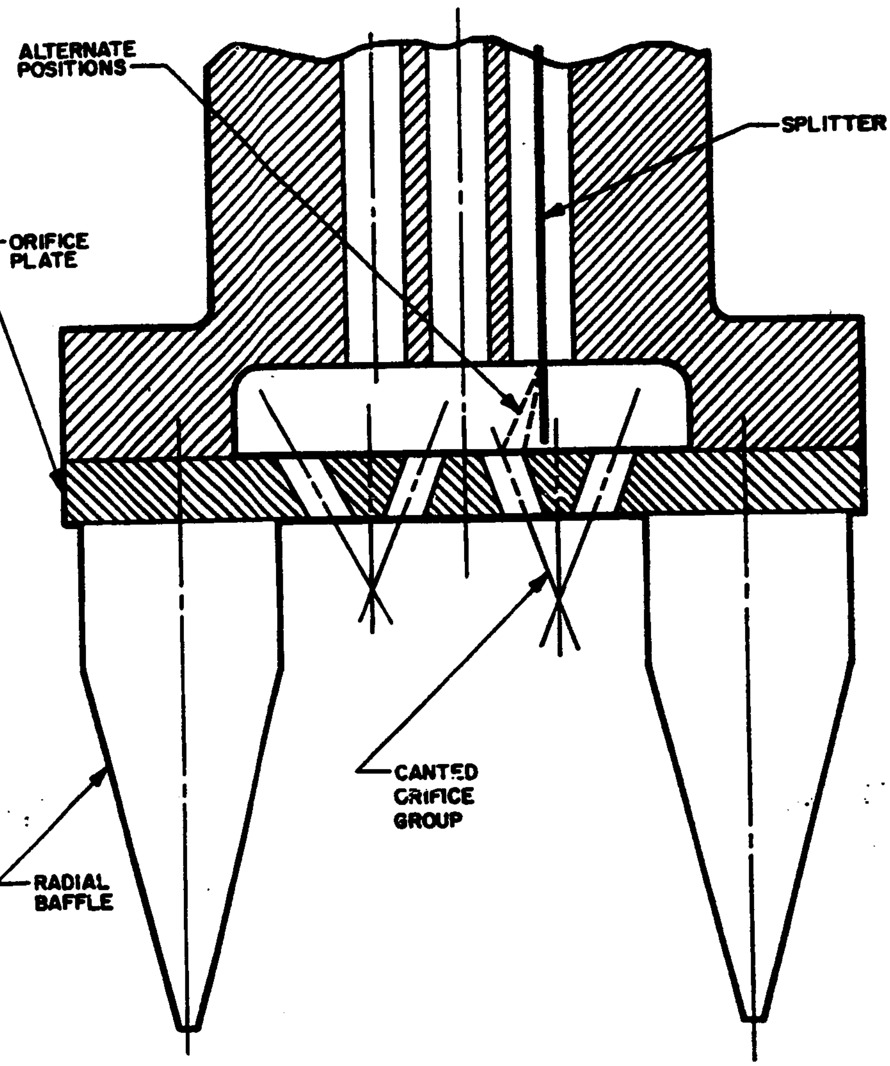

Figure 17. Axial Feed Hole Flow Fixture

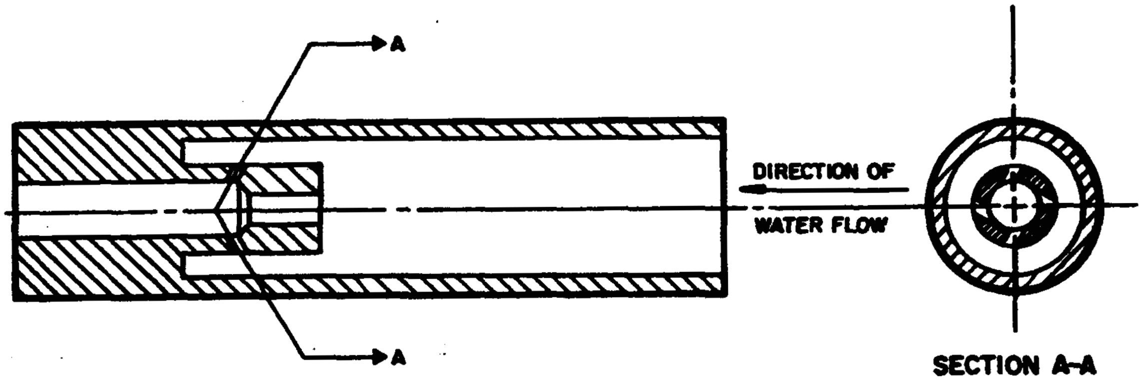

Figure 18. Flow Test Fixture With Swirl Device

[redacted]

However, the pressure drops were excessive: 1750 psi on the oxidizer and 625 psi for the fuel, at rated flowrates.

IGNITER PRIMING STUDIES

A high-speed photographic study was made of the igniter system being primed with water. High-speed solenoid valves were employed to initiate the priming sequence, which was photographed by Fastax cameras.

The results indicated that within 100 milliseconds of the valve opening, all igniters were flowing full, the greatest time interval between valve opening and the beginning of flow appeared to be correlative with the distance from the valve to the igniter.

[redacted]

RESEARCH

TWO-DIMENSIONAL CHAMBER TESTING

During the report period, six tests were conducted on the high-pressure, two-dimensional thrust chamber. Subjects investigated were the effects of baffle length on "buzz" instability, the performance of an injector employing unlike-impinging doublets and showerhead orifices, the injection of "tracers" into the combustion chamber, and the effects of the boundary layer on streak photographs. Spectral, radiation, and thermal measurements were made and a gas sampling was attempted. Results were as follows:

Test 2107

This was an attempt to trigger a buzz instability. Four 3.5-inch-long baffles, equally spaced, were employed. A buzz of approximately 820 cps, 200 psi peak-to-peak resulted during the entire 500 milliseconds of mainstage operation. A bomb-induced disturbance damped within 7 milliseconds.

Test 2108

This was a repeat of Test 2107 above, except for the use of four 6-inch baffles. Buzzing between 800 and 900 cps resulted, and persisted for the entire 490 milliseconds of mainstage operation. Detonation of an explosive charge had no discernible effect.

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Test 2109

This test employed four baffles spaced 3-4-5-4-3. An injection pattern was employed in which 85 percent of the propellants were injected through large showerhead orifices and 15 percent through small, unlike, impinging doublets. The objective was to achieve a high combustion efficiency. The test resulted in a rather high c* of 5370 ft/sec in spite of moderately high injector leakage and damping of a bomb-induced disturbance in 7 milliseconds.

Test 2110

This test employed two 3-inch baffles, spaced to provide compartments 6.5, 7.0, and 6.5 inches wide. The fuels employed were successively ethyl-alcohol and RP-1; the oxidizer was LOX. Aluminum dust was injected into the chamber, normal to the injector face. In addition, one oxidizer doublet flowed nitrogen tetroxide and one of the fuel orifices employed RP-1 during the alcohol phase. These served the function of providing a qualitative picture of the mixing of the combustion gases.

Combustion was stable throughout 400 milliseconds of mainstage operation. Four thermocouples were inserted through the injector face and extended 1 inch downstream. Two heat flux meters at 4.7 and 24.7 inches from the injector face indicated heat fluxes of 3.9 Btu/in.^{2}-sec and 10.8 Btu/in.^{2}-sec, respectively.

[redacted]

Test 2111

This was a repetition of the above test, with additional thermocouples and a grating spectrograph added. Tracers were provided by injector saturated barium chloride and blue-dyed water through orifices in the injector face, while retaining the propellant injection approach employed in the previous test.

A bomb-induced disturbance damped in 60 milliseconds. Data from the heat flux meter located 24.7 inches from the injector face indicated a heated flux of 11.7 Btu/in.^{2}-sec. A gas sampling device was employed, but did not remain open long enough for adequate sampling.

Test 2112

This test employed two 3-inch baffles, spaced as in tests 2110 and 2111. To determine the effect of a boundary layer upon streak photography, streak photographs were taken both upstream and downstream of a hole bleeding combustion gases to the atmosphere.

Spectral and radiation measurements were also made during this test.

ACOUSTIC ABSORPTION STUDIES

A number of instances were reported in which stable combustion was achieved after hardware modifications were made that resulted in blind slits coupled to the combustion chamber. Consequently, acoustic bench tests were conducted to analyze the effects of slits coupled to a cylindrical cavity. These consisted of exiting the air in a cavity 4 inches in diameter and 1 inch long and communicating to slits of various configurations.

[redacted]

Initially, radial slits were introduced by means of gaskets. It was found that the optimum slit configuration produced attenuations of 6.5 to 7.9 decibels for the first tangential mode, 13 decibels for the second tangential mode, and 5.1 decibels for the first radial mode.

The tests were repeated in a different chamber to investigate the effects of longitudinally directed slits. Slits 1/2 inch and 1 inch long were investigated, with widths increasing in increments of 0.015 inch.

It was found that attenuation increased with increased slit depth, as in the case of the radial slits. An optimum slit width was found for each slit height and mode of vibration. The attentuation, at the optimum slit configuration, was found to be 3.8 and 9.2 decibels for the first and second tangential and first radial modes respectively, for the 1/2-inch-long slit. For the 1-inch-long slit, the attenuations, listed in the same order, were 9.1, 17.8, and 7.0 decibels.

[redacted]

ANALYSIS

COMPONENT TESTING (Table 1)

During the report period covered, component tests were conducted to investigate the following areas:

1. Evaluation of the FRT injector configuration
2. Investigation of the effects of oxidizer splitters and splitter shifting on stability
3. Investigation of the effects of oxidizer spray shapes adjacent to baffle surfaces
4. Investigation of a tribaffled injector
5. Investigation of a rotated fan injector
6. Investigation of injector modifications to suppress the buzz mode
7. The effects of removing the oxidizer dome cone on stability
8. The investigation of vented radial baffles as a stabilizing agent
9. Injector performance evaluation tests

Evaluation of the FRT Configuration

During October and November, 17 tests were conducted on the FRT configuration injector (type 084E). Fourteen bomb-induced instabilities damped in times ranging from 8 to more than 400 milliseconds. Four tests took

[redacted]

TABLE 1

COMPONENT TESTING

Tests:	325-327 (2A-1) 9-28-64
Injector Type:	5895V, U/N: F1002, Aot: 49.85, Aft: 62.3, Vo(1500K): 163.5, Vf(1500K): 75.7
Description:	Standard 5U baffled (13 x 3 wide-base, fuel-cooled, rotated), 0.228-inch-diameter fuel doublets at 40-degree included angle, 0.085-inch-diameter LOX triplets at 40-degree included angle (128 LOX showerheads adjacent to radial baffles plugged, remaining LOX doublets have the orifice adjacent to baffle drilled to 0.209-inch-diameter at 28 degrees 12 minutes half angle except in outer LOX ring), nine LOX triplets in outer ring plugged, 100 body coolants remain at 0.076-inch diameter, injector has ASME orifices except in outer ring, hydraulic Mod. II, 10.8-percent wall coolant.
Objectives:	Investigate effect of canted LOX fans along radial baffles on stable combustion
Results:	Two bomb-induced instabilities in a solid-wall thrust chamber damped in 52 and 41 milliseconds
Frequency Analysis:	The instabilities were resurging type with high-amplitude spikes (5000 psi) in chamber pressure; the feed systems had predominant 500 cps.
Tests:	328-331 (2A-1) 10-3-64(4)
Injector Type:	5885X3, U/N: X051, Aot: 61.8, Aft: 85.0, Vo(1500K): 132.2, Vf(1500K): 53.7

[redacted]

TABLE 1

(Continued)

Description:	Modified baffled 5U (13 x 3 wide-base, fuel-cooled, rotated). 0.281-inch-diameter fuel doublets at 30-degree included angle except outer fuel ring, 0.228-inch-diameter doublets at 40-degree included angle outer fuel ring orificed for 70-percent normal flow, 0.242 LOX doublets at 40-degree included angle (LOX doublets along radial baffles in LOX rings -53, -49, -45, -41, -37, -27, -23, -19, -15 have orifices adjacent to radial baffles drilled to 0.250-inch diameter at 28 degrees 12 minutes half angle). Baffle-to-land gap not sealed, 270 LOX splitters, the stainless steel outer ring of the injector body, immediately outside outer fuel ring, was replaced with a copper ring, 3.2-percent wall coolant.
Objectives:	To evaluate performance and operating characteristic of a modified 084E-type injector.
Results:	Four tube wall thrust chamber tests; one bomb-induced instability damped in 122 milliseconds.
Frequency Analysis:	Tests 330 and 331 had low amplitude (150 psi) 400 cps in the P_c and LOX side. Bomb-induced instability on test 331 was a resurging-type instability coupled with 500 cps in the feed systems. LOX injection parameters exhibited abnormally steep fronted high-amplitude (4000 psi) spikes.
Tests:	332-333 (2A-1)
Injector Type:	5891-W3, U/N: X054, Aot: 60.15, Aft: 83.60, Vo(1500K): 136, Vf(1500K): 36.70
Description:	Modified 5U baffled (13 x 3 wide-base fuel-cooled, rotated), 0.281-inch-diameter fuel doublets at 30-degree included angle (fuel doublets adjacent to radial baffles in

[redacted]

TABLE 1

(Continued)

Description (Continued): -13 and -35 are 0.199-inch diameter, all doublets along radial canted about 8 degrees away from baffle except outer ring which has doublets at 0.228-inch diameter at 40-degree included angle), the -9, -11, -31, and -33 LOX rings have orifices at 0.182-inch diameter and 40-degree included angle, the remaining orifices 0.242-inch diameter and 40-degree included angle except LOX doublets along radial baffles which had orifice adjacent to radial baffle drilled to 0.250-inch diameter at 28 degrees 12 minutes half angle and the remaining orifice 0.243-inch diameter at 12 degrees 35 minutes half angle; 302 LOX splitters, 40 baffle dams, outer ring orificed for 70-percent normal flow, baffle-to-land gap not sealed, 3.2-percent wall coolant.

Objective: To investigate effects of unsealed baffle-to-land gap

Test Results: Both the tests ran full duration without bomb or self-induced instabilities. Inspection after test 332 indicated the outer can was partially eroded in compartment No. 6. Bomb on test 333 failed to detonate during mainstage.

Tests: 334-338 (2A-1) 10-6-64(2) 10-7-64(3)

Injector Type: 588583, (084E type), U/N: 099, Aot: 61.8, Aft: 85.0, Vo(1500K): 132.2, Vf(1500K): 55.7

Description: Modified 5U baffled (13 x 3 wide-base, fuel-cooled, rotated), 0.281-inch-diameter fuel doublets at 30-degree included angle except in the outer ring where fuel doublets are 0.228-inch diameter at 40-degree included angle, (outer fuel ring orificed for 70-percent normal flow), LOX doublets are 0.242-inch diameter at 40-degree included angle, except where the orifice next to the baffle of each LOX doublet adjacent to

TABLE 1

(Continued)

Description (Continued):	the radial baffles in rings -53, -49, -45, -41, -37, -27, -23, -19, and -15 is drilled to 0.250-inch diameter at 28 degrees 12 minutes; outer LOX ring and rings adjacent to circumferential baffles have 0.209-inch-diameter orifices at 40-degree included angle; 286 LOX splitters, baffle-to-land gap not sealed, 3.2-percent wall coolant
Objective:	To investigate performance and operating characteristics of an 084E-type injector and to investigate the effect upon combustion of air and gaseous nitrogen injected into the igniter system during mainstage operation
Results:	The first test had no bomb- or self-induced instability and exhibited no reaction to air pulsed into the igniter system. The remaining four tests were bomb tests in a solid-wall chamber which damped in 56, 65, 222, and 312 milliseconds. There was no evidence of a disturbance because of igniter system air and gaseous nitrogen pulse during final four tests.
Frequency Analysis:	The four instabilities were resurging coupled with 500 cps in the feed systems and 1200 to 1500 cps in the chamber pressure between resurges.
Tests:	339-342 (2A-1) 10-7-64(2) 10-8-64(2)
Injector Type:	5897V, U/N: F1002, Aot: 50.65, Aft: 62.3, Vo(1500K): 161, Vf(1500K): 75.7

TABLE 1

(Continued)

Description:	Standard 5U baffled (13 x 3 wide-base, fuel-cooled, rotated), 0.228-inch-diameter fuel doublets at 40-degree included angle, 0.185-inch-diameter LOX triplets at 40-degree included angle, nine LOX triplets in outer ring plugged, 128 LOX showerheads adjacent to radial baffles plugged, remaining LOX doublets drilled out to 0.209-inch diameter with orifice adjacent to baffle at 28 degrees 12 minutes halfangle and remaining orifice of doublet at 20-degree half angle except in outer LOX ring where included angle remains 40 degrees, 100 body coolants at 0.076-inch diameter. Injector has ASME orifices except in outer ring. Hydraulic Mod. II, 10.8-percent wall coolant.
Objectives:	To investigate the effect upon resurging instability of reducing the cant of the LOX fans adjacent to the radial baffles
Results:	One 13.5-grain bomb was detonated during each of the four tests in a solid-wall chamber. The resulting instabilities were damped in 8, 5, 85, and 6 milliseconds. Only the third instability, which failed to damp in one cycle, recorded high-amplitude pressure spikes, and on the first resurge (not the initial surge due to the bomb).
Frequency Analysis:	The 85-millisecond instability was resurging coupled with 500 cps in the feed systems.

TABLE 1
(Continued)

Tests:	343-345 (2A-1) 10-10-64(1) 10-12-64(2)
Injector Type:	5885Y3, U/N: X051, Aot: 61.8, Aft: 85.0, Vo(1500K): 132.2, Vf(1500K): 55.7
Description:	Modified 5U baffled (13 x 3 wide-base, fuel-cooled, rotated), fuel doublets of 0.281-inch diameter at 30-degree included angle, except outer fuel ring where doublets are 0.228-inch diameter at 40-degree included angle and the flow is orificed to 70-percent nominal. LOX doublets are 0.242-inch diameter at 40-degree included angle except in LOX rings -53, -49, -45, -41, -27, -23, -19, and -15 where the orifice of each LOX doublet adjacent to the radial baffle is drilled to 0.250-inch diameter at 28 degrees 12 minutes half angle, outer LOX ring has doublets at 0.209-inch diameter and 40-degree included angle. Injector has 302 LOX splitters and an unsealed baffle-to-land gap. The stainless steel periphery of the injector body immediately outside the last fuel ring was replaced with copper. Wall coolant is 3.2 percent.
Objectives:	To investigate the effect of a copper outer injector periphery on the outer fuel ring-to-land separation and distortion of outer fuel ring.
Results:	Four 13.5-grain bombs were detonated during the three tests in a tube wall thrust chamber. The resulting instabilities were damped in 58, 27, 242, and 108 milliseconds. The ring-to-land separation appeared improved, but the ring distortion persisted.
Frequency Analysis:	All instabilities were resurging with high-amplitude pressure spikes coupled with 500 cps in the feed system.

TABLE 1
(Continued)

Tests:	346 (2A-1) 10-13-64
Injector Type:	5885S3, U/N: 099, Aot: 61.8, Aft: 85.0, Vo(1500K): 132.2, Vf(1500K): 55.7
Description:	Modified 5U baffled (13 x 3 wide-base, fuel-cooled, rotated); fuel doublets 0.281-inch diameter at 30-degree included angle except in outer fuel ring where doublets are 0.228-inch diameter at 40-degree included angle. The outer fuel ring is orificed for 70-percent normal flow. LOX doublets are 0.242-inch diameter at 40-degree included angle except in LOX rings -53, -49, -45, -41, -37, -27, -23, -19, and -15; the orifice next to the baffle of each LOX doublet adjacent to the radial baffles is drilled out to 0.250-inch diameter at 28 degrees 12 minutes. The outer LOX ring had doublets of 0.209-inch diameter at 40-degree included angle. Injector has 286 LOX splitters and an unsealed baffle-to-land gap; 3.2-percent wall coolant
Objectives:	Investigate operating characteristics and performance of 084E-type injector
Results:	One 13.5-grain bomb caused a resurging instability which did not damp. The radial baffles were bent counter clockwise 3/4 inch.
Frequency Analysis:	The instability was a resurging instability coupled with 500 cps in the feed systems and 1200 to 1500 cps in the chamber pressure between resurges.

