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Thomas W. Haag, Frank M. Curran

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Thomas W. Haag and Frank M. Curran
Lewis Research Center
Cleveland, Ohio

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ARCJET STARTING RELIABILITY: A MULTISTART TEST ON HYDROGEN/NITROGEN MIXTURES

Thomas W. Haag and Frank M. Curran
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

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Abstract

An arcjet starting reliability test was performed to investigate one feasibility issue in the use of arcjets on board a satellite for north-south stationkeeping. A 1 kW arcjet was run on hydrogen/nitrogen gas mixtures simulating decomposed hydrazine. A pulse width modulated power supply with an integral high voltage starting pulser was used for arc ignition and steady-state operation. The test was performed in four phases in order to determine if starting characteristics changed as a result of long term thruster operation. More than 300 successful starts were accumulated over an operating time of 18 hr. Overall results indicate that there is a link between starting characteristics and long term thruster operation; however, the large number of starts had no effect on steady-state performance.

Introduction

Demands for increased specific impulse propulsion on modern communications satellites have led to reevaluation of the role of arcjets. The data base accumulated at the 1 and 2 kW power levels through government-sponsored programs in the late 1950's and early 1960's centered mainly on operation with hydrogen.[1] Efforts to operate a first-generation 1 kW arcjet on propellants other than hydrogen met with little success.[1] Current research indicates that specific impulse levels well above 400 sec are attainable with hydrazine.[2] This makes the arcjet a very attractive candidate to succeed resistojet and low-thrust chemical propulsion, currently in use for geosynchronous stationkeeping of communications satellites. This succession, however, is dependent on the resolution of issues concerning the practical application of the arcjet. A typical mission will involve literally hundreds of starting cycles. Development of a reliable starting procedure is therefore critical to the application of this thruster.

Many procedures have been used to ignite arcjet thrusters. In one common technique,[3] the discharge was initiated with a moderate open circuit voltage in an easily ionized gas such as argon or neon. The propellant of choice was then blended in and the starting gas reduced, until full transition to steady-state operation with the desired propellant was achieved. This approach decreases the high voltage required for breakdown and is a convenient laboratory technique. The complication of managing an additional propellant for arc ignition, however, presents obvious problems for satellite application.

A drawn arc concept was used in the 1 kW arcjet designed by the Plasmadyne Corp.[4] In this technique the current was initiated with the electrodes in contact, and then the electrodes are pneumatically separated as propellant flow is established.[4] This method simplifies electrical requirements but complicates the mechanical design of the arcjet. In addition, as cathode and anode erosion will certainly affect electrode contact, the reliability of this method cannot be guaranteed.

In a third, often used, method the open circuit voltage was simply set at a high enough level to cause Paschen breakdown of the propellant. This technique was used to start a 2 kW Plasmadyne thruster which was life tested for 150 hr in 1963.[5] At full propellant flow this method requires a power supply capable of thousands of volts and increases the weight and complexity of the system.

In a more recent test[6] of a modified version of the 1 kW Plasmadyne thruster the high voltage requirement was reduced by lowering the propellant flow rate, and consequently the inter-electrode pressure. In that test, large current and voltage transients accompanied startup, and transition to a steady-state occurred slowly, causing significant damage to the anode.

Since that test, the 1 kW class arcjet and its associated power supply have undergone significant development under NASA contract and in-house efforts. The power supply design includes both a starting circuit that provides brief high voltage pulses to initiate the discharge and a main output circuit for rapid current regulation during steady-state operation.[7] The thruster incorporates strong vortex flow stabilization to force the arc rapidly into a steady-state condition.

The major objective of this experimental work is to demonstrate reliable, repeatable starting of the new vortex stabilized arcjet using a well regulated, pulse width modulated power supply. The total number of starts achieved was ~300, which is on the same order as would be expected in normal stationkeeping applications. Since mission application of arcjet thrusters would require utilization of storable propellants, this experimental work was conducted with an arcjet operating on hydrogen-nitrogen gas mixtures to simulate fully decomposed hydrazine.

The first portion of this paper gives a description of the experimental apparatus and facilities, along with chronology of the arcjet starting reliability test. The major portion of this paper focuses on experimental results and observations regarding starting quality and transition to steady-state operation. Arcjet starting characteristics as a function of electrode condition, propellant flow rate, and length of operation are discussed in detail. Suggestions for future research are also proposed.

Apparatus

Thruster

The arcjet thruster used in these tests was a conventionally constricted, vortex-stabilized design (Fig. 1). A thoriated tungsten insert with a constrictor 0.64 mm in diameter and 0.25 mm in length served a dual purpose as both anode and expansion nozzle. Its diverging angle was 20°, with an area ratio of ~150. The cathode consisted of a 3.2 mm diameter thoriated tungsten rod tapered to a 25° half angle at the tip. It was anchored in position by a modified Swagelok fitting held into the rear insulator. Vortex stabilization was accomplished by two 0.25 mm diameter holes separated by 180° injecting gas tangentially into a 6.4 mm diameter arc chamber. With this design, all propellant was directed through these tangential holes in order to maximize vortex intensity.

The anode, cathode, and injection disk were contained inside a stainless steel anode housing. The walls of the housing served as a radiant heat sink through which the propellant and anode current were passed. A rear insulator was bolted to the anode housing to compress the internal arrangement into a gas tight assembly.

The arc gap was set by withdrawing the cathode rod out the back of the thruster assembly to a predetermined distance. The rear Swagelok fitting was then tightened, securing the cathode in position.

Vacuum Facility

All tests involving thrust measurement were performed in the Tank 8 vacuum facility at the Lewis Research Center.[3] This tank is 1.5 m in diameter, 5 m long, and serviced by four 30 000 liter/min oil diffusion pumps. Pumping speeds were such that during maximum propellant flow (typically 0.045 g/sec), the ambient vacuum conditions never exceeded 4×10^{-4} torr. The arcjet to be tested was located within a 0.9 m diameter by 0.9 m long port extension at one end of the tank. This gave the thruster unobstructed access to the main tank during operation but also allowed for port isolation with a 0.9 m gate valve.

Additional thruster operation was carried out in a 0.46 m vertical bell jar facility (Fig. 2), with the exhaust jet directed downward. This vessel was serviced by a 20 000 liter/min mechanical roughing pump which could maintain vacuum conditions of ~0.5 torr under maximum propellant flow rates. Experimental data obtained in this facility were identical to those obtained in Tank 8, with the exception being a lack of thrust measurement.

Propellant Feed System

Propellant supplied to the arcjet thruster consisted of hydrogen and nitrogen gas mixtures at a ratio equal to that of fully decomposed hydrazine. The two gases were stored separately and each regulated down to 1.0 MPa for final metering and mixing in a propellant flow panel.

At the Tank 8 facility, propellant flow measurements were made using thermal laminar flow type transducers and were displayed on the flow panel with digital readouts. Each transducer had a full scale flow output of 5.00 standard liters/min (SLPM). Final gas flow rates were controlled with precision needle valves adjusted manually. Simulated decomposed hydrazine required a 2:1 standard volume ratio of hydrogen to nitrogen. The two gases were mixed and sent through the thrust stand by a flexible feed tube.

