NASA CR 114581
BSR 4036
Available to
the Public

A Study of the Feasibility of Mechanical Pumps for Use With the Pioneer-Venus Probe Mass Spectrometer Inlet System

(NASA-CR-114581) A STUDY OF THE FEASIBILITY OF MECHANICAL PUMPS FOR USE WITH THE PIONEER-VENUS PROBE MASS SPECTROMETER INLET SYSTEM Final (Bendix Corp.) ~~104~~ 108 p HC $7.25 CSCL 13K

N73-23551

Unclas
G3/15 02990

April 1973

Bendix Aerospace Systems Division

108

NASA CR 114581
BSR 4036
Available to
the Public

A Study of the Feasibility of Mechanical Pumps for Use With the Pioneer-Venus Probe Mass Spectrometer Inlet System

By N.C. Thomas, W.E. Crosmer
and D. Nowak

Prepared under Contract No. NAS 2-7384 by
The Bendix Corporation
Aerospace Systems Division
Ann Arbor, Michigan

for

AMES RESEARCH CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

April 1973

Bendix Aerospace Systems Division

CONTENTS

CONTENTS (CONT.)

ILLUSTRATIONS

ILLUSTRATIONS (CONT.)

TABLES

SECTION 1

SUMMARY

This is the final report of "A Study of the Feasibility of Mechanical Pumps for Use with the Pioneer-Venus Probe Mass Spectrometer Inlet System," Contract No. NAS2-7384. The study was initiated on 7 February 1973 and completed 7 April 1973.

A survey of mechanical vacuum pumps has been completed. The results indicate that some development work has been completed on a small Roots blower for flight mass spectrometer applications by the Arthur Pfeiffer Company of Wetzlar, Germany. This pump has been evaluated with respect to system operating parameters in a number of different modes of operation.

The study also shows that a metal bellows pump might be a viable alternative, although no work has been initiated on adapting the bellows approach to space flight conditions. This pump was also analyzed with regard to the system required for its operation.

The remaining contacts with pump manufacturers yielded no positive results. Mechanical vacuum pumps in general are very large and heavy, not suited to space applications, and the manufacturers did not respond favorably to a request for proposals.

This work concludes with specific recommendations to purchase and test the Pfeiffer Roots blower. A plan is presented which covers the tests required to evaluate the potential of the pump.

Appendix D is the New Technology report.

SECTION 2

INTRODUCTION

The purpose of this study is to determine the design feasibility of a small, lightweight, low power mechanical pump for use in an inlet system for the Pioneer-Venus Probe mass spectrometer. Specific tasks included:

- Conduct the necessary analysis to determine the design requirements for a small, lightweight, low power mechanical pump for use in an inlet system for the Pioneer-Venus Probe mass spectrometer.
- Conduct a survey of the state-of-the-art pumps to determine if any of these meet the requirements.
- Provide a preliminary design of a pump considered to be able to meet the requirements.
- Provide a plan to fabricate and test this pump.

This report contains the results of the study, including current status of possible flight-type pumps, a system analysis using available pumps, and recommendations for fabrication and test of a potential flight-type pump.

SECTION 3

BACKGROUND

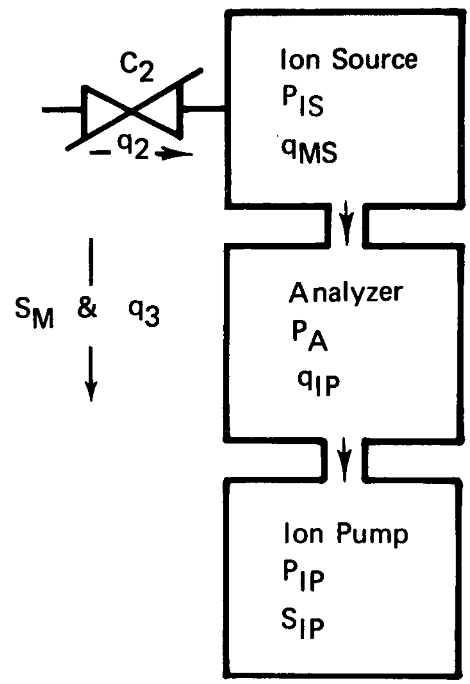
Little is known about the lower Venus atmosphere, especially below the dense cloud layers. A major scientific objective of the Pioneer-Venus Probe series is to determine the content of that atmosphere, including:

- Permanent gases, expected to be mostly CO_2 with some N_2.
- Vapors and condensates which make up the cloud layers, which may be H_2O, HCl, etc.
- Trace constituents, especially the inerts such as He.

The Pioneer-Venus Program as presently conceived includes a series of large and small probes which will measure various characteristics of the planet. Included in the large probe instrument package is a mass spectrometer for in situ measurements of the atmospheric composition. The design of the gas inlet system for the mass spectrometer will be no easy task, since the anticipated Venus atmosphere is characterized by pressures to 10^7 newtons/meter^2 (Pascals) (100 bars) and temperatures to 750°K at or near the surface. Since the mass spectrometer must operate at vacuums of 10^{-2} to 10^{-3} Pascal (10^{-7} to 10^{-8} bars), the pressure drop must cover nearly 10 orders of magnitude without any unknown changes in composition. In addition, it has been proposed that gas sampling be initiated at the time of parachute deployment at an altitude of 70 KM. This has a pressure on the order of 3×10^3 Pascals (30 millibars) which will require the inlet system to operate over almost four decades of pressure change.

The mass spectrometer itself will undoubtedly be a type which has already been designed and flown but with its mass range extended to 140 or 150 atomic mass units, to be consistent with the partial pressures expected in the Venus atmosphere due to the high temperature of the ambient gas. Such spectrometers have highly limited pumping capacity because of the weight constraints of their flight-configured design. A typical case is shown in Figure 3-1. The ion source slit, which has a conductance of 0.1 liter per second (ℓ/s) or less, limits the gas flow to approximately 7×10^{-4} Pascal ℓ/s. If the spectrometer is connected directly to the ambient atmosphere, then at 10^7 Pascals (100 bar), the conductance C_2 must be on the order of 10^{-10} ℓ/s.

	SI	General Use
P_2	100 Bar	7.4×10^{4} Torr
q_2	7×10^{-4} Pa ℓ/s	5×10^{-6} Torr ℓ/s
C_2	7×10^{-11} ℓ/s	7×10^{-11} ℓ/s
P_{IS}	1.3×10^{-2} Pa	10^{-4} Torr
q_{MS}	7×10^{-4} Pa ℓ/s	5×10^{-6} Torr ℓ/s
C_{MS}	50 cc/sec	50 cc/sec
Pa	1.3×10^{-3} Pa	10^{-5} Torr
Max q_{IP}	1.3×10^{-3} Pa ℓ/s	10^{-5} Torr ℓ/s
P_{IP}	1.3×10^{-3} Pa	10^{-5} Torr
S_{IP}	1 ℓ/s	1 ℓ/s



Assumptions :

1) Ion Source Slit C_{MS} = 50 cc/sec

2) Max $P_{IS} = 1.3 \times 10^{-3}$ Pa

3) Ion Pump = 1 ℓ/s

4) Max $P_{IP} = 1.3 \times 10^{-3}$ Pa

Thus:

→ $q_{IP} = 1.3 \times 10^{-3}$ Pa ℓ/s

→ $q_{IP} = 7 \times 10^{-4}$ Pa ℓ/s

11346-2

Figure 3-1 Schematic for Flight Mass Spectrometer

Making such conductance presents some difficulties. A capillary tube with a 0.01-mm inside diameter would be many kilometers long. An orifice, on the other hand, would be a couple of hundred angstroms in diameter and would have no mechanical strength capable of holding off 10^7 Pascals pressure. A compromise between these two even seems beyond reason.

Even if construction difficulties are overcome, the effect of a 10^{-10}-ℓ/s restrictor is an even more serious problem. Long capillaries would have long time constants. Extremely small orifices such as the microcracks in a sintered porous plate may have selective pumping characteristics. The large surface area as compared to the low flow rate can affect sample integrity through selective sorption and desorption processes.

The recommended solution is to bring a larger quantity of gas into the probe. The pumping capability of the system would have to be increased, but several advantages are immediately realized. Specifically, the restrictor conductance values are increased and are thus easier to fabricate. Response time will decrease. And the sorptive processes will have a less adverse effect since the hardware surfaces will more quickly saturate.

If this approach is accepted, the pump type and system design can be determined. These two items are not independent since the different types of vacuum pumps operate most efficiently at different pressures. For example, an additional ion pump could be added to the mass spectrometer, either in the analyzing or ion section. Such a pump is near ideal because active gases are turned to solid and hence removed from the system. But the throughput of ion pumps is extremely poor per kilogram of pump mass. A mercury diffusion pump, even with a mechanical backer, would provide superior throughput and may be operated at higher pressures; but the problems associated with the pump fluid encourage the investigation of other pump types.

This study, then, was initiated to investigate one of the more promising approaches to a high flow, space-suited vacuum pump — the mechanical vacuum pump.

SECTION 4

MECHANICAL PUMP AND INLET SYSTEM DESIGN MODEL

A basic inlet system model was established to assist in the investigation of mechanical vacuum pumps. As shown in Figure 4-1, it consists of two restrictors—one, C_1, to drop the Venus ambient pressure to an intermediate level, P_2, and a second, C_2, to drop P_2 to approximately 1×10^{-2} Pascals, the maximum working level of the ion source. The volume midway between the restrictors is pumped by the mechanical vacuum pump. The characteristics of the mass spectrometer from Figure 3-1 have been included in the chart, and the flow into the system q_1 is tentatively assumed to be 10 thousand times the flow into the mass spectrometer. Variations of this model include pressure-adjusted flow and throughput-adjusted flow, as discussed below.

4.1 INLET SYSTEM NOMOGRAM

To assist in the process of determining the remainder of the inlet system design parameters, a "nomogram" has been constructed which provides ready answers to design changes. It is based on "worst case" conditions of 10^7 Pascals at the planet surface, but may be used at any point in the mission. A description of its construction coincident with an example will be used to explain the chart.

4.1.1 Viscous Flow - Step 1

The first stage pressure drop is accomplished across C_1. Conductance is given by the flow divided by the pressure drop across the restrictor

$$C = \frac{q}{P_{in} - P_{out}} \text{ or } \frac{q}{\Delta p} \qquad (4-1)$$

This formula can be simplified for pressure drops greater than about 100, depending on the use. In the viscous flow region, the conductance becomes

$$C_{vis} \simeq \frac{q}{P_{in}} = \frac{q}{100 \text{ bar}} \qquad (4-2)$$

for the worst case condition.

	SI	General Use
P_1	100 Bar	74,000 Torr
V_1		
q_1	6.7 Pa ℓ/s	5×10^{-2} Torr ℓ/s $\simeq 10^4 q_2$
C_1		
P_2		
V_2		
q_{MS}	6.7×10^{-4} Pa ℓ/s	5×10^{-6} Torr ℓ/s
q_2	6.7×10^{-4} Pa ℓ/s	5×10^{-6} Torr ℓ/s
C_2		
P_3		
V_3		
q_3	6.7 Pa ℓ/s	5×10^{-2} Torr ℓ/s
SM		
P_{IS}	1.3×10^{-2} Pa	10^{-4} Torr
C_{MS}	50 cc/sec	50 cc/sec
Pa	1.3×10^{-3} Pa	10^{-5} Torr
q_{IP}	1.3×10^{-3} Pa ℓ/s	10^{-5} Torr ℓ/s
P_{IP}	1.3×10^{-3} Pa	10^{-5} Torr
S_{IP}	1 ℓ/s	1 ℓ/s

11346-3

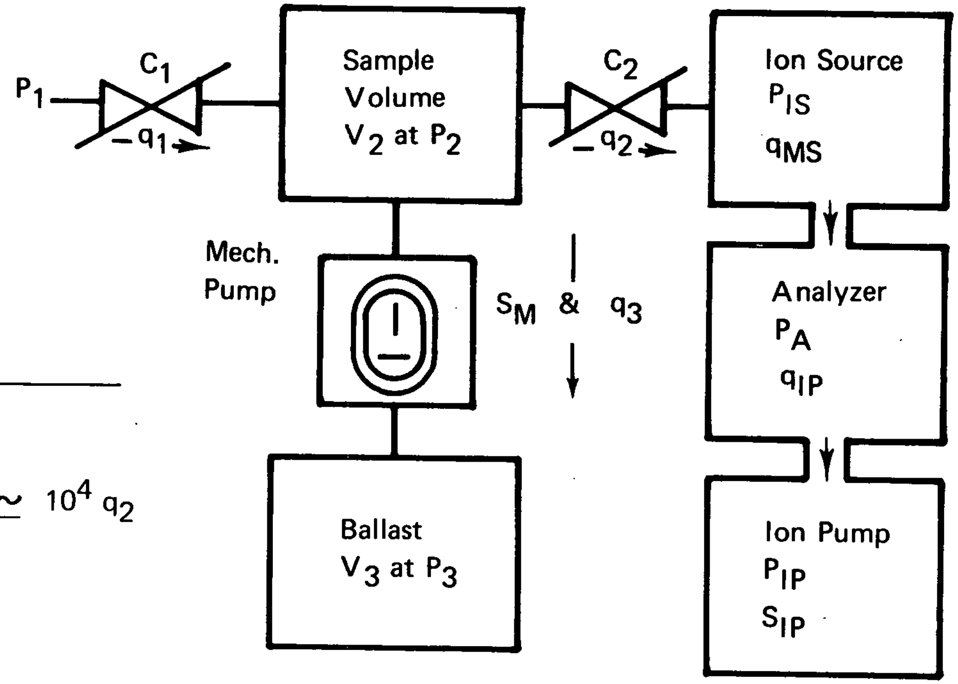


Figure 4-1 Mechanical Pump Inlet System Schematic

We enter the chart, Figure 4-2, near the left at the desired input flow contour level of 6.7 Pa ℓ/s (from Figure 4-1). This yields a conductance value of 8 x 10^{-7} ℓ/s for an output pressure less than about 1 bar.

4.1.2 Sample Volume Pressure and Mechanical Pump Speed—Step 2

For this example, the sample volume pressure P_2 is arbitrarily chosen midway between Venus atmosphere and the ion source pressure on a log scale at 3 x 10^2 Pascals. The required pump speed is derived from

$$S = \frac{q_1}{P_2} \tag{4-3}$$

Both the calculations and the nomograph yield a required mechanical pump speed of 2 x 10^{-2} ℓ/s (Figure 4-3).

4.1.3 Mass Spectrometer Flow and Molecular Conductance — Step 3

The molecular or ion source conductance is obtained from

$$C_{mol} \simeq \frac{q_2}{P_2} \tag{4-4}$$

where P_2 is the pressure of the sample chamber and is much greater than the ion source pressure. Again, calculations and the nomograph provide an answer of 2 x 10^{-6} ℓ /s (Figure 4-4) molecular conductance for q_2 = 6.7 x 10^{-4} P_a-ℓ /s.

The nomograph was designed to go from Venus ambient atmosphere to mass spectrometer pressure reading from left to right. This results in the pressure and molecular conductance being plotted in a manner contrary to accepted practice. Figure 4-5 updates the inlet design model. Thus far, the system analysis has used only an input pressure of approximately 10^{-7} Pascals (100 bars).

4.2 SYSTEM ANALYSIS FROM VENUS ATMOSPHERIC PRESSURE MODEL

Other analyses of the basic system requirements can be made from the Venus atmospheric model. Figure 4-6 is a plot of the Venus atmospheric model in bar-seconds (10^5 Pascals seconds) as a function of the descent time. This was calculated by multiplying the mean pressure for each sample by the sampling time, either 3 or 6 minutes (Reference 1). The sum of all the sample points totals 9.3 x 10^9 Pascal-seconds (9.3 x 10^4 bar-seconds).