[redacted]

TABLE 1
(Continued)

Tests:	347-355 (2A-1) 10-14-64(4), 10-15-64(5)
Injector Type:	5881A4 (Type 084C), U/N: 084, Aot: 61.4, Aft: 85.1, Vo(1500K): 133.0, Vf(1500K): 55.7
Description:	Modified 5U baffled (13 x 3 wide-base, fuel-cooled, rotated); fuel doublets are 0.281-inch diameter at 30-degree included angle except in outer ring where doublets are 0.228-inch diameter at 40-degree included angle; LOX doublets 0.242-inch diameter at 40-degree included angle except in LOX rings -53, -49, -45, -41, -37, -27, -23, -19, and -15; the orifice adjacent to the baffle of each LOX doublet along the radial baffles is at 28 degrees 12 minutes half angle. The doublets in LOX ring -9, -11, -31, and -33 are 0.209-inch diameter. Injector has 40 baffle dams, no splitters and outer fuel ring orificed for 70-percent normal flow; 3.2-percent wall coolant
Objectives:	To evaluate self-triggering tendencies with all LOX splitters removed
Results:	There were no self-initiated instabilities. Slight baffle bending occurred during test 349.
Frequency Analysis:	Tests 347, 348, 349, and 351 had 400 cps in LOX, fuel, and P_c. Tests 350, 352, 353, and 354 had no 400 cps in fuel or LOX systems but the chamber pressure had low-amplitude 400 cps.

[redacted]

TABLE 1
(Continued)

Tests:	356 (2A-1) 10-16-64
Injector Type:	5898W3, U/N: X054, Aot: 61.75, Aft: 83.60, Vo(1500K): 132.5, Vf(1500K): 56.70
Description:	Modified 5U baffled (13 x 3 wide-base, fuel-cooled, baffled); fuel doublets are 0.281-inch diameter at 30-degree included angle except along the radial baffles where the fuel fans are canted 7 degrees 49 minutes away from the baffles. The fuel doublets in the -13 and -35 rings adjacent to the radial baffles are 0.199-inch diameter and the fuel doublets in the outer ring are 0.228-inch diameter at 40-degree included angle. LOX doublets are 0.242-inch diameter at 40-degree included angle except in LOX rings -9, -11, -31, and -33 where orifices are 0.209-inch diameter, and along the radial baffles where the orifice adjacent to the baffle of each LOX doublet is 0.250-inch diameter at 28 degrees 12 minutes half angle and the remaining orifice is 0.242-inch diameter at 12 degrees 35 minutes half angle. The injector has 302 LOX splitters and 40 baffle dams and has outer fuel ring orificed for 70-percent normal flow.
Objectives:	To investigate the operating characteristics of an 084D-E-type injector
Results:	Programmed duration test in a tube wall thrust chamber with no bomb- or self-induced instability and no hardware damage
Tests:	357-361 (2A-1) 10-19-64(1) 10-20-64(4)
Injector Type:	5898W3, U/N: X054, Aot: 61.75, Aft: 83.60, Vo(1500K): 132.5, Vf(1500K): 56.70

TABLE 1
(Continued)

Description:	Modified 5U pattern with 13 x 3 wide-base, fuel-cooled, rotated baffles; fuel doublets are 0.281-inch diameter at 30-degree included impingement angle except for the fuel doublets along the radial baffles which are canted 7 degrees 49 minutes away from baffles. The fuel doublets in rings -13 and -35 are 0.199-inch diameter and the doublets in the outer fuel ring are 0.228-inch diameter at 40-degree included angle. The LOX doublets are 0.242-inch diameter at 40-degree included angle except the outer LOX ring. LOX rings -9, -11, -31, and -33 have doublets of 0.209-inch diameter at 40-degree included angle. The LOX doublets along the radial baffles have 0.250-inch diameter orifices at 28 degrees 12 minutes half angle adjacent to the baffle impinging on a 0.242-inch diameter orifice at 12 degrees 35 minutes half angle. The injector has 302 LOX splitters and 40 baffle dams. The outer fuel ring is orificed for 70-percent normal flow and the baffle-to-land gap is not sealed. Wall coolant is 3.2 percent.
Objectives:	To investigate the operating and damping characteristics of this injector.
Results:	Three 13.5-grain bombs induced instabilities that damped in 32, 73, and 7 milliseconds. Test 357 had no bomb and test 361 had bomb blown out without detonation.
Frequency Analysis:	The two disturbances that damped in 32 and 73 milliseconds were resurging instabilities coupled with 500 cps in the fuel and LOX feed systems.
Tests:	362-364 (2A-1) 10-21-64(1) 10-22-64(2)
Injector Type:	588583, (084E) U/N: X045, Aot: 61.8, Aft: 85.1, Vo(1500K): 132.2, Vf(1500K): 55.7

[redacted]

TABLE 1

(Continued)

Description:	Modified 5U pattern with 13 x 3 wide-base, fuel-cooled, rotated baffles; the fuel doublets are 0.281-inch diametor at 30-degree included angle except in outer fuel ring where the doublets are 0.228-inch diameter at 40-degree included angle. The LOX doublets are 0.242-inch diameter at 40-degree included angle except in rings -53, -49, -45, -41, -37, -27, -23, -19, -15 where the orifice next to the baffle of each LOX doublet adjacent to the radial baffle is drilled to 0.250-inch diameter at 28 degrees 12 minutes half angle; the remaining orifice of each LOX doublet is 0.242-inch diameter at 20-degree half angle. The outer fuel ring is orificed for 70-percent normal flow. The injector has 286 LOX splitters, unsealed baffle-to-land gap and 3.2-percent wall coolant.
Objectives:	To investigate the operating and damping characteristics of this injector
Results:	Two 13.5-grain bombs induced instabilities that damped in 55 and 10 milliseconds; there was no bomb installed for test 362.
Frequency Analysis:	The disturbance that damped in 55 milliseconds was a resurging instability coupled with 500 cps in the LOX feed system.
Tests:	365-367 (2A-1) 10-23-64(3)
Injector Type:	5885C4, U/N: 099, Aot: 61.8, Aft: 85.0, Vo(1500K): 132.2, 1500K): 55.7
Description:	The injector is a modified 5U with 13 x 3 wide-base, fuel-cooled, rotated baffles. The fuel doublets are 0.281-inch diameter at 30-degree included angle except in the outer fuel ring where the doublets are 0.228-inch diameter at 40-degree included angle. The LOX doublets are 0.242-inch diameter at 40-degree included angle except

[redacted]

TABLE 1
(Continued)

Description (Continued):	in rings -53, -49, -45, -41, -37, -27, -23, -19, -15 in which the orifices next to the baffles of each LOX doublet adjacent to the radial baffles are 0.250-inch diameter at 28 degrees 12 minutes half angle, and the other orifice of each doublet is 0.242-inch diameter at 20-degree half angle. The outer fuel ring is orificed for 70-percent normal flow. The injector has no LOX splitters, 40 baffle dams, an unsealed baffle-to-land gap and 3.2-percent wall coolant.
Objectives:	To investigate the damping effects of this injector without LOX splitters
Results:	Three 13.5-grain bombs induced disturbances that damped in 12, 7, and 98 milliseconds. Posttest inspection after test 365 revealed that the radial baffles were bent counter-clockwise.
Frequency Analysis:	The 98-millisecond disturbance was a resurging instability coupled with 500 cps. Steady-state oscillations of 400 cps were present in LOX, fuel and chamber pressure parameters at comparatively low amplitudes (250 psi).
Tests:	368-369 (2A-1) 10-27-64(2)
Injector Type:	5885C4, U/N: 099, Aot: 61.8, Aft: 35.0, Vo(1500K): 132.2, Vf(1500K): 55.7
Description:	The injector has a modified 5U pattern with 13 x 3 wide-base, fuel-cooled, rotated baffles. The fuel doublets are 0.281-inch diameter at 30-degree included angle except in the outer fuel ring where the doublets are 0.228-inch diameter at 40-degree included angle. The LOX doublets are 0.242-inch diameter at 40-degree included angle except in rings -53, -49, -45, -41, -37, -27, -32, -19, and -15 where the baffle-adjacent orifice of each LOX doublet next to the radial baffles

TABLE 1
(Continued)

Description (Continued:	is 0.250-inch diameter at 28 degrees 12 minutes half angle and the other orifice of each LOX doublet adjacent to the radial baffles is 0.242-inch diameter at 20-degree half angle. The outer LOX ring has doublets 0.209-inch diameter at 40-degree included angle. The outer fuel ring is orificed for 70-percent normal flow. This injector has 40 baffle dams, unsealed baffle-to-land gap and 3.2-percent wall coolant. This injector has been changed from the previous configuration (Type 588583) by removing all 286 LOX splitters.
Objectives:	To investigate the operating and damping characteristics of this injector with the LOX splitters removed
Test Results:	Two 13.5-grain bombs induced instabilities that persisted for 10 and 370 milliseconds Investigation of injector after test 368 indicated the radial baffle at the 12 o'clock position was bent counter-clockwise approximately 1/2 inch. After test 369 all the radial baffles were bent 1/2-inch counter-clockwise and the upper O-ring was slightly damaged in four places (this is a 70 shore neoprene type O-ring).
Frequency Analysis:	Both tests, during mainstage steady-state operation, exhibited low-amplitude 400-cps oscillations in fuel, LOX, and chamber pressure. The 10-millisecond instability damped in one cycle. The 370-millisecond instability was basically 500-cps oscillations intermixed with random high-amplitude, steep-fronted pressure spikes.
Tests:	370-377 (2A-1) 10-28-64(3), 10-29-64(5)
Injector Type:	5881M3 (084C), U/N: 084, Aot: 61.4, Aft: 85.1, Vo(1500K): 133.0, Vf(1500K): 55.7

TABLE 1

(Continued)

Description:	The injector has a modified 5U pattern with 13 x 3 wide-base, fuel-cooled rotated baffles. The fuel doublets are 0.281-inch diameter at 30-degree included angle except in the outer fuel ring where the doublets are 0.228-inch diameter at 40-degree included angle. The LOX doublets are 0.242-inch diameter at 40-degree included angle except in the LOX rings -53, -49, -45, -41, -37, -27, -23, -19, and -15 where the LOX doublets are 0.242-inch diameter and canted 4 degrees 6 minutes away from the radial baffles. In LOX rings -9, -11, -31, and -33, the doublets are 0.209-inch diameter at 40-degree included angle. The injector has 40 baffle dams and 314 LOX splitters. The outer fuel ring is orificed for 70 percent of normal flow. Wall coolant is 3.2 percent.
Objective:	To investigate the effect of the LOX splitters on self triggering
Test Results:	Eight tests were conducted in a tube wall thrust chamber. Seven tests went programmed duration without self-triggering or buzzing. The first test (370) was cut during build-up transition because of a LOX pressure switch failure.
Tests:	378 (2A-1) 10-30-64
Injector Type:	5892D4, U/N: X037, Aot: 41.9, Aft: 46.1, Vo(1500K): 195.0, Vf(1500K): 102.8
Description:	The injector is a standard 5U pattern with 3 x 3 wide-base, bipropellant cooled baffles. The fuel doublets are 0.199-inch diameter at 30-degree included angle except the doublets along the baffles where the orifice adjacent to the baffle is 22 degrees 49 minutes half angle and the remaining orifice is 7 degrees 11 minutes. The outer fuel ring is 0.199-inch diameter at 40-degree included angle. The LOX triplets are 0.159-inch diameter at 40-degree included angle. The LOX doublets

TABLE 1
(Continued)

Description (Continued):	along the baffles are 0.1935-inch diameter with the orifice adjacent to the baffle at 28 degrees 12 minutes half angle and the outer orifice of each doublet is 12 degrees 35 minutes half angle. The injector had deep fuel and shallow LOX grooves and no hydraulic modifications. Wall coolant is 7.1 percent. There are 194 LOX splitters as opposed to 205 splitters on the previous type (5892V3).
Objectives:	To evaluate the damping characteristics of a tribaffle, bipropellant cooled injector
Test Results:	One 13.5-grain bomb induced an instability that did not damp and which caused severe damage to the dome and injector. The outer 16 injector rings were burned out and the inner face of the dome was severely burned, as was the instrumentation and electrical wiring.
Frequency Analysis:	The instability was predominantly 500-cps oscillations at moderate-to-high amplitudes. Several high-amplitude pressure spikes were recorded by LOX injection parameters 140 milliseconds after the start of the instability. Except for these pressure spikes, the instability was very similar to previous instabilities on injectors X035 and X037. No testing on Test Stand 2A-1 because of damage incurred during test 425-378-104. After repair of the facility, testing resumed 11-9-64.
Tests:	379 (2A-1)
Injector Type:	5882B4, U/N: X055, Aot: 49.2, Aft: 85.1, Vo(1500K): 166.1, Vf(1500K): 55.7

TABLE 1
(Continued)

Description: The injector is a modified 5U pattern with 13 x 3 wide-base, fuel-cooled baffles. The fuel doublets are 0.281-inch diameter at 30-degree included angle except in the outer fuel ring where the doublets are 0.228-inch diameter at 40-degree included angle. The LOX doublets are 0.209-inch diameter at 56 degrees 24 minutes included angle except for the LOX doublets along the radial baffles where the LOX orifice facing the baffle is at 20-degree half angle, the LOX doublets at the intersections of the circumferential and radial baffles are not canted. The -9 LOX ring has doublets at 40-degree included angle. The injector has 164 fuel ring groove dams and deep fuel ring grooves. The outer fuel ring was restricted to 70 percent of normal flow for this test.

Objectives: To evaluate the effect upon 500-cps buzzing of reduced flow in outer fuel ring.

Results: One test of programmed duration was fired in a tube wall thrust chamber. There was no indication of 500-cps buzzing and there was no bomb- or self-induced instability.

Tests: 380-382 (2A-1) 11-12-64(2) 11-13-64

Injector Type: 5896U3, U/N: 082, Aot: 49.6, Aft: 85.0, Vo(1500K): 165, Vf(1500K): 55.7

Description: The injector is a modified 5U pattern with 13 x 3 wide-base, fuel-cooled baffles. The fuel doublets are 0.281-inch diameter at 30-degree included angle except in the outer fuel ring where the doublets are 0.228-inch diameter at 40-degree included angle. The LOX doublets are 0.209-inch diameter at 56 degrees 24 minutes included angle. The doublets along the radial baffles have orifices facing the baffle 0.209-inch diameter at 20-degree half angle and the orifices facing away from the baffle

TABLE 1
(Continued)

Description (Continued):	are 0.21875-inch diameter at 28 degrees 12 minutes half angle. The LOX doublets adjacent to the radial baffles in the outer ring are not canted. The -9 LOX ring has doublets of 0.209-inch diameter at 40-degree included angle. The injector has 164 fuel ring groove dams and 24 baffle dams. The baffle-to-land gap is not sealed and the wall coolant is 4.6 percent.
Objectives:	To evaluate the effect of overlapped LOX fans adjacent to the radial baffle on buzzin conditions
Results:	Four 13.5-grain bombs (two on test 382) induced disturbances that damped in 14, 11, 41, and 43 milliseconds.
Frequency Analysis:	All four disturbances damped without resurging, however, in the last two disturbances the 500-cps mode present in all instabilities on this type of ector, persisted at a level above 114 g (peak-to-peak) approximately 20 milliseconds after the high-amplitude spikes had damped out.
Tests:	383-386 (2A-1) 11-14-64(4)
Injector Type:	5884Z3, U/N: X002, Aot: 61.05, Aft: 85.0, Vo(1500K): 13?.8, Vf(1500K): 55.?
Description:	The injector has a modified 5U pattern with 13 x 3 wide-base, fuel-cooled baffles. The fuel doublets are 0.281-inch diameter at 30-degree included angle, except in outer fuel ring where the doublets are 0.228-inch diameter at 40-degree included angle. The LOX doublets are 0.242-inch diameter at 56 degrees 24 minutes included angle except along radial baffles where the doublets are 0.209-inch diameter and the orifice facing the radial baffle is at 20-degree half angle. In LOX rings -9, -11,

TABLE 1
(Continued)

Description (Continued):	-31, and -33 the doublets are 0.209-inch diameter at 56 degrees 24 minutes included angle except in ring -9 where the doublets are at 40-degree included angle. LOX showerheads with a 0.0625-inch diameter have been drilled between the orifices of each LOX doublet. The injector has 70 LOX splitters and unsealed baffle-to-land gap. The wall coolant is 4.6 percent.
Objectives:	To investigate the effect of the LOX showerheads upon buzzing conditions
Results:	Test 386 was a sequence failure. Tests 383 and 385 had no bomb- or self-induced instabilities and ran the programmed duration. Test 384 experienced a self-induced instability that damped in 78 milliseconds and a bomb-induced instability that damped in 60 milliseconds. Test 385 experienced a disturbance of 100 g.
Frequency Analysis:	The disturbances were resurging coupled with 500 cps in all parameters. During steady-state operation a 500-cps buzzing, out-of-phase across the inlets, was seen in all parameters on all tests.
Tests:	387 (2A-1) 11-16-64(1)
Injector Type:	5884Z3, U/N: X002, Aot: 61.05, Aft: 85.0, Vo(1500K): 133.8, Vf(1500K): 55.7
Description:	The injection pattern is a modified 5U with 13 x 3 wide-base, fuel-cooled baffles. The fuel doublets are 0.281-inch diameter at 30-degree included angle, except in the outer fuel ring where the doublets are 0.228-inch diameter at 40-degree included angle. The LOX doublets in rings -11, -31, and -33 are 0.209-inch diameter at 56 degrees 24 minutes included angle. The LOX doublets in ring -9 are 0.209-inch diameter at 40-degree included angle. The LOX doublets adjacent to the radial

TABLE 1

(Continued)

Description (Continued):	baffles are 0.209-inch diameter with the orifices facing the baffle at 40-degree half angle and the orifices facing away from the baffle at 28 degrees 12 minutes half angle. The remaining LOX doublets are 0.242-inch diameter at 56 degrees 24 minutes included angle. The injector has 24 baffle dams and 70 LOX splitters. The baffle-to-land gap is not sealed. LOX showerheads of 0.0625-inch diameter were drilled between the orifices of each LOX doublet. The wall coolant is 4.6 percent.
Objectives:	To investigate the effects of the LOX showerheads upon buzzing
Results:	One test resulted in an observer cutoff because of a gas leak between nozzle and combustion zone. Cutoff was initiated during buildup transient so that mainstage operating conditions were achieved momentarily before entering shutdown transient. During chamber pressure decay a self-induced instability damped in 32 milliseconds.
Frequency Analysis:	The frequency during instability was predominantly 500 cps, with random pressure spikes.
Tests:	388-390 (2A-1) 11-16-64(2) 11-18-64(1)
Injector Type:	5896U3, U/N: 082, Aot: 49.6, Aft: 85.0, Vo(1500K): 165, Vf(1500K): 55.7
Description:	The injector has a modified 5U pattern with 13 x 3 wide-base, fuel-cooled baffles. The fuel doublets are 0.281-inch diameter at 30-degree included angle except for the outer fuel ring where the doublets are 0.228-inch diameter at 40-degree included angle. The LOX doublets in the -9 LOX ring are 0.209-inch diameter at 40-degree included angle. The LOX doublets along the radial baffles, except in the outer