At the bell jar facility, propellant flow was measured and metered by an automated mass flow controller. The desired flow rate for each gas was dialed into the unit, which maintained the specified output through a feedback control loop.

An important part of both propellant flow systems was a sonic orifice in the gas line immediately upstream of the arcjet (Fig. 1). This orifice prevented flow rate transients due to arc ignition from propagating upstream through the flow system. Without this type of isolation, mass flow through the arc would be temporarily reduced while the entire flow system built up pressure. The sonic orifice allowed for a fast pressure response during starting and permitted rapid transition to steady-state thruster operation, usually within a fraction of a second.

Thrust Stand

Thrust measurements were performed using a calibrated displacement type thrust stand (Fig. 3). The arcjet was mounted on a movable fixture and supported by an up-right flexure arrangement. Displacement was measured with a linear variable differential transformer (LVDT) over an active range of 5 mm. With this design, friction forces were very small and resulted in no measurable hysteresis. This desirable characteristic, however, resulted in a requirement for motion damping. An active damping system was used in which an analog time derivative of the displacement signal was sent through an electric forcing coil to resist thrust stand motion. Damping forces were only needed during transient conditions of startup and termination. Although facility vibrations were continually present, their amplitude was two orders of magnitude less than full-scale thrust stand displacement, and did not require filtering of the thrust output signal.

In order to prevent thermal drift, cooling water was channeled through vulnerable parts of the trust stand assembly. The arcjet mounting column was fabricated from a coil of brazed tubing in which water was supplied through a flexible feed tube arrangement. Thermal radiation from the thruster was blocked by a water-cooled enclosure which surrounded the entire assembly. As a result of these precautions, thermal drift in thrust measurement was not detected during the test.

Electrical power to the arcjet was supplied by two electrically insulated wires which hung down from inside the vacuum vessel. Because the restoring force of the thrust stand resulted from a combined effect of support flexures, propellant tubes, water circulation tubes, and gravitational effects, it was necessary to establish the slope and zero of the thrust signal prior to each test run. The thrust stand could be calibrated in place and under vacuum conditions within 2 min. This was carried out by loading the device with free-hanging weights attached to a fine, monofilament thread. The 4 g weights were lowered using a windlass and pulley arrangement identical to that used in Ref. 3. This calibration technique proved repeatable to within 1 percent, and simple to use. Figure 4 displays the arcjet and thrust stand in the Tank 8 vacuum facility.

Power Supply

A pulse width modulated power supply with fast current regulation was used throughout the tests.[7] Open circuit voltage of this unit was 180 Vdc and its maximum current output was 12 A. A unique capability of this power supply was a built-in high voltage, starting pulse generator. This starting circuit could produce a 4 kV pulse once every second until arc ignition was achieved.

The high voltage starting pulse was produced across the power supply output inductor. A low voltage winding was used to build up magnetic flux in the inductor, such that when current was interrupted a high voltage pulse was emitted from the output. Figure 5 shows an open circuit voltage trace of a single starting pulse on an oscilloscope.

Once Paschen breakdown is achieved, the main power supply takes over to sustain the arc and the pulser circuit stops when positive current is detected. While very high voltages can be obtained with the starting circuit, total energy content of each pulse is too small to cause arcjet electrode damage.

Data Recording

Experimental data obtained include arc voltage, current, thrust, propellant flow rates, and inlet pressure. These signals were recorded on an eight channel chart recorder with a frequency response capability of 150 Hz. An analog storage oscilloscope with differential inputs was used to observe high speed voltage and current transients.

A 100 V Zener diode was used in conjunction with a resistive voltage divider to block high-voltage pulses from the chart recorder input. Cross-channel noise problems were prevented through the use of isolation amplifiers and shielded cable.

Experimental Procedure

Because arcjet electrodes may be subject to considerable erosion over their useful life, it was decided that a starting reliability test should reflect the changing characteristics an individual thruster may exhibit. The starting reliability test was carried out in four phases, as illustrated in Fig. 6. Each phase examined the starting characteristics of an arcjet after increasingly longer periods of operation. The first phase compared starting characteristics of a new arcjet before and after 10 min of operation. The second phase accumulated 30 min of steady operation, and the third and fourth phases included 1 hr, and 10 hr, respectively.

Each test phase was divided into three parts. The first part of each phase was a series of short reference starts. Each individual start usually lasted about 10 sec, or until arc stabilization was achieved. There were typically 15 to 40 starting attempts made during this part of each phase.

The second part of each phase was a burn-in operation of the arcjet. The length of the burn-in was dependent on the particular test phase. As mentioned previously, Phases 1 through 4 were distinguished by burn-in times of 10 min, 30 min, 1 hr, and 10 hr, respectively. Thrust measurements were taken mainly to ensure that there were no major deviations in arcjet performance. At the conclusion of each burn-in, the thruster was cooled convectively by continuing to flow unheated propellant after the arc had been extinguished.

The third part of each phase was a second series of short starts to determine the marginal effect caused by the burn-in. These starts were intended to verify any degradation in starting characteristics due to electrode erosion.

At the conclusion of each phase, the thruster was disassembled, inspected, and then reassembled without alteration. The purpose of this was to provide data for a companion report, where detailed photographs of the electrodes and discussion of surface damage can be found.[8]

One hour prior to taking data, all electronic equipment was turned on and allowed to warm up. The thrust stand was calibrated by cycling the weights to establish a thrust zero and slope. Once this had been accomplished, gas was metered at a 2:1 hydrogen/nitrogen ratio for the desired mass flow rate. Typical mass flow rates ranged from 0.0337 to 0.045 g/sec. When steady flow rates were obtained, the data recording system was turned on and the power supply was activated. As described previously, a high-voltage pulse was applied to the thruster electrodes once every second until arc ignition was achieved. For a short start, the arc was maintained about 10 sec before the power supply was turned off, extinguishing the arc. The thruster was allowed to cool for about 3 min until the next starting attempt. Because of this light-duty cycle, it was found that the thruster body temperature usually leveled off at about 65 °C between starts.

Results

In the first phase of testing the thruster was operated for 42 short starts followed by a 10 min burn-in period. Flow rates were maintained at 0.0337 g/sec throughout and the arc current was nominally set to 10 A. For the very first start, a 0.21 mm orifice was placed in the propellant line just upstream of the thruster, and the arc gap was set to 0.51 mm. The cathode was new and the anode was recently reconditioned.[8]

When the power supply was activated the arc ignited immediately upon the first high-voltage pulse and stabilized at 60 V for the 10 sec run. This start was followed by four additional starts which responded similarly. Beginning with the sixth start, however, voltage traces during thruster operation became noticeably rough. Thrust levels for all of these starts were lower than expected and a leaking propellant line was found to be the cause. In order to avoid further gas leaks, the propellant system back pressure was reduced by increasing the sonic orifice diameter from 0.21 to 0.25 mm. It was also decided that increasing the arc gap to 0.59 mm might increase arc voltage.

With the next start the arc voltage came up to 70 Vdc, as can be seen in Fig. 7(a). The voltage trace, however, was not as smooth as the initial starts. After eight more starts the voltage excursions subsided and each successive start was very smooth.

