N.I.

TRW
SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

Contract NAS3-11227

INVESTIGATION OF THRUSTORS

FOR CRYOGENIC REACTION CONTROL SYSTEMS

Fourteenth Monthly Progress Report

28 June 1969 through 25 July 1969

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Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
Cleveland, Ohio 44135

by
R. J. Johnson, Program Manager

TRW SYSTEMS
SCIENCE & TECHNOLOGY DIVISION
One Space Park, Redondo Beach, California 90278

Fourteenth Monthly Progress Report

INVESTIGATION OF THRUSTORS FOR CRYOGENIC REACTION CONTROL SYSTEMS

Contract No. NAS3-11227

25 August 1969

Prepared by: R. J. Johnson

R. J. Johnson
Program Manager

Approved by:

S. J. Van Grouw, Head
Combustion & Process
Technology Section

Approved by:

H. L. Burge, Manager
Applied Technology
Department

1. INTRODUCTION

This report summarizes the technical progress accomplished during the fourteenth monthly reporting period of the "Investigation of Thrustors for Cryogenic Reaction Control Systems" program being performed by TRW Systems, Science and Technology Division, under NASA/LeRC Contract NAS3-11227. The reporting period covered is the July accounting month, 28 June 1969 through 25 July 1969.

The "Investigation of Thrustors for Cryogenic Reaction Control Systems" program is a fifteen month technical effort comprised of an experimental and supporting analytical evaluation of the ignition delay, reactor design, thrustor response times, and delivered performance for a gaseous hydrogen-oxygen reaction control thrustor. The specific goals of this program are:

- Establish design criteria for a pilot bed catalytic reactor capable of igniting a gaseous hydrogen-oxygen thrustor.

- Define an operating map for reliable thrustor ignition and operation, including the operating variables of propellant temperatures, propellant inlet pressures, vacuum effects, and catalyst bed temperature.

To accomplish these goals, a six-task program will be conducted to include the following:

- Laboratory tests to determine catalyst activity.

- Design and fabrication of igniters and thrustors.

- Test firing of igniters and combined thrustor/igniters at selected vacuum levels, propellant inlet pressures and temperatures, and catalyst bed temperatures.

- Evaluation of data to provide complete ignition and operating maps, and catalyst bed design criteria.

2. PROGRESS DURING THE REPORTING PERIOD

During the July reporting period, progress was made on Tasks IVB, IVC, V, and VI, as shown on the Contract Reporting Schedule NASA-C-63 at the end of this report. The Task IVB thrustor/igniter bed optimization tests were completed during the month of July, and a fixed igniter bed and thrustor configuration for each chamber pressure level was selected for the subsequent Task IVC baseline performance and Task V pulse mode test series.

Thrustor/igniter catalyst bed optimization tests at both the 10 and 100 psia chamber pressure levels were performed during this reporting period. Details of the high pressure bed configurations evaluated and preliminary experimental results are described in Section 2.1 of this report (Task IVB).

Facility preparations for the baseline response and performance tests were completed during this period. Based on Task IVB results, an optimum thrustor/igniter configuration for each pressure level was selected for this test series (Task IVC).

The electronic control equipment required for pulse mode operation of the thrustors was assembled and checked out. Capability of thrustor/igniter pulsing in either of three modes of igniter valve sequencing plus variability of pulse duration and off-time have been incorporated in this equipment, as described in Section 2.3. The thrustor pulse mode test series will be initiated during the next reporting period, after approval of the detailed test plan by the NASA/LeRC Project Manager (Task V).

Data analysis and evaluation was continued in support of the experimental test effort (Task VI).

2.1 TASK IVB - THRUSTOR/IGNITER BED OPTIMIZATION

The catalyst bed optimization tests were completed during the month of July. Combined thrustor/igniter firings at both the 10 and 100 psia chamber pressure levels were performed, as outlined in the approved test plan*.

* Contract NAS3-11227, "Task IVB Test Plan - Igniter Bed Optimization Tests", dated 28 May 1969.

Altitude stand installation of the thrustor hardware was described in the previous monthly progress reports.

