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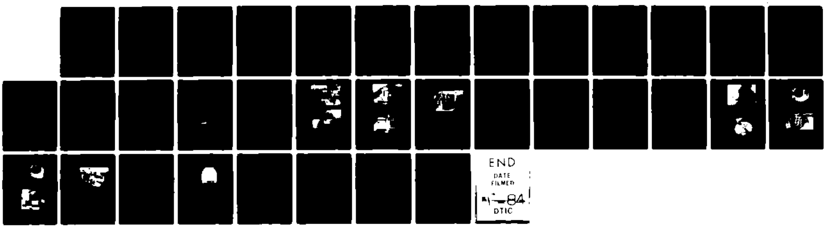

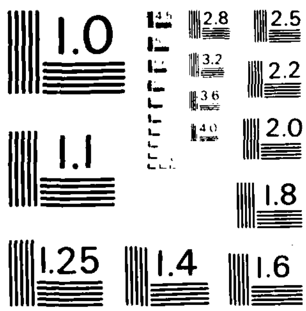

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ION SOURCE FOR A ROCKET PAYLOAD

Julius Perel

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1536 Highland Avenue
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FINAL REPORT
September 1980 - September 1982

August 1983

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AIR FORCE GEOPHYSICS LABORATORY
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UNITED STATES AIR FORCE
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report covers the design, development, testing and delivery of ion source and electron gun systems as part of a sounding rocket payload. A Prototype model was delivered for laboratory test mapping and compatibility with power supplies. A Flight Model was also delivered which is scheduled to be part of a sounding rocket payload. The Flight Model is designed to eject ions and electrons into the upper atmosphere according to a specified schedule. The basic ion source is the Capillaritron which can produce ions using any gas. It is composed of a very fine capillary nozzle from which gas is emitted when high voltage is applied

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20. ABSTRACT (cont'd.)

The source produces a small luminous plume from which ion and fast neutrals are ejected into a beam. It requires neither a cathode nor any preparations to turn on or off. Both the delivered Prototype Model and the Flight Model contain nine (9) capillary nozzles, each able to produce from less than one microamp to over one milliamp of beam current. The electron gun is composed of a 10 mil Ta wire about 2.5cm long and is capable of emitting over 10 milliamps when heated by about 16 watts. Both the ion source and the electron gun are capable of operating from about one microamp to ten milliamps independently of each other. Specifications, operational data and photographs of these models are included in this report.

FOREWORD

This report contains the results of the development of an ion source system supported by Air Force Geophysics Laboratory at Hanscom Air Force Base, under Contract Number F19628-80-C-0201 and performed by Phrasor Scientific, Inc., Duarte, California. The 6th Quarterly Status Report and Final Report have been combined into this "Final Report".

The technical monitor for the Air Force is Mr. William B. Huber of AFGL. The Principal Investigator for the program is Dr. Julius Perel (213) 357-3201 of Phrasor Scientific, Inc. Other individuals who contributed to work done on this program include Mr. John F. Mahoney, Mr. Scott D. Taylor, Mr. J. Robert Otto and Mr. Paul G. Pauls of Phrasor Scientific, Inc., and J. Owen Maloy, consultant.

The views and conclusions contained in this document are those of Phrasor Scientific, Inc. and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the Air Force Geophysics Laboratory or the United States Government.

A-1

TABLE OF CONTENTS

1. INTRODUCTION

This report discusses the design, development, fabrication testing, and delivery of a Flight Model ion source and electron source system. The source system is scheduled to be part of a sounding rocket payload and is designed to eject ions and electrons according to a specific schedule. The basic source is a new type gas fed ion generator termed the Capillaritron(Ref.1). It is composed of several small capillary nozzles which generate an intense ion beam when gas passes through the nozzles to which high voltage has been applied. The source requires no cathode to supply electrons, or heating preparation to turn on. Nor does it require any special procedures to turn off. This Final Report includes the initial specifications and describes operation of the two Prototype Models and the Flight Model delivered to AFGL.

The ion source design is based upon the application of capillary discharge ionization which occurs when gas is bled into a vacuum through a small capillary nozzle, elevated to a high electrical potential. With the gas flow and the applied electric field at a sufficiently high level, the discharge occurs at the tip of the nozzle and ions are generated. The ions are then accelerated by the potential difference between the nozzle and extractor electrode planer to the nozzle and at ground or slightly negative potential. The ions form a narrow beam. The discharge is accompanied by a visable glow of light whose color (spectrum) reveals the gas supporting the discharge.

The capillaritron ion source initially showed some distinct advantages over other ion sources (Ref. 1 & 2). It is small and compact in size and simple in mechanical design. No special filaments and discharge chambers are required nor is the power supply and controls to run an auxillary discharge needed. The initiation of the discharge is instantaneous requiring no pre-heating or conditioning. Thus it can be turned on when desired and can be exposed to air immediately after operation. It operates with any gas or mixture.

During thorough examination of the characteristics of the Capillaritron (Ref.3) a theoretical investigation was made to predict the gas flow rate dependance upon several critical parameters (Ref.4). These investigations showed that most of the advantages of the Capillaritron initially anticipated were substantiated by theory and experiment (Ref.5). However, a broad energy spread and low ionization efficiency (mass utilization efficiency) was found. In addition to its intended application discussed in this report, the ejection of charge from a sounding rocket, the Capillaritron has been used for sputtering experiments, in Mass Spectrometry Applications (Ref. 6-9) and plasma chemistry studies.

2. SPECIFICATIONS, DELIVERABLE ITEMS AND OPERATING CONFIGURATION

The initial operational specifications for the positive ion source requirements for sounding rocket is listed in Table I and specifications for the electron emitter is listed in Table II.

TABLE I

SPECIFICATIONS FOR A SOUNDING ROCKET PAYLOAD
POSITIVE ION EJECTION SOURCE

A.	Current Dynamic Range	Ten microamperes to ten milliamperes.
B.	Current Values	Either continuously settable over the complete dynamic range or settable to six discrete values each separated from the rest by at least a factor of three.
C.	Type	Positively charged noble gas ions.
D.	Energy - Dynamic Range	0.5 to at least 4.5KeV.
E.	Energy Values	Settable to at least three values in this range, and separated by at least a factor of two.