Figure 7(b) displays an ideal arcjet start. Flow rates were preset to 1.5 SLPM nitrogen and 3.0 SLPM hydrogen, resulting in a mass flow rate of 0.0337 g/sec. The voltage trace of the start indicates smooth and rapid transition of the arc to steady-state operation. When the power supply was activated an open circuit voltage of 180 Vdc was present. One second later a high-voltage pulse ignited the arc and stable voltage of 74 Vdc was established within a fraction of a second. Because the power supply had very fast current regulation, the current trace was essentially a step function during thruster operation. Arcjet thrust increased from 39 mN (cold flow) to 113 mN within 1 sec of ignition, which corresponded to a specific impulse (Isp) of 118 and 342 sec, respectively. Overshoot seen on the chart recording was a characteristic of the thrust stand and not the thruster.

A 10 min burn-in began with a smooth voltage trace at 74 Vdc. By the end of 10 min, the voltage had risen to 88 Vdc and the Isp had reached 400 sec. The thruster ran flawlessly and was allowed to cool to room temperature before further starting attempts.

The 10 min burn-in was followed by seven short starts. The first start began at 72 Vdc but fluctuated with a ticking behavior seen in Fig. 8(a). The voltage then stepped up to 78 Vdc where smooth operation proceeded. Three following starts behaved similarly but each one stabilized progressively sooner.

On the fifth start following the burn-in, flow was increased to 0.045 g/sec to determine its effect on arc stabilization. Arc voltage increased to 82 V quickly and remained stable (Fig. 8(b)). Ten starts were conducted at this higher flow rate and all had smooth voltage traces. The flow rate was then returned to 0.0337 g/sec and smooth starts continued.

Phase 2 of the testing included seven initial short starts followed by a 30 min burn-in. Starting was smooth and the thruster again ran flawlessly. Voltage at the end of 30 min was 97 Vdc and the Isp was 407 sec.

After a cooling period, mass flow was set to 0.0337 g/sec and the arcjet was started. This particular start was unusually rough in that voltage excursions were larger than had been seen before and lasted for 20 sec after ignition before stabilizing (Fig. 9(a)). Each subsequent start, as in Phase 1, stabilized progressively sooner. By the fifth start, smooth voltage traces had returned (Fig. 9(b)).

After 10 starts the thruster was removed from the facility and dismantled for a first inspection of the electrodes. The tip of the cathode was slightly blunted but no unusual damage was observed.[8] While some mechanical variation was inevitable, care was taken to reassemble the thruster as close as possible to its previous condition.

Phase 3 of the test involved a 1 hr burn-in, which brought the accumulated operating time to over 100 min. The first short starts after reassembly were to verify repeatability of the thruster. Due to facility problems with diffusion pumps, the maximum mass flow rate permissible at that time was 0.031 g/sec, which was lower than previous starting attempts. The starts were rougher than before and only improved slightly after ten starting attempts. When the facility pumping problem was corrected, flow rates were increased to 0.045 g/sec and smooth operation returned.

A 1 hr burn-in was then performed in which the thruster operated smoothly throughout. This time the flow rate was 0.045 g/sec and corresponding Isp was 363 sec.

Subsequent starts after the burn-in were conducted with this higher flow rate. While fluctuations in arc voltage lasted only a few seconds, the excursions did not subside with following starts as they had before. This was the first time where higher flow rates did not produce smooth starts (Figs. 10(a) and (b)).

The thruster was removed for the second disassembly and inspection. It was noticed that the cathode was visibly off-center, which might account for the poorer starts. Reassembly was performed with more attention given to cathode centering.

Phase 4 of the test was carried out in a vacuum bell jar facility. Data acquisition was identical to that of Tank 8 except for the lack of thrust measurement.

Flow rates were set at 0.045 g/sec and current to 10 A. Preliminary starts stabilized quickly and voltage traces were fairly smooth.

The last burn-in was for 10 hr. Due to facility related problems this burn-in was not a single continuous run but an accumulation of the total required time. In the first half of the burn-in, arcjet operation was interrupted three times due to propellant line failures. Because arcjet operation was immediately terminated, it is not believed that these incidents resulted in any damage to the thruster.

Starts following the 10 hr burn-in were performed at a flow rate of 0.045 g/sec. The first start was very smooth, as were the next 40 attempts (Figs. 11(a) and (b)). After two starts, however, the steady-state voltage trace did not completely stabilize. It is believed that this was simply a mechanical problem with the thruster. When thruster was disassembled for a final inspection it was discovered that the cathode rod had become jammed within the core insulator, preventing free axial movement. Related thermal expansion and sealing problems may account for the noisy arc voltage during steady operation.

It was later decided to reassemble the thruster to take additional performance data and observe further arcjet starting characteristics. Table 1 presents a summary of all arcjet operation throughout the entire test in tabular form.

Discussion

The original purpose of this study was to demonstrate reliable arcjet starting using a thruster incorporating strong flow stabilization and a well regulated, pulse width modulated power supply. This was accomplished in that with every one of 300 starting attempts, rapid ignition was observed. In most cases an arc was established on the first high-voltage pulse. In the few cases where the first pulse did not suffice, a second pulse always led to successful startup. Most of the two pulse starts occurred early in the test, before the Phase 1 burn-in. This, however, may be a power supply related phenomenon as the starting circuit does not always develop its full voltage on the first pulse.[7]

Perhaps the most important observation was the fact that starting reliability did not change much over the course of the test. While the cathode tip recessed appreciably early in the test, the tip geometry soon stabilized.[8] Arc starting characteristics at the end of Phase 4 were quite similar to those at the end of Phase 1.

An unusual observation made during the test was a pattern that developed as starts were repeated within each phase. The first start following the Phase 1 burn-in period displayed an unusually rough voltage trace. As described previously, this roughness took the form of quick voltage excursions which occurred during the first 20 sec after arc ignition. At all times the presence of a fully expanded plume and high-voltage levels indicated that this was not a transition from low mode operation, where an arc attaches upstream of the constrictor. The duration of the voltage excursions was shorter with each successive start until no instabilities occurred on startup. The short starts following the Phase 2 burn-in displayed the same rough voltage traces. As before, each successive start became smoother until there were no voltage excursions. While Phases 3 and 4 did not fit this pattern as strictly as Phases 1 and 2, it is likely that if the test was conducted under more ideal circumstances the pattern would be more visible in all phases.

Because of this pattern, it would appear that extended operation of the arcjet has an effect on the voltage stability of the thruster in following starts. This is especially apparent on the first start following an extended burn. This effect, however, only involves a brief period after ignition and is somehow reversed by a series of short starts.

In order to suggest an explanation of what is happening, attention must focus on properties of the thruster that can be changed by as little as five short starts. The most dynamic physical parts of an arcjet are the electrodes. It is usually the cathode which undergoes the most change during its life. Photomicrographs of cathode tips that have endured long extended operation, often reveal a crater shaped formation at the apex.[8] This crater typically is surrounded by a raised ring of crystallized material and has a small depression at its center where the arc attaches. It has been shown that, upon startup, initial arc attachment often occurs on a tapered side of the cathode.[9] As the arc is forced to migrate forward by the gas flow field, it must somehow pass over the ring of material to reach its steady operating location at the cathode center. It is possible that the brief voltage excursions (Figs. 8(a), 9(a), and 10(a)) are a result of arc interactions with the ring of material before moving to its steady-state position at the center. Deflection of the arcjet plume that was observed during this instability has previously been seen in other studies where misaligned cathodes were diagnosed.[9] An offset attachment point on the cathode crater ring could similarly cause this plume behavior. Possible asymmetry of the cathode molten region might be different for the case of horizontal orientation (Tank 8) compared to the vertical case (bell jar). Controlled testing may be needed to address the importance of any such gravitational effects.