11346-4

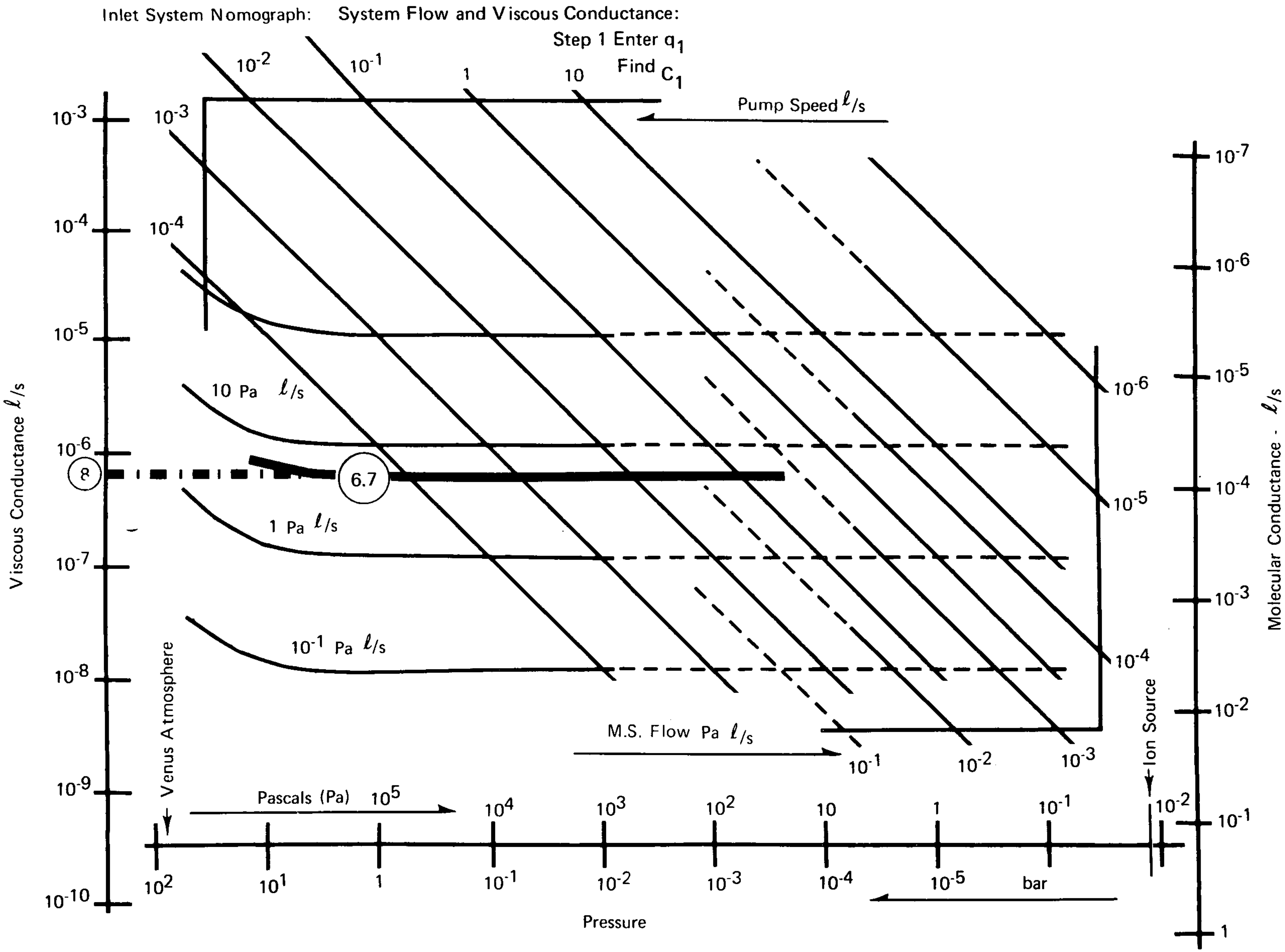


Figure 4-2 Nomograph—Viscous Conductance, Step 1

11346-5

Inlet System Nomograph: Sample Volume Pressure and Mechanical Pump Speed:

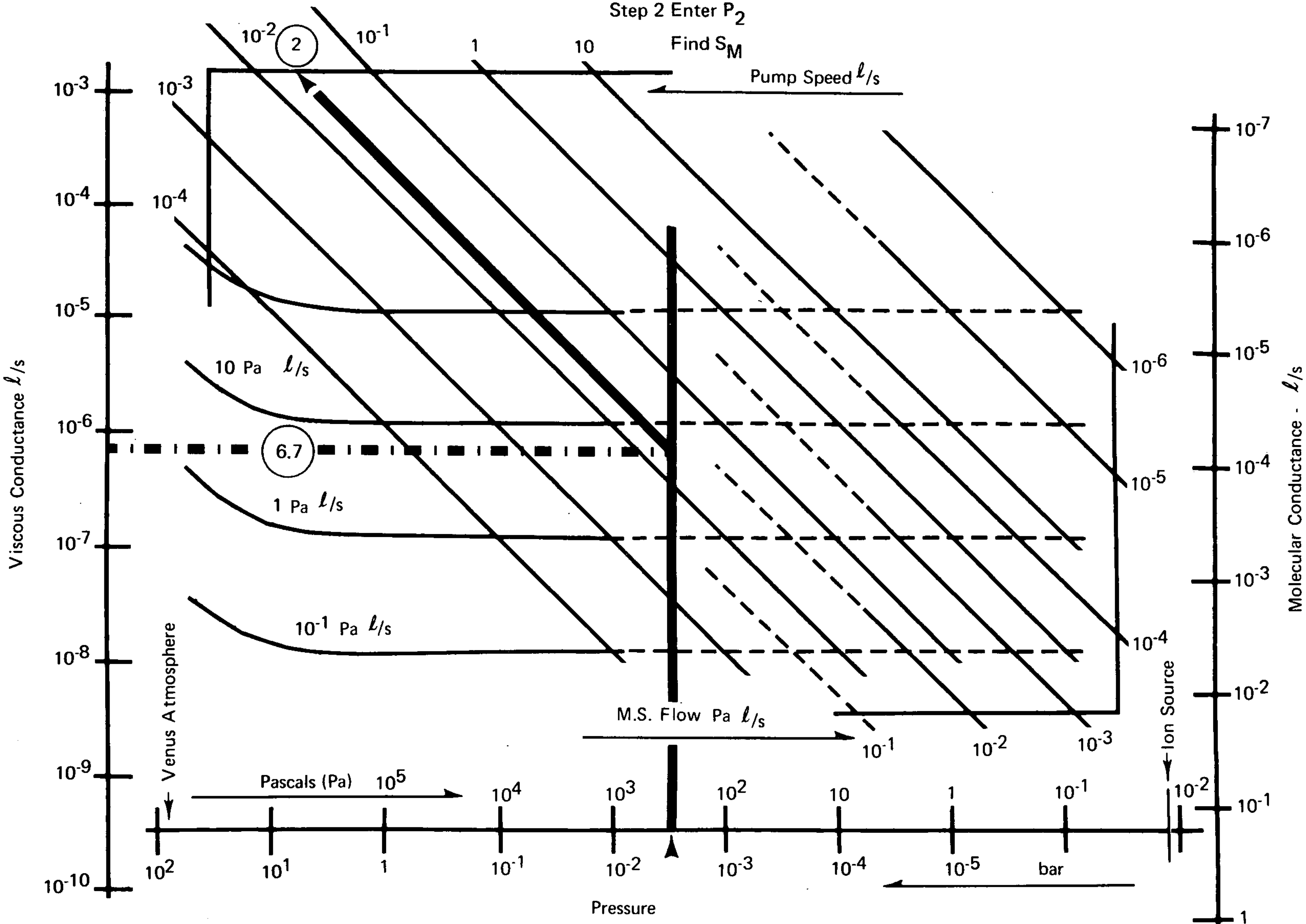


Figure 4-3 Nomograph—Sample Volume Pressure and Mechanical Pump Speed, Step 2

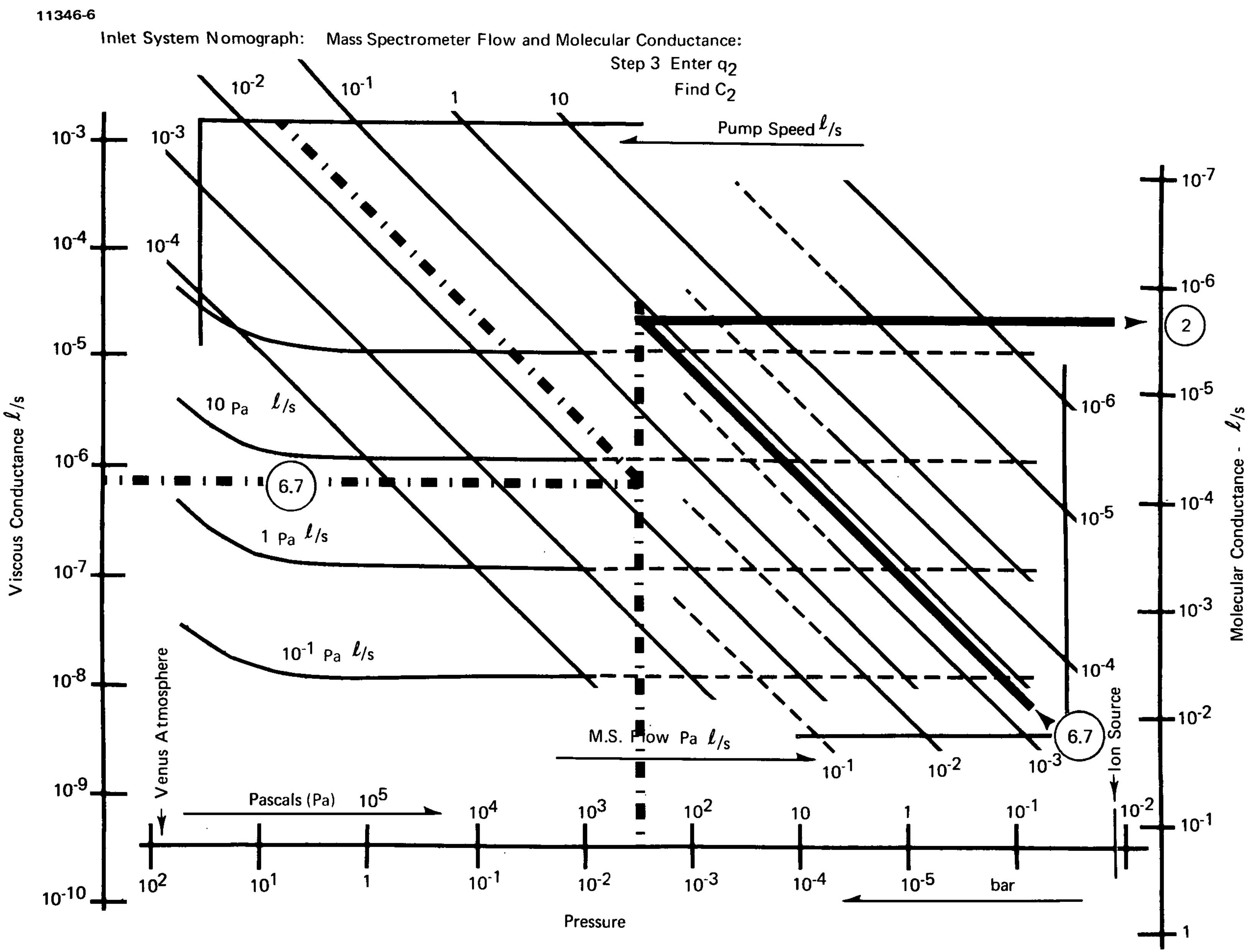
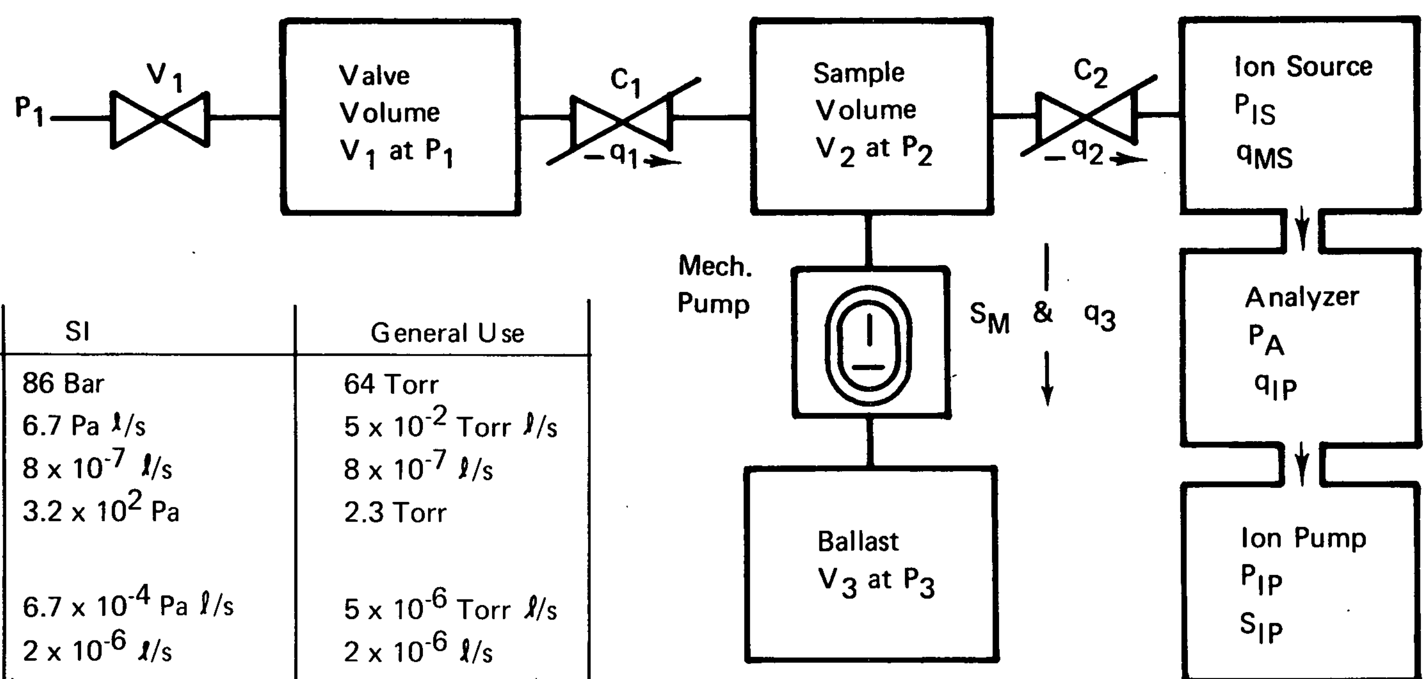


Figure 4-4 Nomograph—Mass Spectrometer Flow and Molecular Conductance, Step 3



	SI	General Use
P_1	86 Bar	64 Torr
q_1	6.7 Pa ℓ/s	5×10^{-2} Torr ℓ/s
C_1	8×10^{-7} ℓ/s	8×10^{-7} ℓ/s
P_2	3.2×10^{2} Pa	2.3 Torr
V_2		
q_2	6.7×10^{-4} Pa ℓ/s	5×10^{-6} Torr ℓ/s
C_2	2×10^{-6} ℓ/s	2×10^{-6} ℓ/s
P_3	} Depends on	
V_3	} Pump Type	
q_3	6.7 Pa ℓ/s	5×10^{-2} Torr ℓ/s
S_M	2×10^{-2} ℓ/s	2×10^{-2} ℓ/s
P_{IS}	1.3×10^{-2} Pa	10^{-4} Torr
q_{MS}	6.7×10^{-4} Pa ℓ/s	5×10^{-6} Torr ℓ/s
C_{MS}	50 cc/sec	50 cc/sec
Pa	1.3×10^{-3} Pa	10^{-5} Torr
q_{IP}	1.3×10^{-3} Pa ℓ/s	10^{-5} Torr ℓ/s
P_{IP}	1.3×10^{-3} Pa	10^{-5} Torr
S_{IP}	1 ℓ/s	1 ℓ/s

Figure 4-5 Mechanical Pump Inlet System Schematic—Example

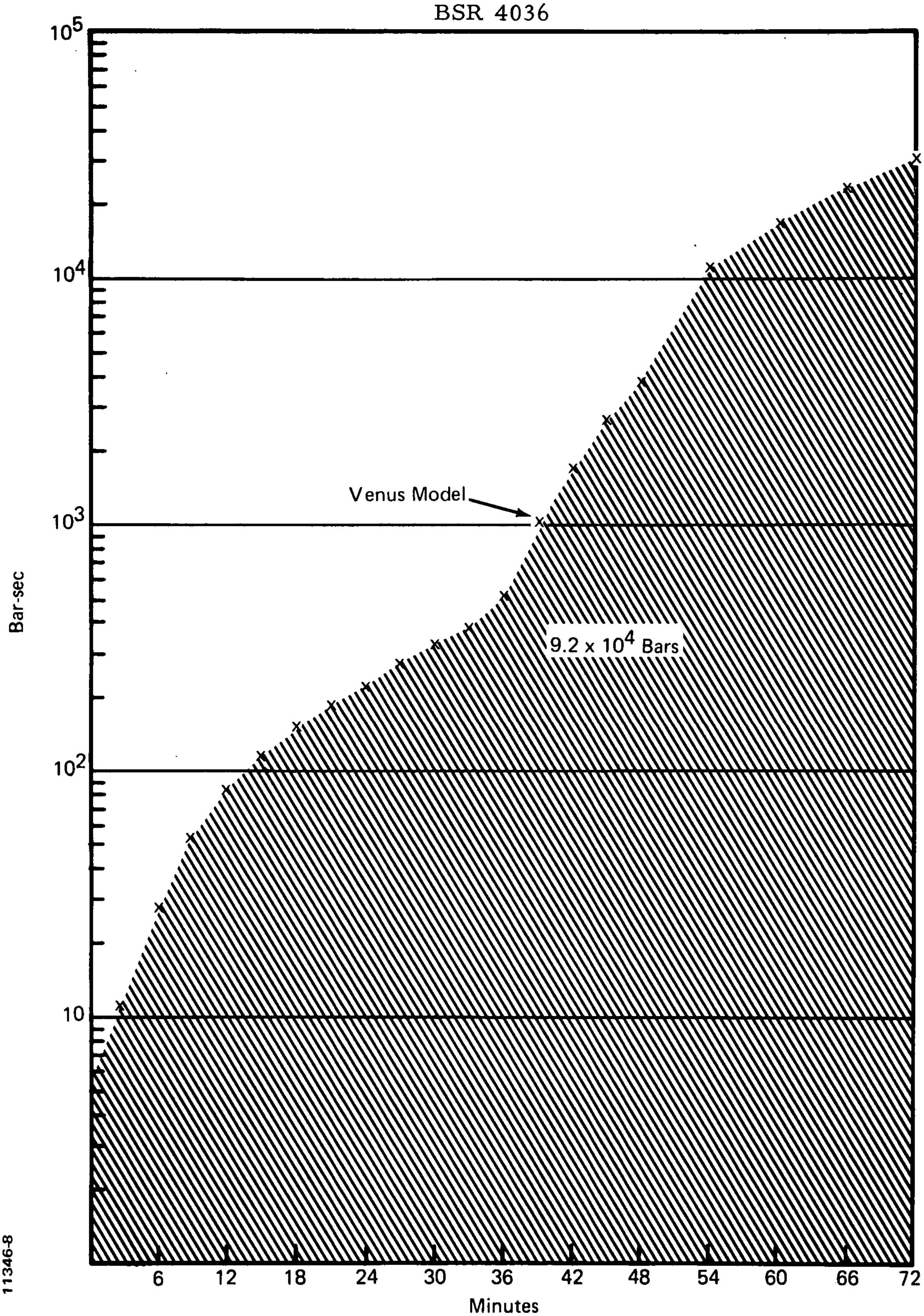


Figure 4-6 Venus Atmosphere Pressure Model

The quantity of gas passing through a single, fixed restrictor with the input pressure profile as above would be:

$$Q_1 = 9.3 \times 10^9 \text{ Pa} \cdot \text{sec} \cdot C_1. \tag{4-5}$$

For

$$C_1 = 7 \times 10^{-6} \ \ell/\text{s} \tag{4-6}$$

$$Q_1 = 64{,}000 \text{ Pascal liters (0.64 bar liter).} \tag{4-7}$$

It is unlikely that a single fixed restrictor (C_1, as shown in Figure 4-1) will be used for the entire mission, because the ion source pressure would track the Venus atmosphere over a three-decade or more change (assuming constant pumping speed, S_M, and fixed volumes, V_2). Inlet system models have been proposed using three restrictors, with conductance values one order of magnitude apart, which would be valved into the system sequentially as the ambient pressure increases. Figure 4-7 shows the pressure-time profile of such a system, where

$$x = C_{1a} \text{ conductance} \tag{4-8}$$

$$0.05\,x = C_{1b} \text{ conductance} \tag{4-9}$$

$$0.005\,x = C_{1c} \text{ conductance} \tag{4-10}$$

Here, the total quantity of gas entering the system is

$$Q_1 \cong 1.2 \times 10^7 \text{ Pascal sec} \cdot x \tag{4-11}$$

where x is to be determined.