TABLE 1
(Continued)

Description (Continued):	LOX ring, have those orifices facing the baffle 0.209-inch diameter at 20-degree half angle and those facing away from the baffles 0.21875-inch diameter at 28 degrees 12 minutes half angle. Those LOX doublets in the outer LOX ring and adjacent to the radial baffles are 0.209-inch diameter with the orifices facing the baffle at 20-degree half angle and the orifices facing away from the baffles at 28 degrees 12 minutes half angle. The injector has 24 baffle dams and 164 fuel ring groove dams. Wall coolant is 4.6 percent.
Objectives:	To evaluate the effect of the overlapped LOX fans on the buzzing tendencies of this injector
Results:	There were three tests, two ran the programmed duration. Test 389 was an observer cutoff because of the LOX pressure oscillations at the tank. There were no bombs employed in any of the tests and there was no self-induced 500-cps oscillations.
Tests:	391-393 (2A-1) 11-19-64(2) 11-20-64(1)
Injector Type:	5833E4, U/N: X021, Aot: 49.2, Aft: 85.0, Vo(1500K): 166.1, Vf(1500K): 55.7
Description:	The injector has a modified 5U pattern with 13 x 3 wide-base, fuel-cooled baffles. The fuel doublets are 0.281-inch diameter at 30-degree included angle except in the outer fuel ring where the doublets are 0.228-inch diameter at 40-degree included angle. The LOX doublets adjacent to the radial baffles are 0.209-inch diameter with the orifices facing the baffles at 20-degree half angle and those orifices facing away from the baffles at 28 degrees 12 minutes half angle. The remaining LOX doublets are 0.209-inch diameter at 56 degrees 24 minutes included angle. The injector has 24 baffle dams, 164 fuel dams and 314 LOX splitters. The fuel ring grooves were

TABLE 1
(Continued)

Description (Continued):	enlarged from 0.400 to 0.450 inch; 132 vent holes of 0.209-inch diameter were drilled through the bases of the radial baffles.
Objectives:	To investigate the effect of vented baffles on the damping capabilities and the 500-cps oscillations
Results:	One 13.5-grain bomb was employed on test 393 inducing a disturbance that persisted for 475 milliseconds. Tests 391 and 392 had no self- or bomb-initiated instabilities, and in both cases received a programmed cutoff.
Frequency Analysis:	The frequency during instability was predominantly 500 cps with random high-amplitude, steep-fronted pressure spikes that reached 7500 psi in the chamber area.
Tests:	394 (2A-1) 11-20-64(1)
Injector Type:	6101Q3, U/N: X040, Aot: 63.7, Aft: 88.4, Vo(1500K): 128.3, Vf(1500K): 53.6
Description:	The injector has a modified 5U pattern with 13 x 3 wide-base, fuel-cooled baffles. The fuel doublets are 0.281-inch diameter at 30-degree included angle except in the outer fuel ring where the doublets are 0.228-inch diameter at 40-degree included angle; 240 fuel doublets 0.094-inch diameter at 30-degree included angle were added between the existing fuel doublets except in the outer ring. The LOX doublets are 0.238-inch diameter at 76-degree included angle. There are 164 fuel ring groove dams and 24 baffle dams. Wall coolant is 4.44 percent.
Objectives:	To investigate the effect of the additional fuel doublets upon buzzing

TABLE 1
(Continued)

Results:	The injector experienced a self-initiated instability that started ≈30 milliseconds after 90-percent chamber pressure, and continued into chamber pressure decay.
Frequency Analysis:	130 milliseconds after 90-percent chamber pressure, buzzing started and built in amplitude until going unstable 100 milliseconds later. The frequency during instability was 500 cps with random high-amplitude pressure spikes.
Tests:	395, 396 (2A-1) 11-21-64 to 11-23-64
Injector Type:	6102V, U/N: F1002, Aot: 49.85, Aft: 59.5, Vo(1500K): 163.5, Vf(1500K): 80
Description:	The injector has a 5U orifice pattern with 13 x 3 wide base, fuel-cooled baffles. The fuel doublets are 0.228-inch diameter at 40-degree included angle. The LOX triplets are 0.185-inch diameter at 40-degree included angle. Adjacent to the radial baffles, the showerheads of the LOX triplets were plugged producing LOX doublets of 0.209-inch diameter with the orifices facing the baffles at 20-degree half angle and the orifices facing away from the baffles at 28 degrees 12 minutes half angle. The outer LOX ring has nine plugged LOX triplets and no canted fans. The orifices are ASME except in outer ring and all film and body coolant holes are plugged. The injector is a Mod. II, wall coolant is 6.6 percent.
Objectives:	To investigate operating characteristics with plugged film and body coolant holes.
Results:	The two tests were ended by observer cutoffs because of oscillations in the LOX tank pressure.

TABLE 1

(Continued)

Tests:	397-402 (2A-1) 12-1-64(2) 12-3-64(1) 12-5-64(3)
Injector Type:	6102V, U/N: F1002, Aot: 49.85, Aft: 59.5, Vo(1500K): 163.5, Vf(1500K): 80
Description:	The injector has a 5U orifice pattern with 13 x 3, wide-base, fuel-cooled, rotated baffles. The fuel doublets are 0.228-inch diameter at 40-degree included angle. The LOX triplets are 0.185-inch diameter at 40-degree included angle. The showerheads of the LOX triplets adjacent to the radial baffles were plugged producing LOX doublets which were then enlarged to 0.209-inch diameter. The orifice facing the baffle of each LOX doublet has a half angle of 20 degrees, the orifices facing away from the baffles are at 28 degrees 12 minutes half angle. The outer LOX ring has nine plugged LOX triplets and no canted fans. The orifices are ASME except in the outer ring and all film and body coolants are plugged. The injector is a hydraulic Mod. II and has 6.6-percent wall coolant.
Objectives:	To evaluate operating and performance characteristics of this injector with the film and body coolant orifices plugged
Results:	Test 397: Programmed cutoff, but with poor LOX tank regulation for first 5 seconds 398: Observer cutoff because of poor LOX tank regulation 399: Observer cutoff because of poor LOX tank regulation 400: Programmed cutoff with good LOX tank regulation 401: Sequence failure cutoff because main oxidizer valve was slow in opening 402: Programmed duration with good tank regulation There were no bomb- or self-induced instabilities during the tests

TABLE 1
(Continued)

Tests:	403-404 2A-1, 12-7-64 (2)
Injector Type:	6102V, U/N: F1002, Aot: 49.85, Aft: 59.5, Vo(1500K): 163.5 Vf(1500K): 80.0
Description:	The injector has a 5U pattern with 13 x 3 wide-base, fuel-cooled with rotated baffles. The fuel doublets are 0.228-inch diameter at 40-degree included angle. All LOX triplets adjacent to the radial baffles, except in the outer LOX ring, have the showerhead orifices plugged, producing doublets which were drilled out to 0.209-inch diameter. The orifices of the doublets are facing toward the baffles at 20-degree half angle and the orifices facing away from the baffles are at 28 degrees 12 minutes half angle. There are nine plugged LOX triplets in the outer LOX ring. The orifices are ASME except in the outer ring. All film and body coolant holes are plugged. The injector is a Mod. II, and has 6.6-percent wall coolant.
Objectives:	To investigate the operating characteristics of this injector with plugged film and body coolant.
Results:	There were three 13.5-grain bomb-induced instabilities, one on test 403 and two on test 404. The respective damp times were 27, 30, and 105 milliseconds. Two thrust chamber tubes failed during test 404.
Frequency Analysis:	The first two instabilities damped without resurging, however, the third instability persisted at 500 cps in the feed systems and 250 to 300 cps were present in the chamber (Tap CG1a). There were comparatively high-amplitude spikes in the chamber at 4000 psi.

[redacted]

TABLE 1
(Continued)

Tests:	405-406 2A-1, 12-7-64(1), 12-8-64(1)
Injector Type:	5899E5, U/N: R004, Aot: 61.40, Aft: 85.8, Vo(1500K): 133, (1500K): 55.7
Description:	The injector is a flat-face with the injection pattern designed to give a uniform mixture ratio across the injector. Fuel rings -5, -9, -13, -17, and -21 have doublets of 0.261-inch diameter at 30-degree included angle. The remaining fuel rings, except for the outer ring, have doublets of 0.250-inch diameter at 30-degree included angle. The outer fuel ring has doublets of 0.228-inch diameter at 40-degree included angle. All LOX doublets have an included angle of 40 degrees. The LOX doublets in rings -7, -11, -15, -19, and -23 are 0.221-inch diameter and the doublets in the remaining LOX rings are 0.213-inch diameter. The injector has 120 LOX splitters and has the outer LOX ring canted 4 degrees 45 minutes toward the center of the injector. The outer fuel ring is orificed for 70-percent normal flow and is canted 9 degrees 30 minutes toward the center of the injector. Forty-eight fuel orifices adjacent to the igniters are at 0.221-inch diameter.
Objectives:	To investigate the performance of an injector programmed for uniform mixture ratio
Results:	There were no bombs employed in either test. Both tests received a programmed cut-off without experiencing buzz or a self-induced instability. The c* efficiencies for the two tests were 91.7 and 91.3 percent, respectively.

[redacted]

TABLE 1

(Continued)

Tests:	407-410: 2A-1, 12-8-64(1), 12-9-64(3)
Injector Type:	6105F4, U/N: X049, Aot: 57.9, Aft: 85.0, Vo(1500K): 141.0, Vf(1500K): 55.7
Description:	The injector has a modified 5U orifice pattern with 13 x 3, wide-base, fuel-cooled rotated baffles. The fuel doublets are 0.281-inch diameter at 30-degree included angle except in the outer ring where the fuel doublets are 0.228-inch diameter at 40-degree included angle. The LOX doublets adjacent to the radial baffles have orifices facing toward the baffles at 0.185-inch diameter and a 20-degree half angle while the orifices facing away from the baffles are at 0.209-inch diameter and 28 degrees 12 minutes half angle. The LOX doublets in the outer ring and the doublets adjacent to the circumferential baffles are 0.209-inch diameter at 40-degree included angle. The remaining LOX doublets are 0.242-inch diameter at 40-degree included angle. The injector has 40 baffle dams, 270 LOX splitters and 70-percent normal flow in the outer fuel ring. The wall coolant is 3.2 percent.
Objectives:	To investigate the effect upon stability of accentuated canting of the LOX doublets adjacent to the baffles with this type of injector
Results:	Test 407 employed no bomb, did not experience a self-induced instability, and received a programmed cutoff. Tests 408 through 410 employed four 13.5-grain bombs which damped without resurging in 27, 33, 22, and 26 milliseconds; all tests ran their programmed duration.
Frequency Analysis:	The LOX injection, fuel injection, and chamber pressure parameters exhibited a low-amplitude 400-cps mode.

TABLE 1

(Continued)

Tests: 411-413 2A-1, 12-10-64(2), 12-11-64(1)

Injector Type: 5882H4, U/N: X055, Aot: 49.2, Aft: 85.2, Vo(1500K): 166.1, Vf(1500K): 55.7

Description: Injector has a modified 5U orifice pattern with 13 x 3, wide-base, fuel-cooled baffles. The fuel doublets are 0.281-inch diameter at 30-degree included angle except in the outer fuel ring where the doublets are 0.228-inch diameter at 40-degree included angle. All LOX doublets have 0.209-inch diameter orifices. Those LOX doublets adjacent to the radial but not adjacent to the circumferential baffles have the orifices facing toward the radial baffles at 20-degree half angle, while the orifices facing away from the radial baffles at 28 degrees 12 minutes half angle. The LOX doublets in the -9 ring are at 40-degree included angle. The remaining LOX doublets are at 56 degrees 24 minutes included angle. The injector has 314 LOX splitters, 24 baffle dams, 164 ring groove dams and deep fuel ring grooves. There were 88 fuel orifices in the outer circumferential baffle opened from 0.0635-inch diameter to 0.076-inch diameter. The outer fuel ring is orificed for 70-percent flow. The wall coolant is 3.2 percent.

Objectives: To evaluate the effect of increasing the selected circumferential baffle coolant orifices, upon performance.

Results: Test 411 had an observer cutoff during the start transient and never reached mainstage; a hypergol inlet gasket was blown out during the test. Test 412 was terminated by an observer cutoff when the flight instrumentation boss on the thrust chamber inlet manifold failed. Test 413 was terminated by a rough combustion cutoff (RCC) because a faulty accelerometer erroneously indicated over 282 g for a sufficient time to initiate the RCC signal.

TABLE 1
(Continued)

Frequency Analysis:	Test 412 and 413 had strong 500 cps in the chamber (500 psi) with less severe oscillations in the feed systems.
Tests:	414-417 2A-1, 12-15-64(1), 12-16-64(3)
Injector Type:	6105F4, U/N: X049, Aot: 57.9, Aft: 85.0, Vo(1500K): 141.0, Vf(1500K): 55.7
Description:	The injector has a modified 5U orifice pattern with 13 x 3, wide-base, fuel-cooled rotated baffles. The fuel doublets are 0.281-inch diameter at 30-degree included angle. The LOX doublets adjacent to the radial baffles have orifices facing toward the baffles at 0.185-inch diameter and a 20-degree half angle while the orifices facing away from the baffles are at 0.209-inch diameter and 28 degrees 12 minutes half angle. The LOX doublets in the outer ring and the doublets adjacent to the circumferential baffles are 0.209-inch diameter at 40-degree included angle. The remaining LOX doublets are 0.242-inch diameter at 40-degree included angle. The injector has 40 baffle dams, 270 LOX splitters and 70-percent normal flow in the outer fuel ring. The wall coolant is 3.2 percent.
Objectives:	To investigate the effect of using a LOX dome without a cone
Results:	Damped four 13.5-grain bomb-induced instabilities in 24, 64, 9, and 13 milliseconds, respectively; the 64-millisecond instability damped after two resurges. Using a LOX dome without a cone did not appear to cause any unusual roughness in the LOX parameters during either ignition or mainstage. There was some external leakage under the exhausterator that required repair after test 417.

[redacted]

TABLE 1
(Continued)

Frequency Analysis:	The one disturbance that did not damp after the initial surge was a resurging instability, coupled with 500 cps in the feed systems. There was some low-amplitude intermittent 400 cps in the chamber and the feed systems during mainstage.
Test:	418 2A-1 12-19-64(1)
Injector Type:	610314, U/N: 077, Aot: 58.8, Aft: 84.0, Vo(1500K): 138.4, Vf(1500K): 55.0
Description:	The injector is a flat-face with the fuel and LOX orifices programmed to give constant mixture ratio and controlled injection density. The fuel doublets vary in diameter from 0.173 to 0.290 inch, all at 30-degree included angle except in the outer ring where the fuel doublets are at 40-degree included angle. The LOX doublets vary in diameter from 0.191 to 0.221 inch, all at 40-degree included angle. The fuel radial feed ports have been multistep drilled for improved flow distribution and there are 388 fuel ring groove dams. The wall coolant is 2.91 percent.
Objectives:	To investigate performance with this type of injection pattern
Results:	The test was terminated by an observer cutoff because of apparent LOX depletion. There were no bomb- or self-initiated instabilities.
Test:	001 2A-2, 12-18-64(1)
Injector Type:	588583, U/N 095, Aot: 61.8, Aft: 85.0, Vo(1500K): 132.2 Vf(1500K): 55.7
Description:	The injector has a modifified 5U orifice pattern with 13 x 3, wide-base, fuel-cooled, rotated baffles. The fuel doublets are 0.281-inch diameter at 30-degree included angle except in the outer fuel ring where the doublets are 0.228-inch diameter at 40-degree included angle. The LOX doublets along the radial baffles, except in the

[redacted]

TABLE 1
(Continued)

Description (Continued):	LOX rings adjacent to the circumferential baffles and in the outer LOX ring, have the orifices facing the baffles at 0.242-inch diameter at 20-degree half angle and the orifices facing away from the baffles are 0.250-inch diameter at 28 degrees 12 minutes half angle. The outer LOX ring has doublets of 0.209-inch diameter at 40-degree included angle. The remaining LOX doublets are 0.242-inch diameter at 56 degrees 24 minutes included angle. There are 286 LOX splitters, 40 baffle dams and 3.2-percent wall coolant. The outer fuel ring has been orificed for 70-percent nominal flow and the baffle-to-land gap is unsealed.
Objectives:	An ignition test for stand activation
Results:	Ignition was run without any unsuspected results
Test:	419 (2A-1) 12-21-64 (1)
Injector Type:	610314, U/N: 077, Aot: 58.8, Aft: 84.0, Vo(1500K): 138.4, Vf(1500K): 55.0
Description:	The injector is a flat-face with the fuel and LOX orifices programmed to give constant mixture ratio and controlled injection density. The fuel doublets vary in diameter from 0.173 to 0.290 inch, all at 30-degree included angle except in the outer ring where the fuel doublets are at 40-degree included angle. The LOX doublets vary in diameter from 0.191 to 0.221 inch, all at 40-degree included angle. The fuel radial feed ports have been multistep drilled for improved flow distribution and there are 388 fuel ring groove dams. The wall coolant is 2.91 percent.
Objectives:	To investigate performance with this type of injection pattern

TABLE 1
(Continued)

Results:	Test terminated by programmed cutoff; c* efficiency for the test was 91.8 percent and there was no instability or buzzing.
Tests:	420-422 (2A-1), 12-22-64 (2), 12-23-64 (1)
Injector Type:	5881L4, U/N: 084, Aot: 61.4, Aft: 85.1, Vo(1500K): 133.0, Vf(1500K): 55.7
Description:	Injector has a modified 5U injection pattern with 13 x 3, wide-base, fuel-cooled, rotated baffles. The fuel doublets are 0.281-inch diameter at 30-degree included angle except in the outer ring where the doublets are 0.228-inch diameter at 40-degree included angle. The LOX doublets along the radials in rings -53, -49, -45, -41, -37, -27, -23, -19, and -15 are 0.242-inch diameter with the orifices facing the baffle at 20-degree half angle and the orifices facing away from the baffle at 28 degrees 12 minutes. The LOX doublets in rings adjacent to the circumferential baffles are 0.209-inch diameter at 40-degree included angle. The outer LOX ring is also 0.209-inch doublets at 40-degree included angle. The remaining LOX doublets are 0.242-inch diameter at 40-degree included angle. The injector has 40 baffle dams, no LOX splitters, and the outer fuel ring orifices for 70-percent normal flow. The orifices in the radial baffles were plugged except for two in each radial baffle adjacent to the outer circumferential baffle and three in each radial baffle adjacent to the inner circumferential baffle. The orifices in the outer baffle can were enlarged to 0.089-inch diameter and those of the inner baffle can were enlarged to 0.120-inch diameter, retaining the same baffle coolant area. Wall coolant is 3.2 percent.

TABLE 1
(Continued)

Objectives:	To investigate the performance characteristics of an injector with radial baffle fuel holes plugged
Results:	No bomb- or self-induced instabilities were experienced during the three tests and all tests were terminated by programmed cutoffs. Erosions appeared in the inner radials after test 420 and grew worse with each test; the erosions were 1/2-inch deep after test 422.
Frequency Analysis:	All three tests had 400-cps buzz. The strongest and clearest 400 cps (300 psi peak-to-peak) was in the LOX injection parameters, while the fuel side and chamber pressure had an intermittent and lower amplitude (150 to 200 psi peak-to-peak) mode.
Tests:	423-425 (2A-1), 12-30-64 (3)
Injector Type:	6107M4, U/N: X033, Aot: 59.6, Aft: 59.7, Vo(1500K): 137.0, Vf(1500K): 79.5
Description:	The injector has 13 x 3, wide-base, fuel-cooled, rotated baffles. The orifice pattern is programmed to give constant injection density. The outer compartments have the same orifice pattern and, the inner compartments have the same pattern, however, they are not identical. All fuel doublets have 30-degree included angle except in the outer fuel ring where the included angle is 40 degrees. The LOX doublets have 40-degree included angle. The fuel doublet diameters vary from 0.172 to 0.302 inch and the LOX doublet diameters vary from 0.161 to 0.250 inch. The injector has 286 LOX splitters, and 40 baffle dams. The wall coolant is 3.75 percent.

