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CONFIDENTIAL

(Unclassified Title)

FEASIBILITY DEMONSTRATION OF ADVANCED ATTITUDE CONTROL SYSTEMS

TECHNICAL DOCUMENTARY REPORT NO. AFRPL-TR-66-55
MARCH 1966

QUARTERLY PROGRESS REPORT
FOR PERIOD 1 NOVEMBER 1965 THROUGH 31 JANUARY 1966

Rocket Propulsion Laboratory
Research and Technology Division
Air Force Systems Command
Edwards Air Force Base, California

DOWNGRADED AT 3 YEAR INTERVALS:
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Program Structure No. 750G
BPSN No. 623058
Task No. 3058504

(Prepared under Contract No. AF04(611)-10818
by The Bell Aerosystems Company, Buffalo 5, New York)

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(This Foreword is Unclassified)

(U) FOREWORD

(U) Presented in this report is the work accomplished by the Bell Aerosystems Company during the period 1 November 1965 to 31 January 1966 for the Air Force Rocket Propulsion Laboratory, Research and Technology Division, Edwards Air Force Base, California, under Contract AF04(611)-10818. The program is directed toward the feasibility demonstration of promising attitude control system concepts for space vehicles.

(U) The contractor's secondary report number is 8429-933002.

(U) The principal contributors to the report were:

L. Baker	L. Montanino
C. Brown	W. Pearson
A. Friona	J. Tramuta

(This Abstract is Unclassified)

(U) ABSTRACT

(U) The second quarterly period was devoted to accomplishing the following work for the respective tasks:

(U) Task 1 - Summarizing the results of the material test program, completing injector and thrust chamber designs, fabrication of the injectors, fabrication of the thrust chambers, design and fabrication of the bipropellant valves, and test cell buildup.

(U) Task 2 - Completion of system transient analyses, design of the bellows pumps, completion of a bellows test program, heat exchanger design and fabrication, and system test installation coordination.

(U) This technical documentary report has been reviewed and is approved.

(U) TABLE OF CONTENTS

[redacted]

(U) ILLUSTRATIONS

(U) TABLES

SECTION 1

(C) INTRODUCTION

(U) The objective of this program is to demonstrate the feasibility of promising attitude control system concepts for space vehicles.

(C) Independent studies conducted by Bell Aerosystems Company defined the propulsion system characteristics for a Maneuvering Satellite. The first study was conducted in 1961 under Contract AF04(611)-7429 (Report No. SSD-TDR-62-9) and was based on the use of storable main propellants, N_2O_4/50% UDMH-50% N_2H_4, with a gaseous bipropellant attitude control system (OF_2/CH_4). The second study was conducted in 1964 under Contract AF04(611)-8183 (Report No. RPL-TDR-64-120) and was based on the use of high energy liquid main propellants, F_2/H_2, with a liquid bipropellant attitude control system (N_2O_4/50% UDMH-50% N_2H_4) based on minimum weight and development status considerations. The attitude control system portion of the latest study was a small part of the overall study; therefore, only a cursory evaluation of attitude control systems was made.

(U) The use of attitude control propellants in a gaseous state is desirable to minimize shutdown performance losses, control of small impulse bits and to improve ignition response. The use of storable propellants presents the additional problem of high freezing points, which are not compatible with mission compartment temperatures.

(C) Initial testing with the OF_2/CH_4 propellant combination indicated ignition problems at low environmental temperatures. The use of suitable additives had eliminated this problem and made these propellants attractive for additional analysis. Therefore, these reactive gases, stored at high pressure, will be analyzed for use as an independent attitude control system. Thrust chamber performance will be demonstrated.

(C) The second system selected for feasibility demonstration during this program utilizes the cryogenic propellants (LF_2/LH_2) from the main propulsion system tankage. The propellants are extracted from the main tanks with a differential area gas-liquid injector pump and converted to gas in a heat exchanger. The expended gases from the injector pump are used in a combustor, at a ratio corresponding to the thrust chamber mixture ratio, as the heat source. The converted propellants are then stored in an accumulator in preparation for thrust chamber demand.

(U) Subsequent to a system analysis, a breadboard system shall be fabricated and demonstrated utilizing simulated thrust chamber demand requirements.

SECTION 2

(U) SUMMARY

A. (U) TASK 1 - STORED REACTIVE GAS ATTITUDE CONTROL SYSTEM

(U) The results of the material test program were summarized. The coupon HF exposure tests serve to point out the need for precautionary propellant loading procedures. The bomb tests with the oxidizer mixture at various pressure levels indicated no visible detrimental effects.

(U) Two injector design configurations were completed and released for fabrication. One complete assembly and sufficient details for a second of each configuration were ordered. The orifice plate for the first configuration, single coaxial primary with a modified showerhead secondary, was completed and water and nitrogen gas flowed prior to final EB welding and machining.

(U) The second injector design, multiple coaxial configuration with film cooling, is being fabricated at La Mesa Tool Company, San Diego, California, with a promised delivery date of 18 February 1966 for the details. Assembly of the details will be made at Bell after flow tests.

(U) The necessary flow and pressure test fixtures for the injectors were also designed and fabricated during this period.

(U) Two thrust chamber design configurations were released and fabricated. Both chambers are fabricated from tantalum-10% tungsten with the first having a tungsten internal coating and a hafnium-tantalum external coating, and the second having a hafnium-tantalum coating internally and externally.

(U) Start chambers incorporating graphite liners, to be used for injector performance evaluation, were designed and fabricated. A chamber extension for L* evaluation was also completed.

(U) An order for a bipropellant valve design was placed with Hydraulic Research and Manufacturing Company. The design was completed and fabrication is approximately 75% complete. Delivery is scheduled for 15 February 1966. A heat transfer analysis to determine the effect of heat soakback to the valve during fire test was completed and indicates no problem.

(U) The test cell buildup was initiated and is approximately 95% complete with a 15 February 1966 completion date.

B. (U) TASK 2 - ATTITUDE CONTROL SYSTEM USING MAIN PROPULSION SYSTEM PROPELLANTS

(U) Specification control design drawings for the fuel and oxidizer bellows injector pumps were completed and cor . ated with the vendor, Sealol. A test bellows program was conducted by Se . . to demonstrate cycle life capability prior to initiation of pump fabrication. A tot ' 318 cycles was completed prior to a bellows failure. Inspection of the fail re area indicated no apparent discrepancies.

(U) The design point heat exchanger heat transfer analysis was completed and a design configuration was established. Design drawings were completed and fabrication was initiated. elivery of the drilled heat exchanger chambers is scheduled for 18 February 196 rom the vendor. The remaining assembly details have been completed.

(U) The system transient computer work was completed and the data were plotted.

(U) System test installation requirements were established and component orders placed.

SECTION 3

(U) TASK 1 - STORED REACTIVE GAS ATTITUDE CONTROL SYSTEM

A. (U) TANK MATERIAL TESTS

1. (U) Coupon Tests

(U) The results of the material compatibility tests with 1% and 60% HF solutions at room temperature and 160°F for a total of 14 days have been summarized as follows:

(U) The following materials were utilized in coupon form: maraging steel 250, 7039 aluminum, 2219 aluminum, nickel beryllium 440, 15-7 PH stainless steel and nickel plated titanium (0.0005 inch nickel minimum). All materials were tested in annealed condition in order to avoid comparison of heat treatments on corrosion effects.

(U) Preliminary work was started using 50% HF acid until 60% HF acid could be obtained, then confirmation tests were performed to be sure there was no gross deviation from results of the 50% HF acid work. Initially, the metals were placed in the acid at room temperature to check the severity of the reaction. Kel-F bottles were used for the 160°F tests and polyethylene bottles for the room temperature tests.

(U) Maraging steel was attacked immediately by HF. At room temperature a slow reaction occurred with 1% HF while 50% HF promoted a fast reaction with gas evolution. After 20 hours, the 1% HF panels showed much loose black skin peeling off into a pink solution while greenish stains occurred in the vapor section. The 50% HF panels were very blackish and badly attacked in the immersed portion. By 48 hours the 50% HF panels were badly eaten away and disintegrating with the formation of heavy salt deposits. The 1% HF panels were attacked slowly and this condition continued with time. After two weeks, the 1% HF panels still had a loose grainy skin which peeled off easily into a dirty brown acid solution. The vapor section contained a loose brown-black corrosion product. After cleaning and rubbing, the panels showed much pitting and corrosion along with a strong liquid-vapor interface attack and a noticeable thinning of the metal at that point. The 50% HF panels just continued to dissolve readily. No attempt was made to conduct the 160°F test with 50% HF and maraging steel for obvious reasons. The 1% HF at 160°F test was conducted with the same results as above but at a faster rate. There are no weight changes available for the room temperature 50% HF work since all panels disintegrated. The 1% HF tests, however, showed a rate of attack four times greater at 160°F than at room temperature with percent weight changes of 12.8% compared to 2.29%.

(U) A panel placed in 60% HF corroded very badly at room temperature. A sample allowed to remain at 160°F lost 15% of its weight in 10 days and 21.6% in two weeks but was still intact. This solution also is very destructive.

(U) 7039 aluminum was also attacked immediately by HF. At room temperature a slow reaction occurred with 1% HF. The 50% HF solution promoted a vigorous reaction with considerable gas evolution with the panels turning black. By 20 hours the 1% HF settled down to no apparent reaction. The solution remained clear and the panels changed to a gray-black color in the immersed sections. This visual condition continued for two weeks. The 50% HF room temperature solution blew the top off the bottle and continued to react quickly until all the acid was exhausted and only a heavy white dried salt condition remained at 20 hours. At 160°F, this condition was accelerated with the 50% HF. The 1% HF maintained a slight reaction and completed the two-week immersion with a heavy white tightly adhering salt deposit on the vapor section of the metal surface. The vapor surface was attacked but remained smooth. The immersed section of the aluminum was colored a very deep gray and etched. The 160°F solution attacked the 7039 aluminum at twice the rate of the 1% HF room temperature solution with weight percent changes of 2.65% compared to 1.51%.

(U) Panels placed in 60% HF at room temperature dissolved completely in less than 48 hours.

(U) 2219 aluminum was very badly attacked by HF. At room temperature a reaction started immediately with 1% HF which blackened the metal and promoted vigorous gas evolution. By 20 hours no further action was taking place. The solution remained clear and the panels had a spotted black adherent coating in the immersed section. This visual condition continued for two weeks. The section of the panel exposed to the vapor remained clean. The total percent weight change averaged 1.13% for a two-week immersion period so apparently the adherent coating was protective. The 160°F test of the 1% HF with 2219 aluminum was allowed to continue but the aluminum totally dissolved within 48 hours.