4.2.1 Model 1 - Constant Flow

If the flow into the mass spectrometer is held constant with a variable speed pump at 7.4×10^{-4} Pascal ℓ/s, a total quantity of

$$Q_1 = q_2 \cdot 72 \text{ min}$$

$$\simeq 3.2 \text{ Pa} \cdot \ell \tag{4-12}$$

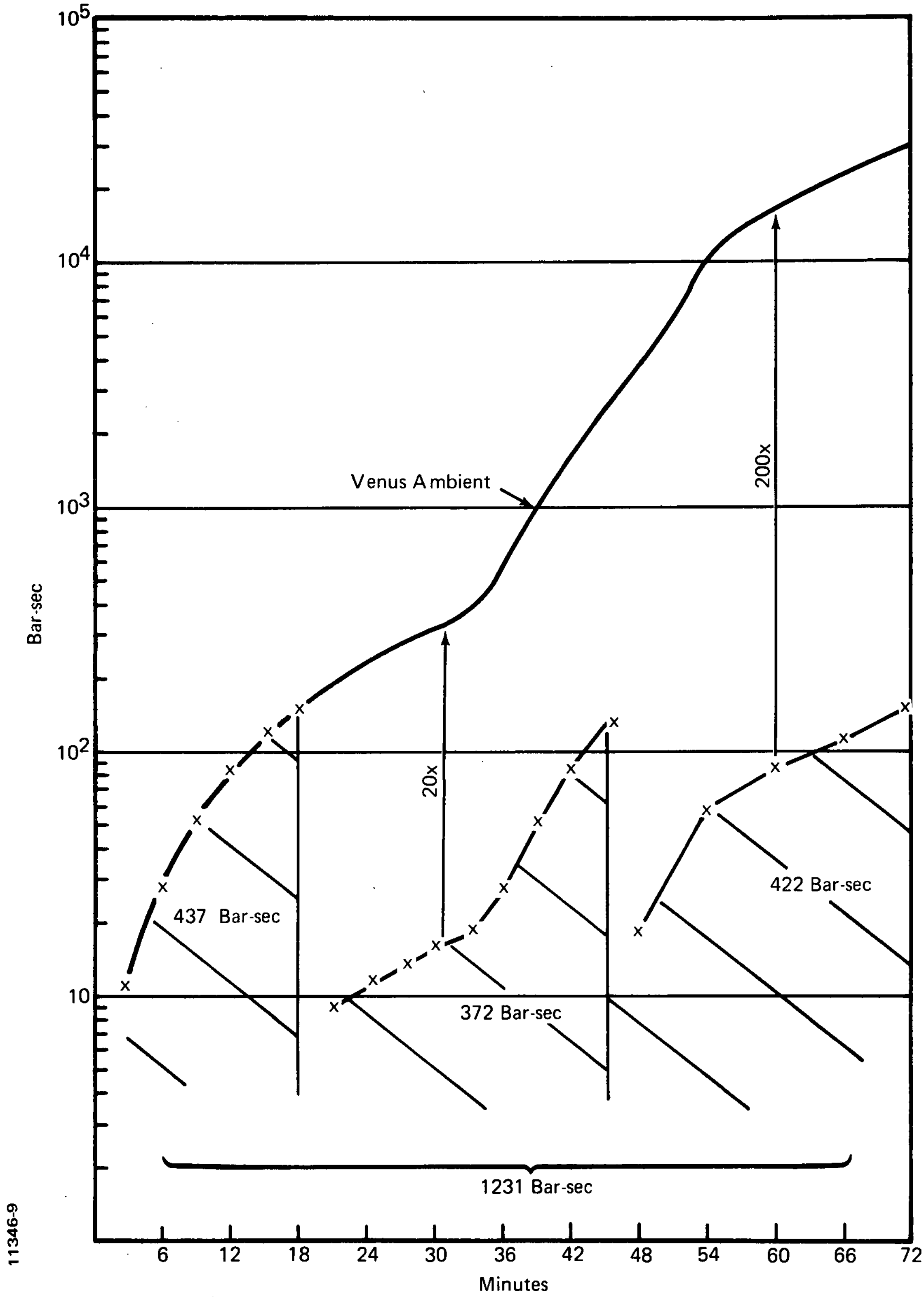


Figure 4-7 Pressure-Time Profile for Three-Restrictor System

If q_1 is to be 10^4 q_2, then $Q_1 = 10^4 Q_2$ and

$$Q_1 = 32{,}000 \text{ Pa-}\ell \tag{4-13}$$

Thus, from equation 4-11 above,

$$x = 2.6 \times 10^4 \ \ell/\text{s}.$$

The other two restrictors follow:

$$\begin{aligned} 0.05\ x &= 1.3 \times 10^{-5}\ \ell/\text{s} \\ 0.005\,x &= 1.3 \times 10^{-6}\ \ell/\text{s} \end{aligned} \tag{4-14}$$

For this model a total quantity of 3.2×10^4 Pa-ℓ must be pumped. If this is pumped into a vacuum ballast, then depending on the ballast size, there will be a certain pressure rise, e.g.,

$$\text{for } 1\ell \rightarrow 3.2 \times 10^4 \text{ Pa} \tag{4-15}$$

$$\text{for } 3\ell \rightarrow 1.1 \times 10^4 \text{ Pa} \tag{4-16}$$

This pressure must be developed by the mechanical pump or handled in some other way— such as a chemical backing pump. Table A-1, Appendix A, summarizes these data.

4.2.2 Model 2 - Constant Flow, Pressure Adjusted

Adjustments can be made to the existing model inlet system depending on the desired characteristics. For example, the end point pressure for the three stages (effected by the three different restrictors) would be:

a) 21.2 Pa

b) 19.6 Pa (4-17)

c) 11.6 Pa

If the molecular conductance was of a fixed value, then the sensitivity of the mass spectrometer is far from optimized. But by changing the last restrictor to a 0.010-x from a 0.005-x value, the three P_2 end point pressures become:

a) 21.2 Pa

b) 19.6 Pa (4-18)

c) 22.6 Pa

if x remains at 2.6×10^{-4} ℓ/s. This would result in an increase in q_1 to greater than $10^4\ q_2$, and the ballast volume would increase

$$\text{for } 1\ell \rightarrow 4.3 \times 10^4 \text{ Pa} \tag{4-19}$$

$$\text{for } 3\ell \leftarrow 1.4 \times 10^4 \text{ Pa} \tag{4-20}$$

The data for Model 2 are found in Table A-2 of Appendix A.

4.2.3 Model 3 - Constant Flow, Throughput Adjusted

By readjusting the value of x to 1.92×10^{-4} ℓ/s, q_1 can be held to $10^4\ q_2$; and with a 1, 0.05, 0.01 ratio, the three P_2 end point pressures become

a) 15.6 Pa

b) 14.4 Pa (4-21)

c) 16.2 Pa

Table A-3 of Appendix A summarizes the above data.

4.3 RESTRICTORS (CONDUCTANCE)

Some understanding of restrictor design and performance is helpful before attempting to determine the remaining parameters in the inlet design model. Concern has been expressed regarding possible sample modification by these restrictors. An optimum design would be small, with a minimum surface area as compared to the "transport" volume. The annular slit restrictor design approaches these criteria. It is constructed by inserting a close-fitting rod into a tube. The desired conductance is adjusted by concentrically swaging the outside of the tubing.

Calculations show that the molecular and viscous conductance values of a given size restrictor of this type are roughly equivalent at 7×10^{-6} ℓ/s, as shown in Figure 4-8. At this point, the gas molecules would have equal difficulty passing through the restrictor in the two regions of gas flow. These calculations need experimental verification. A system nomograph, showing operation for a system with equal-sized conductances, is given in Figure 4-9.

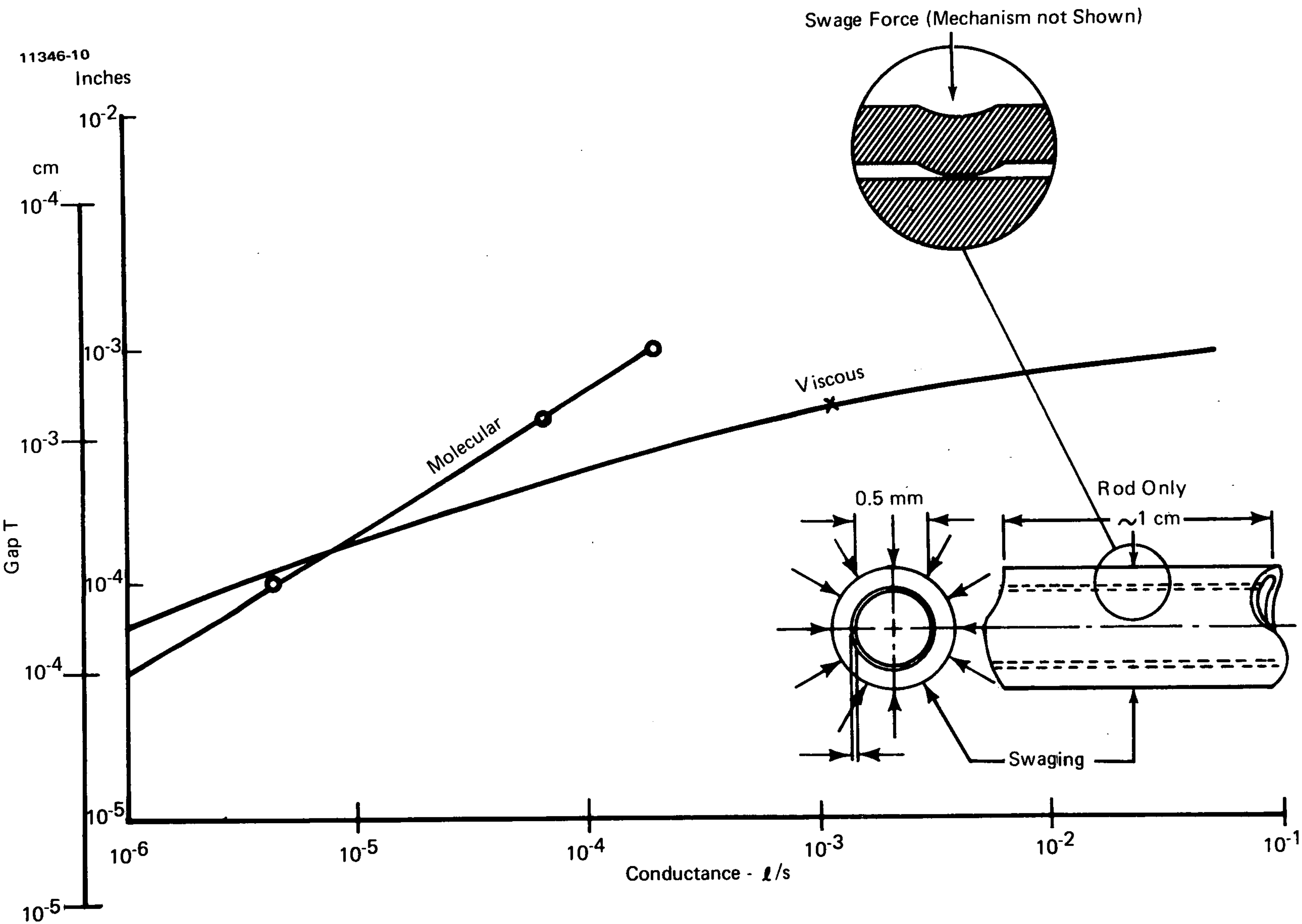


Figure 4-8 Annular Slit Restrictor

11346-11

Inlet System Nomograph: Equal Value Restrictors

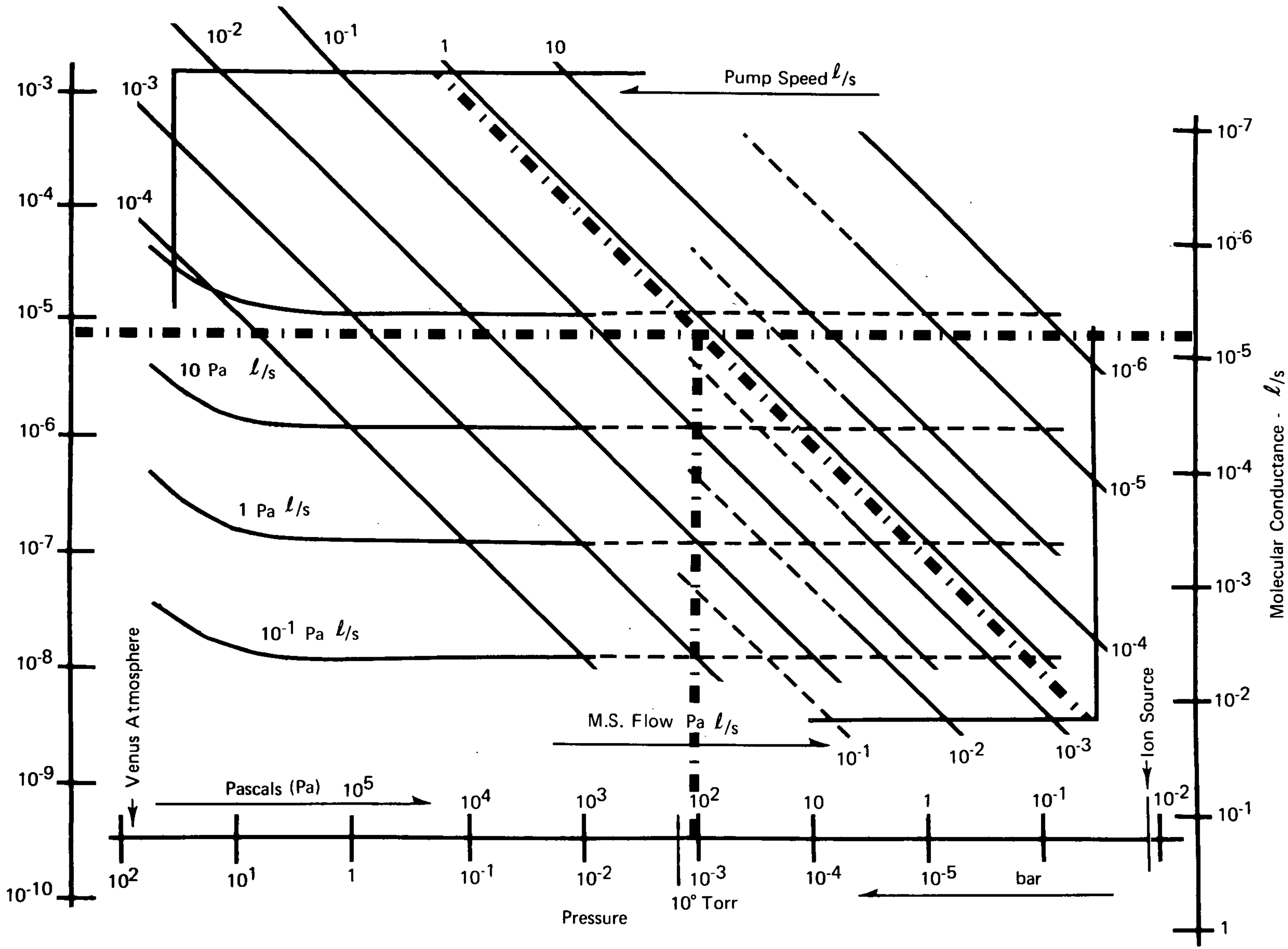


Figure 4-9 Nomograph with Equal Value Restrictors

SECTION 5

MECHANICAL VACUUM PUMPS

A variety of mechanical pump types have been developed over past years, but only a few have found widespread use in the vacuum field. No serious attempt has been made in this study to consider the development of a new type of pump; rather, emphasis has been placed on evaluating the state-of-the-art with respect to the mission requirements. The process of elimination made it unnecessary to evaluate each pump point by point. Thus, effort was saved for investigation of only the more obvious contenders. However, a rather lengthy list of characteristics was kept in mind to serve as a guideline. These included:

- Input pressure range.
- Compression ratio—output pressure.
- Speed.
- Throughput per unit mass.
- Efficiency—power requirements.
- Necessity of fluids.
- Backstreaming.
- Sample contamination.
- Effect of G-force loading.
- Preferred orientation.
- Bakeout temperatures.
- Starting power.
- Reliability.

Several characteristics seemed common to almost all available pumps regardless of type:

- They are large, heavy, and intended for heavy duty laboratory and industrial purposes.
- Power requirements are likewise excessive.
- Little consideration is given to the drive design; drive motors are often assumed to be available from stock— sometimes from another supplier.

For these reasons, it was difficult to project a flight design, with one exception. In this case, flight design development preceded this study by some months.

5.1 POSITIVE DISPLACEMENT PUMPS

The most common mechanical vacuum pump is the positive displacement pump (PDP) which, by one method or another, traps gas in a given volume and transfers it to a second volume. Some pumps compress the gas into a smaller volume at a higher pressure before exhausting the gas from the chamber to ambient or into another pumping stage. The common piston pump, with input and output valves, readily illustrates the principle.

5.1.1 Bellows Pumps

Piston pumps as such are not generally used in vacuum work; however, the bellows pump closely resembles the piston, as shown in Figure 5-1. Many advantages can be realized in this type of pump. Specifically, it:

- Has an extremely high throughput for its size due to the high pressure operation.
- Is simple in construction; highly reliable.
- Contains no contaminating fluids.
- Can handle high temperature gases.

There is one limiting disadvantage; it exhibits negligible pumping speed at pressures below about 10^4 Pascal (0.1 bar).

