File

September 14, 1962

AIR MAIL

Mr. Jerry Thompson (Code P&VE-PL)
National Aeronautics and Space Administration
Geo. C. Marshall Space Flight Center
Huntsville, Alabama

Dear Jerry:

After our discussions at Rocketdyne regarding possible injector designs that would improve F-1 stability, I have the following suggested designs for testing:

I. Flat-faced injectors

A. Increased burning rate

1) Unlike triplet with approximately 2280 LOX holes of approximately 0.15" dia. and 1140 fuel holes of approximately 0.15" dia.; fuel and LOX $\Delta P$ of approximately 200 psi; approximately 1.0" spacing between triplets. Predict 99 percent theoretical $c^*$ performance.

2) Fine self-impinging doublet fuel with approximately 32,000 fuel holes of approximately .030" dia.; self-impinging triplet LOX with approximately 48,000 holes LOX of approximately .033" dia.; fuel and LOX $\Delta P$ of approximately 200 psi; 0.40" spacing. Predict 99 percent theoretical $c^*$ performance.

3) Fine showerhead fuel and LOX; approximately 41,000 fuel holes of approximately .025" dia. and 82,000 LOX holes of approximately .025"; fuel and LOX $\Delta P$ of approximately 200 psi; spacing of 0.30" between fuel and 0.15" between LOX. Predict 99 percent theoretical $c^*$ performance.

B. Decreased burning rate

1) Coarse fuel doublet with approximately 210 fuel holes of approximately 0.35" dia.; LOX triplet with approximately 630 LOX holes of approximately 0.30" dia.; fuel and LOX $\Delta P$ of approximately 200 psi; approximately 10" spacing between fuel doublets. Predict 92 percent theoretical $c^*$ performance.

2) Biplanar with self-impinging doublet fuels; 156 holes of approximately 0.40" dia.; self-impinging triplet LOX with 900 holes of approximately 0.25" dia; fuel and LOX $\Delta P$ of approximately 200 psi; 8.0" spacing between elements. Predict 91 percent theoretical $c^*$ performance.

3) Biplanar showerhead of approximately 0.30" dia.; 90 fuel holes (self-impinging) of approximately .065" dia. with 1200 holes (self-imp. triplet) LOX of approximately 0.065"; fuel and LOX $\Delta P$ of approximately 200 psi; 4.0" spacing on fuel. Predict 93 percent theoretical $c^*$ performance.

II. Baffled injectors

A. Decreased burning rate

1) Coarse doublet; with approximately 210 fuel holes (self-imp.) of approximately 0.35" dia.; approximately 630 of approximately 0.30" dia. LOX holes (self-imp. triplet); fuel and LOX $\Delta P$ of approximately 200 psi; 10" spacing between fuel doublets. 13 compartment baffles (wide base); fuel cooled with impinging jets at end of baffles; baffles 10.0" long. Predict 91 percent theoretical $c^*$ performance.

2) Biplanar with approximately 150 fuel holes (self-impinging doublet) of approximately 0.40" dia. and 150 fuel holes (self-imp. doublet) of approximately .065" dia. with a self-impinging LOX triplet with approximately 600 LOX holes of approximately 0.30" dia.; 7.0" spacing between fuel doublets; baffles 10" long. 13 compartments (wide base) fuel cooled and impinging jets at end of baffles. Predict 90 percent theoretical $c^*$ performance.

3) Biplanar showerhead; 260 fuel holes (showerhead) of approximately 0.30" dia.; 84 fuel holes (self-imp. doublets) of approximately .065" dia. with 1100 holes (self-imp. triplet) LOX of approximately .065" dia.; fuel and LOX $\Delta P$ of approximately 200 psi; 4.0" spacing on fuel baffles 10" long. 13 compartments (wide base) fuel cooled and parallel jets at end of each baffle. Predict 89 percent theoretical $c^*$ performance.

