THE Marquardt CORPORATION

VAN NUYS, CALIFORNIA

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THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

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RCS ENGINE

LUNAR MODULE GAS BUBBLE INGESTION
TEST PROGRAM

PRODUCT IMPROVEMENT PROGRAM

NAS 9-7281

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I. SUMMARY

Empirical data were obtained under circumstances simulating the initial LM RCS engine firings on the Apollo 5 mission. On this mission bubble volumes of nearly 5 cubic inches were expected to be trapped in the propellant lines adjacent to the RCS engine valves prior to initial engine operation. Tests were conducted to determine the operational characteristics and to ascertain the structural integrity of the engine when fired with such bubble volumes in the propellant lines. Bubble expulsion from the propellant lines required up to 0.170 seconds of steady state operation and fifteen, 0.013 second pulses. Structural integrity was maintained under safe operating conditions even when the engine ingested a bubble volume of greater than 5 cubic inches.

An analytical model was developed which can be used to accurately predict the steady state run time or number of pulses required to expel a non-reactive gas bubble of any given volume from a propellant line of the specified geometry and any given dimensions.

II. INTRODUCTION

Spacecraft launch procedures for the unmanned first Lunar Module flight to be flown as part of the Apollo 5 mission specified the Reaction Control System (RCS) propellant lines be filled with gaseous nitrogen at a pressure of one atmosphere during the launch phase. Subsequent to obtaining earth orbit, the RCS propellant systems were to be primed with propellants by opening the main shutoff valves. Since this procedure results in nitrogen bubbles trapped in the propellant lines adjacent to the RCS engine valves, the National Aeronautics and Space Administration (NASA) directed The Marquardt Company (TMC) -- "to initiate effort to determine the size and quantity of bubbles that the Service Module (SM) - Lunar Module (LM) RCS engine can successfully ingest during steady state and pulsing operation and the resultant effects of this ingestion".

Since bubble effects are strongly dependent on bubble volume engine duty cycle, and propellant feedline dynamics, the possible permutations of these variables were limited by mutual agreement between NASA and TMC to obtain empirical data for the most severe circumstances expected during the Apollo 5 flight. To determine bubble effects for all other circumstances, a computer program was to be devised which would predict both steady state and pulse mode bubble expulsion time and pressure variations at the engine inlet during pulse mode operation.

III. DISCUSSION

A. Determination of Bubble Volumes

Figure 1 illustrates the LM RCS propellant feed line system where attitude control redundancy is achieved using two separate propellant systems each of which normally supplies two engines of each quad. Crossover valves in the system (not shown) allow all four engines of each quad to be operated from one propellant system, if necessary. Spacecraft launch procedures for the Apollo 5 mission specified that the LM RCS propellant lines be filled with gaseous nitrogen at a pressure of one atmosphere during the launch phase. Consequently, when the lines are subsequently primed with propellants pressurized to 181 psia, gas bubbles of various sizes will be formed adjacent to the engine valves.

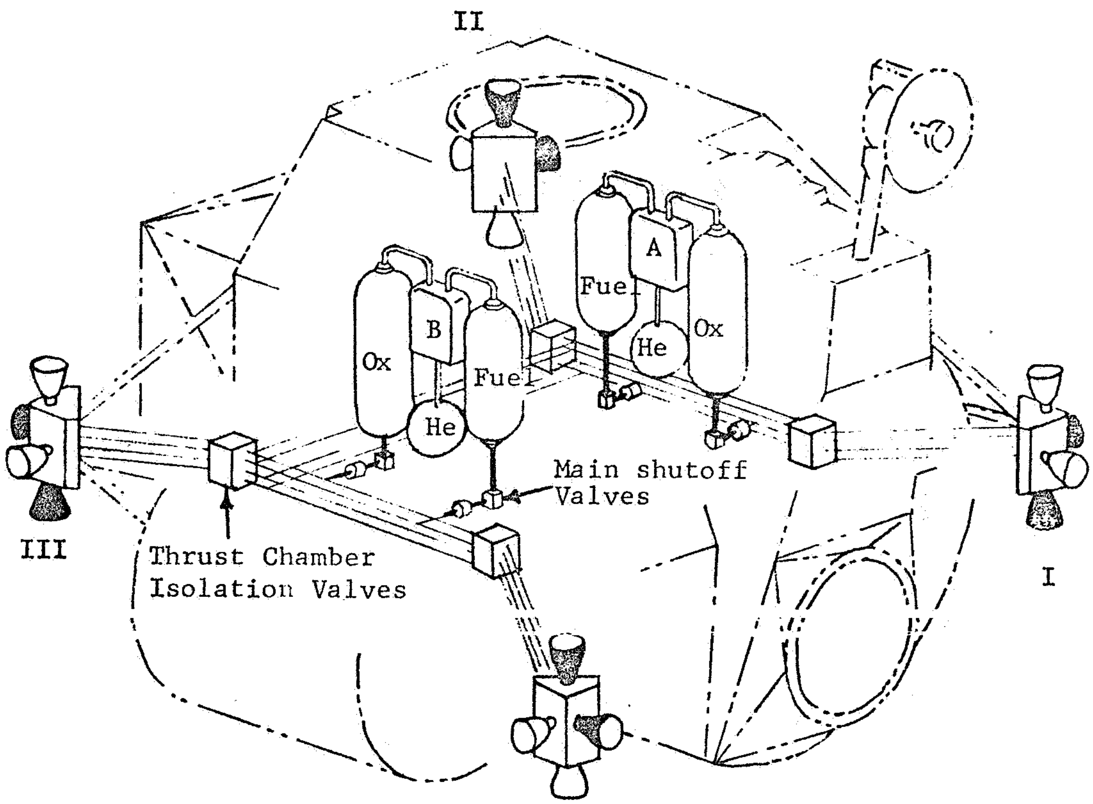
Bubble volumes resulting from this priming were calculated assuming isothermal compression of the nitrogen by the incoming propellant. Line volumes from the propellant tank of system A to each of the engine quad assemblies are shown in Figure 2. It was assumed that the nitrogen while being compressed was homogenous in pressure. The mass of the nitrogen in each quad increases until the quad feed line is closed off by the incoming liquid. The final bubble volume in each quad can now be determined since the mass of the trapped gas and the final pressure (181 psia) are known. The calculated bubble volumes are shown in the following table:

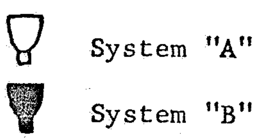
CALCULATED BUBBLE VOLUMES DUE TO PRIMING

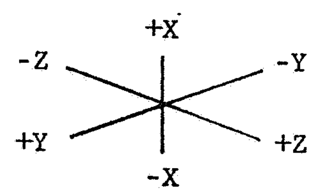
Engine			Initial GN_2 Volume, in.^{3}	Final Bubble Volume, in.^{3}	
System	Quad	Direction		Fuel	Oxidizer
A B	I IV	+Z, +X	25.2	2.0	2.2
A B	II III	-Z, -X	21.8	1.8	1.9
A B	III II	+Y, +X -Y, +X	29.8	2.4	2.6
A B	IV I	+Y, -X -Y, -X	55.6	4.5	4.9

The largest bubbles calculated for both the A and B systems will be expelled during a 5-second steady state firing in the "-X" direction to separate the LM from the SIVB stage. The largest bubble likely to be ingested by an engine in the pulse mode is the 2.4 in.^{3} fuel bubble and the 2.6 in.^{3} oxidizer bubble. Consequently, bubble volumes of approximately 5.0 in.^{3} and 2.5 in.^{3} were selected for steady state and pulse mode evaluation testing.

REACTION CONTROL SYSTEM INSTALLATION







AXES ORIENTATION

FIGURE 1

LM SPACECRAFT LINE VOLUMES

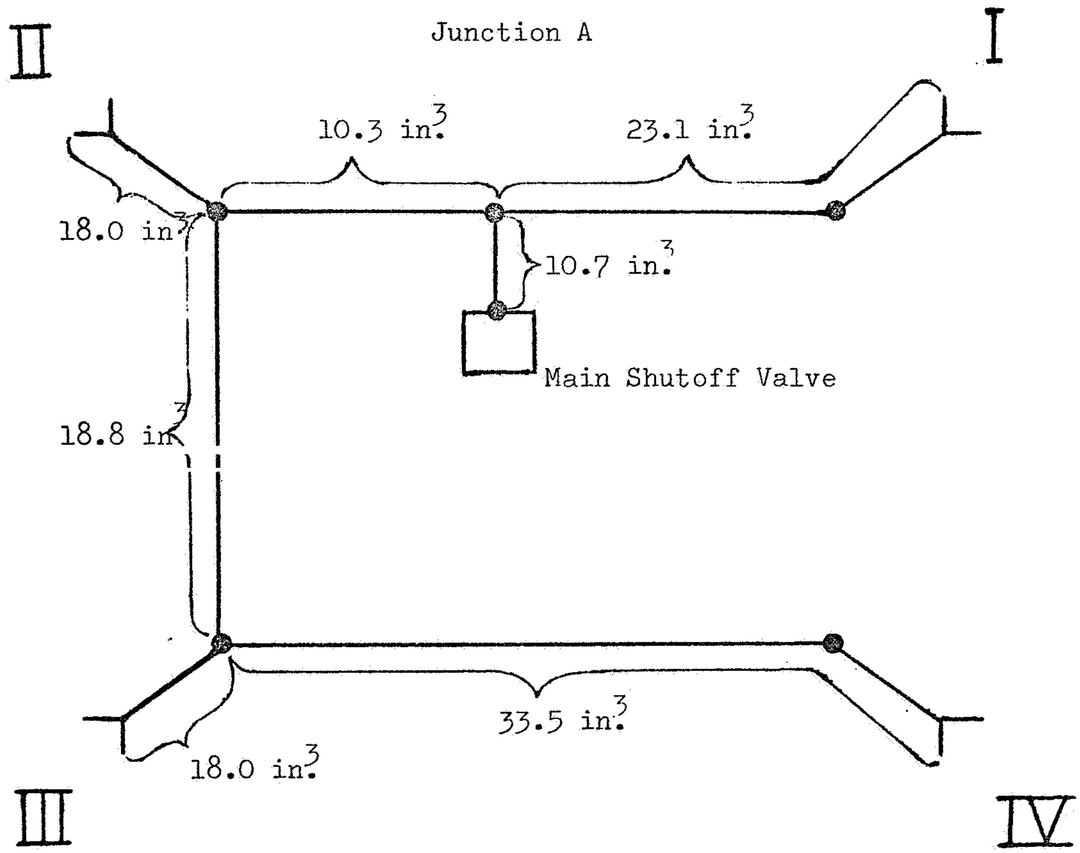


FIGURE 2

B. Test Facilities and Procedures

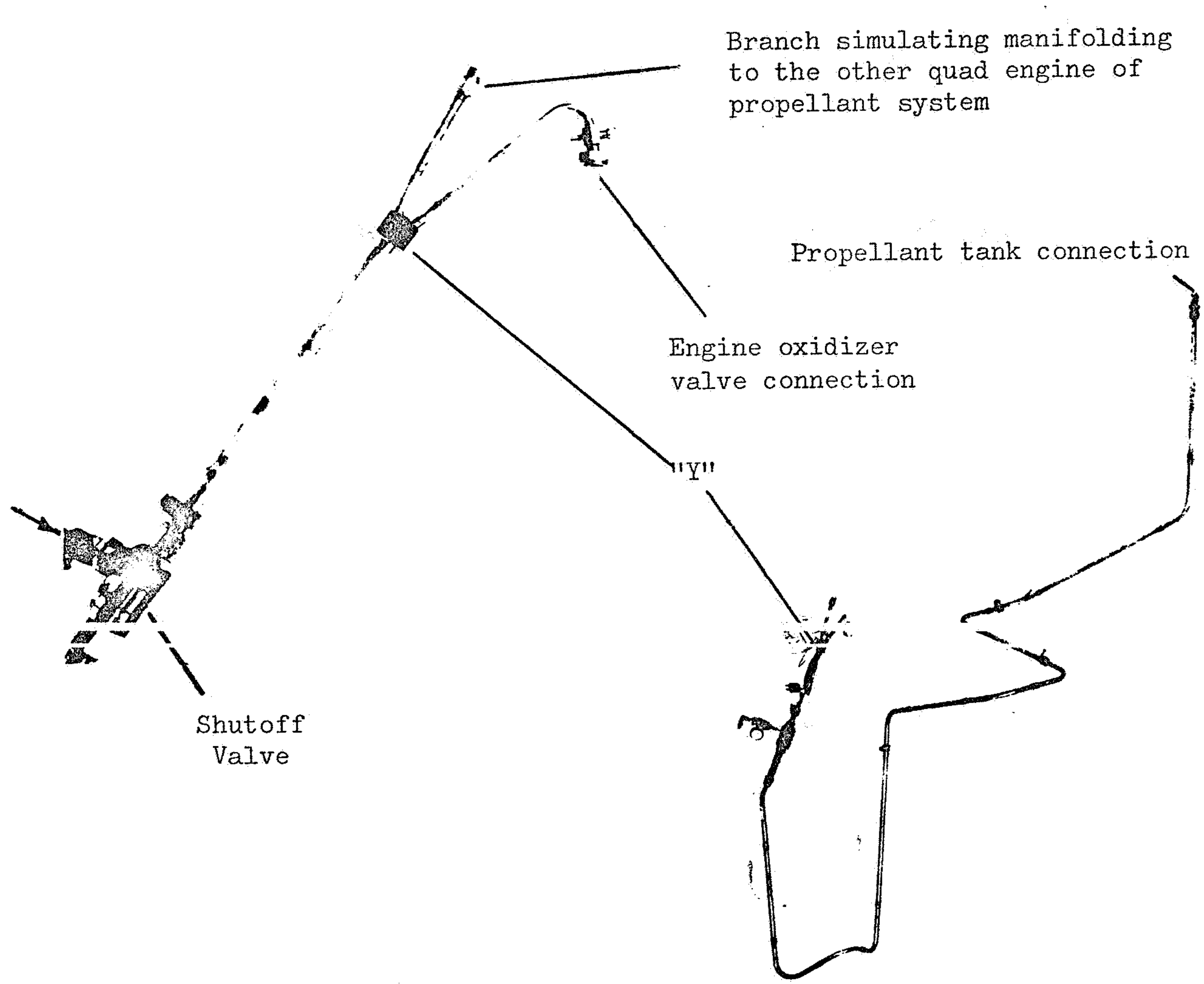
The test was conducted in Pad "G" of the Precision Rocket Laboratory (PRL) at TMC in Van Nuys, California, between 5 December and 15 December 1967. This test was conducted with the engine mounted in the vertical down firing attitude on a low altitude (~ 115,000 ft) test stand. Propellant line dynamics are of most concern during pulsing operation, so the propellant system of the Pad "G" low altitude test stand was fabricated to simulate the propellant lines to the engine with the largest bubble to be expelled during pulsing operation, i.e., System A, Quad III and System B, Quad II. The propellant lines used in this test are shown in Figures 3 and 4. Figure 5 is a photograph of the Pad "G" low altitude test setup with engine P/N X228687-517, S/N 0034, installed in the down firing altitude and connected to the propellant lines shown in Figures 3 and 4. The engine, after installation in the test stand, was subjected to the tests specified by Marquardt Test Plan (MTP) 0079 (Appendix A). The firing matrix was designed to determine how many milliseconds (in the case of steady state firing) or how many pulses (in the case of pulsing operation) it takes to expel the sized gas bubbles from the propellant inlets. Two bubble sizes were evaluated - a bubble of approximately 2.5 in.^{3} and 5.0 in.^{3} - first in one propellant line, then the other and then in both lines.

In determining bubble expulsion times for steady operation the engine was fired for one second or greater which was calculated to be more than enough time to rid the lines of the bubble. The number of pulses required for bubble expulsion was accomplished by firing a pulse train of a given number of pulses followed by a steady state run. If the ignition delay on the steady state run was greater than the pulse width then the pulse train was rerun and the number of pulses was increased. This process was repeated until engine ignition did occur on the steady state run within the time span of the programmed pulse width. The steady state run at the end of the pulse train ensured that the propellant residue accumulated during bubble expulsion would be consumed prior to the next engine firing. At higher altitudes or in a space environment the residue would evaporate more rapidly.