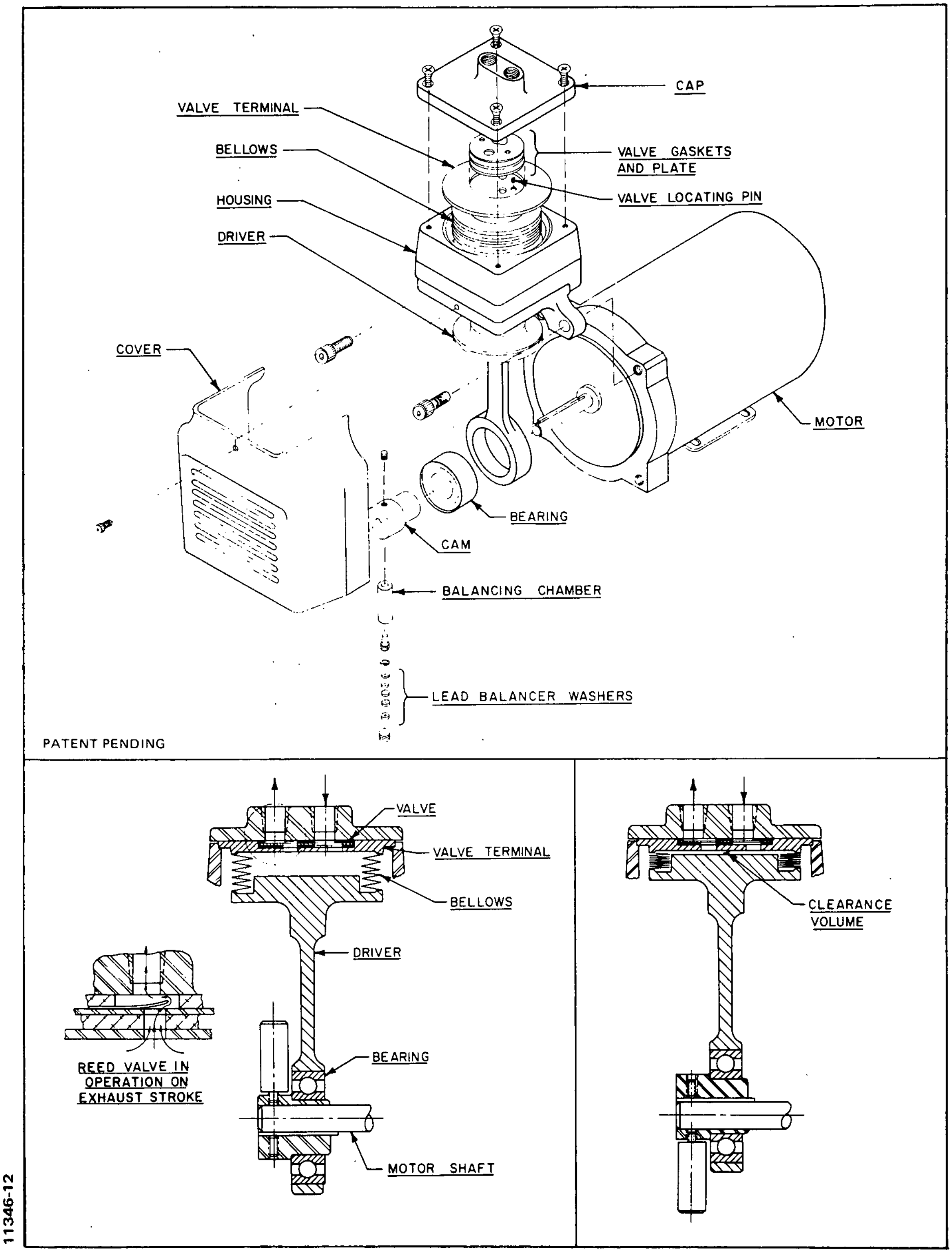


Figure 5-1 The Bellows Pump - Manufactured by Metal Bellows Corporation

The input and output reed valves limit the pump to higher pressure applications. A real, mechanical pressure is required to operate the valves. Positive actuators might be incorporated into the pump design for lower pressure operation, but this would require some development effort.

5.1.2 Diaphragm Pumps

The diaphragm pump does not need to be discussed in detail because of its similarity to the bellows variety. Frequently, the diaphragm is made of a synthetic, rubber-like material, perhaps Teflon; but it could be fabricated like an aneroid barometer of stainless steel. The problems and advantages are common to the bellows. No diaphragm pump models suitable for flight use have been identified.

5.1.3 Trochoid Pumps

The name "rotary piston" has been applied to a variety of different designs. With some exceptions, as noted in the following sections, pumps designed on the principle of a rotating piston have not found widespread use in the vacuum. Recently, renewed interest in this design has been sparked by the Wankel engine. This pump is quite similar in construction to the sliding vane design (covered in Section 5.1.6) except that the trochoid principle eliminates the need for the vanes to have the in-out sliding motion. Some disadvantages remain, i.e., the need for oil sealing and a lack of small-size experience in the state-of-the-art. Leybold-Heraeus recently introduced trochoid vacuum pumps in two sizes, both large. Current development by the company is centered around even larger pumps.

5.1.4 Sliding Piston Pumps

The rotary piston pump most used for vacuum work today is shown in Figure 5-2. This pump is also frequently called the "eccentric piston and slide" or "rotating plunger" pump. Not of a trochoid design, there is sliding action between the piston assembly and the housing. No actual metal-to-metal contact takes place, since sealing is accomplished by a thin layer of oil between the two parts.

This pump has two major disadvantages, the requirement for oil and the imbalance due to the eccentric motor. At rotation speeds of a few hundred revolutions per minute, such pumps vibrate wildly unless firmly anchored.

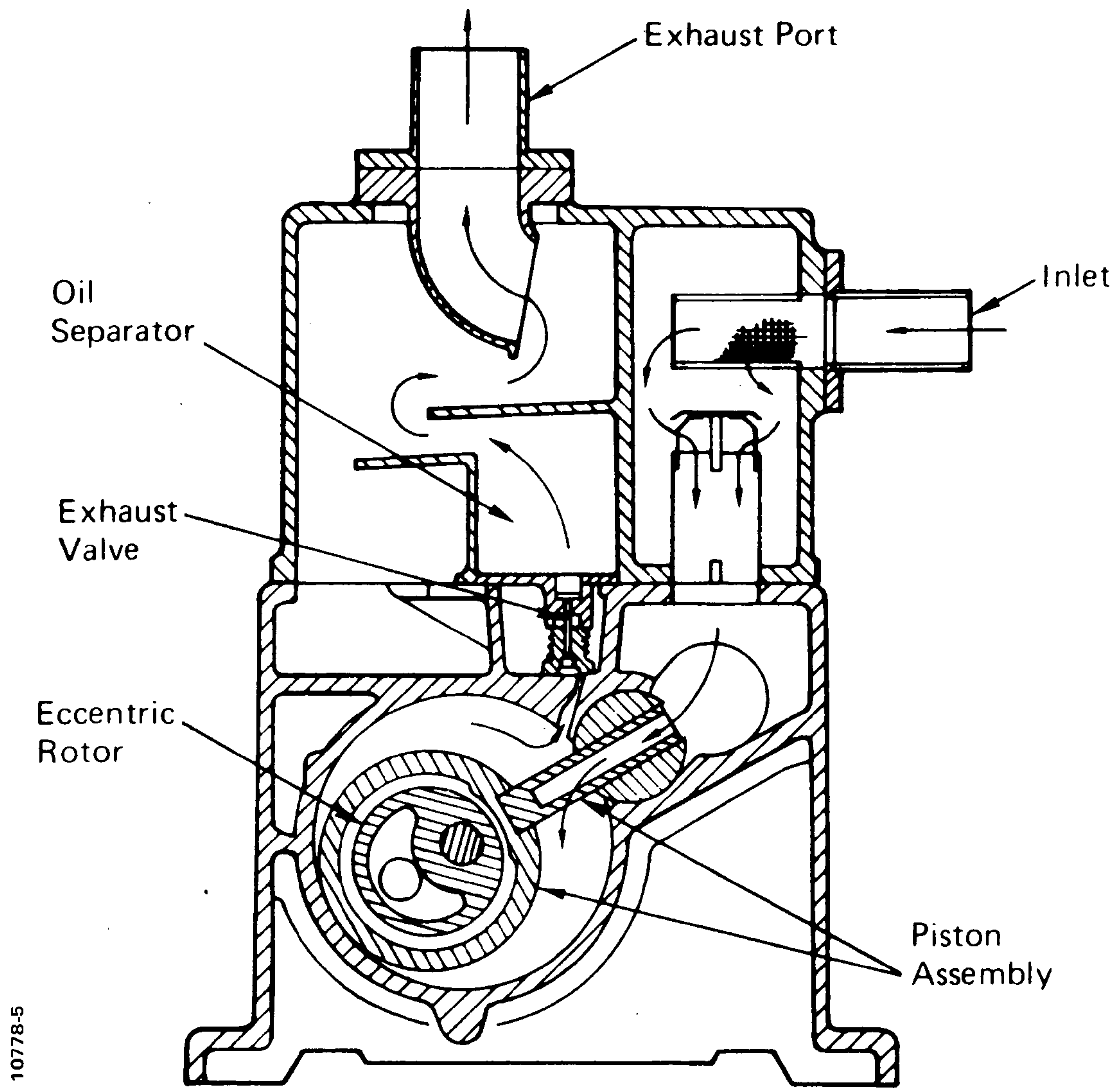


Figure 5-2 Rotating Plunger Mechanical Pump

5.1.5 Sliding Vane Pumps

The sliding vane shown in Figure 5-3 does not have major vibration problems. The rotor is concentrically driven but placed eccentrically in the housing. The compression chamber is defined by the vanes, rotor, and casing.

The sliding vane pump is available in two types—one which uses oil for lubrication and sealing, and the other which is constructed with carbon or graphite composition vanes. Oil, as pointed out earlier, would be a disadvantage in a flight type pump, because of possible contamination of the sample. Weightless flight compounds this problem. Carbon vane "dry" pumps are free of oil and are inherently less complicated. They are frequently constructed without valves, run at higher speeds, and have high throughput for the size. But the dry pump does not have the ultimate vacuum capability that is characteristic of the oil sealed type. Oil pumps can obtain vacuums to 10 Pascals (1 Pascal in the two-stage, compound variety), whereas the carbon vane pump bottoms out at about 500 to 1,000 Pascals.

In addition to the previously noted disadvantages, all the positive displacement, rotary pumps discussed thus far have a major common disadvantage—friction. The sealing is positive, either by a solid to solid, or by a film of oil. And as a result, starting and running power requirements are high and heat is generated, which in common use is dissipated by convection, forced air, or water or oil cooling. This is not generally compatible with the probe constraints if better means can be determined. The bellows pump is superior in this respect.

5.2 MOLECULAR PUMPS

Molecular pumps transfer gas in a given direction by means of molecular drag of a rapidly rotating member. In 1913, Gaede first developed a pump with a rotating disk in close proximity to the casing or stator, as shown in Figure 5-4. A number of variations of this design were developed. Multi-staged disks were employed. Holweck used a rotating cylinder in a grooved cylindrical housing. Geeghahm used a single disk which spun inside shields cut with spiral grooves. Williams and Beams suspended the rotor on a vertical shaft magnetically in order to have a completely vacuum sealed, friction free pump. The rotor was driven by induction.

Most molecular pumps require tolerances of 0.025 mm making such pumps subject to seizure from small entrained dirt particles.

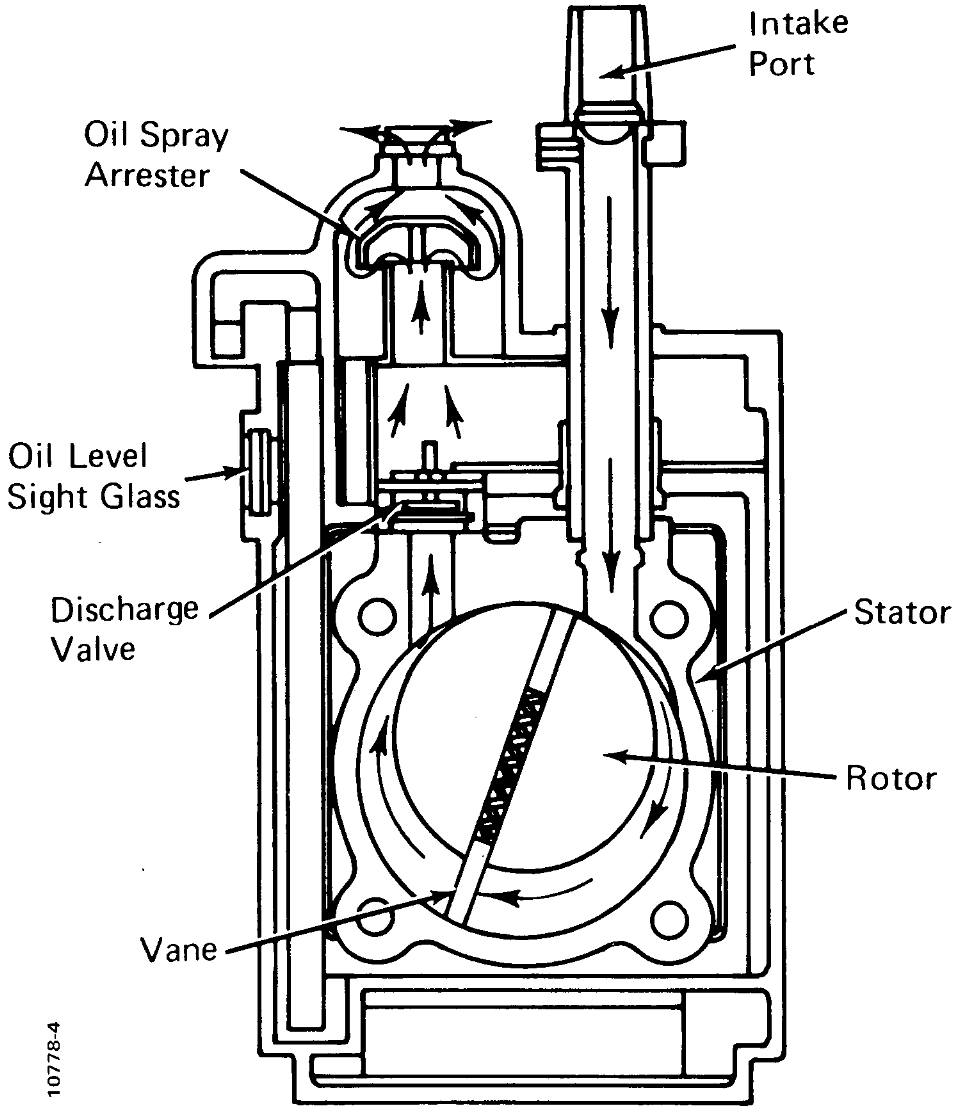


Figure 5-3 Sliding Vane Pump

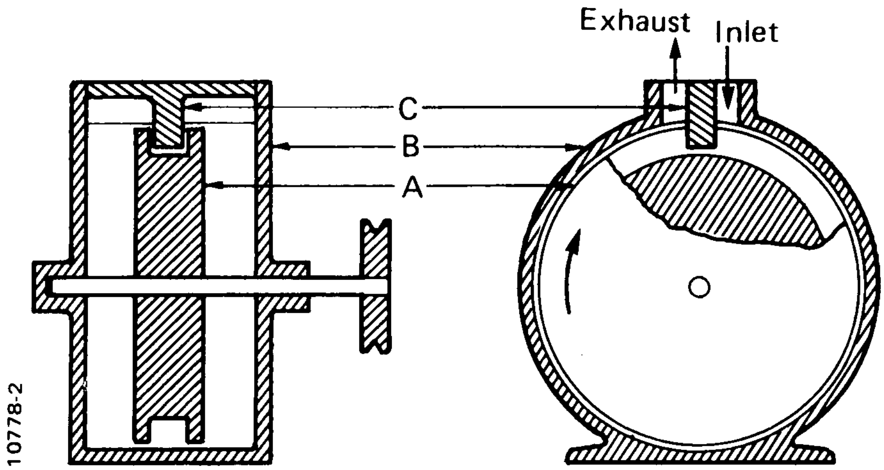


Figure 5-4 Gaede Type Molecular Pump

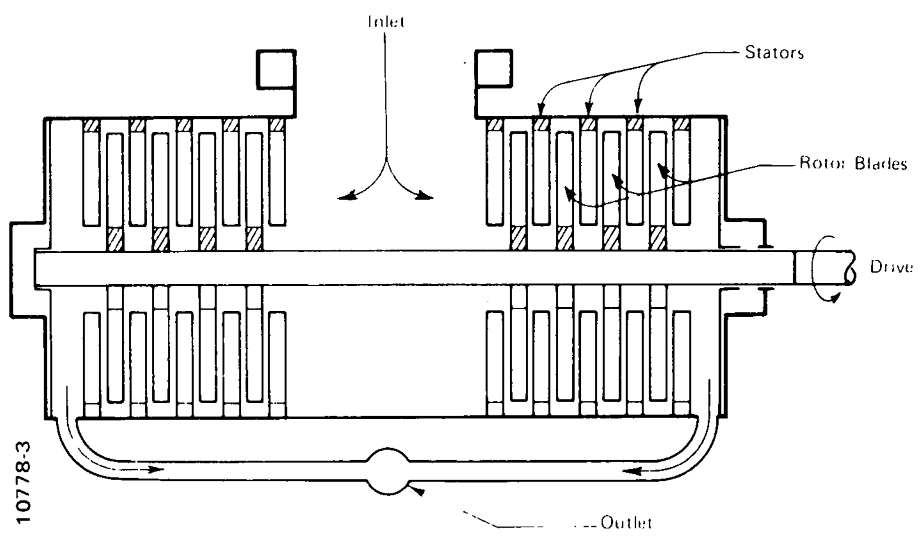


Figure 5-5 Turbo-Molecular Pump - Horizontal

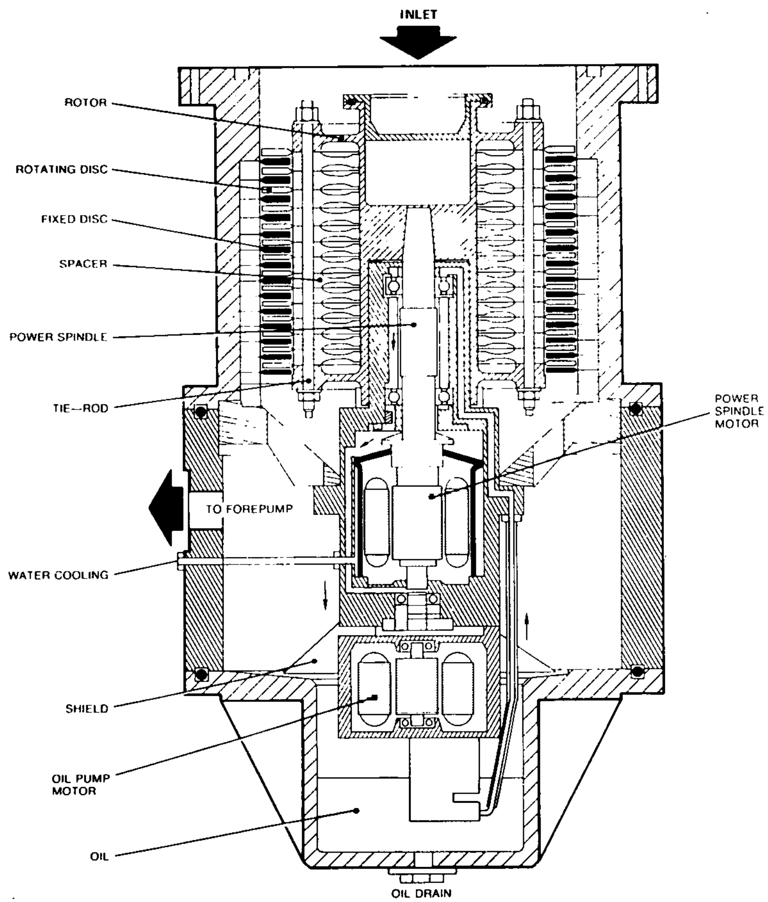
The turbo-molecular pumps have been more viable in vacuum applications. Figure 5-5 shows the development of the technique by Pfeiffer, who used rotating and stationary blades in a cylindrical housing in a series of axial flow compressor stages. Tolerances between blades for this type were opened to 1 mm. A typical pump with 17 stages and a diameter of 17 cm is rotated at 16,000 rpm. Sealed oil bearings are employed, but because their location is at the high-pressure region of the pump, they are less of a problem than in some other mechanical designs. More recently, vertical designs have been introduced on the market. Two are shown in Figure 5-6.