(U) The 50% HF room temperature test was much too vigorous to continue for long. This test was stopped after a few minutes. Panels placed in 60% HF dissolved immediately with a very vigorous reaction.

(U) The nickel-beryllium 440 gave a visual impression of being the least affected metal of the series in test. There was no immediate reaction on immersion except for a few black stains on the 1% HF samples only. The blackening remained visually the same but the panel was slowly being attacked overall by the acid. After two weeks immersion, both the room temperature and 160°F 1% HF solutions attacked the metal badly at the liquid-vapor interface,breaking some in two and leaving very black reaction deposits along the break line. Both temperature conditions equally stained the immersed sections a black color while the 1% HF at 160°F also caused the deposition of tightly adhering green salts in the vapor section of the panels. Weight percent losses for both conditions were about equal at 6% each.

(U) The 50% samples at room temperature were attacked somewhat in the vapor phase with a blackish stain effect while the immersed section was relatively clean. At 160°F, the samples were blackened somewhat on one side only in the immersed section with a very thin, very adherent coating, while the vapor section had many black stains. The percent weight change of the 50% HF panels showed that while the room temperature panels looked like they had been attacked more severely, they actually only lost half the weight when compared to the 160°F panels; that is, 5.56% instead of 11%. Both sets of panels had relatively smooth surfaces with no pitting.

(U) Panels of nickel beryllium placed in 60% HF acid showed the same attack pattern as with the 50% HF. There was no apparent reaction upon immersion but a thin blackish coating was formed within 48 hours at room temperature that could be flaked off with agitation. The sample was then subjected to 160°F for the remaining 12 days. The metal remains dark and very rough and pitted as compared to the smoothness of the 50% HF series. The weight loss appeared to progress at the same approximate rate, however, averaging 10.3% for the two-week period.

(U) 15-7 Mo PH stainless steel was attacked badly by the room temperature 50% HF solution. Immediately upon immersing the metal a fast reaction continued unabated. Within 20 hours, the metal was very badly corroded and by 48 hours it had disintegrated into small sections. Much green salt was also formed at this time. At 160°F, the reaction and subsequent disintegration of the metal was accelerated. The 60% HF solution also acted the same way with total solution of metal.

(U) Upon immersing the panels in 1% HF solution at room temperature and 160°F, a slight reaction occurred initially. After the two week period at room temperature, the immersed section of the metal was etched and cleaned while the vapor phase had rainbow-colored stains but was not etched. The interface had a very tightly adhering brown deposit on it. The 160°F solution also showed little activity but it left the immersed section of the metal coated with heavy, very tightly adhering brown-black coating that was very smooth. The vapor section of the metal also had some of this coating but was spotty. The percent weight changes of both solutions were not too different, however. The room temperature panels lost 1.68% and the 160°F temperature panel lost 2.69%of its weight.

(U) The nickel plated titanium showed a very slight reaction when immersed in 60% HF and no effect at all in the 1% HF. By 48 hours, the 60% HF had penetrated the nickel coating and totally dissolved the titanium metal leaving the nickel plate intact, as in a sandwich, in both the room temperature and the 160°F solutions. Within 48 hours at room temperature, the 1% HF attacked the metal at the liquid-vapor interface, buckling the metal which was then totally immersed. The nickel plate was again lifted intact and peeling. This test was then terminated. The 160°F, 1% HF panels appeared visually unaffected with a few black stains in the vapor section and clean looking metal in the immersed portion. Weight losses after 14 days were in the 0.03% range.

(U) The results of all tests are summarized in Table I and shown in Figures 1, 2, 3 and 4.

(U) In general, all the metals tested were attacked in varying degrees by HF acid. The 50% and 80% HF was very destructive to all metals including the nickel-beryllium 440 which appeared visually unaffected but was gradually dissolving and losing weight, with no protective coating being formed. A review of previous HF material compatibility work conducted by Bell Aerosystems during the Integrated Components Program conducted under Contract AF04(611)-9077, reference Report No. AFRPL-TR-65-93, showed that Berylco 440 in an aged condition withstood HF attack to a much greater extent, a factor of approximately 5, than the annealed samples tested during this program.

(U) The 1% HF attacked all metals to a lesser degree as evidenced by the comparatively low metal weight losses. Both the 7039 and 2219 aluminums formed a protective coating at room temperature while at 160°F the 2219 aluminum dissolved, and the 15-7 Mo PH stainless steel developed a heavy smooth brown protective layer. The 7039 aluminum still had a gray protective coating but was more severely affected in the vapor area.

(U) These tests have served to indicate the need for precautionary propellant loading procedures in a system installation to prevent moisture in the system and also possible suitable external material coatings for leakage considerations.

2. (U) Bomb Tests

(U) The eight bombs were all cut open longitudinally, following the oxidizer exposure tests, using no cutting fluid in order to prevent possible masking of any detrimental test effects. A visual examination of the interior surfaces of all samples disclosed no apparent adverse effects from the test environment exposure. Metallographic test sections of the weld and heat affected zones were made of the two 2219 aluminum bombs and the maraging steel bomb which had been pressurized to 3000 psig. No corrosion or deterioration of the surface could be found in any of the samples.

(U) These tests have served to verify that the use of the maraging steel 250 used in the system analysis optimization is satisfactory and provides the best strength-to-density ratio material available within the present state-of-the-art.

(U) Figure 5 shows the test setup for the bomb tests.

B. (U) THRUST CHAMBER DESIGN

1. (U) Injector Design

(U) The design of the two injector configurations was completed and both were released for fabrication. One complete assembly and sufficient details for a second of each configuration were ordered.

TABLE I

(U) EFFECT OF 1%, 50% AND 60% HF SOLUTIONS ON METAL SPECIMENS 14 DAY EXPOSURE

Metal	Temp.	% HF	Av. % Wt. Change	Remarks
Maraging Steel 250	RT	1	2.92	Interface attacked - loose skin panels - very blackish
		50	--	Panels disintegrated - fast reaction
		60	--	Attacked badly - discontinued
	160°F	1	12.8	Black, pitted, interface attack
		50	--	Panels disintegrated and dissolved
		60	21.6	Black, pitted, interface attacked badly
7039 Aluminum	RT	1	1.51	Immersed section - very gray
		50	--	Dissolved in hours
		60	--	Dissolved immediately
	160°F	1	2.65	Immersed section gray, heavy salts
		50	--	Dissolved immediately
		60	--	Dissolved immediately
2219 Aluminum	RT	1	1.13	Spotted heavy black protective coating on immersed section
		50	--	Dissolved immediately
		60	--	Dissolved immediately
	160°F	1	--	Dissolved immediately
		50	--	Dissolved immediately
		60	--	Dissolved immediately

(U) TABLE 1 (Cont)

Metal	Temp.	% HF	Av. % Wt. Change	Remarks
Nickel - Beryllium 440	RT	1	6.20	Interface attacked and broken
		50	5.56	Vapor phase attack - blackish stains
		60	8.43	Black loose flaky coating - 48 hr.
	160°F	1	5.63	Interface attacked and broken, tightly adhering stains all over
		50	11.0	Black adhering stains all over
		60	10.3	Panel very rough and pitted all over Dull copper color on immersed section.
15-7 Mo PH Stainless Steel	RT	1	1.68	Vapor phase-stained, brown interface deposit
		50	--	Dissolved immediately
		60	--	Dissolved immediately
	160°F	1	2.69	Smooth, tightly adhering brown-black protective coating on immersed section
		50	--	Dissolved immediately
		60	--	Dissolved immediately
Nickel Plated Titanium	RT	1	--	Nickel peels off - Titanium buckled at interface - 48 hr.
		60	--	Titanium dissolved - 48 hr. Nickel sandwich remains
	160°F	1	0.03	Appeared unaffected - except black stains - immersed section clean
		60	--	Titanium buckled and dissolved Nickel peeling left