When the arcjet is started repeatedly for short periods of operation, the migrating cathode attachment point may have a tendency to erode away the sharp crater ring formation. It is possible that the erosive destruction of the ring formation returns the arcjet to a period of smooth starting capability. If this is true, then this period will be temporary; for the next extended operation of the arcjet will form a new ring structure and the process would repeat itself in the next phase of the test.

It should be emphasized that arcjet thrust was only slightly affected during the voltage excursions, and that this phenomenon had no effect on steady state thuster operation.

The mass flow rate of propellant was also found to affect starting behavior. When facility pumping problems forced flow rates to be reduced to 0.031 g/sec, arcjet stability was noticeably impaired. While the original flow rate (0.0337 g/sec.), always gave successful starts, the higher flow rate (0.045 g/sec.), normally resulted in smoother starts and was accompanied by a shorter transition period. The slight penalty in measured specific impulse taken at the higher flow rate was offset by increased efficiency and higher thrust.

There are a number of possible reasons for the more stable arc characteristics at higher flow rates. Reynolds numbers increase, and larger dynamic pressures at higher flow rates may improve the effectiveness of vortex flow stabilization.

One area which needs further study is the effect of higher static pressure on arc attachment to electrode surfaces. If higher chamber pressures associated with higher flow rates are responsible for smooth starting characteristics, then consideration should be given to starting stability when constrictor size is chosen.

A further link between smooth starting characteristics and flow rate is supported by the effect of a sonic orifice placed in the propellant gas line. Increased flow impedance due to arc ignition usually requires a higher inlet pressure to maintain the same propellant flow rate. In a bulky propellant feed system a finite amount of time is required to build up pressure. During this time period, flow rate through the arcjet is briefly reduced as the flow system adjusts. Previous studies[3,6] have often shown arc voltage gradually rises to its final value as late as 10 sec after ignition. It is likely that this, in part, is a result of slow pressure response of the propellant system. Addition of a sonic orifice just upstream of the thruster used in the present test ensured an uninterrupted flow rate at its choke point. The relatively small volume of gas between this choke point and the arc permits a faster pressure response of the propellant. Rapid starts were observed and the voltage instabilities associated with reduced flow were avoided. Locating a hydrazine gas generator close to an arcjet thruster may have an effect similar to that of placing a sonic orifice in the propellant line. Not only is this location thermally efficient, but it also could reduce the transition time encountered prior to steady-state operation.

Concluding Remarks

The observations and results presented in this paper allow several conclusions and suggestions for future research. Most importantly, the fact that 300 starts were accumulated with no apparent degradation in starting quality indicates that no basic feasibility issue exists with the arcjet/power supply combination used.

The appearance of voltage excursions on startup after extended duration runs, particularly at the lower flow rate implies that the starting process is dependent on the condition of the cathode after steady-state operation. Evidently arc motion on the ring of molten material that resolidifies at the tip is responsible. That the voltage fluctuations do not involve low mode operation and can be reduced or eliminated by using higher flow rates makes this more a cosmetic issue than anything else.

Throughout the test it became apparent that electrode alignment plays an important role in both starting quality and stability of operation. The small dimensions in the region of the arc make proper assembly difficult. This type of mechanical problem can be solved through tighter machining tolerances and a more careful assembly procedure. Further research to determine whether some of the small dimensions, such as arc gap width, can be opened without compromising thruster performance would be beneficial as this would likely alleviate some sensitivity to assembly.

Finally, it should be noted that while no starting problems were observed in this test, the fact that a real application will require 200 to 400 cold starts following extended runs suggests that a complete test of starting reliability will have to include a full, cycled lifetest.

References

1. Wallner, L.E. and Czika, J. Jr., "Arc-Jet Thrustor for Space Propulsion," NASA TN D-2868, 1965.

2. Knowles, S.C., Smith, W.W., Curran, F.M., and Haag, T.W., "Performance Characteristics of a Low Power Hydrazine Arcjet," AIAA Paper 87-1057, May 1987.

3. Nakanishi, S., "Performance Evaluation of a 1 KW Arc Jet Thruster," AIAA Paper 85-2033, Oct. 1985.

4. Ducati, A.C., Humpal, H., Meltzer, J. Muehlberger, E., Todd, J P., and Waltzer, H., "1-KW Arcjet-Engine System-Performance Test," Journal of Spacecraft and Rockets, Vol. 1, No. 3, May-June, 1964, pp. 327-332.

5. McCaughey, O.J., Geideman, W.A., Jr., and Muller, K., "Research and Advanced Development of a 2 KW Arc-Jet Thruster," GRC-1646, Plasmadyne Corp., Santa Ana, CA, 1963, (NASA CR-54035).

6. Curran, F.M. and Nakanishi, S., "Low Power dc Arcjet Operation with Hydrogen/Nitrogen Propellant Mixtures," AIAA Paper 86-1505, June 1986, (Also, NASA TM-87279).

7. Gruber, R.P., "Power Electronics for a 1-KW Arcjet Thruster," AIAA Paper 86-1507, June 1985.

8. Curran, F.M. and Haag, T.W., "Arcjet Component Conditions Through a Multistart Test," AIAA Paper 87-1060, May 1987.

9. Sarmiento, C.: Private Communication, NASA Lewis Research Center, Cleveland, OH, 1987.

TABLE I. - TABULATED SUMMARY OF STARTING TEST

Test phase	Vacuum facility	Range of mass flow, g/sec	Number of starts	Hours of operation
Preliminary starts	Tank 8	0.0337	10	0.028
Phase 1	Tank 8	.0337 to .045	51	.305
Phase 2	Tank 8	.0337 to .045	18	.547
Phase 3	Tank 8	.0331 to .045	41	1.40
Phase 4	Bell jar	.0337 to .045	71	11.5
Continued operation	Tank 8	.0337 to .045	111	4.28
Total			302	18.1

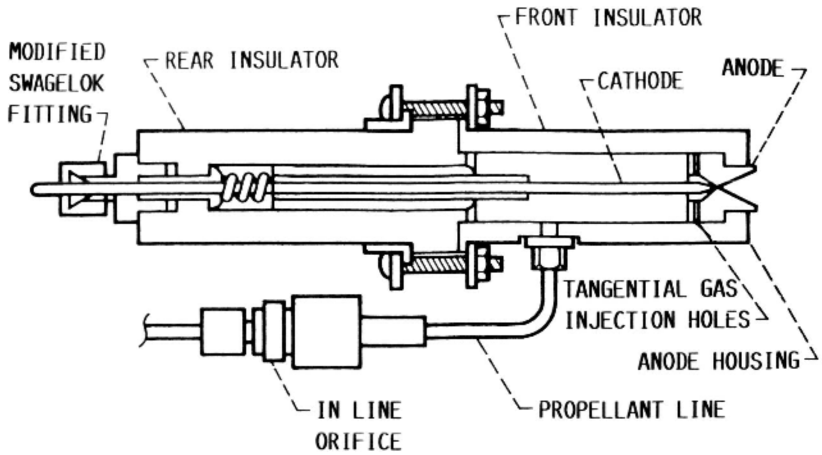

FIGURE 1. - CUTAWAY VIEW OF ARCJET THRUSTER.