Table II

Electron Current Specifications

Beam Current	Neutralizer Current
10mA	10mA (100%)
	1mA (10%)
	0.1mA (1%)
1mA	1mA (100%)
	0.1mA (10%)
	10μA (1%)
0.1mA	0.1mA (100%)
	10μA (10%)
	1μA (1%)

The deliverable Prototype and Flight Model Ion Sources consist of the following items:

- Ion Source Assembly
- Electron Source
- Mounting Fixtures
- Gas Feed Tubing with Isolators
- Vacuum Interface Flange Equipped with Electrical and Gas Feedthroughs

The vacuum interface flange allows the ion source to be operated in a vacuum while the electronics are at atmospheric pressure.

The suggested configuration for the operation of the source is shown in the schematic diagram, Fig. 1. Only a single array of two nozzles is shown in the figure. Gas is fed into the plenum which distributes it to each of the nozzles. Voltage is applied between the nozzle plenum and the extractor electrode by the Current Control Power Supply. When the gas flow rate and the applied voltage are sufficiently

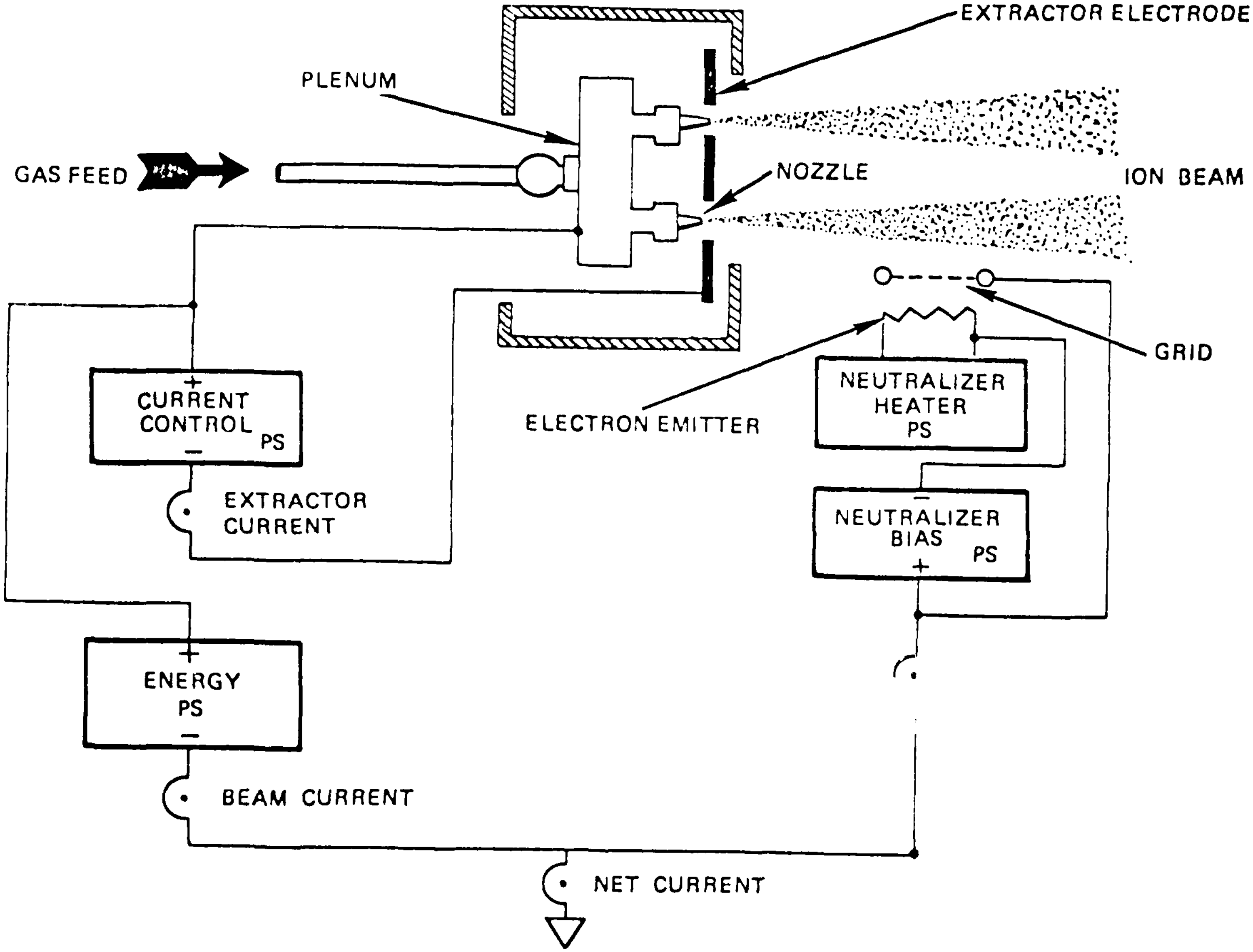


FIG. 1 SCHEMATIC DIAGRAM OF THE ION SOURCE AND ELECTRONICS

high, a plasma is struck at the nozzle tips and ions are emitted. The energy of the ion beam is determined by the Energy Power Supply as shown in the figure. The current flowing through the Energy Power Supply is the beam current, while that flowing through the Current Control Power Supply is the extractor current. It may not be necessary to measure the extractor current. In keeping with their identification, these power supplies control the current and energy separately. It had been experimentally determined that the current output from the nozzle is dependent upon the voltage difference between the nozzle and extractor. There are other ways to arrange these power supplies.

3. PROTOTYPE SOURCE CONFIGURATIONS AND OPERATION

The first designed Prototype Source was fabricated then tested. It was then determined that this model would not meet mechanical requirements such as rugged configuration and would be heavier than necessary. Based upon the results of the first design, an improved version was made and subsequently delivered to AFGL.

3.1. Prototype I Configuration

A Prototype Model design, shown in Fig. 2, is based upon utilizing 16 nozzles in two clusters of 4 and 12. Each cluster has a separate plenum and separate gas feed so that the gas control could be separate. They are both attached to the same base plate and therefore not electrically separated. Insulators are used to mount the extractor that contains 16 apertures. The inner plenum contains 4 nozzle holders and a hollow cylindrical insulator in the center. Within the cylindrical insulator are the electron beam filaments mounted on separate insulators. A bias, applied to the filaments with respect to the grounded screen cover is used to control the electron current emitted from the heated filaments. The nozzle holders shown in the figure are special fittings allowing for the removal and replacement of nozzles. The entire source system is 10cm by 10cm in the frontal area, and about 5cm thick.

The Prototype Model I tests included measurements of the flow rate as a function of the plenum pressure, current vs. voltage measurement for various plena pressures and electron emission tests.