Four pulsing duty cycles were chosen to represent probable LM-1 short pulse operation. These duty cycles were:

On Time (sec)	Off Time (sec)
0.013	1.987
0.020	0.480
0.030	0.172
0.050	0.172

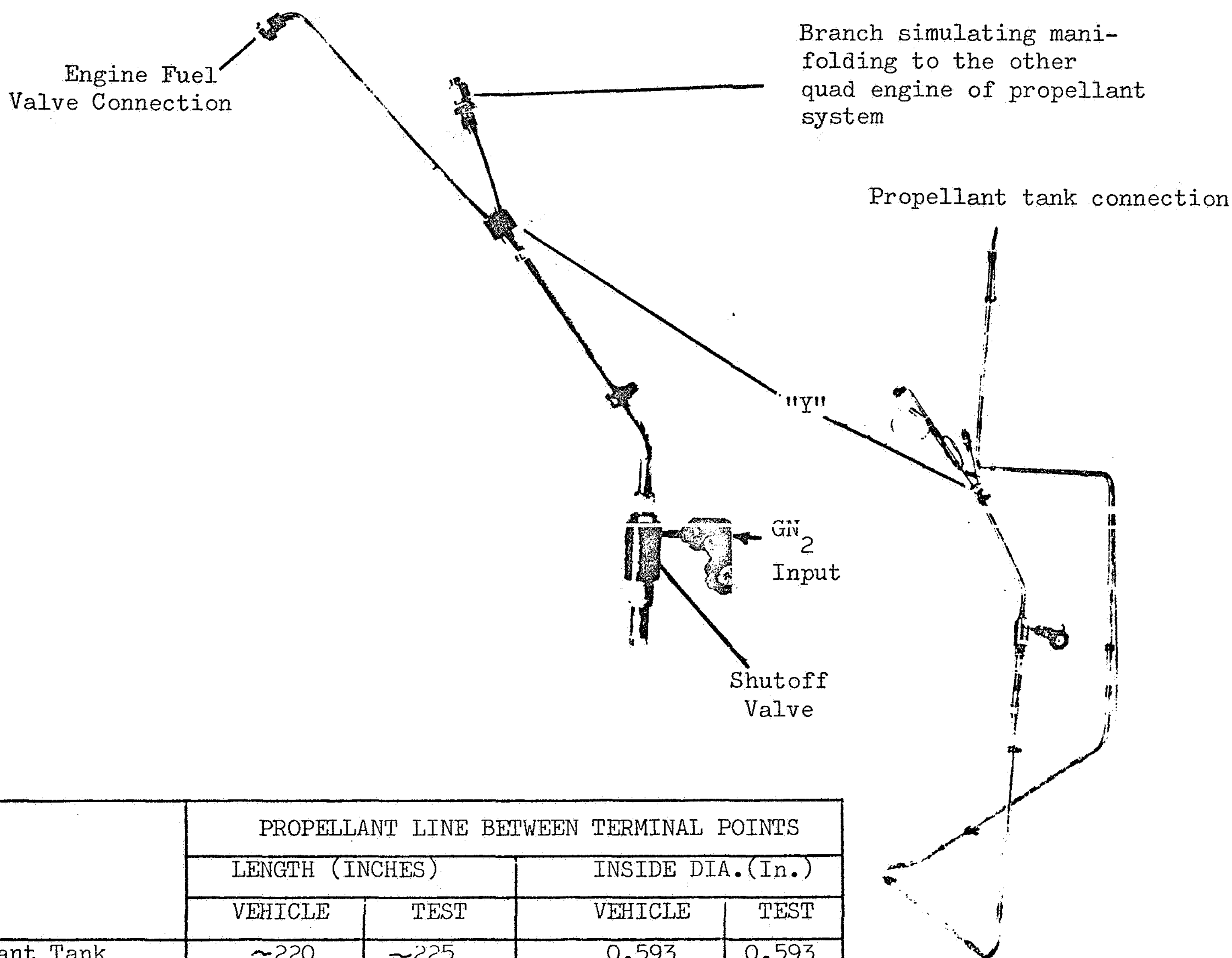
PAD "G" OXIDIZER LINE FOR BIG BUBBLE TEST



TERMINAL POINTS	PROPELLANT LINE BETWEEN TERMINAL POINTS			
	LENGTH (INCHES)		INSIDE DIA. (In.)	
	Vehicle	Test	Vehicle	Test
Propellant Tank to "Y"	~220	~210	0.593	0.593
"Y to Engine Valve	10	10	0.343	0.343
"Y" to Branch Terminal	6	6	0.343	0.343

Figure 3

PAD "G" FUEL LINE FOR BIG BUBBLE TEST



	PROPELLANT LINE BETWEEN TERMINAL POINTS			
	LENGTH (INCHES)		INSIDE DIA. (In.)	
	VEHICLE	TEST	VEHICLE	TEST
Propellant Tank to "Y"	~220	~225	0.593	0.593
"Y" to Engine Valve	15	15	0.343	0.343
"Y" to Branch Terminal	5	5	0.343	0.343

Figure 4

Pad "G" Low Altitude Setup

NEG. T3556-3

Figure 5

The bubble volumes tested were generated in the propellant manifolds by closing the shutoff valves (see Figures 3 and 4) on the oxidizer and/or fuel lines, as required; purging the propellants from the lines upstream of this valve (including the branch) with GN_2 and filling the purged volume with GN_2 at the pressure necessary to provide the required volume at run pressures. The volume of the oxidizer manifold between the shutoff valve and the engine valve (including the branch) was 5.86 in.^{3}; that of the fuel manifold was 6.76 in.^{3}. With these volumes and the required bubble sizes the pressures at which the GN_2 was to fill the manifolds was calculated using Charles Law and the total pressure at run conditions:

Approximate Bubble Size	Oxidizer Pressure	Fuel Pressure
2.5 in.^{3}	77 psia	67 psia
5.0 in.^{3}	154 psia	134 psia

Actual bubble sizes tested for the oxidizer system were 2.75 in.^{3} and 5.5 in.^{3} because at the time the tests were conducted no allowances were made for the partial pressure of the oxidizer which contributes to the total run pressure (for N_2O_4, the partial pressure is approximately 15 psia; for Aerozine-50, the partial pressure is negligible). The oxidizer system test results are, therefore, for a bubble volume even larger than can be expected on the Apollo program. Testing was conducted at lower engine temperatures than would be used in actual operating conditions, adding still more confidence that engine operation in the actual mission will be safe.

It had been thought that the bubble expulsion time or number of pulses required to expel the bubble would be within TMC's experience, and that from these data, safe engine operation with bubbles in the line could be postulated. The results of the initial test phase did not allow such a conclusion to be drawn since overall propellant mismatch time was greater than TMC's previously documented test experience, and a second phase of testing was directed by NASA as documented in Deviation No. 11 to MTP 0079. For this phase the engine was installed in the high altitude ($\simeq$ 250,000 ft) test cell in the horizontal attitude to best simulate zero-g conditions. No effort was made to generate a bubble in the propellant lines, instead the bubble was simulated by opening only one valve during a number of pulses and subsequently opening both valves simultaneously. The valve that was opened to allow "cold flow" of the propellant simulated the "no bubble" condition; the valve remaining closed simulated the condition where only gas would flow through the valve during bubble expulsion. The number of "cold flow" pulses required to simulate the bubble was determined from the initial "low altitude" tests.

C. Discussion of Test Results

Table I summarizes the runs conducted during the low altitude tests, the results of which are presented in Figures 6 and 7. These figures

LOW ALTITUDE TEST RESULTS

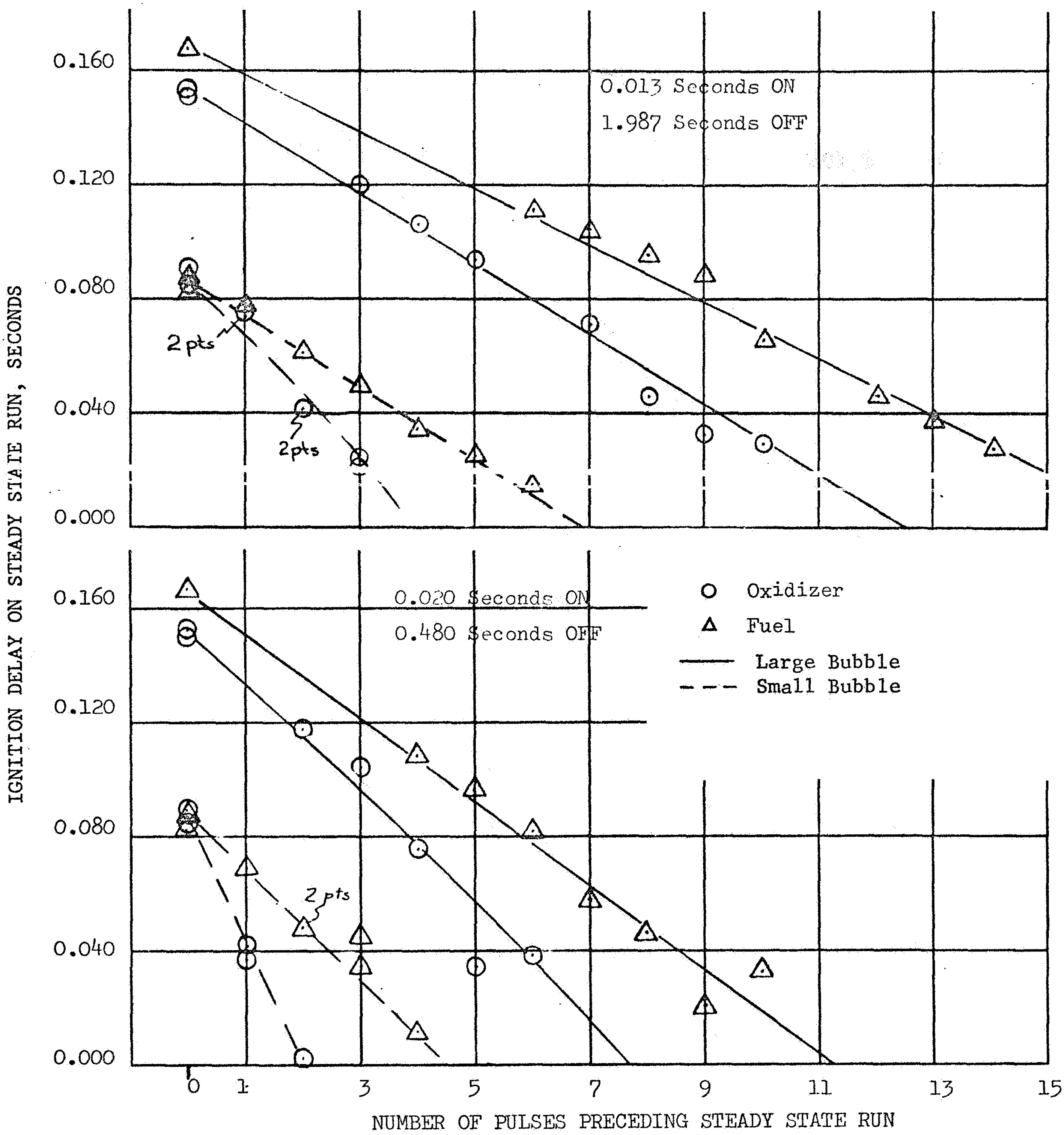


FIGURE 6

LOW ALTITUDE TEST RESULTS

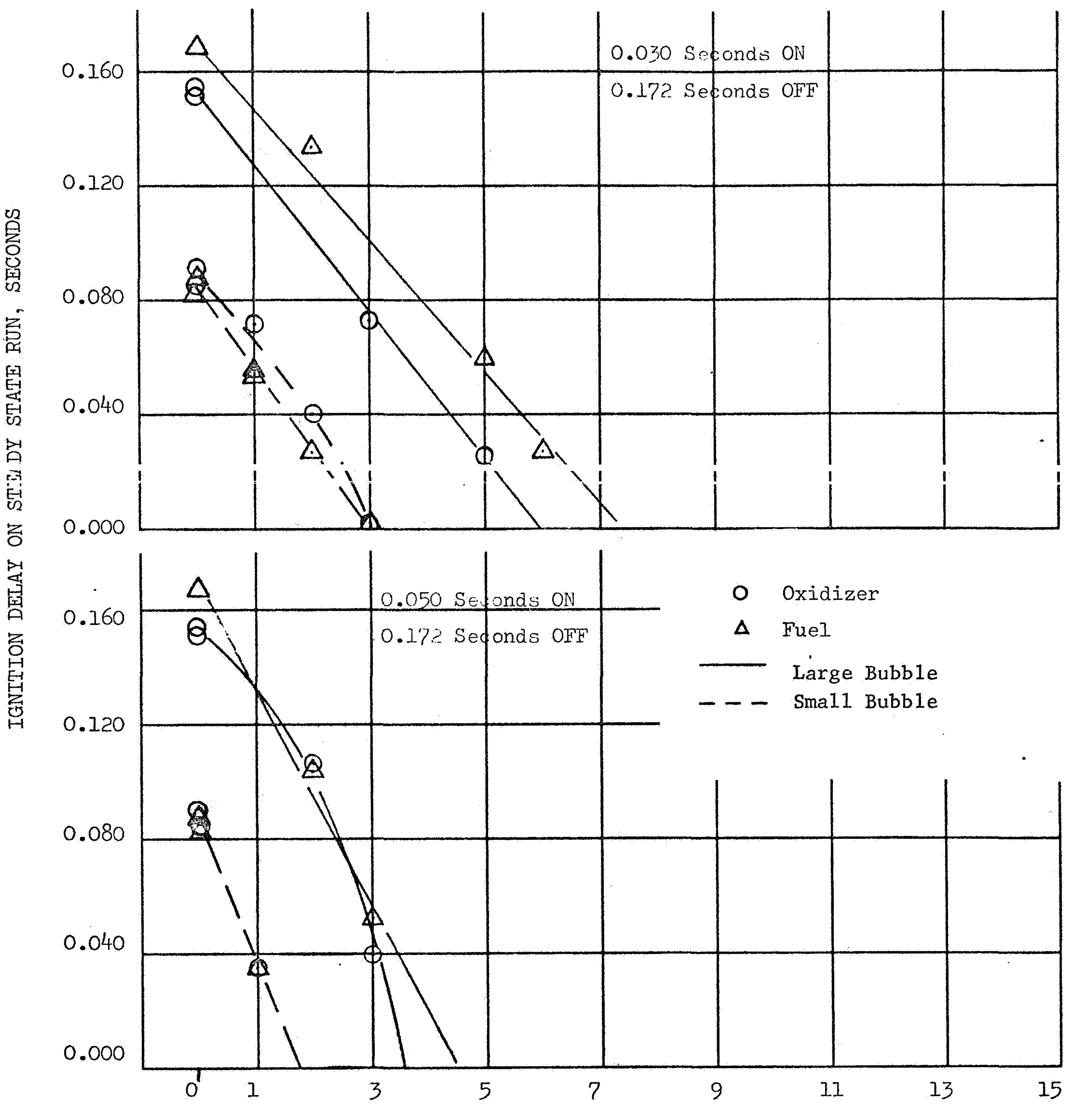


FIGURE 7

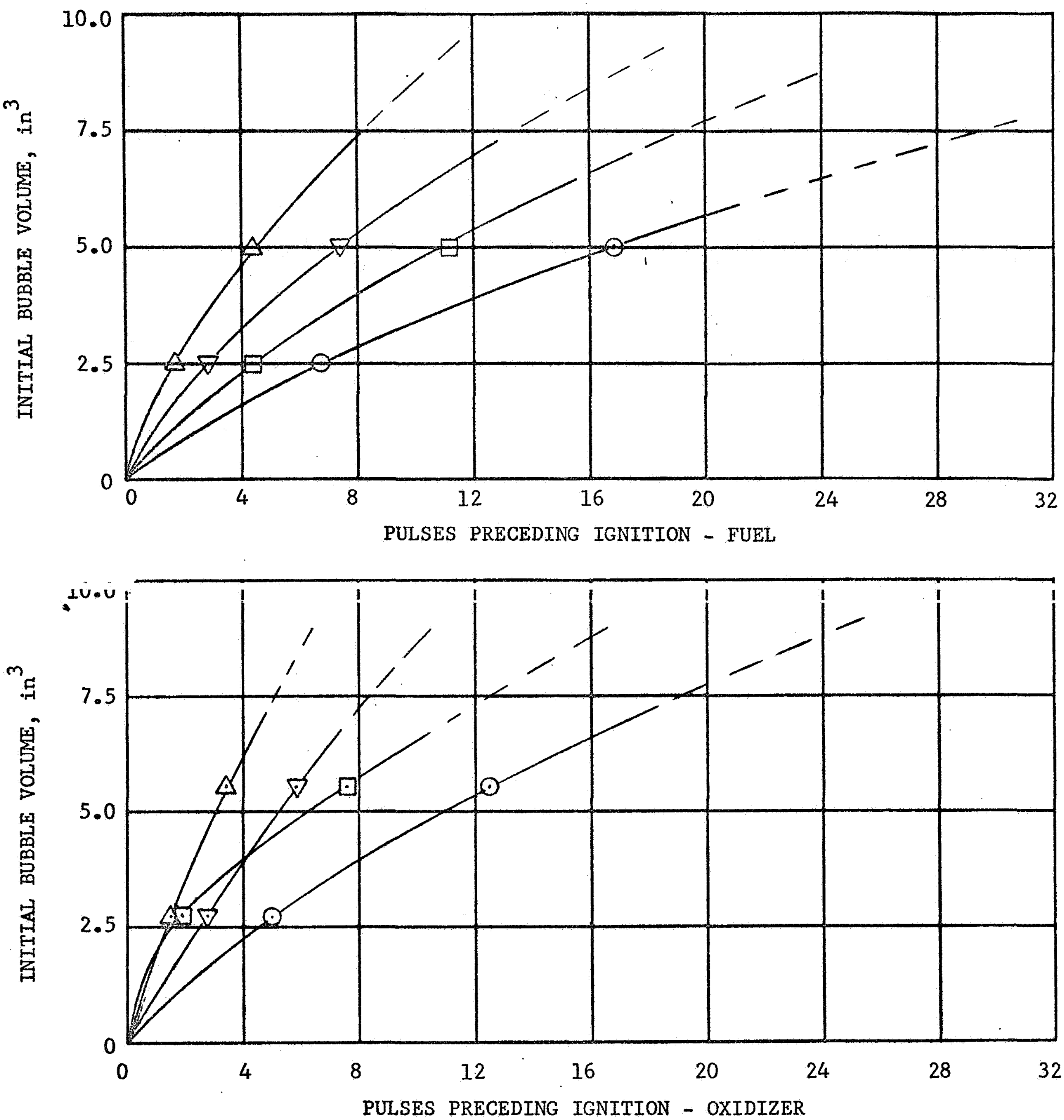
show the decrease in ignition delay on the steady state run as the number of pulses conducted prior to the steady state run is increased. The intersection of the mean line drawn through the data and the X-axis indicates the number of pulses required to expel a bubble of that particular size and duty cycle from the propellant lines and engine. The intercept points for the four duty cycles tested with each propellant are shown in Figure 8. The family of curves shown in Figure 8 for the fuel side bubbles appear well behaved and the number of pulses needed to expel a gas bubble from other pulse widths and bubble volumes can be extrapolated using this data. The oxidizer side data is not so well behaved. The obvious disparity is that a fewer number of 20 ms pulses than 30 ms pulses evacuates a 2.75 in^3 bubble from the lines.

An investigation of this phenomenon showed the line dynamics are such that the oscillating manifold pressure at the start of succeeding 20 ms pulses is greater than on the succeeding 30 ms pulses and consequently, expels the bubble more rapidly. Had the test been conducted at a different duty cycle (longer "off" times), this disparity in the data would not have been evident.