The high pressure catalyst bed configurations tested are illustrated in Figure 1. Shown from left to right in the foreground of the photograph are the catalyst cartridges for the .50 inch long nominal and reduced diameter beds, and the 1.0 and 1.5 inch long nominal diameter beds. The nominal catalyst bed diameter for the 100 psia igniter is .430 inch (inside diameter of .035 wall, 1/2" O.D. tubing). The reduced diameter cartridge (.305" I.D., 3/8" tubing) provided a catalyst bed of one-half the cross-sectional area of the .430 inch diameter beds. The .50 and 1.0 inch nominal diameter beds were previously tested during Task IIB. The 1.5 inch and the reduced diameter beds were selected as additional configurations for Task IVB evaluation.

Shown in the background of Figure 1 are the diffusion zone spacer, stainless steel ball diffusion bed, and additional spacers used to retain the shorter catalyst cartridges within the igniter housing. The 1.5 inch long catalyst bed was tested without the ball diffusion bed with no igniter flashback or other adverse effects. The low pressure igniter was also tested successfully without a diffusion bed being required to arrest flashback, as described in the previous progress report.

Successful high pressure thrustor/igniter firings were performed for all propellant inlet conditions tested, except for helium in oxygen dilution of 25% or greater. Helium dilutions of 25% (by weight) in the main thrustor oxygen had been ignited at this pressure level in Task IVA, however, pure oxygen was supplied to the igniter for these tests. Theoretical analyses have indicated that ignition with helium dilution can be achieved by raising the propellant mixture ratio. Attempts to ignite with 25% helium in oxygen at high mixture ratios during this series resulted in localized overheating of the present igniter, designed for a mixture ratio of 1.0 as specified in the contract work statement. Ignition with dilutions of at least 25% helium in oxygen is very likely to be attainable by modifying the igniter for operation at higher mixture ratio without streaking (oxidizer-rich zones).