The 4 inner nozzles were run together with a combined gas flow rate of 8.8 SCCM at 800 Torr plenum pressure. The flow rate showed the typical curve shape seen for single nozzles, but about four times larger (Ref. 2, 3,4). The total current as a function of the voltage was

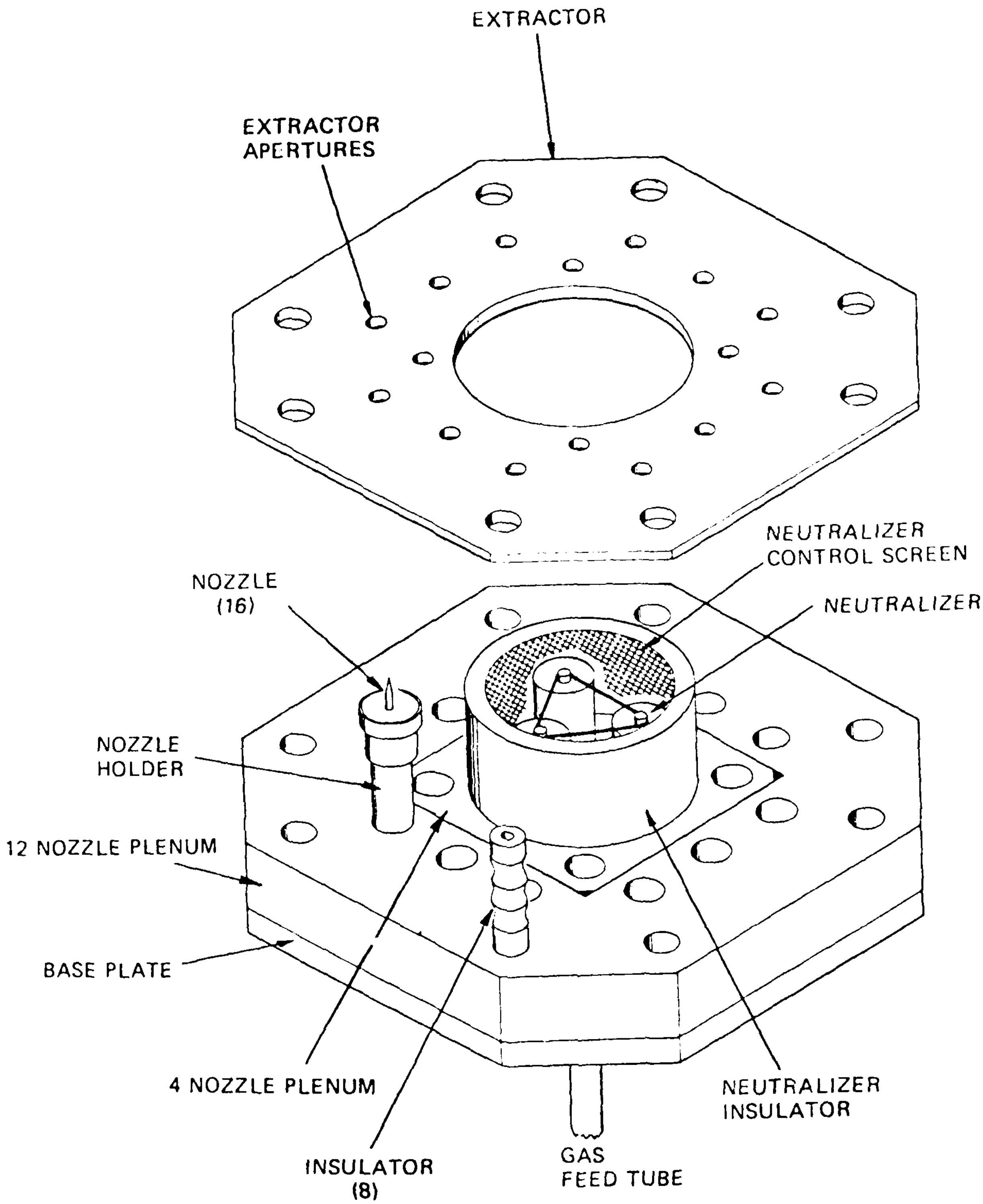


FIG. 2. ILLUSTRATION OF THE PROTOTYPE ION SOURCE SYSTEM

measured at four plena pressures as shown in Figure 3. The current typically goes up with the pressure at a given accelerating voltage. For a plenum pressure of 800 Torr at a voltage of 4.5kV the current is 4.3mA. Thus about 1.1mA is produced by each nozzle. At these levels only 9 nozzles in the multinozzle source are required to fulfill the specifications.

The electron source consisted of a Ta filament having a diameter of 0.25mm (0.010 inches) and a length of 25mm (1 inch). When 5.5V was applied across the filament the heater current was 4.3A. When 18V bias was applied, an electron emission current of 1mA was obtained. The electron emission was not affected by the presence or absence of the ion beam. The filament was operating in the emission limited mode because the emission current increased when the heater power was increased. For example at a heater voltage of 6V and 4.5A the emission current doubled to 2mA.

3.2. Prototype Model II

3.2.1. Design

Prototype Model I contained two plena which were operated at the same electric potential, though each plenum had a separate gas inlet. Therefore the gas flow rate could be different for each. The plena through which the gas flowed to the separate nozzles was large and bulky adding unnecessary weight to the source. No difficulties were encountered in operating two or more nozzles at a time and no interaction between them was observable.

As a result of these tests, it was determined that several changes could be made in the design that would make the source more rugged, more reliable and more versatile. The nozzles were found to