The second phase of the test program summarized in Table II consisted of 31 runs, 24 of which simulated engine operation with bubble volumes of approximately 2.5 in^3. Only the fuel valve was pulsed for a number of pulses to simulate engine operation with a bubble in the oxidizer valve, or vice versa, followed by several pulses where both valves were operated to simulate ignition following bubble expulsion. The number of pulses of singular valve operation to simulate bubble expulsion was determined from the data used to plot Figures 6 and 7 for the particular bubble volume, bubble location and duty cycle being simulated. Emphasis was placed upon evaluating safe ignition with the smaller (2.5 in^3) bubbles since this is the largest volume likely to be contained in the Apollo 5 LM RCS manifolds prior to pulsing engine operation. The larger bubbles were simulated in test to explore the margin of safe operation. Previous test experience at off-design conditions has shown that engine operation is more severe at shorter pulse widths, therefore, the tests shown in Table II concentrate on evaluating the short pulse width duty cycles.

None of the tests conducted which simulated either 2.5 in^3 or 5.0 in^3 gas bubbles resulted in any engine anomalies or damage. Chamber pressure measurements indicated that none of the ignitions resulted in significant ignition overpressures. From these results it can be concluded that the Apollo LM RCS engine will operate safely at the pulsing conditions expected during the Apollo 5 mission since safe ignition was demonstrated with simulated bubbles equal to and greater than those expected.

NUMBER OF PULSES REQUIRED TO EXPEL A BUBBLE



LEGEND:
- ⊙ 0.013 Seconds ON, 1.987 Seconds OFF
- ⊡ 0.020 Seconds ON, 0.480 Seconds OFF
- ▽ 0.030 Seconds ON, 0.172 Seconds OFF
- △ 0.050 Seconds ON, 0.172 Seconds OFF

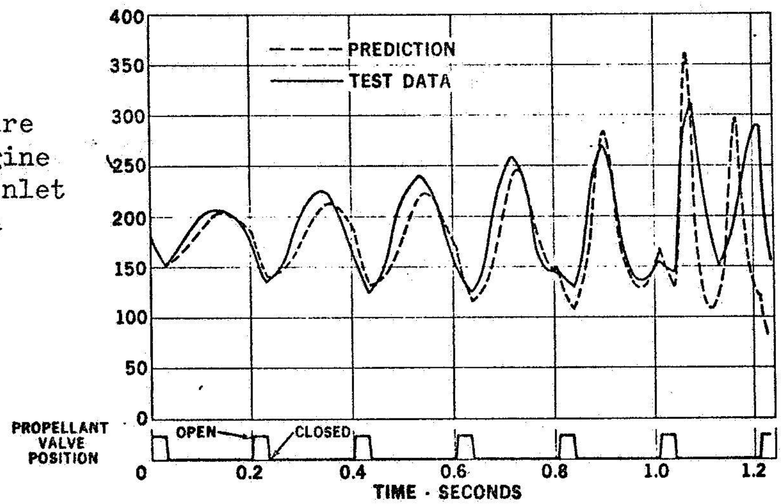
FIGURE 8

D. Comparison of Empirical Results with Analytical Prediction

A computer program was developed to predict the propellant line pressure dynamics and the steady state run time or number of pulses required to expel a bubble of given size. This program is presented in Appendix B. Liquid compressibility was ignored in this program. An earlier iteration in the development of the program considered compressibility, but the computer did not have sufficient core space to handle all the storage required. The assumption of an incompressible liquid becomes incompatible with test results only when the bubble volume becomes small; this comparison is presented in Figure 9 for one duty cycle and bubble volume in the fuel line. This program was also used to predict the steady state bubble expulsion time; this prediction is compared with test results in Figure 10. It is seen that the test results agree quite well with the predicted values. This program is completely general except that the valve response time for the Apollo valves is an integral statement of the program. This statement is clearly marked in Appendix B.

COMPARISON OF ANALYTICAL AND EMPIRICAL
DATA FOR PULSING OPERATION

Pressure at Engine Fuel Inlet Psia



Initial Bubble Volume = 5.0 In.^{3}

Pulsing Duty Cycle: 30 ms ON/172 ms OFF

FIGURE 9

COMPARISON OF ANALYTICAL AND EMPIRICAL
DATA FOR STEADY STATE OPERATION

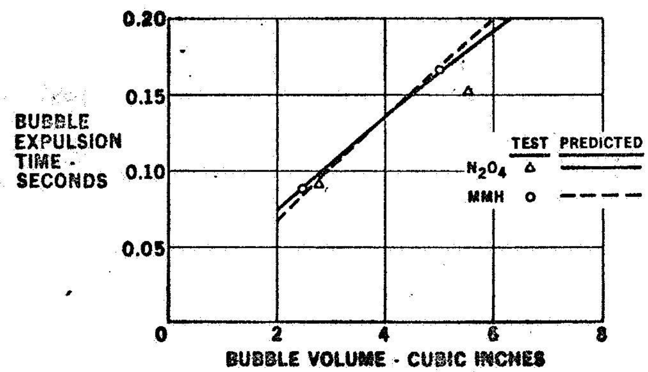


Figure 10

IV. CONCLUSIONS AND RECOMMENDATIONS

1. Bubble volumes as large as 5.0 $in.^3$ can safely be ingested by the SM-LM RCS system in the steady state mode of operation, and as large as 2.5 $in.^3$ in the pulsing mode. These volumes are not safety limitations, as such, but only establish that expected bubble volumes can be safely ingested. Safe pulse mode engine operation was demonstrated for a limited number of tests, with simulated bubble volumes of approximately 5.0 cubic inches.

2. An analytical model has been developed which can be used to accurately predict the steady state run time or number of pulses required to expel a nonreactive gas bubble of any given volume from a propellant line of the specified geometry (see Appendix B) and any given dimensions.

TABLE I

BIG BUBBLE TEST - PHASE I

Summary of Firing Test

Run No.	Run Duration (seconds)		Number of Pulses	Initial Bubble Volume (cubic inches)		Ignition Delay (ms)	Controlling Document	Remarks
	On	Off		Oxidizer	Fuel			
748	0.013	1.987	10	0	0	--	MTP 0079	
749	5	--	1	2.5	0	85	Para. A-4.3	
750	5	--	1	0	2.5	88		
751	5	--	1	2.5	2.5	96		
752	0.013 5	1.987 *	1 1	2.5 --	0 0	75		*The time between the last pulse and the steady state run is the same as the time between pulses.
753	0.013 5	1.987 *	2 1	2.5 --	0 0	41		
754	0.013 5	1.987 *	3 1	2.5 --	0 0	24		
756	0.013 5	1.987 *	1 1	0 0	2.5 --	77		
757	0.013 5	1.987 *	2 1	0 0	2.5 --	61		
758	0.013 5	1.987 *	3 1	0 0	2.5 --	49		
759	0.013 5	1.987 *	4 1	0 0	2.5 --	35		
760	5	--	1	0	2.5	82		
763	0.013 1	1.987 *	5 1	0 0	2.5 --	26		Deviation No. 2 shortened steady state run time

TABLE I (Continued)

Run No.	Run Duration (seconds)		Number of Pulses	Initial Bubble Volume (cubic inches)		Ignition Delay (ms)	Controlling Document	Remarks
	On	Off		Oxidizer	Fuel			
764	0.013 1	1.987 *	6 1	0 0	2.5 --	15	MTP 0079 Para. A-4.3	
765	0.013 1	1.987 *	6 1	0 0	2.5 --	15	Dev. No. 4	
766	0.013 1	1.987 *	3 1	2.5 --	0 0	21		
767	0.013 1	1.987 *	6 1	2.5 --	2.5 --	24	MTP 0079 Para. A-4.3	
768	0.020 1	0.480 *	1 1	2.5 --	0 0	38		
769	0.020 1	0.480 *	2 1	2.5 --	0 0	2		
770	0.020 1	0.480 *	1 1	0 0	2.5 --	70		
771	0.020 1	0.480 *	2 1	0 0	2.5 --	49		
772	0.020 1	0.480 *	3 1	0 0	2.5 --	44		
774	0.020 1	0.480 *	2 1	0 0	2.5 --	49	Dev. No. 5	
775	0.020 1	0.480 *	3 1	0 0	2.5 --	35		
776	0.020 1	0.480 *	4 1	0 0	2.5 --	13		

TABLE I (Continued)

Run No.	Run Duration (seconds)		Number of Pulses	Initial Bubble Volume (cubic inches)		Ignition Delay (ms)	Controlling Document	Remarks
	On	Off		Oxidizer	Fuel			
777	0.020 1	0.480 *	4 1	2.5 --	2.5 --	28	MTP 0079 Para. A-4.3	See Deviation No. 6
778	0.030 1	0.172 *	1 1	2.5 --	0 0	72		
779	0.030 1	0.172 *	2 1	2.5 --	0 0	40		
780	0.030 1	0.172 *	3 1	2.5 --	0 0	1		
781	0.030 1	0.172 *	1 1	0 0	2.5 --	54	MTP 0079 Para. A-4.3	
782	0.030 1	0.172 *	2 1	0 0	2.5 --	27		
783	0.030 1	0.172 *	3 1	0 0	2.5 --	1		
785	1	--	1	5.0	0	150		
786	1	--	1	0	5.0	167		
787	1	--	1	5.0	5.0	167		
788	0.013 1	1.987 *	3 1	5.0 --	0 0	120		See Deviation No. 7
789	0.013 1	1.987 *	4 1	5.0 --	0 0	106		
790	0.013 1	1.987 *	5 1	5.0 --	0 0	94		

TABLE I (Continued)

Run No.	Run Duration (seconds)		Number of Pulses	Initial Bubble Volume (cubic inches)		Ignition Delay (ms)	Controlling Document	Remarks
	On	Off		Oxidizer	Fuel			
791	0.013 1	1.987 *	7 1	5.0 --	0 0	71	MTP 0079 Para. A-4.3	
792	0.013 1	1.987 *	9 1	5.0 --	0 0	33		
793	0.013 1	1.987 *	10 1	5.0 --	0 0	30		
795	0.013 1	1.987 *	6 1	0 0	5.0 --	111		See Deviation No. 7
796	0.013 1	1.987 *	7 1	0 0	5.0 --	105		
797	0.013 1	1.987 *	8 1	0 0	5.0 --	96		
798	0.013 1	1.987 *	10 1	0 0	5.0 --	66		
799	0.013 1	1.987 *	12 1	0 0	5.0 --	46		
800	0.013 1	1.987 *	14 1	0 0	5.0 --	29		
801	0.013 1	1.987 *	14 1	5.0 --	5.0 --	40		
802	0.020 1	0.480 *	2 1	5.0 --	0 0	118		
804	0.020 1	0.480 *	3 1	5.0 --	0 0	105		

TABLE I (Continued)

Run No.	Run Duration (seconds)		Number of Pulses	Initial Bubble Volume (cubic inches)		Ignition Delay (ms)	Controlling Document	Remarks
	On	Off		Oxidizer	Fuel			
805	0.020	0.480	4	5.0	0		MPT 0079	
	1	*	1	--	0	76	Para. A-4.3	
806	0.020	0.480	5	5.0	0			
	1	*	1	--	0	35		
807	0.020	0.480	6	5.0	0			
	1	*	1	--	0	39		
808	0.020	0.480	4	0	5.0			
	1	*	1	0	--	109		
809	0.020	0.480	5	0	5.0			
	1	*	1	0	--	97		
810	0.020	0.480	6	0	5.0			
	1	*	1	0	--	81		
811	0.020	0.480	7	0	5.0			
	1	*	1	0	--	59		
814	0.020	0.480	8	0	5.0			
	1	*	1	0	--	46		
815	0.020	0.480	9	0	5.0			
	1	*	1	0	--	22		
816	0.020	0.480	10	0	5.0			
	1	*	1	0	--	36		
817	0.020	0.480	10	5.0	5.0			
	1	*	1	--	--	30		

TABLE I (Continued)

Run No.	Run Duration (seconds)		Number of Pulses	Initial Bubble Volume (cubic inches)		Ignition Delay (ms)	Controlling Document	Remarks
	On	Off		Oxidizer	Fuel			
818	0.030	0.172	3	5.0	0		MTP 0079	See Deviation No. 9
	1	*	1	--	0	73	Para. A-4.3	
819	0.030	0.172	5	5.0	0			
	1	*	1	--	0	26		
820	0.030	0.172	2	0	5.0			
	1	*	1	0	--	133		
821	0.030	0.172	5	0	5.0			
	1	*	1	0	--	60		
822	0.030	0.172	6	0	5.0			
	1	*	1	0	--	28		
823	0.030	0.172	6	5.0	5.0			
	1	*	1	--	--	36		
825	1	--	1	0	2.5	88	Dev. No. 10	
826	0.030	0.172	1	0	2.5		↓	
	1	*	1	0	--	55	↓	
827	1	--	1	2.5	0	90	↓	
828	0.013	1.987	1	2.5	0		↓	
	1	*	1	--	0	75	↓	
829	0.013	1.987	2	2.5	0		↓	
	1	*	1	--	0	42	↓	
830	0.020	0.480	1	2.5	0		↓	
	1	*	1	--	0	41	↓	
831	1	--	1	5.0	0	153	↓	

TABLE I (Continued)

Run No.	Run Duration (seconds)		Number of Pulses	Initial Bubble Volume (cubic inches)		Ignition Delay (ms)	Controlling Document	Remarks
	On	Off		Oxidizer	Fuel			
832	0.013 1	1.987 *	8 1	5.0 --	0 0	40	Dev. No. 10	
833	0.013 1	1.987 *	9 1	0 0	5.0 --	90	↓	
834	0.013 1	1.987 *	13 1	0 0	5.0 --	38	↓	
835	0.050 1	0.172 *	1 1	2.5 --	0 0	36	↓	
836	0.050 1	0.172 *	1 1	0 0	2.5 --	35	↓	
837	0.050 1	0.172 *	2 1	5.0 --	0 0	107	↓	
838	0.050 1	0.172 *	3 1	5.0 --	0 0	40	↓	
839	0.050 1	0.172 *	2 1	0 0	5.0 --	104	↓	
840	0.050 1	0.172 *	3 1	0 0	5.0 --	53	↓	

NOTE: Trim runs are not included in this table.

TABLE II

BIG BUBBLE TEST - PHASE II

Summary of Firing Tests

Run No.	Run Duration (seconds)		Number of Cold-Flow Pulses		Number of Hot-Fire Pulses	Controlling Document	Remarks
	On	Off	Oxidizer	Fuel			
844	0.013	1.987	5	0	5	Dev. No. 11	
845	0.013	1.987	5	0	5		
846	0.013	1.987	5	0	5		
847	0.013	0.487	5	0	5		
848	0.013	0.487	5	0	5		
849	0.013	0.487	5	0	5		
850	0.013	1.987	0	3	5		
851	0.013	1.987	0	3	5		
852	0.013	1.987	0	3	5		
853	0.013	0.487	0	3	5		
854	0.013	0.487	0	3	5		
855	0.013	0.487	0	3	5		
856	0.020	0.480	4	0	4		
857	0.020	0.480	4	0	4		
858	0.020	1.980	4	0	4		
859	0.020	1.980	4	0	4		
860	0.020	0.480	0	1	4		

TABLE II (Continued)

Run No.	Run Duration (seconds)		Number of Cold-Flow Pulses		Number of Hot-Fire Pulses	Controlling Document	Remarks
	On	Off	Oxidizer	Fuel			
861	0.020	0.480	0	1	1	Dev. No. 11	
862	0.020	1.980	0	1	1	↓	
863	0.020	1.980	0	1	1	↓	
864	0.030	0.225	2	0	5	↓	
865	0.030	1.970	2	0	5	↓	
866	0.030	0.225	0	2	5	↓	
867	0.030	1.970	0	2	5	↓	
868	0.013	1.987	15	0	0	Dev. No. 14	No Engine Firing
869	0.013	1.987	15	0	5	Dev. No. 11	
870	0.013	0.487	15	0	5	↓	
871	0.013	1.987	0	10	5	↓	
872	0.013	0.487	0	10	5	↓	
873	0.020	0.480	10	0	4	↓	
874	0.020	0.480	0	5	4	↓	

NOTE: Trim runs are not included in this table.

APPENDIX A

MARQUARDT TEST PLAN (MTP) 0079

BIG BUBBLE TEST

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

TMC A084 STANDARD EO — THE Marquardt CORPORATION

DEC 5 1967	
SHEET 1 OF 1	DWG. NO. MTP 0079
NEW: X	E O ISSUE NO. 1
INFORMATION & INSTRUCTIONS	DRAWING CHANGE LETTER
MEMO	SALVAGE NUMBER

TITLE: BIG BUBBLE TEST

CHG DES — PROPOSED BY: PROJECT

CHANGE — CLASS / TYPE

REASON – DESCRIBE CLEARLY IN A CONCISE MANNER.

INITIAL RELEASE OF MTP 0079

228687-517	S/N 0034	5035-6-3901	5035-6-3
IDENTIFICATION & SERIAL NUMBER EFFECTIVITY		ENG. TASK NUMBER	MANUF. PHASE NO.

DISPOSITION

SEND COPIES TO

CUSTOMER APPROVAL DATE:		
ORIG'G SECTION	PROJECT	
PREPARED BY	R. Moffett	12/4
GROUP LEADER	K. Steele	12/4
PROJECT ENGINEER	R. Moffett	12/4
CHECK	[illegible]	12/4
STRUCTURES	R. Moffett	
MATERIAL & PROCESS		12/4
RELEASE	K. Carberry	12-5-6

1.0 OBJECTIVE

The objective of this test is to evaluate the operation of the Apollo LM RCS engine following the priming of the LM #1 propellant supply lines.

2.0 SCOPE

Operation of the Apollo LM RCS engine will be evaluated by engine firing tests with GN_2 bubbles trapped in the propellant supply lines. The bubble volumes tested will simulate expected bubble volumes formed by inflight priming of the LM #1 propellant lines. Since the LM #1 lines are pressurized with gaseous nitrogen prior to priming the test will be done with entrapped GN_2 bubbles. Two bubble volumes will be evaluated. The largest one, 5.0 in^3, approximates the maximum sized bubble that can be formed during priming - the first firing of an engine adjacent to this bubble will be steady state. The other one, 2.5 in^3, approximates the maximum bubble that can be formed during priming adjacent to an engine where the first firing will be a pulse.