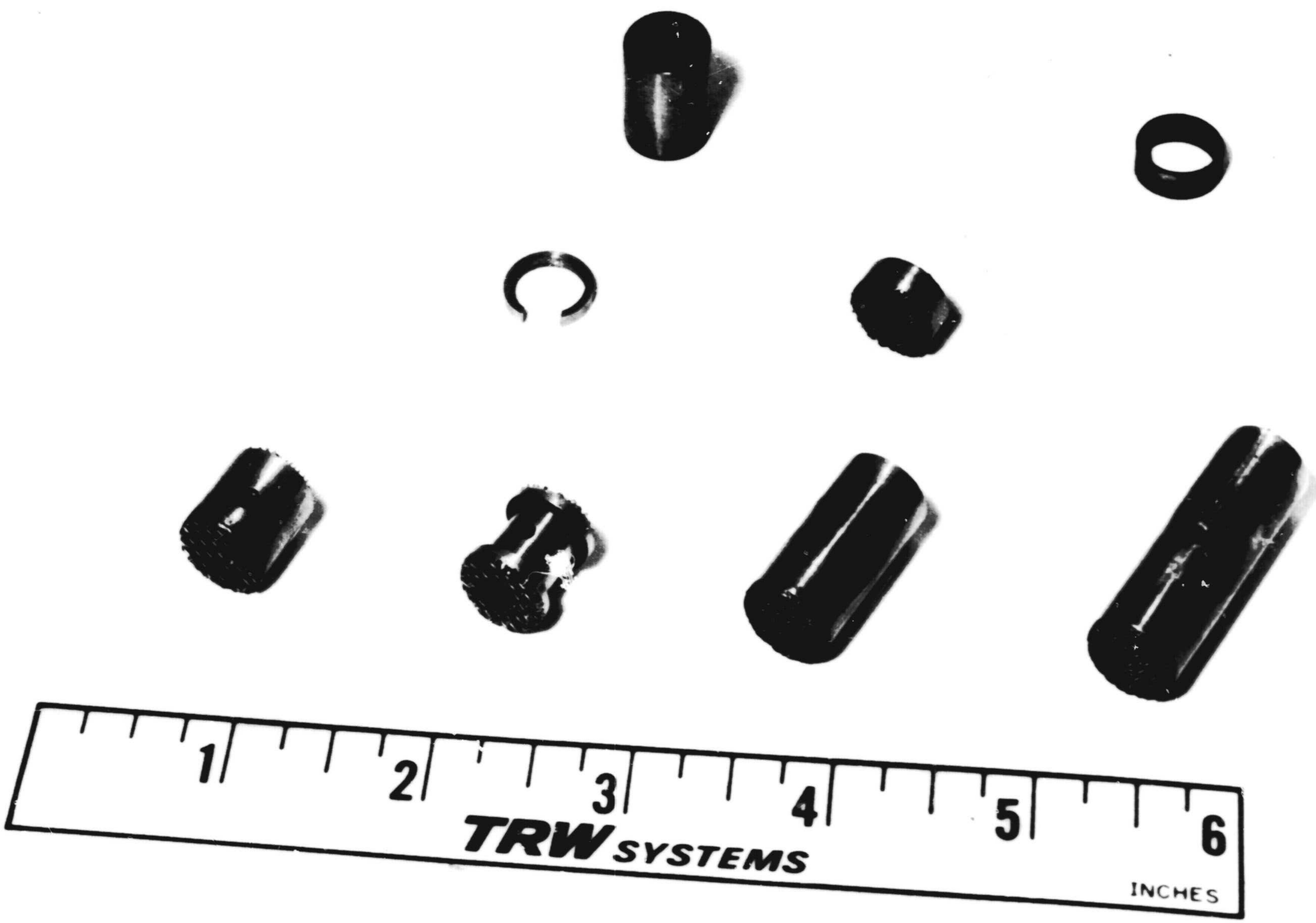

Figure 1. Igniter Catalyst Bed Configurations - 100 psia P_c, 20 lb. Thrust Engine

Figure 2. High Pressure Catalytic Igniter - 100 psia P_c Thrustor
(Eroded igniter tips and throat inserts shown in foreground)

Ignition of the 100 psia chamber pressure thrustor was achieved at igniter effluent temperatures as low as 1220°F, confirming the Task IVA results. Tests incorporating the optional igniter throat resulted in successful main thrustor ignitions, but burning of the throat exit and igniter tip occurred in some of these firings. The eroded igniter tips and throats are shown in the foreground of Figure 2. Since these throat inserts had a nozzle expansion ratio of over 20:1, it was considered that flow separation had allowed the main oxygen lead to react with the fuel rich igniter effluent, resulting in temperatures sufficiently high enough to melt stainless steel. One of the eroded igniter throats was machined to an expansion ratio of less than 3:1, as shown in the left foreground of Figure 2, to insure against nozzle flow separation prior to thrustor ignition. Testing of this configuration still resulted in some erosion of the igniter tip, apparently caused by oxidizer recirculation. The high pressure igniter (Figure 2, background) was then returned to the original configuration by welding on an open-tube igniter tip, as shown, which was used to complete the test series.

A summary of the catalyst bed optimization test results is presented in Table 1. Three different bed configurations were evaluated at each thrustor chamber pressure level to investigate the effects of diameter changes and bed length on the overall thrustor response time. Ignition of the thrustors at onset of main propellant flows was achieved with each of the configurations tested. However, as indicated in Table 1, the longer catalyst beds exhibited increased delay times and higher temperatures within the catalyst bed in achieving the minimum effluent temperature required for thrustor ignition. A higher igniter effluent temperature was required for main thrustor ignition at both pressure levels with the reduced diameter catalyst beds. Best overall performance in each case was attained with the shorter, nominal diameter bed configurations.