These pumps may be started at 10^2 to 10^3 Pascals, reach full pumping speeds at 10^{-1} Pascals, and have a flat characteristic out to 10^{-8} Pascals. Ultimate pressures of 5×10^{-8} Pascals can be obtained with hydrogen as the principal residual constituent. Pumping speed is greatest for the lighter gases; however, the ratio of outlet to inlet pressure increases with molecular weight. The maximum compression ratio for hydrogen is 250 to 1, while for air it is 5×10^7 to 1. The backstreaming of heavy oil molecules is extremely low, and clean vacuums can be obtained with a minimum of cold trapping.

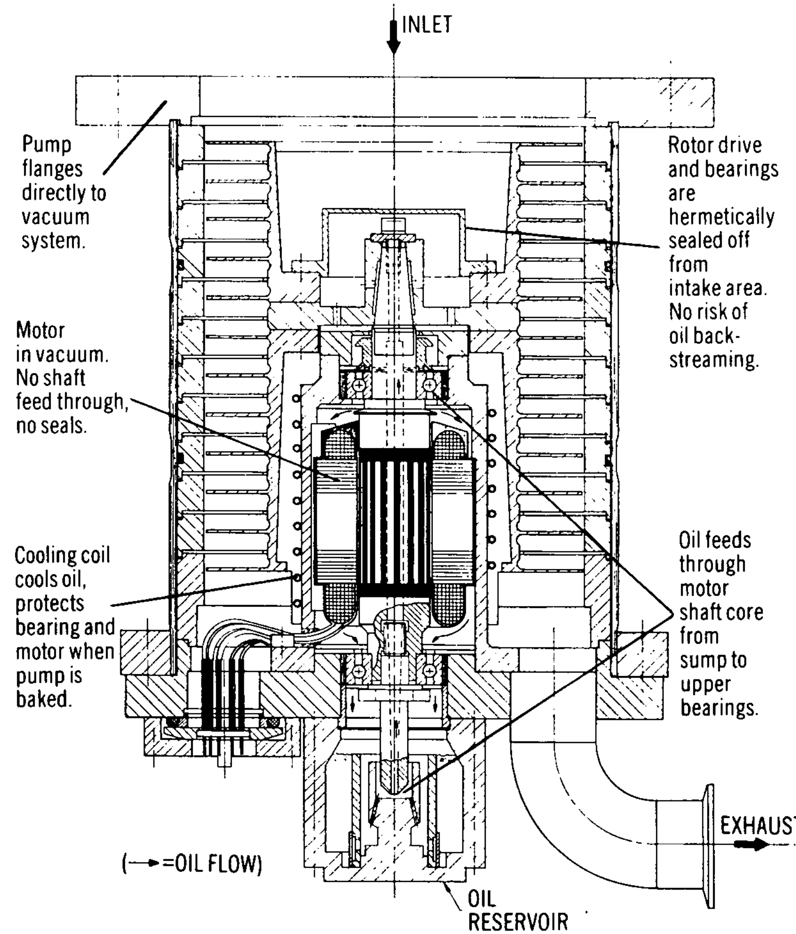
A number of disadvantages exist with the turbo-molecular pump, especially for the Pioneer-Venus application. The pump operates well in the high-vacuum region and has good compression ratio in the high-vacuum region, but has negligible pumping speed when backing pressures approach 100 Pascals or higher. For any sizable throughputs the pump requires a backing pump, adding to the weight, power, and volume requirements. Pump construction is more complex, adding to the cost and, perhaps, decreasing reliability. No very small sized turbo-pump or its development was discovered during this study.

5.3 ROOTS TYPE BLOWERS

The Roots principle (also called a rotary piston) was first proposed in 1857, and has been used in the manufacture of compression pumps for over 100 years. Its application in the high-vacuum field has been more recent. It is constructed of two synchronized, counter-rotating lobes generally of a figure-eight cross section, housed in a casing of a larger size but similar shape. The rotors are driven by a single motor and a set of timing gears. The lobes do not touch each other or the casing. Clearances are on the order of 0.25 mm. The pump is valveless.



AIRCO Temescal



Leybold-Heraeus

Figure 5-6 Two Vertical Type Turbo-Molecular Pumps

Figure 5-7 indicates the mode of operation. Gas in the chamber being evacuated enters the pump and fills the available area (a). As the rotors advance (b), this gas becomes trapped (c) and is finally exposed to the outlet side of the pump in (d). At this point, gas from the outlet side, at a higher pressure, rushes in until the pressure differential is overcome. The volume trapped by the rotor and casing is then discharged into the outlet by the rotor. This process is repeated four times for each revolution of the driveshaft.

It can be seen that the Roots pump does not operate in the compression mode as do the other positive displacement pumps. Rather, it pumps gas by the volumetric transfer of a low-pressure gas to the high-pressure side. This characteristic together with its valveless, frictionless design produces unique pumping characteristics. Most significant is the dependence of pumping speed on the backing or fore pressure.

If V_s is the swept volume in a Roots pump and n the number of revolutions per unit time, the product of these two quantities is the theoretical pump speed S_{th}, also designated as the nominal pumping speed:

$$S_{th} = n \cdot V_s \tag{5-1}$$

It is usually given in liters per second (ℓ/s).

If P_a is the inlet pressure, the theoretically transported quantity of gas through a Roots pump is given by:

$$q_{th} = P_a \cdot S_{th} = P_a \cdot n \cdot V_s \tag{5-2}$$

The effective quantity of gas q_{eff} transported by a Roots pump results from the theoretically transported quantity of gas q_{th}, which a lossless Roots pump would handle, minus the lost quantity of gas q_v, which streams back to the high vacuum side through gaps and through other causes:

$$q_{eff} = q_{th} - q_v \tag{5-3}$$

A part (q_{v1}) of the lost quantity of gas q_v is concerned with that quantity which traverses the unsealed gaps between the rotors and adjacent to the pump housing. If L is the conductance of these gaps and P_v the pressure at the backing vacuum side of the Roots pump, this part is given by:

$$q_{V1} = L\,(P_v - P_a) \tag{5-4}$$

10778-6

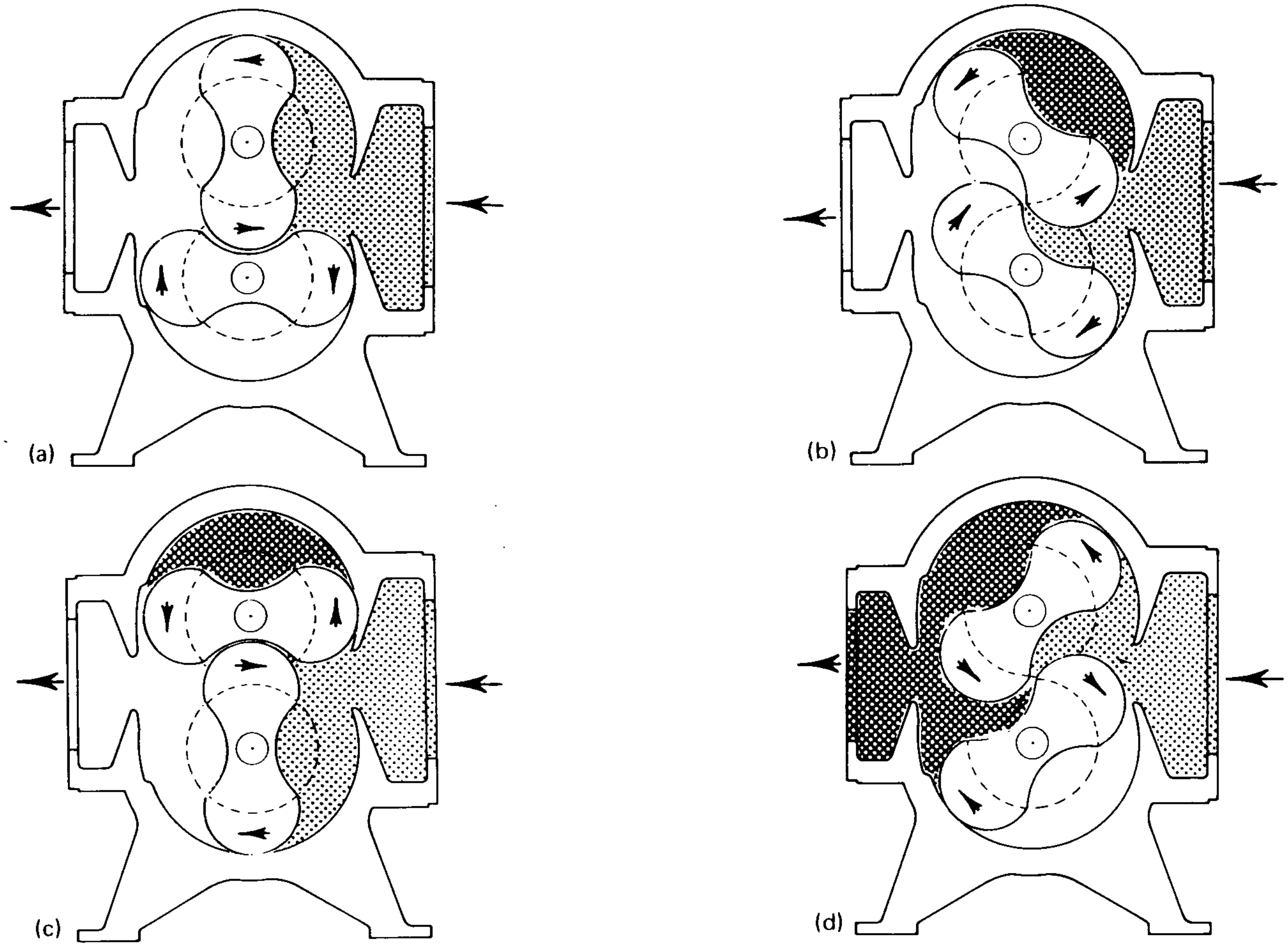


Figure 5-7 Roots Pump and Its Operation

The second part (q_{V2}) of the lost quantity of gas, q_v, is a result of sorption processes. During the very rapid revolution of the rotors, not all the transported gas molecules stream into the backing vacuum which is at higher pressure. On further rotation, these unpumped molecules return again into the high-vacuum space. Furthermore, back-diffusion takes place because the rotors on the backing vacuum side become loaded with gas which, on the high-vacuum side, desorbs again. Back-diffusion arises also from the cavities within the rotors. All these influences are designated as "deleterious back-diffusion" q_r, which produces the other part q_{V2} of the lost quantity of gas:

$$q_{V2} = q_r = S_r \cdot P_v \tag{5-5}$$

Collecting together the Equations 5-3 to 5-5 gives the effective quantity of gas q_{eff} transported by a Roots pump:

$$q_{eff} = P_a \cdot S_{eff} = P_a \cdot S_{th} - L(P_v - P_a) - S_r \cdot p_v \tag{5-6}$$

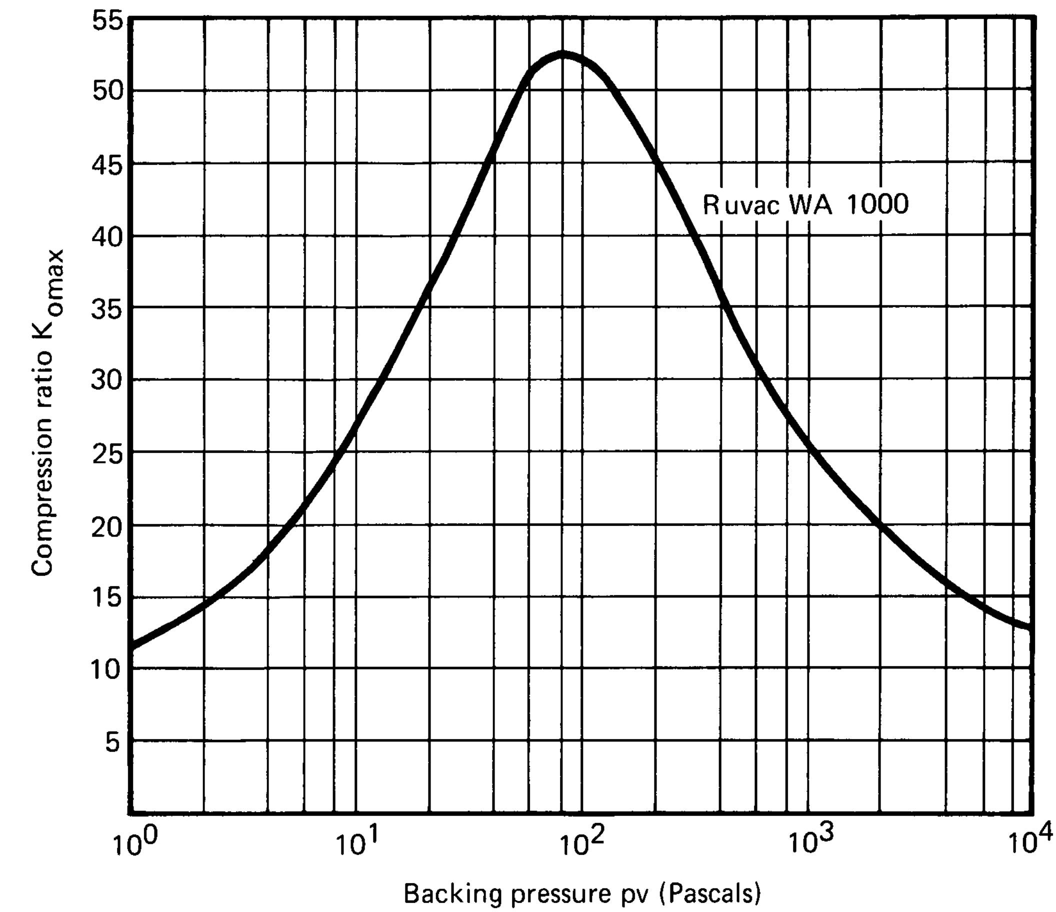
The maximum pumping speed K_{omax} can be determined from Equation 5-6. The compression ratio K_o of a Roots pump reaches the greatest value when the transported stream of gas is zero; this will be realized in practice if the inlet port of the Roots pump is closed with a cover plate. For $q_{eff} = 0$, it follows immediately that:

$$K_{omax} = \frac{P_{out}}{P_{in}} = \frac{S_{th} + L}{S_r + L} \tag{5-7}$$

The value of L can generally be neglected in comparison with S_{th}, so that this relationship can be simplified to:

$$K_{omax} = \frac{S_{th}}{S_r + L} \tag{5-8}$$

For the higher pressures ($P_v > 10^3$ P_a) the deleterious back-diffusion can be neglected and $S_r \rightarrow 0$. However, the back-flow of gas due to conductance, L, will increase in the region of viscous flow. For the lower pressures ($P_v < 10$ P_a), pure molecular flow prevails and L becomes negligible in comparison to S_r as S_r increases. The result is that the maximum compression ratio decreases toward both higher and lower pressures. A typical curve (Figure 5-8) shows the dependence of compression on the backing pressure.



Dependence of compression ratio K_{omax} of the Roots pump series Ruvac WA on the backing pressure pv. Valid for air. Values for helium are about 20% lower.

Figure 5-8 Roots Blower—Compression vs. Backing Pressure

It may be noted that with decreasing pump size, the nominal pump speed, S_{th}, shrinks faster than the conductance because the ratio of gap size to the pump volume becomes larger. Correspondingly, the maximum compression ratio becomes less in the smaller pumps.

The ultimate pressure P_{in-u} is ascertained from the obtainable backing pressure divided by the compression ratio at that point:

$$P_{out-u} = \frac{P_{in-u}}{K_{omax}} \qquad (5\text{-}9)$$

For a multistage pump, the same equations pertain. Therefore, the compression ratio is roughly a power function of a single stage compression. The ultimate pressure is correspondingly lower.