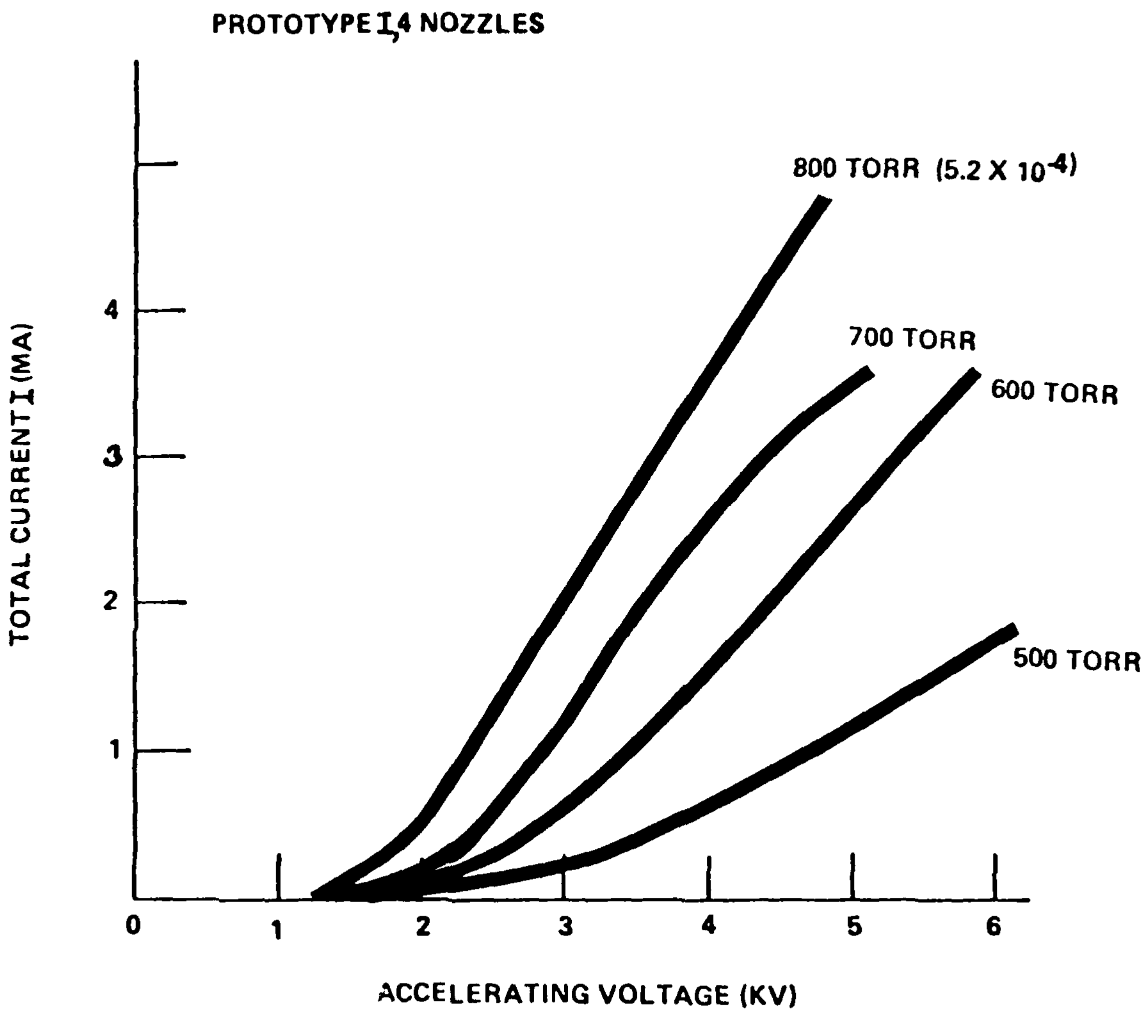


Figure 3. Current vs. Voltage for Prototype I 4 Nozzles.

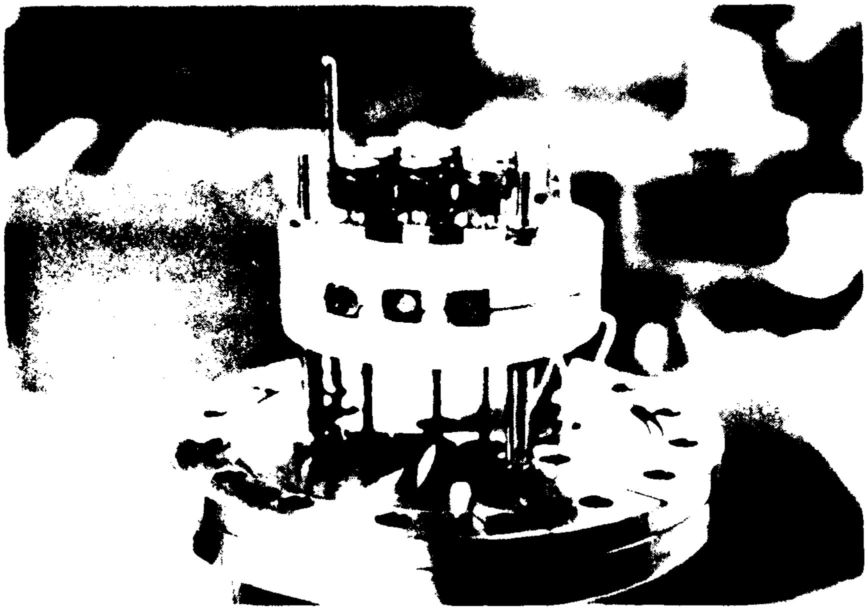
exceed one milliamp in current. Ten milliamps of current could be easily obtained from 9 nozzles. A better design was conceived by splitting the plenum into three different ones, each containing three nozzles, all of which are mounted on a 6 inch conflat vacuum flange. The three plena are electrically isolated and gas isolated so that each can be operated independently from the others. If desired, different gases could be used for each. For a given plenum the three nozzles have the same voltage and gas pressure. Thus the nozzles on a given plenum should be matched to each other to avoid large differences in current resulting from differences in flow rate.

To make the system more rugged, the bare nozzles, which are difficult to handle because of their small size,are brazed into a stainless tube having a 1/8 inch diameter and this nozzle unit mounted in the Swagelok fitting. These nozzle units are easier to handle and made a sturdier mount than the bare nozzles.