The post-firing condition of the 100 psia chamber pressure thrustor/igniter hardware is illustrated by Figures 3, 4, and 5. Figure 3 shows the complete thrustor, disassembled at the main injector/chamber interface. Figures 4 and 5, respectively, are upstream and exit views of the high pressure altitude thrust chamber. No damage to the hardware was observed, except for some metallic slag deposited on the injector face and chamber

Table 1. Summary of Experimental Results - Task IVB Bed Optimization Tests

Chamber Pressure	Catalyst Bed Configuration			Results
	Length	Diameter	L/D	
10 psia	.50"	.870"	.58	Good thermal response, lowest effluent temperature required for thrustor ignition.
	.50	.620	.81	Higher effluent temperature required for thrustor ignition.
↓	1.48	.870	1.70	Longest thermal lag, higher bed temperatures required for thrustor ignition.
100 psia	.50	.430	1.16	Good thermal response, lowest effluent temperature required for thrustor ignition.
	.50	.305	1.64	Higher effluent temperatures required for thrustor ignition.
↓	1.50	.430	3.49	Longest thermal lag, higher bed temperatures required for thrustor ignition.

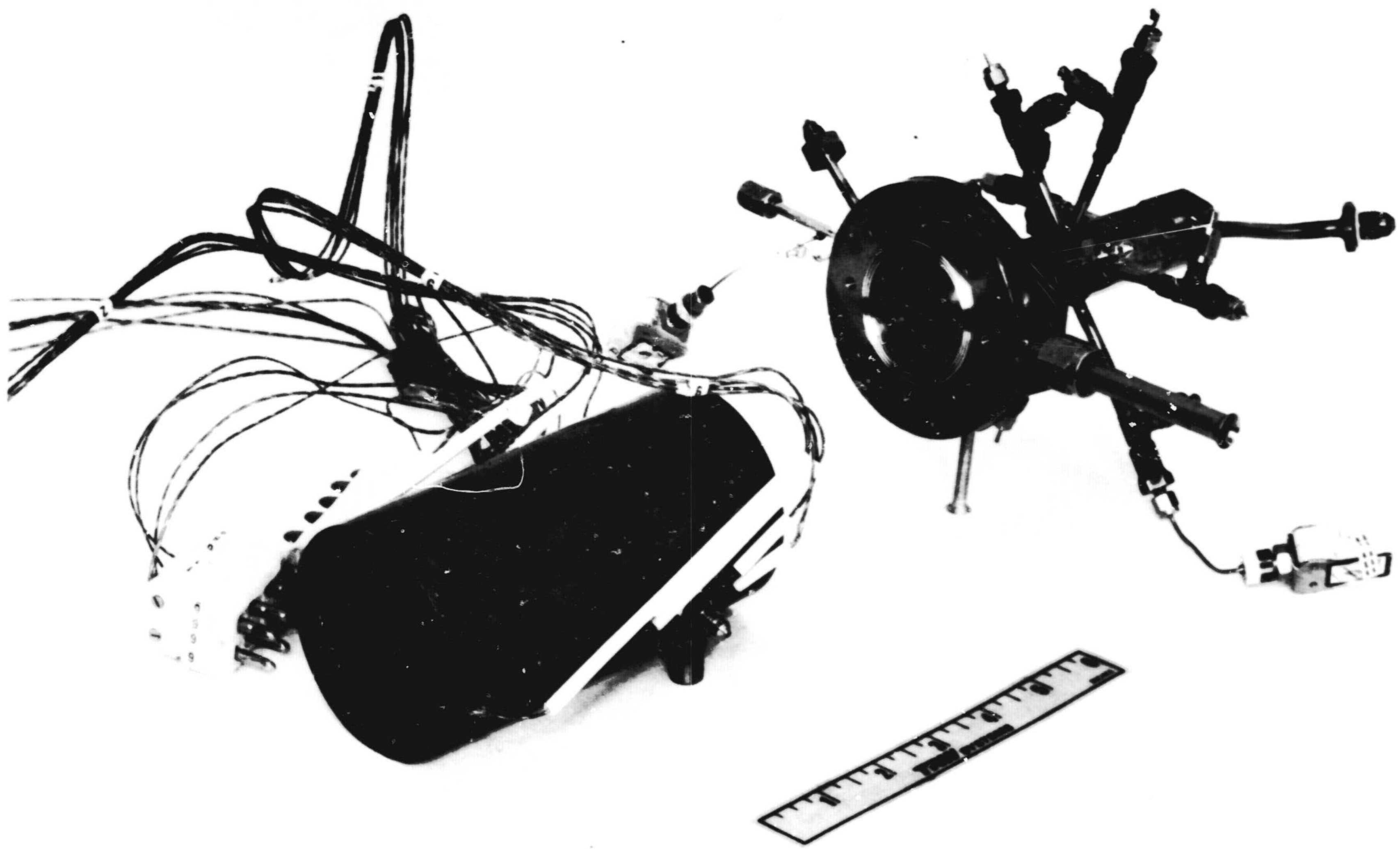

Figure 3. Post-Firing Condition of 100 psia P_c Thrustor/Igniter Hardware

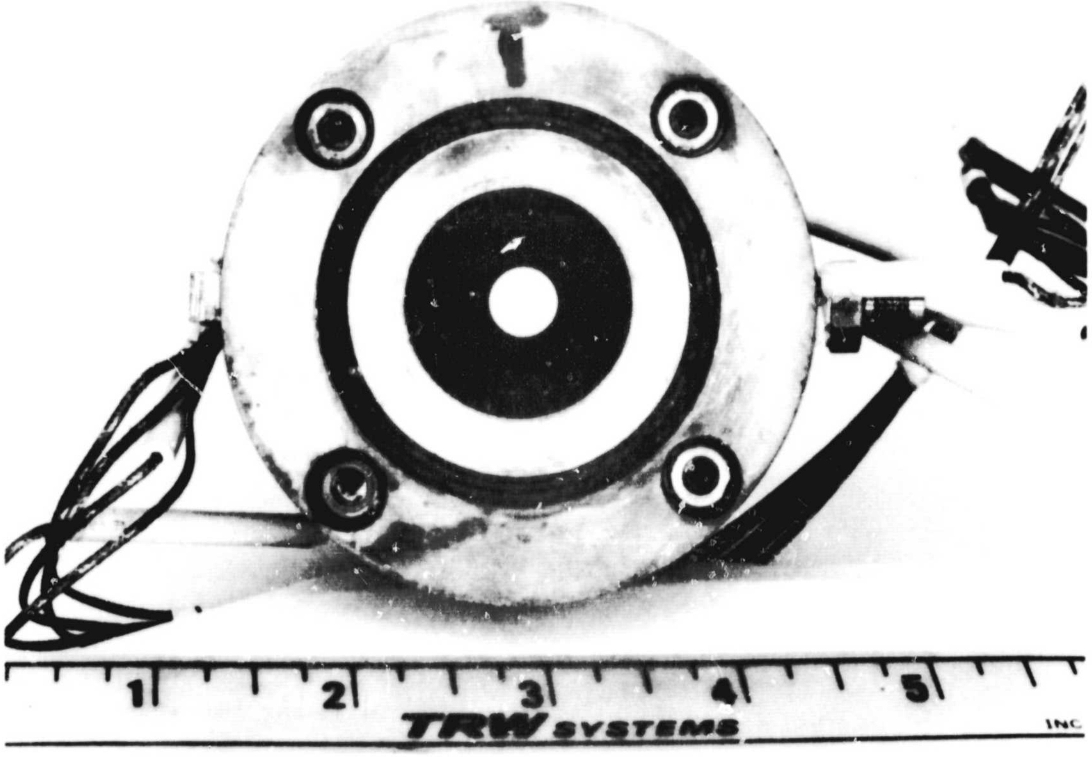

Figure 4. Post-Firing Condition of 100 psia P_c Altitude Thrust Chamber - Viewed from Upstream End