Figure 1. (U) Material Coupons Subjected to 1% HF at Room Temperature

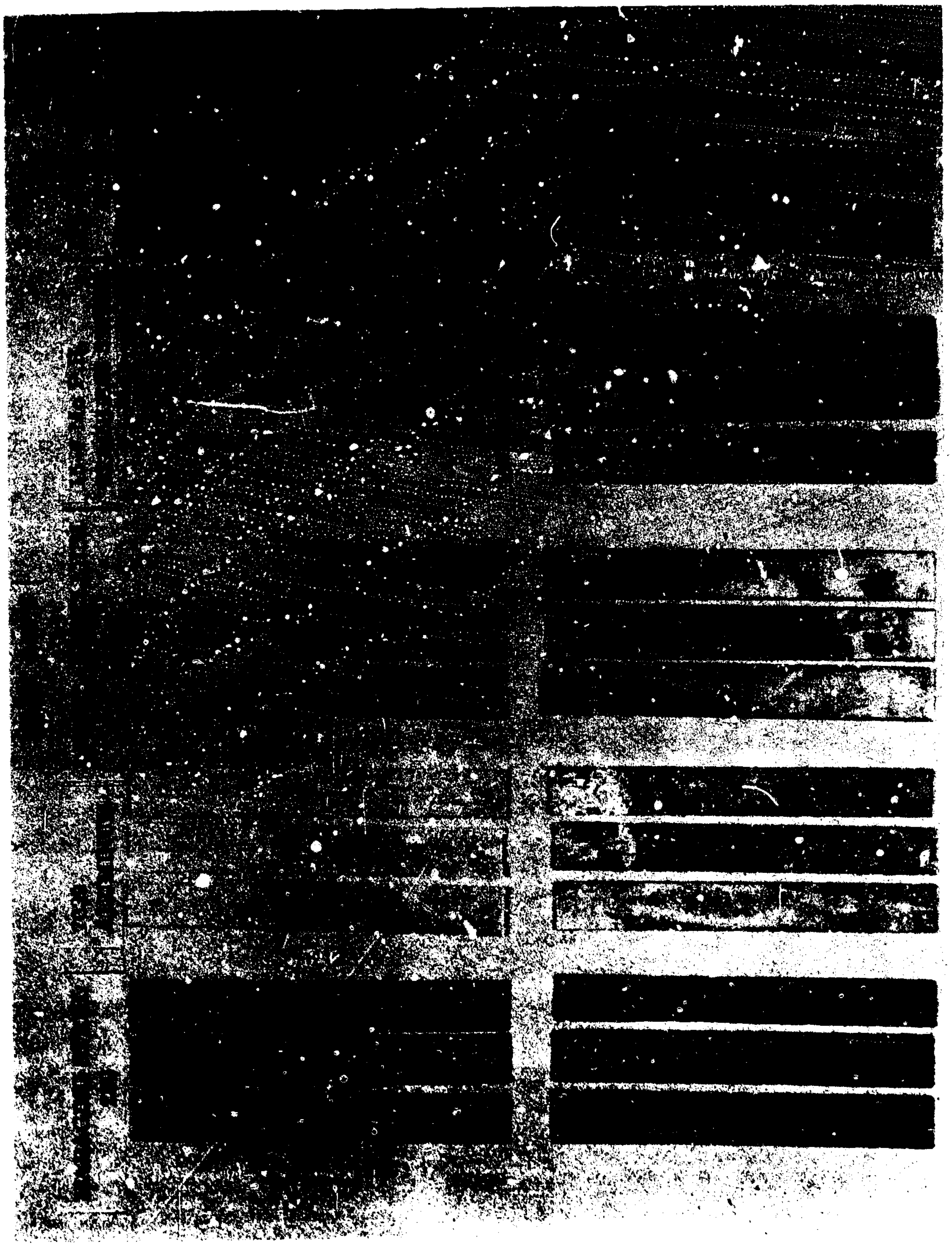

Figure 2. (U) Material Coupons Subjected to 1% HF at 160°F

Figure 3. (U) Material Coupons Subjected to 50% HF and 60% HF at Room Temperature

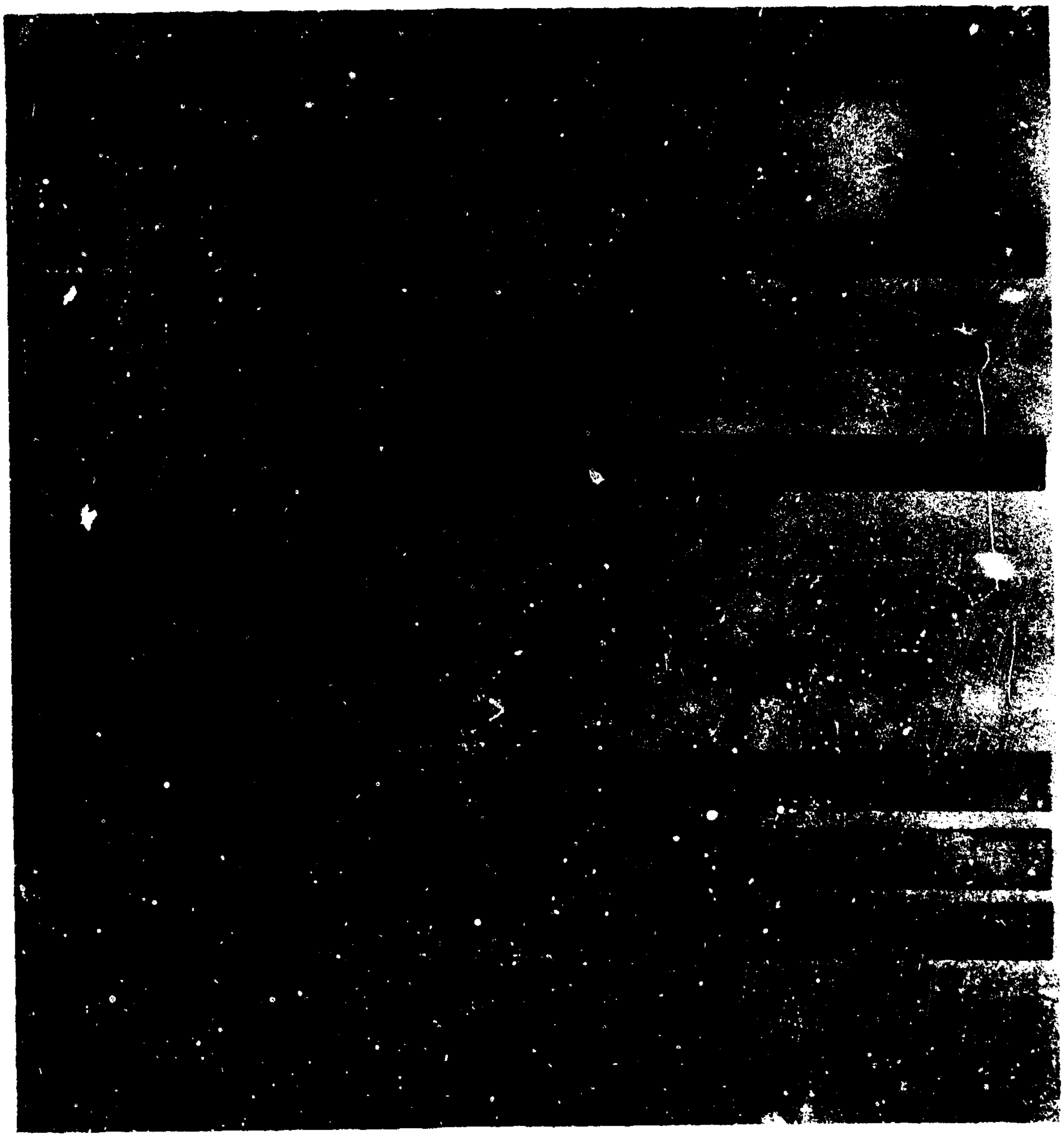

Figure 4. (U) Material Coupons Subjected to 50% HF and 60% HF at 160°F

Figure 5. (U) Bomb Test Setup

(U) The first injector orifice plate for the first injector configuration, single coaxial primary with a modified showerhead secondary, was completed and water flowed to establish pressure drops and flow distribution between primary and secondary circuits. The oxidizer primary flow was within 1% of the design percentage. The fuel primary flow was approximately 5% higher than design. This results in a primary mixture ratio of 3.88 as compared to a design value of 4.14. The secondary mixture ratio is 2.36 as compared to a design value of 2.00. The orifice plate can be seen in Figure 6.

(U) A nitrogen gas flow pressure drop check was also made prior to sending the injector out for final EB welding of the manifold covers.

(U) The orifice blank and remaining details for a second injector were also completed. The necessary flow and pressure test fixtures for the injectors were also designed and fabricated.

(U) The fabrication of the details for the second injector design, multiple coaxial configuration with film cooling, is being accomplished by La Mesa Tool Company of San Diego, California. The flowing of the orifice plate and the assembly of the injector will be accomplished at Bell. Some difficulty was experienced in delivering the material to the vendor causing an approximate two week delay in fabrication. A delivery date of 18 February 1966 has been scheduled.

2. (U) Thrust Chamber Design

(U) Two thrust chamber configurations were selected for design and fabrication. Both designs utilize tantalum-10% tungsten with one having a tungsten internal coating and a hafnium-tantalum external coating, and the second having a hafnium-tantalum coating internal and external.

(U) One thrust chamber of each configuration has been completed. A slight discrepancy was noted in the tungsten coated thrust chamber. An approximate 1/8 inch chip in the coating at the nozzle exit, A_e/A_t of 1.1, was noted. The area has an overlap of the hafnium-tantalum external coating and therefore is protected. Discussions with Sylcor and materials personnel at Bell were conducted and, although the vendor indicated there was a possibility of stripping the tungsten coating and reapplying it, the conclusion was reached that the best approach would be to leave the chamber as is with the discrepant area noted for reference after fire test. The coated chamber, with a 10X view of the discrepant area, can be seen in Figure 7. Machining of the sealing surfaces of the flanges of both thrust chambers is being accomplished.

(U) A third chamber design was also evaluated in favor of a previous design utilizing carbitex or pyrolytic graphite. It would utilize tungsten-25% rhenium coated externally with hafnium-tantalum. The rhenium provides the ductility required with tungsten for thermal shock purposes. At the present time material costs appear prohibitive for this design but it will be considered as a contingency backup.

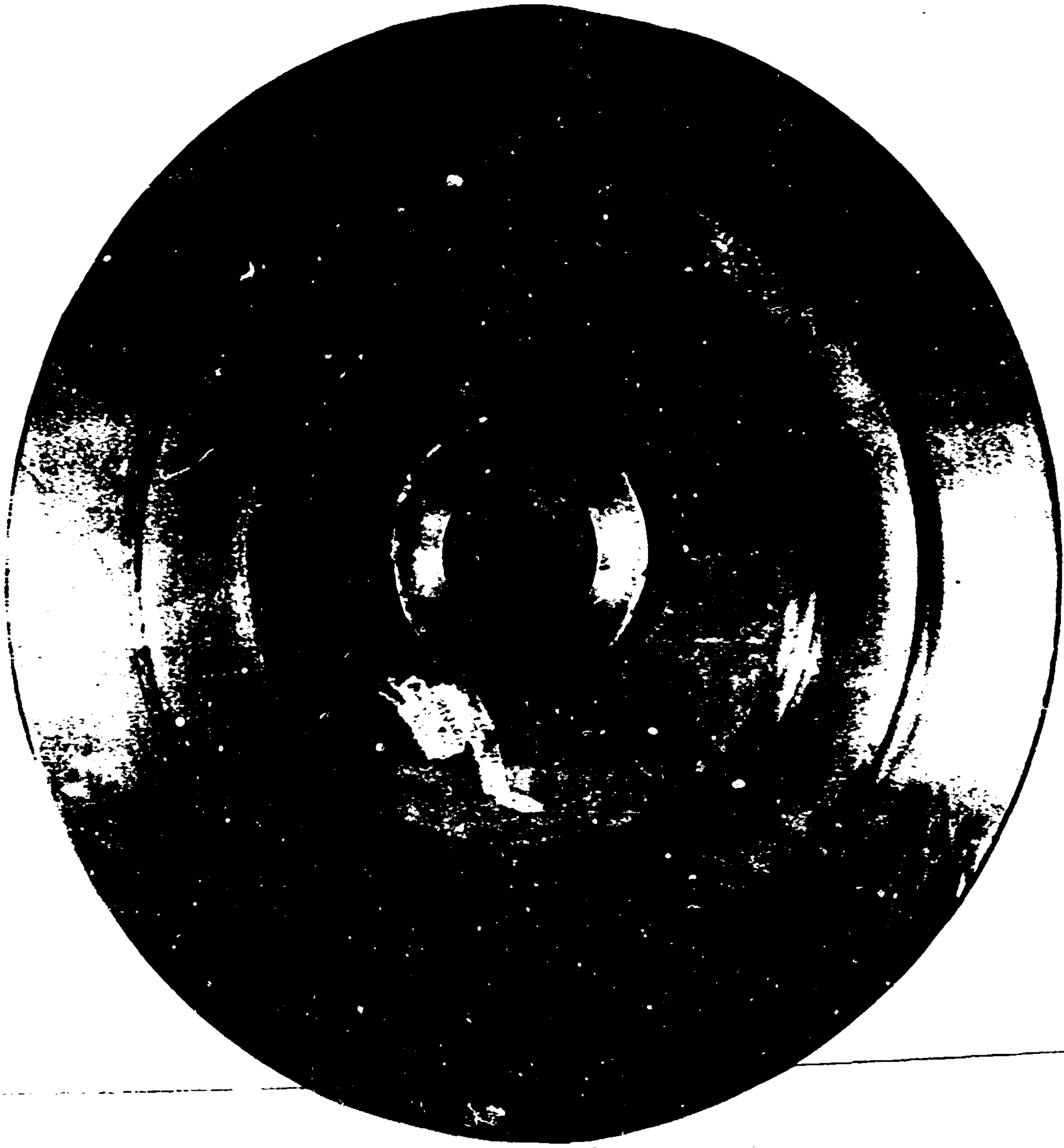

Figure 6. (U) 8429-473001 Injector; Single Coaxial Primary with Modified Showerhead Secondary