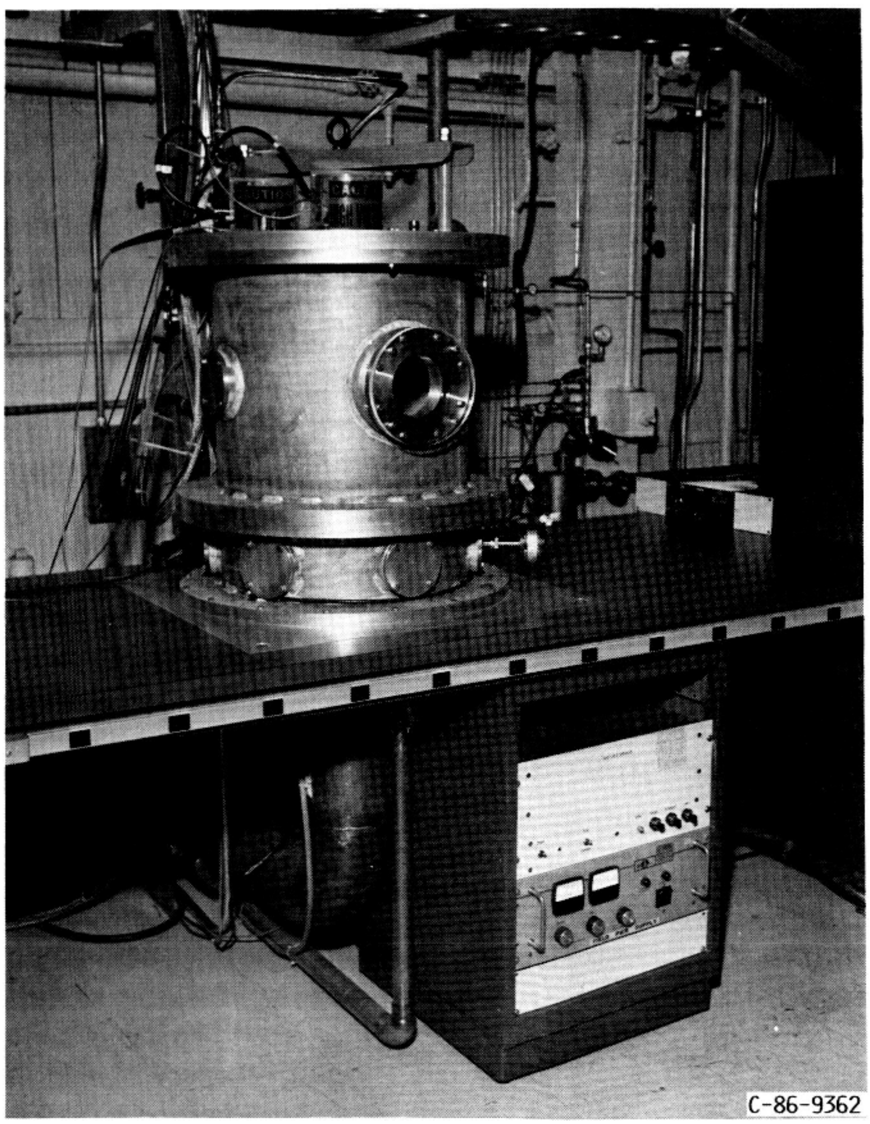

FIGURE 2. - VERTICAL BELL JAR TEST CHAMBER AND PULSE WIDTH MODULATED POWER SUPPLY (BELOW).

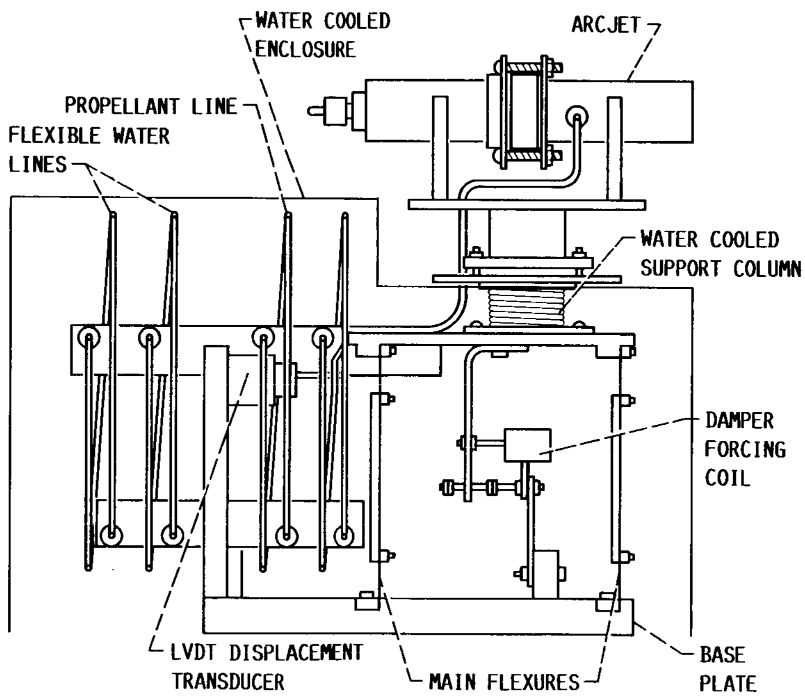

FIGURE 3. - SCHEMATIC DIAGRAM OF THRUST STAND WITH ARCJET MOUNTED.