TABLE 1
(Continued)

Objective:	To investigate the performance and damping characteristics with this injection pattern
Results:	A 13.5-grain bomb induced an instability on test 425 that persisted into chamber pressure decay. Tests 423 and 424 did not experience self- or bomb-induced instabilities. Thrust chamber erosions appeared after the first test. After test 425 the thrust chamber erosions were 3/4-inch deep and the tips of the radial baffles had been eroded.
Frequency Analysis:	None of the tests exhibited buzzing. The disturbance on test 425 was a resurging instability with a 500 cps in the feed systems. The chamber pressure measurement exhibited compartment modes.
Test:	426 (2A-1) 12-31-64
Injector Type:	5896U3, U/N: 082, Aot: 49.6, Aft: 85.0, Vo(1500K): 165, Vf(1500K): 55.7
Description:	The injector is a modified 5U pattern with 13 x 3, wide-base, fuel-cooled baffles. The fuel doublets are 0.281-inch diameter at 30-degree included angle except in the outer fuel ring where the doublets are 0.228-inch diameter at 40-degree included angle. The LOX doublets are 0.209-inch diameter at 56 degrees 24 minutes included angle. The doublets along the radial baffles have orifices facing the baffle 0.209-inch diameter at 20-degree half angle and the orifices facing away from the baffle are 0.21875-inch diameter at 28 degrees 12 minutes half angle. The LOX doublets adjacent to the radial baffles in the outer ring are not canted. The -9 LOX ring has doublets of 0.209-inch diameter at 40-degree included angle. The injector has 164 fuel ring groove dams and 24 baffle dams. The baffle-to-land gap is not sealed and the wall coolant is 4.6 percent.

TABLE 1
(Continued)

Objectives:	To determine LOX and fuel ring and injector body temperatures during hot firing, for injector durability program
Results:	Test was terminated by programmed (10.2 seconds) cutoff.
Tests:	002-003 (2A-2) 12-21-64 (2)
Injector Type:	588583, U/N 095, Aot: 61.8, Aft: 85.0, Vo(1500K): 132.2 Vf(1500K): 55.7
Description:	The injector has a modified 5U orifice pattern with 13 x 3, wide-base, fuel-cooled, rotated baffles. The fuel doublets are 0.281-inch diameter at 30-degree included angle except in the outer fuel ring where the doublets are 0.228-inch diameter at 40-degree included angle. The LOX doublets along the radial baffles, except in the LOX rings adjacent to the circumferential baffles and in the outer LOX ring, have the orifices facing the baffles at 0.242-inch diameter at 20-degree half angle and the orifices facing away from the baffles 0.250-inch diameter at 28 degrees 12 minutes half angle. The outer LOX ring has doublets of 0.209-inch diameter at 40-degree included angle. The remaining LOX doublets are 0.242-inch diameter at 56 degrees 24 minutes included angle. There are 286 LOX splitters, 40 baffle dams and 3.2-percent wall coolant. The outer fuel ring has been orificed for 70-percent nominal flow and the baffle-to-land gap is unsealed.
Objectives:	Completion of test series run for stand activation
Results:	Test 002, ignition test only; test 003 ran programmed duration and was a satisfactory test.

more than 100 milliseconds to damp; each was characterized by injector and O-ring damage. The instability mode in each case was resurging coupled with 500-cps and 1500-cps oscillations.

Analysis of Brush records indicated the following:

1. The 1500-cps mode had the characteristics of a first transverse mode within an outer compartment. The frequency of this mode, calculated on the basis of an acoustic velocity of 3500 fps, was 1727 cps. Thus, it appeared that an acoustic velocity of 3000 fps was more realistic for this compartment.
2. The amplitude of both 500-cps and 1500-cps modes was at least twice as high at 0.8 inches from the injector face as at 5 inches from the injector face.

Investigation of the Effects of Oxidizer Splitters and Splitter Shifting on Stability

During component testing in a tubular wall thrust chamber, popping occurred in two successive tests with injector 084C. Posttest inspection revealed that several splitters in the oxidizer feed holes had shifted in the region believed to correspond to the origin of the pops. To determine whether shifing of the splitters could cause popping, they were removed from the injector, and a series of nine tests was conducted without a pop. However, upon replacing the splitters, no popping was experienced during a subsequent seven-test series, in spite of the fact that some of the splitters had shifted.

As a result of these tests, the cause of popping was believed to be injector leakage rather than shifting of the oxidizer splitters.

Three test series were conducted with injectors X051 and 099 to evaluate the effects of oxidizer splitters on stability. With injector X051, employing 270 splitters, the average damping time was 122 milliseconds. This was decreased to 109 milliseconds when 302 splitters were used. A similar injector (099) employing no splitters, was then tested five times. The average damping time for the first four tests was 34 milliseconds, a significant improvement. The conclusion was subject to question, however, when the fifth test did not damp. The three test series were characterized by injector leakage and O-ring failure during the final series, rendering the test results inconclusive.

Investigation of the Effects of Oxidizer Spray Shapes Adjacent to Baffle Surfaces

Three test series were conducted with injector F-1002 to determine the effects on stability of various oxidizer spray shapes adjacent to the radial baffles. In all, three modifications were tested: overlapped oxidizer doublets adjacent to the baffle, i.e., unequal diameter impinging orifices; doublets resulting in fans being canted away from the baffle; and a combination of both. The remainder of the oxidizer injection pattern consisted of triplets.

For the test series employing overlapped doublets only, the maximum damping time in four tests was 13 milliseconds. In the series employing both overlapped doublets and canted fans, four tests damped in less than 13 milliseconds, while two other damped in 52 and 41 milliseconds. The final series, employing canted fans alone, resulted in damp times of 3, 5, 85, and 6 milliseconds. Because these damp times did not differ significantly, the three test series demonstrated no clear-cut advantage of one concept over another.

Two bomb tests were conducted with injector F-1002 in which canted oxidizer fans were employed adjacent to the radial baffle surfaces and body and film coolant holes were plugged. The first test damped a bomb-induced disturbance in 27 milliseconds, and two bomb-induced disturbances in 30 and 105 milliseconds during the second test. The plugging of the body and film coolant orifices did not, evidently, exert any appreciable stabilizing influence.

A re-evaluation was made of the concept of canted and overlapped oxidizer fans adjacent to radial baffles during a test series with injector 049. The oxidizer doublets adjacent to the radial baffles consisted of 0.185-inch-diameter orifices angled toward the radial baffles at a half-angle of 20 degrees and 0.209-inch-diameter orifices angled away from the radials at a half-angle of 28.2 degrees. The results indicated a loss of 1 second in specific impulse over the FRT injector. Each of two bomb-induced disturbances damped in one cycle, reconfirming the importance of the oxidizer pattern adjacent to the baffle surfaces.

Testing of injector X054 seemed to demonstrate the importance of the oxidizer orifices adjacent to the circumferential baffle. Three tests were, therefore, conducted in which the diameter of these orifices was increased from 0.195 to 0.209 inch. The impingement angle was 40 degrees. The bomb tests resulted in damp times of 32, 73, and 7 milliseconds, the average damp time increasing from 20 to 37 milliseconds. This was not felt to be a significant increase.

Investigation of Tribaffled Injector

Three tests were conducted with injector X037, a tribaffled injector. All tests resulted in strong 500-cps oscillation. The third test resulted in the destruction of the injector and dome, and severe stand damage. It was concluded that three baffles are insufficient to guarantee a stable injector. The test did not damp. The mode of instability appeared to be a first transverse compartment mode with traces of the 500-cps oscillation. Evidently, rotation of the fans was not sufficient to guarantee suppression of the transverse compartment mode.

Investigation of Injector Modifications to Suppress the "Buzz" Mode

The effect of a shallow oxidizer impingement upon stability was investigated in five test series employing injectors 082B, X055, and X002. The first two series employed injector 082B and were designed to investigate the effect of a baffle-to-land gap on buzz. In all tests the buzz amplitude was low, tending to indicate that a gap between the base of a baffle and a land is not necessarily conducive to triggering of this mode.

Injector X002 was modified by adding a showerhead orifice between impinging oxidizer orifices. With this modification, the buzz amplitude was lower than that obtained with the injector in its unmodified form.

Injector 082B was modified by overlapping the oxidizer doublets adjacent to the radial baffles and was tested in both uncooled and cooled thrust chambers. All tests damped without resurging, and buzzing was recorded on fuel parameters only. Five-hundred-cps oscillations, which attenuated slowly, were triggered.

This series indicated that the buzz mode could be reduced in severity by keeping the oxidizer sprays away from the radial baffles. Because of the possibility that the buzzing previously observed with injector 040 might have been caused by mismatching of the fuel and oxidizer impingement distances, the injector was modified by the additions of 240 small, close-impinging fuel doublets between the existing doublets. However, a test revealed no attenuation of the buzz.

A test series was conducted with injector X055 to determine the effect of increased outer circumferential baffle flow on buzzing. Testing in both the uncooled and cooled thrust chambers indicated that the buzz level had increased from what it had been before.

The Effects of Removing the Oxidizer Dome Cone on Stability

A stability rating series was conducted with injector X049 to evaluate the effects of removal of the cone from the dome cavity. Of four bomb-induced disturbances, three damped within a single cycle, the fourth re-surging twice, but still damping within 100 milliseconds. Transition appeared smoother with this configuration. As a result of this test series, it was determined that removal of the cone from the dome cavity had little or no effect on stability.

The Investigation of Vented Radial Baffles as a Stabilizing Agent

A series of three tests was conducted with injector X021. This injector employed canted oxidizer fans adjacent to the radial baffles. In addition, 132 holes of 0.209-inch diameter were drilled through the bases of the radial baffles.

The first two tests were stable tests in which the buzz level was much lower than normal with this injector pattern. The third test, however, did not damp a bomb-induced disturbance, the predominant mode being a 500-cps oscillation.

As a result of this series, it was concluded that the venting of the baffles near the bases may reduce the buzz level significantly but in itself does not ensure the damping of a strong 500-cps mode.

Injector Performance Evaluation Tests

Performance evaluation tests were conducted with injectors 077, 084, 033, and 2004.

Tests with injector 077, a uniform mixture ratio, flat-face injector, yielded only a slight increase in c* efficiency as compared to the FRT injector.

A modification of injector 084, consisting of plugging the radial baffle coolant holes and enlarging the circumferential baffle coolant holes a corresponding amount, resulted in decreasing the c* efficiency by 1 percent. The radial baffles were uncooled during these tests.

Three tests were conducted with injector X033 to evaluate uniform injection density and mixture ratio across the injector face. A considerable increase in performance was achieved at the expense of stability. A bomb-induced disturbance did not damp, but resulted in a resurging and baffle compartment resonance mode of instability.

As a result of a component test series, the specific impulse of flat-face injector 2004, employing uniform radial flow distribution, was determined to be approximately 1 second higher than that of the FRT injector.

ENGINE TESTING (Table 2)

Engine testing during this period was devoted to the evaluation of the 084E-type injector as the FRT candidate. By the end of the report period, this injector type had accumulated 9860 seconds of mainstage operation in 143 tests with 15 different injectors. In addition, the engine damped three bomb-induced instabilities within the required maximum time of 100 milliseconds. Specific impulse is well above the required minimum of 260 seconds.

Two cases of popping occurred with the engine. One incident occurred at 85 percent of nominal chamber pressure during test 072 with engine 022. The disturbance persisted for 25 milliseconds, after which it damped in 1 cycle. Posttest inspection revealed injector leakage. The cause of the pop was attributed to either injector leakage or a shortened pretest preparation procedure.

The other popping incident occurred during test 070 with engine 023. The disturbance persisted for 35 milliseconds. Posttest inspected revealed randomly located sources of injector leakage.

TABLE 2

ENGINE TESTING

Test Stand 1A

Tests:	099-101, engine 022
Injector Type:	5885S3, U/N: 098, Aot: 61.8, Aft: 85.1, Vo(1500K): 132.2, Vf(1500K): 55.7
Description:	Modified 5U baffled (13 x 3 wide-base, fuel-cooled), 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees and is orificed to 70-percent normal flow in the axial feed holes), 0.242-inch diameter LOX doublets at 40 degrees (fans along radial baffles are canted by drilling the LOX orifices next to the radial to 0.250-inch diameter at 28 degrees 12 minutes half angle, outer ring and rings next to the circumferential baffles are 0.209-inch diameter at 40 degrees), 286 LOX splitters, 32 dams in the outer and 8 dams in the inner circumferential baffle, no film or body coolant orifices, 3.2-percent wall coolant.
Objective:	Investigation of performance and burning characteristics of this injector in the F-1 engine
Results:	Test durations were 42, 42, and 40 seconds, respectively. The average specific impulse was 262.0 seconds. No thrust chamber damage was reported as a result of the testing.
Test:	102-123, engine 013-1
Injector Type:	5885S3, U/N: 085, Aft: 85.1, Vo(1500K): 132.2, Vf(1500K): 55.7

[redacted]

TABLE 2

(Continued)

Description:	Modified 5U baffles (13 x 3 wide-base, fuel-cooled), 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees and is orificed to 70-percent normal flow in the axial feed holes), 0.242-inch diameter LOX doublets at 40 degrees (fans along radial baffles are canted by drilling the LOX orifices next to the radial to 0.250-inch diameter at 28 degrees 12 minutes half angle, outer ring and rings next to the circumferential baffles are 0.209-inch diameter at 40 degrees), 286 LOX splitters, 32 dams in the outer and 8 dams in the inner circumferential baffle, no film or body coolant orifices, 3.2-percent wall coolant orifices, 3.2-percent wall coolant.
Objective:	Investigation of performance, stability, and burning characteristics of this injector in the F-1 engine
Test Results:	Test durations were 1, 3, 15, 149, 152, 150, 151, 18, 152, 0, 152, 152, 138, 152, 0, 138, 152, 152, 49, 59, 1, and 38 seconds, respectively. The average specific impulse was 260.9 seconds. As a result of testing, numerous leaks were reported in the combustion zone and convergent portion of the thrust chamber and an additional one at the injector end ring.
Test:	124-146, engine F2004
Injector Type:	588583, U/N: F2010, Aot: 61.8, Aft: 85.1, Vo(1500K): 132.2, Vf(1500K): 55.7

[redacted]

[redacted]

TABLE 2

(Continued)

Description: Modified 5U baffled (13 x 3 wide-base, fuel-cooled), 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees and is orificed to 70-percent normal flow in the axial feed holes), 0.242-inch diameter LOX doublets at 40 degrees (fans along radial baffles are canted by drilling the LOX orifices next to the radial to 0.250-inch diameter at 28 degrees 12 minutes half angle, outer ring and rings next to the circumferential baffles are 0.209-inch diameter at 40 degrees), 286 LOX splitters, 32 dams in the outer and 8 dams in the inner circumferential baffle, no film or body coolant orifices, 3.2-percent wall coolant.

Objective: FRT safety limits testing

Results: The test durations were 1, 0, 19, 44, 19, 0, 41, 45, 18, 18, 61, 77, 42, 17, 17, 17, 17, 15, 15, 42, 17, 0, and 19 seconds, respectively. The average specific impulse was 262.5 seconds. Erosion of the inner circumferential baffle was noted posttest 028. Four leaks developed in the convergent portion of the thrust chamber during this test series.

<u>Test Stand 1B-1</u>

Test: 058-070

Injector Type: 588583. U/N: 095. Aot: 61.8. Aft: 85.1, Vo(1500K): 132.2, Vf(1500K): 55.7

Description: Modified 5U baffles (13 x 3 wide-base. fuel-cooled), 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees and is orificed to 70-percent normal flow in the axial feed holes), 0.242-inch diameter LOX doublets at 40 degrees (fans along radial baffles are canted by drilling the

[redacted]

TABLE 2

(Continued)

Description: (continued)	LOX orifices next to the radial to 0.250-inch diameter at 28 degrees 12 minutes half angle, outer ring and rings next to the circumferential baffles are 0.209-inch diameter at 40 degrees), 286 LOX splitters, 32 dams in the outer and 8 dams in the inner circumferential baffle, no film or body coolant orifices, 3.2-percent wall coolant.
Objective:	Investigation of performance and burning characteristics of this injector in the F-1 engine
Results:	Test durations were 3, 41, 150, 150, 150, 150, 151, 150, 150, 151, 151, 150, and 111 seconds, respectively. The average specific impulse was 260.9 seconds. Erosion of the GSE throat plug and the exit ring and leaks in the convergent portion of the nozzle were noted posttest 060. Additional leaks (one each) were incurred in the convergent and bell portions of the thrust chamber during test 061. No additional damage was caused by the remaining tests in the series. A bomb-induced instability was damped in 30 milliseconds during test 065.
Test:	071, engine 024
Injector Type:	5885S3, U/N:F2009, Aot: 61.8, Aft: 85.1, Vo(1500K): 132.2, Vf(1500K): 55.7
Description:	Modified 5U baffled (13 x 3 wide-base, fuel-cooled), 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees and is orificed to 70-percent normal flow in the axial feed holes, 0.242-inch diameter LOX doublets at 40 degrees (fans along radial baffles are canted by drilling the LOX orifices next to the radial to 0.250-inch diameter at 28 degrees 12 minutes half angle, outer ring and rings next to the circumferential baffles are 0.209-inch diameter at 40 degrees), 286 LOX splitters, 32 dams in the outer and 8 dams

TABLE 2

(Continued)

Description: (continued)	in the inner circumferential baffle, no film or body coolant orifices, 3.2-percent wall coolant.
Objective:	Evaluation of alcohol-water prefill solution
Results:	Test was programmed for transition only. Ignition pop was experienced with 30-percent alcohol solution. No performance data were taken due to the short duration of the test.

<u>Test Stand 1B-2</u>

Test:	069-075, engine 022
Injector Type:	5885S3, U/N: 098, Aot: 61.8, Aft: 85.1, Vo(1500K): 132.2, Vf(1500K): 55.7
Description:	Modified 5U baffles (13 x 3 wide-base, fuel-cooled), 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees and is orificed to 70-percent normal flow in the axial feed holes), 0.242-inch diameter LOX doublets at 40 degrees (fans along radial baffles are canted by drilling the LOX orifices next to the radial to 0.250-inch diameter at 28 degrees 12 minutes half angle, outer ring and rings next to the circumferential baffles are 0.209-inch diameter at 40 degrees), 286 LOX splitters, 32 dams in the outer and 8 dams in the inner circumferential baffle, no film or body coolant orifices, 3.2-percent wall coolant.
Objective:	Investigation of performance and burning characteristics of this injector in the F-1 engine

TABLE 2
(Continued)

Results:	The test durations were 150, 150, 150, 151, 150, 150, and 150 seconds, respectively. The average specific impulse was 263.7 seconds. Numerous leaks in the convergent portion of the thrust chamber and the exit manifold-to-tube joint were noted during the series. During test 072, a pop occurred at approximately 85 percent of nominal chamber pressure. This disturbance damped in one cycle after 25 milliseconds.
Test:	077-078, engine F2007
Injector Type:	5885S3, U/N: F2006, Aot: 61.8, Aft: 85.1, Vo(1500K): 132.2, Vf(1500K): 55.7
Description:	Modified 5U baffled (13 x 3 wide-base, fuel-cooled), 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees and is orificed to 70-percent normal flow in the axial feed holes), 0.242-inch diameter LOX doublets at 40 degrees (fans along radial baffles are canted by drilling the LOX orifices next to the radial to 0.250-inch diameter at 28 degrees 12 minutes half angle, outer ring and rings next to the circumferential baffles are 0.209-inch diameter at 40 degrees), 286 LOX splitters, 32 dams in the outer and 8 dams in the inner circumferential baffle, no film or body coolant orifices, 3.2-percent wall coolant.
Objective:	Acceptance testing of the engine prior to delivery to customer
Results:	The test durations were 28 and 41 seconds. Test 077 was terminated by an observer due to an instrumentation failure. No thrust chamber damage was incurred as a result of the testing. Specific impulses were 262.6 and 262.2 seconds.