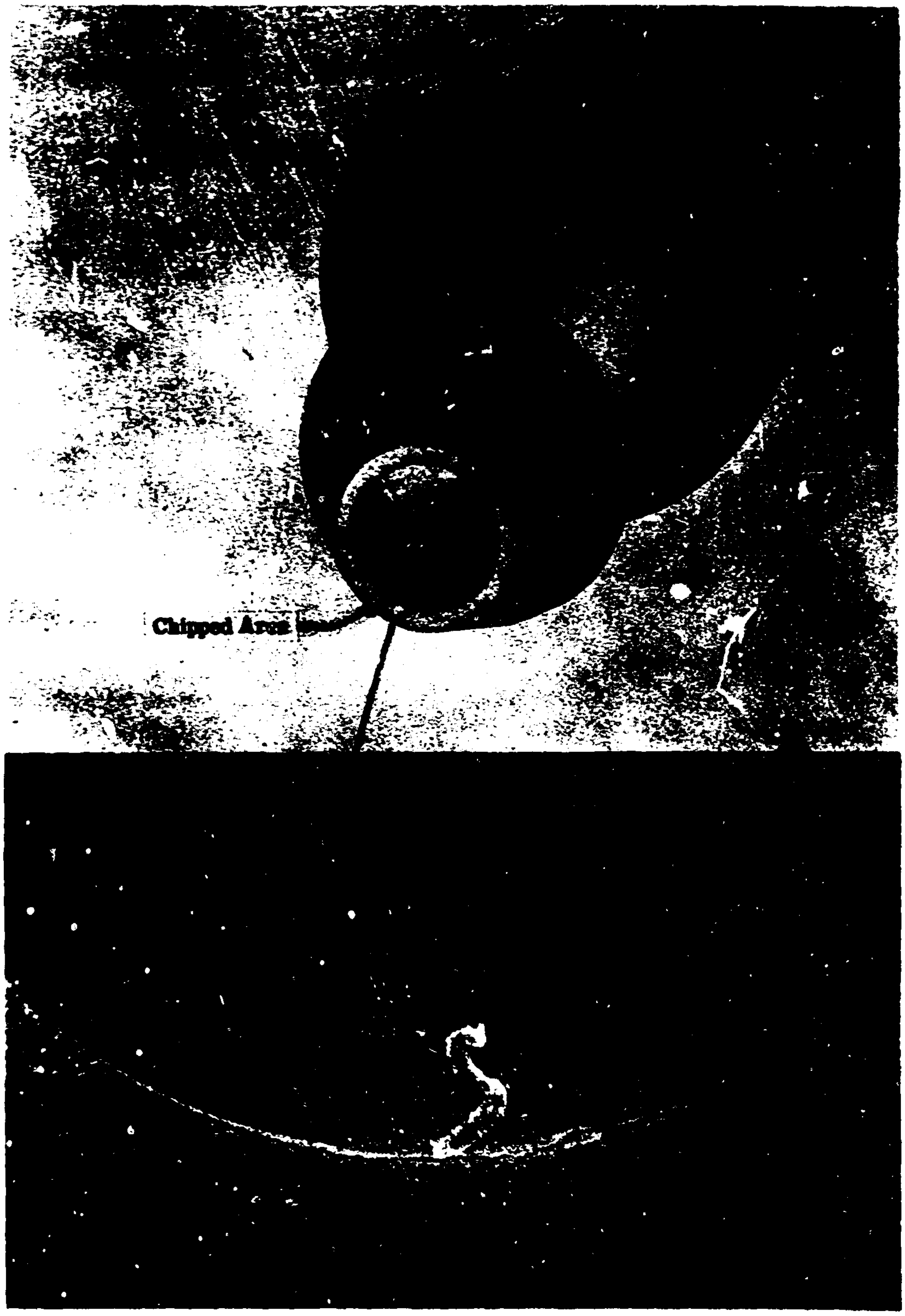

Figure 7. (U) 8429-470001 Thrust Chamber; Tungsten Internal Coating/ Hafnium-Tantalum External Coating (10X View of Discrepant Area)

(U) Start chambers incorporating graphite liners, to be used for injector performance evaluation, were designed and fabricated. A stainless steel chamber extension sized for an additional 15 L* was also completed.

C. (U) BIPROPELLANT VALVE

(U) A review of two vendor design proposals resulted in the selection of Hydraulic Research and Manufacturing Company for the purchase of two valves. Their design incorporates Berylco 440 metal-to-metal seats with a spring loaded feature, which enables good sealing characteristics with a much lower preload. This allows for a smaller torque motor. They have demonstrated a similar design satisfactorily on another program. Monetary and scheduling advantages were also influencing factors.

(U) The design and fabrication of the two valves is approximately 85% complete with a promised delivery date of 15 February 1966.

(U) A heat transfer analysis was conducted to determine heat soakback temperatures to the motor of the valve, in addition to the temperature adjacent to the fuel passages in the injector and the seal temperature between the injector assembly and the thrust chamber. Computer program 1740 was utilized for this analysis.

(U) A duty cycle of 200 seconds firing duration with a 300 second soak period was used in order to impose the worst possible thermal condition.

(U) A sketch of the model is shown in Figure 8 and the time-temperature results are shown in Table II. No problems are anticipated with the torque motor since the allowable temperature is 450°F whereas the maximum run temperature at 200 seconds is 194°F with a soakback temperature of 206°F after 300 seconds.

D. (U) TEST CELL BUILDUP

(U) Buildup of the test cell is approximately 95% complete with a scheduled completion date of 15 February 1966. The oxidizer regulators were received from the vendor with rubber seats. The vendor was notified and the correct copper seats have been forwarded.

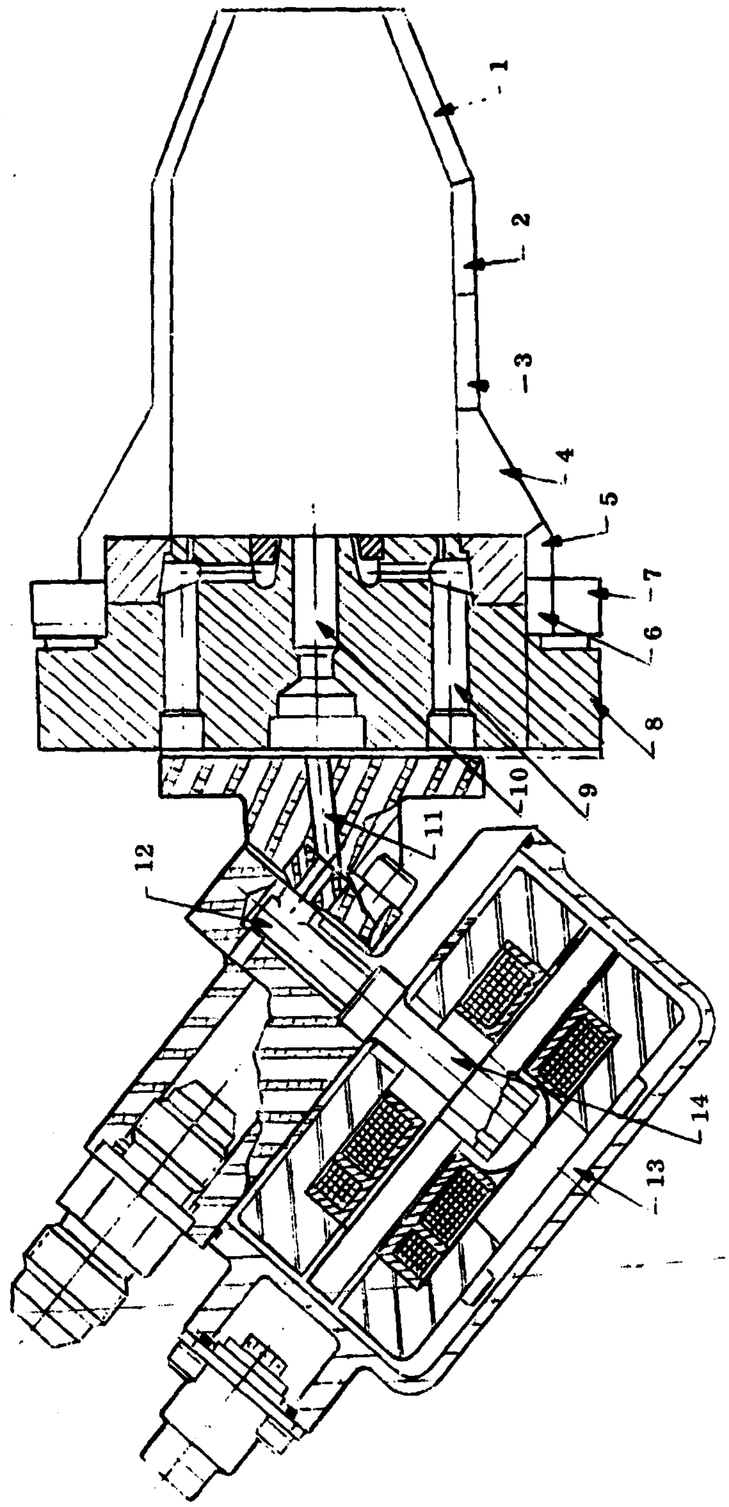

Figure 8. (U) Bipropellant Valve Heat Transfer Model

TABLE II

(U) NODAL TEMPERATURES
HEAT TRANSFER MODEL

Location	Time (sec)	Temperatures (°F)
NODE 2 (Chamber Wall)	50	3060
	100	3060
	200	3060
	300	783
	400	532
	500	433
Seal	50	733
	100	896
	200	930
	300	712
	400	605
	500	525
NODE 9 (Injector Fuel Passage)	50	450
	100	574
	200	603
	300	708
	400	620
	500	540
NODE 14 (Torque Motor)	50	106
	100	143
	200	194
	300	174
	400	187
	500	206