The effects on steady state and pulsing performance while firing with the large bubbles adjacent to the valves will be determined. The pulsing duty cycles tested will correspond to the LM #1 mission ON and OFF times.

Down firing tests in Pad G will explore firing delay (time from electrical ON to ignition) caused by the bubbles where both steady state and pulse firing will be conducted. The propellant feed system will approximate the LM #1 lines from the System A tanks to the Quad III up firing engine. The down firing tests will be conducted as specified in Appendix A.

3.0 DESCRIPTION OF TEST ITEMS

3.1 Engine Description

The LM RCS engine (P/N 228687-517) is a pulse modulated, pressure fed, bipropellant, 100-pound thrust engine that can be used for position stabilization and attitude control.

3.1.1 Engine Component Description

3.1.1.1 Propellant Valves

Oxidizer valve with propellant sediment strainer (P/N 228684-501)

Fuel valve with propellant sediment strainer (P/N 228683-501)

3.1.1.2 Injector Head Assembly (P/N 228685)

3.1.1.3 Thrust Chamber and Bell Assembly

Molybdenum Combustor (P/N 228128-501)

Adaptor (Pad G Fixed) Bell (P/N T13785)

4.0 REFERENCES

The following documents form a part of this test plan and are applicable only as specified by the requirements of this test plan.

4.1 Government Documents

MIL-P-27402 25 August 1961	Propellant, Hydrazine, uns-Dimethylhydrazine (50% N_2H_4/50% UDMH)
MIL-P-26539 per MSC-PPD-2A 1 June 1966	Propellant, Inhibited Nitrogen Tetroxide
MIL-P-27401B	Propellant, Pressurizing Nitrogen
MIL-P-27407 Amendment 1	Propellant, Pressurizing Helium

4.2 Industry Documents

ASTM-D-1193-56	Standard Specification for Reagent Water

4.3 The Marquardt Company Documents

TDP 7005	Apollo RCS Hardware Handling, General Requirements
TDP 7012	General Operation and Maintenance Procedures for Controlled Area No. 2, Building No. 32
TDP 7013	General Operation and Maintenance Procedures for Controlled Area No. 1, Building No. 32
MPS 210	Cleanliness Requirements for Reaction Control System Engines
MPS 607	Handling and Storage Protection of Reaction Control Engine Parts during In-Plant Operations
TDP 7162	SMRCE Qualification Engine Test Stand Buildup Procedure
TDP 7163	SMRCE Qualification Engine Test Stand Teardown Procedure
TDP 7110	Big Bubble Test - Performance

5.0 GENERAL TEST REQUIREMENTS

Corrective action for test discrepancies shall be implemented according to the procedures of paragraph 6.2.

5.1 General Considerations

5.1.1 Cleanliness

All test hardware and facility connections shall be carefully handled per the cleanliness requirements of the applicable TDP to prevent the introduction of contaminants. The cleanliness of engine components shall comply with the levels specified in MPS 210.

5.1.2 Test Designation

The Severe Off Limits Test Program engines shall be released to the Test Department by an Engineering Order (E.O.). This E.O. shall designate the tests to be conducted per MTP 0079.

5.2 Facility Considerations

5.2.1 Equipment

All facility plumbing, i.e., seals, fittings, valves, etc. shall be of materials that are compatible with the propellants and shall be so constructed to assure that the contamination into the propellant system is minimized.

5.2.2 The propellant supply lines shall duplicate, within facility limitations, the LM System A propellant lines to the Quad III up firing engine.

5.2.3 Leakage Check

Each time the engine assembly is installed into the test cell, that portion of the propellant system which is vented to allow installation of the engine shall be pressurized to 250 psig $^{+10}_{-0}$ with GN_2 and tested for leaks using "Snoop" or equivalent. No leakage is allowed as detectable with "Snoop" or equivalent.

5.2.4 Operation of Injector Valves

5.2.4.1 The injector valves shall always be operated through an electrical pulse generator referenced in TDP 7110 unless otherwise specified. Propellant valves shall be operated with zero electrical delay and on automatic coils, except as specified in the appendices.

5.2.4.2 The operating voltage for the injector valves shall be 24 ± .02 volts d-c.

5.2.4.3 The voltage shall be set to the required level for the engine firing sequences by using a resistance simulating the engine valve. The specified voltage shall be set during periods of valve actuation with measurements taken at the valve.

5.2.4.4 The operational limitation of the valves when subjected to gas flow (GN_2 or GHe) shall be the same as those for the condition of zero liquid flow. The limits for gas flow are as follows:

5.2.4.4.1 The continuous or pulse mode operation of the automatic coil shall not exceed 15 minutes in any 30 minutes at 15 ± 1 vdc, 3.5 minutes in any 30 minute period at 27 ± 1 vdc, and 2.0 minutes in any 15 minute period at 32 vdc. The maximum voltage shall be 32 vdc.

5.2.4.4.2 The continuous operation of the direct coil shall not exceed 45 minutes in a 60 minute period. The maximum voltage shall be 32 volts d.c. with direct coils connected in series, or 16 volts d.c. on the individual direct coil.

5.2.4.4.3 No more than 200 cycles under conditions of gas flow (GN_2 or GHe) or zero liquid flow shall be conducted on any valve of the engine. The runs conducted in Appendix A with gas bubbles in the propellant lines are not considered gas flow cycles.

5.2.5 Facility Operation

5.2.5.1 The Test Department will use Project Engineering approved TDP's describing instrumentation and facility operation. The TDP's shall include a listing of all instrumentation, specifying the type of instrument, manufacturer, range identification number, and any calibration corrections required.

5.2.5.2 TMC Test Operations Inspection will examine the test setup prior to each test. No changes are to be made without prior documentation and approval of TMC Test Operations Inspection. This requirement shall not apply to instrumentation, which may be replaced at any time provided it is documented and these replacement instruments are certified and meet the instrumentation equipment list specified in the applicable TDP.

5.3 Engine Consideration

5.3.1 Installation

5.3.1.1 General - The engines shall be installed and instrumented as specified in TDP 7110. Instrumentation requirements are listed in Table I. Installation and instrumentation schematics for each type of testing are shown in Figure 1.

5.3.1.2 Fabrication of Propellant System Interconnections - All propellant line connections made downstream of the manifold line filter shall be lubricated with a minimum of Dri-lube or other approved lubricants.

5.3.1.3 Electrical Hookup - A wiring schematic of the two coils for each valve, showing polarity, lead color code, and pin connections is presented in Figure 2. Extreme care should be taken to insure that the valves are connected exactly as detailed.

5.3.1.4 Priming Procedure (for engine firing in the cell) - The engine propellant lines shall be primed, including bypassing, to eliminate gas in the lines, per TDP 7110. The priming procedure shall ensure that no damage to the sediment strainers result from its implementation.

5.3.1.5 Purge Procedure (for engine firing in the cell)

5.3.1.5.1 Post Test Propellant GHe Purge - Prior to removal after a test firing, the engine shall be purged as specified in TDP 7110.

5.3.1.5.2 Water Flush - After the above GHe purge, the engine shall be removed from the altitude chamber and purged with distilled water, using the automatic cell with a voltage of 16 volts d.c. (+10, -1), for a period of three minutes at a manifold pressure of 60 psig, plus or minus 5 psi. The valve of the section being purged, fuel or oxidizer, shall be cycled closed and open at the rate of ON for 5 seconds, OFF for 1 second, for a minimum of 20 actuations, during the flushing period. Following the water purge, each section, fuel then oxidizer, shall be purged with dry nitrogen per MIL-P-27401B, for a period of 5 minutes at an inlet pressure of 100 psia ($\pm$ 10).

5.3.1.5.3 Oven Drying

5.3.1.5.3.1 The engine assembly shall be oven dried within 12 hours after any water flushing. The engine shall not be installed in the burn test facility if such oven drying has not been accomplished since the last water flush of the engine.

5.3.1.5.3.2 The engine propellant passages shall be dried by heating for a minimum of one and one-half hours at a temperature of 150°F plus or minus 10 degrees, and pressure of 0.3 psia or less.

5.4 Propellants

5.4.1 Oxidizer - The oxidizer used in the Big Bubble Test Program shall be nitrogen tetroxide (N_2O_4) and shall conform to MIL-P-26539, per MSC-PPD-2A, dated 1 June 1966.

5.4.2 Fuel - The fuel used in the Big Bubble Test Program shall be Aerozine-50, a blend of 50% hydrazine (N_2H_4) and 50% unsymmetrical dimethylhydrazine (UDMH), conforming to MIL-P-27402.

5.4.3 Propellant Samples - Propellant samples shall be taken at a minimum rate of one every 7th day, and each time the facility storage tanks are filled. Samples shall be analysed to determine compliance with the applicable specifications. The previous sample analysis shall be applicable until the results of the latest sample are determined. These samples shall be taken as close as possible to the engine inlet connections. In the case of propellant failure to meet specifications, the discrepancy will be handled per the procedure of Section 6.2.

5.4.4 Propellant Saturation

5.4.4.1 Propellants used for Appendix A testing will be helium saturated according to the Propellant Saturation Procedures of TDP 7110.

5.5 Other Test Fluids

5.5.1 In addition to the propellants described in 5.4, only the fluids described below shall be used in processing the engine. All engine influents must pass through a filter before entering the engine.

Helium, in accordance with MIL-P-27407

Nitrogen, in accordance with MIL-P-27401B.

Distilled water, in accordance with ASTM-D-1193-56, Standard specification for reagent water

Commercial Freon TF

99% anhydrous isopropyl alcohol

5.5.2 Helium shall be used as the pressurant gas during all firing tests.

5.5.3 Nitrogen shall be used for gas bubble formation.

5.6 Instrumentation

5.6.1 Accuracy - The accuracy of the instrumentation (entire data acquisition system) shall be within ± 2% of the specified steady state value of the measurement.

5.6.2 Requirements - The instrumentation requirements for each test are specified in Table I. Additional instrumentation may be prescribed if necessary by the Development Engineer through the use of a Test Program Deviation Sheet (Figure 3).

5.6.3 Calibrations - The instrumentation equipment shall be calibrated and maintained according to TDP 70-24, "Calibration and Maintenance of Test Instrumentation and Test Equipment". A copy of all instrumentation calibrations shall be forwarded to the RSD Data Analysis Group.

5.6.4 Major Calibrations - Prior to and following the testing of each Appendix, where performance data is being recorded, a complete set of electrical "R" values, thermocouple recorder calibrations, and thrust calibrations shall be taken. Additional calibrations may be deemed necessary at any time by the Test Operations Engineer and/or the Development Engineering delegate.

5.6.5 Minor Calibrations - Electrical "R" values shall be taken as directed by the applicable TDP.

5.6.6 Required Parameters - Only those parameters required by the Appendix under test shall receive mandatory calibrations, as specified in paragraphs 5.6.4 and 5.6.5. Other recorded parameters may be calibrated as a test convenience, or as specified by the Development Engineering delegate.

5.7 Data Handling and Processing

5.7.1 Marking - All data shall be marked externally with all necessary information to completely identify it. Identification shall include, but not be limited to, the following:

Test number
Last run number
Facility identification
Date
Part Number and Serial Number of test item
Parameter identification
MTP number and Appendix identification

5.7.2 Disposition - All data shall be logged in with the Dept. 136 Data Reduction group who will notify the RSD Data Analysis Group of data availability.

5.7.3 Reduction - Detailed requirements are in each appendix.

6.0 BIG BUBBLE TEST PROGRAM

6.1 Test Requirements

The detailed requirements for each test are defined in Appendix A.

6.2 Test Discrepancy Procedure

6.2.1 Classification

6.2.1.1 Procedural Deviation - A procedural deviation is defined as any change to the test plan, test procedure, test setup, or instrumentation which affects engine operation or data reduction.

6.2.1.2 Performance Deviation - A performance deviation is defined as abnormal engine performance for on-design operating conditions. During this test program, most of the testing will be with various size and quantity gas bubbles up stream of the valve inlet where no standards or acceptable performance limitations are defined.

6.2.1.3 Malfunction - A malfunction is defined as any operation of the test facility equipment or human error which causes a discrepancy in testing.

6.2.1.4 Failure - A failure during this program will be restricted to the inability of the engine to perform its intended function during the on-design testing prescribed in the appendices. Engine damage may occur at off-design conditions, but this damage will not constitute a failure per this program. Engine damage, when it occurs, will be repaired by rework to Engineering Order (E.O.) and the test shall continue as planned.

6.2.1.5 Others - This classification includes all changes or deviations to the test plan or test procedure which are not defined in Paragraphs 6.2.1.1, 6.2.1.2, 6.2.1.3, or 6.2.1.4. Included in this classification would be typographical and/or obvious errors which occurred during the preparation of test procedures and/or test plan.

6.2.2 Discrepancy Evaluation

6.2.2.1 In the event that any problem occurs during testing, the Development Engineer and the Test Operations Engineer shall make a preliminary investigation. No action shall be taken that will destroy evidence.

6.2.2.2 Procedural deviations per paragraph 6.2.1.1 and others per paragraph 6.2.1.5 shall be dispositioned per paragraph 6.2.3.

6.2.2.3 If the problem is suspected to be malfunction, per paragraph 6.2.1.3, or a failure, per paragraph 6.2.1.4, an investigation will be conducted by the Development Engineer, the Test Operations Engineer, and the Project Engineer. When the classification is determined the disposition shall be made per paragraph 6.2.3. The step-by-step trouble shooting procedure shall be documented in the Inspection engine log book, with the reason for and the results of each particular step.

6.2.2.4 The Development Engineer shall determine when a performance deviation as defined in paragraph 6.2.1.2 has occurred. Analysis of quick look data at design point conditions, and comparison to expected results will constitute preliminary evaluation of abnormal operation.

6.2.3 Discrepancy Disposition

6.2.3.1 If the problem is defined per paragraph 6.2.1.5, a deviation sheet (Figure 3) shall be completed. The Deviation Sheet shall be initiated by the Development Engineer and be effective immediately. Written approval shall be obtained during the next regularly scheduled day shift if the discrepancy occurs during other than day shift operation. Approval shall be by the following:

(a) Development Engineering Supervisor
(b) Project Engineer
(c) Test Department Representative

6.2.3.2 If the problem is defined as a procedural deviation or malfunction, as described in paragraphs 6.2.1.1 or 6.2.1.3, a Deviation Sheet (Figure 3) shall be completed. The Deviation Sheet shall be originated by the Development Engineer and approved by the following:

(a) Development Engineering Supervisor
(b) Project Engineer
(c) Test Department Representative

Temporary approval may be obtained by telephone. If the above listed personnel cannot be reached at the time of decision, temporary approval by either the Project Engineer or the Development Group Supervisor shall be sufficient. Written approval shall be obtained during the next regularly scheduled day shift.

6.2.3.3 If the problem is defined as a failure under the terms of paragraph 6.2.1.4, the failure mode of the engine will be thoroughly documented (including photographs of the failed hardware if applicable). An Inspection Rejection Report will be affixed by Inspection to a failed engine. Engine damage at off-design conditions will constitute an "expected" or "probable" test result. This type of engine damage, when it occurs, may be repaired by rework to Engineering Order and the tests continued as planned.

6.2.3.4 If analysis by the Development Engineer indicates a performance deviation per paragraph 6.2.1.2, an investigation will be conducted to determine the causes for abnormal operation. If they are found to fall within any of the classifications described in paragraphs 6.2.1.1, 6.2.1.3, 6.2.1.4, or 6.2.1.5, they will be treated as prescribed therein. All other causes will require an Inspection Rejection Report being affixed to the engine.

6.2.4 Deviation Sheet Distribution

6.2.4.1 Three working copies of the original shall be made at the time the Deviation Sheet is written. These copies shall be distributed as follows:

(a) Development Test Logbook
(b) Test Operations Engineer
(c) Engine Logbook

6.2.4.2 Confirming signatures shall be obtained on the original by the cognizant day shift Development Engineer if temporary approvals were necessary (Ref. Para. 6.2.3.2). The original shall be delivered to the Change Control Group (Product Engineering) and copies distributed as follows:

(a) RSD Data Analysis
(b) Project Engineer
(c) Reliability Engineer
(d) Test Department Project Representative
(e) DCAS Office

6.2.4.3 The original shall be retained by the Change Control Group.

6.3 Additional Testing

Additional testing or reruns must be authorized and approved by the Project Engineer and documented with a Deviation Sheet (Figure 3).

6.4 Documentation

6.4.1 TMC Test Operations Inspection

6.4.1.1 A TMC Test Operations Inspector shall witness the setup and testing on an intermittant or sampling basis and verify that the required test conditions were met during these periods. During the periods when the Test Operations Inspector is not witnessing the tests, the Test Operations Engineer shall be responsible for notification of the Inspector of any test or facility discrepancy or of any facility changes requiring inspection approval per paragraph 5.2.5.2.

6.4.1.2 The TMC Test Operations Inspector with the assistance of the Test Operations Engineer shall maintain a daily log of testing on each engine assembly. These records shall be incorporated into the build-up log book by the inspector to form a complete engine history. The information in the "Daily Record of Test Activity" shall include, but not be limited to, the following information:

1. Part and Serial Numbers of the engine assembly.
2. Facility identification
3. Date and time
4. Cumulative propellant exposure time and number of actuations of each injector valve (dry and wet cycles)
5. Cumulative record of firing time on engine assembly
6. Cognizant Development Engineer and Test Operations Engineer for each shift
7. A record of the Test Department Procedures, or portions thereof, completed on each shift
8. Test number and run numbers.
9. A record and copy of any other pertinent paperwork, i.e., deviation sheets, engineering orders, etc.

6.4.1.3 All discrepancies and malfunctions pertaining to the engine assembly and subsequent corrective action shall be entered in the engine log book.

6.4.2 Development Engineering

6.4.2.1 The Development Engineer shall maintain the "Quick Look Run Data," a run-by-run unofficial record of engine operation.

6.4.3 Test Operations

6.4.3.1 The Test Operations Engineering group shall produce a system of Test Department Procedures (TDP) which shall provide step-by-step instructions for the performance of the tests in compliance with the general and detailed requirements of this test plan. These procedures shall include, but not be limited to, the following information:

1. Engine part number and serial number
2. Identification of test facility
3. Start and stop times of all time controlled requirements, i.e., saturation, valve operation limitations, etc.
4. Method and frequency of propellant or engine influent sampling for compliance with MIL spec.
5. Verification points as required by Test Operations or Reliability and Product Integrity (R&PI).
6. Cleanliness considerations
7. All run numbers and time of runs
8. Engine on times, to three decimal places, for steady state runs from the pulse tubes.

