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F-1 COMBUSTION STABILITY PROGRAM
VOLUME 3, BOOK 2

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FOREWORD

This is Volume 3, Book 2 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 January through March 1965 is presented. Results of studies, tests, and procedures are discussed and graphically presented, and problems encountered are described.

(Unclassified Abstract)

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INTRODUCTION

This report presents a history of the activity of the Combustion Stability Program during the months of January, February, and March 1965. Flight readiness testing (FRT), with the exception of the three declared stability demonstration tests, for the F-1 engine system had been accomplished during the previous quarterly period. Attention during this period, in both testing and analysis, was directed toward the Qualification injector. Major efforts were expended in improving the injector in four categories: stability, performance, durability, and reliability.

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SUMMARY

A major milestone in bringing the F-1 engine system up to flight readiness was accomplished during this period with the completion of three declared FRT stability demonstration tests. Each bomb-induced instability damped well within the 100-millisecond FRT specification limit, as had three previous nondeclared stability demonstration tests. The test series officially concluded the FRT demonstration program.

Efforts on the component stand continued to be directed toward the development of the Qualification injector. Ninety-nine tests were conducted during the period on the two positions of component stand 2A to evaluate the performance and stability characteristics of various injector modifications and Qualification candidate injectors.

A new correlation for predicting the stability of various injector designs and evaluating the merits of proposed modifications to existing injectors was advanced. Its applicability to the F-1 stability program was carefully monitored.

Research effort was temporarily diverted from firing of the high-pressure, two-dimensional chamber to more basic studies. These involved supercritical droplet heating, accelerating droplet breakup, acoustic absorption, and reprogramming Dr. Richard Priem's combustion stability theory to incorporate the unique boundary conditions of the two-dimensional motor.

Hydrodynamics activity was accelerated following completion of installation and checkout of the new flow collection system during the last quarter of the previous year. A major portion of the effort was directed toward improving the performance characteristics of Block 2 type injectors.

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THEORY AND ANALYTICAL STUDIES

STABILITY

The largest and most reliable source of information applicable to the design of improved combustors is the store of experimental data from previous tests. The problem in utilization of these data becomes one of separating the effects of hundreds of design and operational parameters varied during these tests. Statistical mathematical correlation techniques plus theoretical analysis offers the best approach in detecting pertinent variables and the extent to which they affect combustion.

A dual approach of first postulating theoretical explanations for combustion behavior and then using pertinent test results to confirm or deny the theory has been taken. A semiempirical correlation was thus evolved, and was used not only to explain the results from previous tests, but also for extrapolation in estimating the relative importance of the variables under consideration. The basic concepts used for correlating the results are:

1. The overpressures observed result from changes in localized combustion rates corresponding to explosive or detonative proportions and are expected to conform to the laws governing explosive theory.
2. The tendency for unstable combustion increases with those factors conducive to high explosive brisance and decreases with those factors which induce attenuation effects.

Both acoustically coupled unstable combustion processes involving high-amplitude, steep-fronted, pressure waves and the sinusoidal wave, buzz-type instabilities were correlated under the above concepts.

The design and test variables were grouped into two basic equations which express the energy addition, F_m, and the energy absorption or attenuation, F_a. It was theorized that as the energy addition is increased or decreased the energy absorption must be proportionally increased or decreased to maintain the same relative degree of stability. A plot of these two energy terms for combustors with the same relative stability should provide a curve of constant slope passing through the origin.

The problem, therefore, is resolved into determining the answers to the following questions:

1. Which of the design and test variables affect stability?
2. In what manner do they affect stability?
3. To what extent do they affect stability?
4. Why do they affect stability?

The answer to the fourth questions is not a necessary prerequisite to establishing a correlative solution of the variables as functions of F_m and F_a, nor is it necessarily answered by a solution. The criterion used to evaluate the accuracy of tentative solutions is the extent to which experimental data are corroborated.

The current expressions established for F_m and F_a are:

$$F_m = \frac{\tan \theta_i/2 + 0.05}{Sp_m' + 1.5}$$

$$F_a = \frac{R_t}{R_c}\left(\frac{R_c'}{R_z+0.3}\right)\left(\frac{V_0}{V_F}\right)^{-0.25}\left(\frac{1000}{P_c}\right)^{0.7}\left(\frac{\tan^{0.38}\theta_o + 0.07}{x_{oj} + 2.4}\right)\frac{(1+0.5\sin^{0.25}\theta_s)^{fx}}{\cos\theta_d}$$

where

θ_i = Included angle of impingement of fuel and oxidizer sprays, degrees

θ_o = Oxidizer injection angle, degrees

θ_s = Angle of mismatch of oxidizer and fuel sprays, degrees

θ_d = Average thrust chamber divergent angle within the first 3 inches from the injector face, degrees

P_c = Chamber pressure, psia

S_p' = Tangential spacing between propellant intermixing zones, next to confining surfaces, inches

R_t = Radius of thrust chamber throat, inches

R_c = Radius of thrust chamber, inches

R_c' = Equivalent radius of a baffle compartment ($R_c' = R_c$ for flat-face injectors), inches

R_z = Radius of injection zone, inches

V_0, V_F = Injection velocity of the oxidizer or fuel, ft/sec

X_{cj} = Initial oxidizer jet impingement angle, degrees

fx = -1 if the mismatching angle, θ_s, induces the impingement of both fuel and oxidizer sprays on a confining surface

= +1 if the mismatching angle, θ_s, reduces the impingement of both fuel and oxidizer sprays on a confining surface

This correlation generally separates the test results with various injectors into classes which are characterized by specific stability criteria. A plot of the result is shown in Fig. 1. The following were derived from an analysis of the correlation:

1. Combustion stability increases as the oxidizer dispersion is increased near the injector face.
2. Combustion stability decreases as the fuel dispersion is increased near the injector face.
3. Combustion stability decreases as the interdispersion rate of the oxidizer and fuel is increased.
4. Combustion stability decreases as chamber pressure is increased.
5. Combustion stability increases as the oxidizer injection velocity is increased and the fuel injection velocity is decreased.
6. Combustion stability increases with increased spacing between injection elements and between injection elements and confining surfaces.
7. Combustion stability decreases as the degree of joint impingement of oxidizer and fuel on confining surfaces is increased.
8. Combustion stability increases as the thrust chamber contraction ratio is decreased.
9. The tendency for buzz-type instability to occur appears to increase with the initial intermixing rate of the propellant.
10. The nature of the injection method next to the confining surfaces is critical with regard to the high-amplitude, steep-fronted-type instability, as well as to the sinusoidal buzz-type instability.

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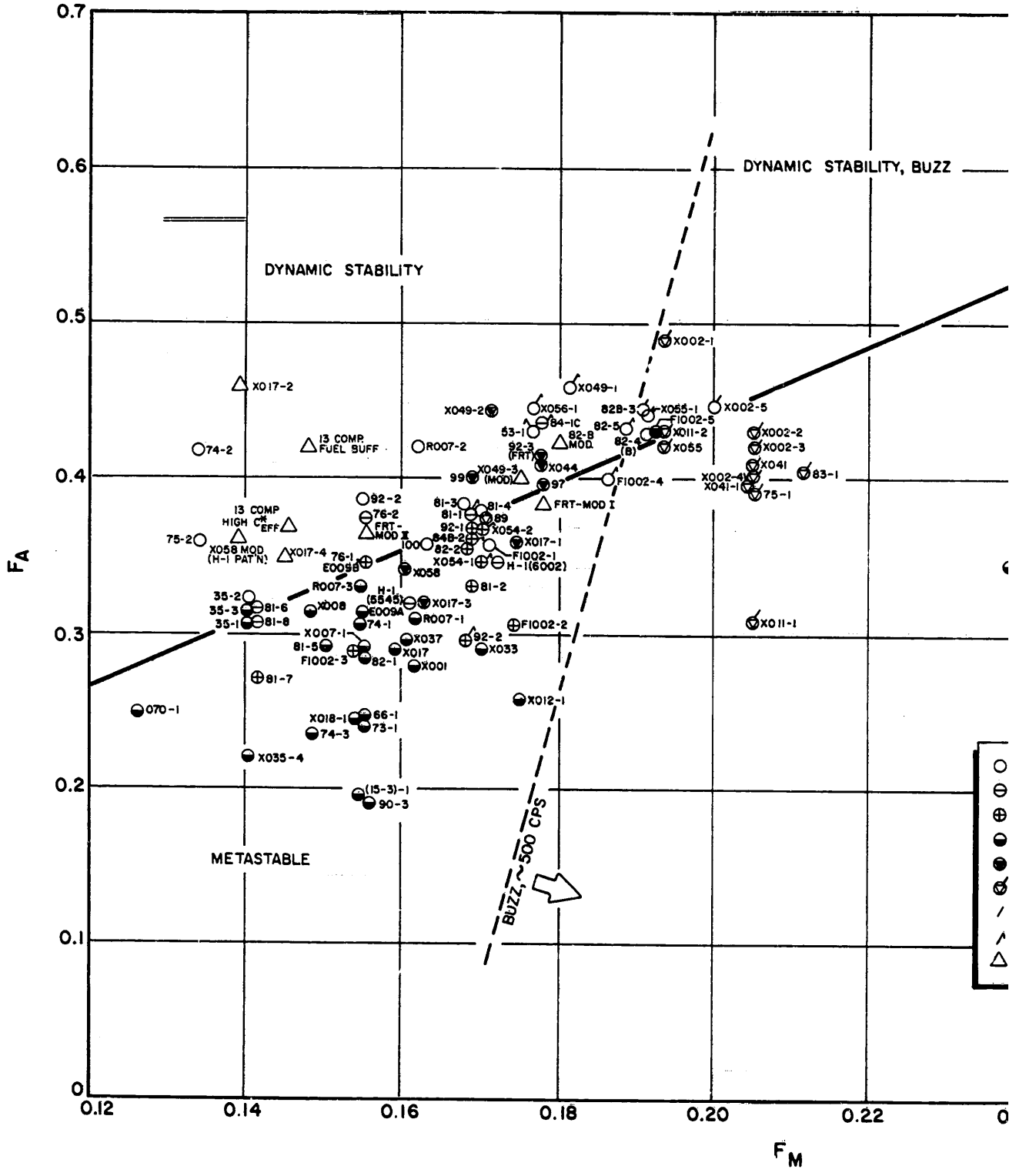

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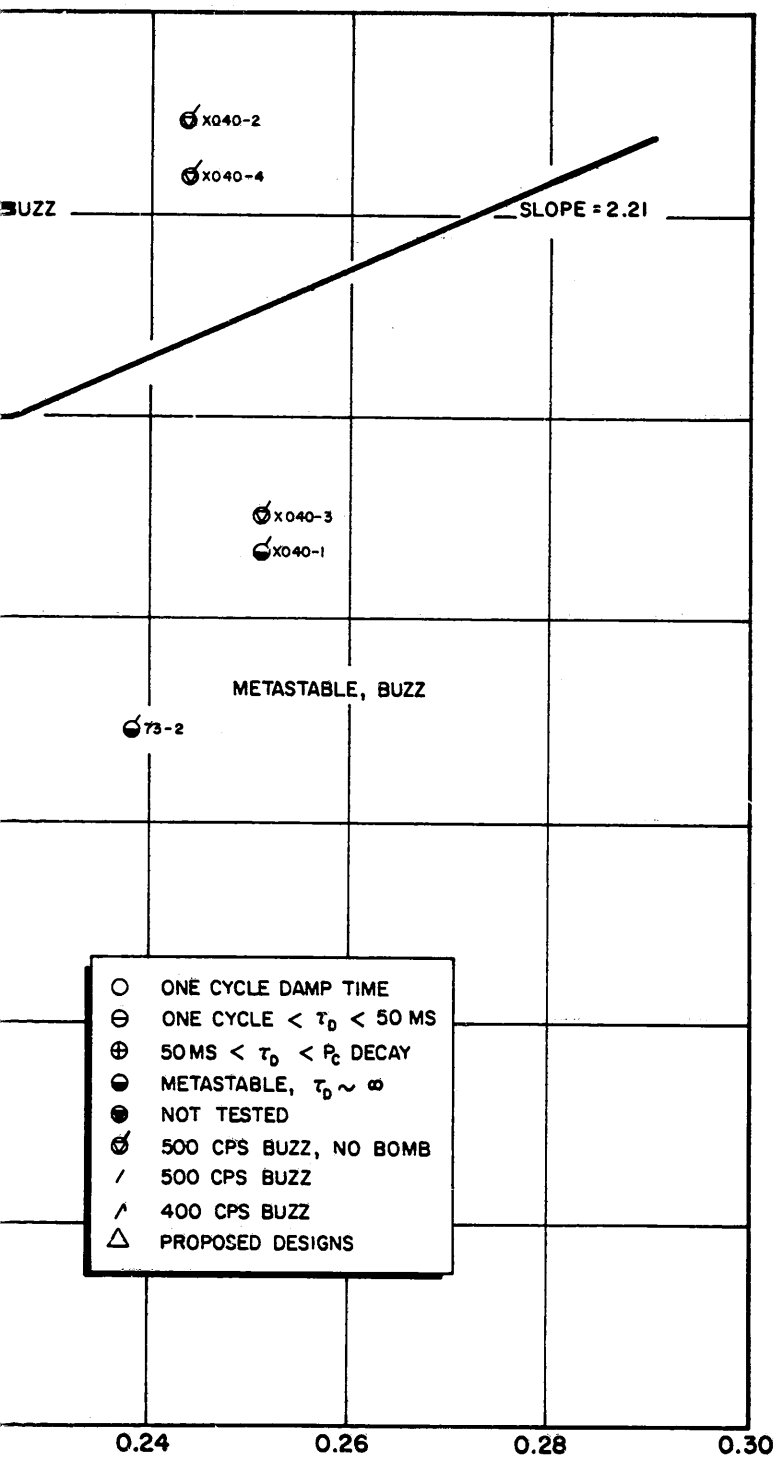

Figure 1. Energy Addition (F_m) vs Energy Attenuation (F_a)

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11. Generally, those factors beneficial for stability appear to be detrimental for performance.

12. The effects of the propellant injection method and the orientation of the injection elements with respect to the confining surfaces appear to affect combustion stability more strongly than do the propellant feed system hydraulic characteristics.

The combustion stability theories of L. Crocco, R. J. Priem, and the Aerojet Company of Azusa, California were reviewed to determine their potential for application to F-1 stability problems. A general comparison of the approaches of each of the investigators indicated that the techniques of Priem and Crocco are quantitative in nature while the Aerojet approach is qualitative.

Crocco considers a macroscopic system and makes little attempt to describe the specific processes or mechanisms involved. He merely assumed that they exist and that, whatever they are, they can be described by a gain and a phase relationship. Priem and Aerojet, on the other hand, consider specific mechanisms and attempt to incorporate them in their combustion models.

Priem constructs a one-dimensional, nonlinear model and considers two different burning rate assumptions. Two solutions are thus obtained, one for the assumption that the burning rate equals the fuel vaporization rate and the other assuming that the burning rate equals the kinetic or Arrhenius burning rate. The former assumption appears to be more applicable to large combustion systems, while the latter is prefereable for small, laboratory-size chambers. In contrast, Crocco appears to incorporate both vaporization and Arrhenius burning rates into one pressure-dependent parameter.

Aerojet's mechanism involves the available energy, i.e., energy which could be released by the passage of a pressure wave through unreacted propellants, and the time required to re-establish this available energy. No method, however, is presented for computing this time. With respect to its applicability to the F-1, the Aerojet theory is not yet developed far enough. Qualitative light, however, is shed on possible mechanisms for both the buzz and resurge problems.

Priem's model is extremely complicated, from the mathematical standpoint, when it comes to application in multidimensional systems such as the F-1. It is, however, being studied by the Rocketdyne Research Department for application to the two-dimensional research thrust chambers. Crocco's investigations have been the most extensive and appear to be the most flexible. He does, essentially, a new investigation for each type of instability mode encountered. His assumptions, however, do not appear to be compatible with the F-1, although the model could explain some facets of the problems.

INJECTOR PERFORMANCE

With the stability development of the F-1 injector progressing into the latter stages, more attention was directed toward performance. A study was initiated to determine whether a correlation could be found between injector type and characteristic velocity efficiency.

A comparison was made of the characteristic velocity efficiency between injectors having double rows and single rows of injection elements. The injectors were grouped into classes according to their pattern, test stand, and date of test. These latter separations were made so that differences

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between test stands and differences in instrumentation over a long period of time would not be confused with differences in the injectors themselves.

Characteristic velocities of theoretical frozen equilibrium values were calculated according to the following empirical equation

$$c^* r^{3/2} = C_1 + \sum_{n=2}^{n=6} C_n r^{n-1} + \sum_{n=7}^{n=12} C_n r^{n-7} \ln P + \sum_{n=13}^{n=18} C_n r^{n-13} (\ln P)^2$$

where

r = Mixture ratio

P = Nozzle inlet stagnation pressure

C_n = Constants

It was assumed that the area of the nozzle was 962 sq in. and that the ratio of injector-end chamber pressure to nozzle entrance stagnation pressure was 1.145.

A general increase in characteristic velocity efficiency was noted as a trend with increasing fuel injection velocity. This was true up to velocities of approximately 150 ft/sec, where a reversal occurred in the trend. This suggests that, at higher injection velocities, droplet residence time in the combustion chamber is considerably reduced.

Specific impulse and characteristic velocity are the primary quantities used to relate the efficiencies of rocket thrust chamber systems. Such values express the collective losses operating on a system in terms of the maximum

theoretical attainable performance. For a given thrust chamber geometry there exists a group of losses that are inherent in the particular hardware configuration and which can only be diminished by design changes. The determination of the operating efficiency of a particular component of a system, in this case the injector, becomes contingent upon the extent to which the rest of the components contribute to lowering the overall efficiency of the system. For example, it would be useless to attempt to improve the injector of a 90-percent efficient system if the accumulated losses in the rest of the system amounted to 10-percent.

The first step in such an efficiency analysis is to outline those effects which contribute to performance losses or gains. For simplicity, the gains and losses inherent in a system may be divided into three groups consisting of chemical, heat transfer, and aerodynamic effects. Under the heading of chemical effects are incomplete combustion, stagnation pressure losses due to combustion, chemical recombination, and errors in thermodynamic data. The first two items are closely related. Other chemical effects are the influence of film coolant and propellant purity.

Heat transfer effects include heat losses from the hot-gas stream to the regenerative cooling fluid, thermal radiation from the nozzle to the ambient environment, and radiation from the exhaust plume to the interior of the nozzle. This in turn adds heat to the regenerative coolant.

Aerodynamic effects to be considered in an efficiency evaluation are friction between the gas stream and the chamber walls, non-one-dimensional flow, shock losses in the nozzle, divergence losses, and non-zero propellant injection velocity. Not all of the items mentioned will contribute to an overall lowering of the efficiency of a thrust chamber system; however, only when a realistic estimation of these items has been made, can a theoretical value be placed on performance increases to be gained from injector improvement.

CHARACTERISTIC VELOCITY MIXTURE
RATIO PROGRAM

The completion of cold flow tests on injector 077 provided the first opportunity to employ the computer program that estimates the characteristic velocity performance of an injector* on the basis of its propellant distribution. In this instance both the design and actual propellant distributions were available for study. Four cases, outlined below, were examined by the program, using both the flat and cosine profile assumptions for the individual elements.

Case I: Design radial distribution and actual circumferential distribution

Cosine profile	87.5 percent Nc*
Flat profile	97.3 percent Nc*
Average	92.4 percent Nc*

Case II: Actual radial distribution and actual circumferential distribution

Cosine profile	88.3 percent Nc*
Flat profile	98.8 percent Nc*
Average	93.5 percent Nc*

Case III: Design radial distribution and uniform circumferential distribution

Cosine profile	89.4 percent Nc*
Flat profile	99.4 percent Nc*
Average	94.4 percent Nc*

*R-5615-9, History: Project First, F-1 Combustion Stability Program, Volume 3, Book 1, Rocketdyne, a Division of North American Aviation, Inc., Canoga Park, California, CONFIDENTIAL.

Case IV: Actual radial distribution and uniform circumferential distribution

Cosine profile	88.8 percent Nc*
Flat profile	99.4 percent Nc*
Average	94.1 percent Nc*

Case II and Case III represent the real and the design cases with injector 077, although in actuality the injector did not perform at 93.5 percent. The differences between Case I and Case II and between Case III and Case IV indicate that radial flow distribution has a smaller overall influence on performance than circumferential distribution. A study of the wide disparity between the cosine profile and flat profile assumptions for the individual flow elements led to the conclusion that these constitute limiting cases for the real situation. Actual performance of an injector will probably always differ from efficiency predictions based solely on mixture ratio distribution. The inclusion of other physical effects, however, is beyond the scope of presently available combustion theory. Predictions of performance based on mixture ratio can be used to establish the relative performance of various designs, but the calculated results should not be interpreted as absolute values.

The program was also employed on the flow data from injector X033. This unit had been programmed for uniform radial and circumferential flow, but cold flow tests indicated that this design goal was not achieved. The program indicated that the outer compartments of injector X033 were operating at an effective mixture ratio of 2.63 as compared to 2.14 and 1.60 for the inner and center compartments, respectively.

By combining the fuel side of injector X033 with the oxidizer side of injector X050 (an FRT-type injector) a potential performance gain of 0.5 percent over the injector X033 performance was indicated. This arose from the improvement in phase condition between the fuel and oxidizer sides established in the programming of injector X033. Outer compartment mixture ratio for the X033-X050 combination was 2.55. The inner and center compartment mixture ratios were 2.33 and 2.00 respectively. Even though the mixture ratio alternated between the inner and outer compartments, the effective c* efficiency obtained with the combined configuration was higher than that of injector X033. This variation was also noted from doublet to doublet in the circumferential direction but the effect was not as detrimental to performance because of the improved phasing.

ACOUSTIC LINER

The objective of the F-1 acoustic liner program was to generate a design which would successfully demonstrate damping of the first tangential acoustic mode at a frequency of 630 cps. The design was based on conditions pertinent to the F-1 regeneratively cooled thrust chamber, although the feasibility demonstration phase was planned to be conducted with uncooled hardware. Data thus generated could directly influence the design of a liner for inclusion in the more sophisticated tubular wall thrust chambers.

A meeting was held in February at the NASA Marshall Space Flight Center, Huntsville, Alabama to discuss the applicability of acoustic liner concepts to the F-1 thrust chamber. Represented were Rocketdyne, United Aircraft Corporation, and MSFC. United Aircraft was present because of their experience in designing screech liners for turbojet afterburners and small liquid propellant rocket engines.

The design of the F-1 uncooled acoustic chamber was presented. This design was basically, a modified, conventional, F-1 uncooled chamber. The manifolding, inlet attach points, and instrumentation configurations were retained. The thickness of the inner wall was reduced to 0.962 inch, representative of regenerative cooling tube thickness, by removing material from the outside diameter. The modified chamber was surrounded by a shroud having spacers that form the cavities of Helmholtz resonators. The necks of the resonance compartments were 0.188-inch-ID tubes, 1.53 inches in length for proper cavity tuning. The outside diameter of these tubes was restricted to 0.250 inch because of the requirement that the design be compatible with tubular wall chamber geometry. Drainage was also provided.

In an effort to reduce weight, the shroud design was abandoned in favor of a design utilizing a series of torus manifolds. Each manifold encompassed three axial rows of resonator neck tubes which were laid out in a triangular pattern on the inner chamber wall. In the tubular wall chamber design, this pattern provided for minimum disruption of the tube coolant flow.

Because, by rocket engine standards, acoustic liners were designed for relatively low sound pressure levels, there was some concern as to their reaction to the higher amplitude oscillations of a true instability. United Aircraft believed that the liner would prevent a gradual build-up to this amplitude. In the case of a bomb-driven disturbance, it was believed that the liner would absorb enough energy to prevent the establishment of a high-amplitude mode. It was suggested that an acoustic velocity of 2800 ft/sec rather than 3500 ft/sec would be a more realistic value for the resonator cavity volume. The idea of using tubes as necks of the resonators appeared to offer no problem.

The question as to the appropriate value of acoustic velocity to be used in calculating resonant frequency for acoustic liner designs has been the subject of considerable study. The question arises in the case of rocket engine applications because the gas in the resonator volume is considerably cooler than that in the main combustion stream. A Helmholtz resonator can be viewed as a spring-mass system. The mass of gas in the neck is set into vibration and the gas in the cavity undergoes compressions and expansions, acting as a spring. The resonant frequency is a function, therefore, of the geometric properties of the resonance cavity and the mass in the neck of the resonator, and is independent of the temperature within the cavity.

The uncooled F-1 acoustic liner employs individual resonators with the necks buried within the cavity volume. This represents a departure from classical Helmholtz resonators in which the cavity is coupled to the neck at a terminal plane common to both. Experiments with cavities having a buried neck showed that this design obeys the classical theory, provided that the volume of the neck is taken into account, and that the neck terminus is sufficiently far from the back wall of the resonator so that there is no disruption of the motion of the end correction mass.

FLOX

The possibility of using FLOX as the oxidizer for the F-1 was studied during this period, and it was determined to be feasible. Previous Rocketdyne experience with fluorine indicated that a 30-percent fluorine, 70-percent liquid oxygen mixture would be optimum from the standpoint of performance and compatibility. Rough estimates indicated a 10- to 15-second increase in specific impulse at F-1 operating conditions.

The main compatibility problem is leakage at seals between moving parts. Extensive cleaning and passivation of the oxidizer system before testing is essential. Increases in fluorine content above 30-percent would require material changes in the engine system to maintain compatibility.

Although the Thor engine tended to run smoother with fluorine added, and although it might be expected that the stability characteristics of the 30-70 mixture would be improved over those for pure liquid oxygen because of a decrease in the possibility of accumulating pockets of unburned propellants, not enough experience has been accumulated to evaluate accurately the stability of the system using FLOX as the oxidizer.

CARBON PATTERNS ON INJECTOR 082B

The face of injector 082B was coated with a gradated Inconel-zirconium oxide protective coating as part of a program to reduce thermal gradients across the rings. After firing, a peculiar pattern of carbon smudges was observed on the coating surface, instead of the normal uniform deposit on all exposed surfaces. This pattern was repeated in all the outer and all the inner compartments. Speculation as to the origin of the patterns led to two theories concerning their cause.

The first theory postulated that an individual compartment mode of combustion instability was set up during the testing and that gas movement was established within the compartment according to the mode. According to this theory, carbon would be smudged into the coating in those areas where the gas movement was the most active. The mode whose flow patterns most closely corresponded to the observed pattern would be the combined first tangential-first radial compartment mode. The frequency of this mode would be approximately 3150 cps. Such a frequency was observed in some of the test records of injector 082B.

The second theory proposed that the orifice pattern of injector 082B sets up recirculation vortices and that, because of the coating, the surface generally runs hotter than the normal bare copper surface. If this were the case, carbon would generally be burned off and the streaks would represent cooler regions where vortices recirculated fuel-rich gases toward the injector face. These inferred vortices affect local mixture ratio in the F-1 injector, and consequently its performance. If the orifice pattern could be arranged to obtain different stable vortex patterns, then one such pattern might be more advantageous than another in obtaining performance or stability.

TEST AND ANALYSIS

Testing at the Edwards component facility, after the beginning of the year, did not resume until February. This delay was caused by the rework of seven liquid-level bosses in the high-pressure liquid oxygen tank. Weld cracks were discovered in some of these bosses during the routine year-end facility inspection. Approximately five weeks were required to rework the welds, during which testing on both facility positions was suspended.

A total of 99 component tests in 32 series, involving 19 injectors, was conducted at EFL during the months of February and March. A majority of the tests were conducted on stand 2A-2. Damage of part of the ducting and some of the stand systems, which occurred on position 2A-1 during test 014, necessitated shutdown of the facility for repairs.

With the successful completion of Flight Rating Tests, the test and analysis effort was directed to the development of the Qualification injector.

The main categories of investigation were performance and compatibility, combustion stability, and injector durability.

The individual concepts pursued under these main categories included:

1. Injector face temperature measurements
2. Improved hydraulics
3. Increased and decreased compartmentation
4. Increased canting and overlapping of oxidizer fans adjacent to radial baffles

5. Regeneratively cooled baffle systems
6. Six-inch baffle
7. H-1 and cluster-type orifice patterns
8. Injector face thermal insulation coatings
9. Removal of splitters from Block 2 type injectors
10. Unlike doublet pilot flame orifice groups
11. Reduced outer fuel ring flow
12. Thicker (0.550 inch) injector rings
13. High-strength braze joints
14. Canting of both fuel and oxidizer orifice groups along radial baffles
15. High-resistance injector body, oxidizer side
16. Radial baffle gap, sealed lands, and decreased injection density along radial baffles

The following conclusions derived from the analysis of testing during this and previous periods are applicable to the Qualification injector design.

1. Baffle-to-land gap sealing does not appear to influence the buzzing or damping characteristics of an injector.
2. Tribaffle and four-baffle injectors exhibit poor damping characteristics; the injection pattern next to the baffles, however, may have influenced stability.

3. Canting of both oxidizer and fuel fans adjacent to the radial baffles does not improve damping when compared with the results of canting the oxidizer fans only.

4. Canting the oxidizer fans and reducing the flow adjacent to the radial baffles markedly improved the damping characteristics of the PFRT injector, thus supporting the theory that the nature of the injection method adjacent to confining surfaces is critical.

5. Canting of the oxidizer fans adjacent to the radial baffles produces significant improvement in damping and buzzing characteristics. This may be the result of removing the oxidizer and fuel intermixing region from the baffles, or decreasing the oxidizer and fuel intermixing rate, or both.

6. Closely spaced propellant fans do not appear beneficial for damping.

7. The use of small showerhead orifices between impinging oxidizer orifice groups appears to have reduced the amplitude of buzz-prone injectors.

8. Venting the baffle compartments adversely affects damping.

9. The addition of small-diameter, close-impinging, fuel pairs between existing fuel doublets does not improve damping or buzzing.

10. A flat-face injector, which had the outboard oxidizer and fuel fans tilted radially inward to improve its stability characteristics, showed approximately a 1 second specific impulse performance increase when compared to the FRT-type injector.

11. Reduced injection density along the radial baffles in addition to canting the LOX fans is superior to canting alone for damping.

12. The removal of the oxidizer axial feed passage splitters from an FRT type injector does not appear to degrade stability and produces a slight increase in performance.

13. Increased oxidizer injection density and severe overlapping of the LOX fans adjacent to the radial baffles appears to be coupled with the tendency for an injector to self-trigger instability.

14. Reduction of the fuel flow to the outer ring to 60 percent of nominal produces no adverse chamber compatibility problems.

15. Regeneratively cooled baffles appear to have superior durability when compared to dump cooled baffles.

The following is a discussion of the major concepts tested and analyzed during the period. The order of presentation is by concept rather than chronology because, in many cases, evaluation of more than one concept was carried out simultaneously. Photographs and injector descriptions referred to in the discussion are included in Tables 1 and 2.

INJECTOR DURABILITY

The first experiments involving installation of thermocouples in the face of an F-1 injector were made with injector 082. A discussion of the installation techniques is contained in the Instrumentation section of this report. The reactivation of test stand 2A in February was made

with injector 082. The temperature data confirmed the results obtained during a December test with this injector. A second injector, X043, was also fired late in the period with thermocouples installed in the rings. An improved installation, different locations, and a different injector pattern, however, yielded diverse, though repeatable results. From these results it was inferred that injector face heating is nonuniform, that ring temperature varies widely with location, and that thermocouples installations are feasible.

Injector 082, because of the thermocouples, was also used to evaluate injector face coatings. All of the injector surfaces, except the baffles, which are exposed to the combustion gas environment, were coated with a gradated layer of Nichrome, Inconel-zirconium oxide. The purpose of the coating was to provide a measure of thermal insulation to the ring surfaces. The durability of the coating was unsatisfactory. Discrepancies in the application procedures, however, were believed to be responsible, and further evaluations of coatings were planned. Figure 39 shows one compartment of injector 082 with coated surfaces, posttest.

In addition to the thermocouple instrumentation mentioned above, injector X043 was involved in other aspects of injector durability investigations. The copper rings were 0.550-inch thick instead of the standard 0.350-inch thickness. This added 0.200 inch to the nominal braze joint which, it was believed, would reduce stresses between the rings and body lands. Testing of the injector showed no discernible benefit from the increased ring thickness in regard to durability.

Along with injectors X058 and X060, injector X043 was also involved in the development testing of high-strength braze joints. Although the primary mode of braze joint development was the hydrostatic testing of

sample bodies and rings, it was felt that some hot fire experience would provide invaluable data. The plating techniques used on each injector were different but ring-land separations with these units were minimal.

PERFORMANCE AND COMPATIBILITY

Among the concepts itemized on page 21 only two were tested purely from the standpoint of performance and compatibility during this period. Other injectors involved with performance concepts were tested, but the results were interconnected as to the effects of such modifications on stability. The seemingly inverse relationship between performance and stability makes it difficult to separate from one area the effects of a design change to improve the other. Consequently, it becomes necessary to investigate both areas when changes are made to one.

Since the film coolant orifices were first eliminated from injector 082*, the amount of fuel delivered to the combustion processes through the outer ring was varied by restricting the flow at the entry point from the radial fuel feed port.

During this period, Block 2 injectors were being delivered with the flow reduced to 70 percent of the nonrestricted condition. Tests during previous periods showed injectors to be incompatible with the chamber when the flow was restricted to 50 percent. However, analysis of the flow

*R-5615-6, History: Project First, F-1 Combustion Stability Program, Volume 2, Book 2, Rocketdyne a Division of North American Aviation, Inc., Canoga Park, California, 23 June 1965, CONFIDENTIAL.

and mixture ratio distribution across the injector face indicated that there was still performance to be gained in the outer zone if an optimum point of compatibility could be established.

Consequently, tests were conducted with injector X060, in which the outer ring flow was restricted to 60 percent of nominal. The injector pattern was basically that of the FRT injector. Compatibility with the chamber was acceptable. However, essentially no difference in performance owing to this change was noted.

Injector X060 was also among those injectors used to evaluate regeneratively cooled baffle systems. The other injectors were X043, X058, and F2009. A discussion of regeneratively cooled baffles and the particular designs used on each of these injectors is contained in the Design section of this report. In general, the performance of these baffle systems under F-1 operating conditions was satisfactory.

STABILITY

The state of the art of damping combustion instabilities, both natural and bomb induced, had progressed significantly in the two years preceding this report period. Understanding of the phenomena and mechanisms of certain types of instabilities, however, was still limited. It had been shown empirically that the addition or elimination of certain design characteristics enhanced the stability properties of an injector.

The single factor most responsible for the excellent stability characteristics of the Block 2 type injectors, as opposed to other versions of this design, was the conditioning of the oxidizer fans adjacent to the radial baffles. In the Block 2 injectors this was achieved by canting and overlapping the oxidizer orifice groups.

In Block 2 injectors the orifice groups adjacent to the radial baffles had diameters of 0.242 and 0.250 inch at respective angles, relative to the chamber thrust axis, of 20 degrees and 28 degrees 12 minutes (Fig. 20). Experimentation with these groups took the form of varying the diameters and/or impingement angles, and of canting the fuel fans in conjunction with the oxidizer. On injector X049 the diameters were 0.185 and 0.242 inch. Consistent single-cycle damping of a bomb disturbance was achieved with this configuration. The performance of the injector, however, was degraded somewhat, and a 420-cps oscillation of considerable amplitude appeared in all parameters. A later modification to the outer fuel ring improved the performance, but the single-cycle damping remained.

An extreme case of orifice diameter overlapping in the opposite sense was tested on injector 084. In this instance the diameters were 0.242 and 0.297 inch. No buzzing or unusual oscillations were encountered with this configuration. Bomb-induced instabilities, however, experienced multiple resurges before damping. An intermediate case of overlapped orifices was tested in injector 095 with diameters of 0.242 and 0.272 inch. With this configuration the injector exhibited a marked propensity toward self-triggering, although the instabilities usually damped without initiating vibration safety cutoff (VSC).

The efficacy of canted orifice groups was clearly demonstrated with the PFRT injector F1002. The oxidizer triplets adjacent to the radial baffles were replaced with 0.209- and 0.209-inch-diameter canted doublets. Canting in this case was achieved only by the difference in angles. This modification was sufficient to produce dynamic stability characteristics in the PFRT injector which conformed to the requirements prescribed for the FRT injector. Another injector that had canting but no overlap was injector 099, in which the orifices were programmed. The stability characteristics of this injector were outstanding. It should be pointed out, however, that this injector had 25 baffle compartments.

Testing with injector X060 demonstrated that care must be taken when conditioning the oxidizer injection adjacent to the radial baffles. As originally fabricated, the diameters of the canted orifice groups were 0.185 and 0.209 inch. This configuration, however, proved to be low performing. Modification of the respective diameters to 0.221 and 0.250 inch produced an approximate 1-percent increase in c* efficiency. The modification produced no apparent change in the damping characteristics of the injector.