SECTION 4

(C) TASK 2 - ATTITUDE CONTROL SYSTEM UTILIZING MAIN PROPULSION SYSTEM PROPELLANTS

A. (U) SYSTEM DESIGN

1. (U) Transient Analysis

(U) The discharge and suction cycle transient investigations of the oxidizer and fuel systems were completed. Analysis was performed over a range of regulator setpoint pressures and gas stagnation temperatures. The influence of liquid propellant tank pressure and liquid density was determined. The gas actuation pressure buildup and discharge stroke transients were determined while using the digital computer program modified to include Fanno frictional pressure losses of the actuation lines. A 30 millisecond override from the end of bellows motion to opening of the three-way valve path between the actuation chamber and combustor was assumed. This is believed to be a representative tolerance on cycle timing. The gas pressure buildups at the end of bellows motion during this time were manually calculated and were used as input data for the suction cycle. During the suction cycle transient, an equivalent C_d A for the gas lines and components was calculated for each propellant. These were consistent with the prototype injector orificing and the gas lines and components of the test installation. The pressure decay transient to start of bellows movement of the suction stroke and displacement of the bellows were obtained using the computer program. Manual calculations were made to determine the pressure blowdown transients after end of bellows movement on the suction stroke.

(U) The cycle times for various oxidizer and fuel gas conditions are shown in Figure 9. Fuel tank pressure effects were found to be minor. A reduction in oxidizer tank pressure from 125 psia to 100 psia results in less than 35 milliseconds increase in cycle time as represented by a longer suction cycle. As gas stagnation temperature was decreased, cycle time was found to increase. A reduction in regulator setpoint showed only a secondary increase in cycle time. Liquid propellant density also was found to have a minor effect on cycle time. The total time shown in Figure 9 does not include the final tailoff at the end of the suction cycle. This is from the start of subsonic flow to the combustor to minimum pressure in the pump actuation gas chamber. However, since zero time was designated as signal to the three-way valve and opening time is approximately 100 milliseconds, then final tailoff can occur during this time period. It is concluded that all propellant conditions investigated would allow system operation of 1 cps or higher.

(U) It is necessary that the fuel and oxidizer three-way valves be simultaneously actuated at the start of the suction cycle. Otherwise, an excessive lead of one propellant would occur. This would be uneconomical from a weight management and performance standpoint. Therefore, the fuel pressure regulator setpoint

[redacted]

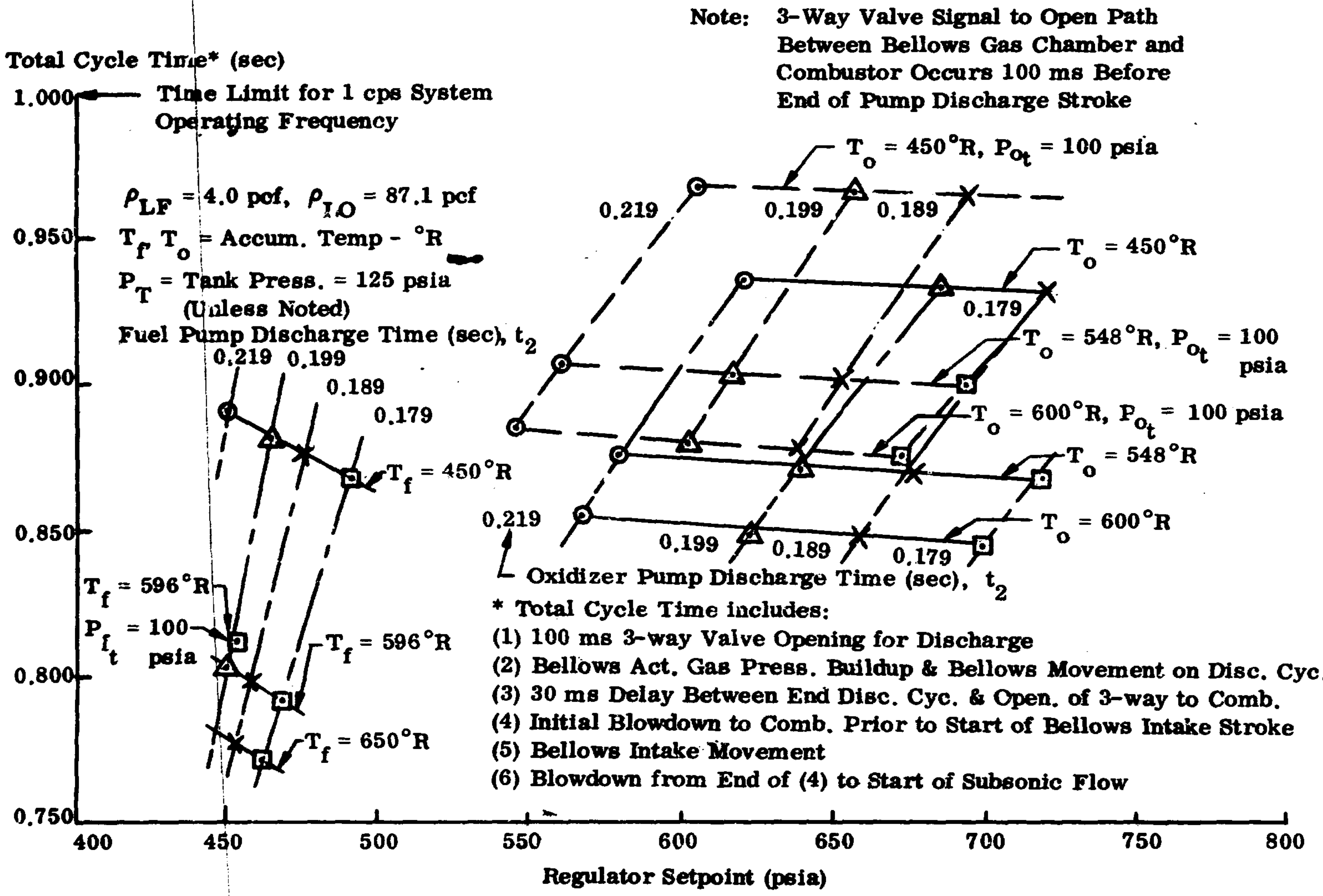

Figure 9. (U) Total Cycle Time for Various Stagnation Temperatures, Regulator Pressures, and Tank Pressures

(U) values shown in Figure 9 are less than the oxidizer values because the fuel pump responds more rapidly than the oxidizer pump on the discharge cycle when compared at identical pressures. The combinations of possible overall mixture ratio values for the combustor gas are shown in Figure 10. It is desired that the combustor mixture ratio and ratio of the liquids pumped be identical to that value at which thrust chamber operation is simulated. The pump inner bellows were sized for a mixture ratio of 8:1 while injecting liquids at saturation temperatures corresponding to 50 psia vapor pressure.

(U) The computer investigation of the displacement of the fuel pump during the suction cycle showed divergence of gas flow rates and pressures during bellows movement. A typical case is represented in Figure 11. Previous computer runs did not show these oscillations. However, for these runs, the fuel suction line and check valve were smaller. The latest cases were consistent with the line and check valve sizes selected for the test installation. However, the line connecting the suction check valve and directed to the bottom of the propellant tank was omitted. It is recommended that this line be 1/2 inch tube and orificed if necessary to allow damping of the fuel pump during bellows intake movement. Other methods such as reducing the diameter of the fuel orifice in the combustor injector manifold or reduction of fuel tank pressure are not recommended because they compromise the flexibility of the system.

B. (U) INJECTION PUMPS

(U) Bell specification control drawings for the oxidizer and fuel pump assemblies were completed and forwarded to the vendor, Sealol. A negotiation meeting was conducted with representatives of Sealol in order to discuss means of reducing costs and improving delivery times. The pacing item was the oxidizer pump which was to be made from Berylco 440. A review of the potential fabrication problems with Berylco at this time and the consideration of the best means of satisfying the feasibility demonstration objective of this program resulted in a mutual agreement to change the material to 347 stainless steel. This is consistent with the fuel pump material and will also result in a considerable cost saving. Although this change has been made, the vendor indicated that Berylco should offer an approximate 20% advantage in cycle life over the 347 stainless steel and any future work toward a prototype flight system should be directed in this direction. A realistic pressure versus bellows length curve, representative of system operation, was provided Sealol for simulation purposes. These values tend to ease the consideration of pressure effect on the bellows during operation since the maximum design peak pressures are experienced only when the bellows are fully compressed. These values can be seen in Figure 12.

(U) The vendor also recommended a satisfactory test program to evaluate the bellows individually to the minimum cycle life specified by Bell, 500 cps, prior to incurring the costs for fabrication of the actual pumps. The program was acceptable, required five weeks to accomplish, and was completed in January.