[redacted]

TABLE 2

(Continued)

Test:	079-100, engine 023
Injector Type:	5885S3, U/N: X051, Aot: 61.8, Aft: 85.1, Vo(1500K): 132.2, Vf(1500K): 55.7
Description:	Modified 5U baffles (13 x 3 wide-base, fuel-cooled), 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees and is orificed to 70-percent normal flow in the axial feed holes), 0.242-inch diameter LOX doublets at 40 degrees (fans along radial baffles are canted by drilling the LOX orifices next to the radial to 0.250-inch diameter at 28 degrees 12 minutes half angle, outer ring and rings next to the circumferential baffles are 0.209-inch diameter at 40 degrees), 286 LOX splitters, 32 dams in the outer and 8 dams in the inner circumferential baffle, no film or body coolant orifices, 3.2-percent wall coolant.
Objective:	Investigation of the performance and burning characteristics of this injector in the F-1 engine and the investigation of an alcohol-water prefill.
Results:	The test durations were 0, 2, 0, 0, 0, 40, 40, and 5, with the remainder being 2 seconds each. The average specific impulse for tests 084 and 085 was 263.6 seconds. Ignition pops were noted on tests 085 and 086 employing alcohol concentrations of 27 and 29 percent, respectively. In the remaining tests, injection pops occurred in all tests except when the prefill level was lowered and a fuel injection purge used.

[redacted]

TABLE 2

(Continued)

Test Stand 1C

Test:	005-009, engine 021
Injector Type:	5885T3, U/N: 096, Aot: 61.8, Aft: 85.1, Vo(1500K): 132.2, Vf(1500K): 55.7
Description:	Modified 5U baffles (13 x 3 wide-base, fuel-cooled), 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.288-inch diameter at 40 degrees and is orificed to 70-percent normal flow in the axial feed holes), 0.242-inch diameter LOX doublets at 40 degrees (fans along radial baffles are canted by drilling the LOX orifices next to the radial to 0.250-inch diameter at 28 degrees 12 minutes half angle, outer ring and rings next to the circumferential baffles are 0.209-inch diameter at 40 degrees), 302 LOX splitters, 32 dams in the outer and 8 dams in the inner circumferential baffle, no film or body coolant orifices, 3.2-percent wall coolant.
Objective:	Investigation of performance and compatibility characteristics of this injector in an F-1 engine
Results:	Test durations were 0, 151, 152, 151, and 150 seconds, respectively, the first test receiving a sequence cutoff. The average specific impulse was 263.2 seconds. The damage included three leaks in the bell portion of the thrust chamber, one leak in the convergent portion of the thrust chamber, and a recurrent leak in the exit manifold-to-tube joint.

[redacted]

TABLE 2

(Continued)

Test:	010-012, engine 2005
Injector Type:	5885S3, U/N: 2005, Aot: 61.8, Aft: 85.1, Vo(1500K): 132.2, Vf(1500K): 55.7
Description:	Modified 5U baffles (13 x 3 wide-base, fuel-cooled), 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees and is orificed to 70-percent normal flow in the axial feed holes), 0.242-inch diameter LOX doublets at 40 degrees (fans along radial baffles are canted by drilling the LOX orifices next to the radial to 0.250-inch diameter at 28 degrees 12 minutes half angle, outer ring and rings next to the circumferential baffles are 0.209-inch diameter at 40 degrees, 286 LOX splitters, 32 dams in the outer and 8 dams in the inner circumferential baffle, no film or body coolant orifices, 3.2-percent wall coolant.
Results:	The test durations were 152, 40, and 41 seconds, respectively. The average specific impulse was 263.3 seconds. No thrust chamber damage was incurred.
Test:	013-016, engine F2008
Injector Type:	5885S3, U/N: F2007, Aot: 61.8, Aft: 85.1, Vo(1500K): 132.2, Vf(1500K): 55.7
Description:	Modified 5U baffles (13 x 3 wide-base, fuel-cooled), 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees and is orificed to 70-percent normal flow in the axial feed holes), 0.242-inch diameter LOX doublets at 40 degrees (fans along radial baffles are canted by drilling the LOX orifices next to the radial to 0.250-inch diameter at 28 degrees 12 minutes half angle, outer ring and rings next to the circumferential baffles are 0.209-inch

[redacted]

TABLE 2

(Continued)

Description: (continued)	diameter at 40 degrees), 286 LOX splitters, 32 dams in the outer and 8 dams in the inner circumferential baffle, no film or body coolant orifices, 3.2-percent wall coolant.
Objective:	Acceptance testing of the engine prior to delivery to customer
Results:	The test durations were 2, 73, 150, and 41 seconds, respectively. The average specific impulse was 261.7 seconds. No thrust chamber damage was incurred as a result of testing.
Test:	017-020, engine F2003
Injector Type:	588583, U/N: F2004, Aot: 61.8, Aft: 85.1, Vo(1500K): 132.2, Vf(1500K): 55.7
Description:	Modified 5U baffles (13 x 3 wide-base, fuel-cooled), 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees and is orificed to 70-percent normal flow in the axial feed holes), 0.242-inch diameter LOX doublets at 40 degrees (fans along radial baffles are canted by drilling the LOX orifices next to the radial to 0.250-inch diameter at 28 degrees 12 minutes half angle, outer ring and rings next to the circumferential baffles are 0.209-inch diameter at 40 degrees), 286 LOX splitters, 32 dams in the outer and 8 dams in the inner circumferential baffle, no film or body coolant orifices, 3.2-percent wall coolant.
Objective:	Acceptance testing of the engine prior to delivery to customer

TABLE 2

(Continued)

Results: Test durations were 0, 48, 151, and 41 seconds, respectively; the first test, scheduled for ignition only, being cut by an instrumentation error. The average specific impulse was 263.8 seconds. No thrust chamber damage was incurred as a result of testing.

Test Stand 1D

Test: 015-016, engine 2004

Injector Type: 5885S3, U/N: 085, Aot: 61.8, Aft: 85.1, Vo(1500K): 132.2, Vf(1500K): 55.7

Description: Modified 5U baffles (13 x 3 wide-base, fuel-cooled), 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees and is orificed to 70-percent normal flow in the axial feed holes), 0.242-inch diameter LOX doublets at 40 degrees (fans along radial baffles are canted by drilling the LOX orifices next to the radial to 0.250-inch diameter at 28 degrees 12 minutes half angle, outer ring and rings next to the circumferential baffles are 0.209-inch diameter at 40 degrees), 286 LOX splitters, 32 dams in the outer and 8 dams in the inner circumferential baffle, no film coolant orifices, 3.2-percent wall coolant.

Objective: Investigation of performance and burning characteristics of this injector in the F-1 engine

Results: Test durations were 99 and 150 seconds, respectively. The average specific impulse was 262.2 seconds. As a result of testing, erosion of the GSE throat plug boss was incurred.

TABLE 2
(Continued)

Test: 017-018, engine 2004

Injector Type: 558583, U/N: F2010, Aot: 61.8, Aft: 85.1, Vo(1500K): 132.2, Vf(1500K): 55.7

Description: Modified 5U baffles (13 x 3 wide-base, fuel-cooled), 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees and is orificed to 70-percent normal flow in the axial feed holes), 0.242-inch diameter LOX doublets at 40 degrees (fans along radial baffles are canted by drilling the LOX orifices next to the radial to 0.250-inch diameter at 28 degrees 12 minutes half angle, outer ring and rings next to the circumferential baffles are 0.209-inch diameter at 40 degrees), 286 LOX splitters, 32 dams in the outer and 8 dams in the inner circumferential baffle, no film or body coolant orifices, 3.2-percent wall coolant.

Objective: Investigation of performance and burning characteristics of this injector in the F-1 engine.

Results: The test durations were 108 and 42 seconds, respectively. The average specific impulse was 262.9 seconds. An erosion of the exit manifold ring was noted posttest 018.

Test: 019-029, engine 2006

Injector Type: 588583, U/N: 2003, Aot: 61.8, Aft: 85.1, Vo(1500K): 132.2, Vf(1500K): 55.7

Description: Modified 5U baffles (13 x 3 wide-base, fuel-cooled), 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees and is orificed to 70-percent normal flow in the axial feed holes), 0.242-inch diameter

TABLE 2

(Continued)

Description: (continued)	LOX doublets at 40 degrees (fans along radial baffles are canted by drilling the LOX orifices next to the radial to 0.250-inch diameter at 28 degrees 12 minutes half angle, outer ring and rings next to the circumferential baffles are 0.209-inch diameter at 40 degrees), 286 LOX splitters, 32 dams in the outer and 8 dams in the inner circumferential baffle, no film or body coolant orifices, 3.2-percent wall coolant.
Objective:	Acceptance testing of the engine prior to delivery to customer (tests 019-021) FRT engine testing (tests 022-029)
Results:	Test durations were 151, 152, 70, 151, 151, 151, 141, 40, 150, 150, and 50 seconds, respectively. The average specific impulse was 262.3 seconds. The only damage noted was a leak in the convergent section of the thrust chamber incurred during the final test.
Test:	030-033, engine 2009
Injector Type:	5885S3, U/N: 101, Aot: 61.8, Aft: 85.1, Vo(1500K): 132.2, Vf(1500K): 55.7
Description:	Modified 5U baffles (13 x 3 wide-base, fuel-cooled), 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees and is orificed to 70-percent normal flow in the axial feed holes), 0.242-inch diameter doublets at 40 degrees (fans along radial baffles are canted by drilling the LOX orifices next to the radial and 0.250-inch diameter at 28 degrees 12 minutes half angle, outer ring and rings next to the circumferential baffles are 0.209-inch diameter at 40 degrees), 286 LOX splitters, 32 dams in the outer and 8 dams in the inner circumferential baffle, no film or body coolant orifices, 3.2-percent wall coolant.

TABLE 2

(Concluded)

Objective:	Acceptance testing of the engine prior to delivery to customer
Results:	Test durations were 150, 4, and 40 seconds, respectively. Test 031 was terminated by observer due to an erratic turbopump balance cavity pressure. The average engine specific impulse was 262.6 seconds. No thrust chamber damage was reported during the testing. This completed acceptance testing of the engine.

WATER TABLE

To obtain information on the effects of injector baffles on the propagation of strong shock waves, a water table program was initiated. In this study, two-dimensional surface waves were diffracted by models of various shape baffles. The height of the surface wave above its quiescent value was analogous to the shock overpressure.

Two methods of data gathering were used. The height of the wave was monitored by a capacitance probe immersed in the water and recorded on a visicorder. Photographic techniques were also employed to yield permanent records of streamlines of floating styrene spheres as they followed the water particles during impingement of the wave. Figures 19 through 21 depict respectively the ratios of reflected-to-incident wave heights, transmitted wave heights-to-quiescent depth,and the coordinate system employed. These data were taken with two different baffle configurations, triangular and inverted triangular. For the extreme difference in shapes, the curves are remarkably similar and differ by less than the accuracy of the transducer.

Figures 22 through 25 depict four stages in the development of plane wave propagation past the base-mounted baffle. Figures 26 through 29 show a similar sequence for a vertex-mounted baffle.

From these photographs, it is evident that the nature of propagation is reflection upstream of the baffle, diffraction downstream of the baffle, while the intermediate zone is one of circulation.

[redacted]

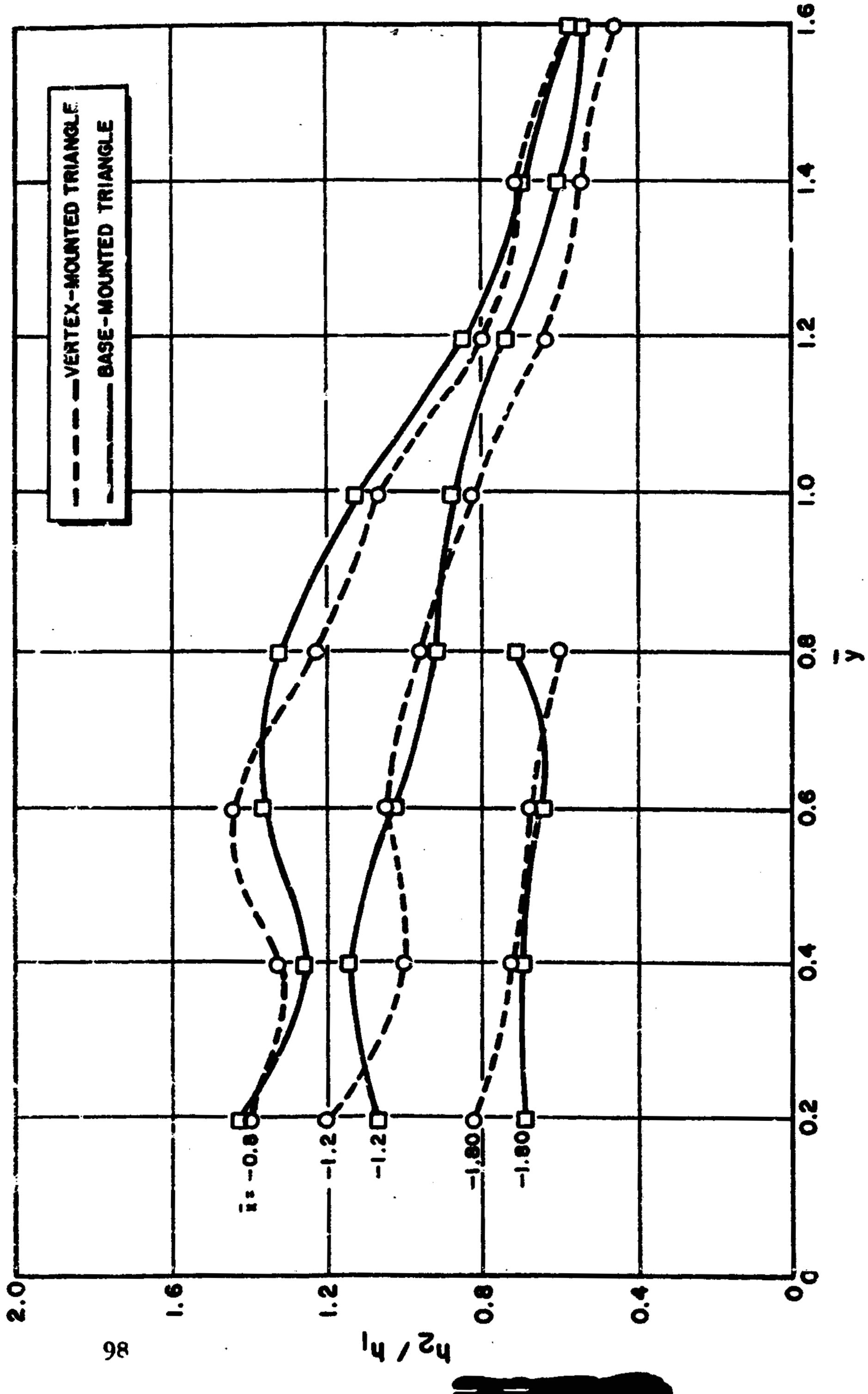

Figure 19. Reflected Overpressure Plane

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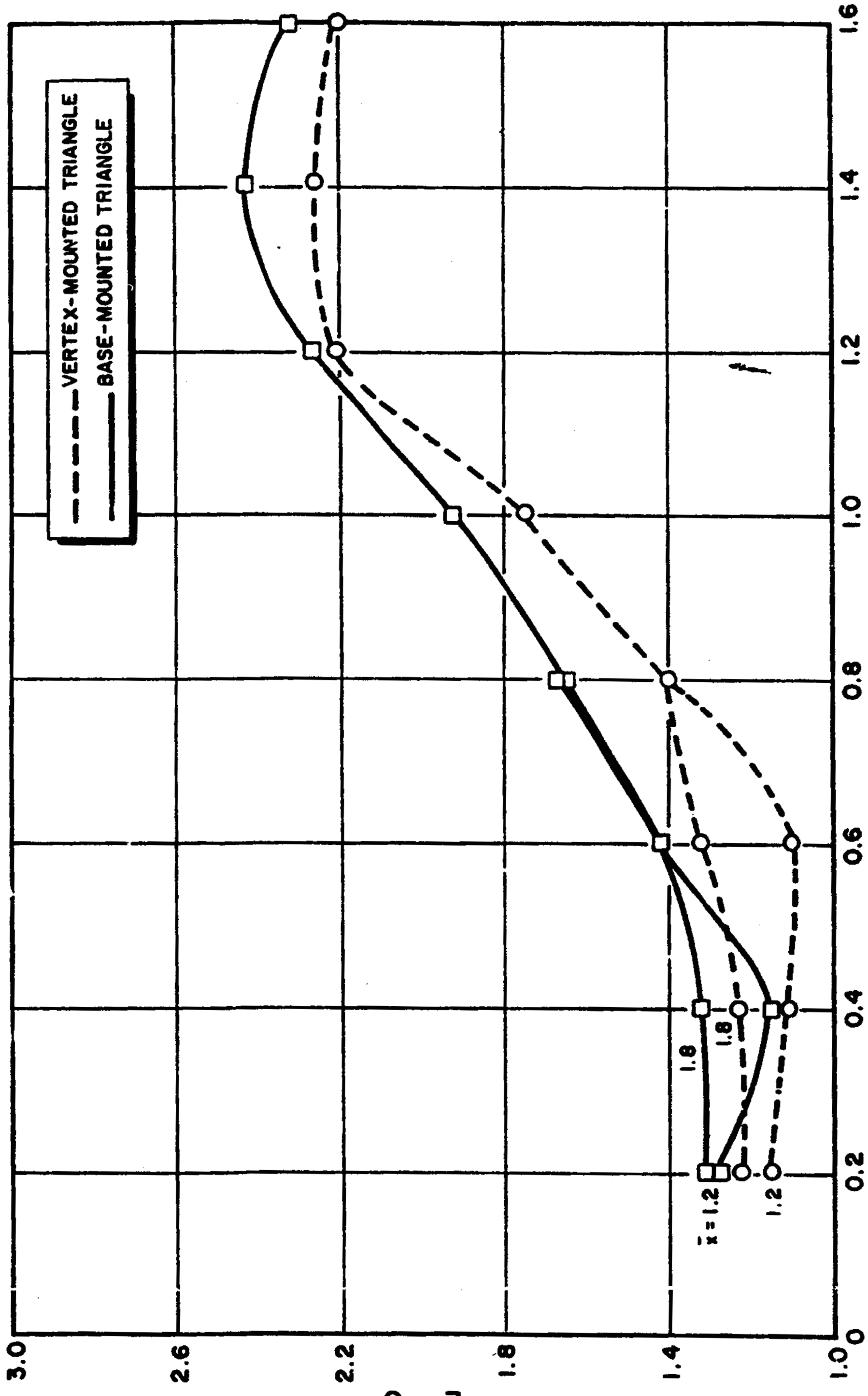