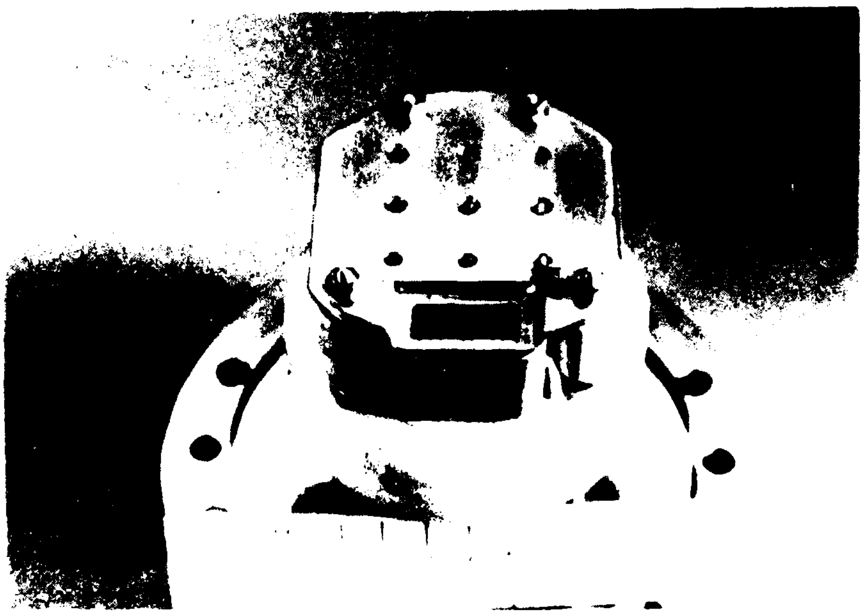
The Prototype Model II source having 9 Swagelok fittings to hold the nozzle units are seen in Fig. 4a. Also seen below the fittings within the white Delrin insulation are the three plena, each electrically isolated from each other. Each 3 nozzle plenum can operate with different gases and at different pressures. The 6 inch flange is seen as the mount for the source system. Figure 4b shows the other side of the source displaying the electron emitter and the nine appertured extractor plate. Figure 5a shows the same view but with the ground cover in place which is 8.5cm (3.35 inches) in diameter. Finally, Fig. 5b shows the side view of the source revealing the 3 gas and high voltage feedthroughs, the extractor feedthrough and the smaller electron emitter feedthroughs. Figure 6 shows the outside view of the flange with the feedthroughs more easily seen.

3.2.2. Tests

At the Phrasor Scientific laboratory, nozzles were mounted in the source and each of the plena was gas flow tested. Table III shows the

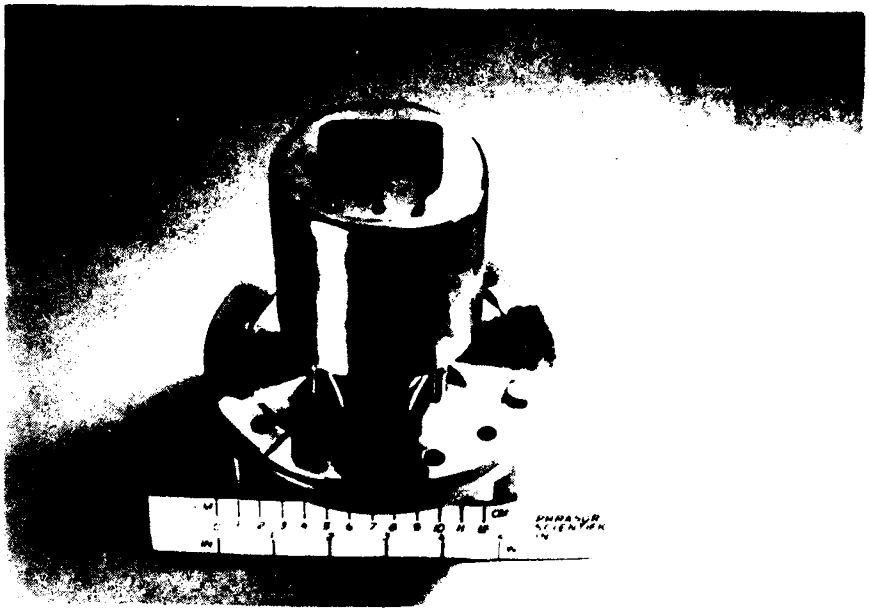


a). Source with ground cover, extractor and nozzles removed.

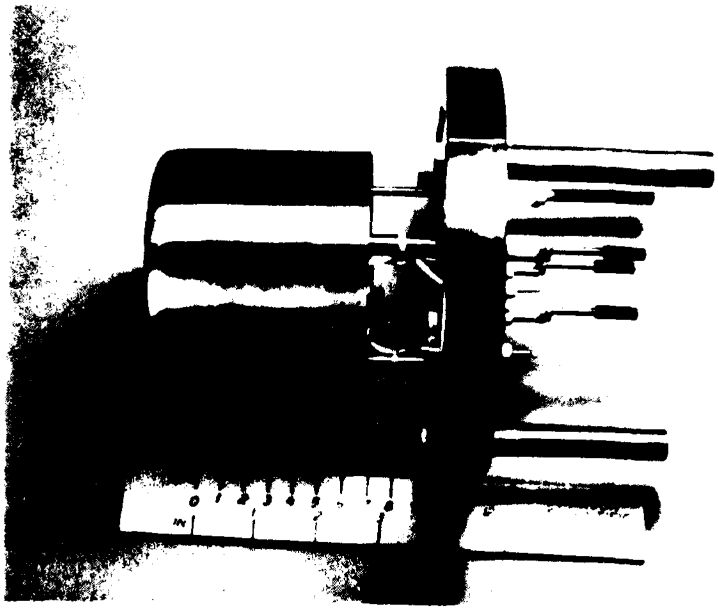


b). Source with ground cover removed.

Figure 4. PROTOTYPE MODEL II.



a). Three quarter view of completed source.



b). Profile view of source.

Figure 5. PROTOTYPE MODEL II WITH GROUNDED COVER.

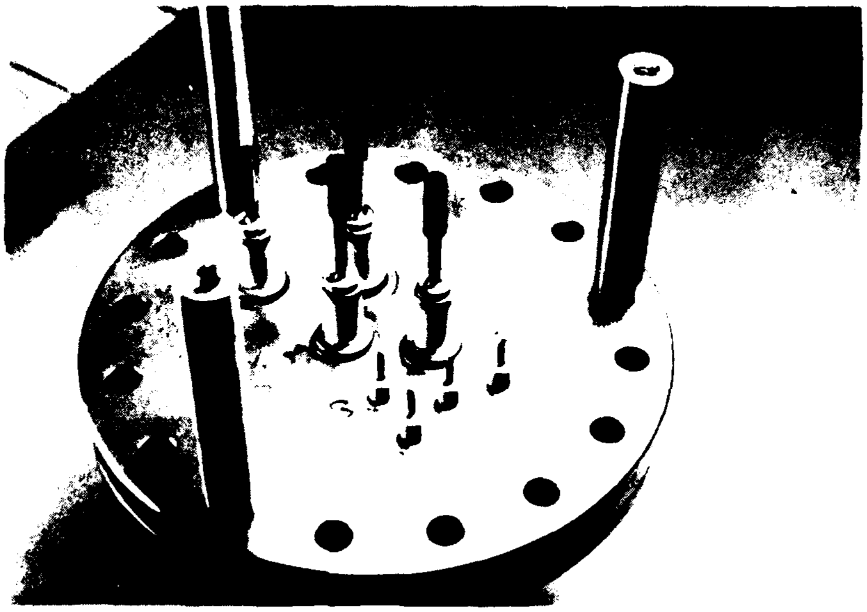


Figure 6. PROTOTYPE MODEL II.