B. Acoustic mismatch or isolation

1) 13 baffled compartments, total. 5 baffled compartments each with 86 fuel holes (self-imp. doublets) of 0.15" dia.; 180 LOX holes (self-imp. triplets) of 0.15" dia. to produce o/f of 2.2 in each compartment. 4 compartments each with 45 fuel holes (self-imp. doublets) of 0.25" dia.; 190 LOX holes of 0.18" dia. holes produce o/f of 1.2 in each. 4 compartments each with 220 fuel holes of .065" dia. holes (self-imp. doublets) 440 LOX holes of 0.30" dia. (self-imp. triplets); o/f of 3.2 in each compartment; LOX and fuel $\Delta P$ of 200 psi; baffles 6.0" long, fuel cooled with impinging jets at end. Predict 94 percent theoretical $c^*$ performance.

2) Choked flow baffles
13 compartment baffles; 6.0" long with 0.125" fuel holes; 1500 holes (self-impinging doublet); 3,000 LOX holes (self-imp. triplets) of 0.125" dia.; fuel and LOX $\Delta P$ of 200 psi. Baffles to have enlargements on the ends to block 30 percent of injector face area in each compartment so that the flow will be sonic with 80 percent of propellants burned. Predict 98 percent of theoretical $c^*$ performance.

I think it is obvious as to what I am trying to accomplish with each injector. If there is any question on any injector, I would be glad to elaborate on the reasoning.

My priority list or rating is as follows:

I,A,1
II,A,2
II,A,1
II,B,2 (cont'd)

I,B,2
I,A,2
II,A,3
II,B,1
I,A,3
I,B,1

Sincerely yours,

S/
Richard J. Priem
Head, Rocket Combustion Section

RJP:eh
GM
~~WTO~~

APPROVED ______________________
Deputy Director

Copies to: Files, Deputy Director, C&EC, G. Morrell, R.J. Priem , W. Dankhoff

File

110-71 / 71
X 171

November 1, 1962

AIR MAIL

Mr. Frank Boffola
Rocketdyne
Division of North American Aviation, Inc.
6633 Canoga Avenue
Canoga Park, California

Dear Frank:

At the last Ad Hoc Meeting on instability in the F-1 engine, Rocketdyne was interested in data regarding different injector shapes. Paul Wieber has recently obtained some data on damping coefficients with several different injector configurations. I am enclosing this preliminary data and description of the apparatus and test procedure. Dan Klute and Joe Erbs would undoubtedly be interested in the fact that the damping coefficient of a coned face with radial and circular baffles was a factor of 3 larger than that for a flat injector.

Sincerely,

S/

Richard J. Priem
Head, Rocket Combustion Section

Enclosure:
Data sheets

Copies to: Mr. A. O. Tischler, NASA Hqtrs.
Mr. J. Thompson, MSFC
Mr. S. Morrea, MSFC