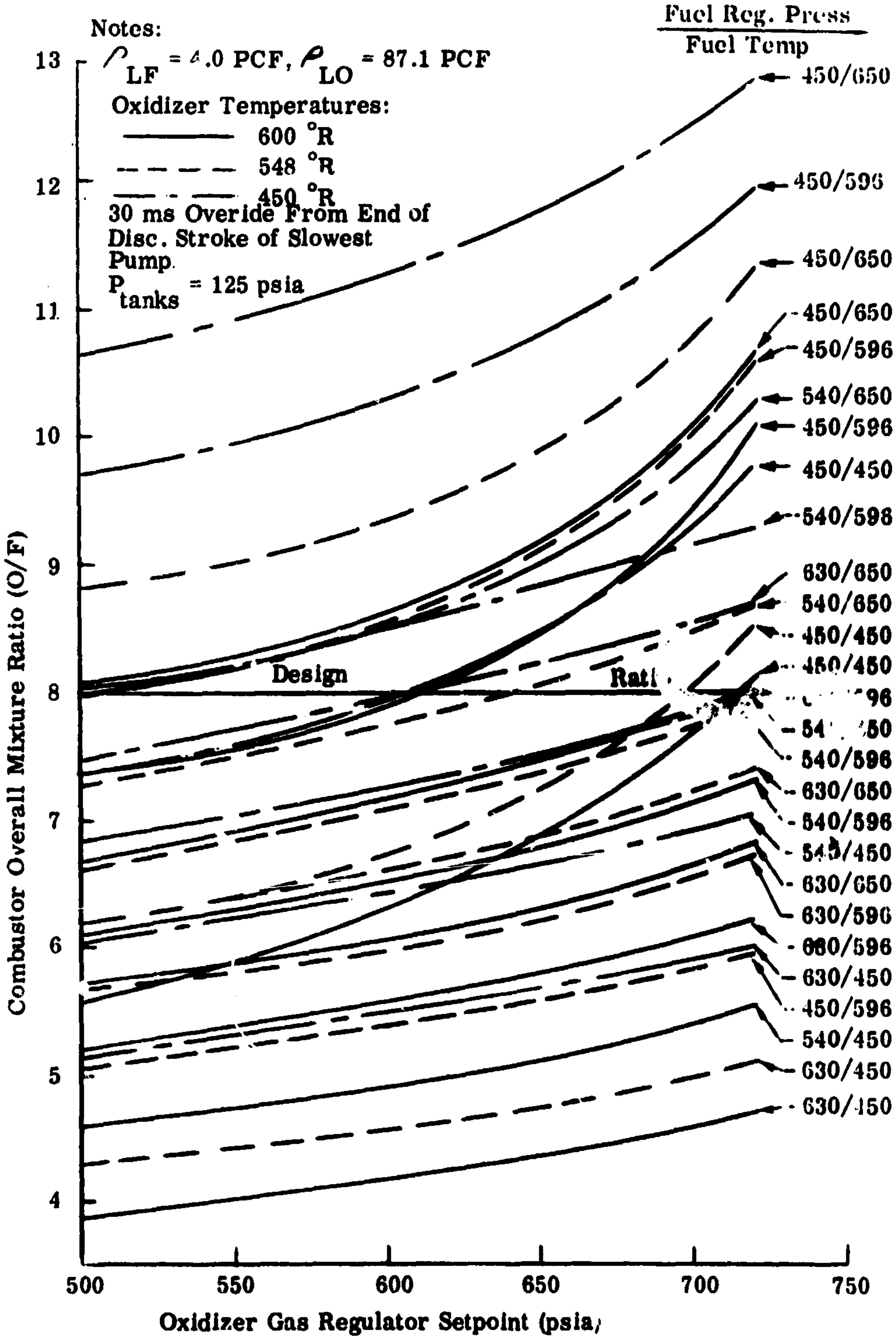

Figure 10. (U) Combustor Overall Mixture Ratio for Various Temperatures and Regulator Pressures

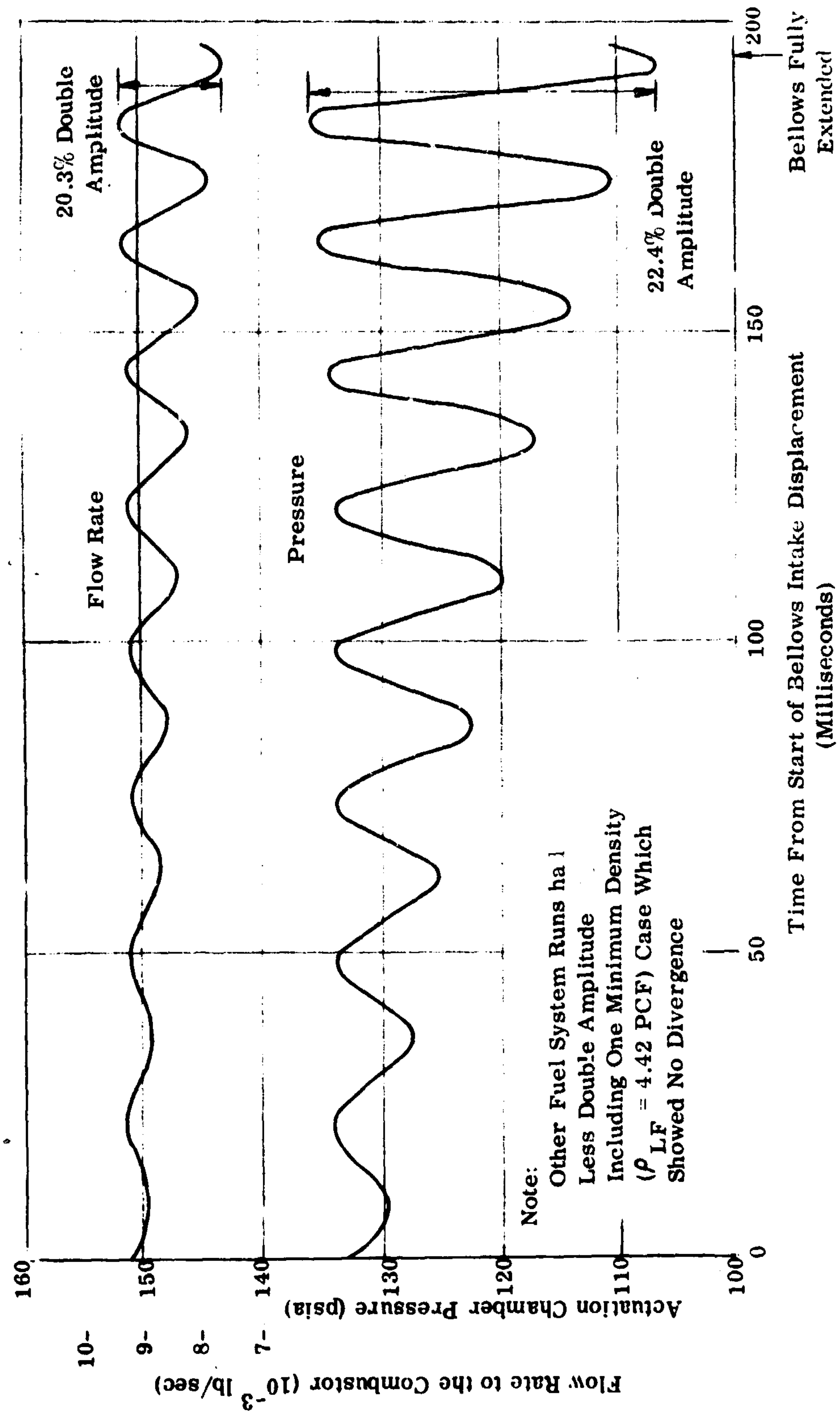

Figure 11. (U) Typical Fuel Gas Pressure and Flow Rate Oscillations During Bellows Suction Displacement

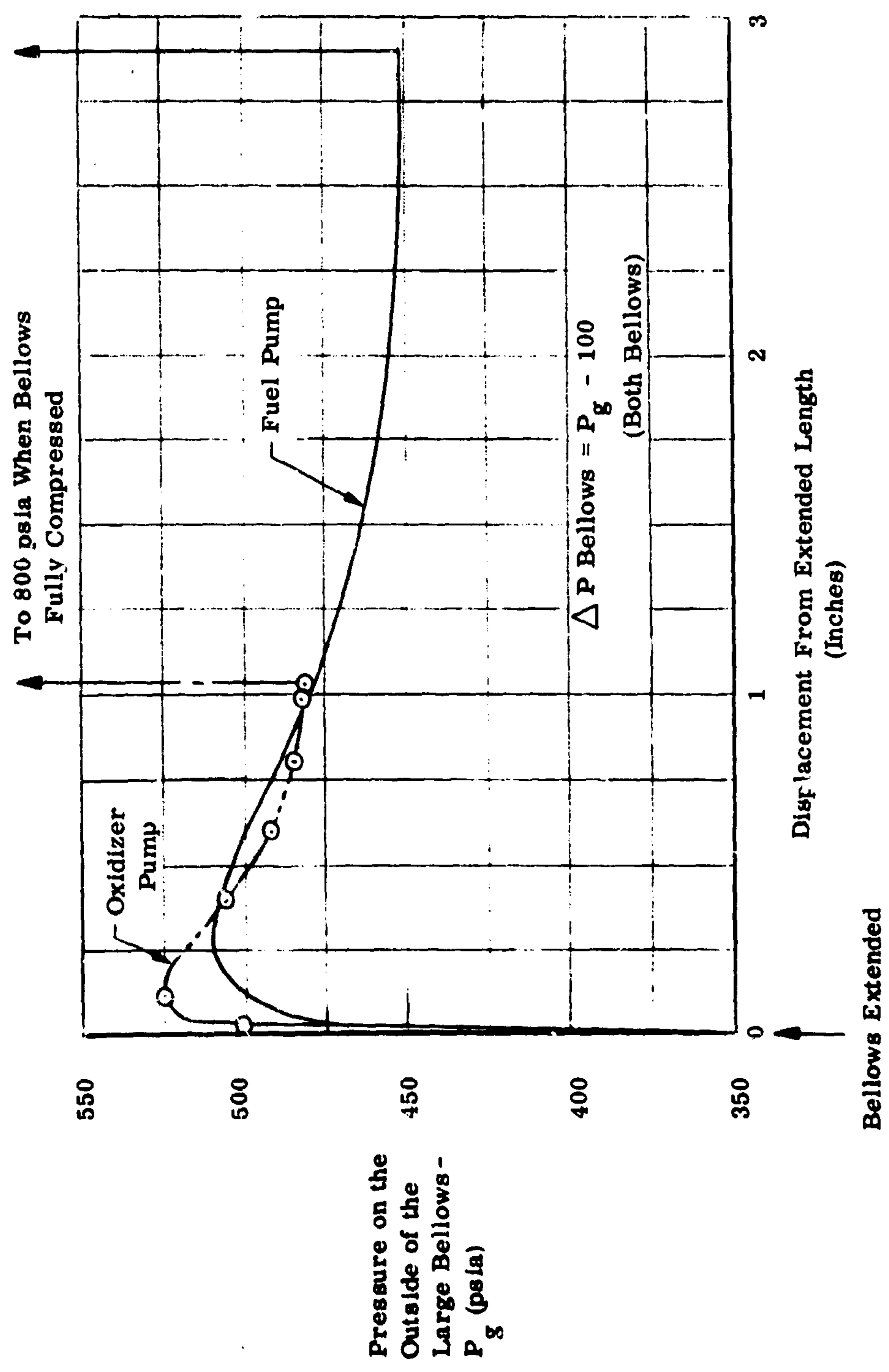

Figure 12. (U) Bellows Maximum Gas Pressure Design Objective

(U) A test bellows simulating the large diameter fuel pump bellows, which is considered to present the most problems because of its length and the possibility of "snaking", was fabricated with suitable end plates for pressurizing and was cycled. A bellows failure was experienced after 318 cycles while trying to achieve the design objective of 500 cycles. The failed section was subjected to a thorough examination and no apparent weld or material discrepancies were detected.