Another approach at increasing the performance, and perhaps the stability, of an injector with canted fans was tested on injector X054, in which both the fuel and oxidizer fans were canted. On the fuel side, the appropriate angles were changed to 7 degrees 11 minutes and 22 degrees 49 minutes, while the diameters remained equal at 0.281 inch. On the oxidizer side the angle of the 0.242-inch-diameter orifice was changed to 12 degrees 35 minutes. The angle of the 0.250-inch orifice remained at 28 degrees 12 minutes, giving an included impingement angle of 40 degrees. The average c* efficiency of this configuration was 90.7 percent, slightly below that of Block 2 injectors. Damping times with the injector were within Qualification specification, but the disturbances were accompanied by a resurge. The injector also possessed a high noise level.

Six-inch baffles were tested on two injectors. On injector 097 which, with the exception of the baffle length, was basically a Block 2 injector, the purpose was to determine the effect on resurging. On injector X040 the purpose of the 6-inch baffles was to determine their effect on the buzz mode of instability. Durability of the longer baffles proved to be a problem with both units. Major erosion damage was sustained by all baffles on injector 097 and four rings were burned out under a

radial baffle. On injector X040 the tips of the outer radi .s were burned back 3 inches. Stability evaluation was not carried out on injector 097 because of the durability problem. A bomb-induced instability failed to damp on injector X040. There was no appreciable change in frequency, although the amplitudes, compared with previous instabilities with this injector, were quite low. A 500-cps buzz at 250 psi was encountered in the chamber pressure during mainstage.

One of the hypotheses regarding the buzz-type instabilities encountered with injectors such as X021 and X040, which had high oxidizer impingement angles (56 and 76 degrees respectively), deals with the inability of hot gases to recirculate in a steady manner because of the high oxidizer vaporization rates created by these high impingement angles. Recirculation, instead, becomes cyclic, giving rise to alternating periods of high combustion rates, which are manifested as buzzing. A method of circumventing the need for recirculation is to provide a hot-gas source close to the injector face, pilot lights as it were. This was done on injector X021 by drilling 146 small, unlike, impinging doublets distributed throughout the various baffle compartments. These doublets were designed to flow at a mixture ratio of 1.0 (Fig. 24). Some erosion about the doublets inboard of the larger circular baffle occurred during the first test series with this configuration. Although the buzz was not eliminated, some improvement was noted. In a later modification, the orifice areas of the unlike doublets were enlarged to accommodate 1 percent of the total propellant flow. Burn-through of an oxidizer ring in the vicinity of a doublet occurred during the first test. However, there was no evidence of the 500-cps buzz.

To evaluate the effects of high injector body resistance on stability and performance, the oxidizer axial feed passage area of injector 098 was reduced from 85.2 to 61.5 sq in. This was accomplished by placing

restrictors at the entrance of the LOX axial feed holes. Some redistribution of the oxidizer flow was accomplished at the same time. The result was a high performing injector with a c* efficiency in excess of 92 percent. The stability results with this injector were somewhat inconclusive. One test damped in 11 milliseconds without resurging. A second test required 45 milliseconds to damp and was accompanied by five resurges. An oxidizer leak at the dome flange occurred during this test, resulting in a fire which destroyed the injector (Fig. 10). A 400-cps, steady-state oscillation was noted in all tests during the series.

Various other items were tested during this period for their effects on stability. Included among these were radial baffle gap, sealed lands underneath the radial baffles, lowered injection density along the radial baffles, etc. These items are discussed elsewhere in this section.

COMBINATION TESTING

As previously stated, it sometimes becomes desirable to evaluate a design concept or an injector modification from the standpoint of both performance and stability. Oxidizer axial feed passage splitters were first installed in the injector body as one of the stability augmentation devices incorporated into the PFRT injectors. In Block 2 injectors they remained as one of two such items retained from the PFRT design. Certain operational and fabrication problems, however, would be eliminated if these devices could be deleted from the injector. There was also an indication that a small performance gain might be realized by so doing. The splitters, consequently, were removed from injector 095, and the injector was tested. An 0.5-second performance increase, as expected,

was indicated. Although the injector was not subjected to stability testing during this series, later testing indicated no degradation of its stability characteristics attributable to the removal of the splitters.

In the search for methods of improving the performance of an injector without changing its basic stability characteristics, attention turns naturally to the injector body. Any design improvements here can be realized as savings in the overall engine system requirements. Hydraulic modifications were made on injector 089 in the ring grooves (double ring), the radial fuel feed ports (tapered), and the oxidizer axial feed passages (slots). Three tests were conducted with the injector in which confusing performance values were obtained. Respective c* efficiencies were 92.8, 91.2, and 90.8 percent. Some damage was sustained on the third test, causing the injector to be removed from the stand. It was discovered that during the process of installing the hydraulic modifications, inter-propellant mixing in the injector body had inadvertently been permitted. This may have been responsible for the 415-cps, buzz-type oscillations encountered during the performance evaluations. No stability evaluation tests were conducted.

Injector orifice pattern designs have always been considered a primary target in both performance and stability analyses. The success of the H-1 engine in both of these areas led to the incorporation of an H-1 type pattern in F-1 injector X058. Three tests were conducted, during which the performance averaged 91.1 percent Nc*. A bomb-induced instability persisted for 260 milliseconds, and a 375-cps buzz mode was observed on all three tests.

Another injector used to evaluate orifice patterns was injector 100, which employed a single-row cluster pattern (Fig. 19). The injector proved to be quite stable in its original configuration, damping a

bomb-induced instability in 9 milliseconds. Performance, however, was quite low, averaging less than 89 percent Nc*. After modification, the injector was better performing but less stable. Performance increased to 91.4 percent, but the injector required 153 milliseconds to damp a bomb disturbance. A comparatively low-amplitude, 400-cps oscillation was observed in all parameters during the latter series.

Still another area of F-1 injector design which offers possibilities for increasing performance and stability is the use of a different number of baffles on the injector face. Two such injectors, X017 and 099, were tested during this period. These are illustrated in Fig.14 and 6.

Injector X017 employed only four bipropellant cooled baffles forming four compartments. The orifice pattern was programmed for uniform injection density and was radially aligned. Fair performance, averaging 90.7 percent Nc*, was obtained from the injector. Although no stability evaluations were performed, some low-amplitude, 400-cps oscillations were encountered.

The outstanding injector to be tested during this period was injector 099. This injector had a baffle system forming twenty-five compartments. Similar to injector X017, the orifice pattern was radially aligned and programmed for uniform injection density.

Fourteen tests were conducted with this injector during the period. The unit was exposed to eight bombs, one of which was 100 grains in size. During the original series, performance averaged 91.9 percent Nc*. Four 13.5-grain bombs were damped in an average of 22 milliseconds, with the longest damp time being 30 milliseconds. The 100-grain bomb damped in 8 milliseconds. The injector gave indications of having a compatibility problem during this series and was returned for modification.

The 70-percent restrictor devices were removed from the outer fuel ring and the injector was placed back in test. Compatibility improved to acceptable standards, but a slight performance loss was experienced. The effect of the modification was exhibited in longer damp times. Although no VSC cutoffs occurred, one test required 295 milliseconds to damp. Reaction to the bombs appeared normal in the first 15 to 20 milliseconds, and then regressed into a low-amplitude, nonresurging type instability requiring a long damping period. In spite of this characteristic, the performance of the injector was high enough to warrant its evaluation in an engine.

[redacted]

COMPONENT TESTING

A summary of all F-1 component testing is contained in Tables 1 and 2.

[redacted]

TABLE 1

SUMMARY OF F-1 TEST SERIES TEST STAND 2A-1

Tests: 001

Injector Type: 5896-U3, U/N: 082

Description: See F-1 Injector Description Sheet Fig. 2

Objective: To obtain injector face temperatures

Test Results: Thermocouple data essentially the same as from previous test

Thrust Chamber Location	425-426-124	425-001-015
LOX Ring Temperature, F	850	875
Fuel Ring Temperature, F	320	330
Stainless Steel Outer Ring, F	200	200

Frequency Analysis: No bomb or instability; intermittent low-amplitude 400-cps buzz in chamber pressure

Tests: 002-004

Injector Type: 6104-J4, U/N: 089

Description: See F-1 Injector Description Sheet Fig. 3 , also Fig. 4

Objective: Performance evaluation

Test Results: The performance in three tests was inconsistent. In test 002, with a 2.84 mixture ratio, Nc* was 92.8 percent, in test 003, Nc* was 91.2 percent at a 2.44 mixture ratio, and in test 004 Nc* was 90.8 percent at a 2.39 mixture ratio. In test 004, six radial baffles were eroded at the base, at ring lands, and the primary and secondary fuel rings were burned through in two places in one outer baffle compartment.

Frequency Analysis: No bomb employed or instability incurred; low-amplitude (300 psi) 415-cps buzz observed in all parameters during all tests

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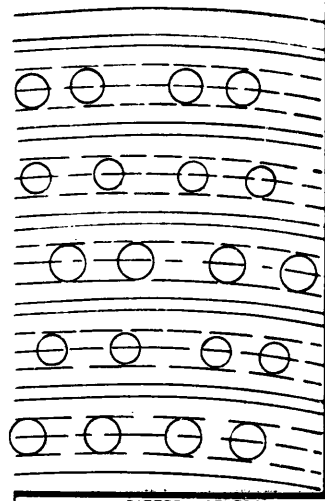
INJECTOR DESCRIPTION

UNIT 082, TYPE 5896-U3, S/N

ORIFICE PATTERN

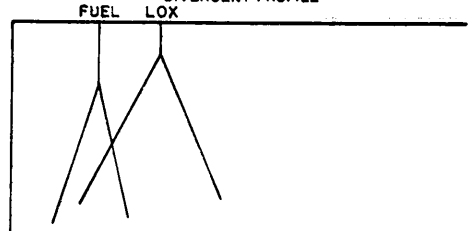


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.776	.228	96/104	.416	20°	1.14	.571	.258
-57	36.746	.209	96/104	.374	28.2	1.11	.349	.153
LOX holes next to baffles				.416	20°		.571	.284
-55	35.626	.281	88/96	.428	15°	1.17	.799	.274
-53	34.506	.209	88/96	.374	28.2	1.13	.349	.153
LOX holes next to baffles				.416	20°		.571	.284
-51	33.386	.281	80/88	.428	15°	1.19	.799	.274

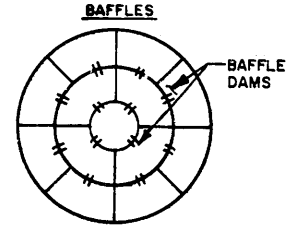
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.0	49.6
RING GROOVE DEPTH		
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	.711	
WALL GAP (OUTER ZONE)	.966	
Inj. Velocity (1500K)	55.7	165

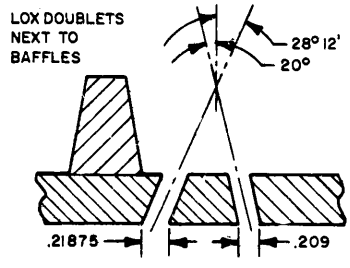
BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 inches

DIVERGENT PROFILE



BAFFLES





REMARKS: Like U/N 082, type 5833D5 except the injector has no splitters. It has 24 baffle dams and 164 fuel ring groove dams. The -9 LOX ring is .209 dia. at 20 degrees. No restricted flow in the outer fuel ring. The baffle-to-land gap is not sealed. 112 orifices as shown at left, except for outer LOX ring, were drilled to .21875 diameter. Percent excess fuel on wall = 2.23, percent film coolant = 4.6

Figure 2. Injector Description Unit 082, Type 5896-U3

[redacted]

[redacted]

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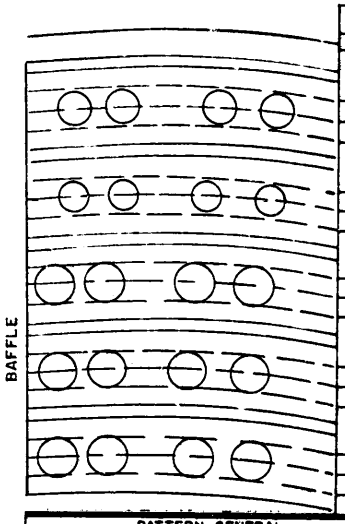
INJECTOR DESCRIPTION

ORIFICE PATTERN

UNIT 089, TYPE 6104-J4, S/N

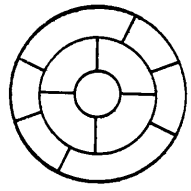


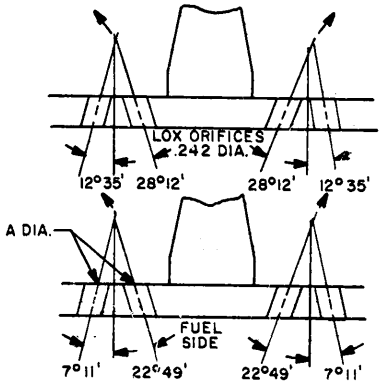
NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xjf
WALL	39.188							
-59	37.776	.228	96/104	.416	20°	1.14	.571	.258
-57	36.745	.209	96/104	.416	20°	1.14	.571	.284
-55	35.626	.281	88/96	.428	15°	1.17	.799	.274
-53	34.506	.242	88/96	.416	20°	1.13	.571	.238
-51	33.386	.281	80/88	.428	15°	1.17	.799	.274

PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	83.1	61.45
RING GROOVE DEPTH	deep	deep
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	.711	
WALL GAP (OUTER ZONE)	.966	
Inj. Velocity (1500K)	57	133

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 inches

BAFFLES





A DIA = .199 DIA. FOR -13 -29 -35 RINGS
= .281 DIA. FOR -17 -21 -25 -39 -43 -47 -51 -55

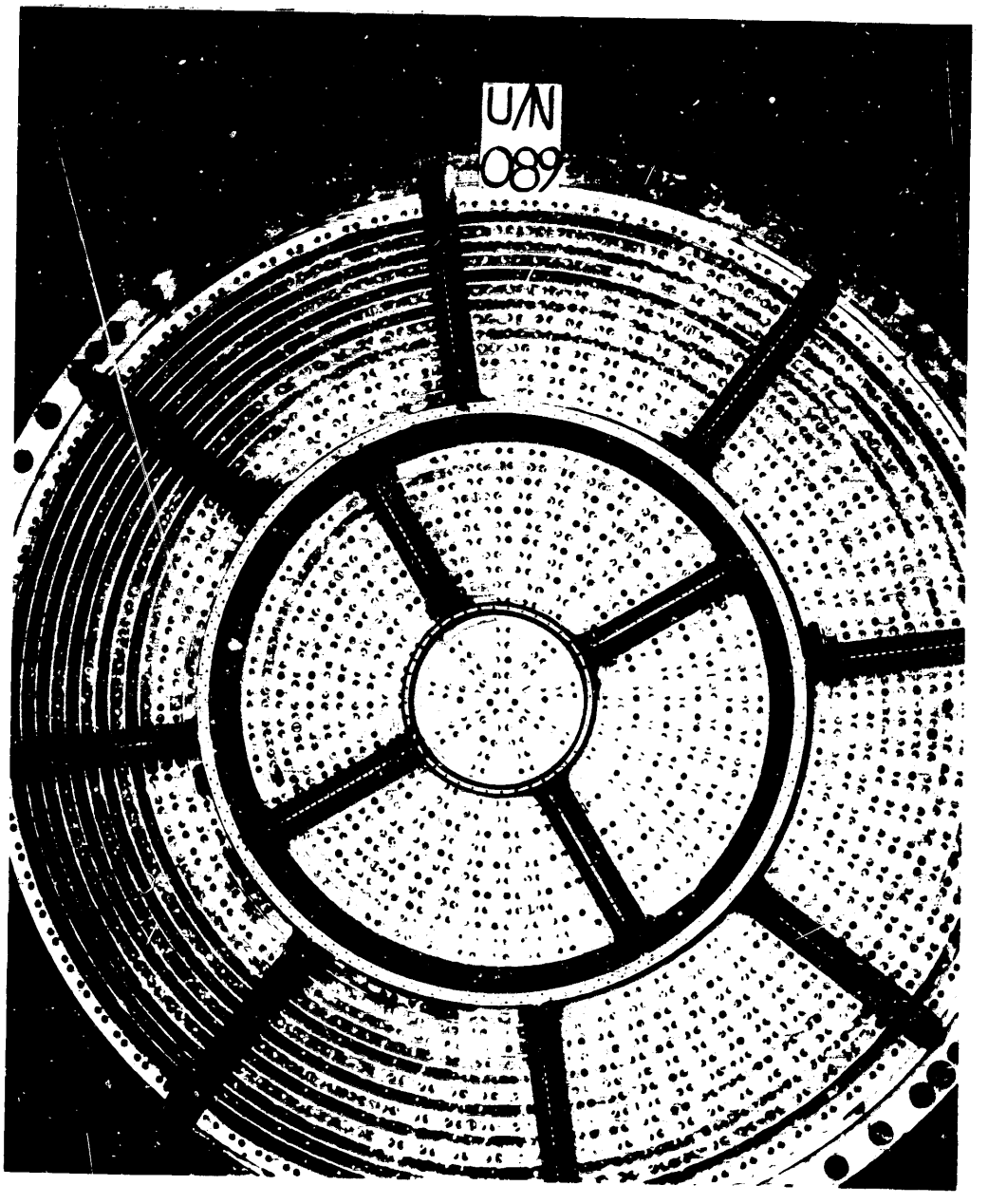
REMARKS: The -9, -11, -31, -33 LOX rings have orifices at .182 inch diameter and 40 degree included angle, and .209 inch diameter in the -57 ring. The remaining orifices are at .242 inch diameter and 40 degree except as shown at left. The oxidizer feed passages are enlarged and there are 82 oxidizer ring groove dams. Fuel orifices are as shown above and to left. The fuel ports are tapered at diameter transitions. There are secondary rings in fuel ring grooves except under baffle cans. Gap exists under radial baffles. There are 40 baffle can dams. Outer CRES ring on injector has been modified for attachment of a copper ring.

Percent film coolant = 4.6; excess fuel on wall = 5.17; 70 percent fuel flow in outer ring.

Figure 3. Injector Description, Unit 089, Type 6104-J4

[redacted]

[redacted]



1DB45-1/14/65-C1B

Figure 4 . Injector 089

[redacted]

TABLE 1

(Continued)

Tests:	005-006
Injector Type:	6106-K4, U/N: 099
Description:	See F-1 Injector Description Sheet Fig. 5 , also Fig. 6
Objective:	Checkout and performance evaluation
Test Results:	Checkout tests were satisfactory. Test 005 was conducted at a 3.1 mixture ratio. The Nc* was 92.4 for test 006 at a 2.5 mixture ratio. The solid-wall thrust chamber was seriously eroded during both tests.
Frequency Analysis:	No bomb employed or instability incurred
Tests:	007-010
Injector Type:	6110-F4, U/N: X049
Description:	See F-1 Injector Description Sheet Fig. 7 , also Fig. 8
Objective:	To evaluate the effect on performance and stability of increased oxidizer fan canting along the radial baffles by using oxidizer doublets next to the baffles which have orifices of 0.242-inch diameter (28.2 degrees) next to the baffles and 0.185-inch diameter (20 degrees) outboard.
Test Results:	Slight reduction in performance. Average Nc* with previous configuration was 90.9 percent; average Nc* with this configuration was 89.9 percent. Hardware inspection following test 010 revealed erosion of lands under several outer radial baffles.
Frequency Analysis:	No bomb was employed in test 007. Steady-state data indicated 420 cps in chamber pressure at 500-psi peak to peak, in LOX injection at 100-psi peak to peak, and in fuel manifold at 200-psi peak to peak. In test 008 the bomb-induced instability damped in 11 milliseconds without resurging. Steady-state data indicated 410 cps in chamber pressure at 350-psi peak to peak, 420 cps in LOX injection at 150-psi peak to peak, and 420 cps in fuel injection at 200-psi peak to peak. In test 009 two bombs were employed. Both disturbances damped in 4 milliseconds without resurging. Steady-state data indicated 410 cps in chamber pressure at 500-psi peak to peak, 420 cps at fuel injection at 200-psi peak to peak, 420 cps at LOX injection at 150-psi peak to peak. In test 010 two bombs were employed. The disturbances damped in 5 and 6 milliseconds without resurging. Steady-state data indicated 410 cps in chamber pressure at 500-psi peak to peak, 400 cps in fuel injection at 200-psi peak to peak, and 420 cps in LOX injection at 150-psi peak to peak.

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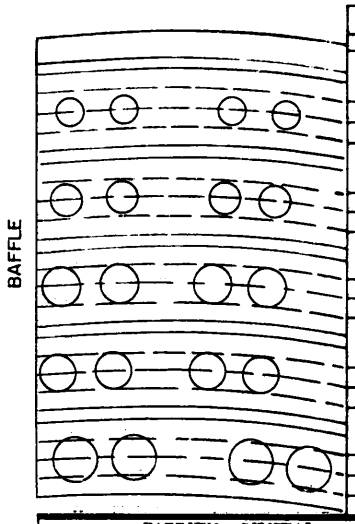
INJECTOR DESCRIPTION

UNIT 099, TYPE 6106-K4, S/N _____

ORIFICE PATTERN

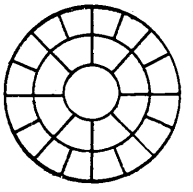


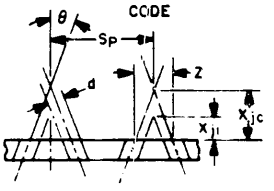
NO.	D	d	GROUP	Z	℄	Sp	Xjc	Xji
WALL	39.188							
-59	37.776	.221	80/96	.416	20	1.24	.571	.268
-57	36.746	.237	80/96	.416	20	1.20	.571	.218
-55	35.626	.281	80/96	.428	15	1.17	.799	.274
-53	34.506	.250	80/96	.416	20	1.13	.571	.228
-51	33.386	.323	64/80	.428	15	1.23	.799	.196

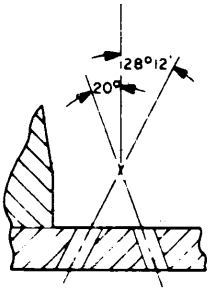
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	81.0	59.9
RING GROOVE DEPTH	.538	.538
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	.711	
INJECTION VEL. (1500K)	58	136
WALL COOLANT, %	3.0	

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	25
BAFFLE CONSTRUCTION	Wide base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 inches
Baffle Area (in.^{2})	3.56

BAFFLES







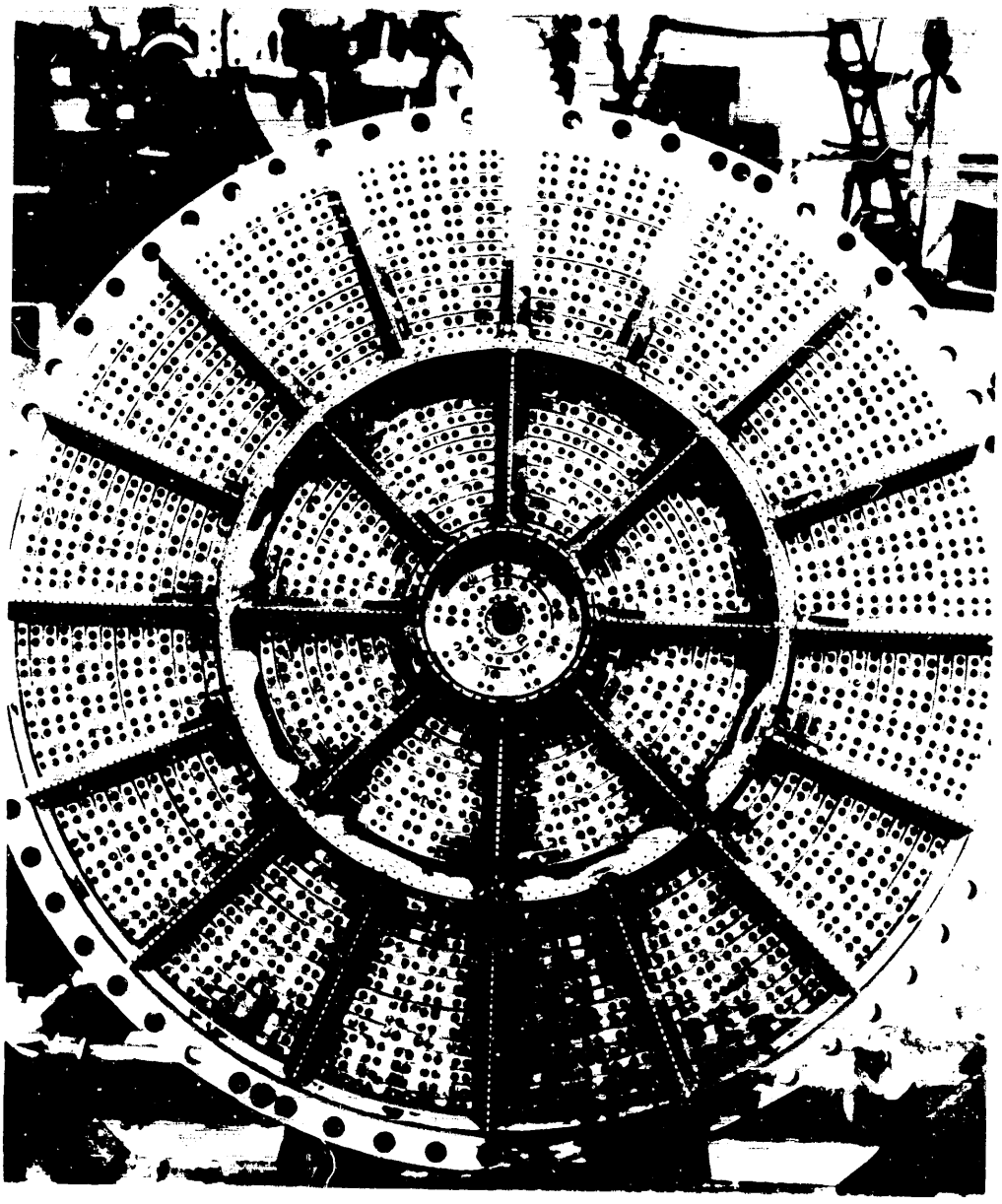
OXID. DOUBLETS NEXT TO RADIAL BAFFLES EXCEPT AS NOTED.

REMARKS: The 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 5. Injector Description, Unit 099, Type 6106-K4

[redacted]

[redacted]



1DB41-1/14/65-C1D

Figure 6 . Injector 099

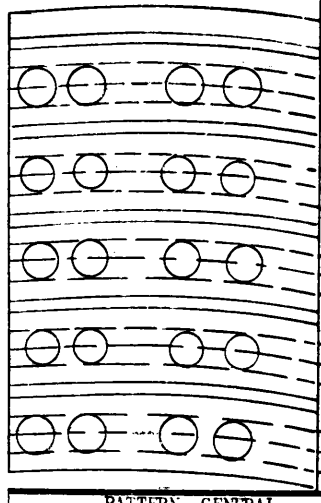
[redacted]

[redacted]

INJECTOR DESCRIPTION

UNIT X 049, TYPE 6110-F4, S/N _____

ORIFICE PATTERN

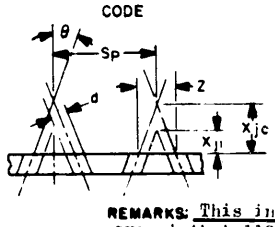


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.776	.228	96/104	.416	20	1.14	.571	.258
-57	36.746	.209	96/104	.416	20	1.11	.571	.284
-55	35.626	.281	88/96	.428	15	1.17	.799	.274
-53	34.506	.242	88/96	.416	20	1.13	.571	.238
-51	33.386	.281	80/88	.428	15	1.17	.799	.274

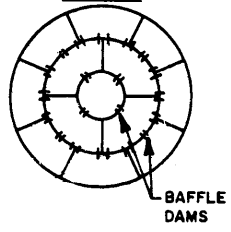
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.0	59.2
RING GROOVE DEPTH	.538	.538
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	.711	
INJECTION VEL. (1500K)	56	138
WALL COOLANT, %	3.2	

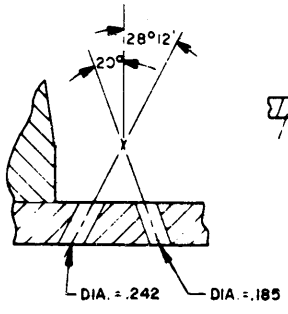
BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	WIDE BASE
BAFFLE COOLANT	FUEL
BAFFLE LENGTH	3 INCHES

CODE



BAFFLES





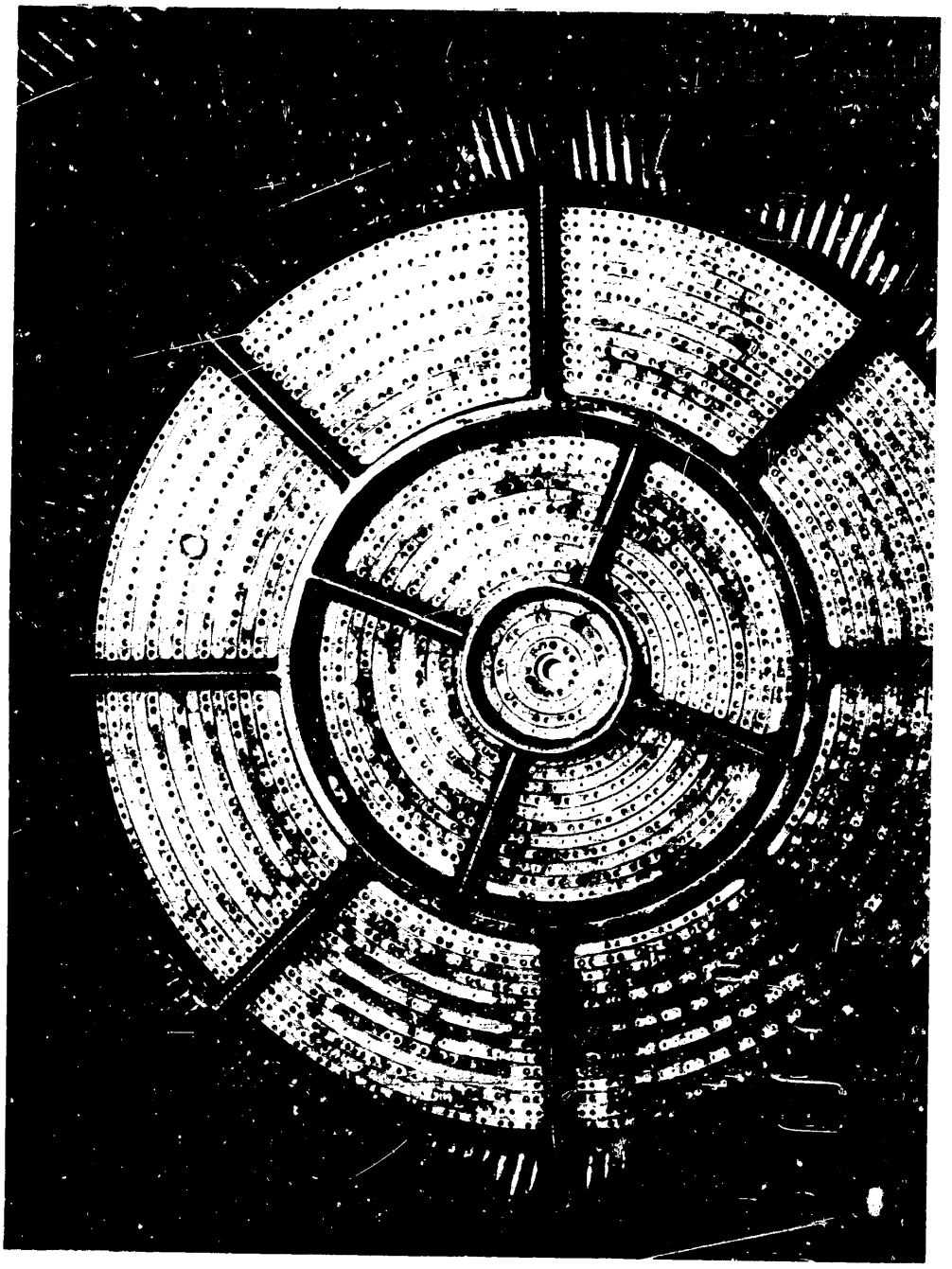
LOX doublets next to radial baffles except outer LOX ring

REMARKS: This injector is like X 049, 6105-F4 except that 112 LOX orifices adjacent to the radial baffles were changed to 0.242-inch diameter (see sketch at left). The LOX orifices in the outer ring and those adjacent to the circumferential baffles are 0.209-inch diameter at 20 degrees. The outer fuel ring is orificed for 70-percent flow. It has 40 baffle dams, 270 broached LOX splitters. The baffle-to-land gap is not sealed.

Figure 7. Injector Description, Unit X049, Type 6110-F4

[redacted]

[redacted]



1DB45-3/24/65-E6

Figure 8. Injector X049

[redacted]

TABLE 1

(Concluded)

Tests:	011-014
Injector Type:	5885-R4 U/N: 098
Description:	See F-1 Injector Description Sheet Fig. 9 , also Fig. 10
Objective:	To evaluate performance and stability of high LOX body differential pressure. The LOX feed area was restricted from 85.2 to 61.5 sq in. with flow restrictors on the back side of LOX axial passages.
Test Results:	The average Nc* was 92.1 percent. Test 011 was satisfactory with no bomb. In test 012, the bomb-induced instability damped in 11 milliseconds without resurging. In test 013 the bomb was blown out. In test 014 the bomb-induced instability damped in 45 milliseconds with 5 cycles of resurges. About 700 milliseconds after the bomb initiation, a fire occurred in the LOX dome area resulting in burning of the LOX dome, fuel manifold, injector, and a part of the thrust chamber.
Frequency Analysis:	In test 012 steady-state frequency of 400 cps was noted in the chamber pressure at 250-psi peak to peak. The same frequency was observed in test 013 in the chamber pressure at 150-psi peak to peak. Steady-state amplitudes in test 014 were below 100-psi peak to peak.

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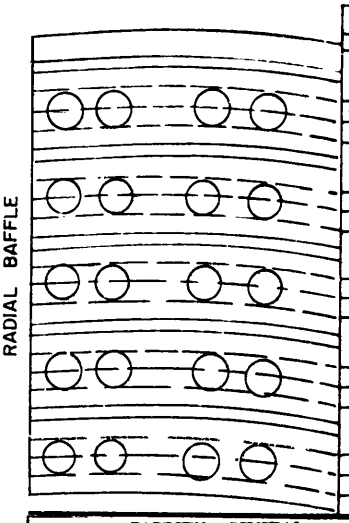
INJECTOR DESCRIPTION

UNIT 098, TYPE 5885-R4, S/N _____

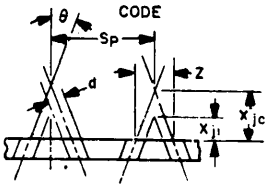
ORIFICE PATTERN



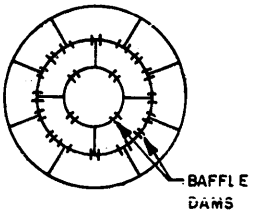
NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-39	37.776	.228	96/104	.416	20°	1.14	.571	.258
-37	36.746	.209	96/104	.416	20°	1.14	.571	.284
-35	35.626	.281	88/96	.428	15°	1.17	.799	.274
-33	34.506	.242	88/96	.416	20°	1.13	.571	.238
-31	33.386	.281	80/88	.428	15°	1.19	.799	.274

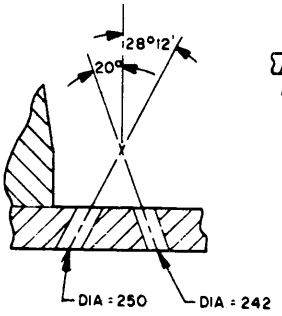
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.0	61.8
RING GROOVE DEPTH	.538	.538
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	.711	
INJECTION VEL. (1500K)	56	132
WALL COOLANT, %	3.2	

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 inches



BAFFLES





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

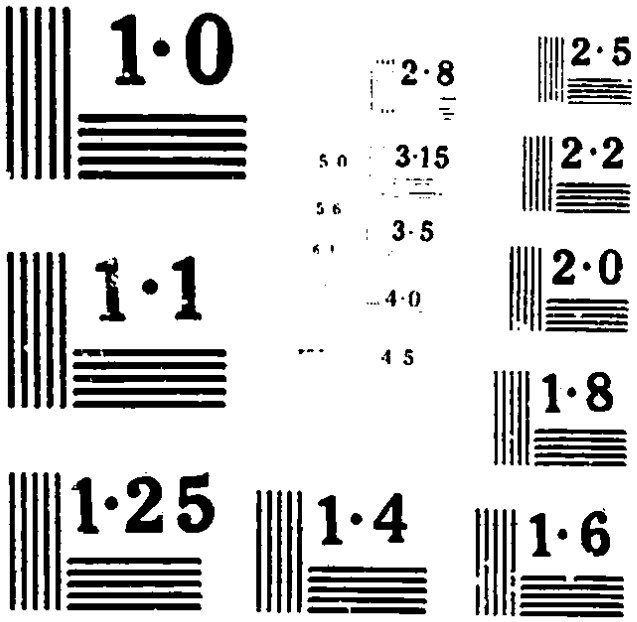
REMARKS: This injector has the FRT pattern. It has 286 LOX splitters (crimped, spoon type). The arrangement of the LOX orifices next to the radial baffles in rings -53, -49, -45, -41, -37, -27, -19, and -15 is shown in the sketch at the left. The outer fuel ring is orificed for 70 percent flow. The baffle-to-land gap is not sealed. New bomb bosses are located at 225 degree and 135 degree locations. The LOX axial feed area was reduced from 85.2 to 61.8 sq in.