√Files, Deputy Director,
C &EC, G. Morrell, R.J. Priem

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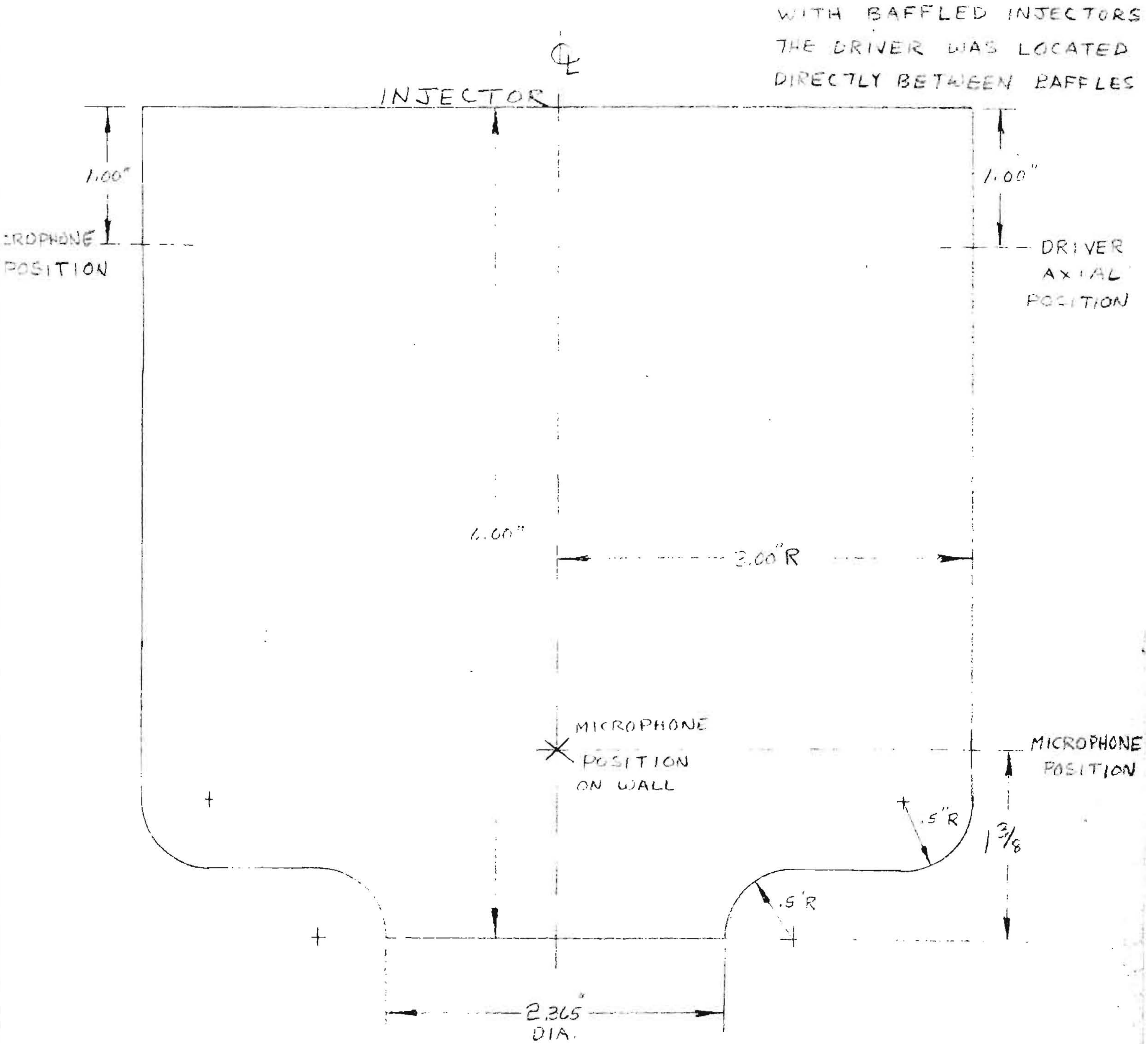
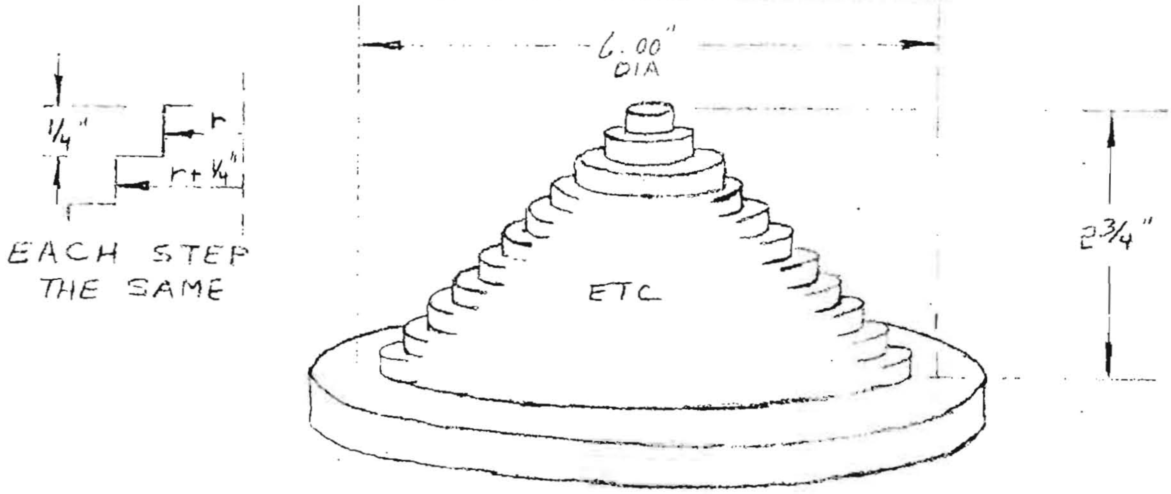
APPROVED ________________
Deputy Director