View of outside flange with feedthroughs.

flow time for each nozzle and the plenum flow time as measured by a special nozzle testing apparatus (Ref. 3). Plenum 3 is next to the electron emitter.

TABLE III

	Row 1	Row 2	Row 3	Plenum Time
Plenum 1	49 sec	45 sec	78 sec	19.5 sec
Plenum 2	48 sec	67 sec	52 sec	18.8 sec
Plenum 3	47 sec	57 sec	45 sec	17.4 sec

Plenum 1 was tested at a plenum pressure of 335 Torr and the flow rate was 2.44 SCCM. When the applied voltage was 5kV the current was 200 microamps and the chamber pressure was 2.4x10E(-4) Torr. The nozzle in Row 3, Plenum 1, showed no nozzle glow until higher pressures were applied. This nozzle is poorly matched in the first plenum.. The neutralizer was operated at 1mA when the filament voltage and current were 4 volts and 5.5 amps respectively. The extraction voltage was maintained at 70 volts.

This test showed no difficulties in operating an array of nozzles and no interactive effects were observed. Plena were grounded, floated and operated independently of each other.

Tests at AFGL

The Prototype Model II was delivered to AFGL on 19 November 1981 by J. Perel. The source mounted on a 6 inch conflat flange, was made 3.35 inches in diameter to be small enough to fit into the chamber port. The power supplies specified for this test and for the Flight Model were as follows:

1.	5kV, 10mA	High voltage
2.	1kV, 1mA	Negative Extractor
3.	50 V, 10A	Filament Heater
4.	100 V, 10mA	Filament Bias

A gas flow control system was devised to control the gas flow into the source. The test was performed in a cryogenic pumping chamber capable of 3000 liters/sec pumping speed.

Without gas flow through the source, the chamber pressure was about 10E(-7) Torr. When 860 Torr (about 2 lb/in^2) pressure was applied to Plenum 1, the chamber pressure increased to 3.1x10E(-5) Torr. A voltage of 1.7kV on this 3 nozzle plenum was required to ignite the beam. The beam current extinguished when the voltage was lowered to 1.0kV. The other two plena showed similar characteristics and when all three were turned on simultaneously the chamber pressure rose to 9.4x10E(-5) Torr.

This initial test at AFGL confirmed the following source capabilities:

1. Turn on and off with no preparation.
2. The plena can be operated independently.

As a result of these tests the source was found to operate properly. The electron emitter shield body on the Flight Model should be biased to prevent current flow from the filament to the body. The following changes were made to improve the mechanical structure and reliability of the design Flight Model.

List of Modifications For The Fabrication and Assembly of the Flight Model

1. Cajon ultra-torr vacuum fittings were replaced by Swagelok fittings to avoid the torque problem of over twisting critical parts.

2. A permanent ground connection was made to the outer can instead of spring loaded technique.

3. The extractor aperture was increased from 1/8" to 5/32" to reduce criticality of nozzle alignment.

4. Wider and stronger studs were needed at bottom between flange and Delrin rings.

5. The plenum tubes were shortened and the ends rounded off to increase the spacing to the grounded outer cover.

6. The plena were made of square stock rather than round tubing for better mounting when Delrin rings are tightened.

7. The mount was shortened to bring source closer to the flange.

4. FLIGHT MODEL

Several features of the Flight Model design were discussed in the previous section. Both the Prototype and Flight Models were fitted to 6 inch conflat vacuum flanges which were used in mounting on the vacuum chamber for tests and for mounting on the rocket.

The component parts of the Flight Model will be described using photographs. Figure 7 shows the major components with the 6 inch flange on the left and proceding to the right, the two delrin insulators, 4 mounting posts with insulators, the extractor plate with 9 apertures, and components of the electron emitter. The high pressure side of the vacuum flange with the mounted feedthroughs are seen in Fig. 8. The six central insulators are three pairs composed of a high voltage connecting banana plug and the voltage and gas feedthroughs. The upper most one is the extractor feedthrough, and the four smaller ones below are the extractor feedthroughs. Figure 9a shows the two delrin insulators with insulating standoffs mounted on the flange. The uppermost four holes in the delrin are for the electron emitter mount and electrical connections. The larger ones are for the filament and the two smaller ones are for connection to the emitter body and the screen. The central three holes are to accomodate the high voltage and gas feed tubes connected to each of the three plena. The lowest hole is for the connection to the extractor plate. Figure 9b shows the same view as Figure 9a, but contains the three square stock plena each having three nozzles and with the electron filament and body mounted. The grid covering the electron emitter body which is electrically isolated from it is shown in Fig. 10a along with the mounted extractor plate. The grounded cover mounted on the completed Flight Model is shown in Fig. 10b. Finally, Fig. 11 shows a side view of the covered source with the safety cover, made of plexiglas, used to isolate the experimentors from high voltage in the laboratory. Three manual valves, all at ground potential, seen in the figure, are connected

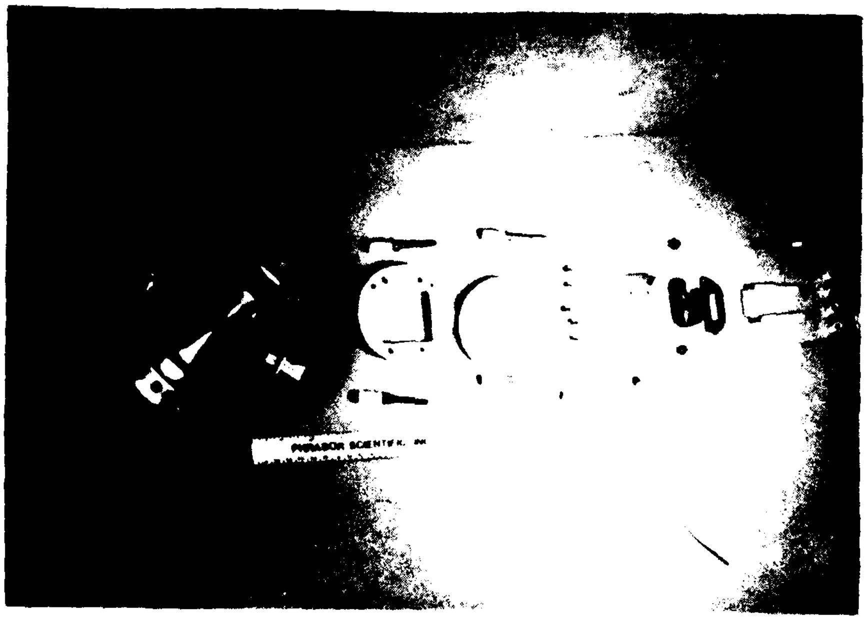


Figure 7. Flight Model component parts.