Figure 9. Injector Description, Unit 098, Type 5885-R4

[redacted]

1DB45-2/23/65-C2C

Figure 10 . Injector 098, Fire Damaged



NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

TABLE 2

SUMMARY OF F-1 TEST SERIES TEST STAND 2A-2

Tests:	001-002
Injector Type:	5881-04 U/N: 084
Description:	See F-1 Injector Description Sheet Fig. 11, also Fig. 12
Objective:	Evaluate performance with the radial baffle coolant orifices plugged
Test Results:	No appreciable change in performance. Nc* with previous configuration was 91.2 percent; 91.2 percent with this configuration. Radial baffles burned during second test.
Frequency Analysis:	No bomb employed or instability incurred; low-amplitude, 360-cps buzz in fuel injection parameters and in chamber pressure during test 001; oscillations were not apparent in test 002, but the mixture ratio was 1.30.
Tests:	003-005
Injector Type:	6111-P4, U/N: X017
Description:	See F-1 Injector Description Sheet Fig. 13 , also Fig. 14
Objective:	Checkout and performance evaluation
Test Results:	Test 003 was satisfactory. Test 004 was terminated because of a LOX tank pressurizing regulator malfunction. Nc* for test 003 was 90.5 percent, and 91.0 percent for test 005.
Frequency Analysis:	No bomb employed or instability incurred; there were some low-amplitude, 400-cps oscillations in LOX, fuel, and chamber pressure.

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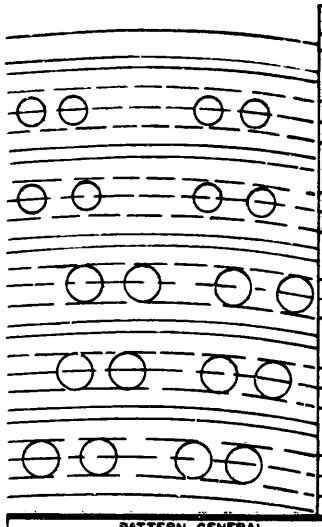
[redacted]

INJECTOR DESCRIPTION

ORIFICE PATTERN

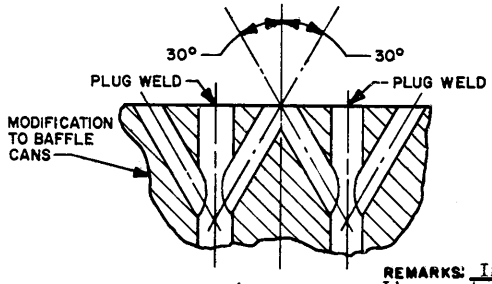
UNIT 084, TYPE 5881-04, S/N



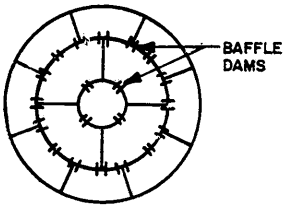
NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.776	.228	96/104	.416	20°	1.14	.571	.258
-57	36.746	.209	96/104	.416	20°	1.11	.571	.284
-55	35.620	.281	88/96	.428	15°	1.17	.799	.274
-53	34.506	.242	88/96	.416	20°	1.13	.571	.238
Except LOX holes (.209) next circumferential baffle								
-51	33.386	.281	80/88	.428	15°	1.17	.799	.274

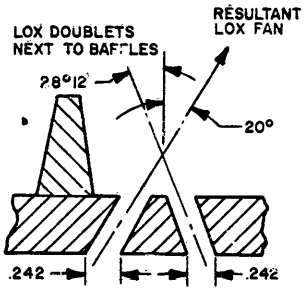
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.1	61.4
RING GROOVE DEPTH		
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	.711	
WALL GAP (OUTER ZONE)	.916	
INJ VELOCITY (1500K)	55.7	133.0

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	WIDE BASE
BAFFLE COOLANT	NOTED
BAFFLE LENGTH	3 INCHES



BAFFLES



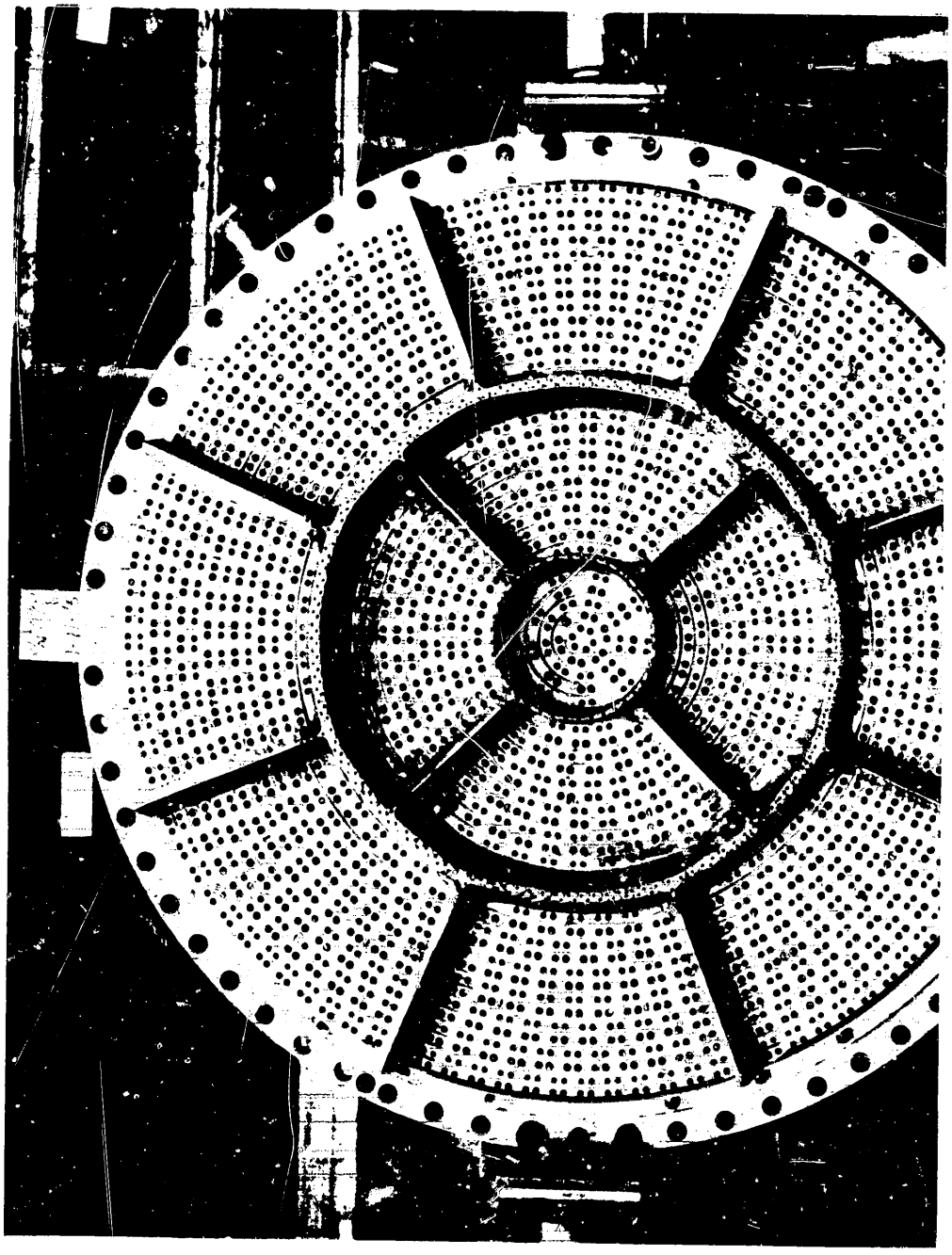


REMARKS: Injector is the same as U/N 084, 5881-L4 except for the baffle cans. The orifices in the radial baffles were plugged, leaving two open next to outer baffle can in both inner and outer radials and two open next to inner can on inner radial baffles. The baffle cans were modified as shown. The diameters of the impinging orifices in the outer can are 0.0635 inch; those in the inner can are 0.086 inch total baffle coolant area is the same. Diameter of doublets next to radial baffles in LOX rings -53, -49, -45, -41, -37, -27, -23, -19, and -15 is 0.242 inch. There are 40 baffle dams and no LOX splitters. Outer fuel ring is orificed for 70 percent flow. Percent film coolant = 3.2 Percent excess fuel on wall = .54.

Figure 11. Injector Description, Unit 084, Type 5881-04

[redacted]

[redacted]



1DB41-1/11/65-C1B

Figure 12 • Injector 084

[redacted]

[redacted]

INJECTOR DESCRIPTION

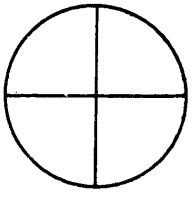
UNIT X-017 TYPE 6111-P4

GENERAL INFORMATION	FUEL	OXID.
ORIFICE AREA	87.803	60.478
INJ. VEL. (1500K)	53.98	135.09
RING GROOVE DEPTH	.538	.538
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)		
WALL GAP (OUTER ZONE)		
% FILM COOLANT	4.27 %	
EXCESS FUEL ON WALL	.254 %	

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	4
BAFFLE CONSTRUCTION	WIDE BASE
BAFFLE COOLANT	BIPROPELLANT
BAFFLE LENGTH	3 INCHES
BAFFLE AREA	

NO.	D	d	GROUPS	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-69	37.414	.234	84/89	.430	15°		.800	.365
-67	36.294	.234	84/89	.473	22.5°		.571	.288
-65	35.174	.277	84/89	.430	15°		.800	.285
-63	34.054	.234	84/89	.473	22.5°		.571	.288
-61	32.934	.266	84/89	.430	15°		.800	.306
-59	31.814	.221	84/89	.473	22.5°		.571	.304
-57	30.694	.257	84/89	.430	15°		.800	.322
-55	29.574	.213	84/89	.473	22.5°		.571	.314
-53	28.454	.302	56/63	.430	15°		.800	.238
-51	27.334	.218	56/63	.473	22.5°		.571	.308
-49	26.214	.290	56/63	.430	15°		.800	.261
-47	25.094	.238	56/63	.473	22.5°		.571	.283
-45	23.974	.277	56/63	.430	15°		.800	.285
-43	23.854	.228	56/63	.473	22.5°		.571	.296
-41	21.734	.261	56/63	.430	15°		.800	.315
-39	20.614	.213	56/63	.473	22.5°		.571	.314
-37	19.494	.296	36/43	.430	15°		.800	.250
-35	18.374	.250	36/43	.473	22.5°		.571	.269
-33	17.254	.290	36/43	.430	15°		.800	.261
-31	16.134	.234	36/43	.473	22.5°		.571	.288
-29	15.014	.261	36/43	.430	15°		.800	.315
-27	13.894	.213	36/43	.473	22.5°		.571	.314
-25	12.774	.290	24/30	.430	15°		.800	.261
-23	11.654	.234	24/30	.473	22.5°		.571	.288
-21	10.534	.261	24/30	.430	15°		.800	.315
-19	9.414	.204	24/30	.473	22.5°		.571	.325
-17	8.294	.234	24/30	.430	15°		.800	.365
-15	7.174	.209	16/30	.348	17°		.571	.233
-13	6.054	.250	16/30	.282	10°		.800	.091
-11	4.934	.302	4	.473	22.5°		.571	.206
-9	3.814	.272	4	.430	15°		.800	.294
-7	2.694		—					
-5	1.574		—					
-3								

BAFFLE DIAGRAM

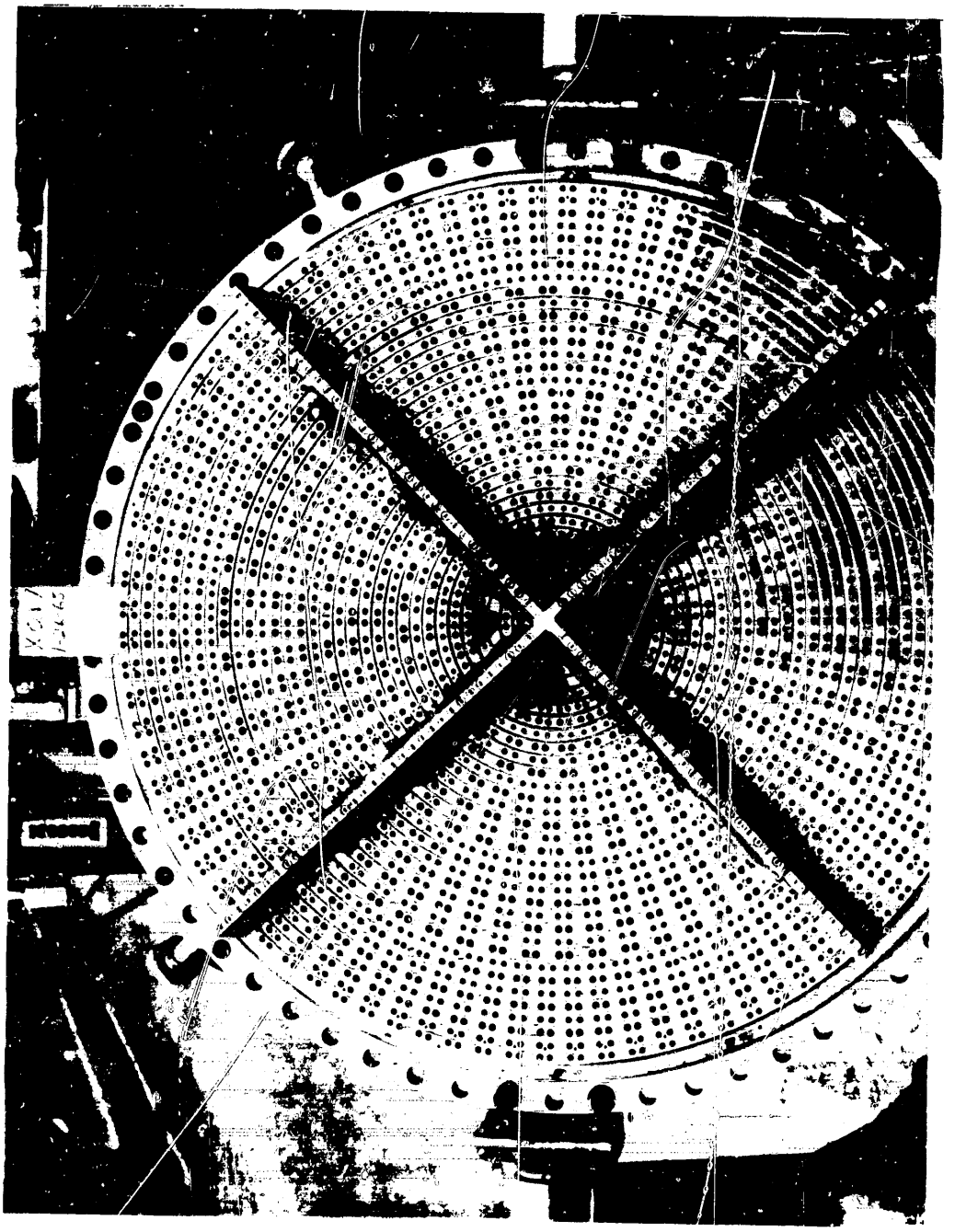


REMARKS: The orifices are programmed for uniform injector density. There are secondary rings in all fuel grooves. The fuel feed ports are tapered at the diameter transition points to improve flow distribution. The oxidizer feed passages are enlarged. The baffles are bipropellant cooled.

Figure 13. Injector Description, Unit X017, Type 6111-P4

[redacted]

[redacted]



1DB41-1/26/65-C1C

Figure 14. Injector X017

[redacted]

TABLE 2

(Continued)

Tests:	006
Injector Type:	5885-F4, U/N Engine Spare No. 1, P/N 209241
Description:	See F-1 Injector Description Sheet Fig. 15
Objective:	Check out NASA spare FRT injector
Test Results:	The Nc* was 91.3 percent, and the test was satisfactory.
Frequency Analysis:	No bomb was employed and no instability was observed. There were some low-amplitude (125-psi peak to peak), 400-cps oscillations in the LOX, fuel, and chamber pressure.
Tests:	007-008
Injector Type:	5885-S3, U/N: 095
Description:	See F-1 Injector Description Sheet Fig. 16 , also Fig. 17
Objective:	To verify the performance of Stand 2A
Test Results:	Two satisfactory tests were run. The performance in the tests was as follows: test 007, Nc* = 91.3 percent; test 008, Nc* = 91.2 percent. Based on these tests, the LOX flowmeter factor was determined to be 8.8033 lb/pip.
Frequency Analysis:	Steady-state data indicated LOX injection pressure oscillations with amplitudes to 150-psi peak to peak. There were some indistinct indications of 400-cps oscillations in LOX injection pressure.
Tests:	009-011
Injector Type:	6112-Q4, U/N: 100
Description:	See F-1 Injector Description Sheet Fig. 18 , also Fig. 19
Objective:	To evaluate the stability and performance characteristics of the injector
Test Results:	Three satisfactory tests were run. The performance in the tests was as follows: test 009, Nc* = 89.4 percent; test 010, Nc* = 88.8 percent; test 011, Nc* = 88.0 percent.
Frequency Analysis:	In test 011, the bomb induced a relatively low-amplitude disturbance which damped in 9 milliseconds. There was no evidence of a buzz mode in any of the tests.

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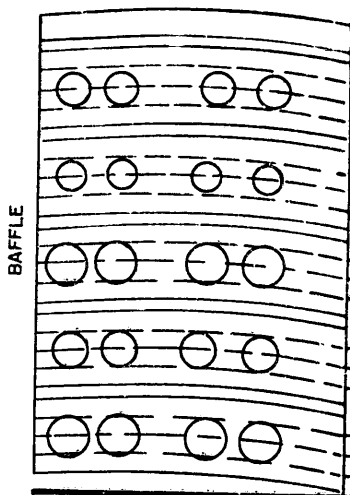
[redacted]

INJECTOR DESCRIPTION

Spare

UNIT Engine No. 1, TYPE 5885-F4, S/N _____

ORIFICE PATTERN

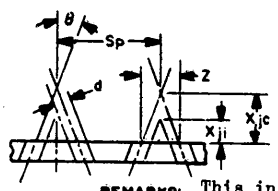


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.767	.228	96/104	.416	20	1.14	.571	.258
-57	36.746	.209	96/104	.416	20	1.11	.571	.284
-55	35.626	.281	88/96	.428	15	1.17	.799	.274
-53	34.506	.242	88/96	.416	20	1.13	.571	.238
(Except next to radial baffles)								
-51	33.386	.281	80/88	.428	15	1.19	.799	.274

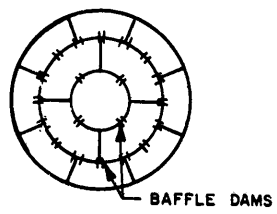
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.1	61.5
RING GROOVE DEPTH	.538	.538
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	.711	
INJECTION VEL. (1500 K)	56	133
WALL COOLANT, %	3.2	

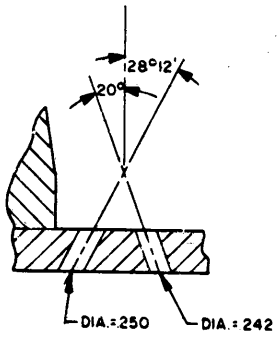
BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	WIDE BASE
BAFFLE COOLANT	FUEL
BAFFLE LENGTH	3 INCHES

CODE



BAFFLES





LOX DOUBLET NEXT TO RADIAL BAFFLE

REMARKS: This injector has the Block 2 orifice pattern. Canting of the LOX fans away from the radial baffles is accomplished by the design shown at the left. There are 270 broached LOX splitters, 40 baffle dams, and the outer fuel ring is orificed for 70 percent flow. The baffle-to-land gaps are not sealed. The injector has a cooled GSE boss.

Figure 15. Injector Description, Spare Engine No. 1, Type 5885-F4

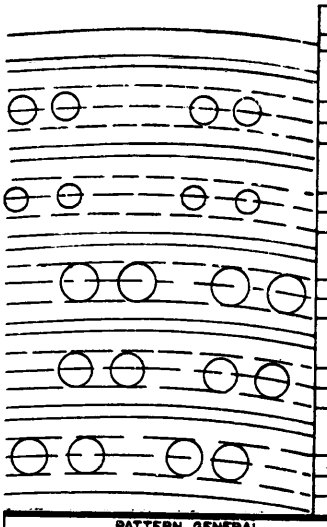
[redacted]

[redacted]

INJECTOR DESCRIPTION

UNIT 095, TYPE 5885-S3, S/N _____

ORIFICE PATTERN

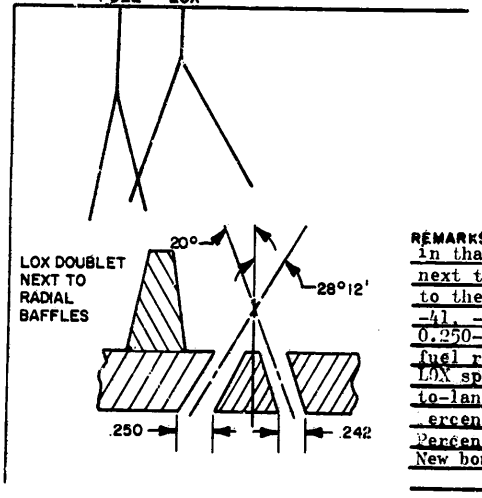


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.185							
-59	37.776	.228	96/104	.416	20°	1.14	.571	.258
-57	36.746	.209	96/104	.416	20°	1.11	.571	.284
-55	35.626	.281	88/96	.428	15°	1.17	.799	.274
-53	34.506	.242	88/96	.416	20°	1.13	.571	.238
-51	33.386	.281	80/88	.428	15°	1.19	.799	.274

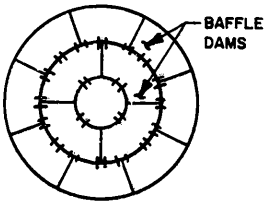
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.0	61.8
RING GROOVE DEPTH	.538	.538
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	.711	
WALL GAP (OUTER ZONE)	.966	
INJ. VELOCITY (1500K)	55.7	132.2

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	WIDE BASE
BAFFLE COOLANT	FUEL
BAFFLE LENGTH	3 INCHES

DIVERGENT PROFILE



BAFFLES

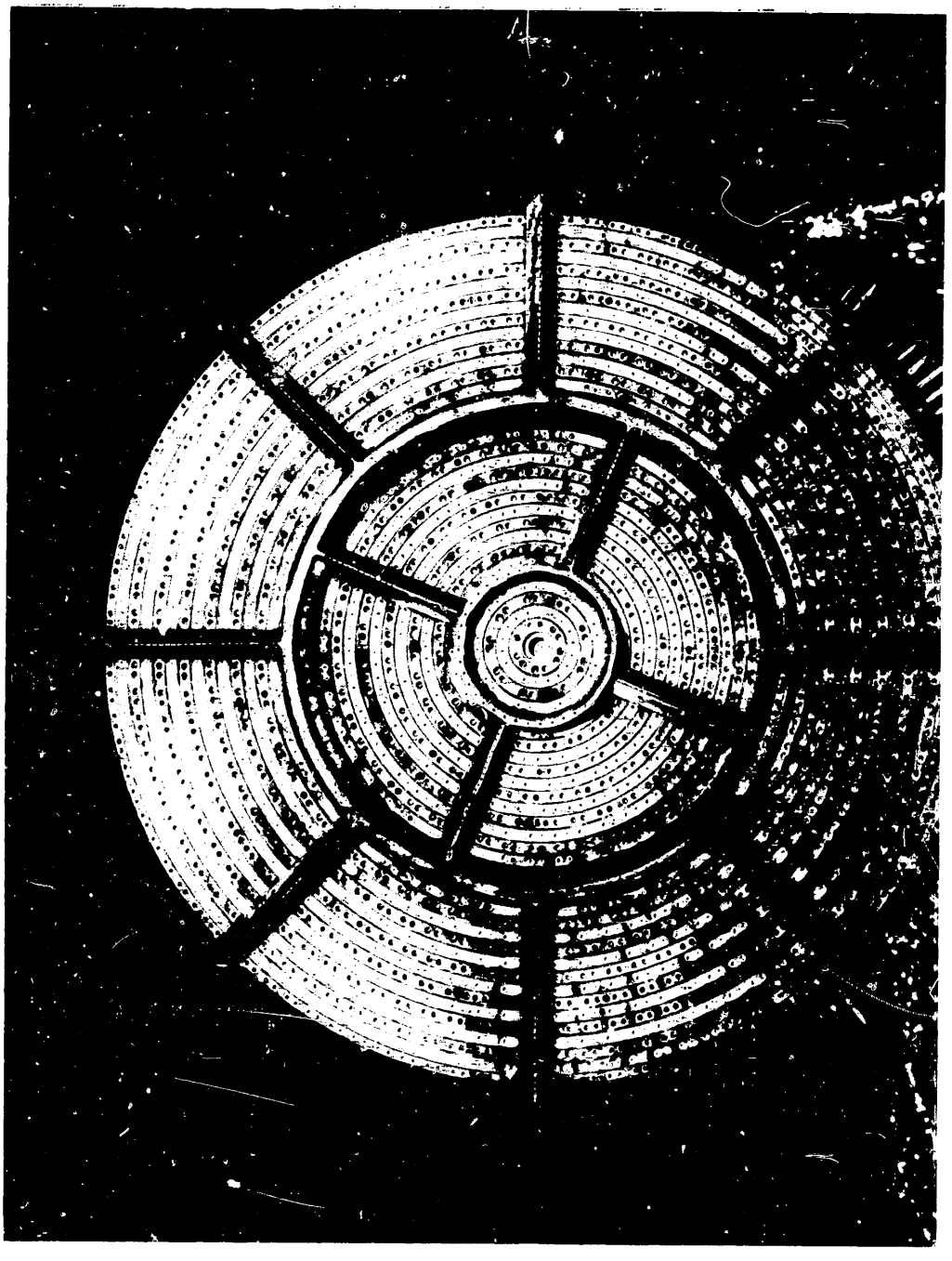


REMARKS: Ths injector differs from X053, 5881-M3 in that it has 286 LOX splitters and the orifice next to the baffle of each LOX doublet adjacent to the radial baffles in rings -53, -49, -45, -41, -37, -27, -23, -19, -15 are drilled out to 0.250-inch diameter at 28 degrees 12 minutes. Outer fuel ring orificed for 70 percent flow. The LOX splitters are a crimped spoon type. Baffle-to-land gap not sealed.
Percent film coolant = 3.2
Percent excess fuel on wall = .51
New bomb bosses at 225 and 135-degree locations.

Figure 16. Injector Description, Unit 095, Type 5885-S3

[redacted]

[redacted]



1DB45-3/31/65-E1

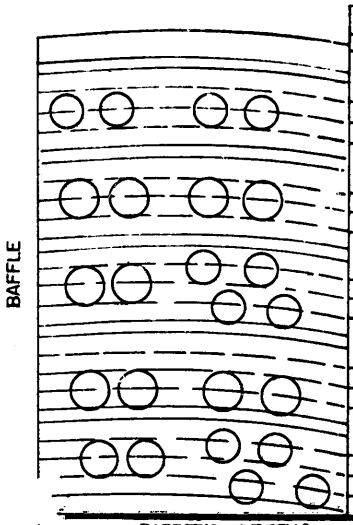
Figure 17. Injector 095

[redacted]

INJECTOR DESCRIPTION

UNIT 100, TYPE 6112-Q4, S/N _____

ORIFICE PATTERN

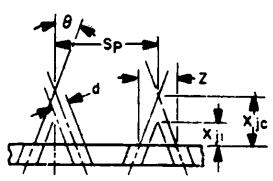


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xjp
WALL	39.188							
-59	37.776	.177	96	.428	15	1.09	.799	.468
-57	36.746	.199	96	.416	20	1.05	.572	.298
	35.826	.177	80	.428	15	1.02	.799	.468
-55	35.626	.250	16	.428	15	—	.799	.332
	35.398	.177	72	.428	15	1.10	.799	.468
-53	34.506	.199	88	.416	20	1.07	.572	.298
	33.584	.177	72	.428	15	1.03	.799	.468
-51	33.386	.250	16	.428	15	—	.799	.332
	33.158	.177	64	.428	15	1.12	.799	.468

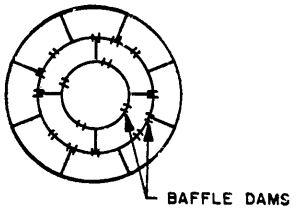
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	68.7	44.4
RING GROOVE DEPTH	.538	.538
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	.711	
INJECTION VEL. (1500K)	69	184
WALL COOLANT, %	2.46	

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	WIDE BASE
BAFFLE COOLANT	FUEL
BAFFLE LENGTH	3 INCHES

CODE

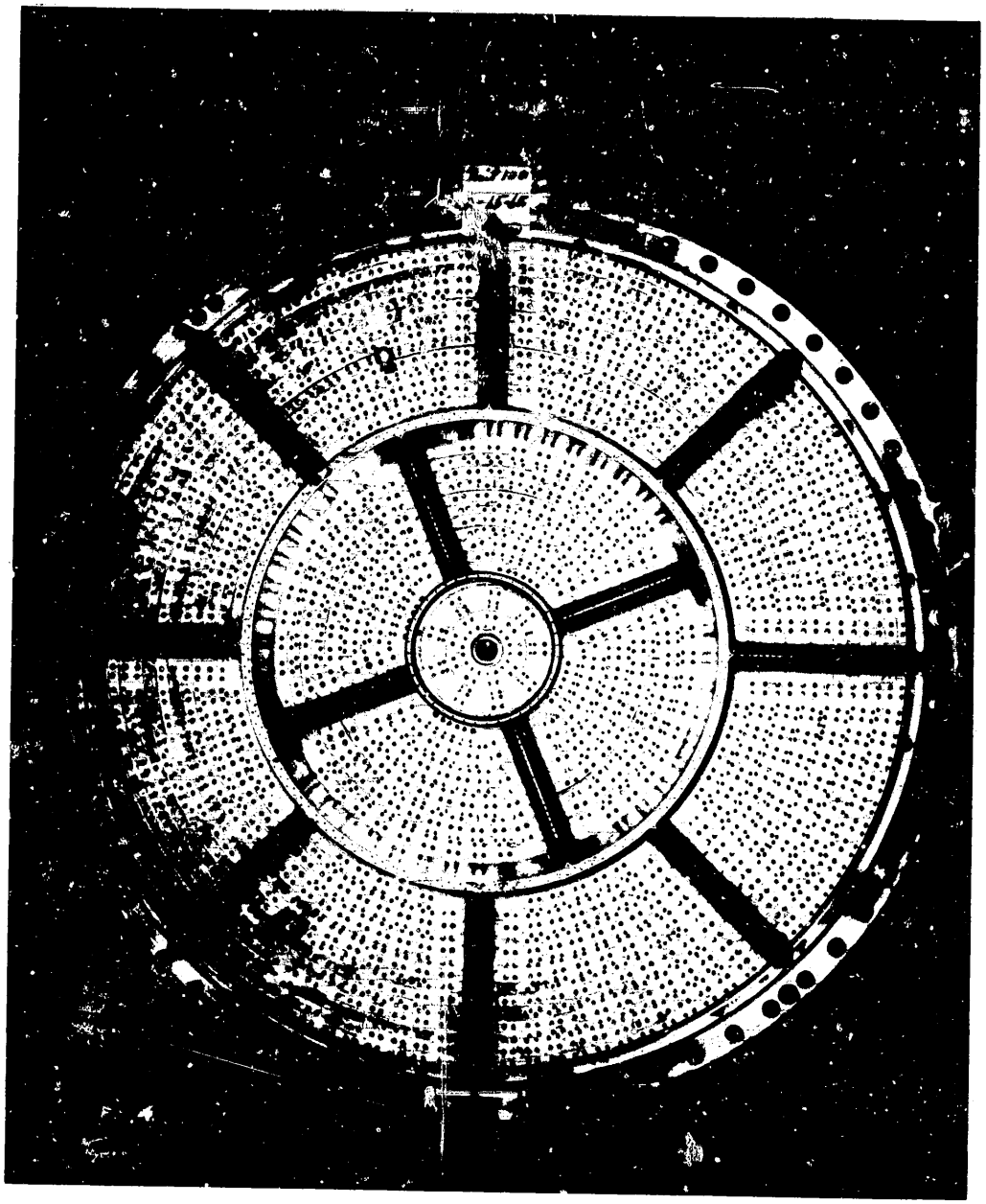


BAFFLES



REMARKS: The basic orifice pattern consists of double rows of fuel orifices per ring and single rows of LOX orifices per ring, with the exception that there are single rows of fuel orifices on the outer fuel ring and along the radial baffles. The fuel doublets are drilled at 30 degrees included angle and the LOX doublets at 40 degrees included angle. There are 164 fuel ring dams and 40 baffle dams. The fuel flow in the outer ring is reduced to 70 percent and the baffle-to-land gap is not sealed. The equivalent total fuel orifice area is 67.3 sq in. It has GSE boss.

Figure 18. Injector Description, Unit 100, Type 6112-Q4



1DB41-2/15/65-C1B

Figure 19. Injector 100

TABLE 2

(Continued)

Tests:	012-014
Injector Type:	5898-W3, U/N: X054
Description:	See F-1 Injector Description Sheet Fig. 20
Objective:	To determine performance and stability characteristics of injector with oxidizer and fuel fans canted away from baffles
Test Results:	Three satisfactory tests were run. The performance in the tests was as follows: test 012, Nc* = 91.1 percent; test 013, Nc* = 91.0 percent; test 014, Nc* = 90.2 percent.
Frequency Analysis:	Steady-state data indicated oscillations to 150-psi peak to peak, but no 400-cps buzz. The two bomb tests, 013 and 014, resulted in disturbances accompanied by a resurge. The respective damp times were 36 and 32 milliseconds. These damp times were significantly lengthened because of the high noise level of the injector (30 to 40 g peak to peak).
Tests:	015-018
Injector Type:	6109-V, U/N: F1002
Description:	See F-1 Injector Description Sheet Fig. 21
Objective:	To determine the performance and stability characteristics of the Block 1 injector modified with close impinging oxidizer triplets
Test Results:	Test 015 was limited to ignition only. Tests 016, 017, and 018 were satisfactory. The performance in the tests was as follows: test 016, Nc* = 89.3 percent; test 017, Nc* = 89.2 percent; test 018, Nc* = 89.0 percent.
Frequency Analysis:	Steady-state data indicated low oscillations, but no buzz. The test 018 bomb disturbance damped in 15 milliseconds.

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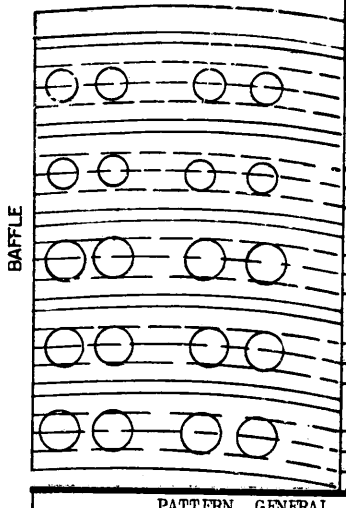
INJECTOR DESCRIPTION

UNIT X-054, TYPE 5898-W3, S/N _____

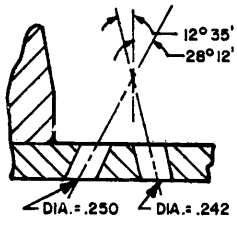
ORIFICE PATTERN



NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.776	.228	96/104	.416	20	1.14	.571	.258
-57	36.746	.209	96/104	.416	20	1.11	.571	.284
-55	35.626	.281	88/96	.428	15	1.17	.799	.274
(Except fuel holes next to radial baffles)								
-53	34.506	.242	88/96	.416	20	1.13	.571	.238
(Except LOX holes next to radial baffles are .250 dia.)								
-51	33.386	.281	80/88	.428	15	1.19	.799	.274

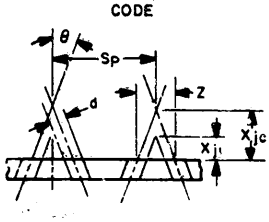
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	83.6	61.8
RING GROOVE DEPTH	.538	.538
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	.711	
INJECTION VEL. (1500K)	57	131
WALL COOLANT, %	3.2	

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	WIDE BASE
BAFFLE COOLANT	FUEL
BAFFLE LENGTH	3 INCHES

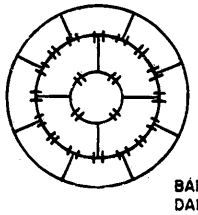


LOX DOUBLET NEXT TO RADIAL BAFFLE EXECT OUTER RING AND BAFFLE CANS

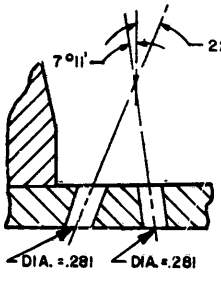
CODE



BAFFLES



BAFFLE DAMS



FUEL DOUBLETS NEXT TO RADIAL BAFFLES. EXCEPT .199 DIA. ON RINGS - 35, 13 AND .228 DIA. ON -59

REMARKS: This injector has the basic FRT orifice pattern with the exception that the fans from the fuel doublets next to the radial baffles are canted to match the canted LOX fans next to the radial baffles (see figures at left). There are 302 splitters (spooned) and 40 baffle dams. The outer fuel ring is orificed for 70 percent flow and the baffle-to-land gaps are not sealed.