(U) Although the design objective of 500 cycles was not achieved, the 318 cycles obtained with the most critical component was considered sufficient justification for ordering the actual pumps. The possibility of ordering replacement bellows, if required, during system testing was pointed out by Sealol. The 318 cycles demonstrated also represents greater than one-third of the attitude control system total impulse requirement, which appears more than adequate for feasibility demonstration of the concept at this time.

(U) Coordination with Sealol with respect to required drawing changes to order the pumps has been made and the changes have been incorporated. Sealol has agreed to a 275 minimum cycle requirements. An eight-week delivery time is required for pump fabrication.

(U) A description of the test setup and the testing sequence is as follows.

1. (U) Test Setup

(U) A schematic of the test setup can be seen in Figure 13 and a photograph of the setup can be seen in Figure 15.

(U) The bellows was installed in a pressure cylinder and was attached to the actuating piston by a threaded connection in the bellows top flange. O-ring seals, between the lower bellows flange and pressure cylinder, were used to prevent leakage and/or loss of pressure when compressing the bellows. Nitrogen gas, fed through a 1/2 in. line, regulator and a two-way solenoid valve, was used to pressurize the bellows in the compression stroke. A two-way solenoid was used to vent the bellows actuation chamber. A Hanna Co. air cylinder was used to extend the bellows from the compression mode. Attached to the air cylinder piston rod was a small bracket which actuated a microswitch to trigger a counter to record the cycles.

2. (U) Test Sequence

(U) Shop air was allowed to enter the air cylinder and extend the bellows. Nitrogen gas was then allowed to enter the bellows chamber at 400 psig through a two-way solenoid. The three-way vent solenoid would then be actuated in order to vent the air cylinder piston chamber, thereby allowing the pressure in the bellows chamber to compress the bellows. This extension and compression of the bellows was considered as one cycle. The bellows chamber was then vented through the two-way vent solenoid and the sequence described above was repeated for each cycle.