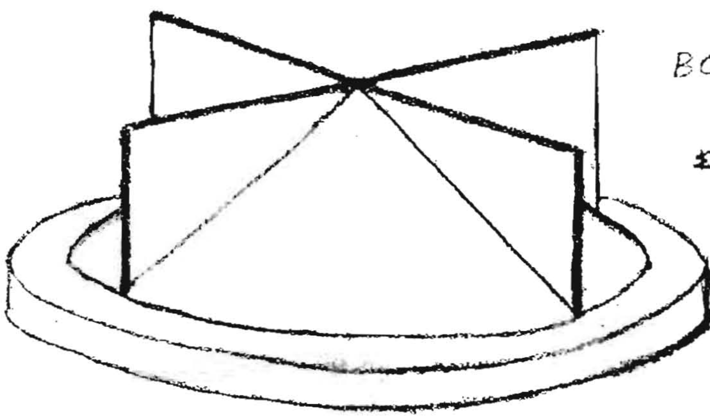
# INTERNAL DIMENSIONS OF TEST CONFIGURATION WITH FLAT INJECTOR



# INJECTOR CONFIGURATIONS




STEPPED CONICAL INJECTOR



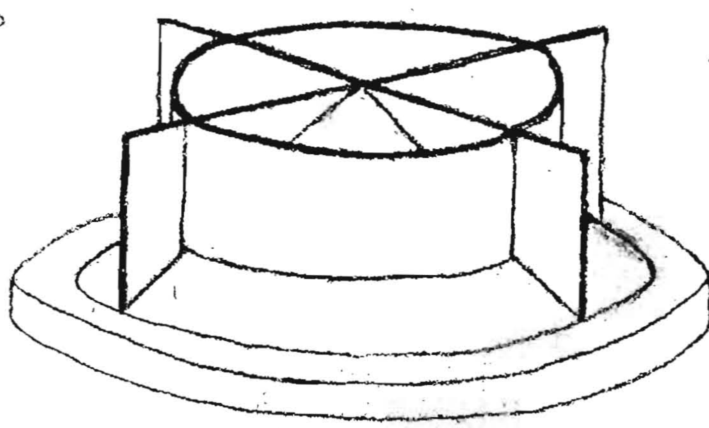
BOTH RADIAL BAFFLES ARE 3" HIGH & 6" LONG, 90° APART

CONE IS 3" HIGH & 6" IN DIAMETER

THERE ARE 2 ADDITIONAL INJECTORS WITH FLAT FACES (NO CONING) AND BAFFLE CONFIGURATIONS AS SHOWN IN THESE SKETCHES

CONICAL INJECTOR WITH RADIAL BAFFLES

THERE IS ALSO ONE DOMED INJECTOR WITH A 3.25" RADIUS AND A DEPTH OF 2"



BOTH RADIAL BAFFLES ARE 3" HIGH & 6" LONG, 90° APART
THE CIRCUMFERENTIAL OR CIRCULAR BAFFLE HAS A RADIUS OF 2" A HEIGHT OF 3" FROM THE BASE OF THE CONE AND ARE 1/8 THICK. CONE IS 3" HIGH & 6" IN DIAMETER.