Figure 20. Injector Description, Unit X054, Type 5898-W

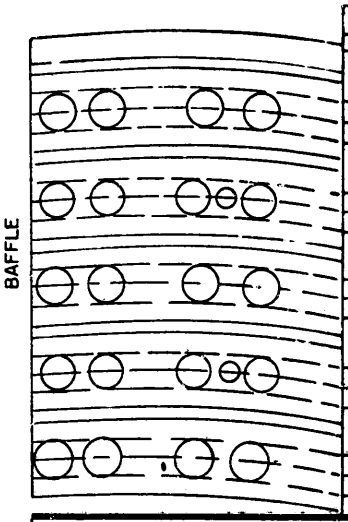
[redacted]

[redacted]

INJECTOR DESCRIPTION

UNIT F-1002, TYPE 6109V, S/N

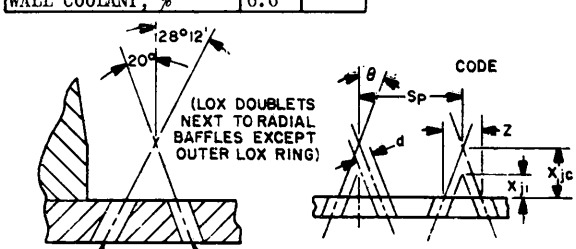
ORIFICE PATTERN



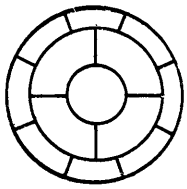
NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.776	.228	96/10[illegible]	.416	20	1.14	.571	.258
-57	36.746	.209	87/104	.416	28.2	1.11	.388	.193
		.185		.416		SH. HDS. ADJACENT TO RADIALS ARE PLUGGED		
-55	35.620	.228	88/96	.416	20	1.17	.571	.258
-53	34.506	.209	88/96	.416	28.2	1.13	.388	.193
		.185		.416				
		ORIFICES AT RADIALS CANTED AS SHOWN						
-51	33.386	.228	80/84	.416	20	1.17	.571	.258

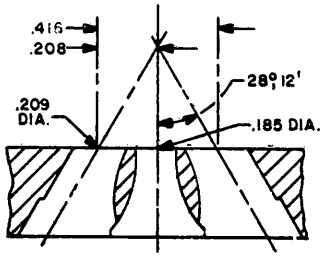
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	59.5	57.7
RING GROOVE DEPTH	.538	.538
RING MATERIAL	CU	CU
WALL CAP(FUEL RING)	.711	
INJECTION VEL. (1500K)	80	142
WALL COOLANT, %	6.6	

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	WIDE BASE
BAFFLE COOLANT	FUEL
BAFFLE LENGTH	3 INCHES



BAFFLES





LOX TRIPLETS (GENERAL)

REMARKS: All LOX clusters are triplets except for the LOX doublets (0.209-inch diameter) next to the radial baffles (sketch at left) and the doublets next to the baffle cans which have 0.120-inch-diameter orifices. The injector body has the hydraulic Mod 2.

Figure 21. Injector Description, Unit F-1002, Type 6109-V

[redacted]

TABLE 2

(Continued)

Tests:	019
Injector Type:	5885-G4, U/N: 097
Description:	See F-1 Injector Description Sheet Fig. 22
Objective:	To evaluate the FRT injector with 6-inch baffles
Test Results:	The Nc* = 93.3 percent and the test was satisfactory. Some baffle erosion occurred during the test. This erosion was most predominant on the inner radial baffles.
Frequency Analysis:	Test data indicated 350-cps buzz in fuel parameters at nearly 200-psi peak to peak.
Tests:	020-027
Injector Type:	6106-K4, U/N: 099
Description:	See Injector Description Sheet Fig. 5
Objective:	To evaluate the performance, stability, and compatibility characteristics of a 25-compartment modified Block 2 type injector
Test Results:	Eight satisfactory tests were run. The average Nc* for the tests was 91.9 percent with a deviation of ±0.4 percent. Test 025 was limited to ignition only. Lack of carbon was noted in the combustion zone, indicating a possible compatibility problem.
Frequency Analysis:	Instabilities induced by 13.5-grain bombs were damped in 21 and 18 milliseconds in tests 023 and 024. Two 13.5-grain, bomb-induced disturbances were damped in 18 and 30 milliseconds in test 026. In test 027, a single instability, induced by a 100-grain bomb, was damped in 8 milliseconds.

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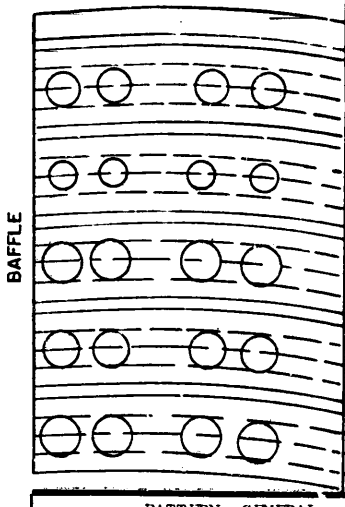
[redacted]

INJECTOR DESCRIPTION

ORIFICE PATTERN

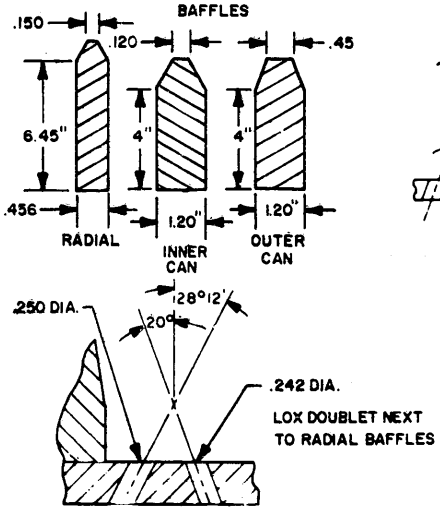
UNIT 097 , TYPE 5885-G4 , S/N _____

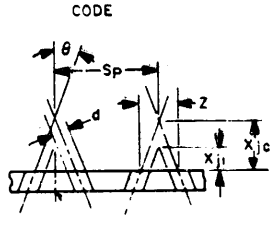


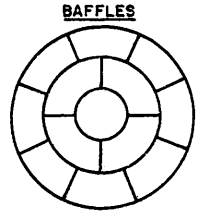
NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.776	.228	96/104	.416	20	1.14	.571	.258
-57	36.746	.209	96/104	.416	20	1.11	.571	.284
-55	35.626	.281	88/96	.428	15	1.17	.799	.274
-53	34.506	.242	88/96	.416	20	1.13	.571	.238
-51	33.386	.281	80/88	.428	15	1.19	.799	.274

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. (,00K)	56	132
WALL COOLANT, %	3.2	

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	WIDE BASE
BAFFLE COOLANT	FUEL
BAFFLE LENGTH	6 INCHES







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 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.

Figure 22. Injector Description, Unit 097, Type 5885-G4

[redacted]

TABLE 2

(Continued)

Tests:	028-030
Injector Type:	6114-T4, U/N: X021
Description:	See Injector Description Sheet Fig. 23 , also Fig. 24
Objective:	To evaluate the performance and stability characteristics of an 082B-type injector with small unlike doublets placed within the main pattern; to evaluate the durability characteristics of radial baffles which were slotted at the base to relieve ring stress
Test Results:	Three satisfactory tests were run. The average Nc* for the tests was 90.6 percent with a deviation of ±0.4 percent. Some injector damage occurred during test 030. This damage was limited to a very slight erosion of the LOX ring adjacent to the center can.
Frequency Analysis:	The bomb-induced instability in test 030 damped in 18 milliseconds without resurging. In all of the tests there was 500-cps buzzing with a maximum chamber pressure amplitude of 300 psi. Test 029 had a beat frequency in all systems. In the other tests a beat frequency occurred mainly in the fuel system.
Tests:	031
Injector Type:	6101-U4, U/N: X040
Description:	See Injector Description Sheet Fig. 25 , also Fig. 26
Objective:	To evaluate the performance and stability characteristics of an injector with close LOX impingement (76-degree included angle) and 6-inch baffles
Test Results:	The test was satisfactory. Nc* was 90.9 percent. Some baffle erosion occurred during the test. One-inch-deep erosions occurred on the center can, and the outer edge of the outer radial baffles was also eroded.
Frequency Analysis:	The bomb-induced instability in this test persisted into chamber pressure decay. In comparison to past instabilities with this injector, the amplitude of this disturbance was low. Prior to the bomb, the system buzzed at 500 cps, 250 psi in chamber pressure.

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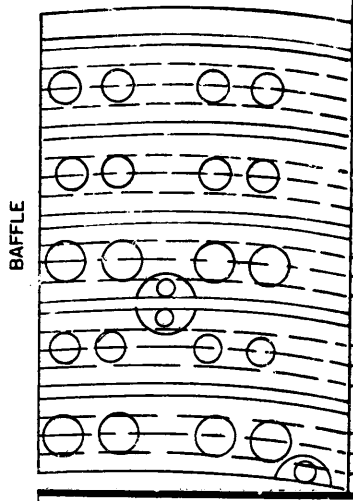
[redacted]

INJECTOR DESCRIPTION

ORIFICE PATTERN

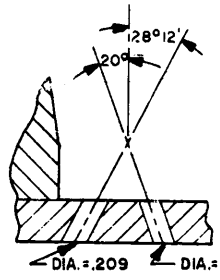
UNIT X021, TYPE 6114-T4, S/N



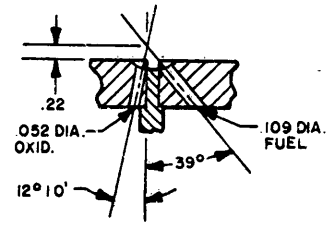
NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.776	.228	96/104	.416	20°	1.14	.571	.258
-57	36.746	.209	96/104	.374	28.2°	1.11	.349	.153
-55	35.626	.281	88/96	.428	15°	1.17	.799	.274
	35.20	.109	32					
	34.91	.052	32					
-53	35.506	.209	88/96	.374	28.2°	1.13	.349	.153
-51	33.386	.281	80/88	.428	15°	1.17	.799	.274
	32.96	.109	24					

PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	86.4	49.5
RING GROOVE DEPTH	.538	.338
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	.711	
INJECTION VEL. (1500K)	55	164
WALL COOLANT, %	4.85	

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	WIDE BASE
BAFFLE COOLANT	FUEL
BAFFLE LENGTH	3 INCHES



LOX DOUBLETS NEXT TO RADIAL BAFFLE EXCEPT AS NOTED



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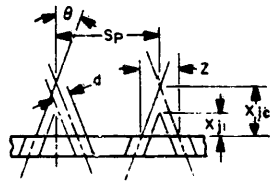
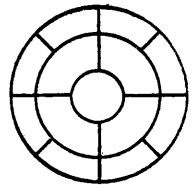


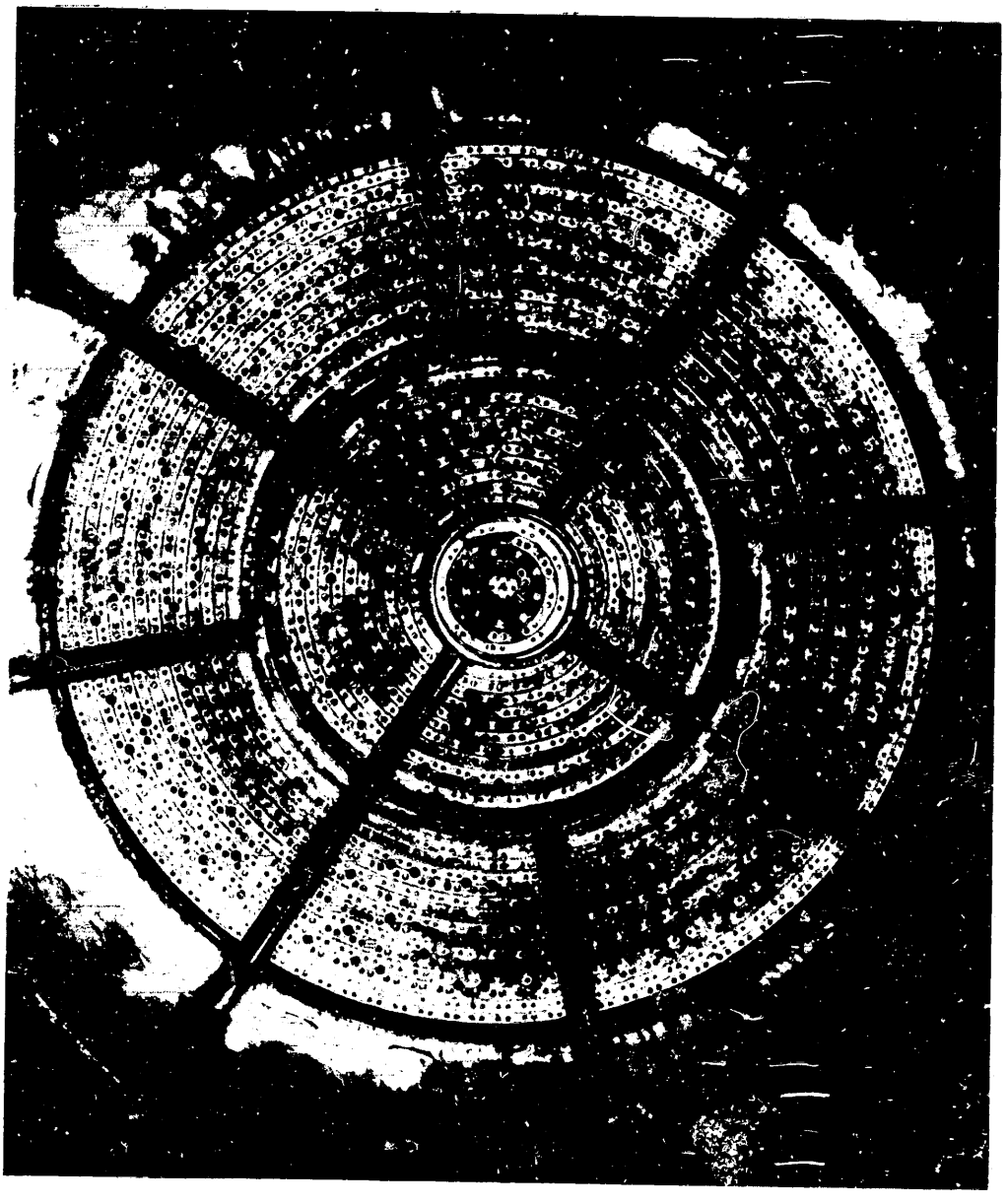
BAFFLES



REMARKS: Unlike doublets (146) which impinge over ring lands are provided as shown at the left. There are 13 unlike doublets in each outer compartment and 11 in each inner compartment. The design of the LOX doublets next to the radial baffles (except for the outer LOX ring) is shown at the left. There are 314 LOX splitters and 164 fuel ring dams.

Figure 23. Injector Description, Unit X021, Type 6114-T4

[redacted]



1DB45-3/3/65-E1

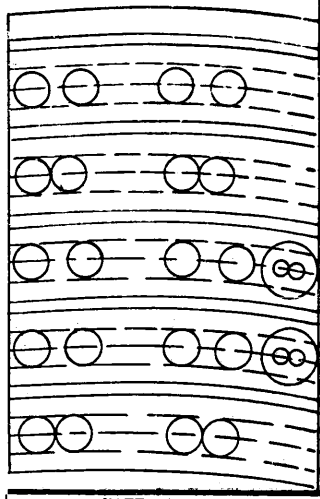
Figure 24. Injector X021

[redacted]

INJECTOR DESCRIPTION

UNIT X040, TYPE 6101-U4, S/N

ORIFICE PATTERN

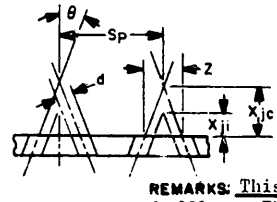


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.776	.228	96/104	.416	20°	1.14	.571	.258
-57	36.746	.238	96/104	.304	38°	1.11	.195	.042
-55	35.626	.281	88/96	.416	15°	1.17	.778	.252
-53	34.506	.238	88/96	.304	38°	1.13	.195	.042
-51	33.386	.281	80/88	.416	15°	1.17	.778	.252

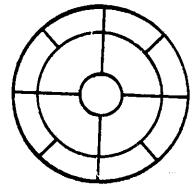
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	88.4	63.7
RING GROOVE DEPTH	.538	.338
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	.711	
INJECTION VEL. (1500K)	54	128
WALL COOLANT, %	4.4	

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	WIDE BASE
BAFFLE COOLANT	FUEL
BAFFLE LENGTH	6 INCHES

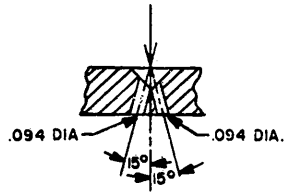
CODE



BAFFLES



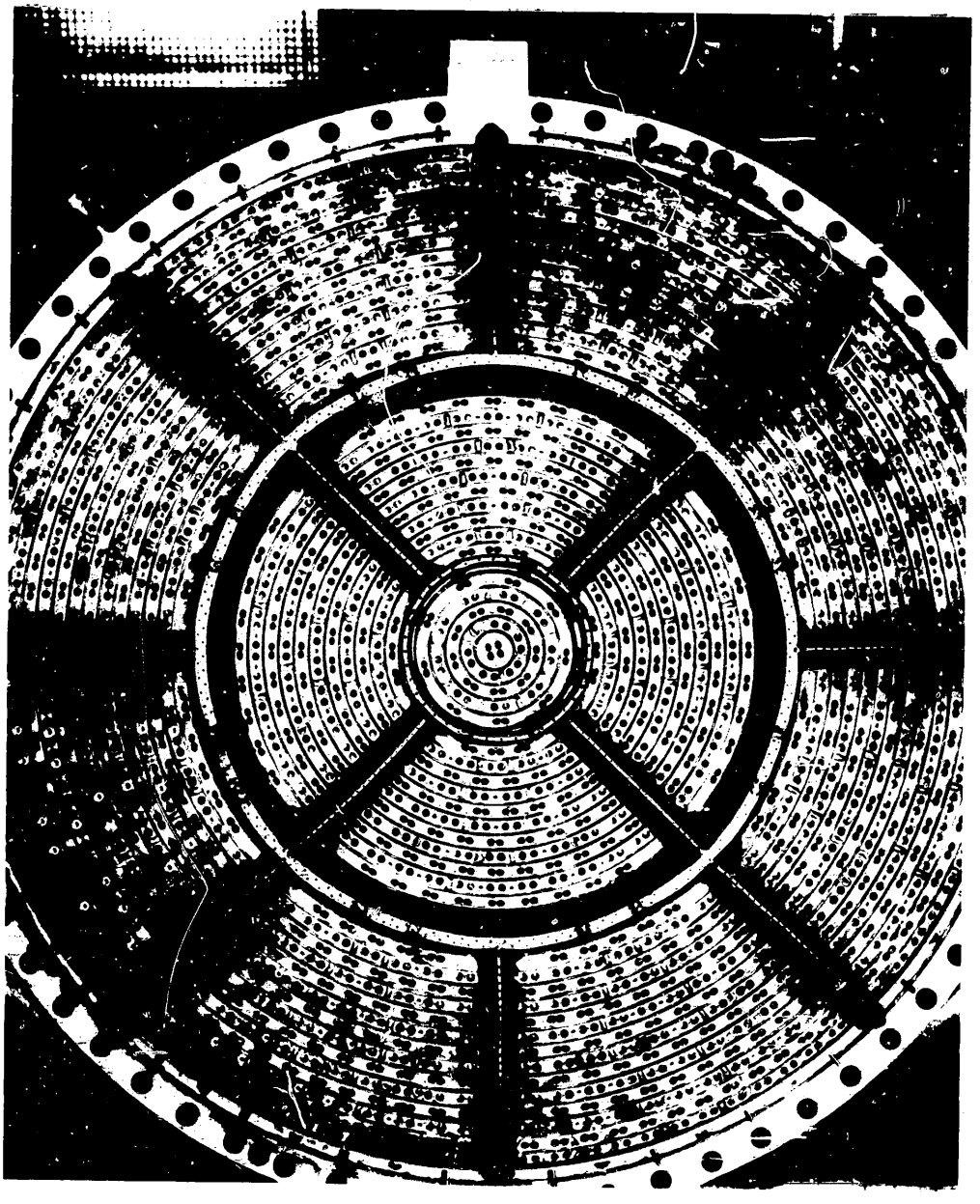
REMARKS: This injector has 6-inch, cooled baffles. There are 22 face-impinging fuel doublets in each outer compartment and 16 in each inner compartment (240 total). A sketch of a fuel doublet is shown at the left. There are 164 fuel ring dams.



FACE IMPINGING FUEL DOUBLETS

Figure 25. Injector Des ription, Unit X040, Type 6101-U4

[redacted]



1DB41-11/2/64-C1A

Figure 26 . Injector X040

TABLE 2

(Continued)

Tests:	032-037
Injector Type:	6115-V4, U/N: X060
Description:	See Injector Description Sheet Fig. 27 , also Fig. 28
Objective:	To evaluate the performance and stability characteristics of a development injector with regeneratively cooled baffles, reduced oxidizer and fuel flow along the radial baffles, 60 percent of the nominal flow to the outer fuel ring, and sealed baffle-to-land gaps.
Test Results:	Six satisfactory tests were run. The average Nc* in the tests was 90.5 percent ±0.2 percent. Three successful bomb tests were conducted during the series.
Frequency Analysis:	Tests 032, 033, and 034 were conducted without the use of bombs and no instability was observed. In tests 035, 036, and 037, 13.5-grain bombs were used to induce disturbances. These disturbances damped in 6, 12, and 20 milliseconds, respectively. Only test 032 showed indications of 400-cps oscillations. The average vibration level was 60 g peak to peak.
Tests:	038-039
Injector Type:	6116-X4, U/N: 084
Description:	See Injector Description Sheet Fig. 29
Objective:	To evaluate the performance characteristics of a development injector which has increased canting of the LOX fans along the radial baffles, no oxidizer splitters, 60 percent of the nominal flow to the outer fuel ring, and sealed baffle-to-land gaps.
Test Results:	Two satisfactory tests were run. The average Nc* for the tests was 91.0 percent ±0.3 percent. Further testing was postponed by local erosion of the baffle system caused by plugging of the baffle orifices with chips.
Frequency Analysis:	These tests were conducted without the use of bombs and no instability was observed.

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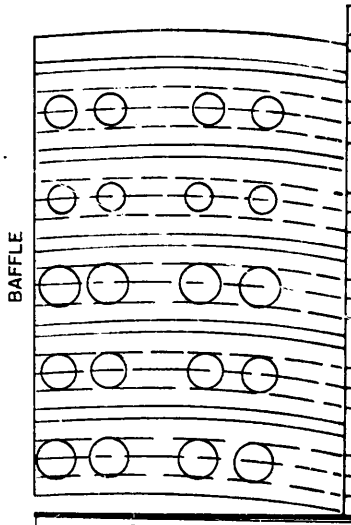
[redacted]

INJECTOR DESCRIPTION

UNIT X060, TYPE 6115-V4, S/N

ORIFICE PATTERN

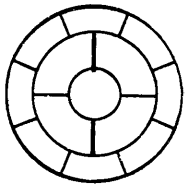


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.776	.228	96/104	.416	20	1.14	.571	.258
-57	36.746	.209	96/104	.416	20	1.11	.571	.284
-55	35.626	.281	72/96	.428	15	1.17	.799	.274
		.228	16	.428	15		.799	.373
		(Next to Radial Baffle Except Outer Ring)						
-53	34.506	.242	76/96	.416	20	1.13	.571	.238
		.209	16 holes		28.2			
		.185	16 holes		20			
-51	32.386	.281	64/88	.428	15	1.19	.799	.274
		.228	16					

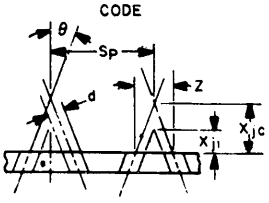
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	80.7	57.7
RING GROOVE DEPTH	.538	.538
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	.711	
INJECTION VEL. (1500K)	59	142
WALL COOLANT, %	2.91	

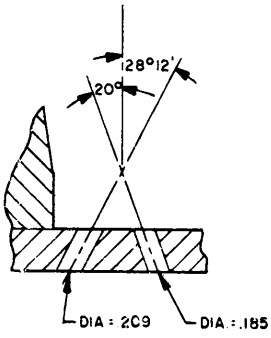
BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	WIDE BASE
BAFFLE COOLANT	FUEL
BAFFLE LENGTH	3 INCHES
BAFFLE COOLANT AREA	3.84

BAFFLES



CODE



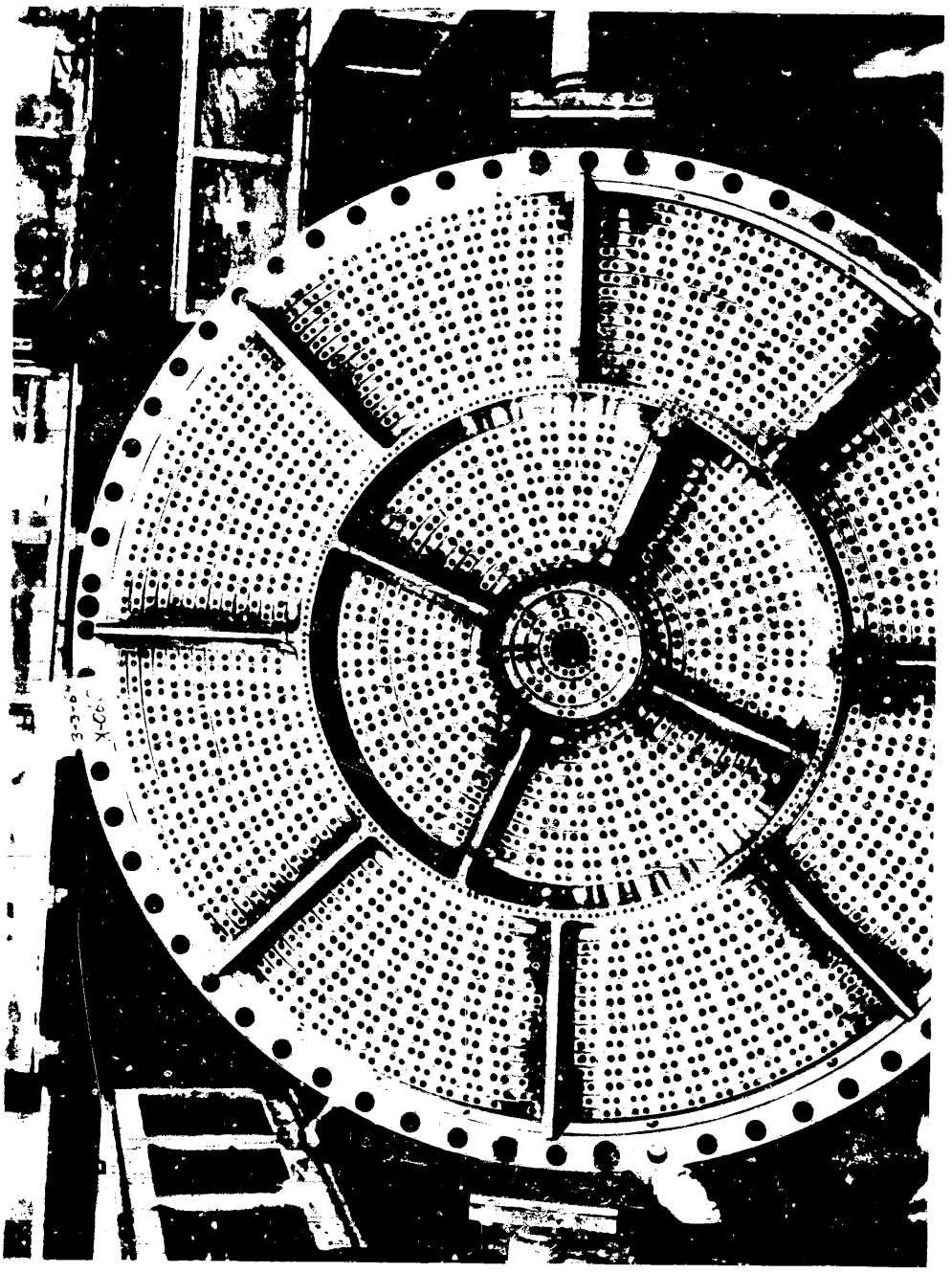


LOX DOUBLET NEXT TO RADIAL BAFFLES (EXCEPT OUTER LOX RING)

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 an uncooled GSE boss.

Figure 27. Injector Description, Unit X060, Type 6115-V4

[redacted]



1DB41-3/3/65-C1A

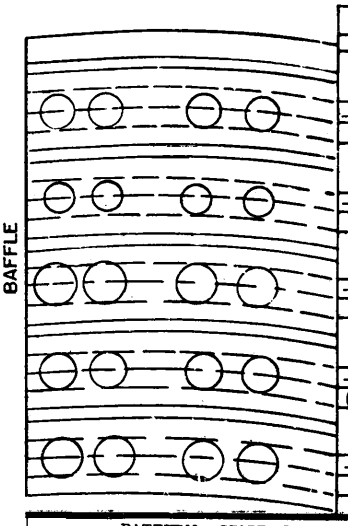
Figure 28. Injector X060

[redacted]

INJECTOR DESCRIPTION

UNIT 084, TYPE 6116-X4, S/N _____

ORIFICE PATTERN

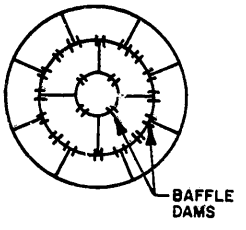


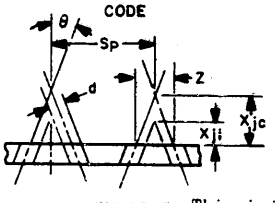
NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.776	.228	96/104	.416	20	1.14	.571	.258
-57	36.746	.209	96/104	.416	20	1.11	.571	.284
-55	35.626	.281	88/96	.428	15	1.17	.799	.274
-53	34.506	.242	88/96	.416	20	1.13	.571	.238
(Except next to radial baffles)								
-51	33.386	.281	80/88	.428	15	1.19	.799	.274

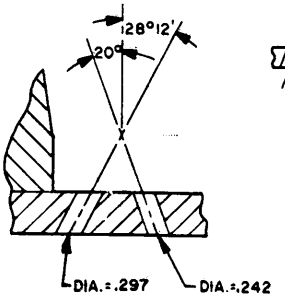
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.1	64.1
RING GROOVE DEPTH	.538	.538
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	.711	
INJECTION VEL. (1500K)	56	128
WALL COOLANT, %	2.8	

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	WIDE BASE
BAFFLE COOLANT	FUEL
BAFFLE LENGTH	3 INCHES

BAFFLES







LOX DOUBLETS NEXT TO RADIAL BAFFLES EXCEPT OUTER LOX RING

REMARKS: This injector has the basic Block 2 injection pattern with the exception that the oxidizer orifices next to the radial baffles (with the exception of those on the outer LOX ring) were enlarged to 0.297 inch diameter (sketch at left). In addition, the fuel flow in the outer fuel ring was reduced to 60 percent and the baffle-to-land gaps were sealed. The dump coolant orifices at the baffle tips were converted to the standard showerhead design. There are 40 baffle dams but no LOX splitters. There is no GSE plug.

Figure 29. Injector Description, Unit 084, Type 6116-X4

[redacted]

TABLE 2

(Continued)

Tests:	040-042
Injector Type:	5885-C4, U/N: 095
Description:	See Injector Description Sheet Fig. 30
Objective:	To evaluate the performance of a development injector which has no oxidizer splitters
Test Results:	Three satisfactory tests were run. The average Nc* in the tests was 91.5 ±0.3 percent.
Frequency Analysis:	The tests were conducted without the use of bombs and no instability was observed.
Tests:	043-047
Injector Type:	6118-Z4, U/N: F2009
Description:	See Injector Description Sheet Fig. 31 , also Fig. 32
Objective:	To evaluate the performance and stability characteristics of a development injector which has fuel injected at the base of the regeneratively cooled outer can, and no oxidizer splitters
Test Results:	Five satisfactory tests were run. The average Nc* in the tests was 90.7 ±0.3 percent. A self-trigger in test 045 caused no apparent injector or chamber damage. Three bombs were successfully damped during the test series.
Frequency Analysis:	Tests 043 and 044 were conducted without the use of bombs and no instability was observed. The bomb-induced disturbances in tests 045, 046, and 047 damped in a single cycle with respective damp times of 17, 20, and 20 milliseconds. A self-trigger in test 045 had the same appearance as a bomb and damped in 24 milliseconds.

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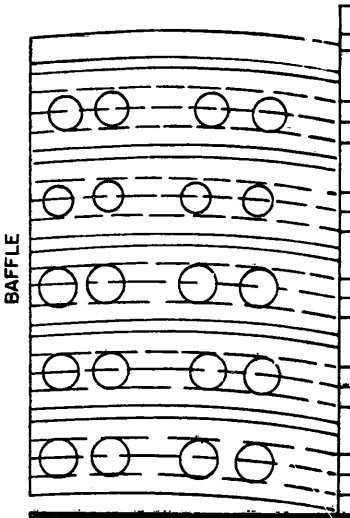
[redacted]

INJECTOR DESCRIPTION

UNIT 095, TYPE 5885-C4, S/N

ORIFICE PATTERN

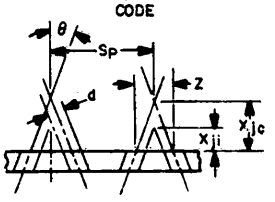


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.776	.228	96/104	.416	20	1.14	.571	.258
-57	36.746	.209	96/104	.416	20	1.11	.571	.284
-55	35.626	.281	88/96	.428	15	1.17	.799	.274
-53	34.506	.242	88/96	.416	20	1.13	.571	.238
(Except Next to Radial Baffle)								
-51	33.386	.281	80/88	.428	15	1.19	.799	.274

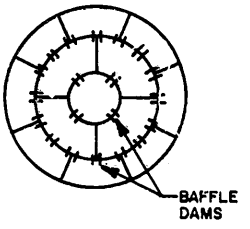
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.1	61.5
RING GROOVE DEPTH	.538	.538
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	.711	
INJECTION VEL. (1500K)	56	133
WALL COOLANT, %	3.2	

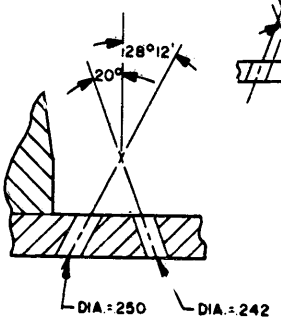
BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	WIDE BASE
BAFFLE COOLANT	FUEL
BAFFLE LENGTH	3 INCHES

CODE



BAFFLES





LOX DOUBLET NEXT TO RADIAL BAFFLE

REMARKS: This injector has the Block 2 injector pattern. There are no LOX splitters. There are 32 dams in the outer circumferential baffle and 8 dams in the inner circumferential baffle. The baffle-to-land gaps are not sealed. The outer fuel ring is orificed for 70 percent flow. The design of the LOX doublets next to the radial baffles on all LOX rings except the outer LOX ring and those LOX rings next to the circumferential baffles is shown at the left. The bomb bosses are placed on the fourth fuel ring at the 225 and 135 degree locations. The injector has a cooled GSE boss.