6.4.3.2 The Operations Engineer shall be responsible for the proper identification of all sight tube photographs. Proper identification shall consist of, but not be limited to, the following information: propellant, run number, whether before or after the run, the cell number, and date.

6.4.3.3 Instrumentation procedures (TDP 7110) shall provide step-by-step instructions for the setup, calibration, and operation of the equipment necessary to monitor the parameters described in each appendix. In addition, these procedures shall include:

1. An instrumentation equipment list providing enough information to positively identify all equipment used, including S/N.
2. Current transducer "R" calibrations.

6.4.3.4 The Test Operations Engineer shall maintain an hourly log of all cell activity. Of special interest are reasons for significant delays and the time that the hardware is moved to and from test cells, bond areas, and clean rooms.

6.4.3.5 The Test Operations Engineer shall assist the TMC Test Operations Inspector by keeping record of the information required in paragraph 6.4.1.2 during the inspector's absence. He shall submit this information to the Inspector for incorporation into the engine log book.

6.4.4 Photographic Documentation

6.4.4.1 The cognizant Development Engineer and the Test Department Project Representative shall define the amount and type of photographic coverage required.

6.4.4.2 The following minimum information shall be used to identify each photograph or reel:

1. Test number and title
2. Test facility identification
3. Part number, serial number, and name of test item
4. Run number(s)

6.4.5 Data Retention

The Data Analysis Group of the Rocket Systems Division shall be responsible for retaining all test data and records for a minimum of three years. The following information shall be compiled by the responsible groups and a copy forwarded, upon request, to the Data Analysis Group of RSD for storage.

Quality Control - Engine and component buildup records and Engine Test Log Books.

Test Operations - Records pertaining to test cycle of the engine (Test Order), applicable TDP's, and data in all forms.

Development Group - Quick Look Data Sheets.

6.4.6 Other Witnesses

A written weekly test schedule shall be published by the Test Department and a copy forwarded to the DCAS office.

6.5 Test Sequence

There shall be one engine used in the Big Bubble Test Program. The sequence of tests for the program appears in paragraph 6.1.

6.6 Test Report

6.6.1 Original Data

Copies of original data shall be limited to sections of oscillograph traces.

6.6.2 Derived Curves and Tabular Listings

All derived curves and tabulated listings required by the appendices of this test plan shall be included in the final Big Bubble Test Report.

6.6.3 Additional Data

Additional data, curves, tables, etc., in excess of that required by the applicable appendix may be included in the final report as specified by the Project Engineer.

TABLE I

INSTRUMENTATION REQUIREMENTS

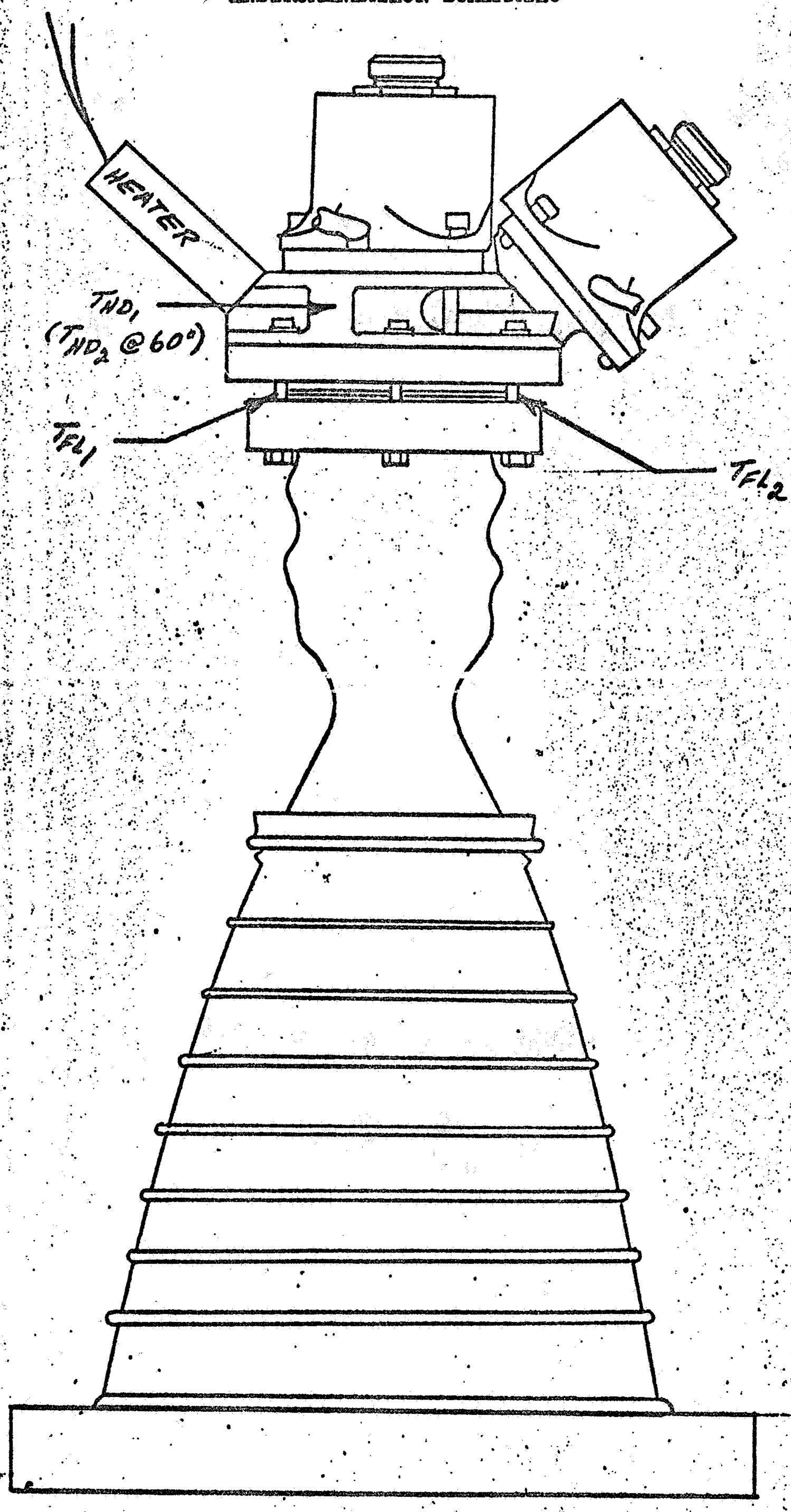
Parameter	Description	Range Interest	Data Readout	Required on Appendix
P_{ch}	Chamber Pressure (Microsystems)	0 to 150 psia	Bristol & Oscillograph	A
P_{mo}	Oxidizer Manifold Pressure (Kistler)	0 to 5000 psia ± 200 psi	Bristol & Oscillograph	A A
P_{mf}	Fuel Manifold Pressure (Kistler)	0 to 5000 psia ± 200 psi	Bristol & Oscillograph	A A
T_{mo}	Oxidizer Manifold Temperature	0 to 200°F	Bristol	A
T_{mf}	Fuel Manifold Temperature	0 to 200°F	Bristol	A
T_{ot}	Oxidizer Tank Temperature	0 to 100°F	Bristol	A
T_{ft}	Fuel Tank Temperature	0 to 100°F	Bristol	A
T_{HD_1}	Head Temperature	0 to 200°F	Bristol	A
T_{HD_2}	Head Temperature (Spare)	0 to 200°F	Bristol	A
T_{FL_1}	Flange Temperature	0 to 200°F	Bristol	A
F_{FL_2}	Flange Temperature (Spare)	0 to 200°F	Bristol	A
T_{L_o}	Oxidizer Line Temperature	0 to 200°F	Bristol	A
T_{L_f}	Fuel Line Temperature	0 to 200°F	Bristol	A
V_f	Fuel Valve Electrical Characteristic		Oscillograph	A
V_o	Oxid. Valve Electrical Characteristic		Oscillograph	A
t	Engine Electrical ON Time		Oscillograph	A
Ref_o	Zero Reference		Oscillograph	A
P_{B_o}	Oxidizer Bubble Pressure	0 - 200 psia	Bristol	A
P_{B_f}	Fuel Bubble Pressure	0 - 200 psia	Bristol	A
P_{cell}	Cell Pressure	0 - .2 psia	Bristol	A

NOTES:

1. Range of Interest is a general requirement and may be changed by Development Test Engineer at any time.

2. Where a thermocouple is denoted as "spare" (THD_2, TFL_2) either thermocouple meets the requirements necessary to conduct the test. Should one of a "matched" pair of thermocouples fail to operate, the remaining thermocouple shall be the sole indicator for the remainder of the test.

INSTRUMENTATION SCHEMATIC



WIRING DIAGRAM - FUEL AND OXIDIZER VALVES

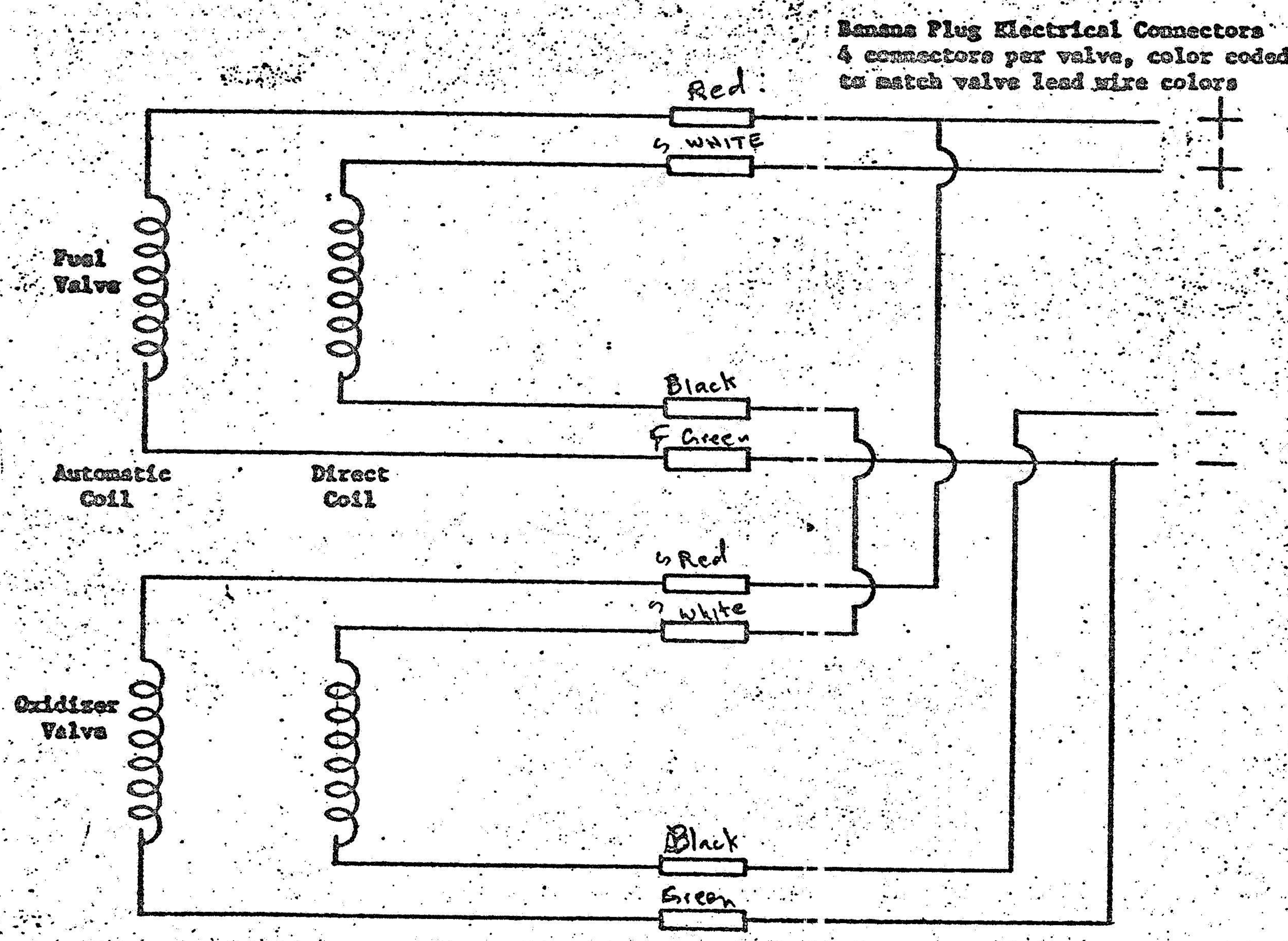


FIGURE 2

TEST PROGRAM DEVIATION SHEET

DATE____________

APPLICABILITY: Number____________

MTP____________ MTN____________ TDP____________

PROGRAM____________

THRUSTOR/ENGINE P/N____________ S/N____________

FACILITY____________ ORIGINATOR____________

APPROVAL REQUIREMENTS (per Test Plan):

1. ☐ Development Test Supervisor
2. ☐ Project Engineer
3. ☐ Test Program Manager
4. ☐ Reliability
5. ☐ Customer
6. ☐ ____________

APPROVALS:

1. ____________
2. ____________
3. ____________
4. ____________
5. ____________
6. ____________

TYPE OF DEVIATION: ☐ Discrepancy ☐ Procedure Change ☐ Document Change

DISCREPANCY/CHANGE:____________

____

____

____

____

____

____

This change affects Runs ________ through________.

CORRECTIVE ACTION/REASON FOR CHANGE:____________

____

____

____

____

____

____

FIGURE 3

DISTRIBUTION (per Test Plan):

☐ Original to Change Control
☐ Original to Development Test
☐ Development Test Logbook
☐ Project Engineer
☐ Data Analysis
☐ Test Program Manager
☐ DCAS Office
☐ Customer
☐ Reliability

A-1.0 OBJECTIVE

The objective of this test is to determine the performance effects of firing the LM RCS engine with large entrapped gas bubbles in either or both propellant supply lines.

A-2.0 SCOPE

Steady state and pulse runs will be conducted to evaluate the effect that large entrapped GN_2 bubbles located in the oxidizer supply line, in the fuel supply line and in both propellant supply lines will have upon the firing delay of the Apollo LM RCS engine. Bubble volume and duty cycle effects will be defined with the engine firing at minimum temperature conditions and in the flame down attitude in PRL Pad G. The bubbles evaluated will be single continuous bubbles located adjacent to the engine injector valves.

A-3.0 TEST REQUIREMENTS

A-3.1 The engine will be installed in the down firing attitude in PRL Pad G per TDP 7110.

A-3.2 The engine shall be instrumented per Table I and Figure 1. The instrumentation shall be setup, calibrated and operated per TDP 7110.

A-3.3 The cell pressure shall be less than 0.20 psia prior to and during all tests.

A-3.4 The valve voltage shall be 24 ± 0.2 volts d-c for all performance testing.

A-3.5 The propellants (nitrogen tetroxide, N_2O_4, per MSC-PPD-2A, and Aerozine-50 per MIL-P-27402) shall be saturated per TDP 7110 for all testing.

A-3.6 The propellants will be at 70 ± 20°F for all tests.

A-3.7 The propellant supply lines will simulate (approximately) the line lengths and diameters of the LM RCS lines from the System A tanks to the quad III up firing engine. The facility propellant system shall be designed such that GN_2 bubbles of volumes between 2.5 and 5.0 in^3 can be formed and held just upstream of either engine injector valve.

A-3.8 Filters of 5-18μ rating shall be integral parts of both propellant lines.

A-3.9 The propellant tank pressures will be 181 ± 2 psia (166.7 ± 2 psig) for all runs.

A-3.10 Should engine damage occur as a result of this testing, the engine shall be removed from the facility and refurbished by E. O. (Engineering Order).

A-3.11 The engine combustor flange temperature shall be 120 ± 5°F prior to each run.

A-4.0 TEST SEQUENCE

A-4.1 Trim Runs

Five (5) second trim runs will be conducted to verify proper engine and facility instrumentation.

A-4.2 Record Runs

Verify that the test conditions of A-3.3, A-3.5, A-3.6, A-3.9 and A-3.11 are satisfied before each run.

Conduct the test matrix specified in A-4.3. The GN_2 bubbles will be formed as specified by TDP 7110 prior to each run.

Appendix A

A-4.3 BIG BUBBLE TEST MATRIX - APPENDIX A

Sequence Number	Bubble Volume Oxid.	Bubble Volume Fuel	On Time (ms)	Off Time (ms)	No. of Pulses
1	0	0	13 ± 1	1987 ± 20	10
2	2.5	0	5000 ± 50	-	1
3	0	2.5	5000 ± 50	-	1
4	2.5	2.5	5000 ± 50	-	1
5	2.5	0	13 ± 1 5000 ± 50	1987 ± 20 -	See Note 1 1
6	0	2.5	13 ± 1 5000 ± 50	1987 ± 20 -	See Note 1 1
7	2.5	2.5	13 ± 1 5000 ± 50	1987 ± 20 -	See Note 2 1
8	2.5	0	20 ± 2 5000 ± 50	480 ± 10 -	See Note 3 1
9	0	2.5	20 ± 2 5000 ± 50	480 ± 10 -	See Note 3 1
10	2.5	2.5	20 ± 2 5000 ± 50	480 ± 10 -	See Note 4 1
11	2.5	0	30 ± 3 5000 ± 50	172 ± 5 -	See Note 5 1
12	0	2.5	30 ± 3 5000 ± 50	172 ± 5 -	See Note 5 1
13	2.5	2.5	30 ± 3 5000 ± 50	172 ± 5 -	See Note 6 1
14-25	Repeat Sequences 2 through 13, replacing all reference to 2.5 cubic inch bubble volume with a 5.0 cubic inch bubble. *				

NOTES:

1. Start with one (1) 13 ms pulse followed by one (1) 5000 ms pulse. Increase the number of 13 ms pulses by one (1) for each succeeding run until ignition occurs within the first 17 ms of the 5 second pulse.