The temperature rise of the pump is a major concern. This is determined by:

$$\Delta T = \frac{F_{TR}\,(K-1)}{\mu} \qquad (5\text{-}10)$$

where μ is the volumetric efficiency,

$$\mu = \frac{S_{eff}}{S_{th}} \qquad (5\text{-}11)$$

and F_{TR} is the temperature rise factor, which is a function of pressure (Figure 5-9a). For larger pumps, the ΔT of 100 °C limits the pump to a backing pressure of about 50 torr if compression is not controlled. If compression is controlled, either by the motor speed or by a bypass line, then the Roots can be used to exhaust directly to atmosphere (Figure 5-9b). Cooling, especially the rotors, improves the performance considerably (Figure 5-9c).

5.4 SUMMARY—MECHANICAL PUMP CHARACTERISTICS

Three different pump types appear to be possible candidates for the Pioneer-Venus mission: the bellows, turbo-molecular, and Roots blower types. The rest were eliminated in favor of these three types because of power requirement considerations and the need for oil in the vacuum chamber of the pump itself. Figure 5-10 shows power as a function of input pressure

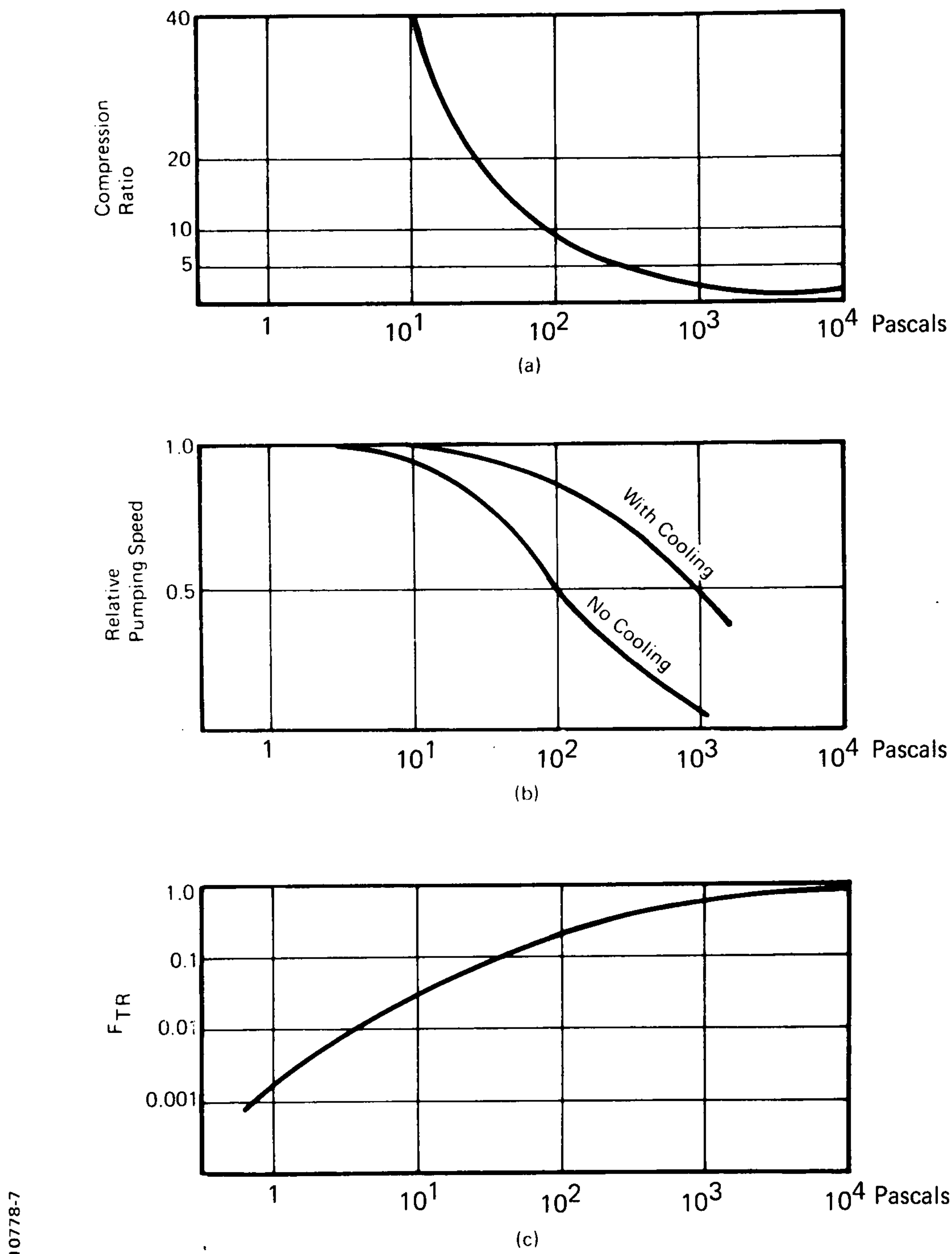
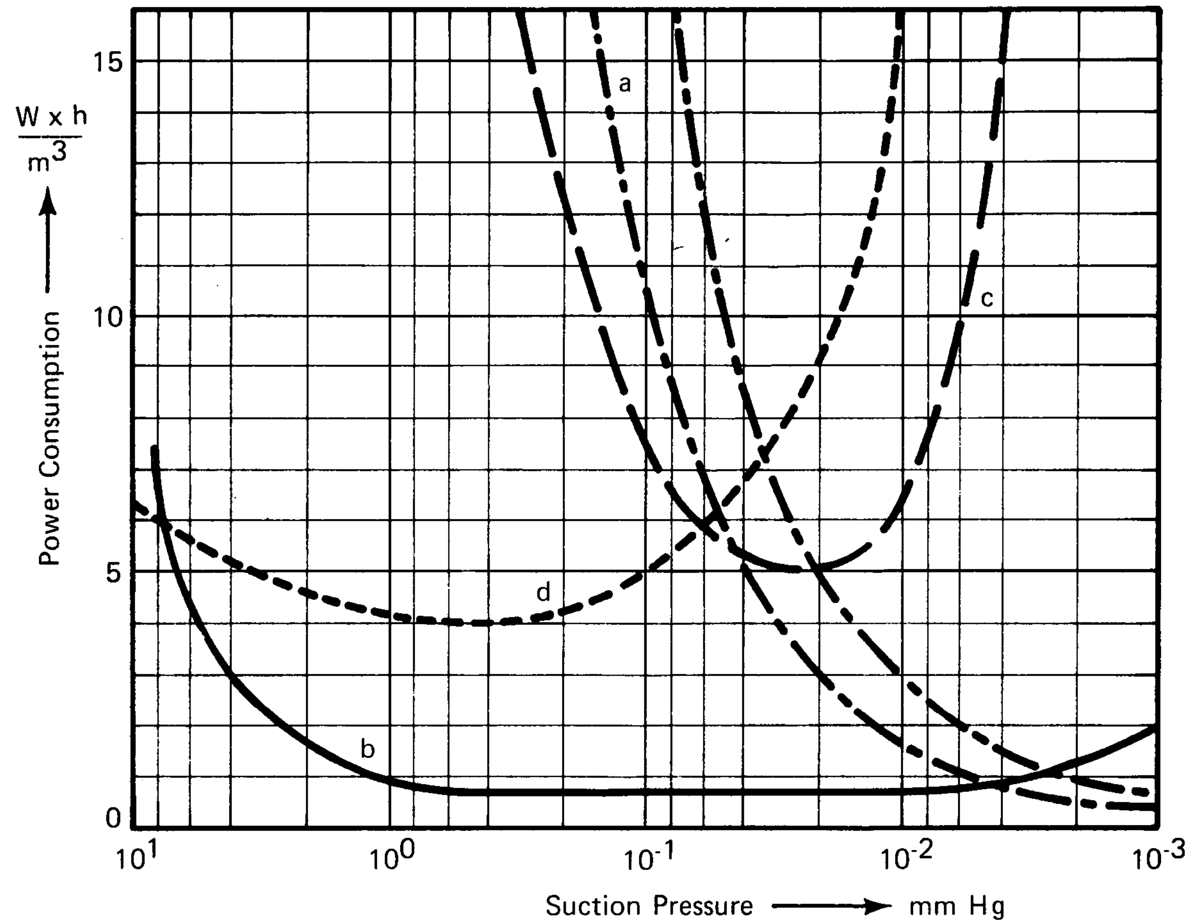


Figure 5-9 Roots Blower — Temperature Effects



Power consumption of different pump types in relation to the working pressure:

(a) Diffusion pump.
(b) Mechanical booster.
(c) Oil ejector.
(d) Oil-submerged rotary pump.

Figure 5-10 Pump Types vs. Power Required for various types of pumps. The bellows is not included, but is expected to be competitive with the Roots since little friction is present. The diffusion pump is added for reference.

Figure 5-11 illustrates the relative throughput of different pump types (per weight) as a function of the operating pressure range. Both the diffusion pump and the ion pump are included for reference. Two facts are obvious from this plot:

- The ion pump requires a great deal of mass for the throughput. This, of course, is one of the reasons the ion pump was not acceptable.

- Each pump type has its own characteristic operating range.

The second point suggests that some knowledge of a possible inlet system is necessary prior to attempting to fit a pump into the system. These basic requirements were generated in the nomograph of Section 4.1.

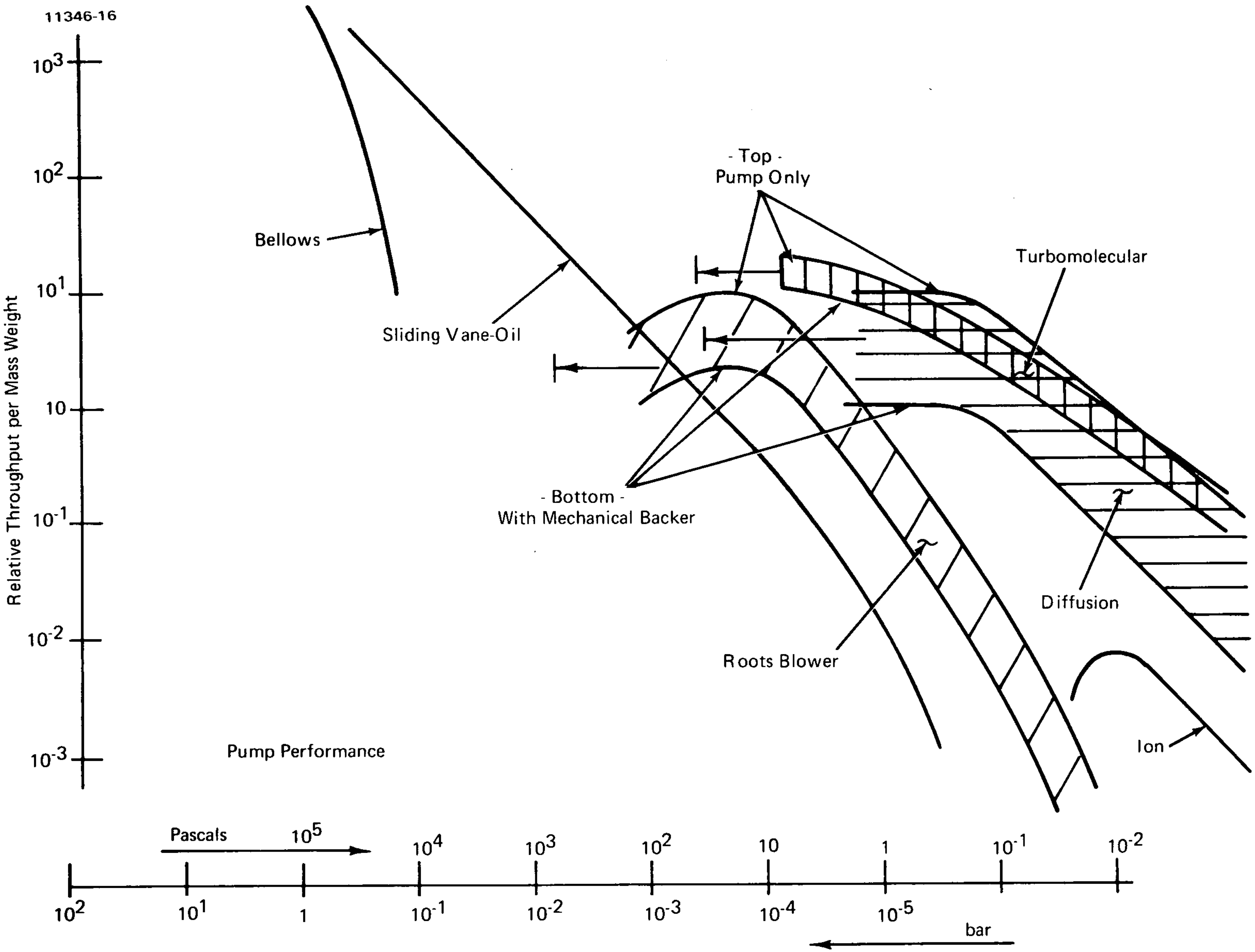


Figure 5-11 Pump Performance

SECTION 6

PUMP SURVEY

Prior to this study it was known that at least one mechanical pump was being considered for space applications — a pump made by Pfeiffer along the Roots design. However, in an attempt to uncover additional sources of supply, a specification was drawn up and sent to 14 companies. The specification is found in Appendix B, and responses are found in Appendix C. Of the three most viable types of mechanical pumps, two appear to have been developed sufficiently to consider them now for the Pioneer-Venus mission:

- The bellows pump has the size and capacity necessary for the mission. However, it would require working at higher sample volume pressures.
- The Pfeiffer Roots blower pump was found to be the most advanced for flight use, but is limited by backing (ballast) pressure.
- No development of a miniaturized turbo-molecular pump was found or proposed. Available sizes were several orders of magnitude larger than required. Thus, this design was dropped as a contender for the Pioneer mission because of the high cost for development. It is considerably more complex than the Roots or bellows designs.

6.1 THE BELLOWS APPROACH

The bellows pump state-of-the-art is shown plotted on the system nomograph in Figure 6-1. This is the performance curve of an actual miniature, production pump weighing about 2 1/2 kilograms. It is shown that P_2 would be held at about 10,000 Pascals (0.15 bar), and the molecular conductance would have a value of 4×10^{-8} ℓ/s.

Additional advantages and disadvantages can be noted. The steep slope of the pumping curve may cause instabilities or pressure fluctuations in the system and therefore the mass spectrometer. However, the high compression capability of the bellows pump — to 270,000 Pascals (2.7 bars) — relaxes the requirements on a ballast volume. If the total quantity of gas pumped is 32,000 Pascal liters (0.32 bar liters), then a volume of only 115 cubic centimeters will be required. A chemical ballast might reduce that even further, maybe as much as a factor of from 2 to 10.

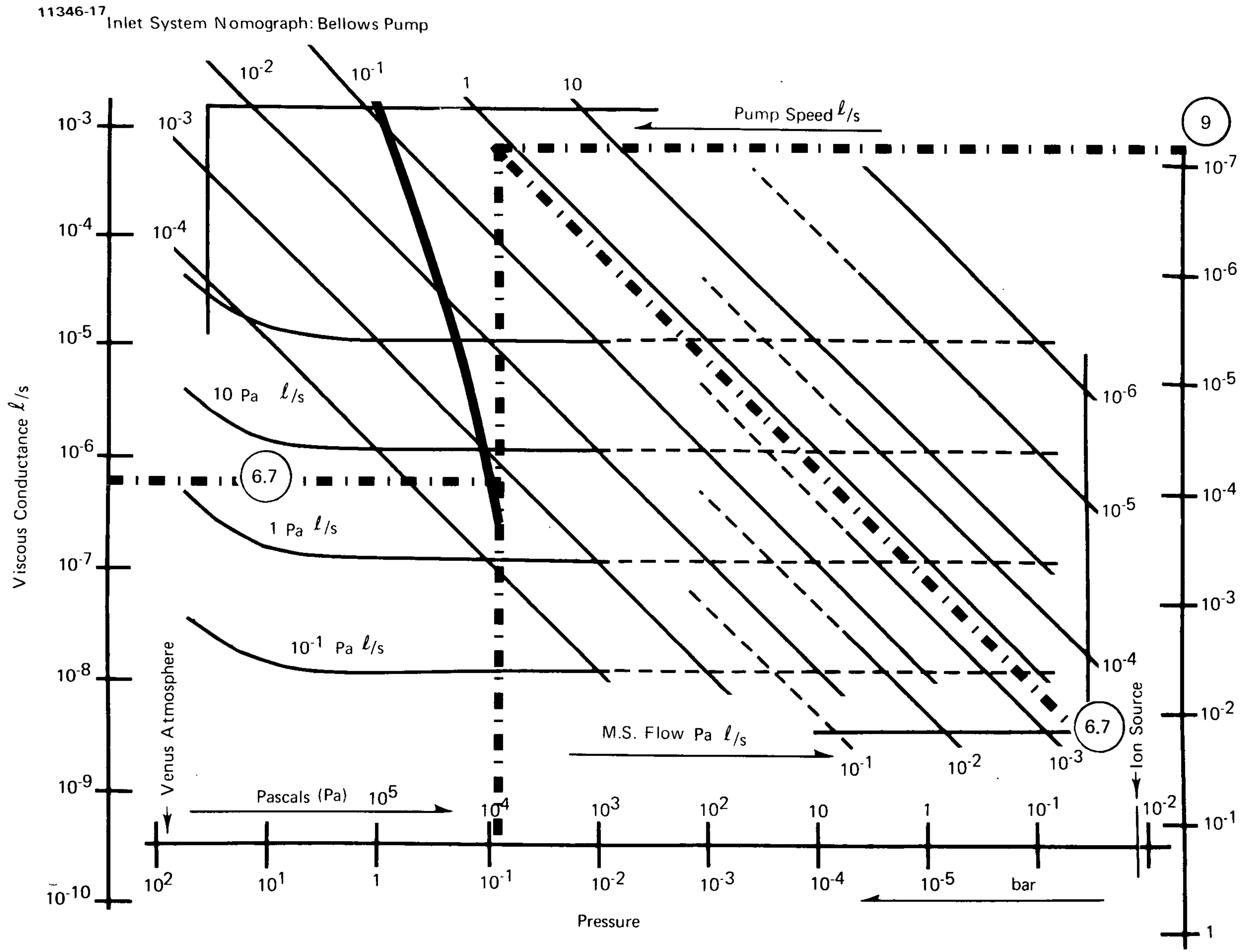


Figure 6-1 Nomograph—Bellows Pump

The use of a bellows expansion ballast chamber is an intriguing possibility. Since $\frac{PV}{T}$ is a constant, the volume could be increased to compensate for the flow into the ballast, thereby maintaining a constant pressure. Certainly the device would be simple. However, from Tables A-1, A-2, and A-3 of Appendix A, we calculate up to a 4,000-fold increase in pressure depending on the model used. Figure 6-2 shows a time-based plot of the accumulated gas. Bellows generally have a dynamic range (expanded to collapsed ratio) of five to one. So the technique could only be used during the latter part of the mission.