Figure 30. Injector Description, Unit 095, 5885-C4

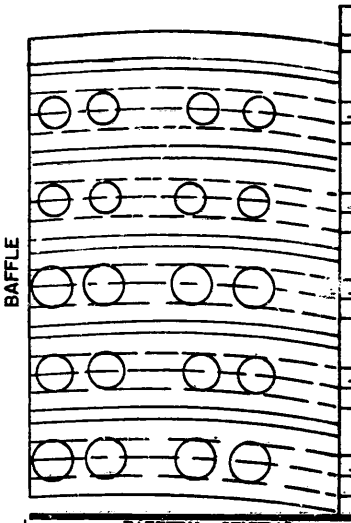
[redacted]

[redacted]

INJECTOR DESCRIPTION

UNIT F2009, TYPE 6118-Z4, S/N _____

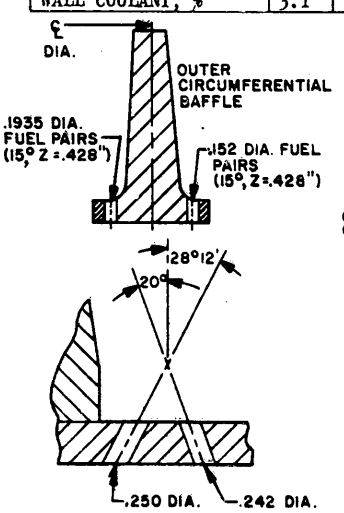
ORIFICE PATTERN



NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.776	.228	96/104	.416	20	1.14	.571	.258
-57	36.746	.209	96/104	.416	20	1.11	.571	.284
-55	35.626	.281	88/96	.428	15	1.17	.799	.274
-53	34.500	.242	88/96	.416	20	1.13	.571	.238
(Except next to radial baffles)								
-51	33.386	.281	80/88	.426	15	1.19	.799	.274

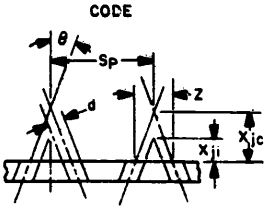
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	89.0	63.2
RING GROOVE DEPTH	.538	.538
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	.711	
INJECTION VEL. (1500K)	53	129
WALL COOLANT, %	3.1	

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	WIDE BASE
BAFFLE COOLANT	FUEL
BAFFLE LENGTH	3 INCHES

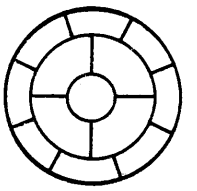


LOX DOUBLETS NEXT TO RADIAL BAFFLE (EXCEPT OUTER LOX RING & NEXT TO CIRCUMFERENTIAL BAFFLES)

CODE



BAFFLES

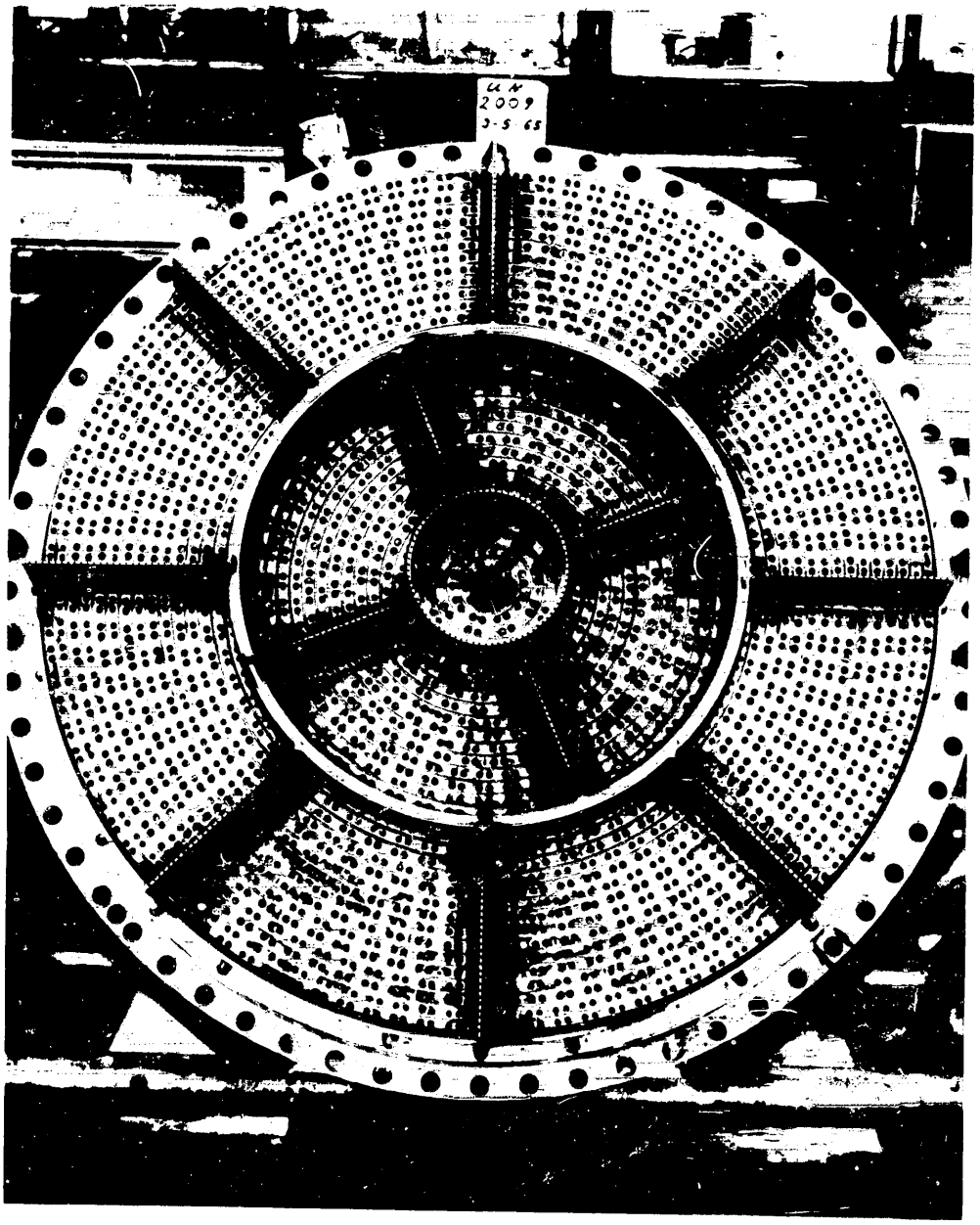


REMARKS: This injector has the basic Block 2 orifice pattern with the exception that the outer circumferential baffle (regeneratively cooled) was reduced in width and orifice groups are drilled at the base as shown in the sketch at the left. The LOX doublets at the intersections of the baffles were reinstated. The baffle-to-land gaps are sealed and the injector has a cooled GSE boss. The flow in the outer fuel ring is reduced to 70 percent and the bomb bosses are positioned at the 225 and 135 degree locations.

Figure 31. Injector Description, Unit F-2009, Type 6118-Z4

[redacted]

[redacted]



U/N 2009
1DB41-3/5/65-C2A

Figure 32. Injector F2009

[redacted]

TABLE 2

(Continued)

Tests:	048-051
Injector Type:	6106-W4, U/N: 099
Description:	See Injector Description Sheet Fig. 33
Objective:	To evaluate performance and stability characteristics of a 25-compartment development injector with no restriction in outer fuel ring and without oxidizer splitters
Test Results:	Four satisfactory tests were run. The average Nc* for the tests was 92.0 percent with a deviation of ±0.3 percent. Bombs were successfully employed in tests 049, 050, and 051.
Frequency Analysis:	Three bomb-induced instabilities persisted for 295, 55, and 18 milliseconds. The first 15 to 20 milliseconds of each instability exhibited a normal reaction to a bomb but in the first two instances the instabilities decayed into low-amplitude nonresurging disturbances that eventually damped. There was no buzzing experienced during any test.
Tests:	052-054
Injector Type:	6113-S4, U/N: X058
Description:	See Injector Description Sheet Fig. 34 , also Fig. 35
Objective:	To evaluate performance and stability characteristics of an H-1 mismatched pattern scaled up to F-1 size
Test Results:	The first two tests were satisfactory. The third test was cut by the VSC device during a bomb-induced instability that persisted for 260 milliseconds. The Nc*'s for the three tests were 91.6, 91.2, and 90.4 percent. The -55 fuel ring in compartments 5 and 6 had erosions that started back into the orifices.
Frequency Analysis:	Buzzing at 375 cps and 400-psi peak to peak in the fuel parameters was present in all tests. The bomb induced a periodic disturbance with high-frequency components in the feed systems.

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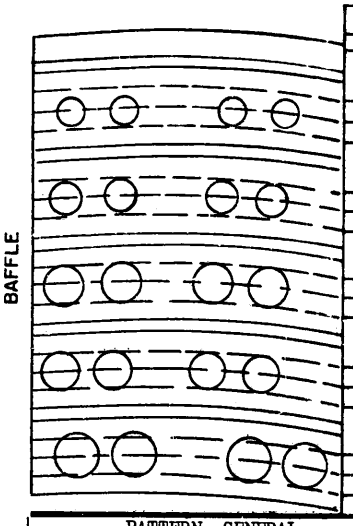
[redacted]

INJECTOR DESCRIPTION

ORIFICE PATTERN

UNIT 099, TYPE 6106-W4, S/N

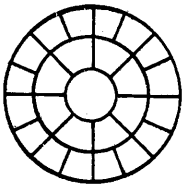


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.776	.221	80/96	.416	20	1.24	.571	.268
-57	36.746	.257	80/96	.416	20	1.20	.571	.218
-55	35.626	.281	80/96	.428	15	1.17	.799	.274
-53	34.506	.250	80/96	.416	20	1.13	.571	.228
-51	33.386	.323	64/80	.428	15	1.23	.799	.196

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, %	4.68	

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	25
BAFFLE CONSTRUCTION	WIDE BASE
BAFFLE COOLANT	FUEL
BAFFLE LENGTH	3 INCHES
BAFFLE AREA (IN^2)	3.56

BAFFLES



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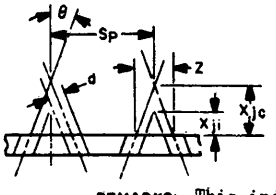
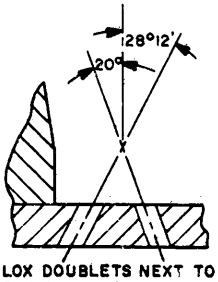




LOX DOUBLETS NEXT TO RADIAL BAFFLES EXCEPT AS NOTED

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. There is 100 percent fuel flow in the outer ring. There are no baffle dams, ring groove dams, or oxidizer splitters.

Figure 33. Injector Description, Unit 099, Type 6106-W4

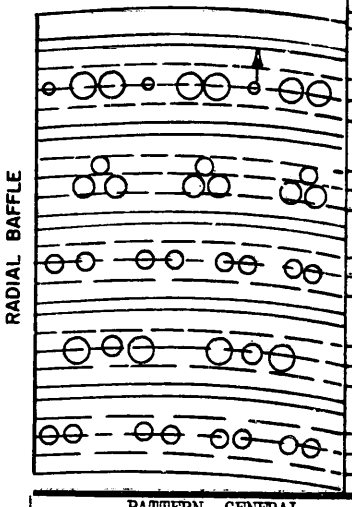
[redacted]

[redacted]

INJECTOR DESCRIPTION

UNIT X-058, TYPE 6113-S4, S/N _____

ORIFICE PATTERN

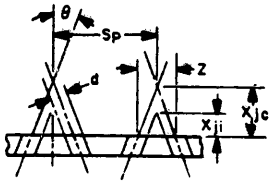


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
		.089	136 holes					
-59	37.766	.144	128/144	.218	20	.824	.300	.102
	36.929	.147	128 holes	SH.HD.		.806		
-57	36.548	.166	128/144	.218	20	.798	.300	.017
-55	35.626	.1405	176/196	.218	20	.574	.300	.107
		.1285	88 holes					
-53	34.506	.1875	88/98	.416	20	1.106	.572	.314
-51	33.386	.1406	160/178	.218	20	.537	.300	.106

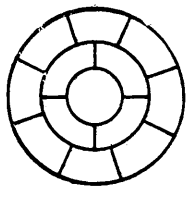
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	46.0	52.5
RING GROOVE DEPTH	.538	.538
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	.711	
INJECTION VEL. (1500K)	103	156
WALL COOLANT, %	4.1	

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	WIDE BASE
BAFFLE COOLANT	FUEL
BAFFLE LENGTH	3 INCHES
BAFFLE COOLANT AREA	3.84 IN^2

CODE



BAFFLES

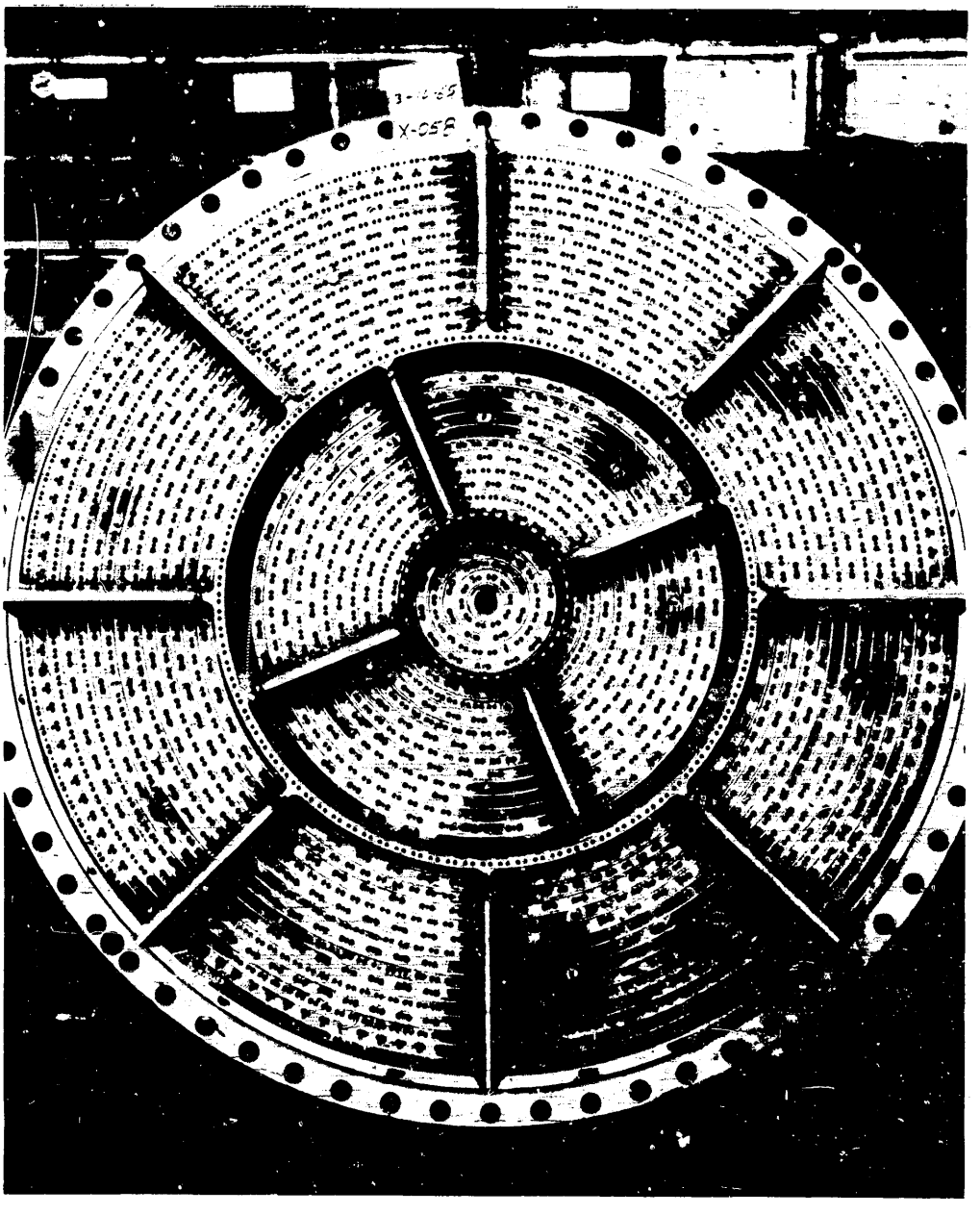


REMARKS: The injector has regeneratively cooled radial baffles and dump cooled circumferential baffles. The ring orifice (oxidizer and fuel) pattern is similar to the H-1 configuration. There are tapered fuel radial feed ports. 5/16-inch bomb bosses are located in -45 LOX ring. The film coolant orifices in outer rings are angled 10 degrees toward the wall except those adjacent to radial baffles, which are angled [illegible] degrees toward wall. The baffle-to-land [illegible]s are sealed. The injector has an unco[illegible]d GSE boss.

Figure 34. Injector Description, Unit X058, Type 6113-S4

[redacted]

[redacted]



1DR41-3/10/65-C1A

Figure 35 . Injector X058

[redacted]

TABLE 2

(Continued)

Tests:	055-056
Injector Type:	6121-V4, U/N: X060
Description:	See Injector Description Sheet Fig. 36
Objective:	To evaluate performance and operating characteristics of a development injector with regeneratively cooled radial baffles, reduced fuel along radial baffles, and 60-percent flow to the outer fuel ring
Test Results:	Two satisfactory tests were run. The average Nc* for the tests was 91.4 percent with a deviation of ±0.1 percent. Posttest inspection showed lack of carbon on the thrust chamber tubes from 9 to 2 o'clock from the injector end ring to 6 inches downstream. The injector metal O-ring was broken in the area of the No. 1 inlet.
Frequency Analysis:	One bomb-induced disturbance damped in 19 milliseconds without resurging. However, three self-triggers occurred, the last of which damped in 49 milliseconds after two resurges. The other self-triggers damped without resurging in 25 and 12 milliseconds. All the self-triggers triangulated to the No. 1 inlet side of the chamber.
Tests:	057-059
Injector Type:	6117-Y4, U/N: 100
Description:	See Injector Description Sheet Fig. 37
Objective:	To evaluate performance and stability characteristics of a baffled injector with double-row fuel doublets and single-row LOX doublets with a constant wall gap along the radials
Test Results:	Tests 057 and 058 were satisfactory. Test 058 was bombed, and damped in 43 milliseconds. Test 059 employed a bomb and the resulting disturbance caused a VSC. The instability persisted for 153 milliseconds. Test 057 operated at a high mixture ratio and test 059 was short because of the VSC. Test 058 had an Nc* of 91.1 percent. The radial baffles were bent 1/4 inch in the counter-clockwise direction and there were collapsed thrust chamber tubes on the closkwise side of each baffle. The thrust chamber also sustained two 4-inch crown splits.
Frequency Analysis:	Test 058 and 059 exhibited comparatively low-amplitude 400-cps in all parameters. The bomb in test 058 produced an instability that did not resurge, however, the bomb-induced disturbance in test 059 was a resurging instability.

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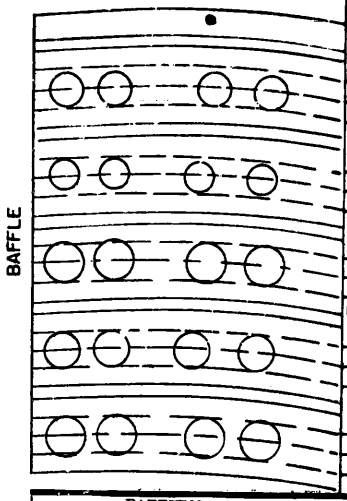
INJECTOR DESCRIPTION

ORIFICE PATTERN

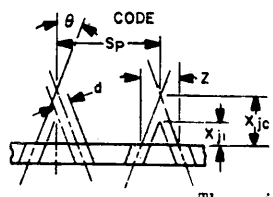
UNIT X 060, TYPE 6121-V4, S/N



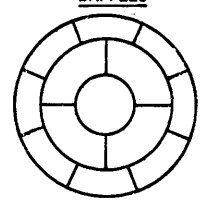
NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.767	.228	96/104	.416	20	1.14	.571	.258
-57	36.746	.209	96/104	.416	20	1.11	.571	.284
-55	35.626	.281	72/96	.428	15	1.17	.799	.274
		.228	16	.428	15		.799	.373
(Next to radial baffle except outer ring)								
-53	34.506	.242	72/96	.416	20	1.13	.571	.238
		.250	16 holes		28.2			
		.221	16 holes		20			
-51	33.386	.281	64/88	.428	15	1.19	.799	.274
		.228	16					

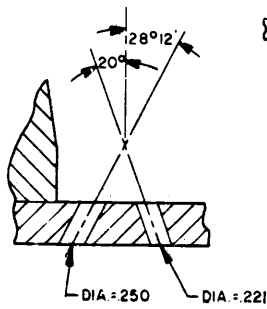
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	80.7	60.5
RING GROOVE DEPTH	.538	.538
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	.711	
INJECTION VEL. (1500K)	59	135
WALL COOLANT, %	2.91	

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	WIDE BASE
BAFFLE COOLANT	FUEL
BAFFLE LENGTH	3 INCHES
BAFFLE COOLANT AREA	3.84 SQ IN.



BAFFLES





LOX doublets next to radial baffles (except outer LOX ring)

REMARKS: The orifice pattern is similar to type 6115-V4 except the LOX doublets adjacent to the radial baffles were opened up according to the sketch at left. 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 an uncooled GSE boss, no splitters, and no dams.

Figure 36. Injector Description, Unit X060, Type 6121-V4

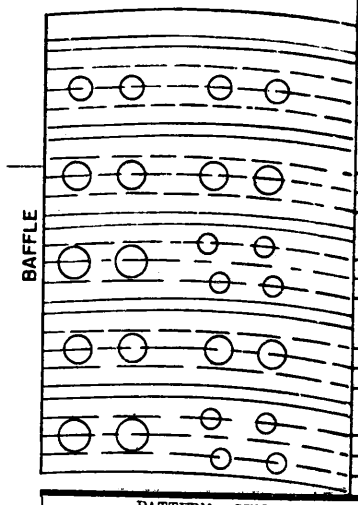
[redacted]

[redacted]

INJECTOR DESCRIPTION

ORIFICE PATTERN

UNIT 100, TYPE 6117-Y4, S/N

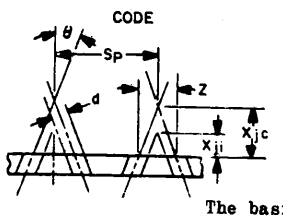


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.767	.177	96	.428	15	1.09	.799	.468
-57	36.746	.242	96	.392	22.5	1.05	.472	.181
	35.826	.177	80	.428	15	1.02	.799	.468
-55	35.626	.250	16	.428	15		.799	.332
	35.398	.177	72	.428	15	1.10	.799	.468
-53	34.506	.242	88	.392	22.5	1.07	.472	.181
	33.584	.177	72	.428	15	1.03	.799	.468
-51	33.386	.250	16	.428	15		.799	.332
	33.158	.177	64	.428	15	1.12	.799	.468

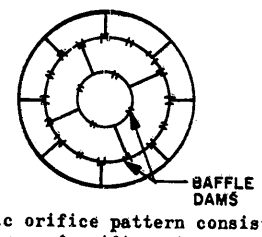
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	68.7	62.3
RING GROOVE DEPTH	.538	.538
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	.711	
INJECTION VEL. (1500K)	69	131
WALL COOLANT, %	2.46	

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	WIDE BASE
BAFFLE COOLANT	FUEL
BAFFLE LENGTH	3 INCHES

CODE



BAFFLES



REMARKS: The basic orifice pattern consists of double rows of orifices in each fuel ring and single rows of orifices in each oxidizer ring. The diameter of the oxidizer orifices is 0.242 inch (45 degrees included angle) except those adjacent to the circumferential baffles and adjacent to the radial baffles on the -31 and -33 rings, which have 0.199-inch orifices (40 degrees included angle). There are 164 fuel ring dams, 40 baffle dams and the fuel flow is reduced to 70 percent in the outer ring. The baffle-to-land gaps are sealed and the injector has a cooled GSE boss.

Figure 37. Injector Description, Unit 100, Type 6117-Y4

[redacted]

TABLE 2

(Continued)

Tests:	060-063
Injector Type:	5896-A5, U/N: 082
Description:	See Injector Description Sheet Fig. 38 , also Fig. 39
Objective:	To evaluate ring and body temperatures with zirconium oxide coating
Test Results:	Three satisfactory tests were run. The average Nc* was 90.4 percent. Test 063 resulted in an observer cutoff.
Frequency Analysis:	There were no bombs employed and there was no instability or buzzing experienced on any of the tests.
Tests:	064
Injector Type:	6122-E5, U/N: X021
Description:	See Injector Description Sheet Fig. 40
Objective:	Evaluate the performance and stability characteristics of an 082B-type injector with unlike doublets (increased diameters) placed within the main pattern and to evaluate the durability characteristics of radial baffles which are slotted at the base to relieve stress
Test Results:	The Nc* was 89.5 percent. The -29 fuel ring burned through at one unlike doublet. There was slight burning at four additional doublets on the same ring. No bombs were employed.
Frequency Analysis:	No instability or buzz was experienced.

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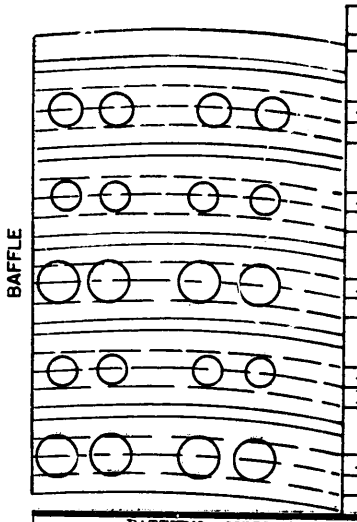
[redacted]

INJECTOR DESCRIPTION

ORIFICE PATTERN

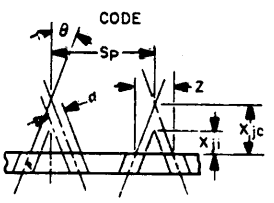
UNIT 082, TYPE 5896-A5, S/N



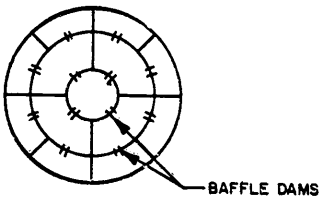
NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	38.188							
-59	37.767	.228	96/104	.416	20	1.14	.571	.258
-57	36.746	.209	96/104	.374	28.2	1.11	.349	.153
-55	35.626	.281	88/96	.428	15	1.17	.799	.274
-53	34.506	.209	88/96	.374	28.2	1.13	.349	.153
LOX	holes next to baffles			.416	20		.571	.284
-51	33.386	.281	80/88	.428	15	1.19	.799	.274

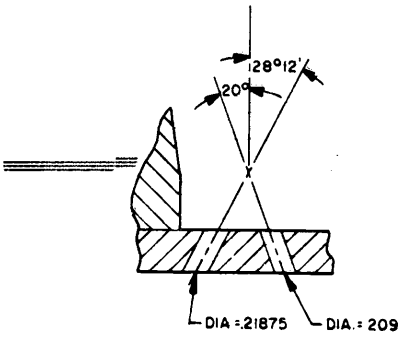
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.0	49.6
RING GROOVE DEPTH	.538	.338
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	.711	
INJECTION VEL. (1500K)	56	165
WALL COOLANT, %	4.6	

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	WIDE BASE
BAFFLE COOLANT	FUEL
BAFFLE LENGTH	3 INCHES



BAFFLES





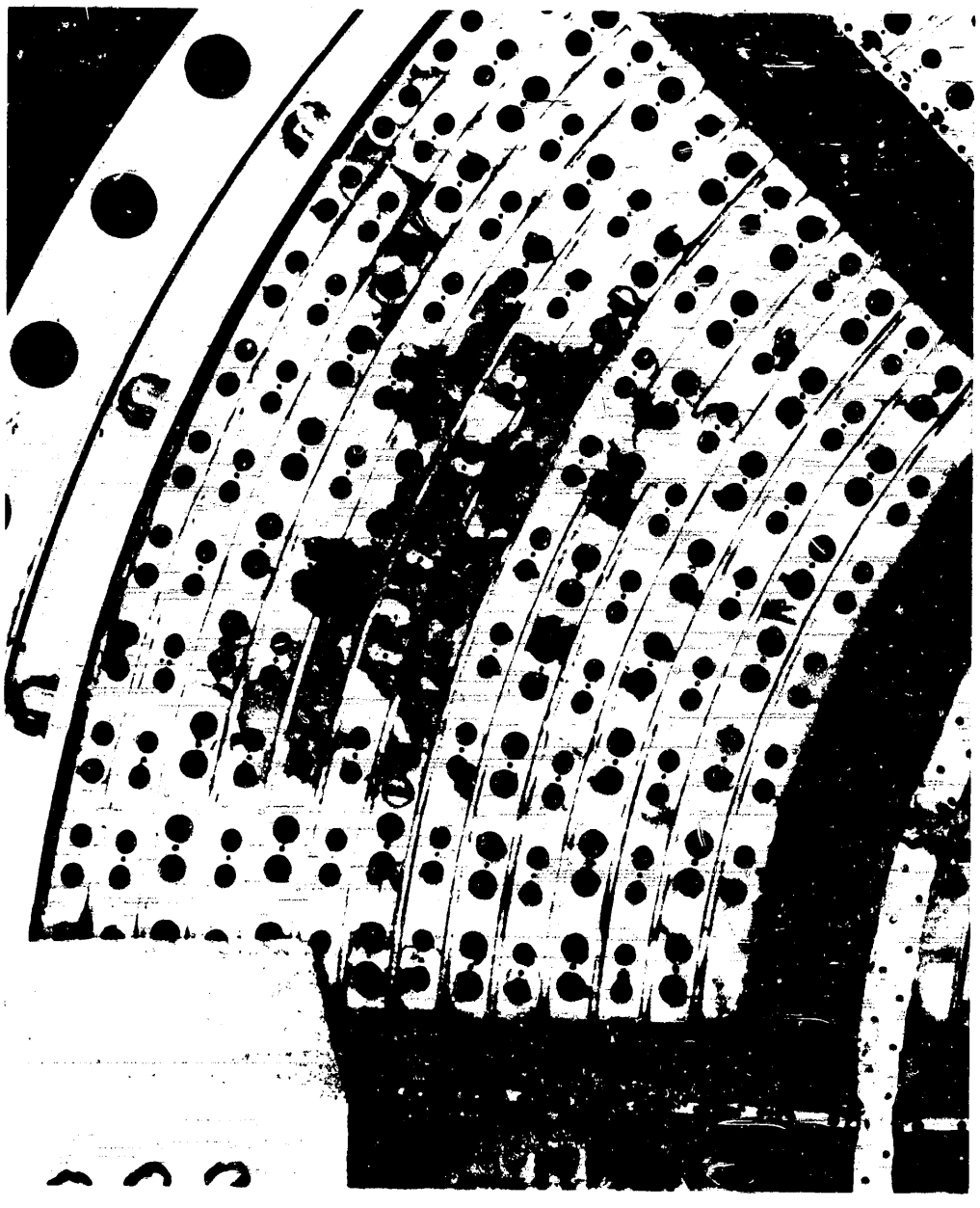
LOX doublets next to radial baffles (except outer LOX ring and next to circumferential baffles).

REMARKS: This injector has the same orifice pattern as the type 5896-U3. The copper rings were coated with a gradated refractory coating of Nichrome, Inconel, and zirconium oxide. A thermocouple is located at each of the following positions: -47 fuel ring (face side), -49 oxidizer ring (face side), and -45 oxidizer ring (back side). The injector has 100-percent fuel flow in the outer ring, no LOX splitters, 164 fuel ring groove dams, 24 circumferential baffle dams (16 outer and 8 inner) and the baffle-to-land gap is not sealed. The injector does not have a GSE boss.

Figure 38. Injector Description, Unit 082, Type 5896-A5

[redacted]

[redacted]



1DB41-3/29/65-C3C

Figure 39. Injector 082

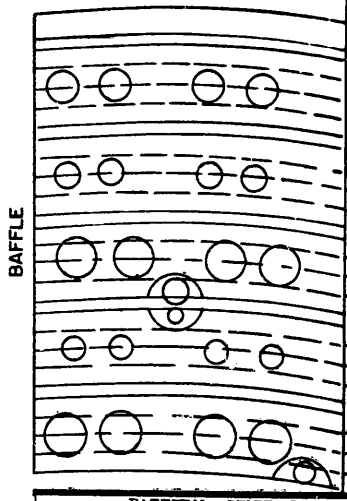
[redacted]

[redacted]

INJECTOR DESCRIPTION

ORIFICE PATTERN

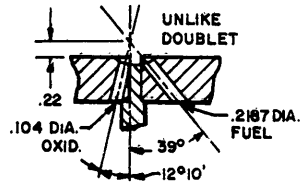
UNIT X 021 , TYPE 6122-E5 , S/N

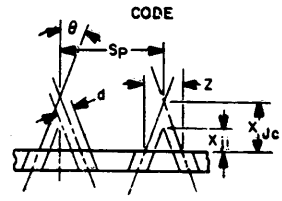


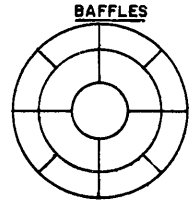
NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.767	.228	96/104	.416	20	1.14	.571	.258
-57	36.746	.209	96/104	.374	28.2	1.11	.349	.153
-55	35.626	.281	88/96	.428	15	1.17	.799	.274
	35.20	.2187	32					
	34.91	.104	32					
-53	35.506	.209	88/96	.374	28.2	1.13	.349	.153
-51	33.386	.281	80/88	.428	15	1.17	.799	.274
	32.96	.2187	24					

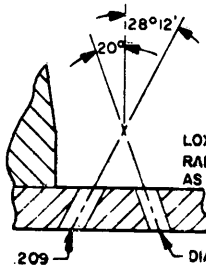
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	90.5	50.4
RING GROOVE DEPTH	.538	.338
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	.711	
INJECTION VEL. (1500K)	52	162
WALL COOLANT, %	4.33	

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	WIDE BASE
BAFFLE COOLANT	FUEL
BAFFLE LENGTH	3 INCHES









REMARKS: The orifice pattern differs from type 6114 by a doubling of the orifice diameters of the unlike doublets (146) which impinge over ring lands as shown in the sketch at left. There are 13 unlike doublets in each outer compartment and 11 in each inner compartment. The design of the LOX doublets next to the radial baffles (except for the outer LOX ring) is shown at the left. There are 314 LOX splitters and 164 fuel ring dams. There are no baffle dams. There is 100-percent flow to the outer fuel ring and no GSE hose. The baffle-to-land gaps are sealed. The radial baffles are slotted.

Figure 40. Injector Description, Unit X021, Type 6122-E5

[redacted]

TABLE 2

(Continued)

Tests:	065-071
Injector Type:	6110-D5, U/N: X049
Description:	See Injector Description Sheet Fig. 41
Objective:	Evaluate performance and stability characteristics of a development injector with 0.242/0.185-inch-diameter oxidizer overlap along the radial baffles, 60-percent flow in the outer fuel ring and no oxidizer splitters.
Test Results:	Seven satisfactory tests were run. The average Nc* was 90.8 percent with a deviation of +0.4 to -0.1 percent. Bombs were successfully employed in the last six tests. One erosion occurred on the outer circumferential baffle during test 071. Three thrust chamber fuel bypass plugs were found in the injector upon disassembly after test 071.
Frequency Analysis:	Eleven bomb-induced instabilities damped in 55, 50, 40, 32, 22, 40, 22, 35, 26, 35, and 22 milliseconds. There were no strong resurges during any of the bomb-induced disturbances. However, a self-triggered instability occurred during test 066, which damped in 58 milliseconds after two resurges. The self-trigger appeared to originate in the general area of a lost bomb boss plug. There was no buzz during test 065. Low-amplitude, 400-cps oscillations were observed in chamber pressure, fuel and oxidizer parameters during all other tests. These oscillations reached a maximum amplitude of 250-psi peak to peak in the oxidizer parameters in tests 066 and 068.
Tests:	072-075
Injector Type:	6121-V4, U/N: X060
Description:	See Injector Description Sheet Fig. 36
Objective:	Evaluate performance and operating characteristics of a development injector with regeneratively cooled radial baffles, reduced fuel along the radial baffles, and 60-percent flow to the outer fuel ring
Test Results:	Four satisfactory tests were run. The average Nc* was 91.0 ±0.3 percent. Bombs were successfully employed in the last three tests. Three tube splits adjacent to the injector end ring were observed after test 075.
Frequency Analysis:	Five bomb-induced instabilities damped in 37, 29, 50, 95, and 35 milliseconds. There were definite resurges in the 37- and 95-millisecond instabilities. There was no buzzing.