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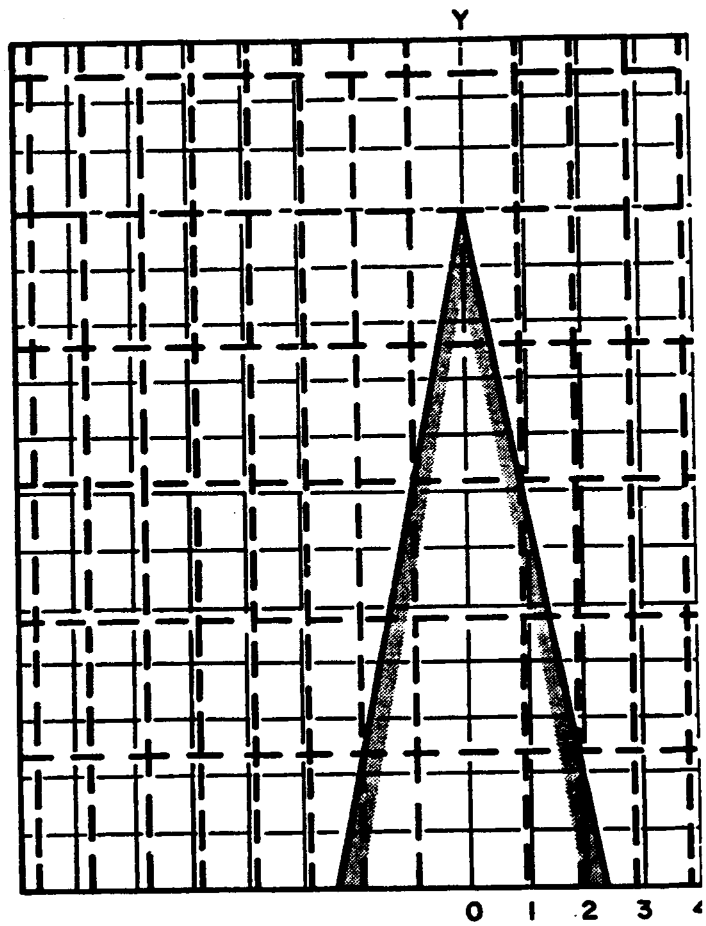

PHYSICAL PLANE

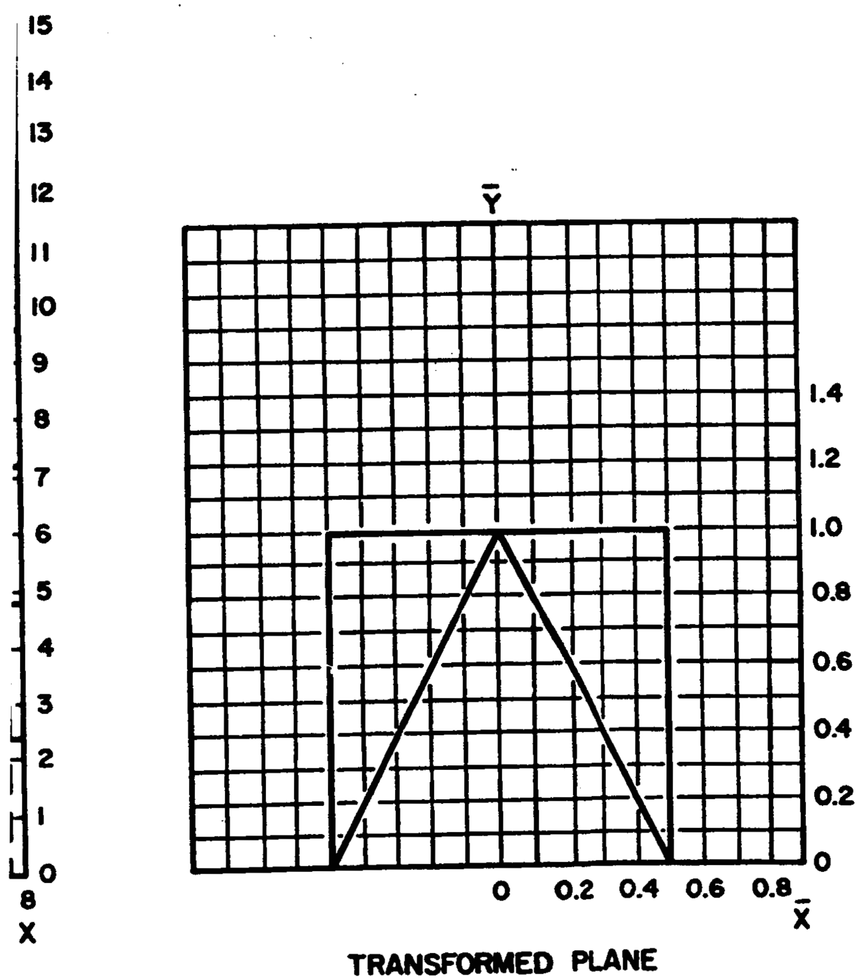

Figure 21. Coordinate System For Water Table Program

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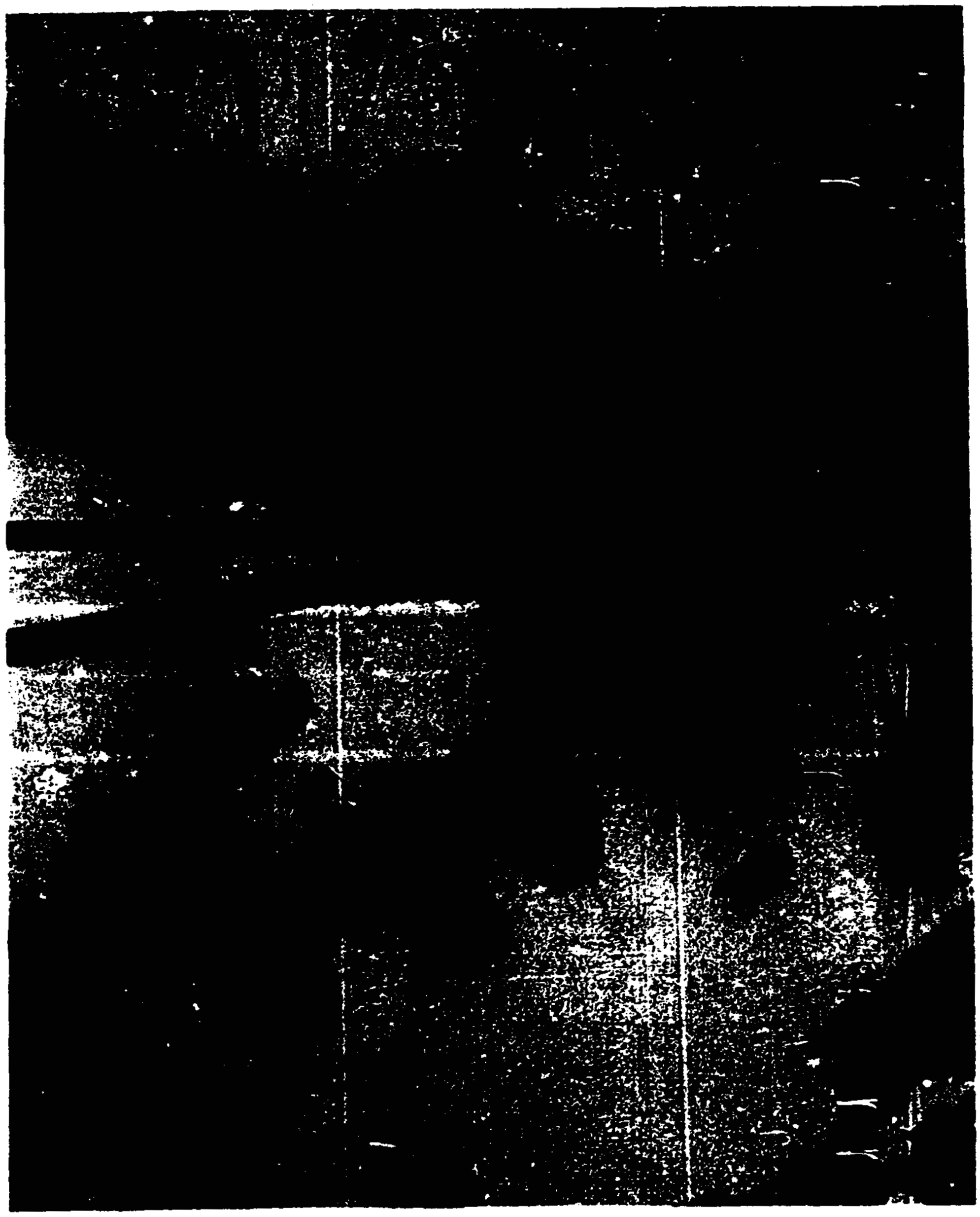

3652 95-4J 12-28-64

Figure 22. Wave Propagation Past Base-Mounted Baffle, Stage 1

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Figure 23. Wave Propagation Past Base-Mounted Baffle, Stage 2

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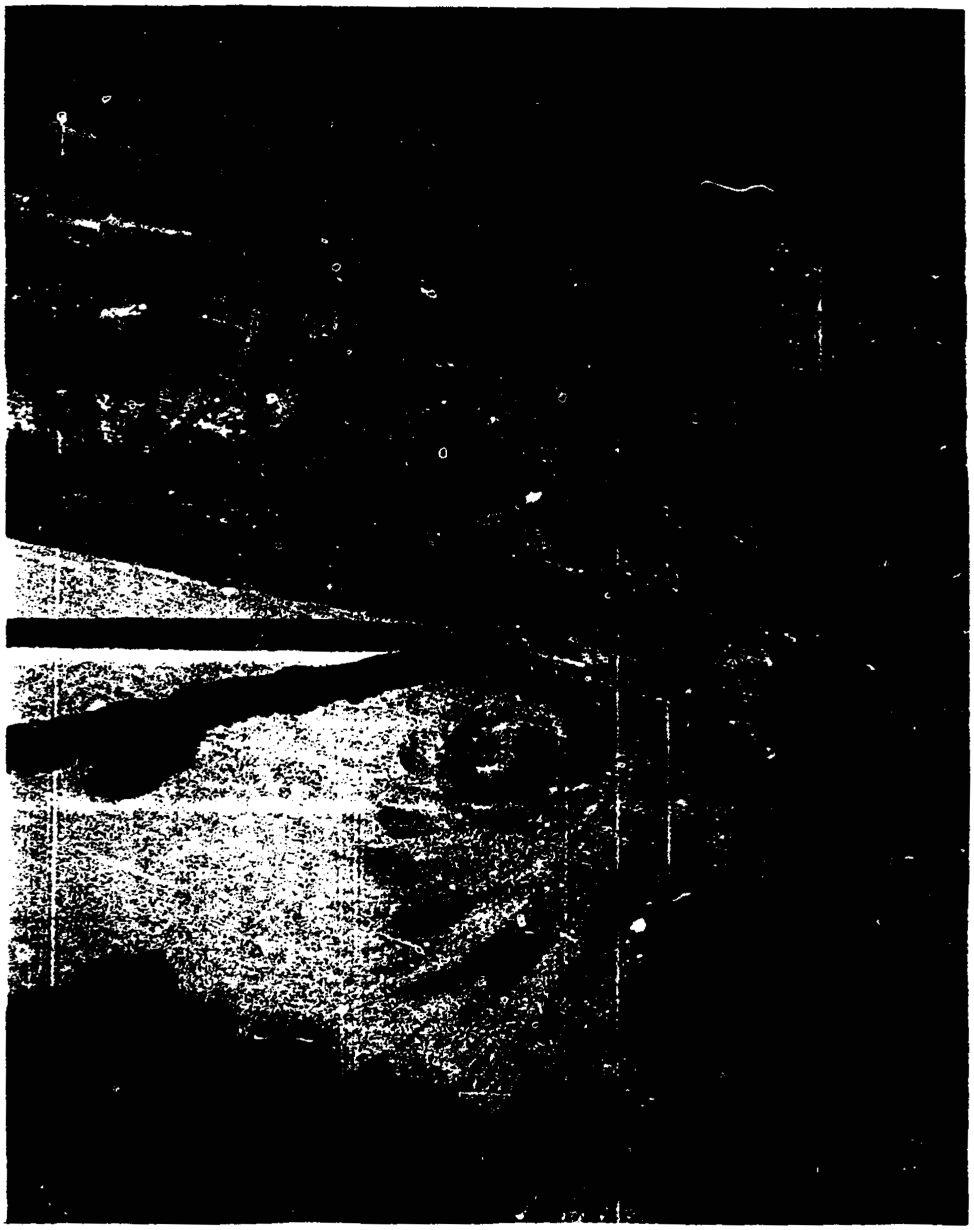

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Figure 24. Wave Propagation Past Base-Mounted Baffle, Stage 3

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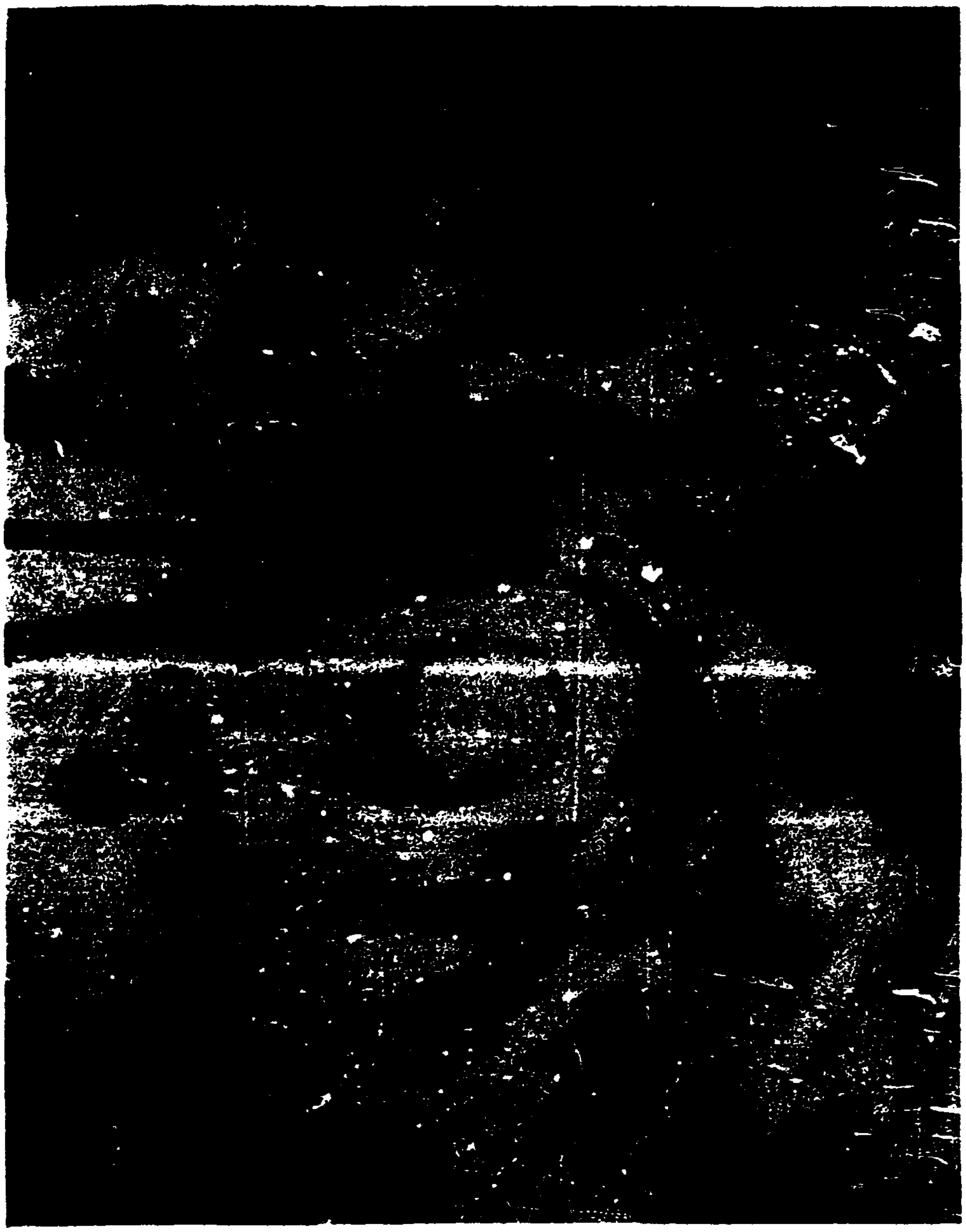

3652-95-4F 12-28-64

Figure 25. Wave Propagation Past Base-Mounted Baffle, Stage 4

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3652-95-4E 12-28-64

Figure 26. Wave Propagation Past Vertex-Mounted Baffle, Stage 1

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3652-95-4I 12-28-64

Figure 27. Wave Propagation Past Vertex-Mounted Baffle, Stage 2

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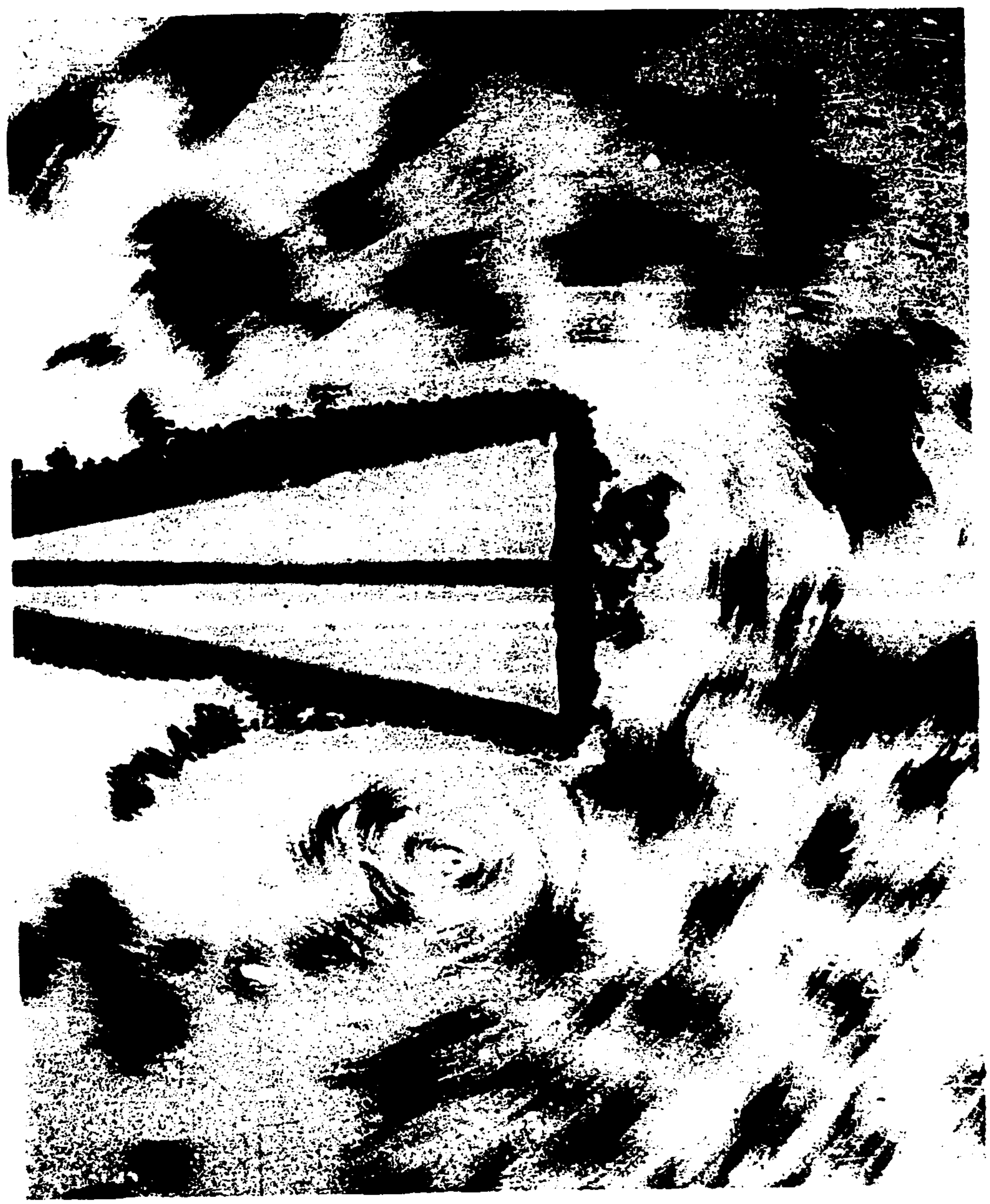
3652-95-4C 12-28-64

Figure 28. Wave Propagation Past Vertex-Mounted Baffle, Stage 3



3652-93-4C 12-28-64

Figure 29. Wave Propagation Past Vertex-Mounted Baffle, Stage 4

CONCLUSIONS

1. Water table techniques are capable of yielding information on baffle shockwave interaction.
2. Difference in overpressure fields were slight for the two baffle shapes investigated.
3. Differences in flow fields were appreciable for the two baffle shapes studied.
4. Vortex generation at the baffle tips is a significant factor in shock wave diffraction by a baffle.
5. The accuracy of the height sensing probe should be increased if quantitative information on overpressure fields is to be obtained.