CONICAL INJECTOR WITH RADIAL & CIRCUMFERENTIAL BAFFLES

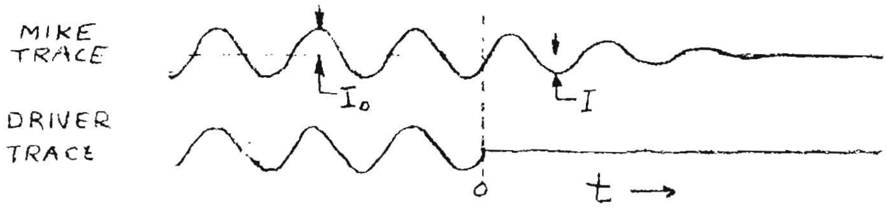
# DECREMENT DATA

| INJECTOR TYPE | ACOUSTIC MODE | DAMPING COEFFICIENT |
|---|---|---|
| FLAT, NO BAFFLES | 1ST LONGITUDINAL | 49 |
| " | 1ST TRANSVERSE | 74 |
| FLAT, RADIAL BAFFLES | 1ST LONG. | |
| " | 1ST TRANS. | |
| FLAT, RADIAL PLUS CIRCULAR BAFFLES | 1ST LONG | |
| | 1ST TRANS. | |
| CONED BY DISCRETE STEPS | 1ST LONG. | 76 |
| | 1ST TRANS. | 158 |
| CONED WITH RADIAL BAFFLES | 1ST LONG | 77 |
| | 1ST TRANS. | 172 |
| CONED WITH RADIAL PLUS CIRCULAR BAFFLES | 1ST LONG. | 163 |
| | 1ST TRANS. | 216 |
| DOME, 2 INCHES DEEP | 1ST LONG | 12 |
| | 1ST TRANS. | 53 |

DATA NOT YET AVAILABLE (flat, radial baffles and flat, radial plus circular baffles)

PROCEDURE: AN ACOUSTIC FIELD IS GENERATED IN THE CONFIGURATION BY A LOUDSPEAKER DRIVER POWERED BY AN AUDIO OSCILLATOR. EACH RESONANT MODE IS DETERMINED BY OBSERVING AMPLITUDE AND PHASE OF THE OUTPUTS OF SEVERAL MICROPHONES MOUNTED ON THE CHAMBER. THE POWER TO THE DRIVER IS INTERRUPTED AND THE DECAY OF THE ACOUSTIC FIELD RECORDED BY FILMING THE MICROPHONE OUTPUTS DISPLAYED ON AN OSCILLOSCOPE.

THE DAMPING COEFFICIENT IS MEASURED ASSUMING THIS LAW APPLIES: $I = I_o e^{-kt}$ WHERE $I$ IS THE INTENSITY OF A SOUND PEAK $t$ SECONDS AFTER THE DRIVER POWER HAS BEEN STOPPED, $I_o$ IS THE INTENSITY OF A PEAK BEFORE $t=0$, AND $k$ IS THE DAMPING COEFFICIENT.



NASA - Lewis

December 12, 1962

MEMORANDUM for Deputy Associate Director for Research

Subject: Combustion Instability with F-1 engine

Reference: Telephone conversation of November 21, 1962 regarding Administration briefing on F-1 engine and ensuing conversation with Dr. Robert C. Seamans

1. The following recommendations have been made by Lewis personnel as techniques to improve the F-1 engine:

a. Use an unlike triplet injection pattern (two Lox streams impinging on one fuel stream);

b. Use a like-on-like injection pattern (i.e. Lox stream impinging on a Lox stream) with large fuel and oxidizer streams, i.e. .35-inch diameter streams, with baffles;

c. Use a concentric tube injection pattern (fuel ring surrounding each Lox jet); and

d. Increase the flow area between the Lox torus and Lox dome by a factor of two.