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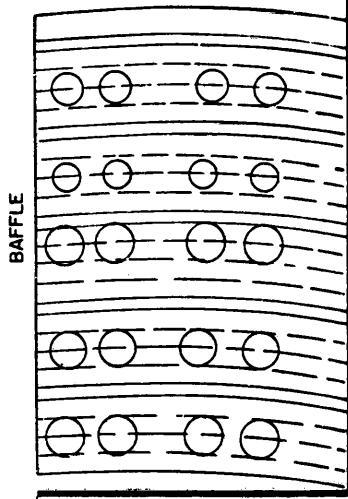
[redacted]

INJECTOR DESCRIPTION

UNIT X 049, TYPE 6110-D5, S/N _____

ORIFICE PATTERN

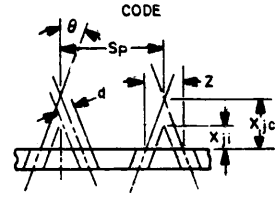


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.767	.228	96/104	.416	20	1.14	.571	.258
-57	36.746	.209	96/104	.416	20	1.11	.571	.284
-55	35.626	.281	88/96	.428	15	1.17	.799	.274
-53	34.506	.242	88/96	.416	20	1.13	.571	.238
(Except next to radial baffles)								
-51	33.386	.281	80/88	.428	15	1.19	.799	.274

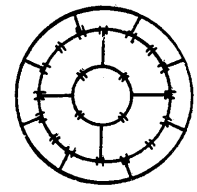
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.0	59.2
RING GROOVE DEPTH	.538	.538
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	.711	
INJECTION VEL. (1500K)	56	138
WALL COOLANT, %	2.8	

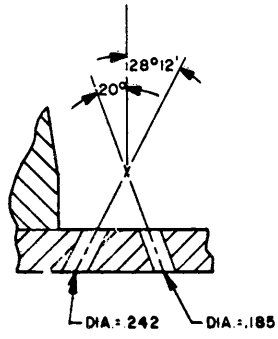
BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	WIDE BASE
BAFFLE COOLANT	FUEL
BAFFLE LENGTH	3 INCHES

CODE



BAFFLES





LOX doublets next to radial baffles (except outer LOX ring).

REMARKS: This injector is the same as the type 6110-F4 with the exception that the fuel flow in the outer ring was reduced to 60 percent, the baffle-to-land gaps have been sealed, and the LOX splitters were removed. The design of the oxidizer orifices next to the radial baffles is shown in the sketch at the left. The injector has a cooled GSE boss. There are 40 baffle dams.

Figure 41. Injector Description, Unit X049, Type 6110-D5

[redacted]

TABLE 2

(Continued)

Tests:	076-077
Injector Type:	6116-X4, U/N: 084
Description:	See Injector Description Sheet Fig. 29
Objective:	Evaluate the performance and stability characteristics of a development injector which has increased canting of the oxidizer fans along the radial baffles, no oxidizer splitters, and 60 percent of nominal flow to the outer fuel ring
Test Results:	The average Nc* was 91.5 percent with a deviation of ±0.1 percent. No bomb was used during the first test. A bomb-induced instability during the last test damped in 66 milliseconds.
Frequency Analysis:	Three resurges occurred during the bomb-induced instability during test 077. No buzzing was observed.
Tests:	078-082
Injector Type:	6115-F4, U/N: X043
Description:	See Injector Description Sheet Fig. 42 , also Fig. 43
Objective:	Evaluate performance and operating characteristics of a development injector with regeneratively cooled radial baffles, reduced fuel and oxidizer along the radial baffles, 70-percent flow to the outer fuel ring and 0.55-inch-thick rings
Test Results:	Four satisfactory tests were run. No mainstage was attained in test 078 due to a sequence failure. The average Nc* was 90.1 percent with a deviation of +0.3 to -0.1 percent. Bombs were successfully employed in the last three tests. The tube wall chamber was severely damaged in the last test, with collapsed and cracked tubes. Four injector ring temperatures were measured.
Frequency Analysis:	Five bomb-induced instabilities damped in 36, 43, 32, 32, and 199 milliseconds. The 199-millisecond instability appeared to damp in about 8 milliseconds, however, a resurge then occurred and induced 250- and 500-cps oscillations at high amplitudes (up to 3000-psi peak to peak). No buzzing was observed.

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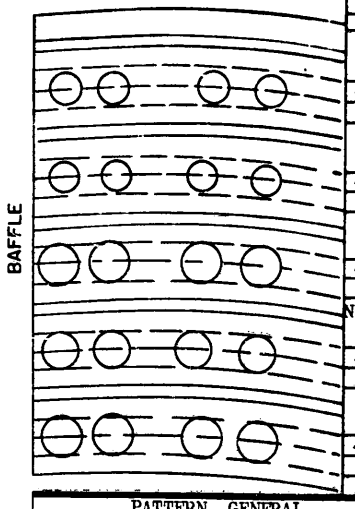
INJECTOR DESCRIPTION

ORIFICE PATTERN

UNIT X 043, TYPE 6115-F4, S/N

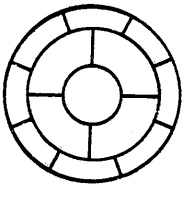


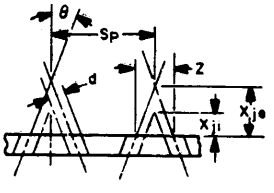
NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.767	.228	96/104	.416	20	1.14	.571	.258
-57	36.746	.209	96/104	.416	20	1.11	.571	.284
-55	35.626	.281	72/96	.428	15	1.17	.799	.274
		.228	16	.428	15		.799	.373
Next to radial baffles except outer ring.								
-53	34.506	.242	88/96	.416	20	1.13	.571	.238
(Except next to radial baffles)								
-51	33.386	.281	64/88	.428	15	1.19	.799	.274
		.228	16	.428	15		.799	.373

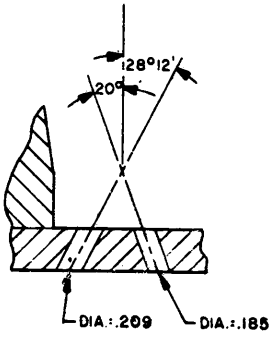
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	80.7	57.7
RING GROOVE DEPTH	.470	.470
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	.711	
INJECTION VEL. (1500K)	59	142
WALL COOLANT, %	3.4	

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	WIDE BASE
BAFFLE COOLANT	FUEL
BAFFLE LENGTH	3 INCHES
BAFFLE COOLANT AREA, SQ IN.	3.84

BAFFLES







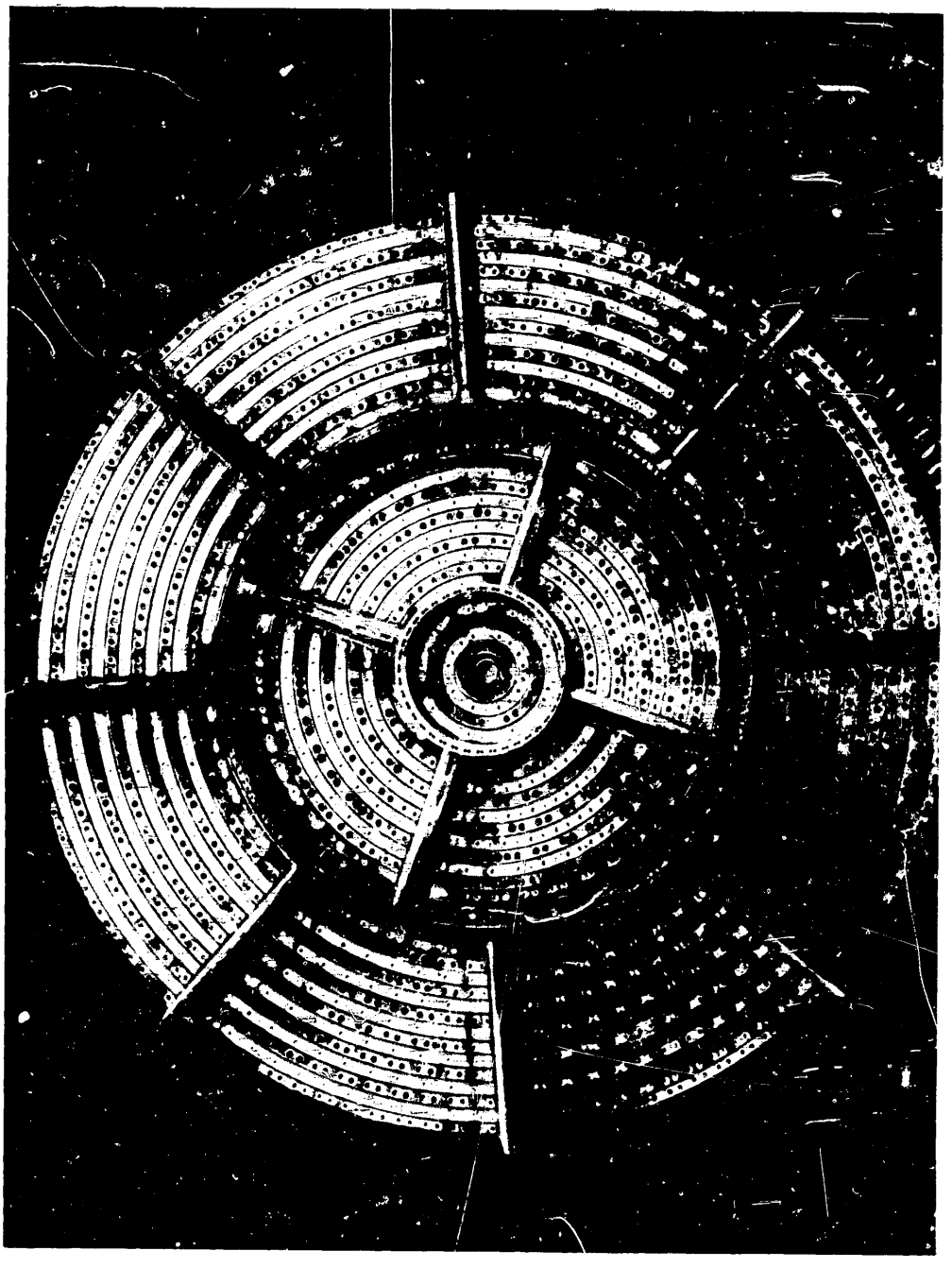
LOX doublets next to radial baffle except for outer LOX ring.

REMARKS: This injector has regeneratively cooled radial baffles and dump-cooled circumferential baffles. The orifice pattern differs from the development injector by smaller diameter orifices in the canted fan oxidizer doublets adjacent to the radial baffles (shown in sketch at left), and smaller diameter orifices in fuel doublets adjacent to radial baffles in all rings. The injector has no splitters, no dams, 70-percent flow in the outer fuel ring, 0.55-inch-thick rings, and an uncooled GSE boss. The baffle-to-land gaps are sealed. There are three injector face thermocouples on the -49 oxidizer ring, and three on the -51 fuel ring.

Figure 42. Injector Description, Unit X043, Type 6115-F5

[redacted]

[redacted]



1DB45-3/27/65-E4

Figure 43. Injector X043

[redacted]

TABLE 2

(Concluded)

Tests:	083-084
Injector Type:	6116-X4, U/N: 084
Description:	See Injector Description Sheet Fig. 29
Objective:	Evaluate performance and stability of a development injector with increased canting of the oxidizer fans along the radial baffles (0.297/0.242-inch diameter at 28.2/20 degrees), 60 percent of nominal flow to the outer fuel ring, sealed baffle-to-land gaps, and no oxidizer splitters.
Test Results:	Two tests were run. Nc* of 90.8 and 89.0 percent were obtained; however, these results are questionable because the test durations were only 1.4 seconds. Two bombs were successfully employed in each test. Three tubes were split at the throat during test 083. After test 084, there were four gate-type tube splits at the throat, three at the injector end ring adjacent to radial baffles, and two near the exit manifold. The inner radial baffles were bent 1/4 to 1/2 inch during test 084.
Frequency Analysis:	The four bomb-induced instabilities damped in 139, 70, 41, and 70 milliseconds. In the three longer instabilities, resurging coupled with 250 and 500 cps oscillations occurred. The extended damp times, at least in part, are attributed to thrust chamber leaks. There was no buzzing.
Tests:	085
Injector Type:	6120-C5, U/N: 095
Description:	See Injector Description Sheet Fig. 44
Objective:	Evaluate performance and stability of a development injector with increased canting of the oxidizer fans along the radial baffles (0.272/0.242-inch-diameter orifices at 28.2/20 degrees), 70 percent of nominal flow to the outer fuel ring, sealed baffle-to-land gaps, and no oxidizer splitters.
Test Results:	Nc* of 90.9 percent at 2.18 mixture ratio was obtained. The c* efficiency was questionable because of the low mixture ratio. No bombs were employed. Three tube splits were observed in the thrust chamber throat posttest.
Frequency Analysis:	A 52-millisecond instability occurred in the tube wall chamber during the test. There was no buzzing.

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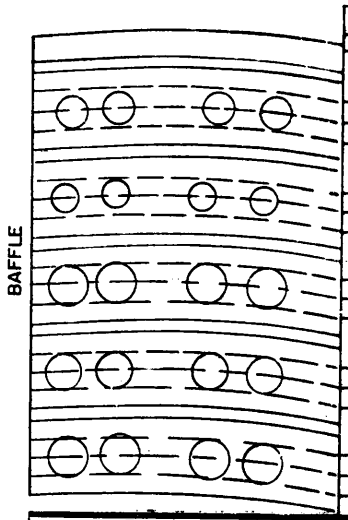
[redacted]

INJECTOR DESCRIPTION

UNIT 095, TYPE 6120-C5, S/N _____

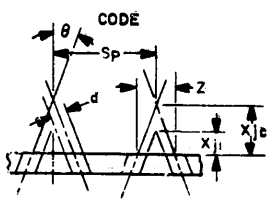
ORIFICE PATTERN



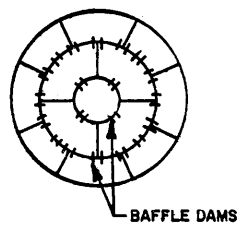
NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.767	.228	96/104	.416	20	1.14	.571	.258
-57	36.746	.209	96/104	.416	20	1.11	.571	.284
-55	35.626	.281	88/96	.428	15	1.17	.799	.274
-53	34.506	.242	88/96	.416	20	1.13	.571	.238
(Except next to radial baffles)								
-51	33.386	.281	80/88	.428	15	1.19	.799	.274

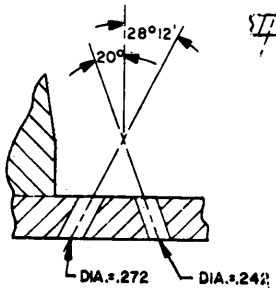
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.1	62.5
RING GROOVE DEPTH	.538	.538
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	.711	
INJECTION VEL. (1500K)	56	131
WALL COOLANT, %	3.2	

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	WIDE BASE
BAFFLE COOLANT	FUEL
BAFFLE LENGTH	3 INCHES



BAFFLES





Oxidizer doublets next to radial baffles except for outer oxidizer ring

REMARKS: This is a development injector with the oxidizer overlap next to the radial baffles increased by drilling out the holes adjacent to the radial baffles (except the outer LOX ring) to 0.272-inch diameter as shown in sketch at the left. There are no LOX splitters, 40 baffle dams, and the outer fuel ring is orificed for 70-percent flow. The baffle-to-land gaps are sealed. The injector has a cooled GSE boss.

Figure 44. Injector Description, Unit 095, Type 6120-C5

[redacted]

HYDRODYNAMICS

With the installation of a new flow data collection system at the High-Flow Facility late in December, it became possible to obtain accurate flow data on a specific problem in a reasonable period of time. The new system also contributed indirectly as the library of data accumulated. Confidence in its repeatability and reliability was established, and methods of application of the data to special problems were evolved.

In the original concept, flow distribution studies were designed as an aid in the understanding of the overall combustion stability phenomena in the F-1 engine system. Such a correlation was not found. Only in a few isolated instances were flow data able to contribute to the solution of an individual stability problem. The major contributions of flow studies came in the fields of performance and compatibility.

Injector X033 is a good example of the uses made of flow distribution data. This unit was a baffled injector with the orifice pattern programmed to obtain uniform flow in both the radial and circumferential directions. Both the oxidizer and fuel sides were so programmed; the basis for the calculations was the flow data obtained from the FRT-type injector X050.

The expected performance gains were not realized when the injector was tested. For this reason, flow distribution studies were conducted on injector X033 itself to determine the efficacy of the programming calculations. The flow tests showed that the desired uniform circumferential profiles were not obtained on either the oxidizer or the fuel sides. Both radial distribution profiles, however, were well within design

limitations. The circumferential profiles showed that on several of the rings where high dynamic head was the predominant factor affecting group flow, programming the orifices had actually resulted in an over-correction. The most significant change was the loss of flow profile symmetry within a baffle compartment. The distribution of injector X033, in general, was an improvement over the FRT injector.

Another injector flow tested during this period was injector 077. This was a flat-face injector designed to obtain uniform mixture ratio across the injector face and uniform injection density except at the outer periphery. The profiles are shown in Fig. 45 and 46 which are, respectively, plots of mixture ratio and flow density as a function of position across the injector face. To achieve these, the orifice sizes were programmed radially across the entire injector. Care was also taken in the body design to match the relative amount of axial feed passage area to that of the rings.

The injector flowed close to design expectation. Only four oxidizer rings were significantly different from what was desired. Two of these flowed higher than the design points and two flowed lower. Two fuel rings flowed higher than design. This was compensated by slightly less than design flow in most of the other rings. The amount of decrease, however, was not considered a significant departure from design. The effects of the high and low flowing oxidizer rings are evident in Fig. 45 where in zones 5, 6, 10, and 11 the mixture ratio deviates from the desired value. The high flowing fuel rings offset the low flowing oxidizer rings in zones 5 and 6 such that the flow density (Fig. 46) was not affected.

It was indicated in flowing the FRT injector without oxidizer feed passage splitters, that such devices, properly placed, could be utilized to secure

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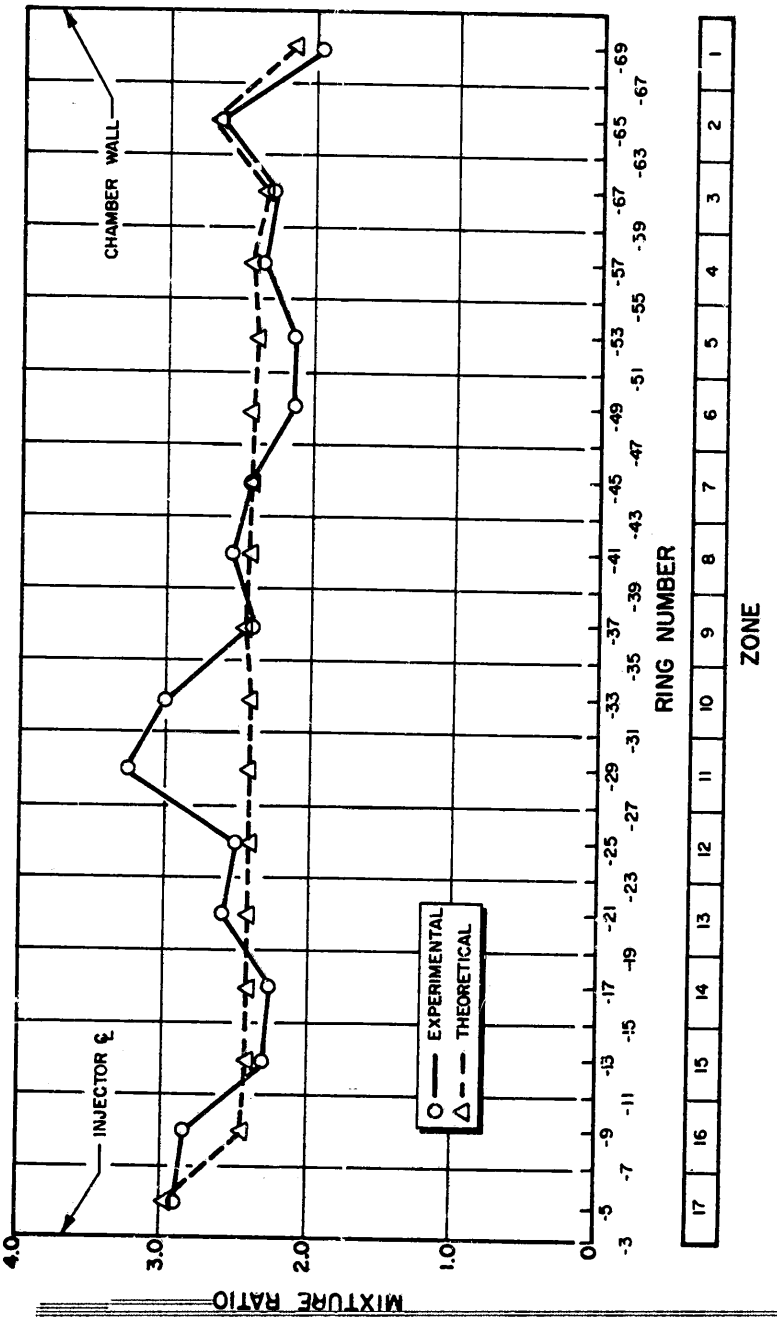

Figure 45. Injector 077, Theoretical vs Experimental Mixture Ratio

[redacted]

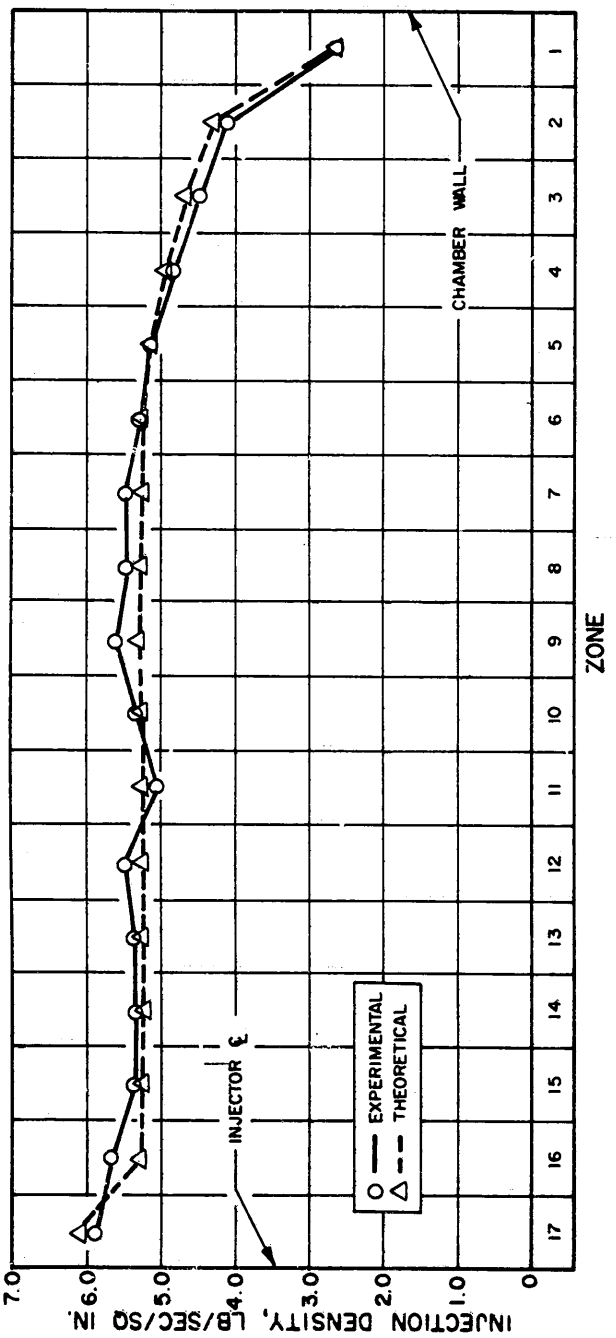

Figure 46 . Injector 077, Theoretical vs Experimental Injection Density

more uniform circumferential oxidizer flow. This theory was tested on injector X050 in which the splitters were arranged in a configuration designated type 084X. The method was partially successful in that the circumferential profiles in several rings were improved over the FRT injector, type 084E. A comparison of this for the -57 ring is shown in Fig. 47 . The hypothesis that splitters may be used in this way was confirmed, however, and from an analysis of the results of type 084X, a configuration to improve the remaining rings was derived.

Flow sampling tests were made of the two rows of orifices inboard and outboard of the larger regeneratively cooled circumferential baffle of injector F2009. These are not separate rings, but are actually drilled into the base of the baffle. The results gave 0.8+ lb/sec/group and 1.45 lb/sec/group for the inner and outer rows respectively as opposed to design values of 0.71 and 1.09 lb/sec/group. These results indicated a slightly fuel rich mixture ratio in these zones, probably accounting for the lower performance of the injector.

A different type of testing from that described above is carried out at the Medium-Flow Facility. Here the testing philosophy encompasses three basic areas: research, development, and support. The primary concern is the gathering of detailed information rather than gross or average data such as are accumulated at the High-Flow Facility.

A study was made to determine the fan formations of two orifice groups having their jets shielded to the point of impingement. The groups were a doublet and a triplet (Fig. 48) with the orifice diameters sized such that the total areas of both groups were approximately equal. As was to be expected, the pressure drops, therefore, were approximately equal. Both groups yielded elliptical cross-section fans. The major axis to

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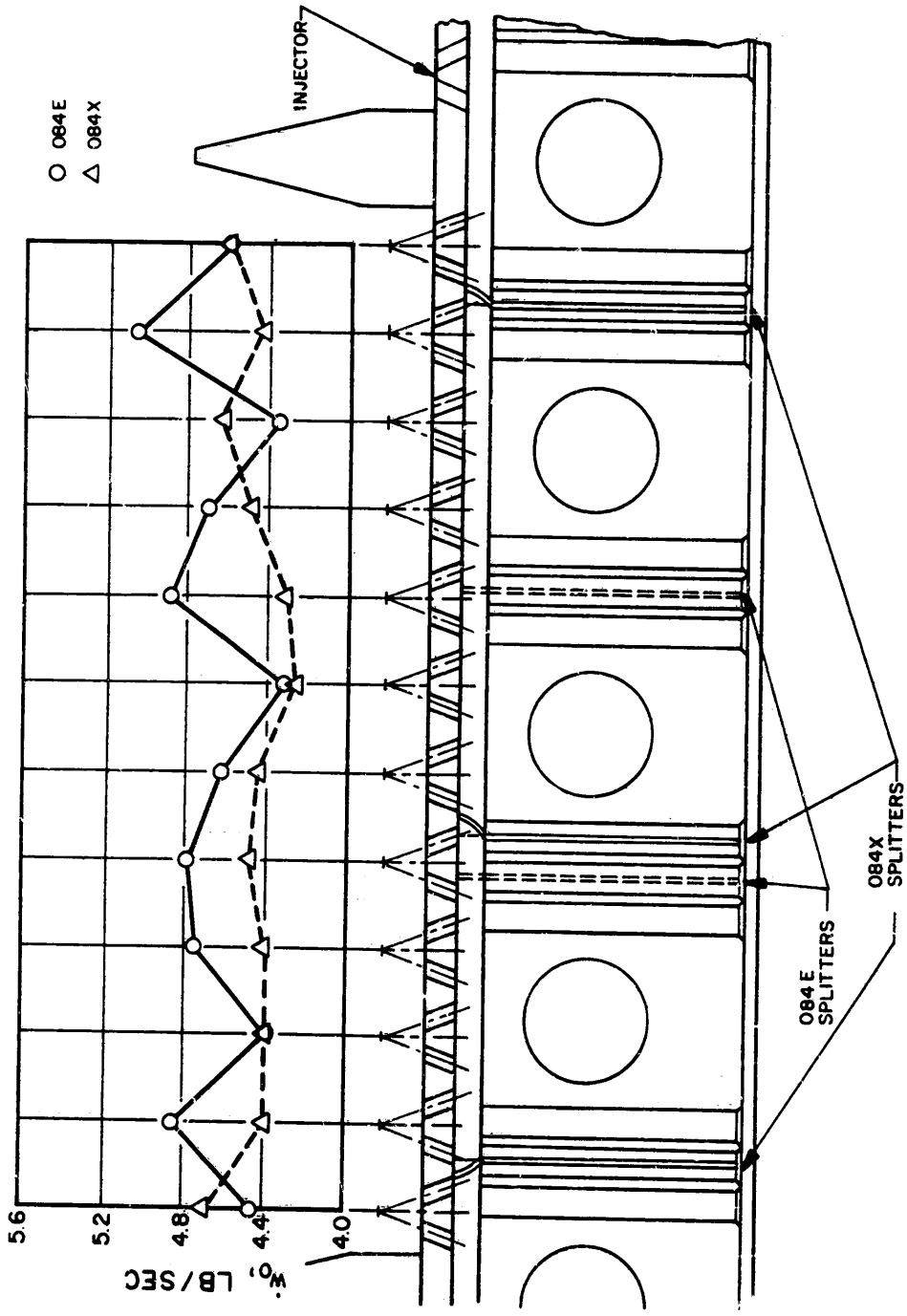
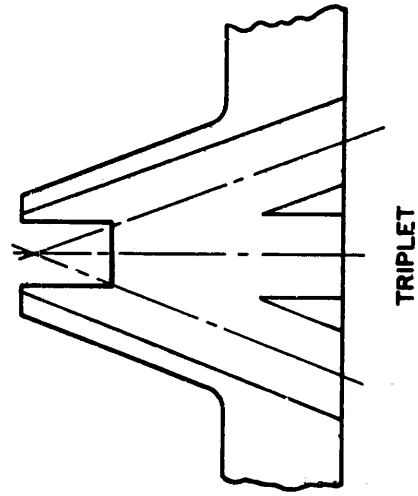


Figure 47. LOX Ring, -57

[redacted]

[redacted]



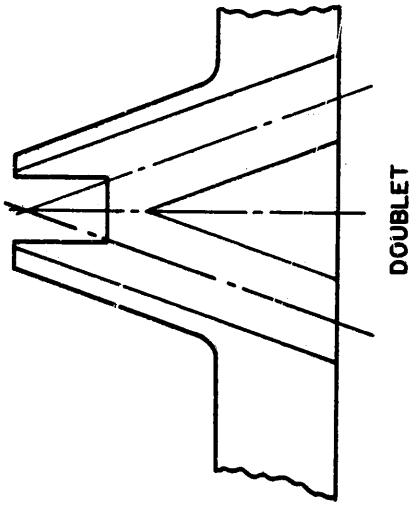


Figure 48. Sheilded Stream Orifices

[redacted]

minor axis ratio of the doublet fan, however, was approximately 2 as compared with 6 for the triplet fan. The frontal fan shape (perpendicular to the plane of impingement) was parabolic for the doublet and triangular for the triplet.

The design of the full-scale F-1 injector employing an H-1 type orifice pattern (injector X058) required that the igniter system housings be set into the rings at an angle of approximately 7 degrees in order not to disturb the basic pattern. It was desirable that the igniter spray, however, be injected parallel to the chamber axis. Flow tests were, therefore, conducted on igniter housings to develop a design that would tilt the spray fan in the desired direction and amount. It was found that offsetting the housing slot from the centerline by a few thousandths of an inch can tilt the fan as much as 13 degrees. The configuration to yield the desired 7 degrees was determined experimentally, and verification tests were conducted on a set of housings fabricated for injector X058. Twelve of the 16 housings gave fans tilted within 1 degree of the desired angle.

A valuable technique for assessing the mixing characteristics of a propellant injection scheme has been the use of different colored dyes in the effluent streams. This technique was used in evaluating a spud device known as the microtangent tube. This device is so called because its design consists of a set of small diameter tubes stacked within a larger tube. Oxidizer flows through the tubes and fuel through the interstices between tubes. The mixing characteristics were found to be fair. A shroud of fuel surrounded the spray core. This is beneficial from the standpoint of chamber compatibility, however. Pressure drop on the oxidizer side was slightly higher than desired, although this could probably be overcome by a slight redesign and better control during fabrication.

As was mentioned in the test and analysis section of this report, considerable experimentation with the canted oxidizer orifice groups adjacent to the radial baffles was undertaken. Hydrodynamics support testing was also accomplished during this period. Three orifice groups, 0.185/0.209, 0.185/0.242, and 0.242/0.297 used respectively on injectors X044, X049, and 084, were flowed and photographed. Figure 49 shows the spray fans obtained with two of these orifice groups. It is from photographs such as this that configurations may be selected for test firing in an injector, the choice depending on the criteria to be evaluated. Of the orifice groups tested during this study, the 0.185/0.242 was superior both from the standpoints of fan density and cant angle.

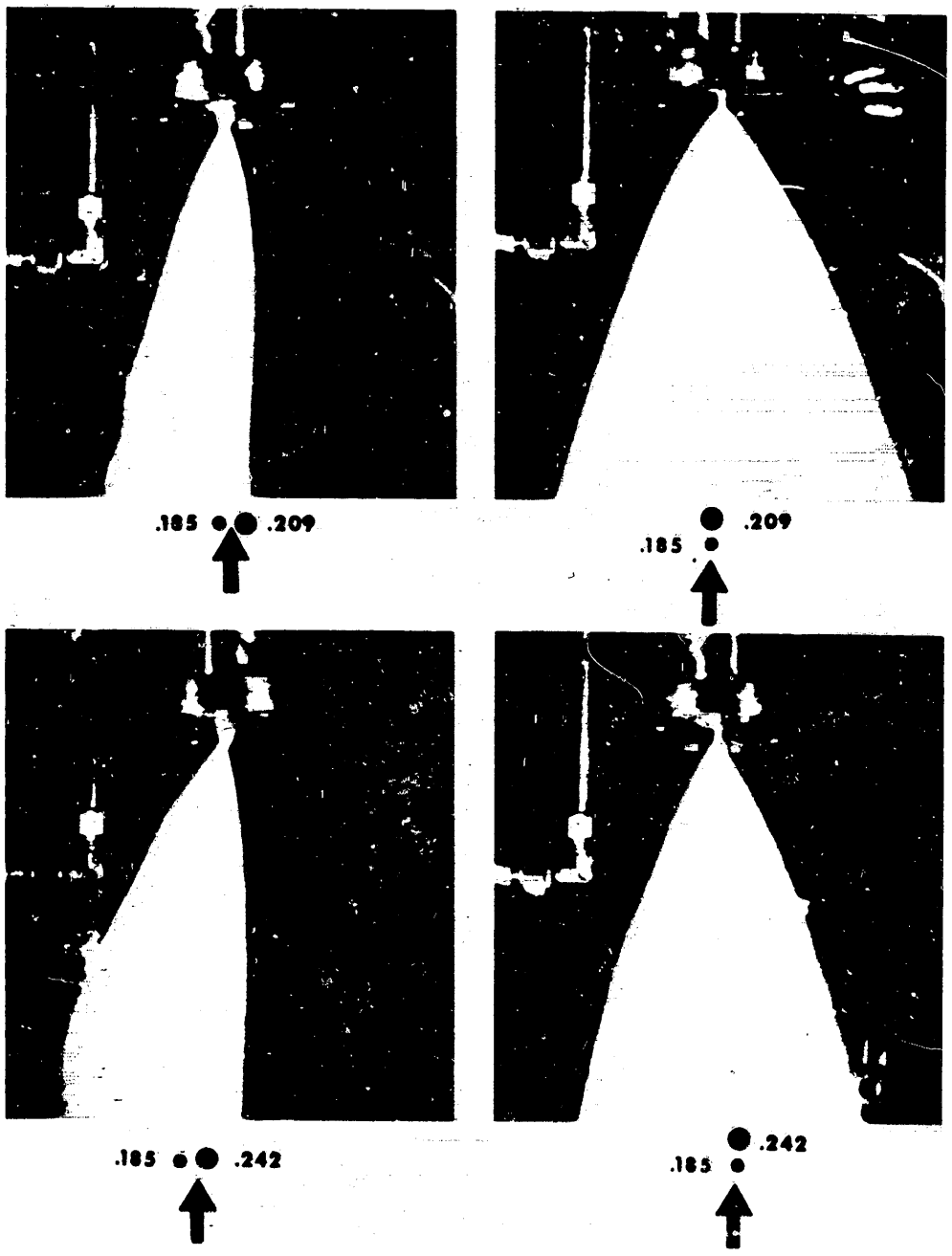


Figure 49. Overlapping LOX Fans

DESIGN

At this point in the program major emphasis in the design phase of Project First activity was being placed on isolating and determining the magnitudes of those factors that would eventually lead to the selection of a Qualification injector. For this reason, work on unconventional, exotic, and advanced concept injectors was temporarily suspended during this period. Efforts were concentrated, instead, on modifications to existing injectors and the design and fabrication of new injectors incorporating features beneficial to performance and stability.

INJECTOR MODIFICATIONS

The stringent requirements for the Qualification injector and the impending incentivation of the F-1 R&D contracts required that the greatest amount of information on proposed injectors and design changes be acquired in the shortest possible time. Past experience indicated that the best way to accomplish this is the modification of existing injectors to incorporate changes for quick evaluation on the thrust chamber test stand, 2A, and a large number of injectors were modified during this period. Most of the modifications* described in the following paragraphs were tested during the period, and a discussion of the results is contained in the Testing and Analysis section of this report.