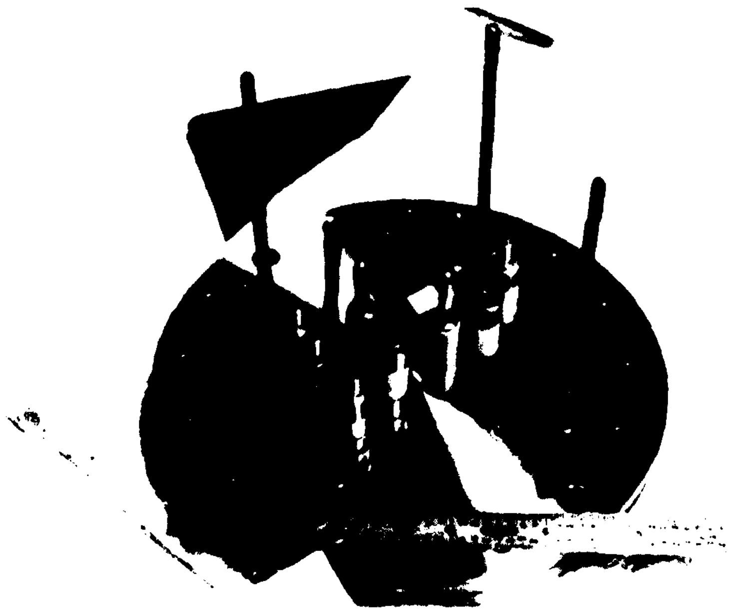
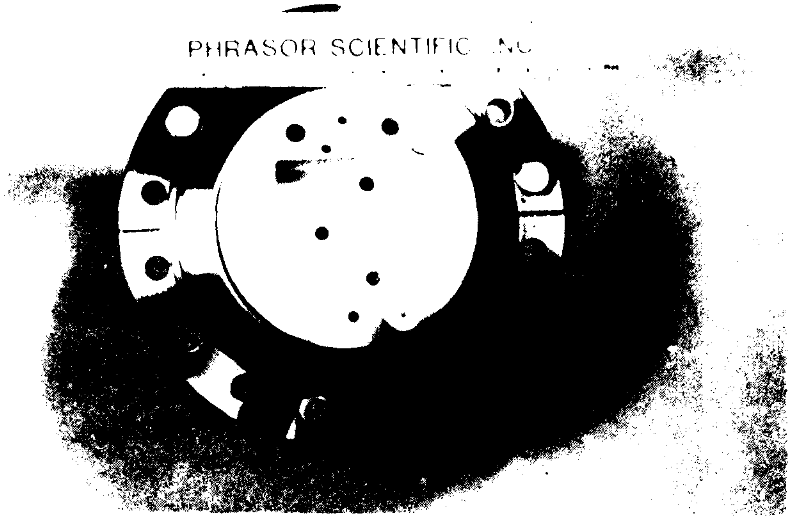
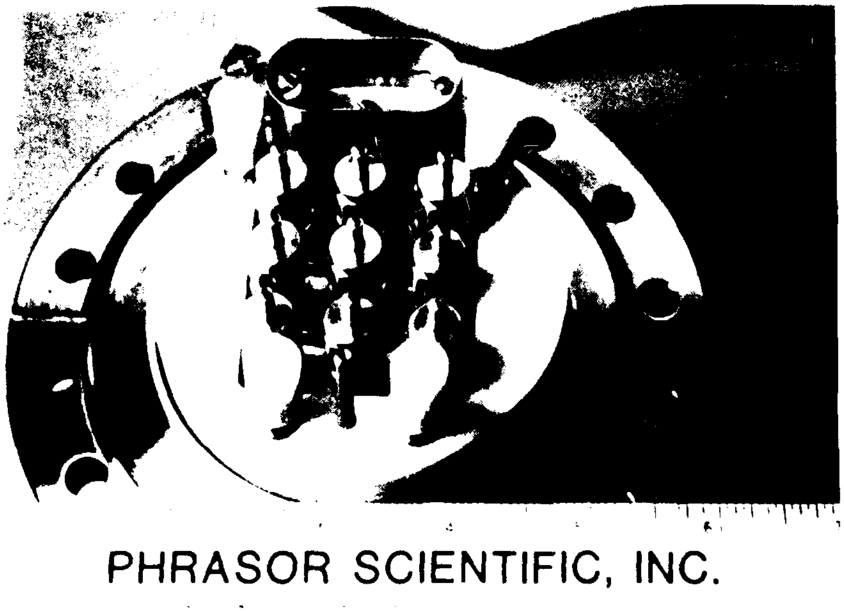


Figure 8. Flight Model view of the back of the flange and the electrical and gas feedthroughs.

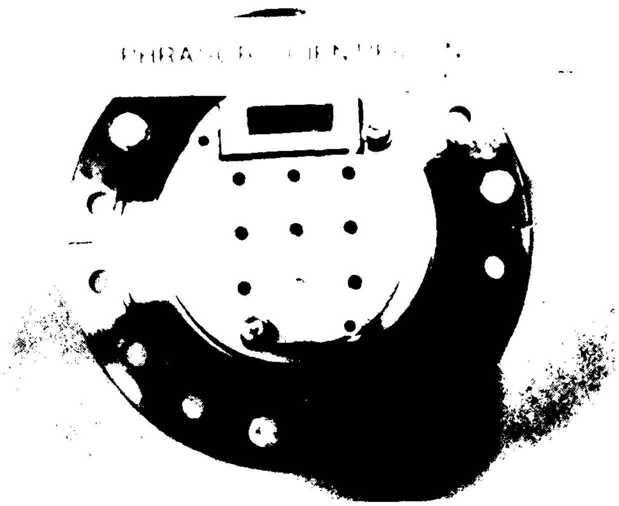


a). View of the delrin mounts and the insulator standoffs.



b). View of the electron emitter and plena in place with all nozzles mounted.

Figure 9. Flight Model assembly.



a). With extractor and electron screen mounted.

b). Complete source assembly.