[redacted]

ACOUSTIC LINER

Three tests were conducted at Bravo 1C on the F-1 gas generator employi an acoustic liner.

Test 630-009 was conducted on 4 November 1964, Test conditions were:

Fuel flowrate, lb/sec	108
Oxidizer flowrate, lb/sec	57.4
Mixture ratio,	0.531
Exhaust temperature, F	1812

The test duration was 1.3 seconds. Inspection of the records revealed the presence of a longitudinal thrust chamber mode in transition. Duri mainstage, a sporadic instability occurred, which was predominately at the longitudinal mode frequency, although the first tangential mode (≈ 2000 cps) was present at low amplitude. The acceleration g level wa sufficient to cause rough combustion cutoff, had there not been a malfunction in this device. No damage was incurred.

Test 630-010 was conducted 6 November 1964. Test conditions were:

Fuel flowrate, lb/sec	118
Oxidizer flowrate, lb/sec	59.3
Mixture ratio,	0.502
Exhaust temperature, F	1503

The test resulted in rough combustion cutoff after 192 milliseconds of mainstage duration. The same roughness in buildup was observed. The

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instability in this test was less sporadic and more uniformly high level. No damage was incurred. The hardware was removed for rework. All small holes forming the "necks" of the resonators in the liners were plugged.

Test 630-022 was conducted 29 December 1964 with the acoustic liner holes plugged. The test was intended to be a repeat of Test 630-010 above. During transition, the same type of high-amplitude oscillations occurred as in the previous two tests. However, they were sufficiently high this time to cause a rough combustion cutoff in transition. The liner was expanded against the chamber wall and was scored during removal. This was the only damage noted.

For purposes of comparison, power spectral density plots were made of the chamber pressure for each test. These are presented in Fig. 30 through 32. Figures 30 and 31 were made for Tests 009 and 010 and apply to the unstable portion of the tests in which the liner holes were open. Figure 32 applies to the transition phase of Test 022 in which the liner holes were plugged.

Although the test results were disappointing in that no run was stable with the liner in operation, there was nevertheless some encouragement in the fact that the presence of the liner evidently permitted the test to reach mainstage.

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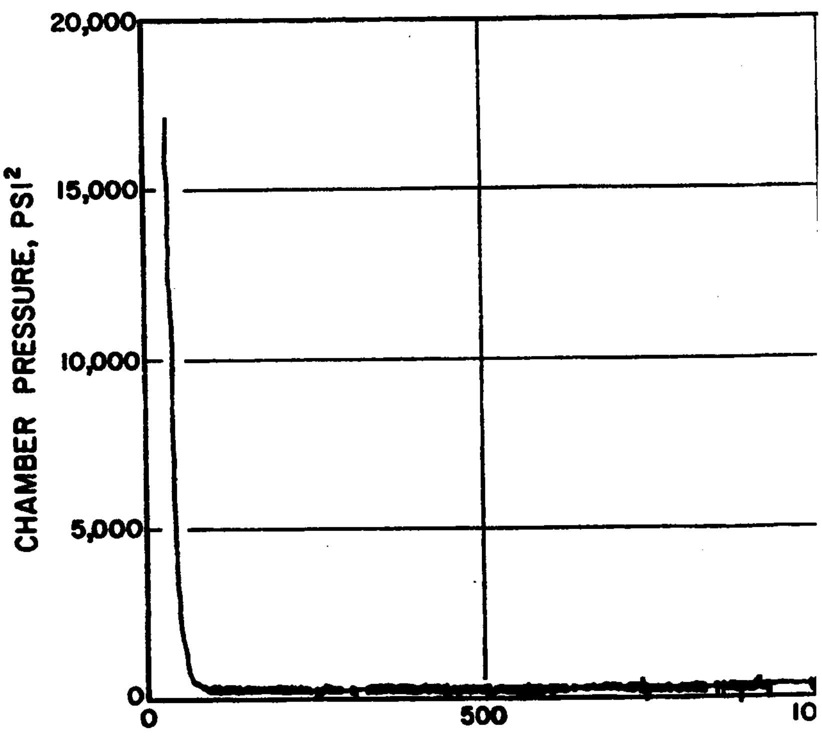

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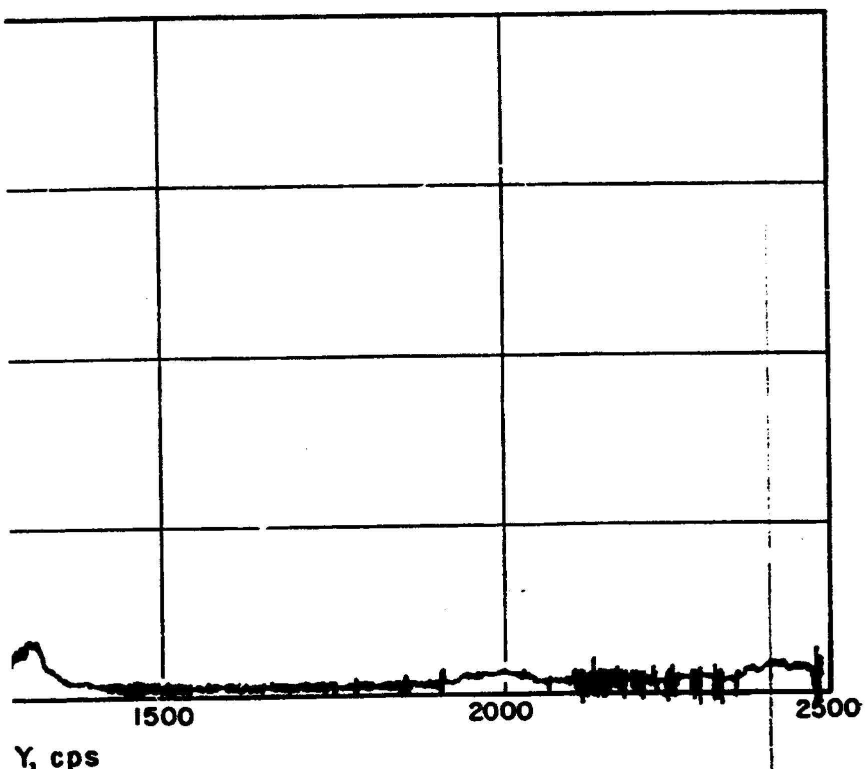

Figure 30. Chamber Pressure: Instabilit
to Instability +100 Milliseconds; Test
633-009A-114; Liner Holes Open

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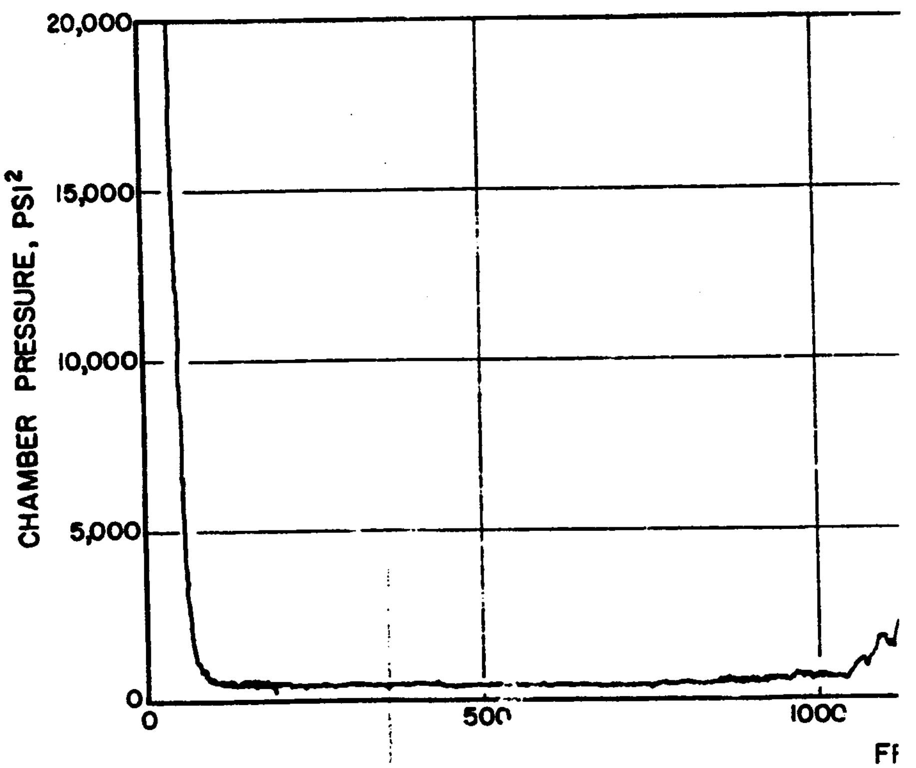

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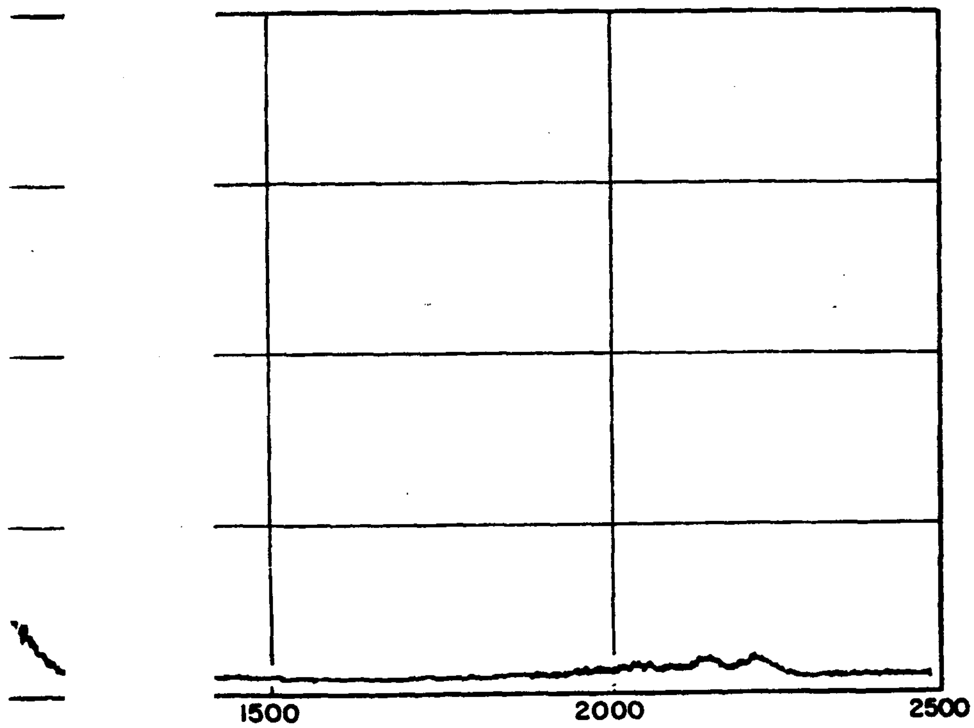

Figure 31. Chamber Pressure: Instability to Instability +100 Milliseconds; Test 633-010A-114; Liner Holes Open

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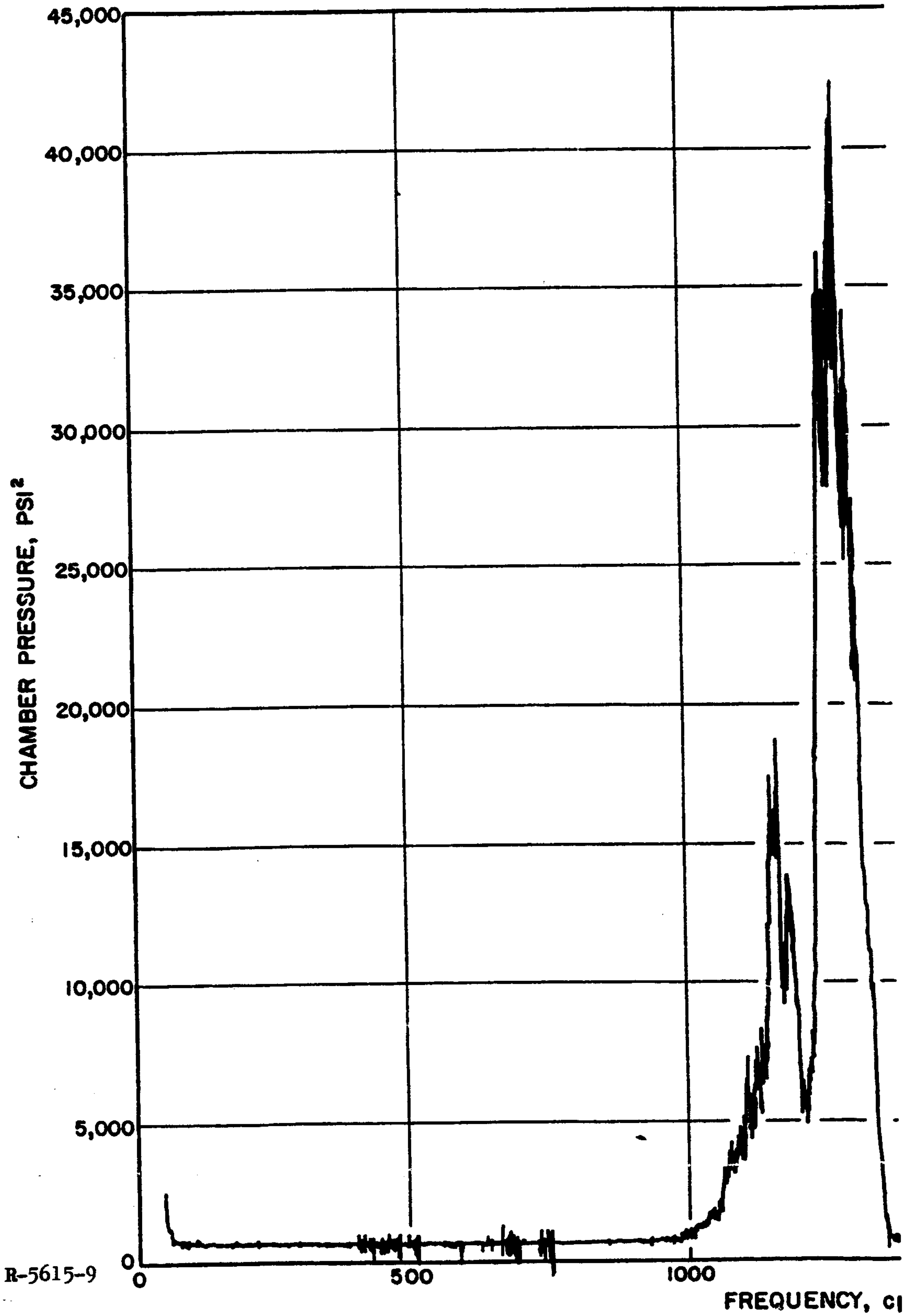

R-5615-9

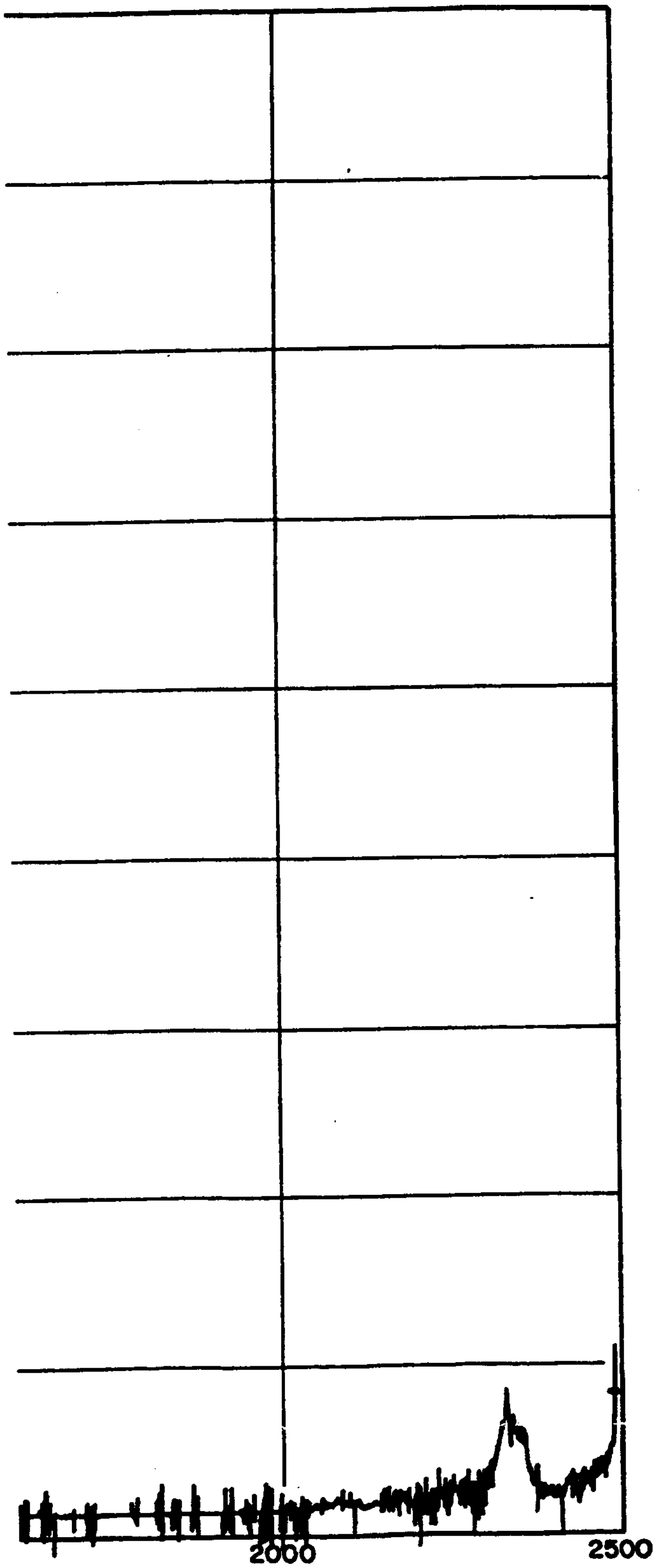

Figure 32. Chamber Pressure: 100 Milliseconds of Transition Phase, Test 630-022A-124; Liner Holes Plugged

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IMPINGING JET WAVE PATTERNS

A cursory review of a group of films taken at the medium flow bench revealed the presence of a spherical wave pattern in the fan formed by impinging jets of water. These waves, emanating from the point of impingement, seemed to become more prominent as the impingement angle was increased.