Injector X021 was similar in design to injector 082B. It had a 13-compartment baffle system, 3 inches in height, with in-line, programmed

*For a description of the previous design characteristics of the injectors described herein, refer to R-5615-9, History: Project First, F-1 Combustion Stability Program, Volume 3, Book 1, Rocketdyne, a Division of North American Aviation, Inc., Canoga Park, California, CONFIDENTIAL.

radial vanes. The fuel side was the same as the standard Block 2 type injectors. The oxidizer side had 0.209-inch-diameter doublets impinging at an angle of 56 degrees 24 minutes. The injector was modified by the addition of 146 unlike doublet orifice groups, 102 in the outer compartments and 44 in the inner compartments. The orifices were sized to flow 1 percent of the total flow at a mixture ratio of 1. In a later modification the orifices were enlarged to accommodate 3 percent of the total propellant.

Injector X049 was similar to the Block 2 type injectors in every respect except for the use of excessive overlap in the oxidizer orifice groups adjacent to the radial baffles. In an effort to improve performance, the axial feed passage splitters were removed from the oxidizer side and the outer fuel ring was further restricted from 70 to 60 percent of nominal flowrate.

Injector X058 was a full-scale F-1 injector employing a modified H-1 configuration orifice pattern. In an effort to gain stability and performance increases, the injector was modified by enlarging the fuel orifice area to lower the fuel injection velocity to 78 ft/sec. Angles of the fuel doublets adjacent to all confining surfaces were changed from 40 to 30 degrees. Fuel flow from the inner and outer circumferential baffles was reduced to 2.7 percent. The radial baffles were regeneratively cooled.

Injector X060 was a rotated, regeneratively cooled baffle configuration with a modified FRT ring set. The radial fuel feed ports were tapered, and fuel flow to the outer ring was restricted to 60 percent. The unit was first tested during this period and was subsequently modified to increase the area of the oxidizer groups adjacent to the radial baffles

for performance improvement. The groups had 0.221-0.250-inch-diameter orifices with typical canted fan impingment angles.

The stability checkout of the regeneratively cooled baffle concept was made with unit 084. The baffles on this injector, however, were not themselves regeneratively cooled. The coolant orifices in the radial baffles had been plugged so that the concept could be checked with short-duration tests. During this period, the radial baffle orificing was restored and the fuel flow to the outer ring was restricted to 60 percent. The large-orifice (0.242-0.297-inch-diameter) canted fan groups adjacent to the radial baffles were retained, providing an oxidizer-rich condition in these areas. This apparently accounts for the lack of performance gain.

Injector 095 was originally a Block 2 configuration injector. It was first modified by increasing the overlap of the canted fan groups adjacent to the radial baffles to 0.242-0.272-inch diameters. During this period the splitters in the oxidizer axial feed passages were removed to simplify the construction. Upon testing, the stability of the Block 2 configuration remained unchanged, and there was a slight performance gain.

Baffle configuration changes were accomplished on two injectors during the period. Such changes, because of the methods of baffle attachment and cooling, require rebrazing the injectors in the furnace and, consequently, are classified as major modifications. The 6-inch-high, dual parallel passage, (Fig. 50) dump cooled baffle system on injector 097 was replaced with a conventional 13-compartment baffle system except for the height, which was only 2.8 inches. The outer dump cooled circumferential baffle of injector 2009 was replaced by a regeneratively unit with fuel injection at either side of the base. The base coolant orifice groups were matched to the adjacent oxidizer rings and were sized to

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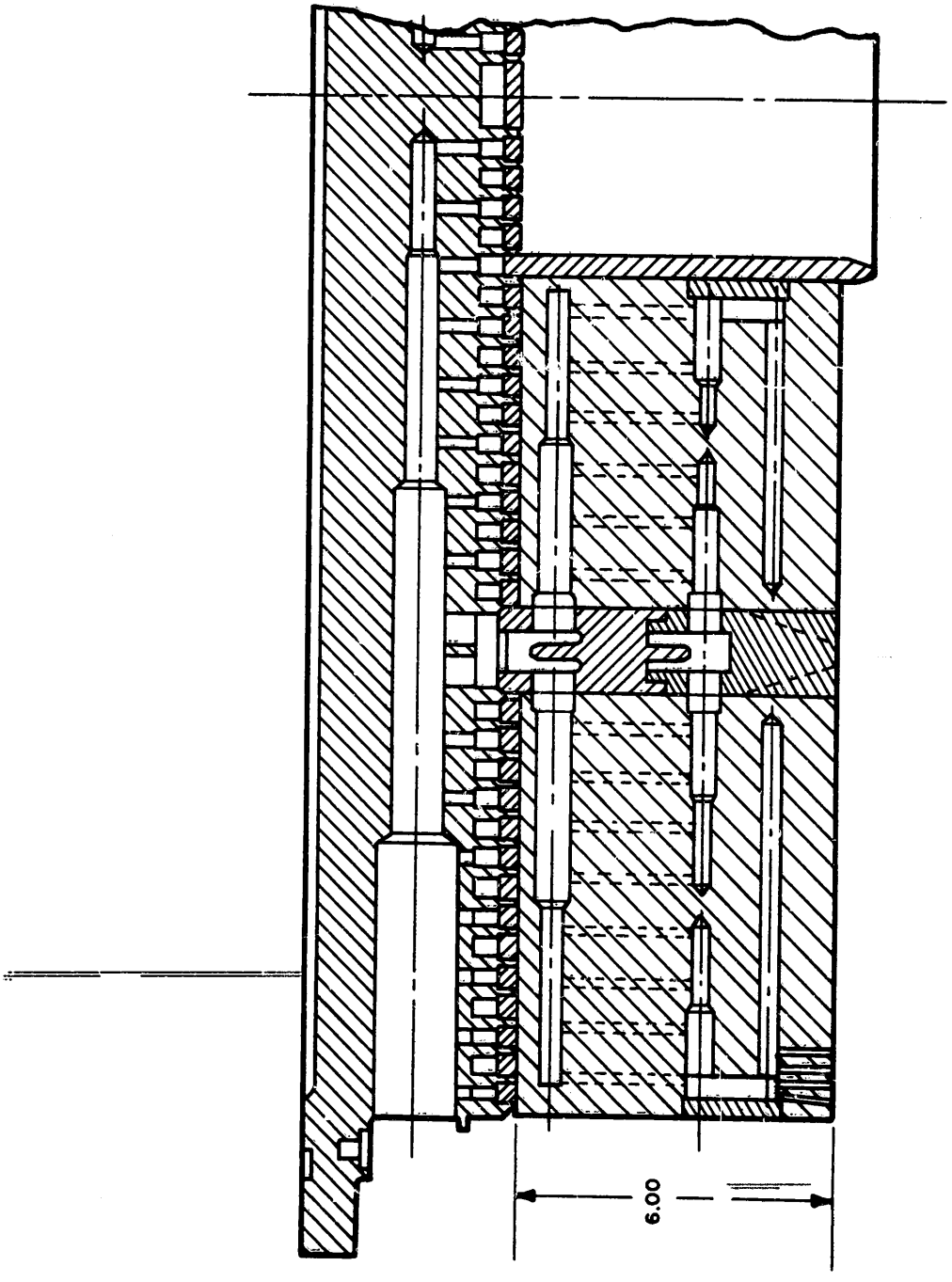

RANDOM SECTION
BAFFLE ORIFICES OMITTED FOR CLARITY

Figure 50. Injector 097, 6-Inch, Rotated Baffles

[redacted]

provide a mixture ratio of 2.4 with half of the oxidizer ring flow. The splitters in the LOX axial feed passages were also removed from this injector.

Injector 099 was a 25-compartment injector with the ring orifice areas programmed to provide a selected radial injection density profile. The baffles were of the conventional dump cooled design except for their greater number owing to the increased compartmentation. A chamber compatibility problem was detected when the injector was tested. The restrictors in the outer ring axial feed passages were removed to eliminate this condition.

Injector 100 was modified to improve its performance. The orifice pattern was basically a double-row fuel, single-row oxidizer design. The oxidizer area adjacent to the radial baffles was increased and the impingement angle was changed from 40 to 45 degrees. Significant improvement in performance resulted from these modifications.

NEW INJECTOR DESIGNS

Four significant new injector designs were released for fabrication during the period. All of the designs employed features directed towards application in the Qualification injector design. Most of these features were not suitable for incorporation as minor modifications to existing injectors. For others, there was sufficient analytical justification to warrant their initial use in a new injector design rather than in existing injectors which might have other undersirable characteristics that could obscure the test results.

Injector X043 was the only newly designed injector to be tested during the period. The orifice pattern of X043 was identical to that of the Block 2 injectors, except for the canted oxidizer groups adjacent to the radial baffles. The orifice diameters of these groups were 0.213 and 0.272 inch, the larger being closer to the radial baffles. To reduce thermal gradients across the rings and lower injector face temperatures, the ring thickness was increased to 0.550 inch. It was believed that this action would help to relieve the high ring-to-land stresses, thereby improving injector durability. High-strength braze joint plating techniques were used on this injector. The baffle system with the regeneratively cooled radial vane design (Fig. 51) was incorporated.

A different regeneratively cooled baffle system was used on injector X044. This design (Fig. 52) had a regeneratively cooled outer circumferential baffle with fuel injection at the base. Other new features were tapered radial fuel feed ports (Fig. 53) with the fuel ring grooves machined deep to intersect these ports. There were no axial fuel feed passages as such in this unit. The oxidizer axial feed passages were enlarged. The orifice pattern, in addition to the fuel injection groups at the base of the outer circular baffle, differed from the Block 2 type injectors in the canted groups adjacent to the radial vanes. The orifice diameters of these groups were 0.185 and 0.209 inches.

Injector X057 was a 13-compartment, rotated, wide-base, baffled injector. The dump cooled baffles had a nonstandard height of 2.8 inches. A radially aligned, programmed orifice pattern, similar to that used on injector 099, was employed in an attempt to obtain the stability and performance characteristics of the 25-compartment injector. High-strength plated rings, 0.550 inch thick, were also used on injector X057.

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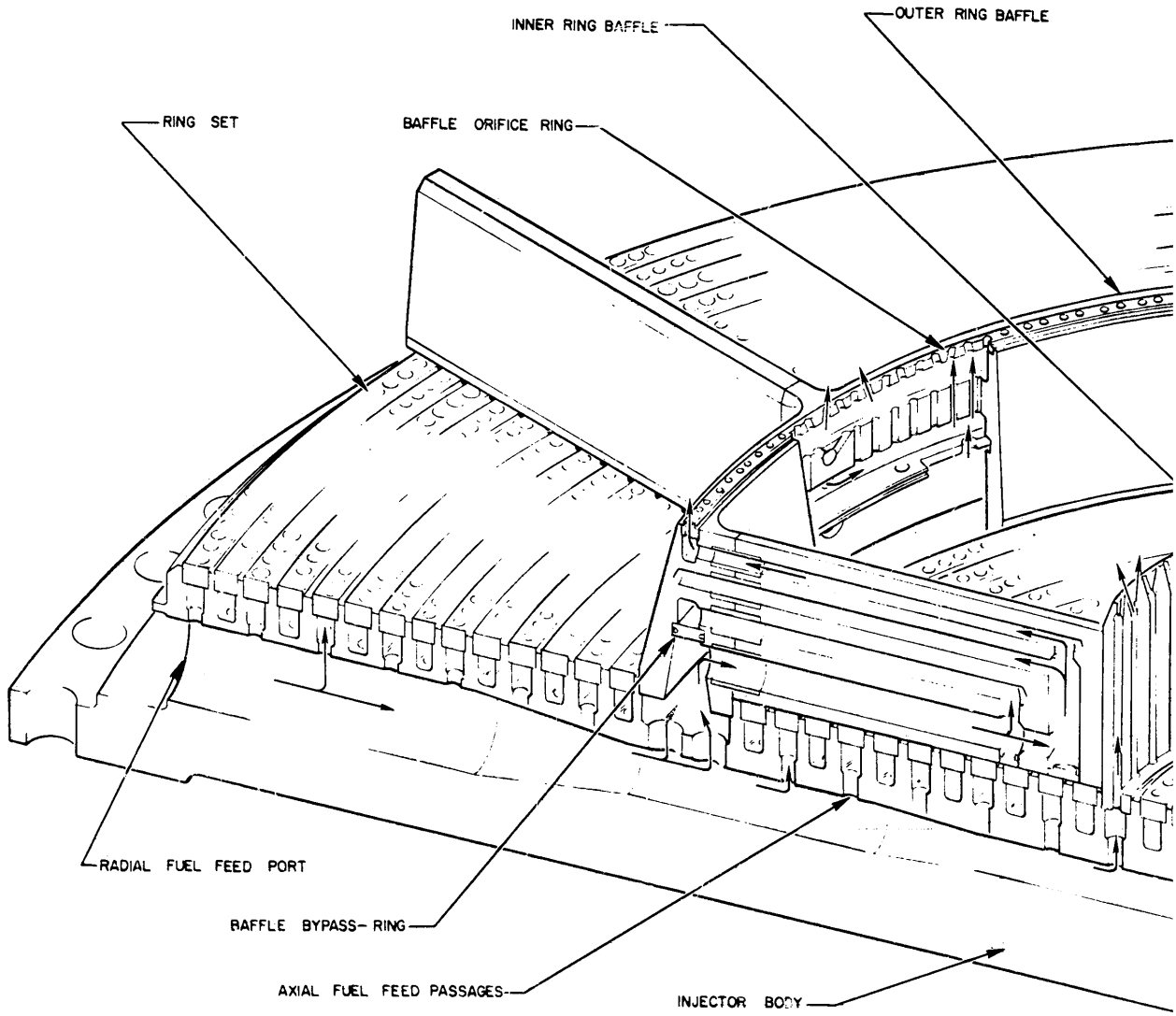

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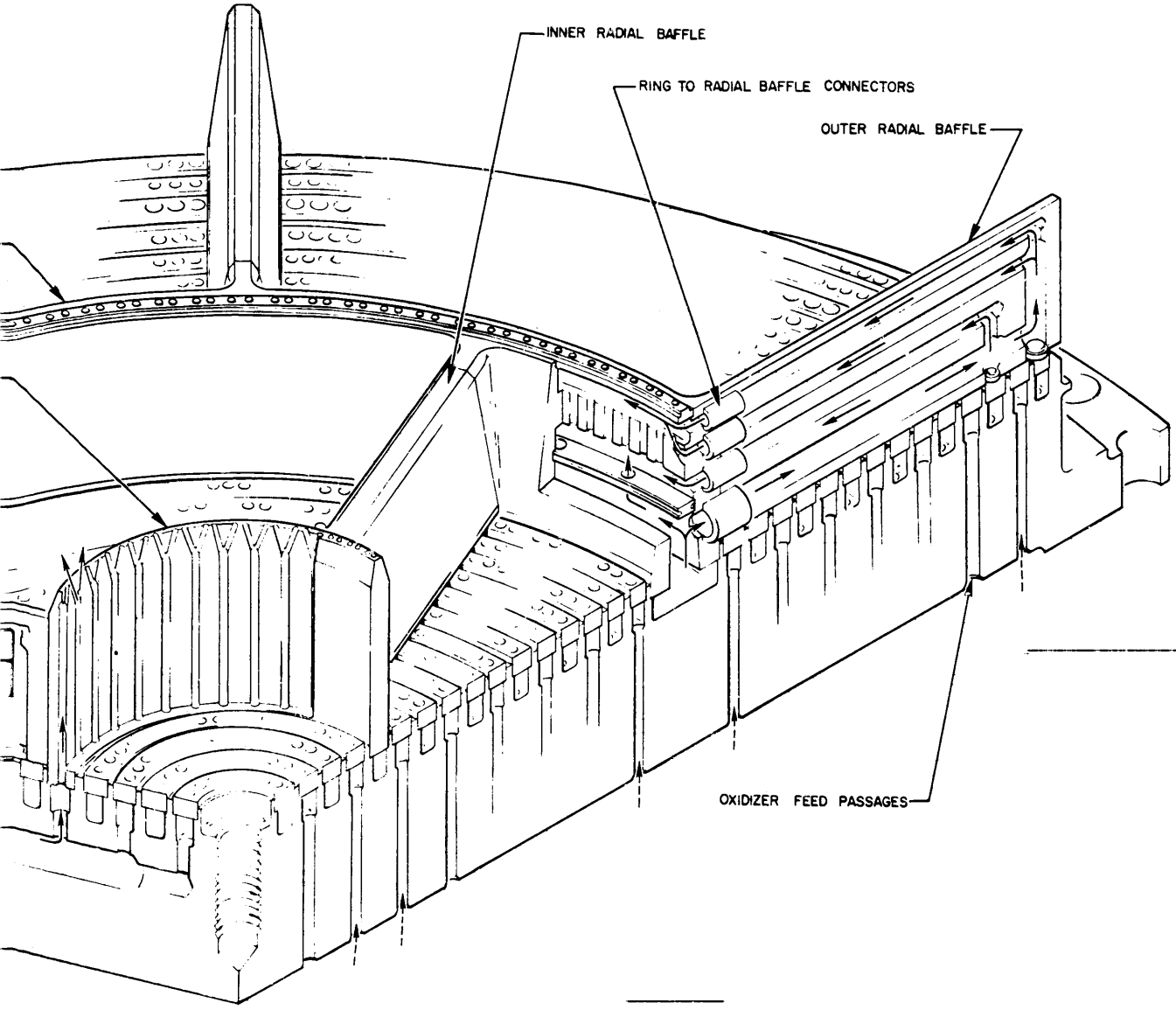

Figure 51 . Regeneratively Fuel-Cooled Radial Baffles

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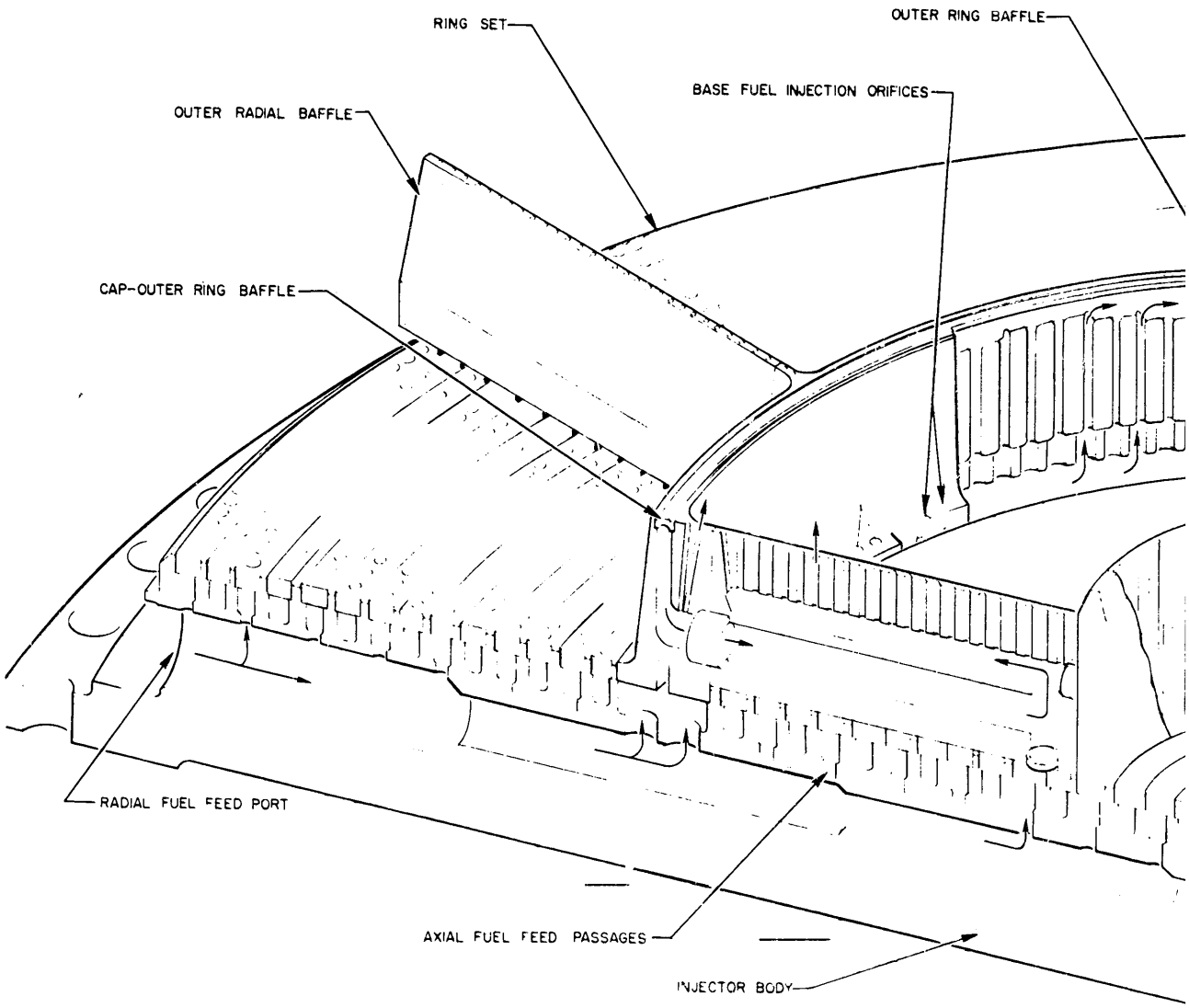
RING SET
OUTER RING BAFFLE
BASE FUEL INJECTION ORIFICES
OUTER RADIAL BAFFLE
CAP-OUTER RING BAFFLE
RADIAL FUEL FEED PORT
AXIAL FUEL FEED PASSAGES
INJECTOR BODY

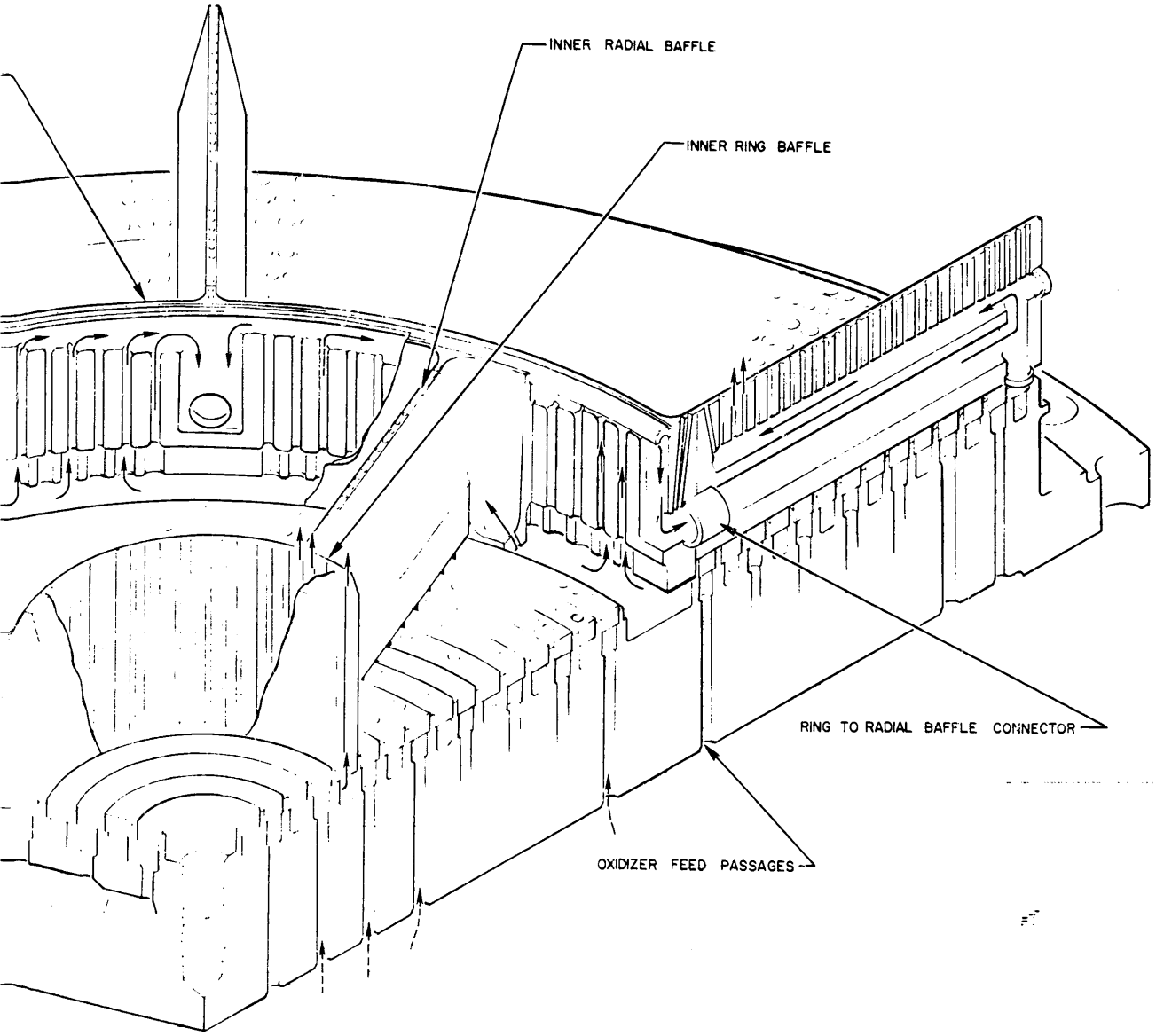

Figure 52. Regeneratively Cooled Outer Ring Baffle With Base Fuel Injection and Dump-Cooled Radial Baffles

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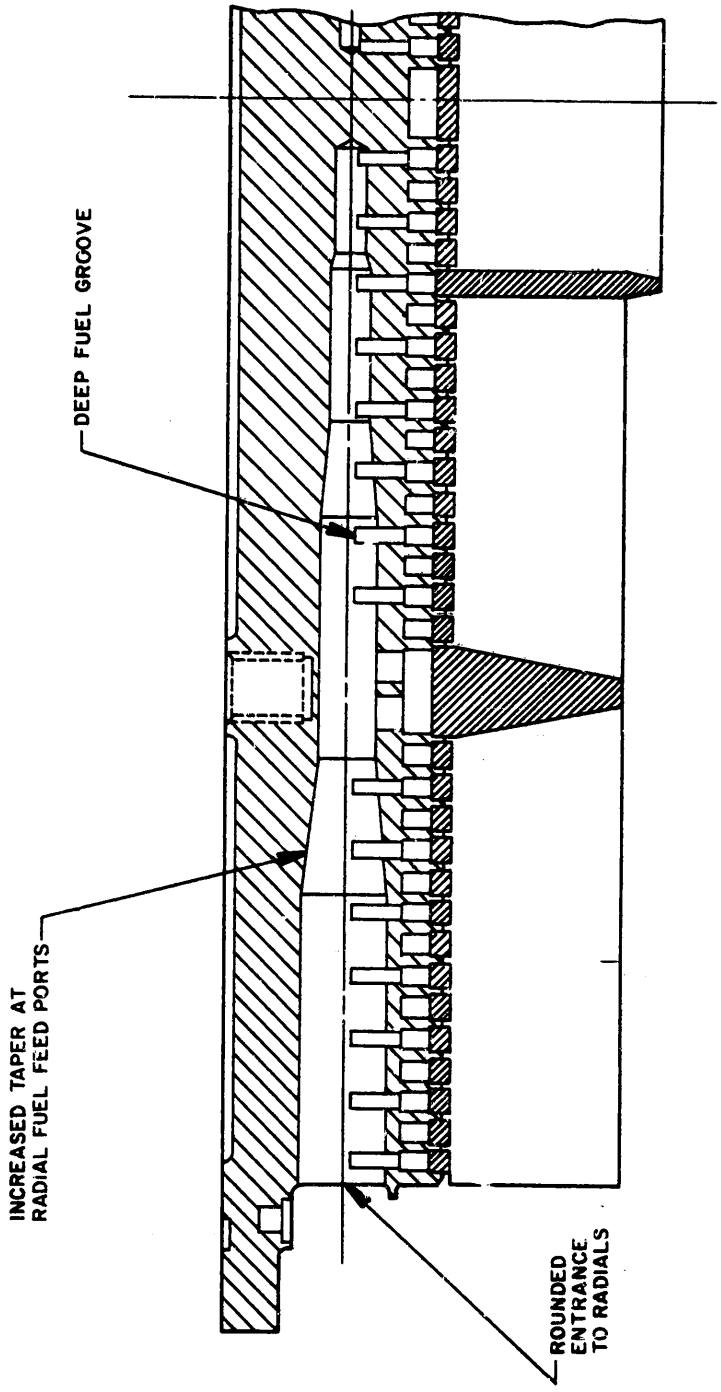

Figure 53. Hydraulic Improvement Configuration, Injector X044

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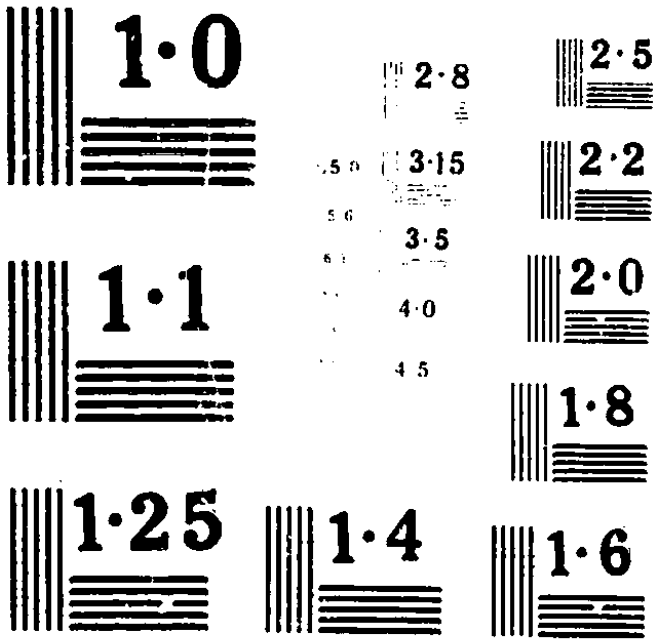

NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

The tapered radial fuel feed ports were again used on injector 105. This, however, was the only hydraulic improvement made on the body of this injector. The orifice pattern was a Block 2 type except for the canted oxidizer orifice groups whose diameters were 0.199 and 0.234 inches. The baffle system was standard except for the 2.8-inch height. This unit also had high-strength plated rings, 0.550 inch thick. Fuel flow to the outer ring was restricted to 60 percent to improve performance.

REGENERATIVELY COOLED BAFFLE SYSTEMS

Since baffles were first adopted as stability devices on F-1 injectors, an ultimate aim was the incorporation of a regeneratively cooled system. The advantages of such a design are obvious, particularly in light of the single-propellant, dump cooled systems used on the F-1. Returning the coolant flow for injection to the combustion process at the injector face would allow all sections of the combustion chamber to burn at the same mixture ratio, thereby increasing the performance potential.

Several regeneratively cooled baffle schemes were proposed for the F-1. In most such concepts the baffle coolant flow is ducted into one or more ring grooves to which feed from the radial fuel feed ports has been eliminated. The flow is then injected in the normal ring-type manner. Another design utilizes the chamber by-pass fuel flow, ducting it into the baffle system through a separate manifold mounted on the injector. The coolant is then combined with the main fuel flow at the entrance to the radial feed ports and distributed through the injector in the normal manner.

A slightly different approach to regenerative baffle cooling was taken on the F-1. Two systems with partial regenerative cooling were tested during the period. All other injector parameters being equal, these designs are stronger than the dump cooled systems. Because none of the coolant flow is lost in the regenerative portion, velocities are higher throughout entire system, thus improving the heat transfer characteristics. An alternative approach would permit maintenance of dump cooled baffle velocities in partial regenerative systems with a reduced amount of flow, the excess being injected through the rings, thus providing for increased performance potential.

The two partial regenerative cooled baffle designs are shown in Fig. 51 and 52 . In the system shown in Fig. 51 the radial baffles are regeneratively cooled. In the system shown in Fig. 52 the outer circumferential baffle is regeneratively cooled. The inner circular baffle of both systems is dump cooled.

Various injector flow analyses had shown that the mixture ratios in the annular zones on either side of the circular baffles was quite high. This arises from the fact that the baffles replace normal fuel rings in these areas and the baffle coolant flow is not sufficient to counterbalance the surrounding oxidizer flow. Consequently, the total flowrate through the regenerative radial baffle design was theoretically set to be higher than that through dump cooled baffles. With this design, flow passage from the injector body to the upper portion of the circular baffles is restricted, forcing much of the coolant into the radial baffles. After flowing through a series of passages in the radials, the coolant is then introduced into the upper portion of the circular baffle where it is injected through the tip. The tip injection orifices are of the self-impinging type to increase propellant atomization, enhancing performance. The amount of flow was set according to the requirements of the adjacent oxidizer rings.

The regenerative circumferential baffle design takes the flow from the injector body through passages to a manifold in the tip. The coolant then flows along this manifold to other passages leading to the radial baffles. Flow in the radial baffles is of the conventional dump cooled design. The problem of supplying fuel to combine with the adjacent oxidizer ring flows is handled in the regenerative circular baffle design by the addition of self-impinging fuel orifice groups at the baffle base. These orifice groups, which are fed directly from the groove which supplies the baffle system, are sized so that their respective flowrates provide an equivalent mixture ratio of 2.4 when combined with half of the adjacent oxidizer ring flow.

INJECTOR DURABILITY

The studies to determine the cause of ring cracking and braze joint failures on F-1 injectors were continued. A test fixture simulating a small area of F-1 oxidizer rings was designed and built. It was planned to thermally cycle the fixtures by induction heating to determine whether ring cracking could be simulated through thermal processes and whether such failures were associated with a given fatigue life. The configuration of the test device is shown in Fig. 54 .

Injector 085 was tested with 11 thermocouples installed in the rings. The results indicated that the oxidizer ring temperatures were lower than those encountered on injector 082. A gradated Inconel-zirconium oxide refractory coating was used on injector 082 in an attempt to insulate the ring surfaces from the combustion process. Durability of the coating was unsatisfactory and the temperature data were inconclusive.

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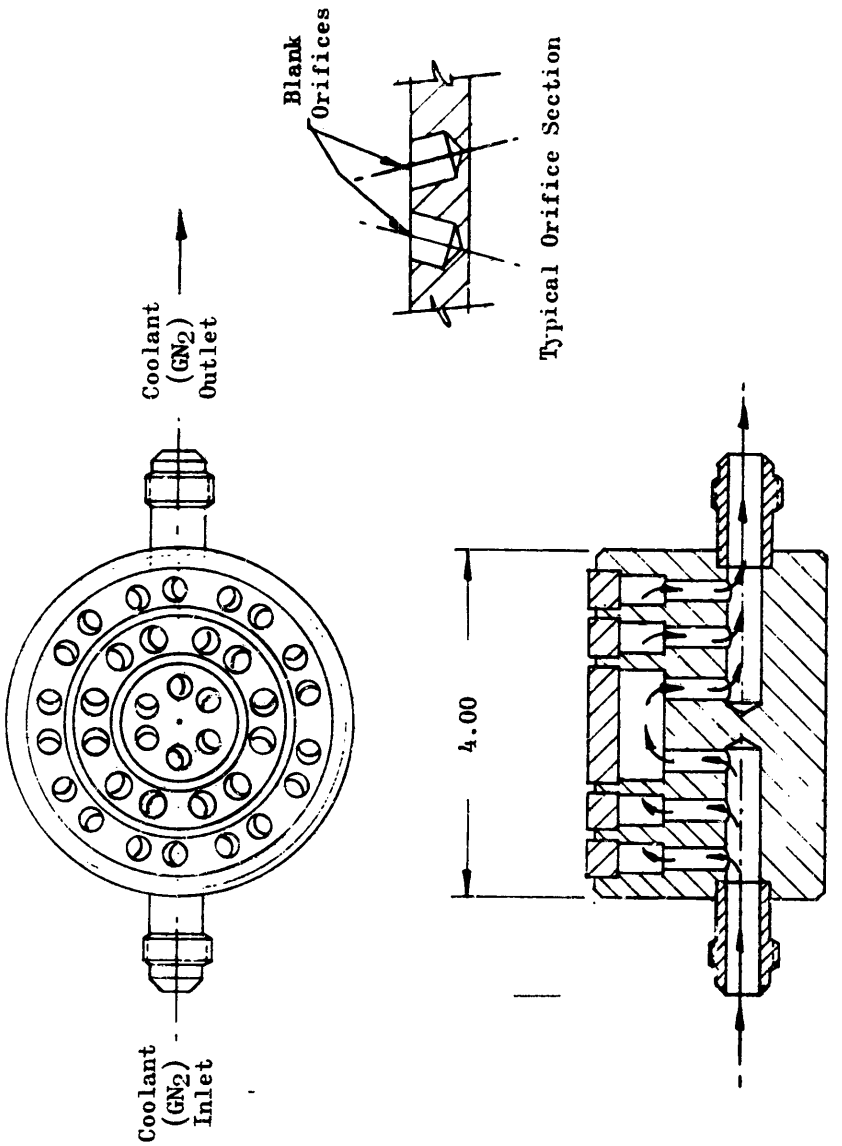

Figure 54. Thermal Cycle Test Fixture

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Eleven braze test bodies and ring sets were fabricated for braze joint evaluation tests. The configuration of the test assemblies was the same as the first 10 rings of the F-1 injector. Various types and combinations of platings were used to evaluate their effects on braze joint strength. The assemblies were alloyed, cycled through the furnace, and then hydrostatically pressure tested until failure of the brazed joint occurred. Sections of the failed joints were analyzed to determine the mode of failure. The average failure pressures and the types of plating used for each test body are summarized on Table 3. The thickness of the ring set is specified by the number in parentheses.