Figure 10. Flight Model.

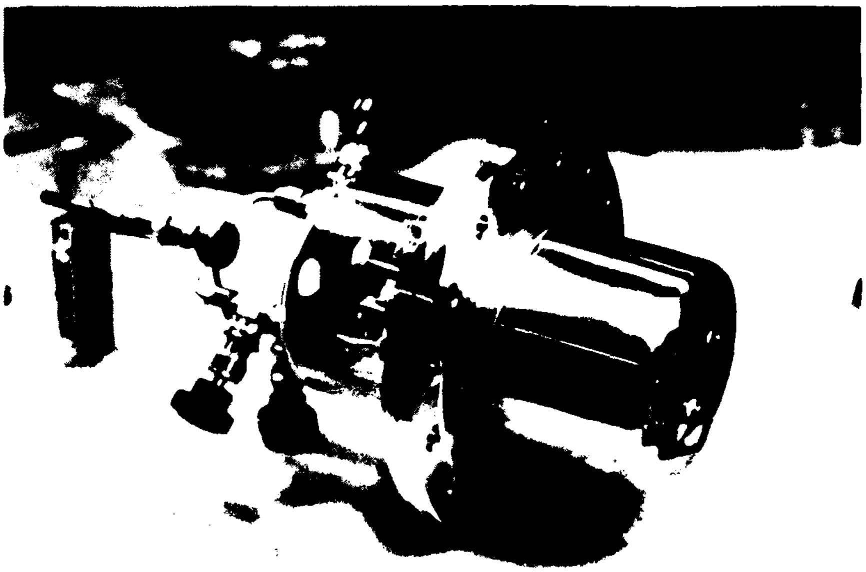


Figure 11. Flight Model showing side view including safety cover, three manual valves and the gas filter.

to each of the plena. The isolation between the valve and the high voltage is plastic tubing. The three valves obtain gas from the manifold after it passes through a gas filter on the left. In this configuration, any or all of the plena can be tested by applying the gas to the filter and opening the appropriate valve. The valves can be operated while high voltage is applied and the source is in operation.

Figure 12 shows a diagram of the extractor with each of the nozzles numbered. The electron emitter screen is seen at the bottom of the figure. Table IV lists the plena and the nozzles mounted for the initial tests refering to Fig. 14. These nozzles were better matched to each other as seen in the time measurements, than those listed in Table III for Prototype Model II. Thus the nozzles all on the same plenum and having the same plenum pressure and voltage tended to turn on and off together.

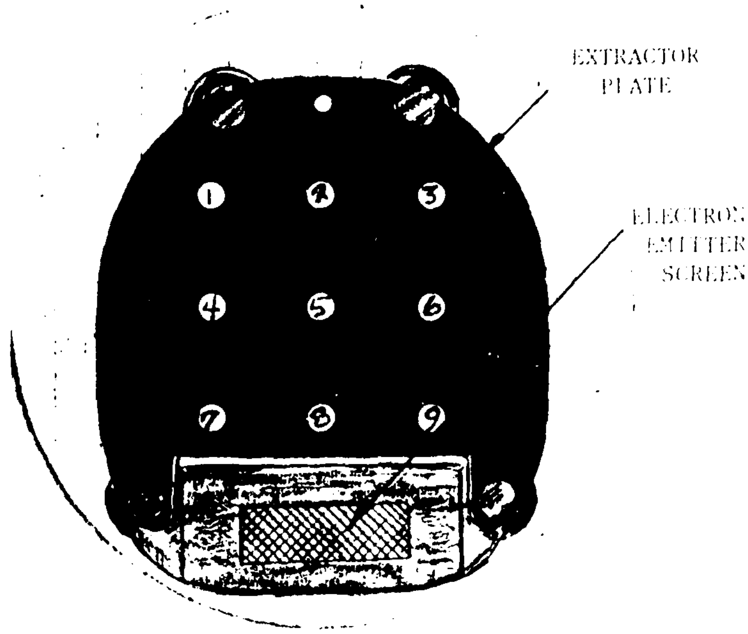


Figure 12. View of Extractor Plate with each of the Nozzles Numbered.

TABLE IV

Flight Model Nozzles

Plenum	Nozzle/Position(Fig.)	Time Sec
1	1	55.9
1	2	56.6
1	3	58.9
2	4	60.2
2	5	60.4
2	6	61.4
3	7	61.9
3	8	62.0
3	9	62.2

Each plenum was tested separately at Phrasor Scientific. Table V shows the plenum pressure and the vacuum chamber pressure when 5kV was applied to each plena and a 1 millamp beam extracted.

TABLE V

Performance of Flight Model for 1mA Beam Current

Plenum	Plenum Pressure	Voltage	Chamber Pressure
	Torr	kV	Torr
1	580	5.0	1.85 x 10E(-4)
2	600	5.0	1.5 x 10E(-4)
3	580	5.0	2 x 10E(-4)

The electron emitter was composed of tantalum wire 10 mils (0.25mm) in diameter and with about a 2.5 cm long emission length. When 3.3V was applied to the filament a current of 4.75A flowed through it produced 15.7 Watts of heat. With the filament and the emitter body biased at -40V the emission current was 11.6mA. This was consistent with the calculated expectations. Of this emission current, 0.1mA went to the emitter body, 7.6mA went to the grounded screen and so 3.9mA was the net emission. This showed it to be in the desired range of operation.

5. CONCLUSIONS

The multinozzle Capillaritron, in the form of the Flight Model described in the previous section, is able to fulfill its design role to eject charge in a sounding rocket experiment. Several of the sources advantages and disadvantages are discussed below.

The Capillaritron, a versatile source, is compact, simple in mechanical design and requires no cathode or similar delicate structure. No special discharge chamber is required to produce the ions and so only a single high voltage power supply is necessary for operation. The generation of ions and also fast neutral atoms occurs in the small plume at the end of the capillary nozzles. These nozzles are easily replaceable. Any gas can be used to operate the source which instantaneously turns on upon the flow of gas and application of high voltage.

The primary disadvantage of this source is the broad energy spread of the ions. This energy spread is produced in the luminous plume at the nozzle tip where the fast neutral atoms are produced. The lifetime of the nozzles, although strongly related to the operational level of the current, has been reported at well over 100 hours. In addition to charge ejection applications, the source has been used in such diverse applications as sputtering experiments, ion plasma chemistry, ion source for mass spectrometry and primary ions in secondary ion mass spectrometry.

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