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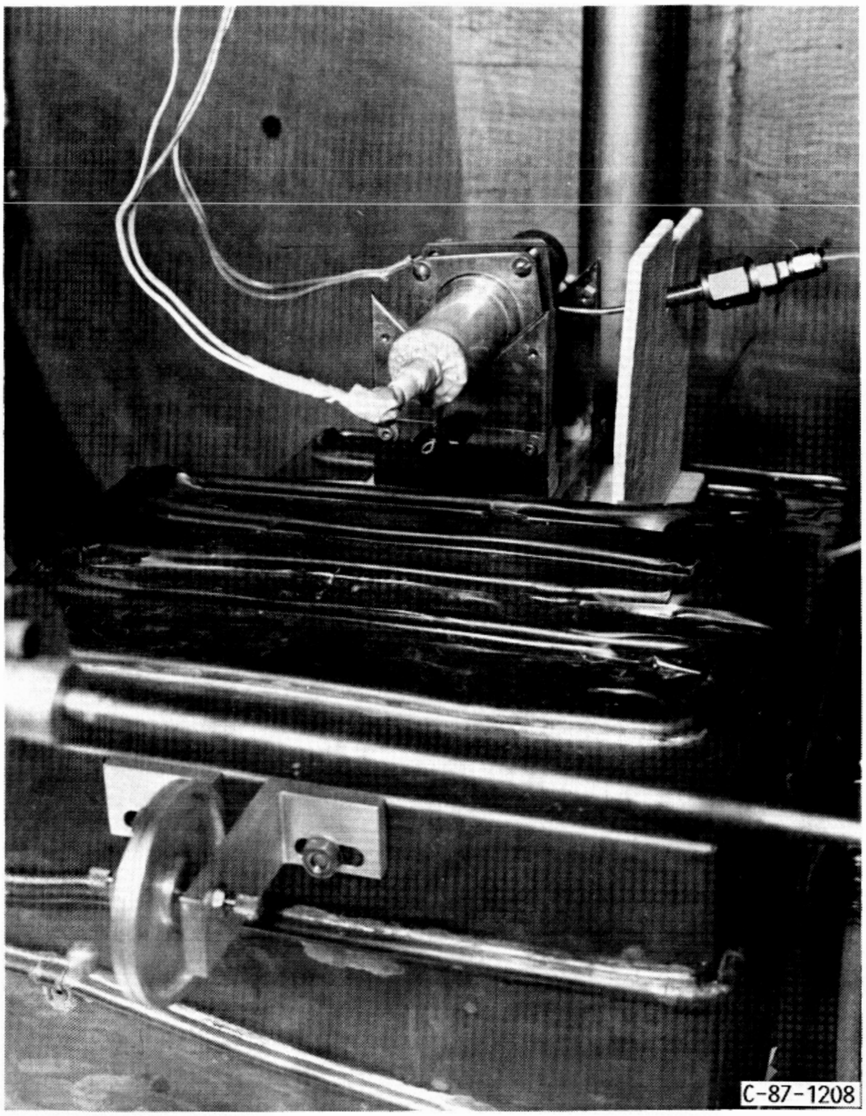

FIGURE 4. - ARCJET MOUNTED ON THRUST STAND IN TANK 8 VACUUM FACILITY.

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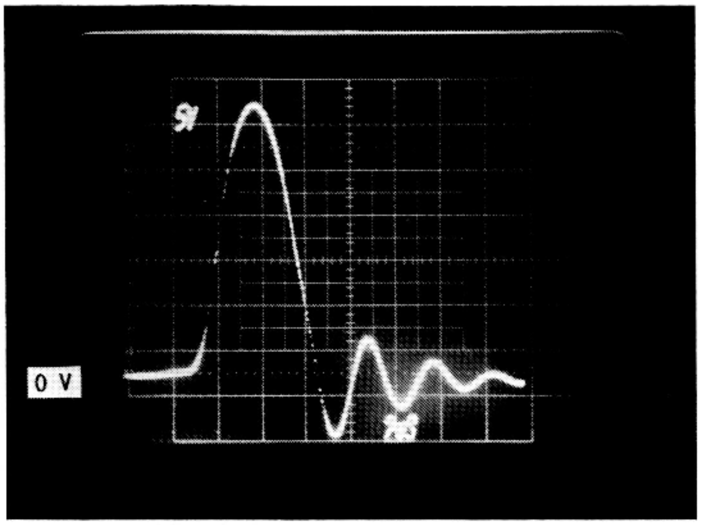


FIGURE 5. - OPEN-CIRCUIT STARTING PULSE. SCALE:
VERTICAL - 500 V/DIVISION, HORIZONTAL - 2 μs/DIVISION.

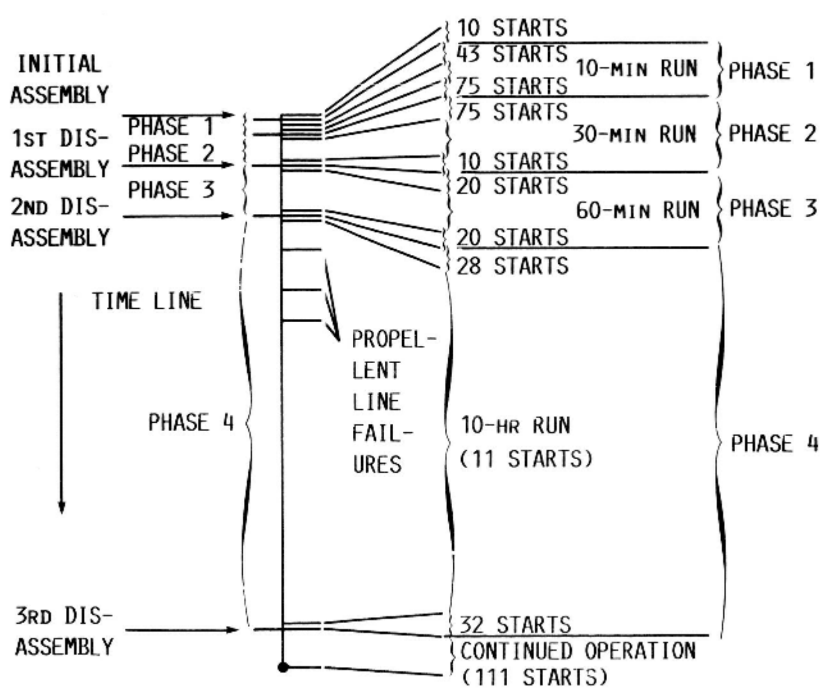
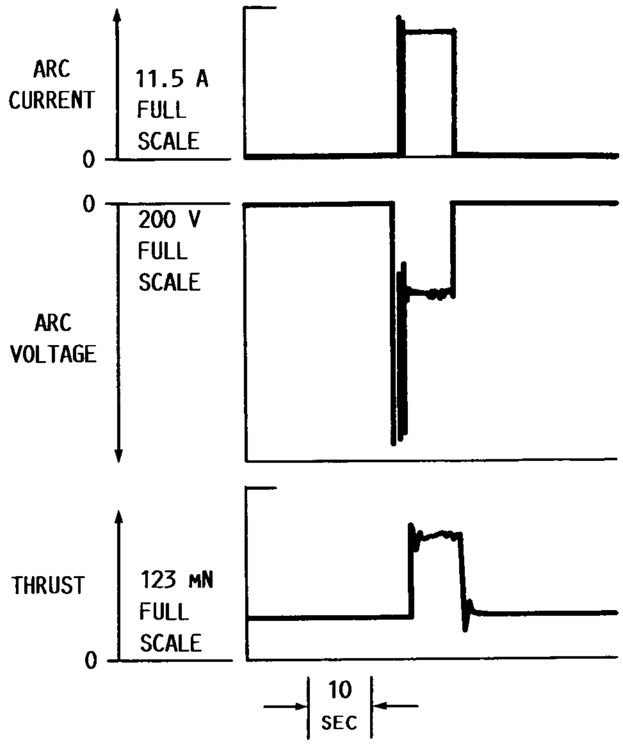
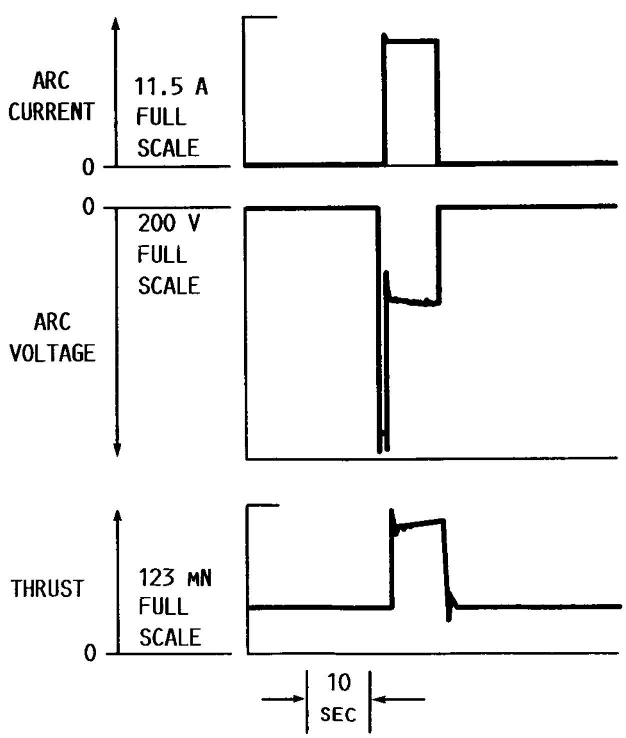