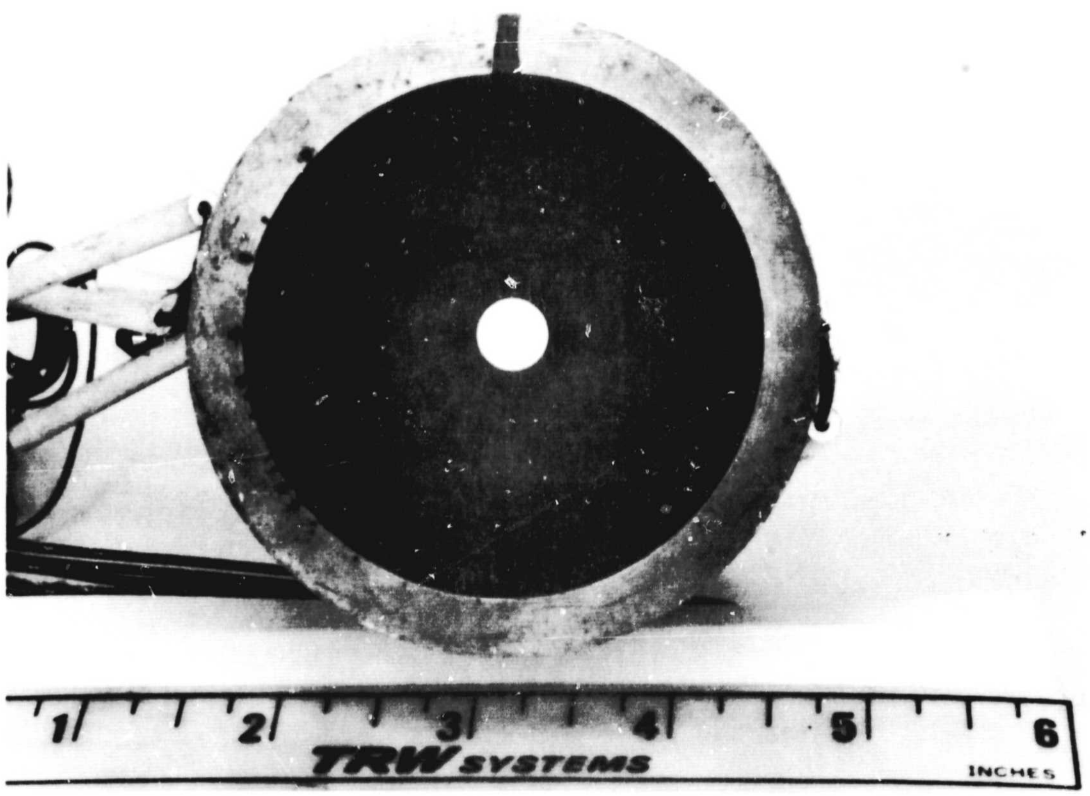

Figure 5. Post-Firing Condition of 100 psia P_c Altitude Thrust Chamber - Viewed from Exit

convergent section by the igniter throat erosion previously described. This slag was removed from the injector and the hardware is ready for the Task IVC baseline tests and Task V pulse mode tests to be initiated during the August reporting period.

2.2 TASK IVC - THRUSTOR/IGNITER BASELINE TESTS

Test facility preparations for the baseline performance tests were completed during this reporting period. These tests will be performed for each chamber pressure level thrustor (10 and 100 psia) to establish igniter and thrustor response characteristics and steady-state altitude performance. The performance effects of propellant inlet temperatures (+70 to -250°F) and helium dilution will also be investigated during this test series.

Based upon the Task IVB experimental results, described previously in this report, the .50 inch long, .430 inch diameter catalyst bed configuration was selected for the 100 psia chamber pressure thrustor baseline tests. Selection of the 1.0 inch long, .870 inch diameter bed configuration for the 10 psia baseline tests was made after detailed analysis of both the Task IVB and Task IIB data. Although the one-half inch bed was the most satisfactory configuration tested in Task IVB, a comparison of the one-half and one inch beds, as tested during the Task IIB reactor series, indicated that the one inch catalyst bed is superior for low temperature and dilute propellant reaction at the 10 psia chamber pressure level. The open-tube (no throat) igniter tip configuration has also been selected for the baseline test series, which will begin during August.