2. The number of pulses will be the larger of the number of 13 ms pulses conducted on the last run of either Sequence 5 or 6.

3. Start with one (1) 20 ms pulse followed by one (1) 5000 ms pulse. Increase the number of 20 ms pulses by one (1) for each succeeding run until ignition occurs within the first 24 ms of the 5000 ms pulses.

2

4. The number of pulses will be the larger of the number of 20 ms pulses conducted on the last run of either Sequence 8 or 9.

5. Start with one (1) 30 ms pulse followed by one (1) 5000 ms pulse. Increase the number of 30 ms pulses by one (1) for each succeeding run until ignition occurs within the first 34 ms of the 5000 ms pulse.

6. The number of pulses will be the larger of the number of 30 ms pulses conducted on the last run of either Sequence 11 or 12.

7. Start with the final number of 13 ms pulses conducted in Sequence 5 or 6, whichever is applicable, followed by one (1) 5000 ms pulse. Increase the number of 13 ms pulses by one (1) for each succeeding run until ignition occurs within the first 17 ms of the 5 second pulse.

8. The number of pulses will be the larger of the number of 13 ms pulses conducted on the last run of either Sequence 17 or 18.

9. Start with the final number of 20 ms pulses conducted in Sequence 8 or 9, followed by one (1) 5000 ms pulse. Increase the number of 20 ms pulses by one (1) for each succeeding run until ignition occurs within the first 24 ms of the 5 second pulse.

10. The number of pulses will be the larger of the number of 20 ms pulses conducted on the last run of either Sequence 20 or 21.

11. Start with the final number of 30 ms pulses conducted in Sequence 11 or 12 followed by one (1) 5000 ms pulse. Increase the number of 30 ms pulses by one (1) for each succeeding run until ignition occurs within the first 34 ms of the 5 second pulse.

12. The number of pulses will be the larger of the number of 30 ms pulses conducted on the last run of either Sequence 23 or 24.

* When the 5.0 in^3 bubble volumes are tested, notes 7, 8, 9, 10, 11 and 12 shall replace notes 1, 2, 3, 4, 5 and 6, respectively.

A-5.0 <u>DATA REDUCTION</u>

A-5.1 Verify that all prerun temperatures and pressures were as required.

A-5.2 Measure the firing delay (electrical "ON" to ignition) for each run.

A-5.3 Additional data reduction requirements may be specified by the cognizant Project Engineer.

JUL 30 1968

TMC 064 STANDARD EO — THE Marquardt CORPORATION	SHEET 1 OF 1		DWG. NO. ADDENDUM 1 MTP 0079
TITLE BIG BUBBLE TEST	NEW	X	E O ISSUE NO. 1
	INFORMATION & INSTRUCTIONS		DRAWING CHANGE LETTER
PROPOSED BY:	MEMO		SALVAGE NUMBER
CHG DES — DEVELOPMENT ENGINEERING	CHANGE		
	CLASS		TYPE

REASON - DESCRIBE CLEARLY IN A CONCISE MANNER.

TO RELEASE TEST PROGRAM DEVIATIONS NUMBERS 1 THROUGH 14 AS SUPPLEMENTAL INFORMATION TO THE BIG BUBBLE TEST PLAN MTP 0079.

NOTE:
DISTRIBUTE COPIES OF THE E.O. ONLY
DO NOT DISTRIBUTE COPIES OF THE DEVIATIONS

IDENTIFICATION & SERIAL NUMBER EFFECTIVITY		ENG. TASK NUMBER	MANUF. PHASE NO.
MTP 0079	RECORD RELEASE	5035-2-8901	—

DISPOSITION

SEND COPIES TO

CUSTOMER APPROVAL	[signature] 7/30
DATE:	
ORIG'G SECTION	DEVELOPMENT
PREPARED BY	R. [signature] 7/29
GROUP LEADER	
PROJECT ENGINEER	
CHECK	
STRUCTURES	R. [signature] 7/29/68
MATERIAL & PROCESS	
RELEASE	[signature] 7/30/68

TEST PROGRAM DEVIATION SHEET

DATE 5 DEC 67

Number 1

APPLICABILITY:

MTP 0079 MTN ______ TDP ______

PROGRAM APOLLO SM-LM RCS ENGINE P.I.P PROGRAM

THRUSTOR/ENGINE P/N VX228687-517 S/N 0034

FACILITY PRL-PAD G ORIGINATOR F. KUHN

APPROVAL REQUIREMENTS (per Test Plan):

1. ☒ Development Test Supervisor
2. ☐ Project Engineer
3. ☒ Test Program Manager
4. ☐ Reliability
5. ☐ Customer
6. ☐ ______

APPROVALS:

1. T.L. KELLY, T. [signature] 1100
2. R.C. [signature] 12/5/67
3. [signature] 12/5/67
4. ______
5. ______
6. ______

TYPE OF DEVIATION: ☒ Discrepancy ☐ Procedure Change ☐ Document Change

DISCREPANCY/~~CHANGE~~: DURING PREPARATION FOR RUN A-4.3.5, THE OXIDIZER MANIFOLD ISOLATION VALVE WAS NOT CLOSED PRIOR TO PURGING THE OX MANIFOLD. THIS RESULTED IN THE EMPTYING OF THE OX PULSE TANK INTO THE SCRUBBER. SUBSEQUENT PURGING THRU THE ENGINE RESULTED IN HEAD & FLANGE TEMPS OF ≅ 50°F WHICH INDICATES THAT ONLY OX VAPOR & HELIUM WAS FORCED THRU THE ENGINE

This change affects Runs ______ through ______.

CORRECTIVE ACTION/~~REASON FOR CHANGE~~: REFILL PULSE TANKS, SATURATE & PRIME PER TDP 7110 AND CONTINUE RUNNING. TEST OPERATIONS ENGINEER WILL MONITOR PURGING & BUBBLE MAKING PROCEDURES MORE CLOSELY.

DISTRIBUTION (per Test Plan):

- ☒ Original to Change Control
- ☐ Original to Development Test
- ☒ Development Test Logbook
- ☒ Thrustor/Engine Logbook
- ☒ Project Engineer
- ☐ Data Analysis
- ☒ Test Program Manager
- ☒ Test Operations Engr.
- ☒ DCAS Office
- ☐ Customer
- ☒ Reliability
- ☐ ______

TEST PROGRAM DEVIATION SHEET

DATE 6 DEC 67

Number 2

APPLICABILITY:

MTP 0079 MTN ______ TDP ______

PROGRAM APOLLO SM-LM RCS ENGINE P.I.P. PROGRAM

THRUSTOR/ENGINE P/N VX 228687-517 S/N 0034

FACILITY PRL-PAD G ORIGINATOR F. KUHN

APPROVAL REQUIREMENTS (per Test Plan):

1. ☑ Development Test Supervisor
2. ☑ Project Engineer
3. ☑ Test Program Manager
4. ☐ Reliability
5. ☐ Customer
6. ☐ ______

APPROVALS:

1. [signature]
2. R. Moffett
3. [signature]
4. ______
5. ______
6. ______

TYPE OF DEVIATION: ☐ Discrepancy ☑ Procedure Change ☐ Document Change

~~DISCREPANCY~~/CHANGE: CHANGE PARAGRAPHS A-4.1 & A-4.3

A-4.1 - TRIM RUN DURATIONS SHALL BE 1 SECOND INSTEAD OF FIVE SECONDS.

A-4.3 ENGINE "ON TIME" SHALL BE 1000 MS INSTEAD OF 5000 MS FOR ALL RUN SEQUENCES, I.E., 1 THRU 25. CHANGE 5000 MS ON TIMES TO 1000 MS ON TIMES IN NOTES 1,2,3,5,7,9 & 11 ON PAGE A-3, APPENDIX A

This change affects Runs 761 through SUBS.

~~CORRECTIVE ACTION~~/REASON FOR CHANGE: IN ORDER TO ACCELERATE THIS PROGRAM, IT IS NECESSARY TO REDUCE THE AMOUNT OF PROPELLANTS USED.

DISTRIBUTION (per Test Plan):

- ☑ Original to Change Control
- ☐ Original to Development Test
- ☑ Development Test Logbook
- ☑ Thrustor/Engine Logbook
- ☑ Project Engineer
- ☑ Data Analysis
- ☑ Test Program Manager
- ☑ Test Operations Engr.
- ☑ DCAS Office
- ☐ Customer
- ☑ Reliability
- ☐ ______

TEST PROGRAM DEVIATION SHEET

DATE 6 DEC 67

Number 3

APPLICABILITY:

MTP 0077 MTN ______ TDP ______

PROGRAM APOLLO SM-LM RCS ENGINE P.I.P PROGRAM

THRUSTOR/ENGINE P/N VX 228687-517 S/N 0034

FACILITY PRL-PAD G ORIGINATOR F. KUHN

APPROVAL REQUIREMENTS (per Test Plan):

1. ☐ Development Test Supervisor
2. ☐ Project Engineer
3. ☐ Test Program Manager
4. ☐ Reliability
5. ☐ Customer
6. ☐ ______

APPROVALS:

1. [signature]
2. [signature]
3. [signature]
4. ______
5. ______
6. ______

TYPE OF DEVIATION: ☐ Discrepancy ☑ Procedure Change ☐ Document Change

~~DISCREPANCY~~/CHANGE: THE SAMPLING OF N_2O_4 SHALL CONTINUE AS STATED IN PARA. A-5.4.3. AEROZINE 50 SHALL BE SAMPLED AS FOLLOWS: 1) AT THE ORIGINAL FILLING OF THE PAD (G) PULSE TANK, A SAMPLE SHALL BE TAKEN. 2) NO SAMPLE IS NECESSARY FOR SUBSEQUENT FILLINGS FROM THE SAME DRUM WITHIN A 7-DAY PERIOD. THE PROPELLANT LOADED AFTER THE 7th DAY SHALL BE SAMPLED. 3) IF IT IS NECESSARY TO TAP A NEW DRUM OR A DIFFERENT DRUM IS USED, THE PROPELLANT SHALL BE SAMPLED AND SUBSEQUENT SAMPLING WILL BE HANDLED AS DESCRIBED IN 2) ABOVE.

This change affects Runs ______ through ______.

~~CORRECTIVE ACTION~~/REASON FOR CHANGE: CLARIFY PROPELLANT SAMPLING PROCEDURES.

DISTRIBUTION (per Test Plan):

- ☑ Original to Change Control
- ☐ Original to Development Test
- ☑ Development Test Logbook
- ☑ Thrustor/Engine Logbook
- ☑ Project Engineer
- ☐ Data Analysis
- ☑ Test Program Manager
- ☑ Test Operations Engr.
- ☑ DCAS Office
- ☐ Customer
- ☑ Reliability
- ☐ ______

TEST PROGRAM DEVIATION SHEET

DATE 7 DEC 67

Number 4

APPLICABILITY:

MTP 0072 MTN ______ TDP ______

PROGRAM APOLLO SM-LM RCS ENGINE P.I.P. [illegible]

THRUSTOR/ENGINE P/N VX228687-517 S/N 0034

FACILITY PPL PAD G ORIGINATOR F. KUHN

APPROVAL REQUIREMENTS (per Test Plan):

1. ☑ Development Test Supervisor
2. ☑ Project Engineer
3. ☑ Test Program Manager
4. ☐ Reliability
5. ☐ Customer
6. ☐ ______

APPROVALS:

1. T.L. Kelly Tele[illegible] 1845 TLKelly
2. R.J. M[illegible]
3. [illegible]
4. ______
5. ______
6. ______

TYPE OF DEVIATION: ☐ Discrepancy ☑ Procedure Change ☐ Document Change

~~DISCREPANCY~~/CHANGE: REPEAT THE SIX PULSES FOLLOWED BY 1 SECOND ON TIME OF A-4.3.6, BUBBLE ON FUEL SIDE ONLY. ALSO REPEAT THE THREE PULSE, FOLLOWED BY 1 SECOND ON TIME OF A-4.3.5, BUBBLE ON OX SIDE ONLY

This change affects Runs 765 through ______.

CORRECTIVE ACTION/REASON FOR CHANGE: VERIFY BUBBLE SIZE ON RUN 764

DISTRIBUTION (per Test Plan):

- ☐ Original to Change Control
- ☐ Original to Development Test
- ☐ Development Test Logbook
- ☑ Thrustor/Engine Logbook
- ☑ Project Engineer
- ☐ Data Analysis
- ☐ Test Program Manager
- ☐ Test Operations Engr.
- ☑ DCAS Office
- ☐ Customer
- ☑ Reliability
- ☐ ______

TEST PROGRAM DEVIATION SHEET

DATE 7 DEC 67

Number 5

APPLICABILITY:

MTP 0079 MTN ______ TDP ______

PROGRAM APOLLO SM-LM RCS ENGINE P.I.P. PROGRAM

THRUSTOR/ENGINE P/N VX228687-517 S/N 0034

FACILITY PRL-PAD G ORIGINATOR E. KUHN

APPROVAL REQUIREMENTS (per Test Plan):

1. ☑ Development Test Supervisor
2. ☑ Project Engineer
3. ☑ Test Program Manager
4. ☐ Reliability
5. ☐ Customer
6. ☐ ______

APPROVALS:

1. T.L. KELLY TELECON TKelly
2. R.L. MOFFETT TELECON RLM
3. ~~[illegible]~~
4. ______
5. ______
6. ______

TYPE OF DEVIATION: ☐ Discrepancy ☑ Procedure Change ☐ Document Change

~~DISCREPANCY~~/CHANGE: REPEAT RUNS 771, 772 & 773 BECAUSE OF THE UNEXPLAINABLE INCONSISTENCIES IN THE IGNITION DELAYS FOR THESE RUNS.

This change affects Runs 774 through ______.

~~CORRECTIVE ACTION~~/REASON FOR CHANGE: INCONSISTENT IGNITION DELAYS.

DISTRIBUTION (per Test Plan):

☐ Original to Change Control
☐ Original to Development Test
☐ Development Test Logbook
☐ Thrustor/Engine Logbook
☐ Project Engineer
☐ Data Analysis
☐ Test Program Manager
☐ Test Operations Engr.
☐ DCAS Office
☐ Customer
☐ Reliability
☐ ______

TEST PROGRAM DEVIATION SHEET

DATE 7 DEC 67

Number 6

APPLICABILITY:

MTP 0079 MTN ______ TDP ______

PROGRAM APOLLO SM-LM RCS ENGINE P.I.P.

THRUSTOR/ENGINE P/N VX228687-517 S/N 0034

FACILITY PRL-PAD G ORIGINATOR F. KUHN

APPROVAL REQUIREMENTS (per Test Plan):

1. ☒ Development Test Supervisor
2. ☒ Project Engineer
3. ☒ Test Program Manager
4. ☒ Reliability
5. ☐ Customer
6. ☐ ______

APPROVALS:

1. [signature]
2. R.L. MOFFETT TELECON @ 1845 RLM
3. [signature]
4. ______
5. ______
6. ______

TYPE OF DEVIATION: ☐ Discrepancy ☒ Procedure Change ☐ Document Change

DISCREPANCY/CHANGE: REVISE FUEL PURGE (PRIOR TO PUTTING IN BUBBLE) AS FOLLOWS: 1. WITH FUEL PURGE SET @ 150 PSIG, PURGE THRU BYPASS VALVE, CYCLING PURGE VALVE 5 TIMES, 10 SECS. ON, 10 SECS. OFF. 2. PURGE THROUGH ENGINE VALVE @ 150 PSIG, cycling THE PURGE VALVE 4 TIMES 15 SECS ON 15 SECS OFF, ON THE LAST CYCLE EVACUATE FOR 30 SECS. Close VALVE for 30 SECS. EVACUATE for 30 more SECONDS

This change affects Runs 777 through SUBS.

~~CORRECTIVE ACTION~~/REASON FOR CHANGE: IMPROVE DELAY CONSISTENCY BY PERFORMING A MORE COMPLETE PURGE OF THE FUEL MANIFOLD.

DISTRIBUTION (per Test Plan):

- ☒ Original to Change Control
- ☐ Original to Development Test
- ☒ Development Test Logbook
- ☒ Thrustor/Engine Logbook
- ☒ Project Engineer
- ☒ Data Analysis
- ☒ Test Program Manager
- ☒ Test Operations Engr.
- ☐ DCAS Office
- ☐ Customer
- ☒ Reliability
- ☐ ______

TEST PROGRAM DEVIATION SHEET

DATE 8 DEC 67

Number 7

APPLICABILITY:

MTP 0079 MTN ______ TDP ______

PROGRAM APOLLO SM-LM RCS ENGINE P.I.P PROGRAM

THRUSTOR/ENGINE P/N VX228687-517 S/N 0034

FACILITY PRL-PADG ORIGINATOR F. KUHN

APPROVAL REQUIREMENTS (per Test Plan):

1. ☑ Development Test Supervisor
2. ☑ Project Engineer
3. ☑ Test Program Manager
4. ☐ Reliability
5. ☐ Customer
6. ☐ ______

APPROVALS:

1. T.L. KELLY [signature]
2. R.L. MOFFETT R. Moffett
3. [signature]
4. ______
5. ______
6. ______

TYPE OF DEVIATION: ☐ Discrepancy ☑ Procedure Change ☐ Document Change

~~DISCREPANCY/~~CHANGE: REF. PARA. A-4.3.17, NOTE 7: SKIP THE SIX PULSE RUN & THE EIGHT PULSE RUN. REF PARA. A-4.3.18, NOTE 1: SKIP THE NINE PULSE RUN, SKIP ELEVEN PULSE RUN, SKIP THIRTEEN PULSE RUN

This change affects Runs of A-4.3.17 through A-4.3.18

~~CORRECTIVE ACTION/~~REASON FOR CHANGE: ACCELERATE THE TEST

DISTRIBUTION (per Test Plan):

- ☑ Original to Change Control
- ☐ Original to Development Test
- ☑ Development Test Logbook
- ☑ Thrustor/Engine Logbook
- ☑ Project Engineer
- ☑ Data Analysis
- ☑ Test Program Manager
- ☑ Test Operations Engr.
- ☑ DCAS Office
- ☐ Customer
- ☑ Reliability
- ☐ ______

TEST PROGRAM DEVIATION SHEET

DATE 12 DEC. 1967

Number 8

APPLICABILITY:

MTP 0079 MTN ______ TDP ______

PROGRAM APOLLO SM-LM RCS ENGINE P.I.P. PROGRAM

THRUSTOR/ENGINE P/N VK228687-517 S/N 0034

FACILITY PAD G ORIGINATOR E. HOHMAN

APPROVAL REQUIREMENTS (per Test Plan):

1. ☒ Development Test Supervisor
2. ☒ Project Engineer
3. ☒ Test Program Manager
4. ☐ Reliability
5. ☐ Customer
6. ☐ ______

APPROVALS:

1. K R [illegible]
2. R Moffett
3. [illegible]
4. ______
5. ______
6. ______

TYPE OF DEVIATION: ☒ Discrepancy ☐ Procedure Change ☐ Document Change

DISCREPANCY/~~CHANGE~~: WHILE HOLDING SATURATION CONDITIONS IN THE FUEL TANK, THE BURST DIAPHRAM ON THE HELIUM PRESSURANT BLEW, CAUSING FUEL PRESSURE TO DROP TO ~30% OF NOMINAL. THIS CONDITION EXISTED FOR APPROX. 10 MIN. AFTER WHICH THE PRESSURE WAS RETURNED TO THE NOMINAL LEVEL.