2. Recent meeting at Huntsville between Rocketdyne and Marshall personnel has shown the following action on these recommendations:

a. Triplet injector tentatively scheduled to be tested in late January or early February. During the meetings with Rocketdyne in September it was stated that this pattern would be ready to be tested in November or December. Testing of this pattern was postponed by Rocketdyne in favor of patterns similar to those being used in the present engines.

b. No plans to test a like-on-like pattern with large streams;

c. A concentric tube injection pattern is being considered. Definite plans have not been made for this pattern, however; and

b. The like-on-like pattern with coarse jets and baffles is based on theories of (1) Princeton, which state that if the combustion dead time is increased or if the combustion zone is spread out the system will be more stable; (2) MIT (Culick) states that if the combustion rate is decreased the system will be more stable; (3) Aerojet, who state that if the available energy or burning rate is decreased the system will be more stable; (4) Lewis, nonlinear theory which states that if the burning rate is decreased the system requires a larger disturbance to produce instability; and (5) Lewis spray theory, which says larger jets will be more stable and therefore will not drive a wave. Experimental data of Princeton, Aerojet and Lewis have shown that a lower performing combustor is more stable than a high performance combustor. Therefore this injector uses large jets to reduce the combustion rate, spread out the combustion zone and decrease the dead time and performance. A few small jets are used to provide flame holding capability and decrease rough combustion during stable operation. Baffles in the combustion zone (first 10 inches) are used to improve stability as shown by data of Lewis, Princeton, Aerojet and Rocketdyne. While most of the experts agree with the fact that large jets will decrease the burning rate and produce more stability most of them are reluctant to go in this direction as it will mean a decrease in combustor performance.

c. This injector is based on data obtained at Lewis, NASA TN D-126 using a coaxial injector in which the chamber pressure was much smoother than other injector configurations. It is believed that with lower disturbances the instability would not be excited. Baffles in the combustion zone (first 3 inches) are used to improve stability as based on data of Princeton, Aerojet, Rocketdyne and Lewis. Sonic flow is produced at the baffle tips to separate the combustion zone from having any disturbances in the main combustor zone, thus eliminating the longitudinal mode. Coaxial pattern is also ideally suited to the baffle design due to the fact that with the NASA engine the heat transfer to walls and injectors was reduced and chamber burning was eliminated due to fuel atmosphere surrounding the Lox jets. Since the data on this injection technique is very limited, some of the experts do not agree to the expected characteristics at the F-1 level. Similarly, the fabrication technology for this type of injector is not well advanced, although it is used in the LR-10 hydrogen-oxygen engine which is very stable.

Rocketdyne is reluctant to make this change as the stress level in the dome would be excessive in the flight configuration with gimbaling, thus requiring a major redesign of the Lox dome and manifold.

4. In addition to the technical reasons for not incorporating the Lewis suggestions in the F-1 Program, there are other factors hindering the progress of the program. It is difficult to convince Rocketdyne personnel that the result from theoretical studies or experimental studies at small thrust can be directly applied to the F-1. Since there are no programs to test these theories and ideas at intermediate thrust levels there exists and will exist the wide gap between these two groups. A second problem is the fact that only a limited number of configurations can be manufactured because of the limited funds and facilities to machine the various parts. The third problem is the limited facilities to test the various configurations. Currently, most of the test facilities are used to check out and test equipment for full engine studies. Since any suggestions would have to undergo component testing with boilerplate hardware first, it would require delaying engine tests to do exploratory-type testing. With all of these problems facing a suggestion, it is easy to see why it will be difficult to change the program or improve the stability of the F-1 engine.