To determine some of the system requirements, assume a bellows expansion ballast of 3 liters expanded, 0.6 liter contracted. If either model I or II is assumed, then at the end of the mission 32,000 Pascal liters (0.32 bar liters) will occupy the expanded 3 liters at a pressure of 11,000 Pascals (0.11 bar).

Thus, the mission would begin with an evacuated, collapsed bellows with a 0.6-liter volume. During the probe descent, the pressure in the bellows would rise until it reached 11,000 Pascals (0.11 bar) at about the 64,500-Pascals (0.645-bar) level. This pressure would be maintained by volumetric expansion in conjunction with the three parallel restrictor inlet manifold. The nomograph for this system is shown in Figure 6-3.

6.2 THE ROOTS APPROACH

An experimental model of a miniature three-stage Roots blower pump has been built and tested by Arthur Pfeiffer Co. It was operated at 8,000 rpm and provided about 1 liter per second with a backing pressure of up to 1,333 Pascals. The pumping speed data provided by Pfeiffer is shown in Figure 6-4. The effects of both backing pressure and rpm compression ratio is shown in Figure 6-5, also as a function of the rotor speed. The curves are remarkably flat, but a definite roll-off at 1,333 Pascals can be seen in the higher-speed test.

Pfeiffer also supplied data on power requirements as follows:

Pump Speed, rpm	Backing Pressure, Pa	Power, watts
8,000	1,333	8
6,000	1,333	6.75
8,000	133	5.5
6,000	133	4.3

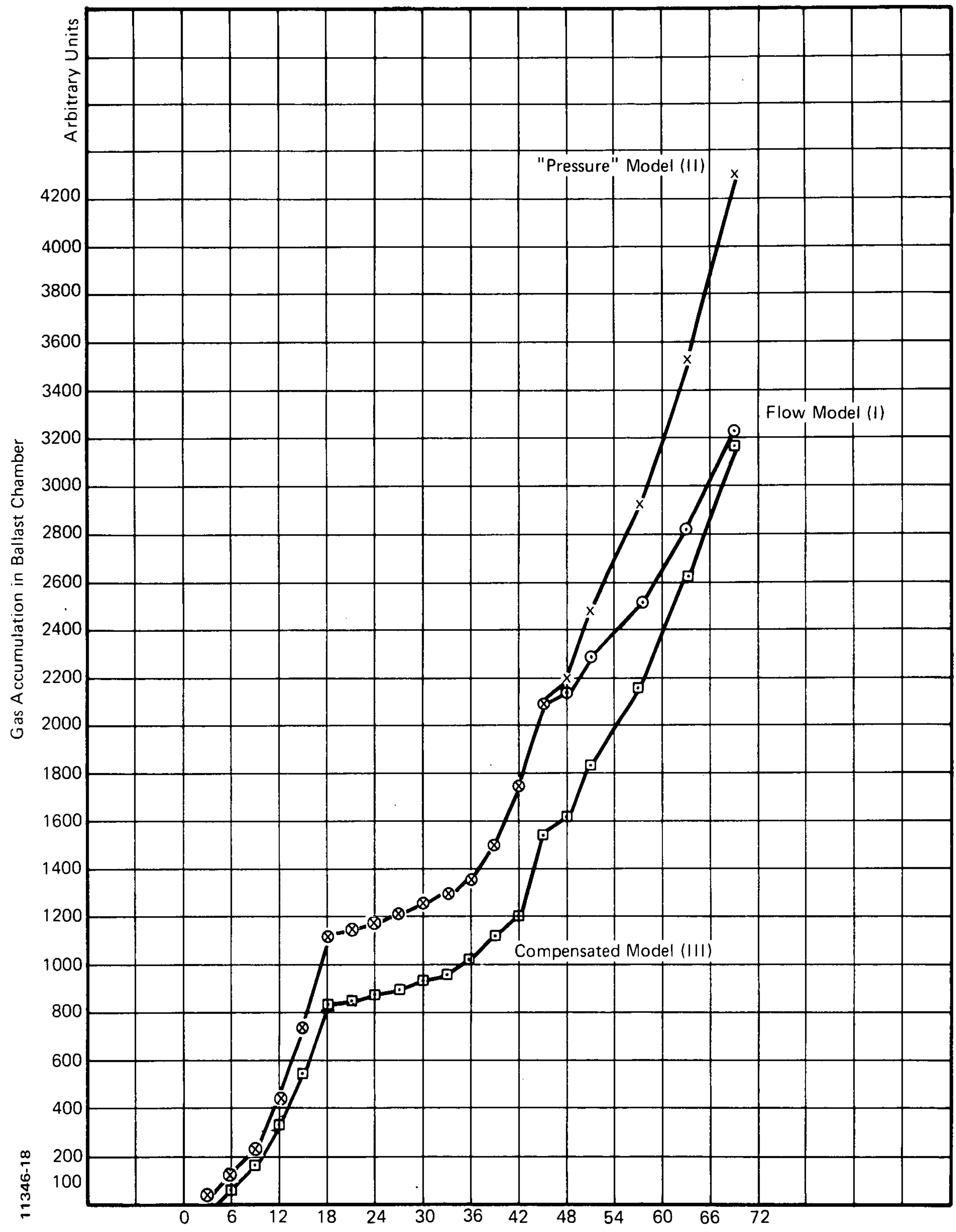


Figure 6-2 Ballast Gas Accumulation as Function of Descent Time

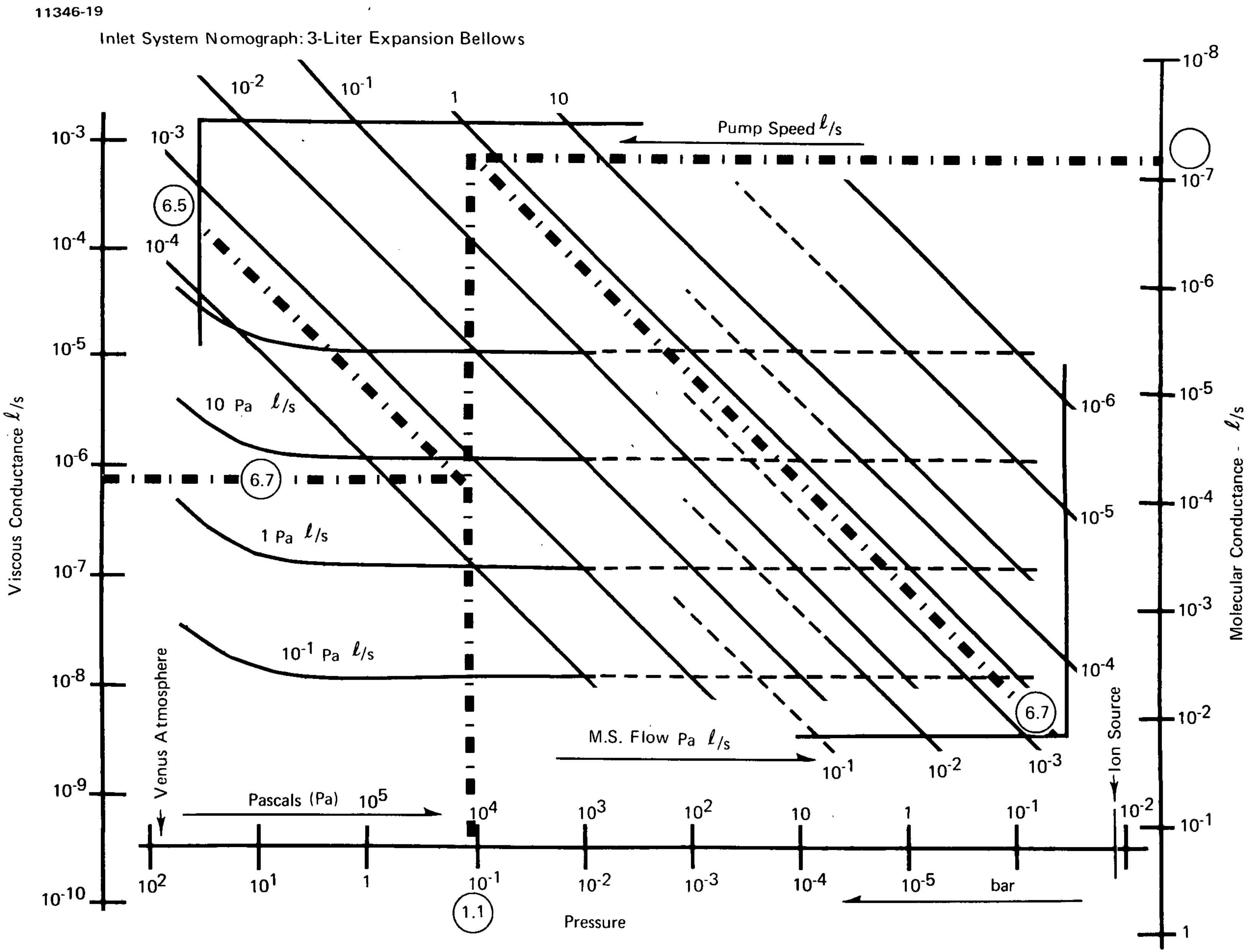
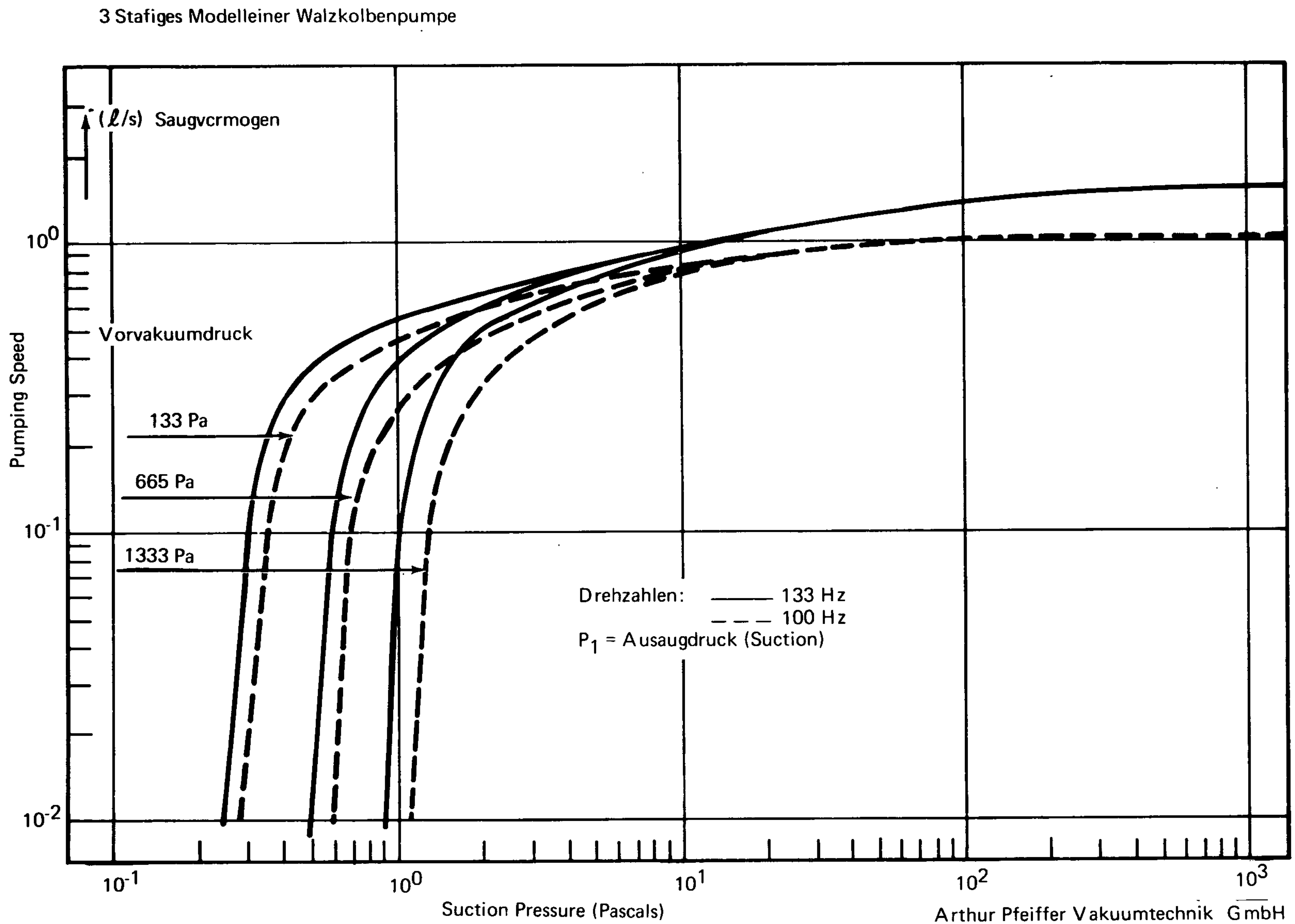


Figure 6-3 Nomograph—3-Liter Expansion Volume

11346-20



Arthur Pfeiffer Vakuumtechnik GmbH
6330 Wetzlar Postfach 147
Germany

Figure 6-4 Pfeiffer Data—Pumping Speed

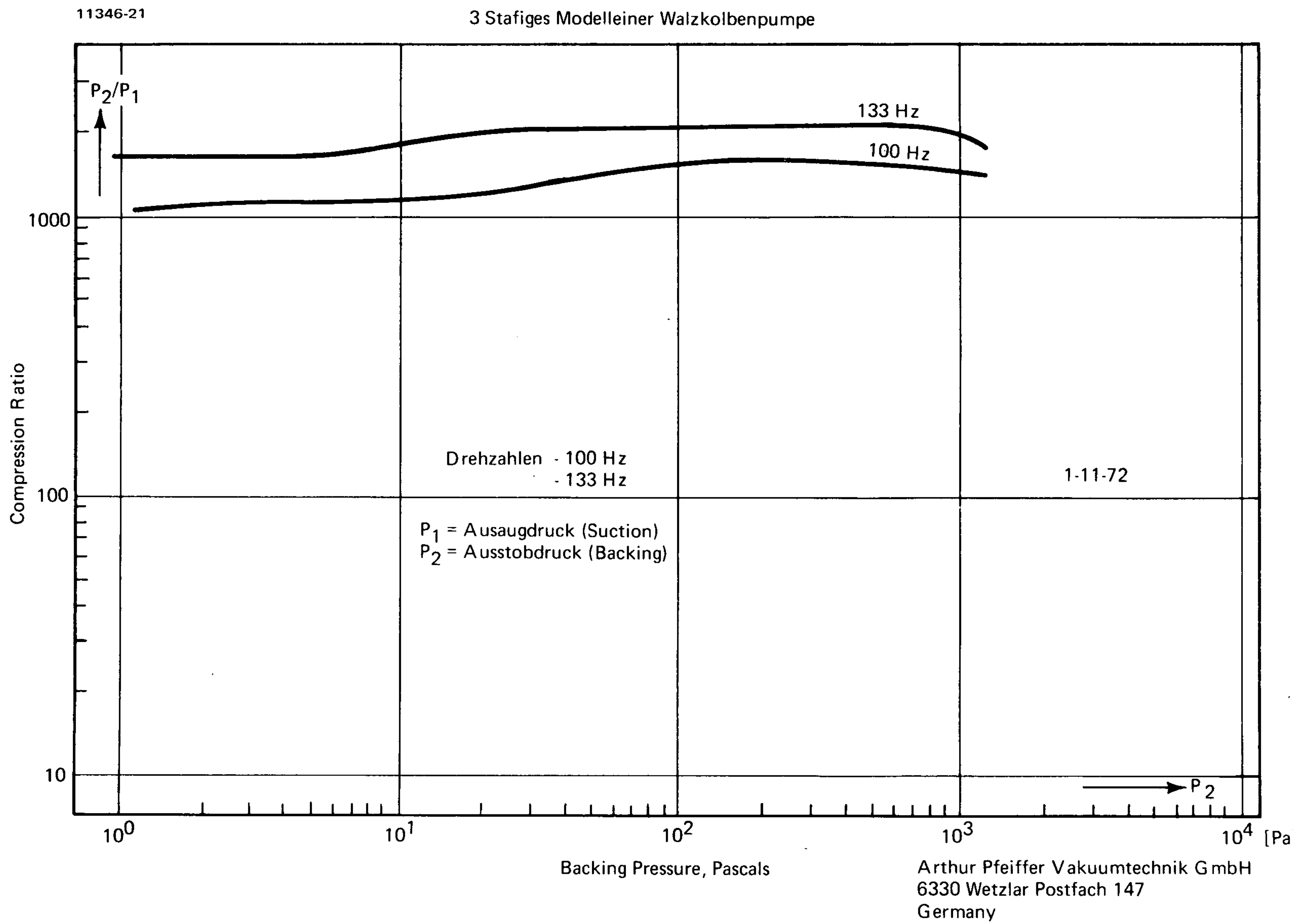


Figure 6-5 Pfeiffer Data — Compression Ratio

From the data supplied, throughput as a function of input pressure was calculated and plotted on the nomograph as shown in Figure 6-6. With a system flow, q_2, of 6.7 Pascal ℓ /s, the pressure in the sample chamber would be 6 Pascals. This is slightly lower than that required for the equal conductance model of Figure 4-9, indicating that the speed of the pump is more than sufficient. In fact, the equal conductance approach could be used with the Pfeiffer pump if a restrictor was placed at the inlet to the pump to limit the speed to about 0.6 ℓ /s.

Difficulties arise, however, at the output side of the pump. Tests performed thus far have been limited to a backing pressure of 1,333 Pascals (0.013 bar). The models, where q_1 was assumed = 10^4 q_2, require a total flow of 32,000 Pascal liters (0.32 bar liters). If the ballast is a vacuum chamber 3 liters in size, the pressure would be on the order of 10,000 Pascal (0.1 bar) or almost 10 times higher than the known capability for compression of this particular pump.