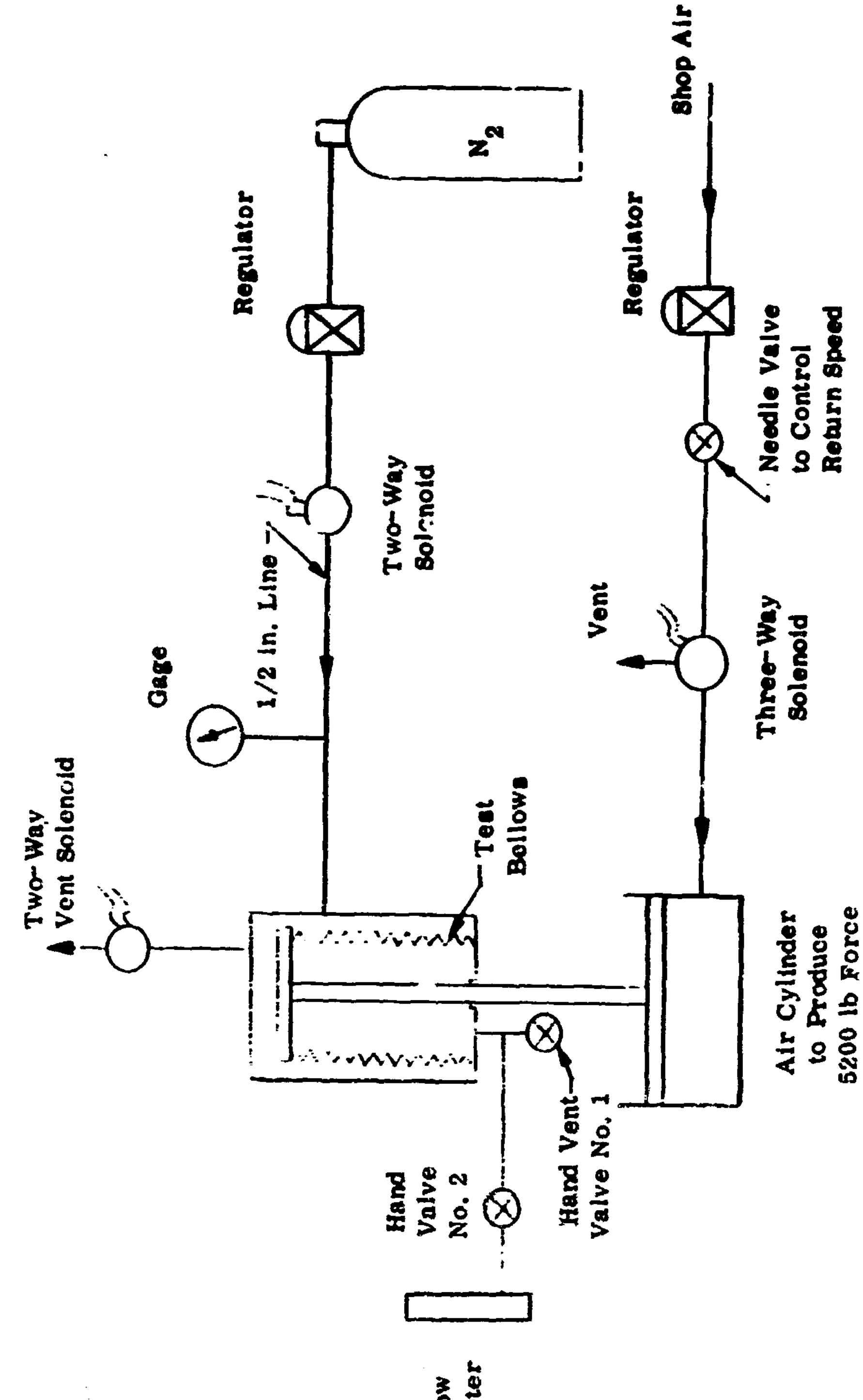

Figure 13. (U) Test Schematic, Test Bellows

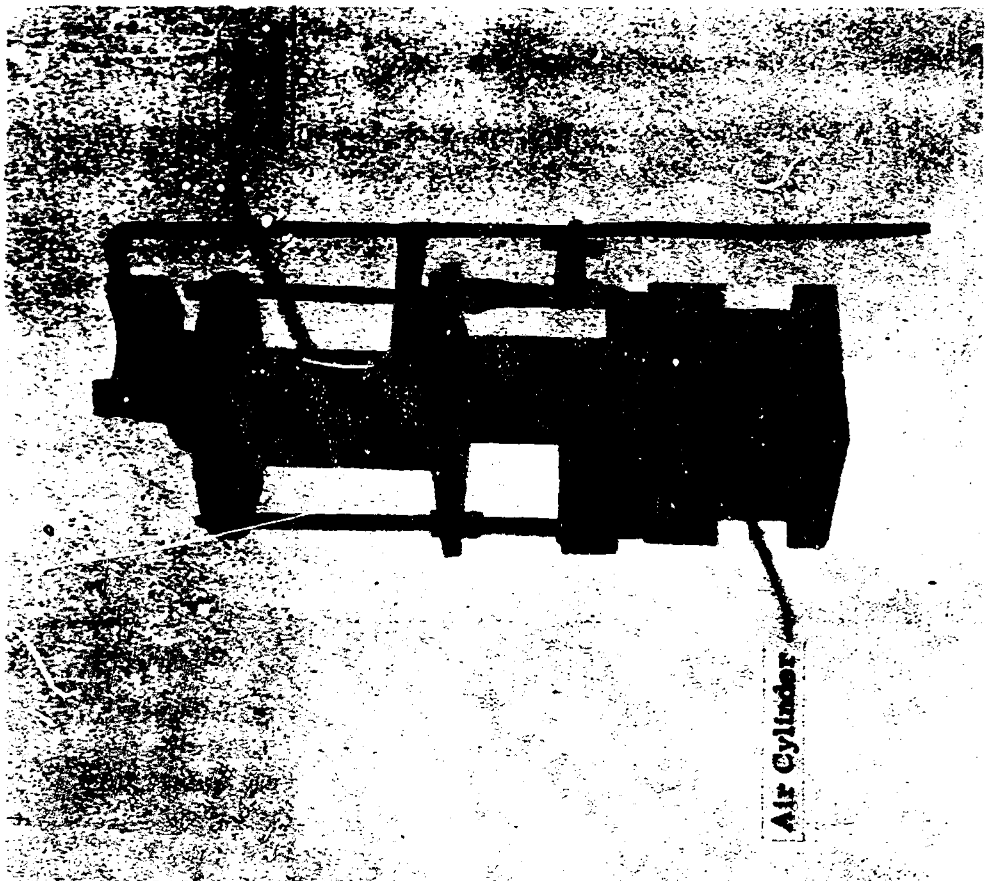

Figure 15. (U) Test Bellows Test Setup

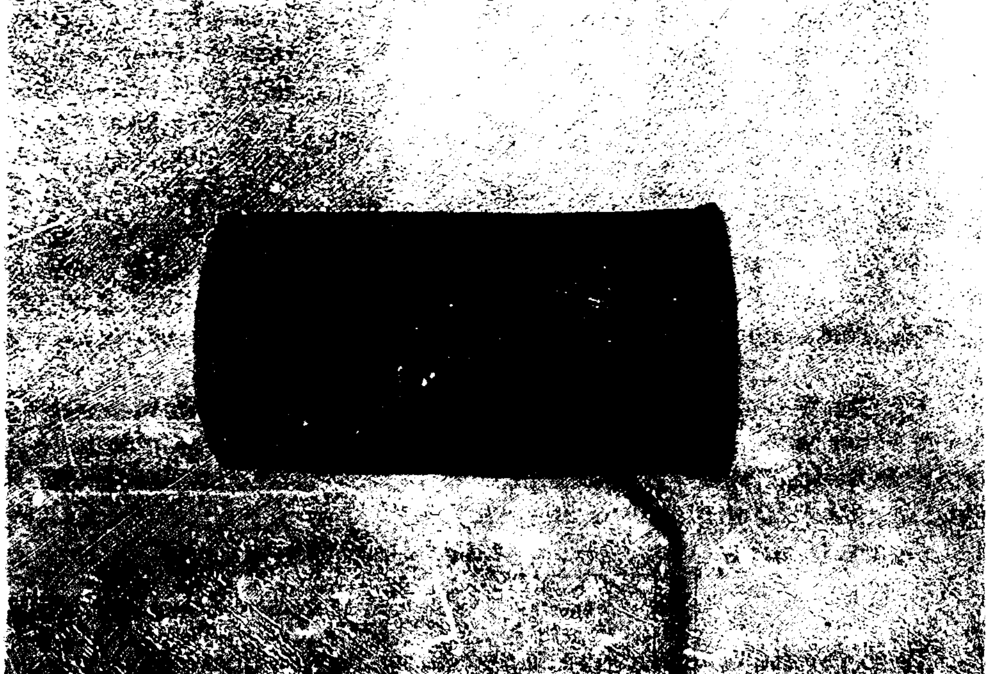

Figure 14. (U) Test Bellows

(U) The bellows was leak checked every 25th cycle by extending the bellows with the air cylinder, applying the 400 psig N_2 pressure in the bellows chamber, closing hand vent valve No. 1, and opening hand valve No. 2 to the flow meter, which was a low volume flow type flow meter.

(U) A tabulation of the cycling accomplished in the bellows can be seen in Table III.

(U) The bellows was removed from the chamber after the leak was detected and was installed in a Veecco vacuum tester. A vacuum could not be maintained in the internal volume of the bellows verifying a bellows failure. A photograph of the bellows with an indication of the failure area can be seen in Figure 14.

TABLE III

(U) BELLOWS CYCLING TABULATION

psig Pressure	Number of Cycles	Remarks
150	9	For Test Setup
150	29	For Test Setup
400	71	For Equip. Adj.
400	89	For Equip. Adj.
400	110	Leak Checked. Bellows OK
400	137	Leak Checked. Bellows OK
400	164	Leak Checked. Bellows OK
400	189	Leak Checked. Bellows OK
400	214	Leak Checked. Bellows OK
400	239	Leak Checked. Bellows OK
400	264	Leak Checked. Bellows OK
400	289	Leak Checked. Bellows OK
400	314	Leak Checked. Bellows OK
400	318	Gas Leakage Noted

3. (U) Test Analysis

(U) The bellows was sectioned to determine the actual failure mode. A break was noted at the edge of one of the inner weld beads approximately two-thirds from the bellows head. As noted previously, no apparent discrepancies could be detected in either the material or the weld. A 3X view of the failed area can be seen in Figure 16 and a cross-section of the failed convolution can be seen in Figure 17.

(U) A portion of the bellows is also being utilized to establish cleaning procedures to be used during fabrication of the oxidizer pump.

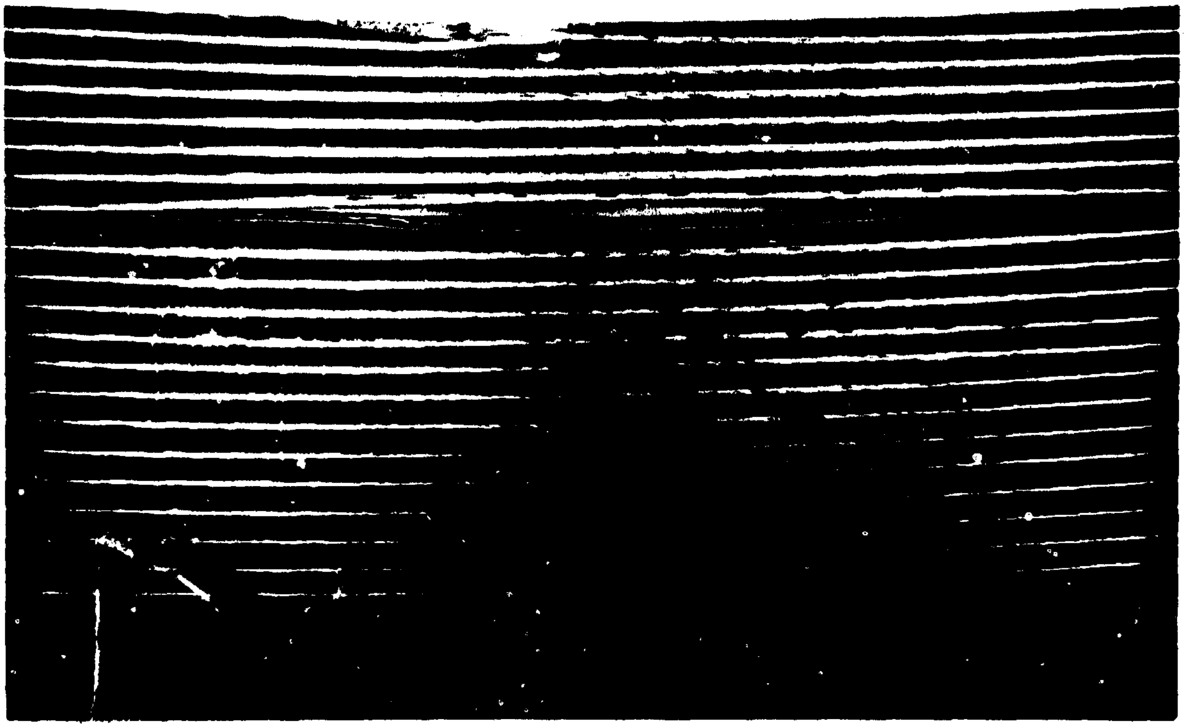

Figure 16. (U) 3X View of Bellows Failure

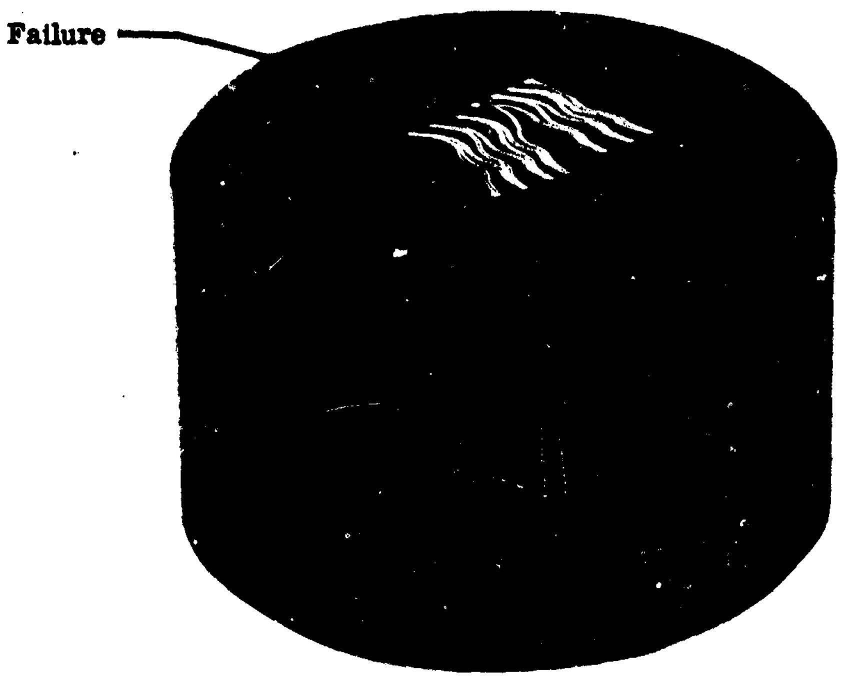

Figure 17. (U) 3X Cross-Section of Bellows Failure

C. (C) HEAT EXCHANGER

(U) Numerous heat exchanger concepts were evaluated with respect to single-pass flow, double-pass flow, segmented chamber for the two propellants versus a series configuration for individual propellants, tradeoffs between chamber diameter and length required. A configuration which would result in the best propellant temperature rise response time was desired.

(U) In order to facilitate the design selection, the chamber diameter was fixed at 1.5 inches to correspond to the Task 1 thrust chamber size. This allows for the use of the Task 1 injectors for this application A flow analysis of the Task 1 injectors was made and approximately the same ΔP and injection velocities exist based on steady state flow conditions.

(C) With the chamber diameter fixed and the required heating rate established for each propellant, 59 BTU/cycle for the hydrogen and 51 BTU/cycle for the fluorine, the required heat exchanger lengths were established as 22 inches for the fluorine and 16 inches for the hydrogen. The two-pass configuration served to provide the best propellant temperature rise times. It is possible to place thirty 1/8 inch diameter holes around the chamber based on a 0.05 inch wall thickness allowance using 304L stainless steel. Therefore, for two-pass flow, fifteen 1/8 inch diameter holes are utilized for each pass with adequate manifolding for inlet and outlet provisions. The propellant temperatures reach 95% of the desired outlet temperatures in approximately five seconds.

(U) Detail chamber drawings for the heat exchangers showing the required drilling patterns were completed and released for fabrication at Twentieth Century Machine Company, in Utica, Michigan. Delivery of these chambers is scheduled for 18 February 1966.

(U) Drawings for the additional heat exchanger details; flanges, manifold covers, water cooled nozzle and bipropellant valve adapter for the injector, were also completed, released for fabrication and have been completed.

D. (U) SYSTEM INSTALLATION

(U) A final schematic of the test system and a list of instrumentation requirements were completed. A decision was made to use two Victor regulators (P/N GD30R-S8A8Z) modified for fluorine service for actuation gas control. The parallel arrangement is required to meet the demand on the discharge cycle while simultaneously simulating thrust chamber operation.

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Rocket Propulsion Laboratory Research and Technology Division Air Force Systems Command

13. ABSTRACT

(U) The second quarterly period was devoted to accomplishing the following work for the respective tasks:

(U) Task 1 - Summarizing the results of the material test program, completing injector and thrust chamber designs, fabrication of the injectors, fabrication of the thrust chambers, design and fabrication of the bipropellant valves, and test cell buildup.

(U) Task 2 - Completion of system transient analyses, design of the bellows pumps, completion of a bellows test program, heat exchanger design and fabrication, and system test installation coordination.

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