Richard J. Priem

Richard J. Priem
Head, Rocket Combustion Section

RJP:eh
GM
WTO

Copies to: Dr. J. C. Evvard
Dr. W. T. Olson
Mr. G. Morrell
Dr. R. J. Priem

NASA - Lewis

December 18, 1962

MEMORANDUM for Deputy Director

Subject: Meeting on F-1 stability at Marshall Space Flight Center, Huntsville, Alabama on December 4, 1962

1. Those present at the meeting were:

Dr. Wernher M. von Braun - MSFC
Dr. Eberhard Reese - MSFC
Mr. Herman Weidner - MSFC
Mr. Carl Heimburg - MSFC
Mr. Hans Paul - MSFC
Mr. Daniel Driscoll - MSFC
Mr. Leland Bellew - MSFC
Mr. S. Morea - MSFC
Mr. Robert Richmond - MSFC
Mr. Jerry Thompson - MSFC
Mr. R. Bledsoe - MSFC
Mr. Frank Boffola - Rocketdyne, Canoga Park (M-P&VE)
Mr. Oscar Bessio - NASA Headquarters
Mr. Charles King - NASA Headquarters
Mr. Sam Hoffman - Rocketdyne
Mr. Joe McNamara - Rocketdyne
Mr. Daniel Klute - Rocketdyne
Mr. Paul Castenholz - Rocketdyne
Dr. Robert Levine - Rocketdyne
Dr. Richard Priem - NASA-Lewis

2. Mr. Weidner opened the meeting by reviewing the history of the F-1 Engine Program and pointing out that this meeting was called to determine what changes Rocketdyne had made in the F-1 Program as a result of a meeting at Marshall in September. In the September Meeting Marshall personnel emphasized the seriousness of the stability problem with the F-1 engine and requested an increased effort on this problem. Mr. Weidner also pointed out that the material Rocketdyne would present had been reviewed in the morning with NASA personnel at the working level, at which time many detailed questions had been asked and discussed. Mr. Weidner then turned the meeting over to Mr. Castenholz, who made the presentation of Rocketdyne's program.

3. Mr. Castenholz explained that the material to be presented represented the thinking of the Rocketdyne stability group. The presentation would not include a formal program inasmuch as the information is still being gathered and the approach used will be dependent on the results obtained. The object of the stability group is to improve the stability of the F-1 engine and to develop a dynamically stable system (a system that will attenuate artificial disturbances). The approach will be to obtain basic information on instability and the instability in the F-1 engine. With this information they will perform tests to indicate the changes required to improve stability. They will then design, fabricate and test the equipment in the F-1 engine. To accomplish this, they will have three groups as follows:

a. Analysis group of about 20 people to analyze data, study theories or produce new theories.

b. Experimental group of about 10 people to perform critical experiments with model combustors, i.e., two-dimensional hardware and 21-inch Atlas engines.

c. Engine program with 30 people to produce new injector designs, test and rate the designs and establish stability limits. This group of 60 people is in excess of the personnel that had been on the F-1 Program prior to establishing the stability group.

Activity to date has been to compile all the data on the F-1 engine at one place and in one form, and to reanalyze this data; also establish a computer program to analyze the data. In addition, several consultants have been called in to discuss the problem and will continue this plan. The major changes in the program have been to increase and improve the data acquisition, so as to make it more reliable and complete. This will include using windows for photographing the combustion process in the regeneratively cooled engines.

Present hardware program consists of studying the spray and combustion characteristics of the 5-U and other current F-1 injector patterns in the two-dimensional combustor. Five baffle patterns will also be tested in the 188K or Atlas engine to determine the effect of propellant injection pressure drop and wall gaps. (These are injectors left over from the H-1 Program.) The F-1 Engine Program will test the following:

December - New pulsers and bombs with 5-U pattern
Divergent ring pattern
Fuel-showerhead pattern
2nd Divergent ring pattern

January - Baffled injector with divergent ring
Short impinging disturbance, Lox with reverse cluster
5-U with 13x13 baffle
Low $\triangle P$ fuel showerhead
2nd baffled divergent ring
Splash ring
5-U flat face

February - Injector with different impinging angles and injection density
30-inch chamber
Unlike triplet
Double-ring injector

Mr. Castenholz also discussed various processes, parameters, phenomena, etc., that could initiate, sustain, damp, etc., the instability. This covered almost everything that could occur in the engine system. While most of this represented "blue-sky" thinking without any positive results or ideas, it did illustrate that they were thinking.