FIGURE 6. - CHRONOLOGY OF STARTING RELIABILITY TEST.

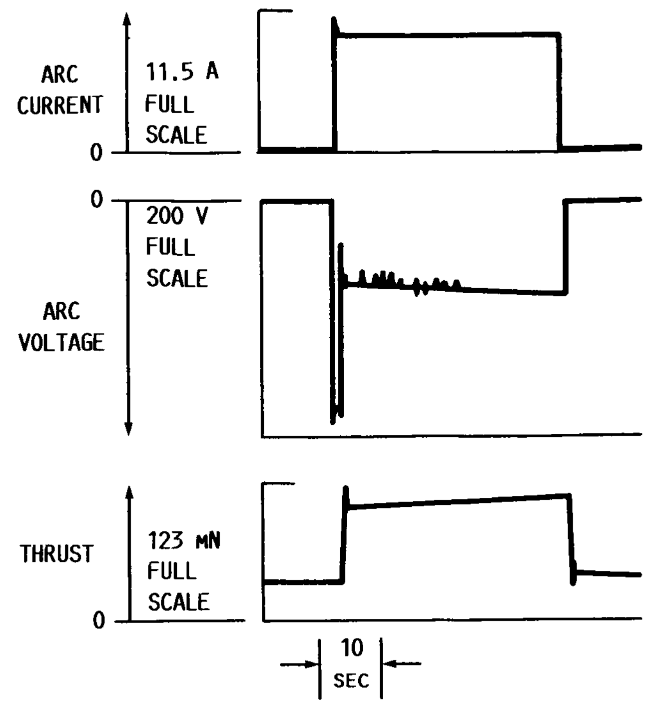


(A) FIRST START ATTEMPT WITH 0.59 MM ARC GAP. (MASS FLOW = 0.0337 G/SEC.)

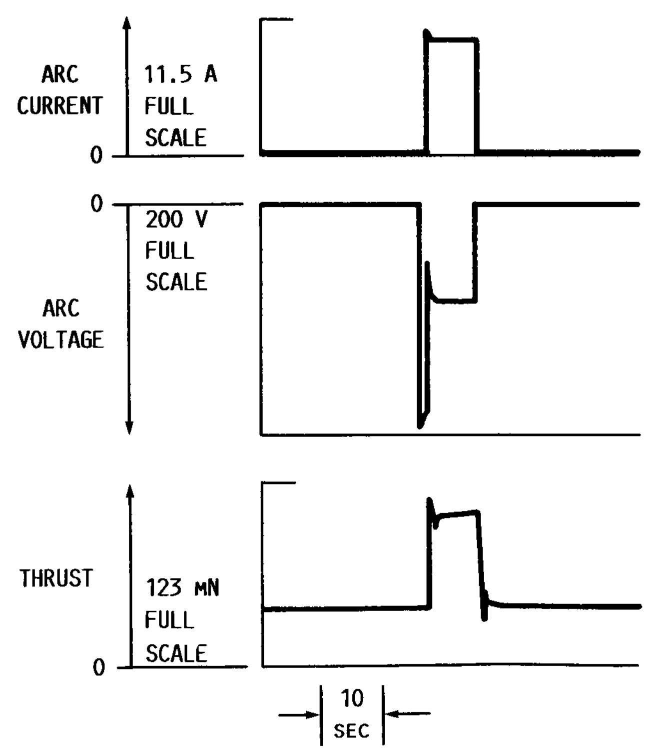


(B) NINTH START ATTEMPT WITH 0.59 MM ARC GAP. (MASS FLOW = 0.0337 G/SEC.)

FIGURE 7. - ARCJET STARTING EARLY IN PHASE 1.

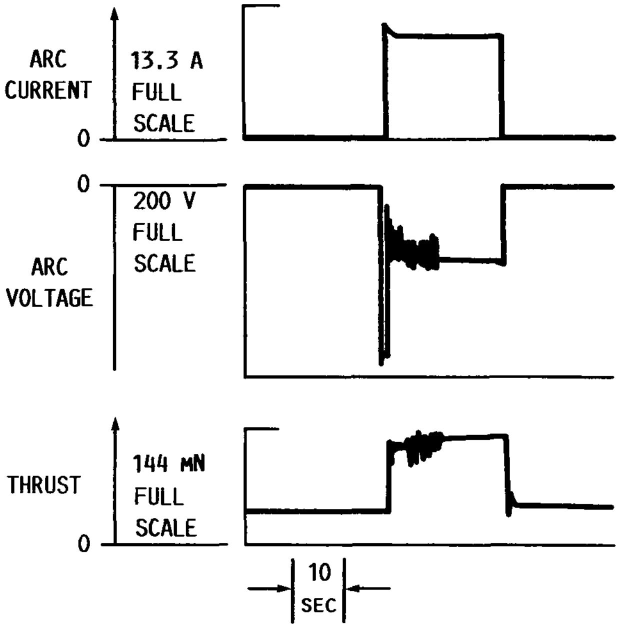


(A) FIRST START ATTEMPT AFTER 10-MIN BURN-IN. (MASS FLOW = 0.0337 G/SEC.)

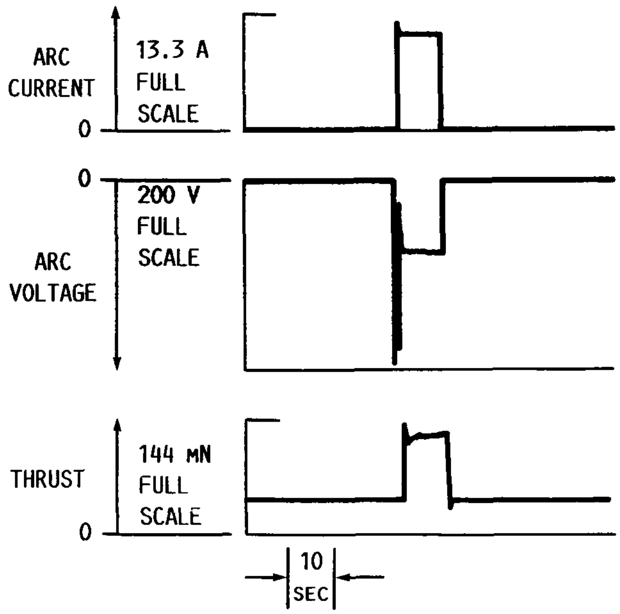


(B) FIFTH START ATTEMPT AFTER 10-MIN BURN-IN. (MASS FLOW = 0.045 G/SEC.)