This change affects Runs 812 through TBD.

CORRECTIVE ACTION/~~REASON FOR CHANGE~~: DO NOT RESATURATE. RUN TEST WITH FUEL AS IS.

DISTRIBUTION (per Test Plan):

- ☒ Original to Change Control
- ☐ Original to Development Test
- ☒ Development Test Logbook
- ☒ Thrustor/Engine Logbook
- ☒ Project Engineer
- ☒ Data Analysis
- ☒ Test Program Manager
- ☒ Test Operations Engr.
- ☒ DCAS Office
- ☐ Customer
- ☒ Reliability
- ☐ ______

TEST PROGRAM DEVIATION SHEET

DATE 12 DEC 67

Number 9

APPLICABILITY:

MTP 0079 MTN ______ TDP ______

PROGRAM APOLLO SM-LM RCS ENGINE PIP PROGRAM

THRUSTOR/ENGINE P/N VX 228687-517 S/N 0031

FACILITY PRL - PAD G ORIGINATOR H. SHERMAN

APPROVAL REQUIREMENTS (per Test Plan):

1. ☑ Development Test Supervisor
2. ☑ Project Engineer
3. ☑ Test Program Manager
4. ☐ Reliability
5. ☐ Customer
6. ☐ ______

APPROVALS:

1. T. KELLY TELCON @ 2130 (signature)
2. R. MOFFITT TELCON @ 2130 R. Moffett
3. [signature]
4. ______
5. ______
6. ______

TYPE OF DEVIATION: ☐ Discrepancy ☑ Procedure Change ☐ Document Change

~~DISCREPANCY~~/CHANGE: REF. PARA. A-4.3.23, NOTE 11: SKIP THE FOUR PULSE RUN.

REF. PARA. A-4.3.24, NOTE 11: SKIP THE THREE PULSE RUN & THE FOUR PULSE RUN.

This change affects Runs A-4.3.23 through A-4.3.24.

~~CORRECTIVE~~ ACTION/REASON FOR CHANGE: TO ACCELERATE TESTING

DISTRIBUTION (per Test Plan):

- ☑ Original to Change Control
- ☐ Original to Development Test
- ☑ Development Test Logbook
- ☑ Thrustor/Engine Logbook
- ☑ Project Engineer
- ☑ Data Analysis
- ☑ Test Program Manager
- ☑ Test Operations Engr.
- ☑ DCAS Office
- ☐ Customer
- ☑ Reliability
- ☐ ______

TEST PROGRAM DEVIATION SHEET

DATE 13 DEC 1967

Number 10

APPLICABILITY:

MTP 0079 MTN ______ TDP ______

PROGRAM APOLLO SM-LM RCS ENGINE PIP PROGRAM

THRUSTOR/ENGINE P/N VX 228687-517 S/N 0034

FACILITY PRL PAD G ORIGINATOR E. HOHMAN

APPROVAL REQUIREMENTS (per Test Plan):

1. ☒ Development Test Supervisor
2. ☒ Project Engineer
3. ☐ Test Program Manager
4. ☐ Reliability
5. ☐ Customer
6. ☐ ______

APPROVALS:

1. [signature]
2. [signature]
3. [signature]
4. ______
5. ______
6. ______

TYPE OF DEVIATION: ☐ Discrepancy ☒ Procedure Change ☐ Document Change

~~DISCREPANCY~~/CHANGE: SEE ATTACHED SHEET FOR ADDED TESTING

This change affects Runs 824 through TBD.

~~CORRECTIVE ACTION~~/REASON FOR CHANGE: ADDITIONAL TEST DATA REQUIRED

DISTRIBUTION (per Test Plan):

- ☒ Original to Change Control
- ☐ Original to Development Test
- ☒ Development Test Logbook
- ☒ Thrustor/Engine Logbook
- ☒ Project Engineer
- ☒ Data Analysis
- ☒ Test Program Manager
- ☒ Test Operations Engr.
- ☒ DCAS Office
- ☐ Customer
- ☒ Reliability
- ☐ ______

MTP 0079
Dev. 10

P.I.P. BIG BUBBLE TEST

1. TEST THE FOLLOWING MATRIX PER MTP 0079 APPENDIX A.

2. ADDITIONAL TESTING, TO BE SPECIFIED BY THE DEVELOPMENT ENGINEER, WILL BE MADE PER THIS DEVIATION IF TIME PERMITS

TEST MATRIX

SEQUENCE NO.	BUBBLE VOL OX.	BUBBLE VOL FUEL	ON TIME (ms)	OFF TIME (ms)	NO. PULSES
1	—	2.5	1000 ± 10	—	1
2	—	2.5	30 ± 3 1000 ± 10	172 ± 5 —	1 - 30 ms pulse followed by 1 1000 ms pulse.
3	2.5	—	1000 ± 10	—	1
4	2.5	—	13 ± 1 1000 ± 10	1987 ± 20 —	1 - 13 ms pulse followed by 1 1000 ms pulse
5	2.5	—	13 ± 1 1000 ± 10	1987 ± 20 —	2 - 13 ms pulse followed by 1000 ms pulse
6	2.5		20 ± 2 1000 ± 10	480 ± 10 —	1 - 20 ms pulse followed by 1000 ms pulse

ADDITIONAL TEST AS SPECIFIED BY DEV. NO. 10.

SEQUENCE No	BUBBLE VOL. OX	FUEL	ON TIME (ms)	OFF TIME (ms)	NO. PULSE
7	5.0	—	1000 ± 10	—	1
8	5.0	—	13 ± 1 1000 ± 10	1987 ± 20	8 - 13 ms pulse followed by 1000 ms pulse
9	—	5.0	13 ± 1 1000 ± 10	1987 ± 20 —	9 - 13 ms pulse followed by 1000 ms pulse
10	—	5.0	13 ± 1 1000 ± 10	1987 ± 20 —	13 - 13 ms pulse followed by 1000 ms pulse
11	2.5	—	50 ± 5 1000 ± 10	172 ± 5 —	1 - 50 ms pulse followed by 1000 ms pulse
12	—	2.5	50 ± 5 1000 ± 10	172 ± 5 —	1 - 50 ms pulse followed by 1000 ms pulse
13	5.0	—	50 ± 5 1000 ± 10	172 ± 5 —	2 - 50 ms pulse followed by 1000 ms pulse
14	5.0	—	50 ± 5 1000 ± 10	172 ± 5 —	3 - 50 ms pulse followed by 1000 ms pulse
15	—	5.0	50 ± 5 1000 ± 10	172 ± 5 —	2 - 50 ms pulse followed by 1000 ms pulse
16	—	5.0 —	50 ± 5 1000 ± 10	172 ± 5 —	3 - 50 ms pulse followed by 1000 ms pulse

TEST PROGRAM DEVIATION SHEET

DATE 12/14/67

Number 11

APPLICABILITY:

MTP 0079 MTN ______ TDP 7112

PROGRAM P.I.P. BIG BUBBLE TEST

THRUSTOR/ENGINE P/N X228687-517 S/N 0034

FACILITY PAD G ORIGINATOR MOFFETT

APPROVAL REQUIREMENTS (per Test Plan):

1. ☒ Development Test Supervisor
2. ☒ Project Engineer
3. ☐ Test Program Manager
4. ☐ Reliability
5. ☐ Customer
6. ☐ ______

APPROVALS:

1. Kelly
2. R. Moffett
3. ______
4. ______
5. ______
6. ______

TYPE OF DEVIATION: ☐ Discrepancy ☐ Procedure Change ☐ Document Change ☒ ADDITIONAL TESTS

DISCREPANCY/CHANGE:

CONDUCT THE TESTS SPECIFIED ON THE ATTACHED PAGES IN THE PAD G HIGH ALTITUDE (ROOTES BLOWER-COLD TRAP) FACILITY. CONDUCT THESE TESTS IN THE HORIZONTAL ATTITUDE.

This change affects Runs ______ through ______.

~~CORRECTIVE ACTION~~/REASON ~~FOR CHANGE~~: TO VERIFY SAFE LM #1 RCS ENGINE OPERATION IN THE HORIZONTAL FIRING ATTITUDE.

DISTRIBUTION (per Test Plan):

- ☒ Original to Change Control
- ☐ Original to Development Test
- ☒ Development Test Logbook
- ☒ Thrustor/Engine Logbook
- ☒ Project Engineer
- ☒ Data Analysis
- ☒ Test Program Manager
- ☒ Test Operations Engr.
- ☒ DCAS Office
- ☐ Customer
- ☒ Reliability
- ☐ ______

1.0 Conduct the runs listed in paragraph 7.0 using engine X223687-517, S/N 0034. These runs shall be conducted in accordance with TDP 7112.

2.0 Valve Voltage

The valve voltage shall be 24 VDC for all tests.

3.0 Cell Pressure

The cell pressure shall be less than 30 μ prior to each run.

4.0 Tank Pressures

The tank set pressures shall be 166.7 ± 2 psig for all runs.

5.0 Engine Temperature

The following engine temperatures shall exist upon initiation of each run.

$$T_{m_o} = T_{m_f} = 40 \pm 5°F$$

$$T_{f1} \text{ (1 or 2)} = 120 \pm 3°F$$

$$T_n \text{ (1 or 2)} = 90 \pm 5°F$$

6.0 Propellants

The propellants shall be A-50 and N_2O_4 and shall be saturated per the procedures of TDP 7112.

7.0 Test Matrix

The following runs will consist of a specified number of cold flow pulses of one or the other of the propellants followed by a specified number of engine firing pulses. The ON times of the cold flows and the firing pulses are the same and the off times between all pulses are the same for each run.

ON (ms)	OFF (ms)	COLD FLOW PULSES	TOTAL PULSES	NUMBER RUNS
13	1987	5 - ox	10	3
13	487	5 - ox	10	3
13	1987	3 - f	8	3
13	487	3 - f	8	3
20	480	4 - ox	8	2
20	1980	4 - ox	8	2
20	480	1 - f	5	2
20	1980	1 - f	5	2
30	225	2 - ox	5	1
30	1970	2 - ox	5	1
30	225	2 - f	5	1

30	[1970]	2 - f	5	1
13	1987	15 - ox	20	1
13	487	15 - ox	20	1
13	1987	10 - f	15	1
13	487	10 - f	15	1
20	480	10 - ox	14	1
20	480	5 - f	9	1

8.0 INSTRUMENTATION

The instrumentation requirements list is attached (Table 1).

TABLE A-II

INSTRUMENTATION REQUIREMENTS

Parameter	Description	Range Interest	Data Readout
P_{ch}	Chamber Pressure (Microsystems)	0 to 110 psia	Bristol Oscillograph
P_{mo}	Oxidizer Manifold Pressure (Kistler)	0 to 5000 psia ± 200 psi	Bristol Oscillograph
P_{mf}	Fuel Manifold Pressure (Kistler)	0 to 5000 psia ± 200 psi	Bristol Oscillograph
T_{mo}	Oxidizer Manifold Temperature	0 to 100°F	Bristol
T_{mf}	Fuel Manifold Temperature	0 to 100°F	Bristol
T_{ot}	Oxidizer Tank Temperature	0 to 100°F	Bristol
T_{ft}	Fuel Tank Temperature	0 to 100°F	Bristol
T_{hd_1}	Head Temperature	0 to 200°F	Bristol
T_{fl_1}	Flange Temperature	0 to 200°F	Bristol
T_{fl_2}	Flange Temperature (Spare)	0 to 200°F	Bristol
T_{N1}	Nut Temperature	0 to 200°F	Bristol
T_{N2}	Nut Temperature	0 to 200°F	Bristol

TABLE A-II (Cont'd)

INSTRUMENTATION REQUIREMENTS

Parameter	Description	Range Interest	Data Readout
V_f	Fuel Valve Electrical Characteristics	--	Oscillograph
V_o	Oxidizer Valve Electrical Characteristics	--	Oscillograph
t	Engine Elecrtical On Time	--	Oscillograph
Ref.	Zero Reference	--	Oscillograph
P_{oxt}	Oxidizer Tank Pressure	0 to 200 psia	Bristol
P_{ft}	Fuel Tank Pressure	0 to 200 psia	Bristol
P_{cell}	Cell Pressure	0 to .2 psia	Bristol Oscillograph
T_{fac}	Facility Flange Temperature	-50 to 150°F	Bristol

NOTES: 1. Range of Interest is a general requirement and may be changed by Development Test Engineer at any time.

2. A closed circuit television system will be used for all-testing. A videotape record will also be required. Should the videotape recording system fail to operate or delay testing, the recording system requirement will be waived.

TEST PROGRAM DEVIATION SHEET

DATE 15 DEC. 1967

Number 12

APPLICABILITY:

MTP 0079 MTN ______ TDP ______

PROGRAM P.I.P. BIG BUBBLE

THRUSTOR/ENGINE P/N VX 228682-517 S/N 0034

FACILITY PADG ORIGINATOR E. HOHMAN

APPROVAL REQUIREMENTS (per Test Plan):

1. ☒ Development Test Supervisor
2. ☒ Project Engineer
3. ☒ Test Program Manager
4. ☐ Reliability
5. ☐ Customer
6. ☐ ______

APPROVALS:

1. T. L. Kelley telecon 1600 T. L. Kelley
2. R. Moffett telecon 1555 R. Moffett
3. [illegible signature]
4. ______
5. ______
6. ______

TYPE OF DEVIATION: ☒ Discrepancy ☐ Procedure Change ☐ Document Change

DISCREPANCY/~~CHANGE~~: 1) WRONG OFF TIME ON PULSER ON RUN 843

2) NO EVENT MARKER ON LAST 5 PULSES OF RUN 844

This change affects Runs 843 through 844.

CORRECTIVE ACTION/~~REASON FOR CHANGE~~: 1) REPEAT RUN

2) ACCEPT AS IS, DO NOT RERUN

DISTRIBUTION (per Test Plan):

☒ Original to Change Control
☐ Original to Development Test
☒ Development Test Logbook
☒ Thrustor/Engine Logbook
☒ Project Engineer
☒ Data Analysis
☒ Test Program Manager
☒ Test Operations Engr.
☒ DCAS Office
☐ Customer
☒ Reliability
☐ ______

TEST PROGRAM DEVIATION SHEET

DATE 15 Dec. 1967

Number 13

APPLICABILITY:

MTP 0079 MTN ______ TDP ______

PROGRAM P.I.P. BIG BUBBLE TEST

THRUSTOR/ENGINE P/N VX 228687-517 S/N 0034

FACILITY PAD 6 ORIGINATOR E. HOHMAN

APPROVAL REQUIREMENTS (per Test Plan):

1. ☒ Development Test Supervisor
2. ☒ Project Engineer
3. ☒ Test Program Manager
4. ☐ Reliability
5. ☐ Customer
6. ☐ ______

APPROVALS:

1. [signature]
2. R. Moffitt
3. [signature]
4. ______
5. ______
6. ______

TYPE OF DEVIATION: ☐ Discrepancy ☐ Procedure Change ☒ Document Change

~~DISCREPANCY~~/CHANGE: THE ON AND OFF TIME TOLERANCES SHALL BE AS FOLLOWS:

ON TIME	TOLERANCE	OFF TIME	TOLERANCE
13 ms	± 1 ms	1987, 1980, 1970 ms	± 20 ms
20 ms	± 2 ms	480, 487 ms	± 10 ms
30 ms	± 3 ms	225 ms	± 5 ms

This change affects Runs 841 through TBD.

~~CORRECTIVE ACTION~~/REASON FOR CHANGE: NO TOLERANCES SPECIFIED ON CURRENT TEST PLAN

DISTRIBUTION (per Test Plan):

- ☒ Original to Change Control
- ☐ Original to Development Test
- ☒ Development Test Logbook
- ☒ Thrustor/Engine Logbook
- ☒ Project Engineer
- ☒ Data Analysis
- ☒ Test Program Manager
- ☒ Test Operations Engr.
- ☒ DCAS Office
- ☐ Customer
- ☒ Reliability
- ☐ ______

TEST PROGRAM DEVIATION SHEET

DATE 15 DEC. 1967

Number 14

APPLICABILITY:

MTP 0077 MTN ______ TDP ______

PROGRAM P.I.P. BIG BUBBLE

THRUSTOR/ENGINE P/N VY 228687 S/N 0034

FACILITY PAD G ORIGINATOR H. SHERMAN

APPROVAL REQUIREMENTS (per Test Plan):

1. ☐ Development Test Supervisor
2. ☐ Project Engineer
3. ☐ Test Program Manager
4. ☐ Reliability
5. ☐ Customer
6. ☐ ______

APPROVALS:

1. D. Woll
2. R. [illegible]
3. [illegible]
4. ______
5. ______
6. ______

TYPE OF DEVIATION: ☐ Discrepancy ☐ Procedure Change ☐ Document Change

~~DISCREPANCY~~/CHANGE:

PRIOR TO PERFORMING PARA 7.0.13 OF
[illegible] 15 [illegible] OX
PULSES ONLY, 13 MS ON, 1987 MS OFF

This change affects Runs 868 ~~through~~ ONLY.