2.3 TASK V - THRUSTOR PULSE MODE TESTS

The electronic sequencing control equipment to be utilized for the thrustor pulse mode test series was designed, assembled, and checked out during July. Variable delay circuits have been incorporated into the pulse control console to allow for precise setting of igniter and thrustor propellant valve lead/lags over the maximum ranges anticipated. Variable lead/lags between the igniter and main thrustor valves can also be pre-set by simple panel adjustments.

The control console also includes a selector switch to provide either of three pulse operational sequences, as shown in Figure 6. Pulse sequence #1

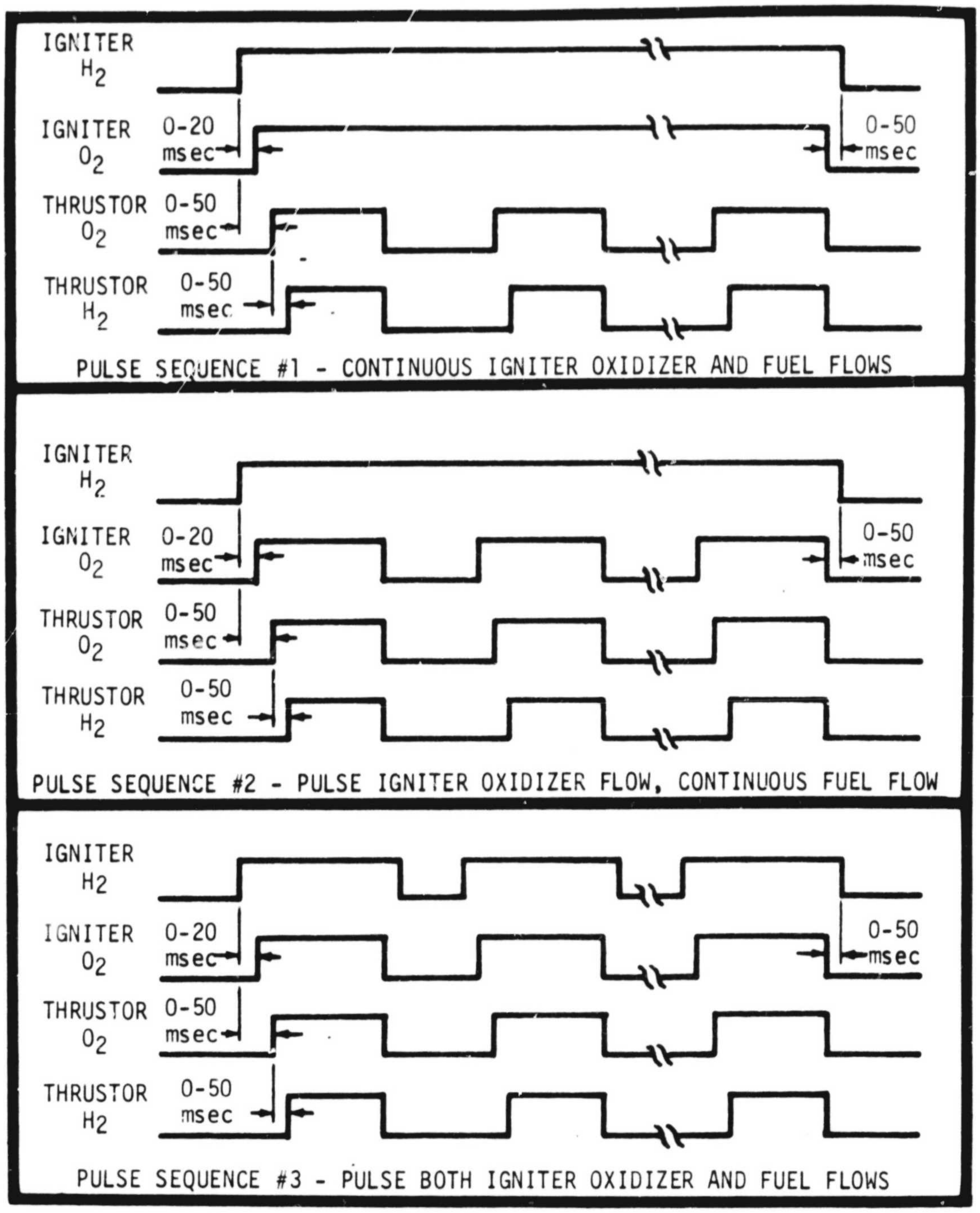

Figure 6. Task V Pulse Mode Valve Sequencing

provides continuous operation of the igniter during pulsing of the main thrustor valves. In pulse sequence #2, the igniter oxidizer valve is pulsed along with the main propellant valves, while the igniter fuel valve remains open. Pulse operation of both igniter propellant valves is performed by pulse sequence #3. For each pulse sequence, the oxidizer/fuel and igniter/thrustor lead/lags may be varied as indicated in Figure 6.

A detailed test plan for this task, including the number and types of tests to be performed, test equipment, and instrumentation requirements, is being prepared for submittal to the NASA/LeRC Project Manager for approval early in August. In order to minimize test installation and instrumentation changes, it is presently intended to conduct the high pressure (100 psia) thrustor pulse mode tests immediately following the high pressure baseline tests, and then perform both the baseline and pulse mode tests on the 10 psia thrustor hardware.

3. CURRENT PROBLEMS

No major problems exist at this time that may impede overall performance of the program.

4. WORK TO BE ACCOMPLISHED DURING THE REPORTING PERIOD

The following program activities are planned for the August reporting period:

Task IVC - Thrustor/Igniter Baseline Tests