4. After the presentation Mr. Weidner asked for comments and received no response. He then asked the author what his views were of the program. The author pointed out that the material presented illustrated that Rocketdyne has developed a long-range approach to the problem and is thinking of things which may help the program in the future. The immediate effort, however, appears to be following the same program and thinking that Rocketdyne has used in the past. This is obvious from the fact that of the five recommendations made by the Ad Hoc Committee on instability for immediate changes in hardware, only the triplet injector appeared in the program and that was late in February. The author pointed out that it would seem to be profitable to include ideas of the experts on the committee in the immediate program as well as Rocketdyne ideas. After some discussion, Mr. Hoffman agreed that using the experts ideas in the immediate program would be worthwhile and that Rocketdyne would see how this could be worked into the program.

5. During the discussions, it became apparent that most of the recommendations made for improving stability were based on theories which have not been tested in reasonable-sized hardware. Dr. von Braun asked whether this type of work was being conducted anywhere and all members agreed that the applied research or testing of theories is non-existent in this country. Mr. Weidner asked the author what the

Lewis Center policy was on doing this type of work. The author then repeated the policy statement obtained from Dr. Evvard, that it was Lewis' interpretation or policy that the Lewis Center would not conduct work directly concerned with the F-1 or other development engines. Dr. von Braun pointed out to the Marshall personnel that this type of work is needed and that it would be their responsibility to maintain the program which Rocketdyne had outlined, even after a stable combustor had been developed. The stability program at Rocketdyne is funded for 13 million for the next three years.

Richard J. Priem
Head, Rocket Combustion Section

RJP:eh
GM
WTO

Copies to: Files
Mr. Manganiello
Chem. & Energy Conversion Div.
G. Morrell
R.J. Priem

<u>NOTE</u>

**The above statement regarding Lewis policy on F-1 and other development engines is a misunderstanding on Dr. Priem's part. Our policy has been, and continues to be, to support any NASA development effort within the range of our competence and capability. The problem relative to F-1 is one of size of engine - we do not have the facilities for handling large scale engines.**

E. J. MANGANIELLO

**E. J. Manganiello**
**Deputy Director**

Files

DEC 27 1962

ORC
FILE
COPY

From Lewis
To NASA Headquarters (AA)
Att: Dr. R.C. Seamans

Subject: Combustion Instability of the F-1 Engine

Reference: (a) Conversation between Dr. R.C. Seamans and Dr. J.C. Evvard at Hdqtrs on November 17, 1962

(b) Lewis memo from Dr. R.J. Priem dated December 12, 1962 to Dr. J.C. Evvard

1. Following our Saturday morning discussion on November 17, 1962 (reference (a)), I asked Dr. Priem of our Chemistry and Energy Conversion Division to summarize for me the status of his suggestions on the combustion instability of the F-1 engine. A copy of his memorandum (reference (b)) is enclosed for your information.

2. You will note that, as yet, none of the listed suggestions has been evaluated. Also, the plans to evaluate some of the suggestions are either inadequate or nonexistent. I cannot, therefore, agree with the statement that "All is being done that can be done to eliminate the instabilities of the F-1 engine."

3. Of course, we at Lewis recognize that every coin has two sides. The combustion and flow processes in an engine are extremely complicated with dozens of modes of potential oscillation. The processes are generally non-linear so that stability or instability depends upon the amplitude of some triggering disturbance. Low amplitude disturbances might damp out whereas larger amplitude disturbances would amplify toward engine destruction. With such complications, the experts are seldom agreed either as to the causes or the cures for the oscillation.