~~CORRECTIVE ACTION~~/REASON FOR CHANGE: TO DETERMINE COOLING CAUSED BY 15 OXIDIZER COLD FLOWS.

DISTRIBUTION (per Test Plan):

- ☐ Original to Change Control
- ☐ Original to Development Test
- ☐ Development Test Logbook
- ☐ Thrustor/Engine Logbook
- ☐ Project Engineer
- ☐ Data Analysis
- ☐ Test Program Manager
- ☐ Test Operations Engr.
- ☐ DCAS Office
- ☐ Customer
- ☐ Reliability
- ☐ ______

FIG. 1

APPENDIX B

ANALYTICAL MODEL

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LIST OF ILLUSTRATIONS

LIST OF TABLES

ANALYTICAL MODEL

The analytical model for which this program was prepared is shown in the attached figure. (Velocities as shown are positive.) The program is derived solely by applying the perfect gas law to the bubble and requiring continuity throughout the system; the liquid is assumed to be incompressible and the expulsion of the bubble is assumed to be isothermal. At any instant the pressure in the bubble is assumed equal at all points.

After providing READ and FORMAT statements for the data cards and WRITE and FORMAT statements for the caluclated results the program calculates constants to be used in the main loop and the location of the liquid/bubble interface. The main loop begins by establishing if the valve is open or closed and proceeds to calculate the gas pressure at time intervals, H (see Table B-1 for a list of data input parameters). Statement lines 0062 through 0122 establish the relationships between gas velocities (V), the branch volumes (VO), the gas volumes (VG), and the volume fraction of gas flow (G), for branches X, Y, and Z. As the program proceeds VY $\leq$ 0 will result in lower pressures at the junction "pulling" gas into branch Y and Z (VGYZ). When these relationships are established the associated pressure ratio (PR) is calculated (statement line 0132); PR is the ratio of the rate of change of gas pressure to the gas pressure, $\mathring{P}/P$. New values are calculated for the velocity, location, and pressure of the interface and the gas volume in each branch (0140 through 0146). The program is then incremented by the integration interval (0155). Calculated results are printed out or the program is re-iterated with the calculated values as determined by the value of IPRINT (see Table B-1). The plotter subroutine is called only if IPLOT is set equal to 1.

The complete program listing is shown in the following pages.

ANALYTICAL MODEL

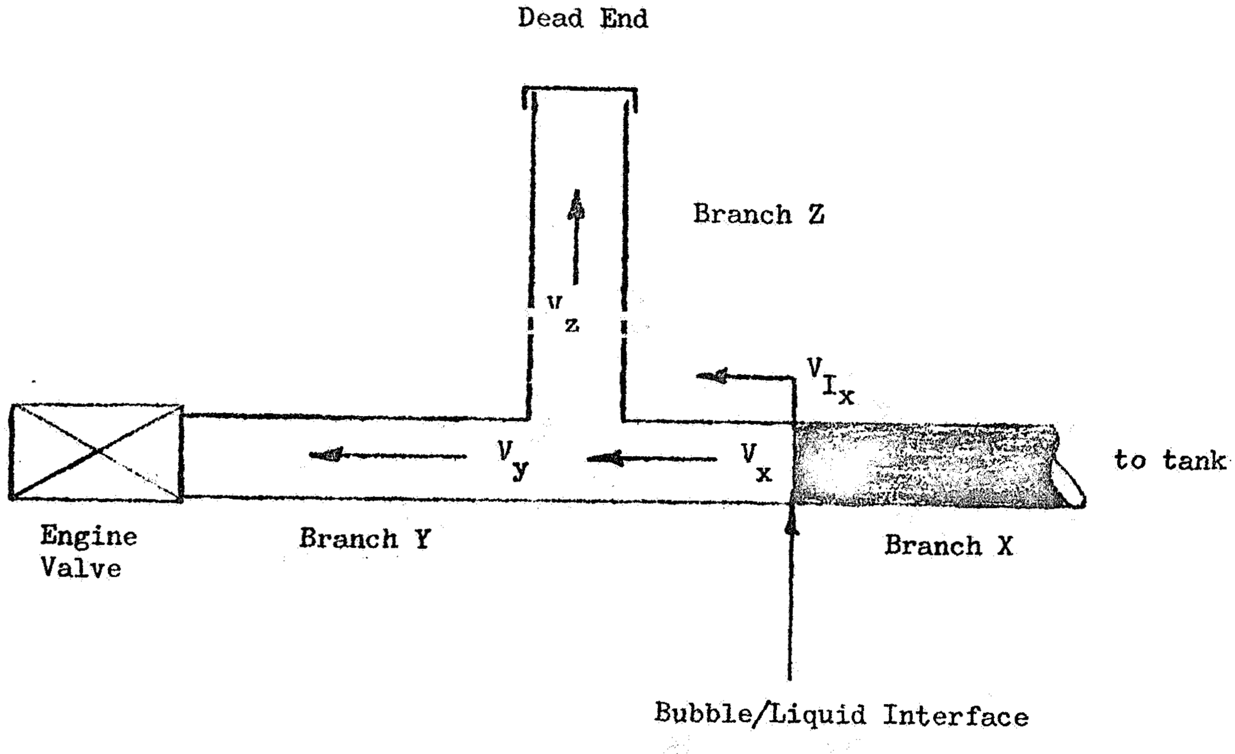

FIGURE B-1

TABLE B-I

DATA INPUT PARAMETERS

Card No.	Parameter	Definition	Units	Format
1	H	Integration Time Interval	seconds	12.6
	FLOSS	Friction Loss Coefficient	--	12.6
	VGO	Initial Bubble Volume	$in.^3$	12.6
	N	Index: If N = 0, the remaining parameters are the same as the previous case. If N = 1, read new input data. If N = 2, read new TON and TOFF only	--	12
	IPLOT	Index: If IPLOT = 0, No plots. If IPLOT = 1, Plots bubble pressure and valve actuations versus time (see Figure 10 of text)	--	12
	IPRINT	Index: If IPRINT = 0 or 1, Prints each point calculated (at intervals determined by H). If IPRINT = n(>1), Prints output at every n^{th} integration time interval	--	12
2	DX	Diameter of branch X	inches	12.6
	DY	Diameter of branch Y	inches	12.6
	DZ	Diameter of branch Z	inches	12.6
3	XJ	Length of branch X	inches	12.6
	VOY	Volume of branch Y	$in.^3$	12.6
	VOZ	Volume of branch Z	$in.^3$	12.6
	VGZI	Initial Volume of the bubble in branch Z	$in.^3$	12.6
4	PO	Initial bubble pressure	psia	12.6
	TG	Initial Gas Temperature	°F	12.6
	CK	Valve Flow Area	$in.^2$	12.6

TABLE B-I (Continued)

Card No.	Parameter	Definition	Units	Format
5	VIS	Liquid Viscosity	$\frac{lbf\text{-}sec}{ft^2}$	12.6
	RHO	Liquid Density	lbm/ft^3	12.6
	GMW	Molecular Weight of Gas	--	12.6
	GG	Gas Specific Heat Ratio	--	12.6
6	TON	Length of time the valve is open during a pulse	seconds	12.6
	TOFF	Time between pulses	seconds	12.6

COMPUTER PROGRAM LISTING FOR BIG BUBBLE TEST ANALYTICAL MODEL

```
      C
      C PROGRAM CCKBUB
      C
      C     N=                          IPLOT=           IPRINT=
      C     0 - OLD DATA                0 - NO PLOTS     0 OR 1 - PRINT (AND PLOT) AT
      C                                                           EACH INTERVAL
      C     1 - NEW DATA                1 - PLOT ON      GTR THAN 1 - PRINT (AND PLOT)
      C     2 - NEW VALVE TIMING          A02 PAPER               AT INTERVALS SPECED
      C
            DIMENSION Q(P,4),XI(4),PI(4),VI(4),VGYI(4),VGZI(4),VGXI(4),
           1 VGYZI(4),TITLE1(18),TITLE2(18),TITLE3(18)
            DIMENSION IPLOT(5002),PPLOT(5002),VALV(5002)
            COMMON IPLOT,PPLOT,VALV,TITLE1,TITLE2,TITLE3,NP
          1 NP=0
            READ (5,10,END=5001) TITLE1,TITLE2,TITLE3,H,FLOSS,VGO,N,IPLOT,
           1   IPRINT
         10 FORMAT (18A4/18A4/18A4/3E12.6,3I12)
            WRITE(6,11) TITLE1,TITLE2,TITLE3,H,FLOSS,VGO,N,IPLOT,IPRINT
         11 FORMAT (1H1,5X,18A4/18A4/18A4//8X,1HH,11X,5HFLOSS,10X,3HVGO,11X,
           1   1HN, 3X,5HIPLOT,2X,6HIPRINT,//2X,3(F8.3,6X), 3(I6,2X))
            IF (IPRINT.EQ.0) IPRINT=1
            IF(N-1)40,20,30
         20 READ (5,12) DX,DY,DZ,XJ,VOY,VOZ,VGZI,PO,TG,CK,VIS,RHO,GMW,GG
         12 FORMAT (3E12.6/4E12.6/3E12.6/4E12.6)
            WRITE(6,13) DX,DY,DZ,XJ,VOY,VOZ,VGZI,PO,TG,CK,VIS,RHO,GMW,GG
         13 FORMAT (///7X,2HDX,12X,2HDY,12X,2HDZ,//2X,3(F8.3,6X),///7X,2HXJ,
           1   11X,3HVOY,10X,3HVOZ,9X,4HVGZI,
           2   [illegible]
           3   F8.4,///7X,3HVIS,[illegible]
           4   3(F8.3,6X))
            RHO=RHO/(32.174*12.**4)
            AX=0.7854*DX**2
            AY=0.7854*DY**2
            AZ=0.7854*DZ**2
            TGI=TG+459.7
            RG=1545./GMW
            CI=(386.088*GG*(2./(GG+1.))**((GG+1.)/(GG-1.))/RG)**0.5
            AKO=CI*RG*CK*TGI**0.5

         30 READ (5,14) TON,TOFF
         14 FORMAT (6E12.6)
            WRITE(6,15) TON,TOFF
         15 FORMAT (///7X,3HTON,10X,4HTOFF//2X,2(F8.3,6X))
         40 P    =PO
            T    =0.
            X    =XJ-(VGO-VOY-VOZ)/AX
            V    =0.
            IF(X   -XJ)50,60,70
         50 VGY    =VOY
            VGZ    =VOZ
            VGX    =VGO-VOY-VOZ
            VGYZ    =0.
            GO TO 49
         60 WRITE (6,17)
         17 FORMAT (22H INTERFACE AT JUNCTION)
            GO TO 50
         70 VGZ    =VGZI
            WRITE (6,16) VGZ
         16 FORMAT(//25HOINTERFACE PAST JUNCTION.,
           1   /33H INITIAL BUBBLE IN BRANCH (VGZO)=F8.3)
            VGY    =VGO-VGZ
            VGX    =0.
            VGYZ    =0.
         49 II=0
            NJ=0
            L=1
            M=0
            AK=AKO
            I=0
```

```
      C
      C    MAIN LCOP ******************
      C
         51 I=I+1
            IF (I.EQ.50000) GO TO 157
            FL=FLOAT(L)
            FM=FLOAT(M)
            IF(T    -FL*TON-FM*TOFF)6,2,2

          2 IF(L-M)4,4,5
      C
      C    OPEN VALVE
      C
          4 L=L+1
            AK=AKO
            LSAK=1
            GO TO 6
      C
      C    CLOSE VALVE
      C
          5 M=L
            AK=0.
          6 CONTINUE
            XI(I)=X
            VI(I)=V
            PI(I)=P
            VGYI(I)=VGY
            VGZI(I)=VGZ
            VGXI(I)=VGX
            VGYZI(I)=VGYZ
            PR=(V    *AX-AK)/(VGY    +VGZ    +VGX    +VGYZ    ) -
            VY=(PR*(VGYZ    +VGY    )+AK)/AY  -
            VX=V    -PR*VGX    /AX
            VZ=PR*VGZ    /AZ
            IF(NJ)101,101,102
        101 GY=1.
            GX=1.
            GZ=1.
            GO TO 120
        102 IF(VY)103,103,104
        103 GY=VGYZ    /(VOY-VGY)
            IF(VZ)105,105,106
        105 IF(VGZ    +VOZ)107,108,108
        107 GZ=0.
            GO TO 119
        108 GZ=1.
            GO TO 119

        106 IF(VX)109,110,110
        110 IF(VGX    )111,111,112
        111 GX=1.0
            GO TO 121
        112 GX=0.
            GO TO 121
        109 GX=GY
            GZ=GY
            GO TO 120
        119 GX=(VY*AY*GY+VZ*AZ*GZ)/(AX*VX)
            GO TO 120
        121 GZ=(VX*AX*GX-VY*AY*GY)/(VZ*AZ)
            GO TO 120
        104 IF(VZ)113,113,114
        113 IF(VGZ    -VOZ)115,116,116
        115 GZ=0.
            GO TO 117
        116 GZ=1.0
        117 IF(VX)125,125,126
        125 GX=GZ
            GY=GZ
            GO TO 120
        126 IF(VGX    )127,127,128
        127 GX=0.
            GO TO 129
        128 GX=1.0
        129 GY=(VX*GX*AX-VZ*GZ*AZ)/(VY*AY)
            GO TO 120
        114 IF(VGX    )130,130,131
        130 GX=0.
            GO TO 132
        131 GX=1.0
        132 GZ=GX
            GY=GX
        120 DO 95 J=1,4
            DPL=128.*XI(J)*VI(J)*VIS/DX**2+FLOSS*RHO*VI(J)*ABS(VI(J))/2.
            DPI=0.632*RHO**0.75*XI(J)*VIS**0.25*VI(J)*ABS(VI(J))**0.75
           1    /DX**1.25+FLOSS*RHO*VI(J)*ABS(VI(J))/2.
```

```
            DP=AMAX1(DPL,DPT)
            FN=FLOAT(NJ)
            Q(1,J)=(PO-PI(J)-DP)/(RHO*XI(J))
            Q(2,J)=VI(J)*(1.-FN)
            Q(3,J)=PI(J)*(VI(J)*AX-AK)/(VGYI(J)*VGZI(J)*VGXI(J)*VGYZI(J))
            Q(4,J)=1.0
            PR=Q(3,J)/PI(J)
            Q(5,J)=-((PR*VGYI(J)+AK)*FN)
            Q(6,J)=-(PR*VGZI(J)*(1.-GZ)*FN)
            Q(7,J)=-(VI(J)*AX*GX)-PR*VGXI(J)*(1.-GX)*FN
            Q(8,J)=(PR*(VGYI(J)*GY-VGYZI(J)*(1.-GY))*AK*GY)*FN
            IF(J-3)199,199,99
        199 CONTINUE
            B=AMSXC(I,J-1)/2.*H
            VI(J+1)=VI(1)+B*Q(1,J)
            XI(J+1)=XI(1)+B*Q(2,J)
            PI(J+1)=PI(1)+B*Q(3,J)
            VGYI(J+1)=VGYI(1)+B*Q(5,J)
            VGZI(J+1)=VGZI(1)+B*Q(6,J)
            VGXI(J+1)=VGXI(1)+B*Q(7,J)
            VGYZI(J+1)=VGYZI(1)+B*Q(8,J)
         99 CONTINUE
            DO 98 K=1,8
         98 Q(K,1)=H/6.*(Q(K,1)+2.*Q(K,2)+2.*Q(K,3)+Q(K,4))
            V      =V     +Q(1,1)
            X      =X     +Q(2,1)
            P      =P     +Q(3,1)
            T=FLOAT(I)*H
            YP=(VGY-VGY    )/AY
            ZP=(VGZ-VGZ)/AZ
            IF (I.EQ.1) WRITE (6,172)
        172 FORMAT(72H1   I        TIME   PRESSURE FEED LINE  ENGINE      BRANCH
           1VELOCITY          )
            IF((I-IPRINT*(I/IPRINT)).EQ.0) GO TO 2515
            GO TO 2520
       2515 WRITE (6,171) I,T,P,X,YP, ZP,V
        171 FORMAT ([illegible]
            IF (IPLOT.NE.1) GO TO 2520

            NP=NP+1
            TPLOT(NP)=T
            PPLOT(NP)=P
            IF (AK.NE.0.) GO TO 2518
            VALV(NP)=0.2
            IF (LSAK.EQ.1) VALV(NP)=0.6
            LSAK=0
            GO TO 2520
       2518 VALV(NP)=0.6
       2520 VGY      =VGY    +Q(5,1)
            VGZ      =VGZ    +Q(6,1)
            VGX      =VGX    +Q(7,1)
            VGYZ       =VGYZ    +Q(8,1)
            VGY      =VGY       +VGYZ
            VGYZ       =0.
            IF(NJ)135,135,136
        135 IF(X       =XJ) 51,138,138
        138 NJ=1
            WRITE (6,17)
            WRITE (6,94) I,T,P,X,VGY,VGZ,VGX,VGYZ
         94 FORMAT(21X,2HI=,I5,6X,2HT=,F8.4,4X,2HP=,F8.3,6H     X=,F8.3/19X,4HV
           1GY=,F7.3,3X,4HVGZ=,F7.3,3X,4HVGX=,F7.3,2X,5HVGYZ=,F7.3)
            WRITE (6,172)
            GO TO 51
        136 IF(VGY)      139,139,51
        139 WRITE (6,22)
         22 FORMAT (//19H INTERFACE AT VALVE)
            WRITE (6,94) I,T,P,X,VGY,VGZ,VGX,VGYZ
        157 IF (IPLOT.NE.1) GO TO 1
            IF((I-IPRINT*(I/IPRINT)).EQ.0) GO TO 100
            NP=NP+1
            TPLOT(NP)=T
            PPLOT(NP)=P
            IF (AK.EQ.0.) VALV(NP)=0.2
            IF (AK.NE.0.) VALV(NP)=0.6
        100 CALL PLOTTR
            GO TO 1
       5001 IF (IPLOT.EQ.1) CALL CLOSE

            STOP
            END
```