FIGURE 8. - ARCJET STARTING LATE IN PHASE 1.

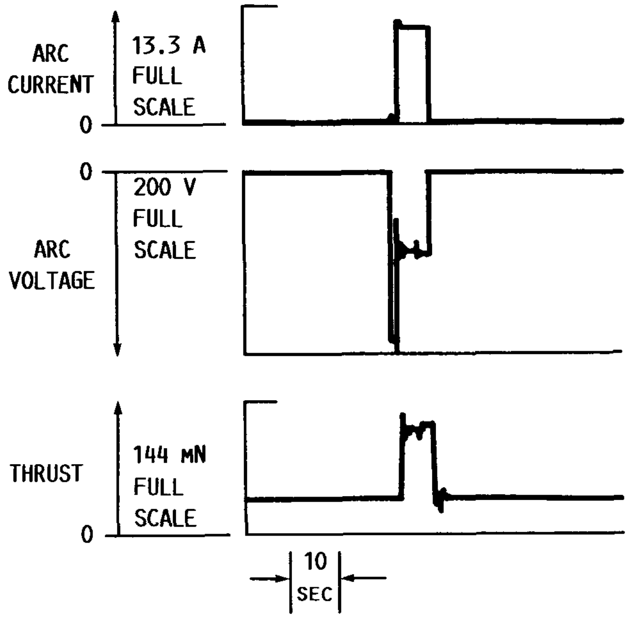


(A) FIRST START ATTEMPT AFTER 30-MIN BURN-IN.
(MASS FLOW = 0.0337 G/SEC.)

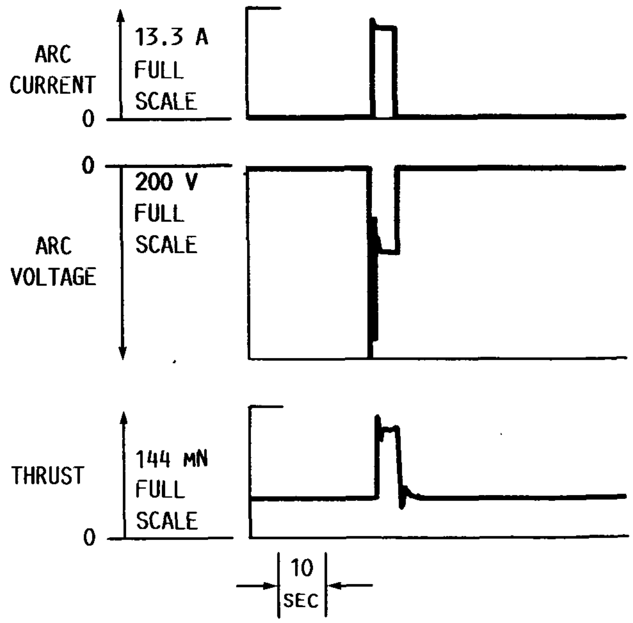


(B) FIFTH START ATTEMPT AFTER 30-MIN BURN-IN.
(MASS FLOW = 0.0337 G/SEC.)

FIGURE 9. - ARCJET STARTING IN PHASE 2.

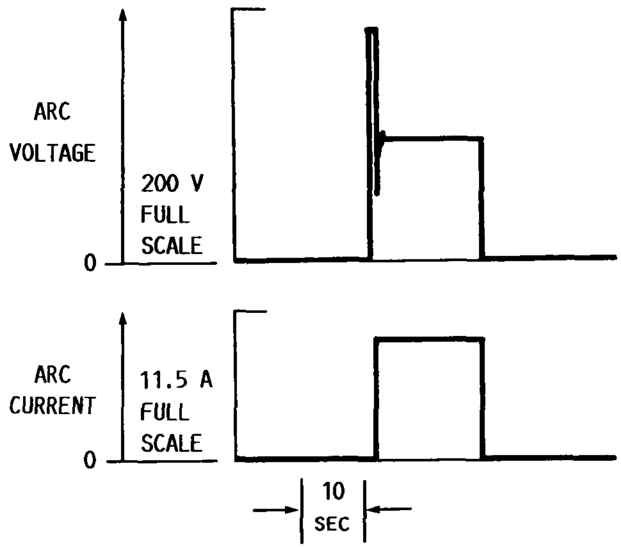


(A) FIRST START ATTEMPT AFTER 1-HR BURN-IN.
(MASS FLOW = 0.045 G/SEC).

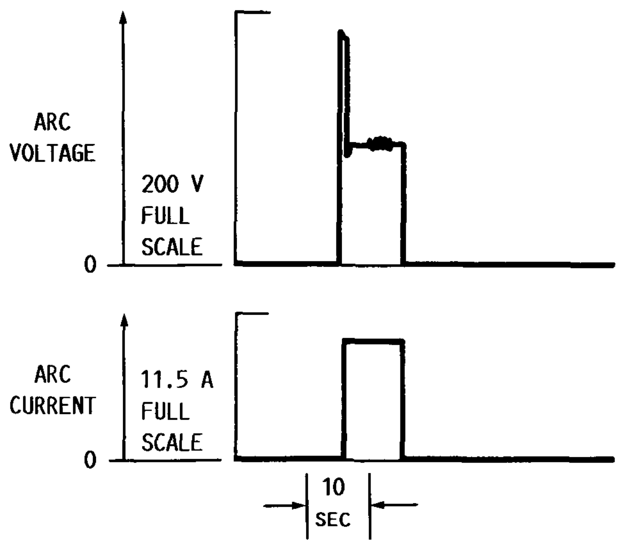


(B) TENTH START ATTEMPT AFTER 1-HR BURN-IN.
(MASS FLOW = 0.045 G/SEC).

FIGURE 10. - ARCJET STARTING IN PHASE 3.



(A) FIRST START ATTEMPT AFTER 10-HR BURN-IN.
(MASS FLOW = 0.045 G/SEC.)



(B) FIFTH START ATTEMPT AFTER 10-HR BURN-IN.
(MASS FLOW = 0.045 G/SEC.)

FIGURE 11. - ARCJET STARTING IN PHASE 4.

1. Report No. NASA TM-89867 AIAA-87-1061	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Arcjet Starting Reliability: A Multistart Test on Hydrogen/Nitrogen Mixtures		5. Report Date 6. Performing Organization Code 506-42-31
7. Author(s) Thomas W. Haag and Frank M. Curran		8. Performing Organization Report No. E-3538 10. Work Unit No.
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135		11. Contract or Grant No. 13. Type of Report and Period Covered Technical Memorandum
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15. Supplementary Notes

Prepared for the 19th International Electric Propulsion Conference cosponsored by the AIAA, DGLR, and JSASS, Colorado Springs, Colorado, May 11-13, 1987.

16. Abstract

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