The test data indicate that the nickel-plated injector bodies (347 stainless steel) and gold-plated orifice rings (oxygen-free, high-conductivity copper) produce excellent braze joint strengths. As a result of the testing, an optimum plating thickness and braze gap was determined. It was planned to incorporate the configuration into development injectors for hot-firing evaluation during the next period. The configuration consists of nickel plating (0.0002 to 0.0004 inch thick) on the ring grooves and gold plating (0.0002 to 0.0004 inch thick) on the rings, the braze gap held between 0.000 and 0.004 inch. Four additional hydrostatic test units of this configuration were also to be fabricated and tested during the following period to establish a confidence level.

[redacted]

TABLE 3

PLATINGS AND FAILURE PRESSURES

Body No. and Ring Thickness, inches	Plating, inches	Failure Pressure, psi
No. 1		
Ring Grooves	Vapor honed	
Ring Set (0.350)	Gold (0.0006/0.0010 thick)	25,500
No. 2		
Ring Grooves	Gold (0.00019 thick)	
Ring Set (0.350)	Gold (0.00011 thick)	28,700
No. 3		
Ring Grooves	Nickel (0.0002/0.0004 thick)	
Ring Set (0.350)	Gold (0.00011 thick)	27,290
No. 4		
Ring Grooves	Nickel (0.0002/0.0004 thick)	
Ring Set	Gold (0.0006/0.0010 thick)	21,800
No. 5		
Ring Grooves	Vapor honed	
Ring Set (0.350)	Liquid gold	26,625
No. 6		
Ring Grooves	Nickel (0.0002/0.0004 thick)	
Ring Set (0.350)	Gold (0.0001/0.0002 thick)	27,600
No. 7		
Ring Grooves	Nickel (0.0002/0.0004 thick)	
Ring Set (0.350)	Nickel (0.0002/0.0004 thick)	19,000
No. 8		
Ring Grooves	Gold (0.00019 thick)	
Ring Set (0.350)	Gold (0.00011 thick)	38,950
No. 9		
Ring Grooves	Nickel (0.0002/0.0004 thick)	
Ring Set (0.350)	Chrome strike and nickel (0.0002/0.0004 thick)	24,410
No. 10		
Ring Grooves	Nickel (0.0002/0.0004 thick)	
Ring Set (0.350)	Chrome strike and nickel (0.0002/0.0004 thick)	14,670
No. 11		
Ring Grooves	Nickel (0.0002/0.0004 thick)	
Ring Set (0.350)	Gold (0.0003/0.0004 thick)	29,200

[redacted]

INSTRUMENTATION

INJECTOR RING TEMPERATURE MEASUREMENTS

When the problem of ring cracking arose on PFRT type injectors being tested at the Marshall Space Flight Center in Huntsville, Alabama, a concerted effort was made to determine F-1 injector face temperature during hot-firing operation. The art of installing thermocouples to measure injector face temperatures was not well developed. Ideally, a good installation is one which does not disturb the parent ring material and which is rugged enough to withstand the rigors of repeated testing. Where the ideal combination could not be attained, the emphasis was first placed on ruggedness.

The first attempts at installing thermocouples on F-1 injectors were made with injector 082. Three thermocouples were installed: one in a fuel ring, one in an oxidizer ring, and one on the steel outer periphery of the injector. Figure 55 shows the installation technique. A 0.090-inch-deep notch was milled into the surface of the ring. An 0.080-inch-diameter electroformed copper tip, which encased the thermocouple hot junction, was placed in the notch. The shielded leads were fed into a bomb boss and through the fuel feed passages of the injector body to a junction box mounted on the main injector flange. The thermocouples were fixed in place by the application of Nioro braze alloy which was then ground flush with the original ring surface.

The initial readings with this installation indicated oxidizer ring temperatures of 900 F and fuel ring temperatures of 550 F. A fair amount of confidence was placed in these first values as being "nominal" ring

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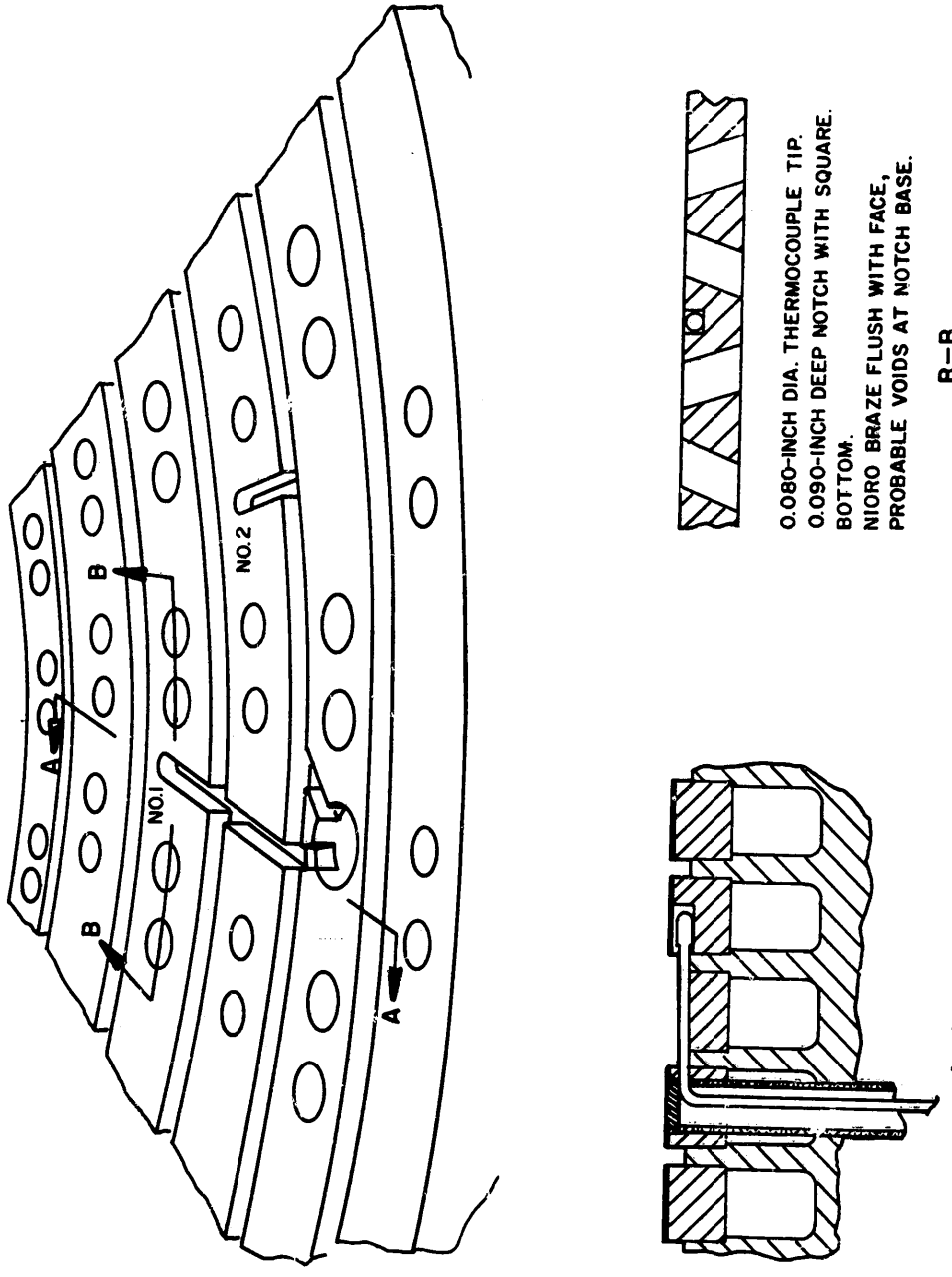

Figure 55 Original Thermocouple Installation

[redacted]

temperatures, however, data from other injectors, such as injector X043, failed to substantiate these results. Referring to section B-B of Fig. 55 the reason for high readings becomes apparent. Should the braze alloy fail to flow around the thermocouple shield, air gaps or voids would result, and heat transfer rates would be reduced, leading to higher recorded temperatures.

An improved installation technique is illustrated in Fig. 56 . The electroformed copper tip was eliminated from the end of the thermocouple. The 0.040-inch-diameter thermocouple sheath was mounted in a 0.050-inch notch, which had a rounded bottom. This allowed more intimate contact of the thermocouple with the parent ring material. A higher fluidity braze alloy, BT, was substituted for the Nioro alloy used in the previous installation to decrease the possibility of air gaps. Other details of the mounting are similar to those described above.

Injector 085 was hot fired with 11 improved installation thermocouples mounted in the injector body and rings. The electroformed copper tip, however, was retained. The thermocouples were located between orifices of a pair and between pairs on both oxidizer and fuel rings, on the steel ring lands, and on the baffles. Seven full-duration engine tests and one short-duration test were conducted with this injector. Table 4 indicates the range of the temperature data obtained.

These results indicated that the temperatures obtained during the steady-state portion of a test were not sufficient to cause ring cracking. The maximum temperature at any particular thermocouple location varied little throughout the mainstage portion. Sharp temperature changes were noted, however, during the start transients.

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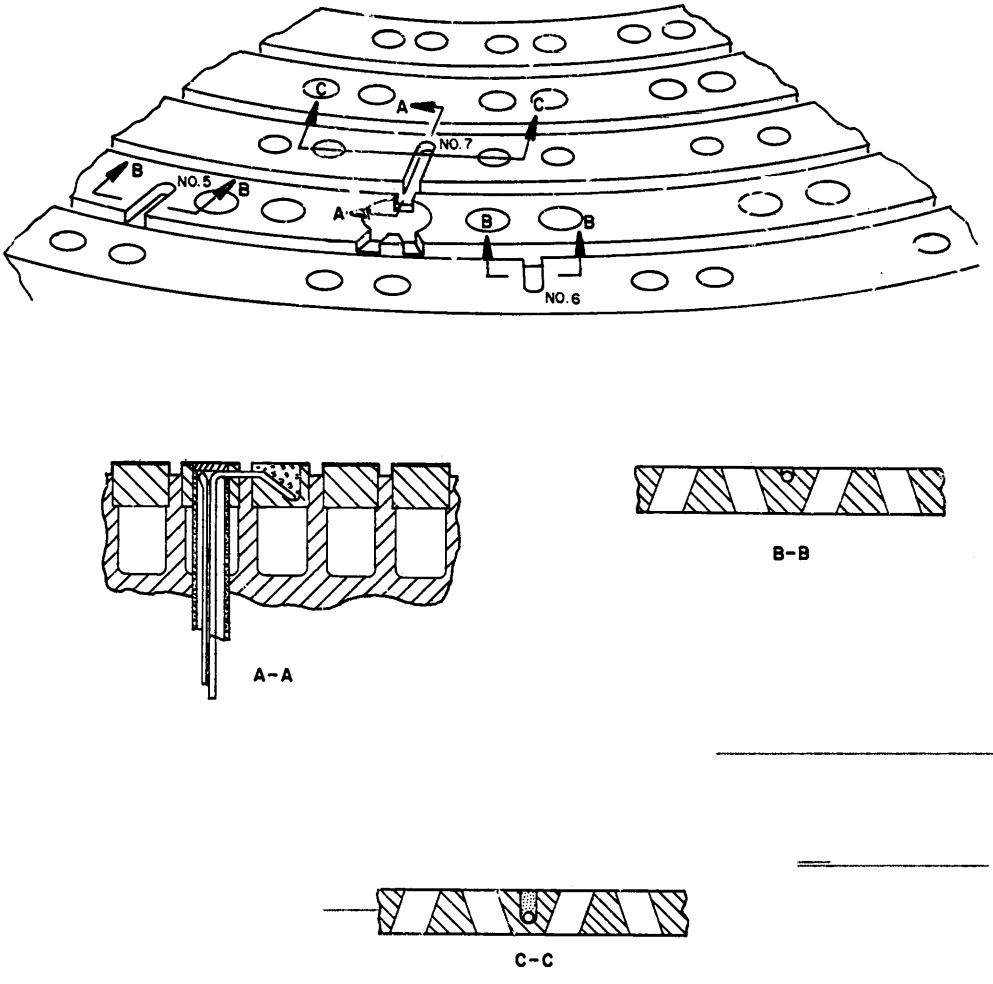


Figure 56. Improved Thermocouple Installation

[redacted]

TABLE 4

F-1 INJECTOR TEMPERATURE DATA

	Thermocouple Location	Temperature Range, F
1.	Fuel ring between orifices of a pair	350 to 400
2.	Fuel ring between pairs	230 to 260
3.	Oxidizer ring 0.040 inch from liquid side	-130 to -160
4.	Oxidizer ring between orifices of a pair	No reading
5.	Oxidizer ring between pairs	50 to -50
6.	Land between rings	50 to 100
7.	Top edge of outer circular baffle	In excess of 1200
8.	Middle side of outer circular baffle	In excess of 1200
9.	Base of outer circular baffle	No reading
10.	Outer steel land	475 to 610
11.	Outer periphery of injector body	540 to 700

Through analyses of the temperature data obtained with different injectors it was concluded that there was no single LOX or fuel ring temperature. Rather there were many. The factors influencing a given temperature reading included local pattern geometry, local injector flow characteristics, local heat flux, the presence or absence of an insulating layer of carbon, etc. The thermocouple installation technique itself can influence the reading. In view of this, conclusions based on temperature data must be derived carefully and only when there is a sufficient sample to establish a high statistical confidence level.

AVERAGE MEAN SQUARE ACCELERATION CHARTS

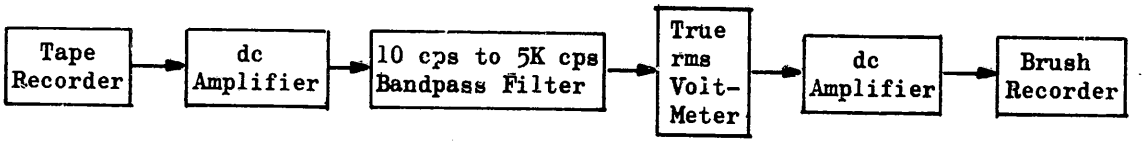
Concern was expressed over identification of a possible "noisy" engine. It was proposed that Average Mean Square Acceleration Charts (MSG) be used to determine the average vibration level of the F-1 engines. These are essentially broad-band plots of energy (vibration level) vs time. This procedure had been successfully used on the Jupiter and Thor engines and was being used to determine the average vibration level of the Atlas engines. The maximum acceptable average vibration level was set at 40 g rms (1600 g ms).

A modified true rms voltmeter is used to detect the average mean square value of the acceleration. To obtain a realistic evaluation of the trend in energy level, the averaging time of the meter was modified to three times (3T time), the time constant (T = RC) of the averaging circuit in the meter. The use of 3T averaging time ensures that at least 95 percent of the available information is considered for highly complex wave forms. A much greater percentage of accelerometer information is utilized because these wave forms are essentially stationary with time. There is a choice

of three different time constants available in the system: 0.833, 0.417, and 0.208 seconds. The recommended time constant for the F-1 analysis is 0.833 seconds (3T = 2.5 seconds).

The voltmeter used in this system had a crest factor (the ratio of the maximum amplitude of a voltage wave to the effective value) of greater than four. To accurately measure the true rms value of a complex wave form, a voltmeter must have a crest factor of at least three.

In practice, the accelerometer signal is played back from a tape recorder and amplified with a wide-band, dc amplifier as shown below.



The signal is then fed to the modified Ballentine true rms voltmeter, where it is converted to a mean squared value and averaged over a time span (3T) throughout the run. The information is channeled through another dc amplifier and graphically presented on a Brush recorder. The Brush recorder plots the averaged mean-squared voltage signal (calibrated in g of acceleration squared) as a function of time.

A summary of the results of MSG charts from 20 F-1 engine tests is tabulated in Table 5 .

TABLE 5

SUMMARY OF MSG CHARTS FROM 20 ENGINE TESTS
USING AN FRT-TYPE INJECTOR

Engine No.	Injector No.	No. of Tests	Arithmetic Mean, g rms	Standard Deviation, g rms	+ 3σ g rms	- 3σ g rms
013-2	X056	3	9.80	0.453	11.16	8.44
025	X052	2	9.95	0.022	10.02	9.88
025	099	4	11.05	0.018	11.10	11.00
024	085	1	11.40	--	--	--
2016	2017	3	11.20	0.530	12.79	9.61
2013	2013	2	11.30	0.000	11.30	11.30
2015	2016	3	10.00	0.290	10.86	9.14
014-1	X-53	1	10.60	--	--	--
014-1	104	1	8.70	--	--	--
All Tests		20	10.44	0.899	13.14	7.74

BOMB PROGRAM

Performance of the standard configuration combustion stability bombs at test stand 2A continued to be satisfactory; no failures or unusual detonation characteristics were experienced. Three FRT engines were successfully bombed with the new bomb, which incorporated a short ablative shield; detonation times averaged 760 milliseconds from 90 percent chamber pressure.

Use of the experimental, full-ablative-shielded, long-duration bomb was discontinued when a detonation failure on a double bomb test was experienced. The most likely failure mode was gradual softening of the thermoplastic inner parts, with consequent expulsion of the inner case and unexploded blasting cap while the ablative shield remained intact.

A new long-duration bomb that utilized only an ablative shield between the combustion chamber and the blasting cap was build but not tested during the report period.

The bomb research program was continued. The program was initiated to provide information on bomb performance relative to forcing combustion instability and to establish a means of characterizing bombs for rating and comparison. The paramount results obtained were with the Beckman and Whitley rotating mirror-streak and framing camera. It was demonstrated that the explosion pattern was primarily directed in a 360-degree radial pattern from the bomb and that the bomb case configuration and strength at the time of detonation can significantly affect the velocity and overpressure of the expanding detonation.

Figures 57 through 59 exemplify the photographs that were obtained and demonstrate the case strength effect. Each picture was taken at 66,600 frames per second or 15.15 microseconds between pictures. Note that the detonation expands much more rapidly as the thickness of the surrounding wall is decreased; it is believed that the reduced wall thickness bomb of Fig. 58 is typical of the configuration at the time of thermal detonation in the combustion zone. The pictured detonating bombs are:

Figure 57 A standard Model 14 bomb with a 13.5 grain E-81 blasting cap charge

Figure 58 A Model 14 bomb with the case wall thickness cut down from 0.235 to 0.100 inch.

Figure 59 An unshielded E-81 blasting cap

[redacted]

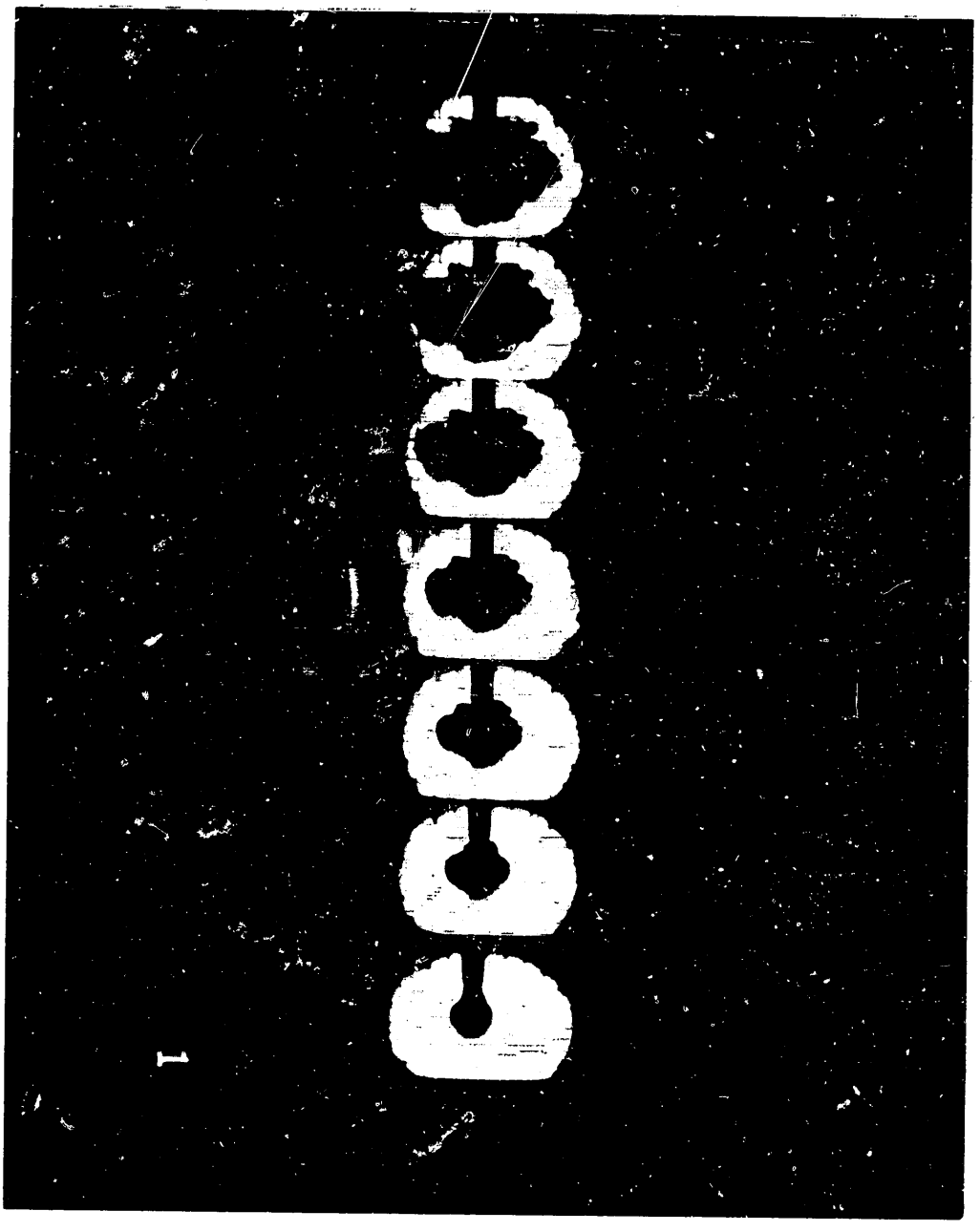


Figure 57 . Model 14 Bomb

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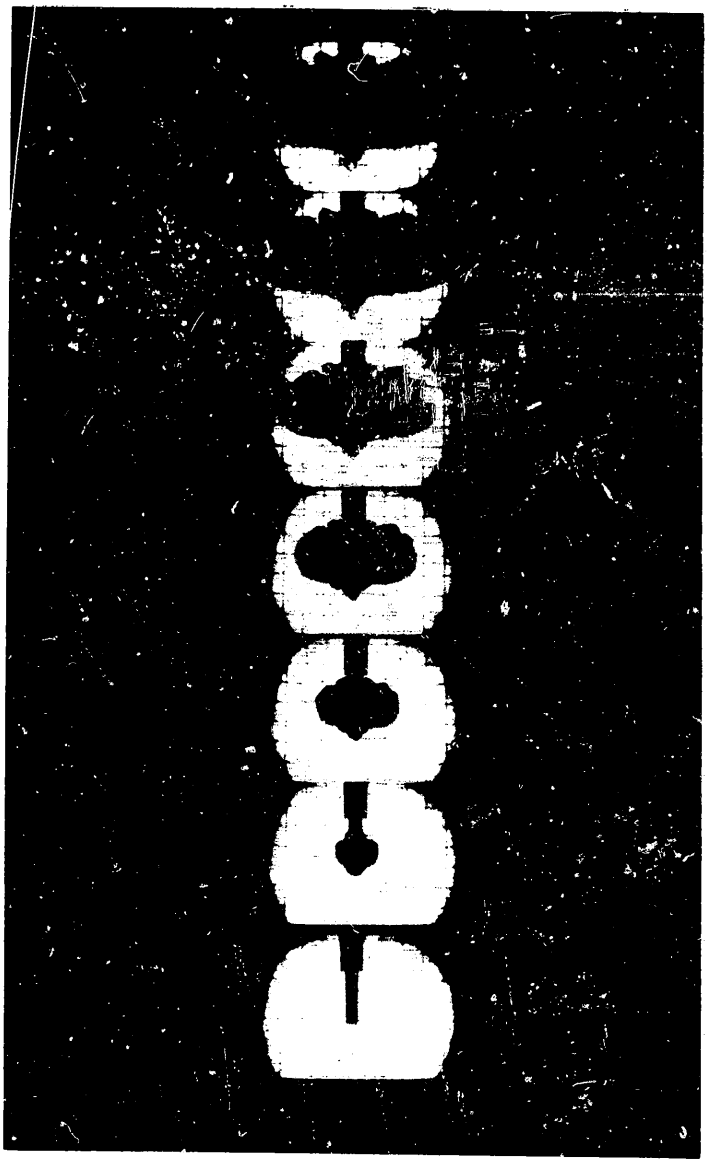

1DB99-3/30/65-S1

Figure 58. Model 14 Bomb With Reduced Wall Thickness

[redacted]

1DB65-5/20/65-S1B

Figure 59 . Unshielded E-S1 Cap

[redacted]

RESEARCH

With testing of the high-pressure, two-dimensional research motor (HP2D) temporarily suspended during this period, research activity was concerned with a variety of other more basic aspects of the combustion instability problem. Included among these were the data reduction and analysis of a backlog of HP2D tests, a review of Priem's combustion instability theory, and the pursuance of studies such as acoustic absorption and supercritical droplet heating.

HP2D ANALYSIS

An effort was made to obtain useful information from the horizontal streak film obtained during unstable operation of the HP2D motor. The data must be reduced during a time period when only axial gas flow exists. This, in turn required reference to the vertical streak film to determine when the flow pattern behind the wave front indicated axial flow. A lack of clarity in the vertical streak film hampered this effort. A reduction of the data from one run, however, indicated that the burning rate during unstable combustion was greater than that during steady state.

A summary of HP2D instability tests was prepared in the form of a plot of amplitude vs frequency for the various injectors employed (Fig. 60). Regions of instability, marginal stability, and dynamic stability are shown. With the exceptions of buzz instability points, no unstable points were found that had an amplitude range lower than 400 to 500 psi peak to peak.

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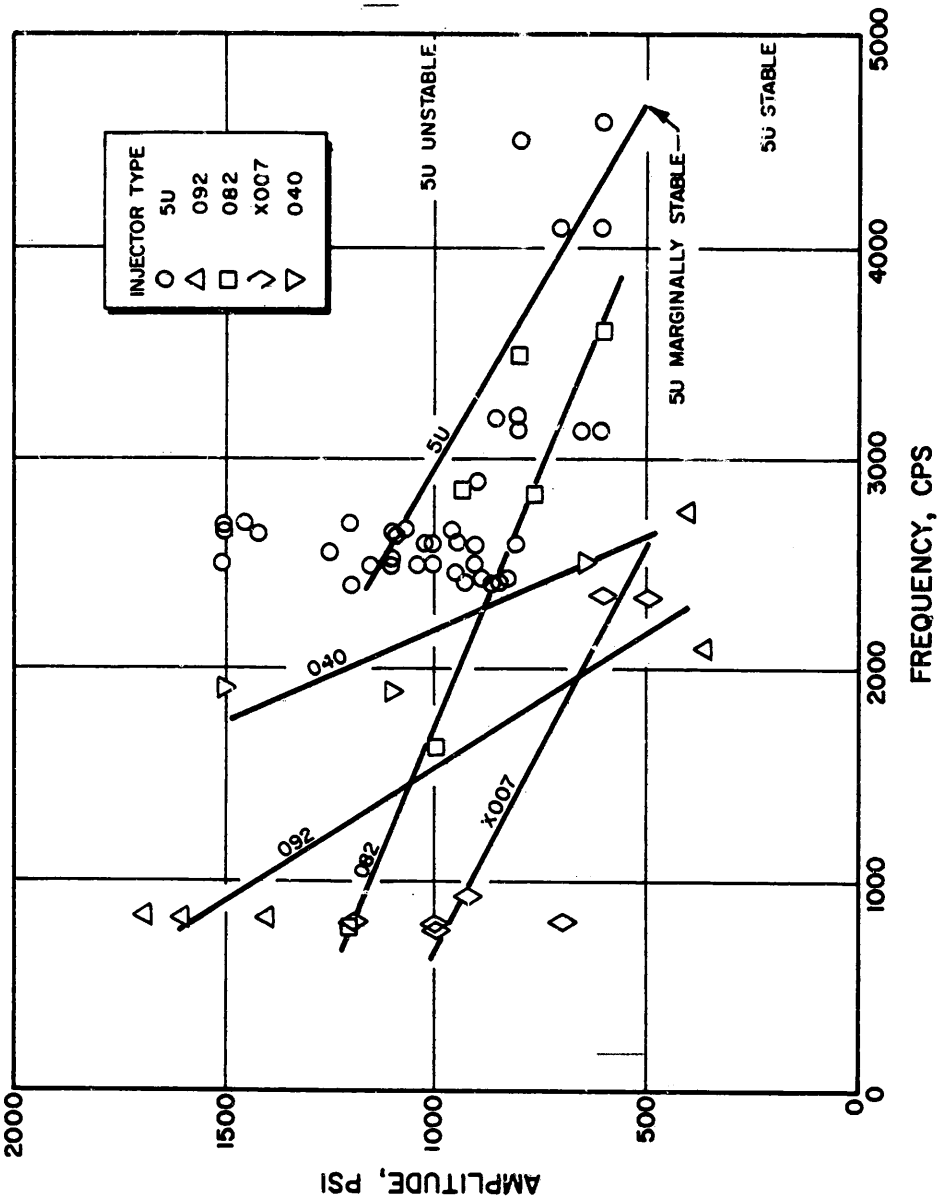

Figure 60 . Summary of High-Pressure, Two-Dimensional Motor Instability

A review of the transverse combustion instability theory of Crocco et al, was undertaken to determine its applicability to the results of HP2D tests. Because of various analytical assumptions, the differences in hardware geometry between Crocco's work and that of the HP2D, and the presentation of stability limits in terms that are difficult to relate to injector design parameters, it was concluded that the Crocco theory was not immediately applicable to the HP2D.

COMBUSTION INSTABILITY THEORY

The combustion stability theory of Priem (NASA Technical Note D-1409) was reviewed and was selected for computer programming. The program was planned to be used to analyze data from the HP2D research motor to verify the theory.

Using a nonlinear approach, Priem calculated regions of combustion instability for an annular combustor of very small thickness and length. The burning rates in the mathematical model were assumed to equal respectively the atomization rate, the vaporization rate, and the chemical reaction rate. Mixing was not taken into account. By assuming that the temperature and velocity of liquid drops were constant, relations were derived from which pressure, temperature, and gas velocity of various positions in the combustor could be calculated at any time following an assumed initial pressure disturbance. The minimum disturbance required to excite instability may be determined through examination of the pressure histories of various cases. The vaporization rate model was found to be more sensitive to such pressure disturbances for design parameters corresponding to large combustors.

The stable and unstable regions were located by determining the marginally stable curve on a plot of disturbance amplitude vs the burning rate parameter, L. For the case of the vaporization rate model, the minimum disturbance necessary to excite instability was found to be a strong function of the velocity difference between gas and liquid drops and the dimensionless group

$$\frac{M_{vap_o}}{W_{inj_o} t_w}$$

(which is dependent on the amount of unvaporized propellant) as well as the burning rate parameter, L. Variations in the viscous dissipation parameter, J, were found to be unimportant.

Successful use of Priem's results depends on the accurate prediction of the above mentioned parameters. This, in turn, involves experimental determination or verification of various quantities, such as gas velocities, pressures, etc. Much consideration went into the modification of Priem's theory necessary for an equivalent rectangular formulation. A solution may be obtained if five boundary conditions stating the tangential velocity, temperature, density, and position are given in addition to the initial conditions. When the first transverse mode of instability in the HP2D motor is considered, a standing wave must be postulated to yield the required number of boundary conditions.

The theory was reprogrammed at Rocketdyne in its annular form to duplicate Priem's results. The checkout runs of the program were in very good agreement with Priem's results. In contrast to Priem's program, however, the Rocketdyne program is numerically stable for all size time

increments. Using the considerations mentioned in the above paragraph, an equivalent rectangular form was derived from the HP2D motor.

Analysis of HP2D data requires determination of the burning rate and mass concentration of unvaporized propellant. These can be found by using the HP2D steady-state velocity profile, propellant injection rates, and theoretical propellant performance data. Values of these parameters were calculated as a function of the axial position in the chamber using a mass balance. For the application to Priem's theory, however, only those values at a distance of 3 to 4 inches from the injector face were employed, since this distance is considered the most sensitive to disturbances.

Two cases were considered while performing the above-mentioned mass balance calculations. In the first case, chamber pressure was assumed constant at 1100 psi, while in the second case, a pressure profile typical of the HP2D was assumed. All the fuel was found to be burned at the beginning of the nozzle convergence in the first case, while only 65 percent of the fuel was burned for the second case.

ACOUSTIC ABSORPTION STUDIES

Effort was expended during this period in overcoming instability with acoustic damping devices. Bench tests of cylindrical cavities, models of combustion chambers, and damping elements were studied.

Experimental investigation of the effect produced in cylindrical cavities by the introduction of a coupled slit was continued. The previously used fixture with a radial slit geometry was modified to allow coupling of the cavity to longitudinally oriented slits. Slit lengths of 1/2 and

1 inch were employed with the widths varying at 0.015-inch intervals. Attenuation of the tangential mode was greater with the deeper slit. For each slit height and vibrational mode, a width exists at which maximum attenuation occurs. Attenuations of 3.8, 11.0, and 8.5 decibels were obtained at optimum width with the 1/2-inch slit for the first and second tangential and the first radial modes, respectively. With the 1-inch slit respective attenuations of 9.1, 17.8, and 7.0 decibels were obtained.

Another aspect of the damping effect of slits on cavity resonance was also investigated. It was established that coupling the cavity with a slit length equal to a quarter wave of the exciting frequency produced marked attenuation of the normal cavity response. Even greater absorption could be obtained by providing grooved annular passages toward the rear part of the slit. It was concluded that the high absorption with the grooves resulted from turbulence in the wave motion produced at the higher acoustic pressure zones in the standing quarter wave established in the slit.

The feasibility of using the Rayleigh-Ritz method of calculating the first tangential mode frequency in three-dimensional baffled chambers was explored. Calculations and experimental measurements were made for a cylindrical chamber 13.5 inches long by 15.6 inches ID, with 13 baffles 2.4 inches long. The measured first tangential frequency was 511 cps without baffles and 470 cps with baffles. The Rayleigh-Ritz method predicted a frequency of 468 cps in the baffled case. It was noted during the experimental testing that the presence of baffles increased the longitudinal frequency slightly.

The analysis, however, failed to predict the frequencies noted during testing of F-1 and HP2D motors. A postulated reason is that, although the length of these chambers is 40 inches, there is some effective length for acoustic waves which is considerably smaller than the physical length. This hypothesis has considerable merit when it is noted that there is gross attenuation of presssure amplitude along the chamber length.

SUPERCRITICAL DROPLET HEATING

The purpose of this study was to examine the dynamic behavior of droplets injected into a gas whose temperature and pressure are supercritical for the liquid. Such conditions existed for both propellants under the operating conditions of the F-1 and HP2D motors. The procedure involved analytical mapping of the behavior of several liquid gas combinations and then choosing experimental conditions to photographically observe the moving droplets as they reach their critical temperature.

Among the various combinations considered was liquid ethane injected into helium and nitrogen gases. Calculations showed that helium pressures in excess of 1750 psia are required to heat ethane droplets through the critical temperature (550 R) at gas temperatures of 750 R. Slightly lower pressures (1500 psia) may be used with gas temperatures up to 950 R. Because vaporization processes at these lower limits remove much of the droplets before the critical temperature is reached, higher pressures would be needed to increase heat transfer rates and conserve more of the droplet mass in the liquid state. Calculations showed that droplets ranging in size up to 1000 microns may be examined in 10 inches of chamber length.

Two major differences between nitrogen and helium are the higher gas density of nitrogen and the higher thermal conductivity of helium. The higher density of nitrogen absorbs the droplet momentum faster, allowing a wider range of droplet sizes to be studied. The higher thermal conductivity of helium is advantageous for producing higher heat transfer rates.

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A history of the F-1 Combustion Stability Program from January through March 1965 is presented. Results of studies, tests, and procedures are discussed and graphically presented, and problems encountered are described.

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