To investigate further these wave phenomena, three orifice plates simulating the oxidizer orifice patterns of the FRT and 082B type injectors were fabricated and water flowed. These orifice plates had the FRT injector oxidizer doublets of 0.209-inch diameter and 0.242-inch diameter impinging at 40 degrees, and type 082B injector oxidizer doublets of 0.209-inch diameter impinging at 56 degrees 24 minutes.

In addition, a group of orifice plates with a modification of the above orifices was built. This modification consisted in drilling two additional small orifices in the plane of the original fan. The purpose of these added orifices was to impart additional axial momentum at the source of the spherical waves.

The assumption behind this program was that oscillations in combustion chamber pressure can result from oscillations in energy addition to the chamber. In particular, these oscillations can occur in a propellant stream. If the burning rate is a function of vaporization rate, the change in degree of atomization of the propellant spray can contribute a change in chamber pressure.

Fastex films at 2600 to 4200 frames per second were used to record the tests. A 60-cycle timing light at 120 flashes per second was added to

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the film strip. Two stroboscopic light sources, synchronized with the camera, provided a 10^{-6} second duration flash per frame. The frequency of the wave pattern was determined by counting the number of frames between succeeding waves projected on a screen.

TEST RESULTS

The results of the examination of the films showed that:

1. The spray from both FRT and 082B injector pattern oxidizer orifices showed waves; however, the wave intensity from the FRT pattern was much less pronounced than that from the 082B pattern. The wave prominence was approximately proportional to the impingement angle and the spray fan angle when viewed normal to the fan.
2. The wave frequency was proportional to the injection velocity and inversely proportional to the orifice diameter. The observed frequencies agreed fairly well with those frequencies calculated by Rayleigh's method of determining frequencies of liquid jets issuing from orifices.
3. The spray pattern from the modified orifice of two 0.187-inch diameter orifices impinging at 56 degrees 24 minutes and two showerhead orifices of 0.096-inch diameter and 0.089-inch diameter drilled in the original fan plane showed considerable reduction of spherical waves when compared to the 082B injector type oxidizer orifices of 0.209-inch diameter impinging at 56 degrees 24 minutes (without modifications).

The spray pattern from the modified orifices of two 0.209-inch diameter orifices impinging at 40 degrees and two showerhead orifices of 0.093-inch diameter drilled in the original fan plane showed considerable reduction of spherical waves when compared to the FRT injector type oxidizer orifices of 0.209-inch diameter impinging at 40 degrees (without modifications).

SPUD PROGRAM

From the single-element testing conducted at Canoga Park and Neosho, the radial and concentric orifice type spuds evolved as the injection elements to be used in the full-scale spud injector. The radial flow type spud has like-on-like impingement and injects propellants in the radial direction. Axial injection was completely eliminated (Fig.33). The concentric orifice spud consists of 21 oxidizer tubes, each surrounded by a fuel annulus. The injection of propellants is in the axial direction (Fig. 34).

By mid-December, the concentric orifice type spud injector was completed and assembled. The injector and solid-wall assembly are illustrated in Fig. 35. The preparation of the test stand to handle the spud injector had not been completed during this period, and the injector was not tested.

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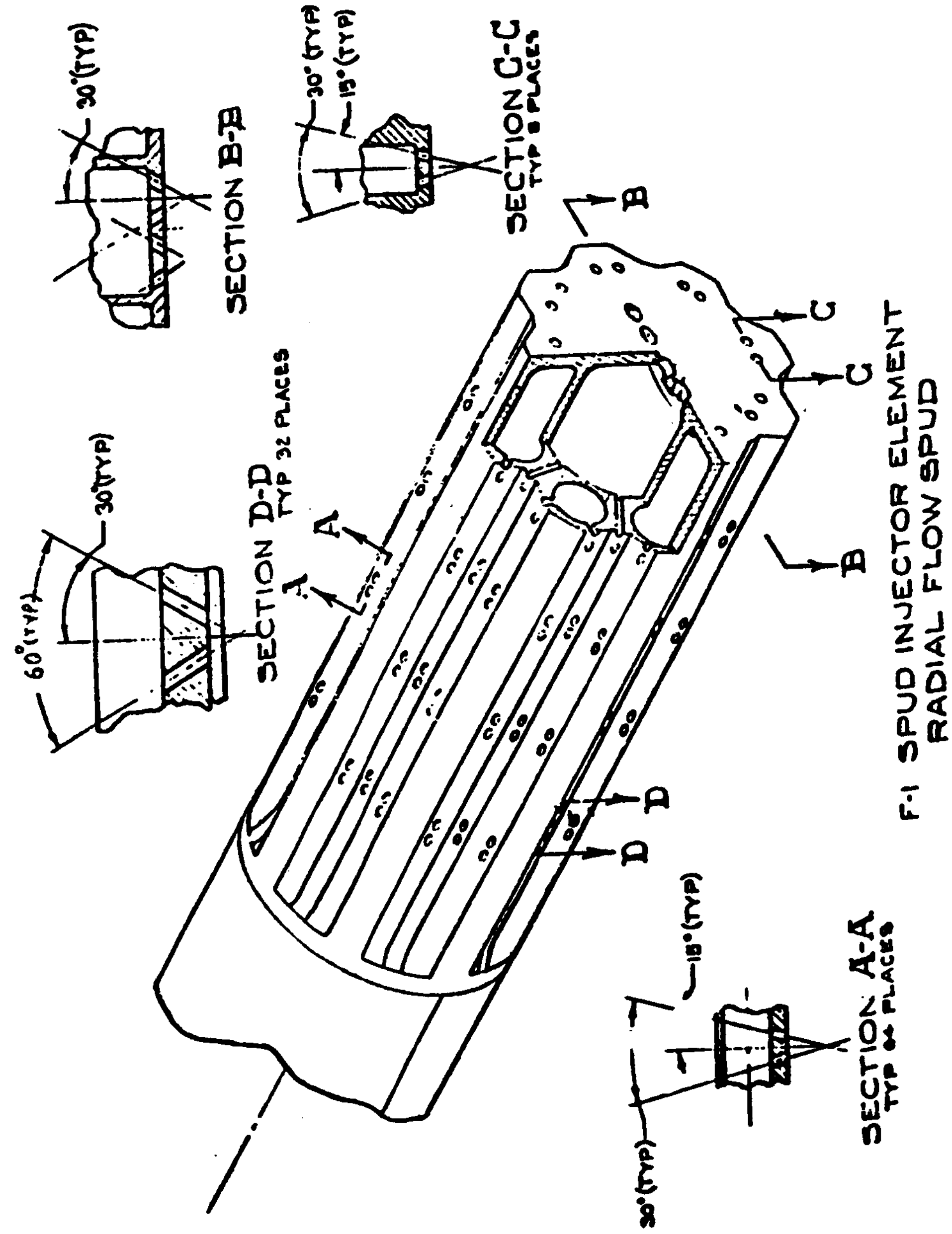

Figure 33. F-1 Spud Injector Element, Radial Flow Spud

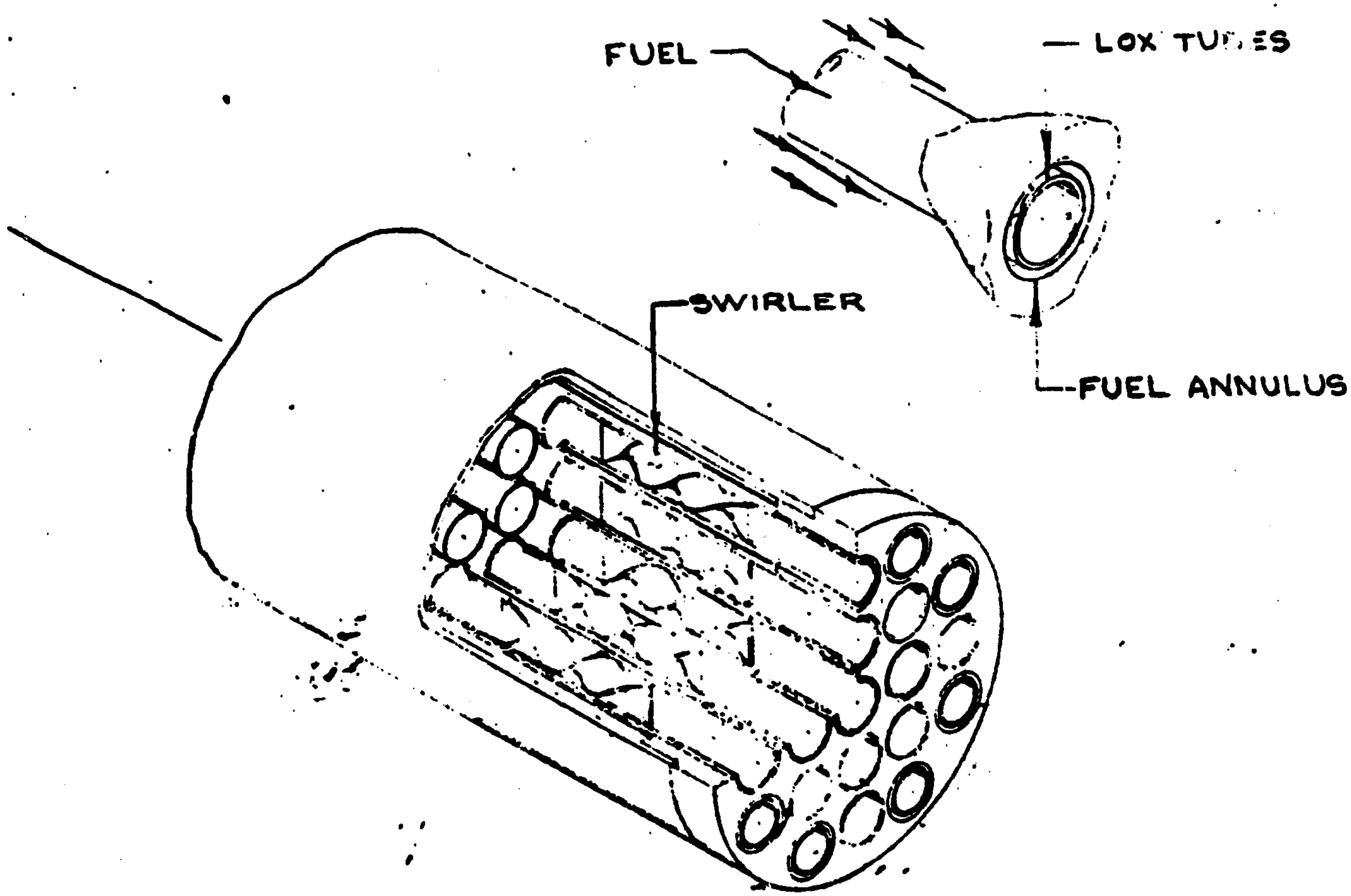

Figure 34. F-1 Spud Injector Element, Concentric Orifice Spud

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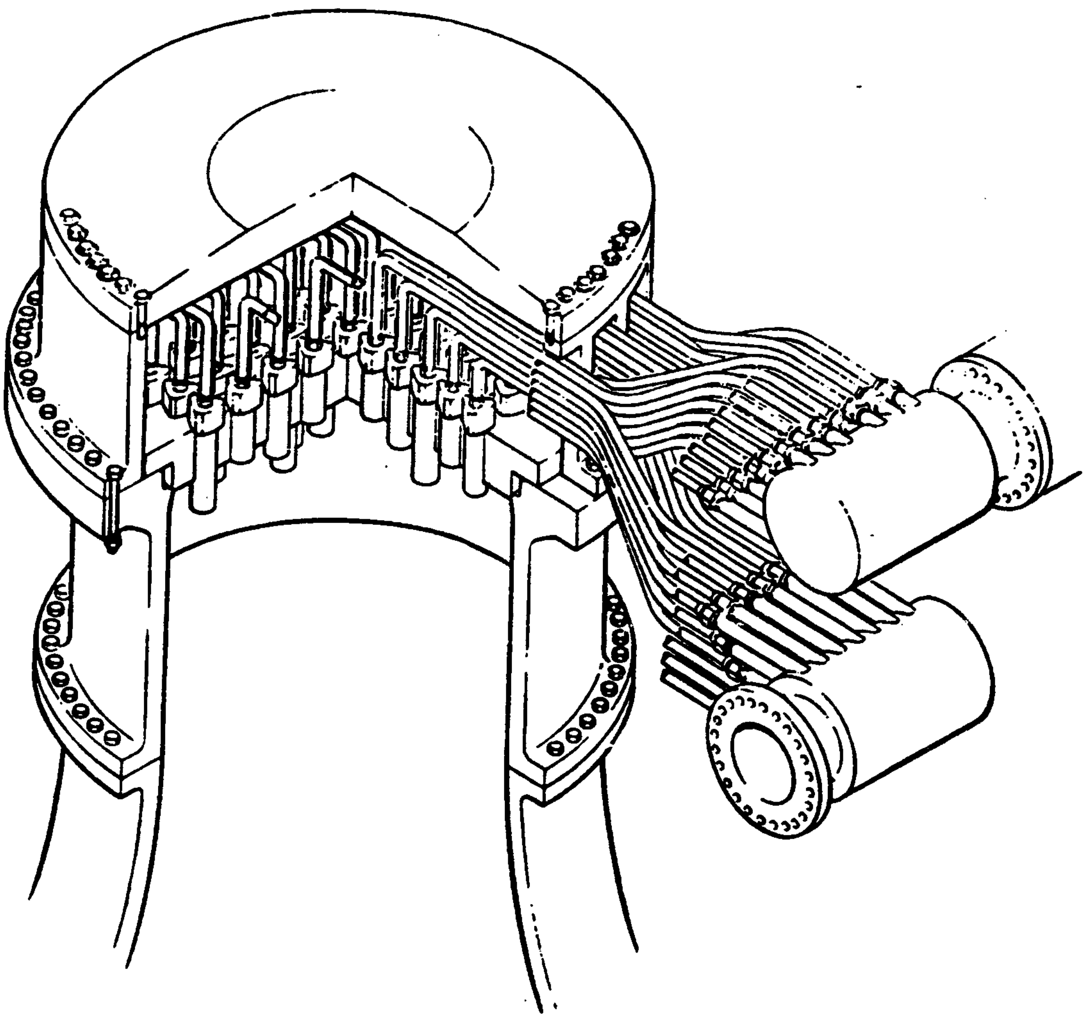

Figure 35. F-1 Spud Injector Assembly

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BOMB EFFORT

Combustion stability bomb performance on F-1 thrust chamber tests continued to be satisfactory. Two bomb failures were experienced with experimental low shrapnel bombs that used the plastic shell Hercules 13.5-grain blasting cap. It was determined that this cap was susceptible to detonation failure with thermal initiation, and its use was stopped.

High-speed photographs of detonating bombs were obtained with a rotating mirror streak and framing camera. Framing pictures at rates from 66,660 to 440,000 frames per second were obtained showing the shape of detonation expansion and showing the shock wave separating from the detonation products. Streak photographs taken simultaneously with the framing pictures yielded a position-time relationship for the expanding detonation. The velocity of the shockwave was correlative by blast tables to the overpressure of the shock front.

Figure 36 is a framing sequence taken at 66,660 frames/second showing the detonation of a Mod. 14 bomb with reduced core wall thickness to simulate thermal erosion.

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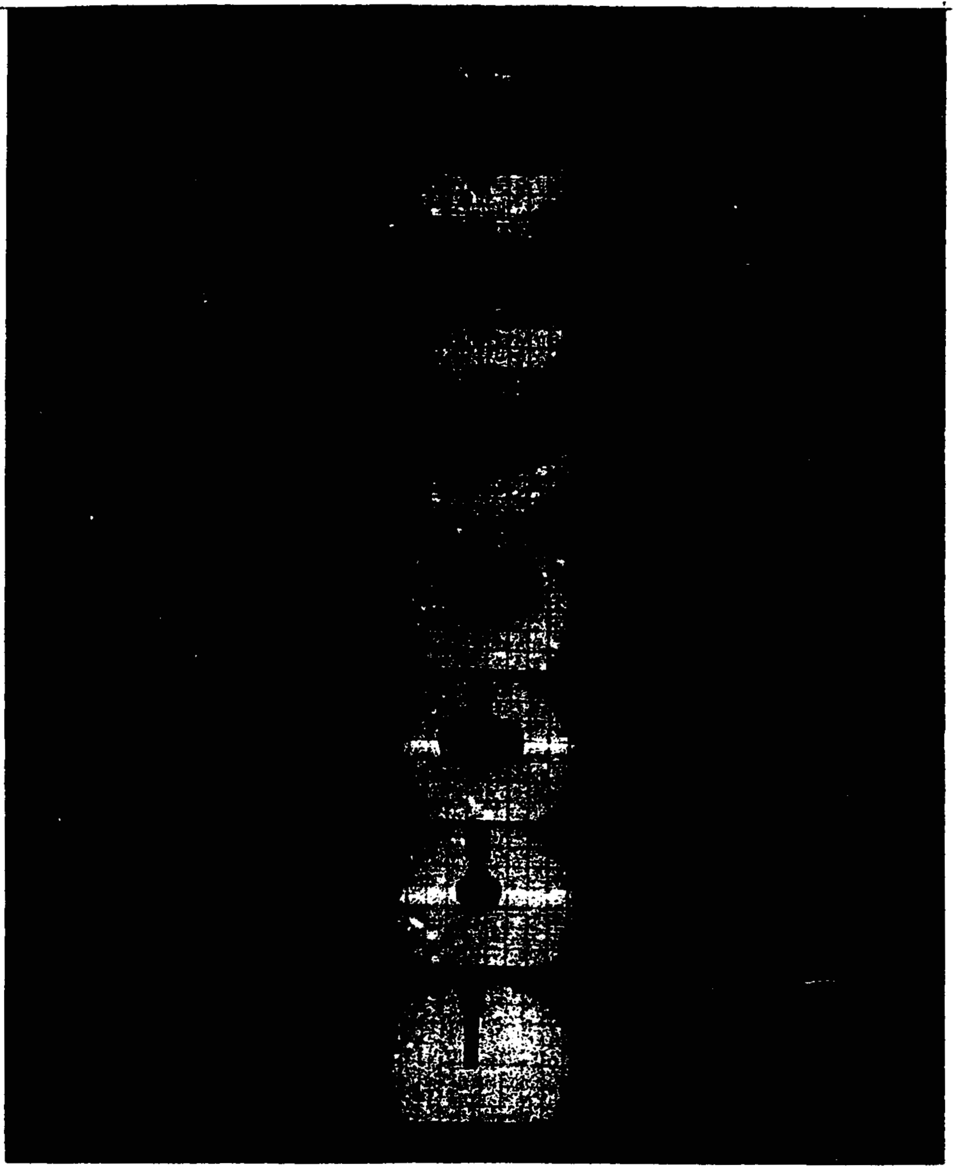

1DB99-3/30/65-S1

Figure 36. Detonation of Mod. 14 Bomb

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Security Classification

DOCUMENT CONTROL DATA - R&D	
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13. ABSTRACT

A history of the F-1 Combustion Stability Program from October through December 1964 is presented. Results of studies, tests, and procedures are discussed and graphically presented, and problems encountered are described. (Unclassified Abstract)

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Security Classification

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Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Combustion Stability Injector [redacted] Hydrodynamics Digital Model Baffles Spud Injector						

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