- Perform combined thrustor/igniter test firings at both chamber pressure levels with the catalyst bed and thrustor configurations selected, based upon Task IVB results.
- Establish baseline performance and response times for the 10 and 100 psia chamber pressure thrustors over a range of propellant inlet conditions and catalyst bed temperatures.

Task V - Thrustor Pulse Mode Tests

- Submit detailed test plan for approval by the NASA/LeRC Project Manager.
- Begin pulse mode duty cycle firings at each chamber pressure level as outlined in the test plan.

Task VI - Data Evaluation

- Continue analysis and evaluation of data from the experimental test effort.

5. NEW TECHNOLOGY DISCLOSURES

No new technology disclosures were reported during this period.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

CONTRACT PROGRESS SCHEDULE

REPORT FOR MONTH ENDING: 25 July 1969

1. CONTRACT TITLE: INVESTIGATION OF THRUSTORS FOR CRYOGENIC REACTION CONTROL SYSTEMS

2. CONTRACTOR (Name and address): TRW INC., TRW SYSTEMS GROUP, One Space Park, Redondo Beach, Calif. 90278

3. CONTRACT NO.: NAS 3-11227

4. APPROVED (Contractor's Project Manager): R. J. Johnson — R. J. Johnson

PREPARATION DATE: 8-20-69

5. NASA APPROVED SCHEDULE DATE: 6-19-68

9. NASA Use Only: a. NASA CODE; b. PROJECT MGR.; c. EVALUATION DATE; d. EXCEPTION CATEGORY; e.; f.; g.

6. REPORTING CATEGORY	7. 1968: J J A S O N D; 1969: J F M A M J J A S O N D	8. TECH. OBJECTIVE a. WEIGHT FACTOR	b. % COMP.	c. % CONTR. COMP.
I - Catalyst Activity Investigation		12	100	12
IIA - Vacuum Effects Design & Fabrication	2	10	100	10
IIB - Vacuum Effects Reactor Tests	2	20	100	20
III - Thrustor/Igniter Design & Fabrication	1, 1	10	100	10
IVA - Thrustor/Igniter Energy Level Tests	2	18	100	18
IVB - Thrustor/Igniter Bed Optimization	3	10	100	10
IVC - Thrustor/Igniter Baseline Tests	3	6	50	3
V - Thrustor Pulse Mode Tests	3	6	30	2
VI - Data Evaluation	2	5	90	4
Reports (a) Work Plan (b) Monthly Reports (c) Final Report	(a) (b) (b) (c)	3*	0	0

NASA-C-63 (6-67)

NASA APPROVED SCHEDULE

CONTRACTOR'S WORKING SCHEDULE

*Final Report Only