Several alternatives exist. The pump may be capable of pumping with a higher back pressure. Commercial Roots pumps are considered good to 7,000 Pascal (0.07 bar) according to the literature, before seizure due to heating becomes likely. Pfeiffer did not measure the temperature rise of the pump, but calculated that in a free convection ambient, the pump temperature would rise only about 45°C including electronics. This alone would not be a sufficient improvement. A fourth stage in the pump might be considered.

A chemical backing pump could be used to absorb the majority of the active gas. The chemical used should not produce any significant vapor by-products, and certainly none with a vapor pressure in excess of a few hundred Pascals. A by-product of water could not be tolerated because it has a vapor pressure at 25°C of nearly 4,000 Pascals. A reactive material such as the Zirconium-Aluminum used in the SAES getter pumps might be adapted. The backing pump would not have to be designed for high vacuum use as are the SAES pumps. Rather, a porous block of the alloy should suffice since the mean free path at 1,333 Pascals is about 10^{-2} millimeter.

The use of a chemical backing pump has a significant advantage with respect to measuring the inert gases. Since such a pump would remove only the reactive gases, the chemical pump or ballast would accumulate the inerts in the gaseous phase, providing, in essence, an enrichment. The ballast

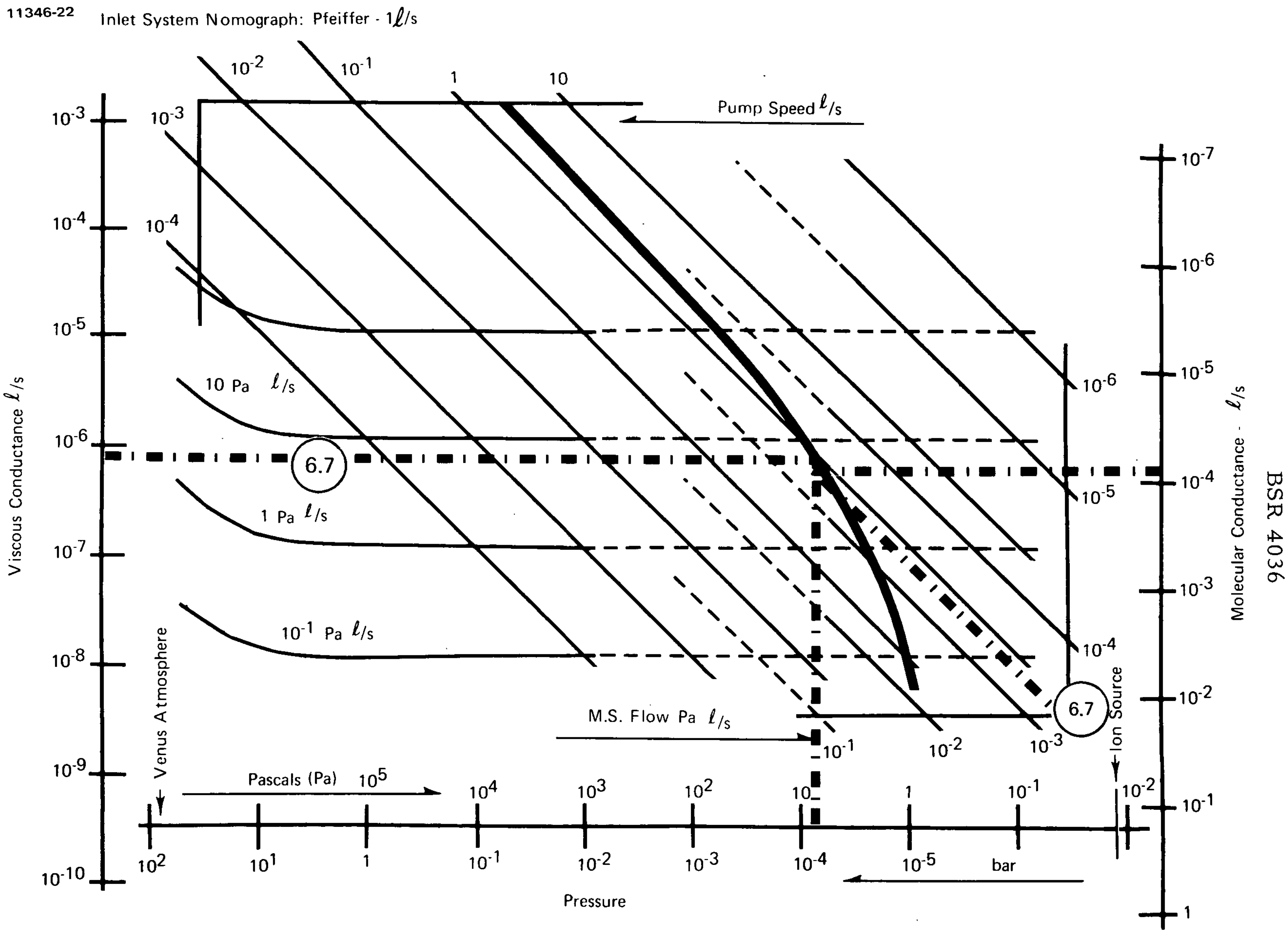


Figure 6-6 Nomograph—With Pfeiffer Roots Pump

could be sampled by the mass spectrometer during the last 6 minutes or so of the mission. The only additional equipment required would be a normally closed, one-shot valve and a restrictor.

For a third alternative, the total gas flow can be reduced if the techniques above are not feasible. The figure of 10^4 q_1 was arbitrary; and, though desirable, it may not be necessary.

SECTION 7

INLET SYSTEMS

Three inlet designs were prepared for consideration in Reference 1. The "Constant Flow," three-restrictor approach of Figure 7-1, has been assumed thus far and has been covered in some detail. It has provided a "baseline" through its simplicity. A discussion of the two remaining systems is presented here.

7.1 DIFFERENTIAL PUMPING SYSTEM

The differential pumping system is shown in Figure 7-2. It has been patterned after laboratory molecular beam sampling systems which are used to sample and collimate a small beam of gas originating from a high-temperature, high-pressure source such as a combustion chamber. In order to reduce the pressure to a level compatible with the mass spectrometer, small orifices are used between a series of pumped chambers. Although the orifices are small, one to a few tenths of a millimeter in diameter, they are sufficiently large that a molecular beam may pass through the orifice with minimal reaction with the orifice itself, and the beam retains its compositional integrity. But the pumping speeds required to reduce the overall ambient pressure to less than one Pascal are on the order of hundreds of liters per second. Clearly, this is not suitable. The conductances calculated earlier as being necessary for the Pioneer-Venus mission are so small that interaction with the conductance walls is inevitable. The molecular beam approach is not applicable to the Pioneer-Venus mission due to power, weight, and space constraints.

If this position is accepted, we can likewise eliminate the shape of the manifold as depicted in Figure 7-2. The cone, including the orifice, is called a skimmer by molecular beam investigators. The purpose of the conical shape is to minimize the formation of a detached shock across the skimmer opening (the Mach number determines the maximum open angle) and to aid in the pumping of a high-velocity, high-flow gaseous stream. There is little advantage in such a shape in a low-flow situation such as is required for this mission.

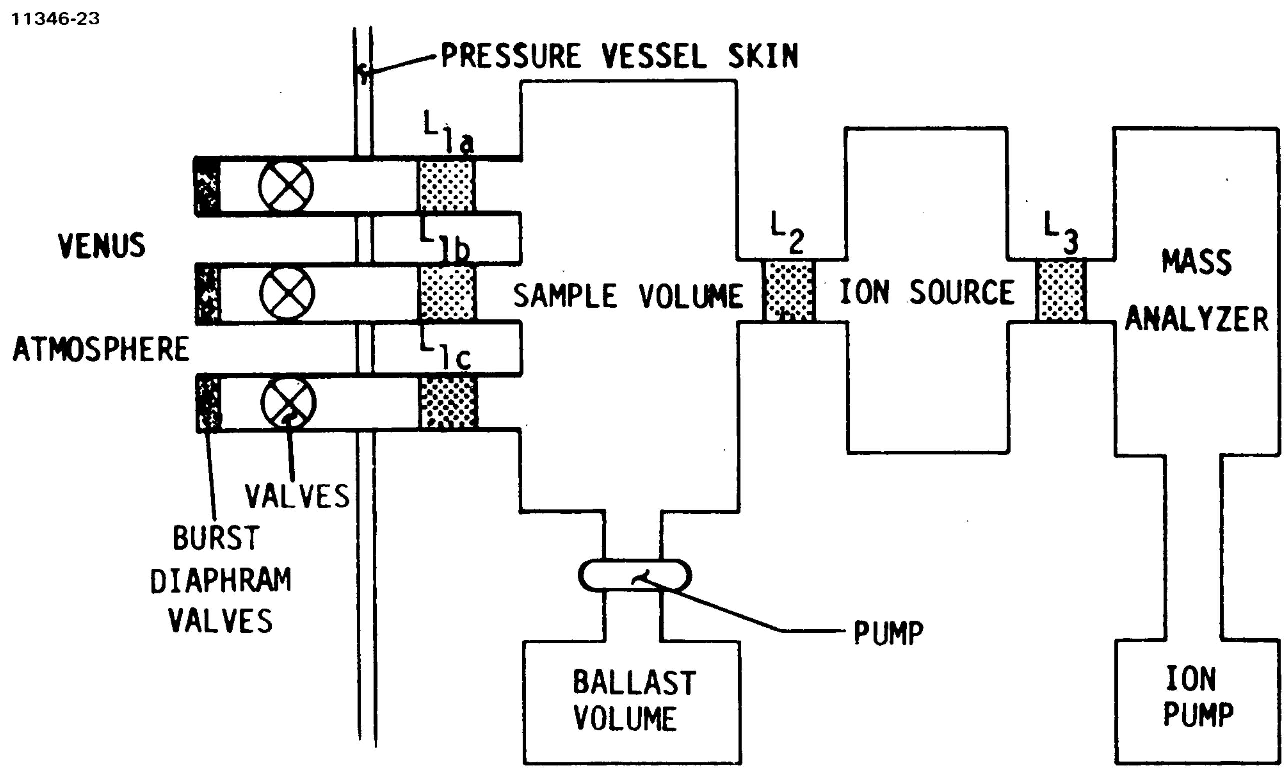


Figure 7-1 Schematic of Constant Flow - Pump System

11346-24

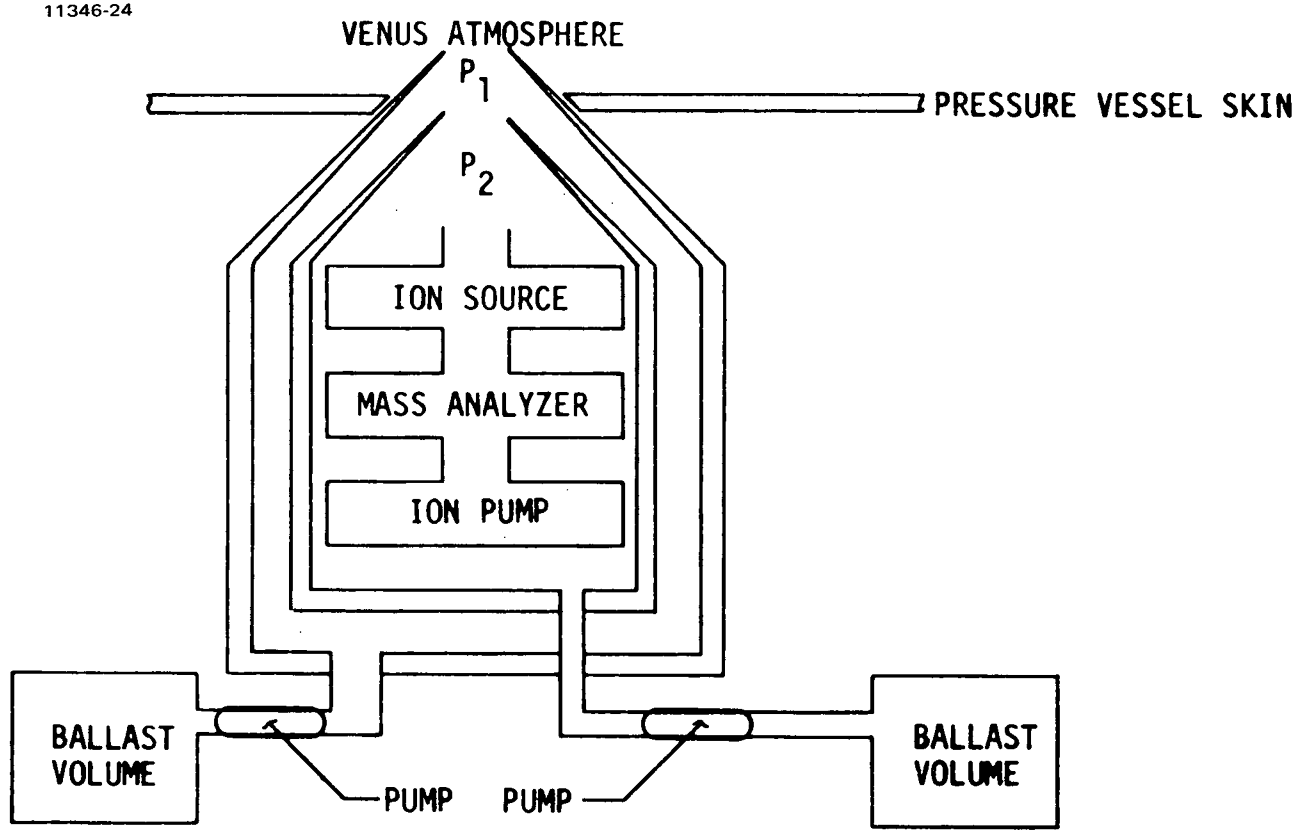


Figure 7-2 Schematic of Differential Pumping System

The constant-flow, three-restrictor system assumes a two-step, two-pump approach. Are there advantages to a three-step approach? Figure 7-3 represents this schematically and Figure 7-4 is a nomograph of the three-step approach. Several assumptions were made.

1. The flow into the system and the flow into the mass spectrometer remain unchanged from previous models.

2. The pressure drop for each restrictor will be equivalent on a log scale. This is about three decades per stage.

These requirements enable stage one and stage three to be constructed on the nomograph as shown by the solid lines. It may be noted at this point that the bellows pump would be a good candidate for the stage one pump. The question that remains is determined in part by the desired flow q_2 through the stage two conductance and the stage two pump. If q_2 is kept high, that is, a tenth of q_1 as shown in Example A of Figure 7-4, then the Roots blower pump would be an acceptable choice. Moreover, this inlet system solves the capacity problem raised earlier by reducing the total flow through the Roots and into the ballast by an order of magnitude. A chemical pump may not be required for satisfactory Roots operation. The sacrifice for this approach would be the additional weight and power requirements for two mechanical pumps.

If the q_2 flow were lowered even farther to one hundredth of q_1, as shown in Option B, then the Roots blower, as has been discussed to this point, is over-designed and a smaller pump might be substituted. A chemical pump might be an answer.

The stage two restrictors C_2 have been calculated for viscous flow and are indicated in Figure 7-4.

A listing of the advantages, disadvantages, and the remaining unknown will help to summarize the differential pumped system. Advantages of the approach include:

- It may enable the use of a more reliable high throughput pump, e.g., the bellows type.

- It may increase the conductance between sample chamber and mass spectrometer.

- It may better match pump characteristics to actual conditions.

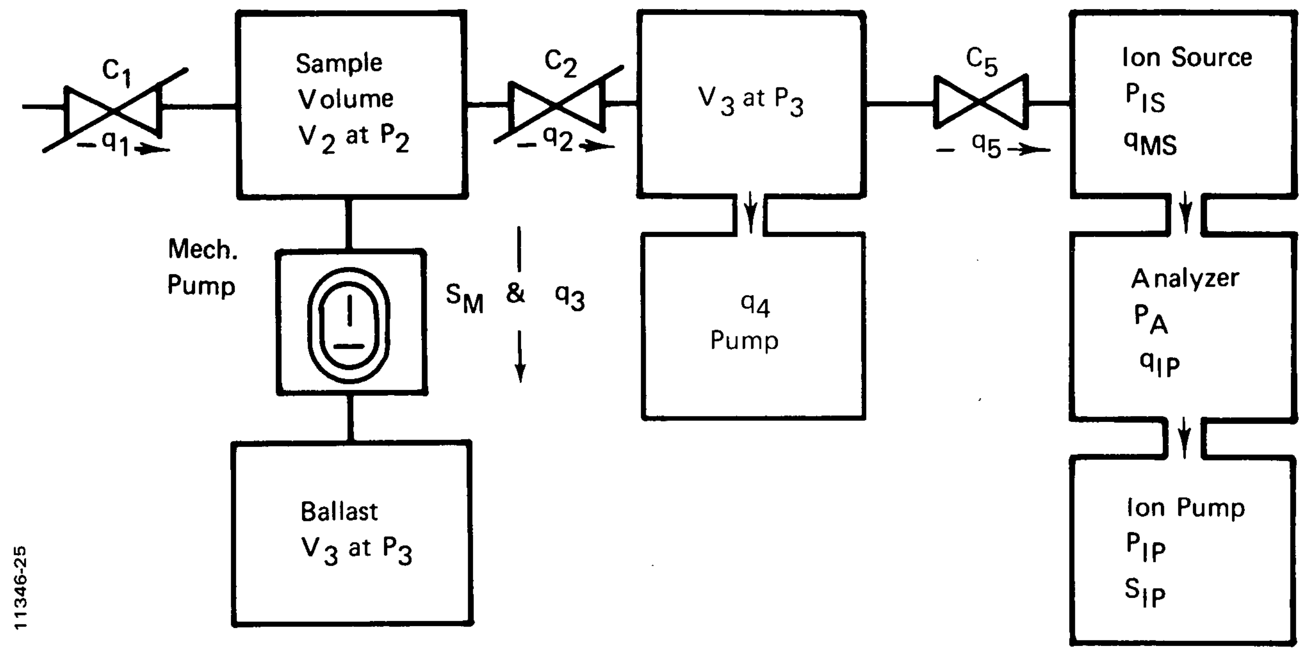


Figure 7-3 Detailed Schematic of Differential Pumping System

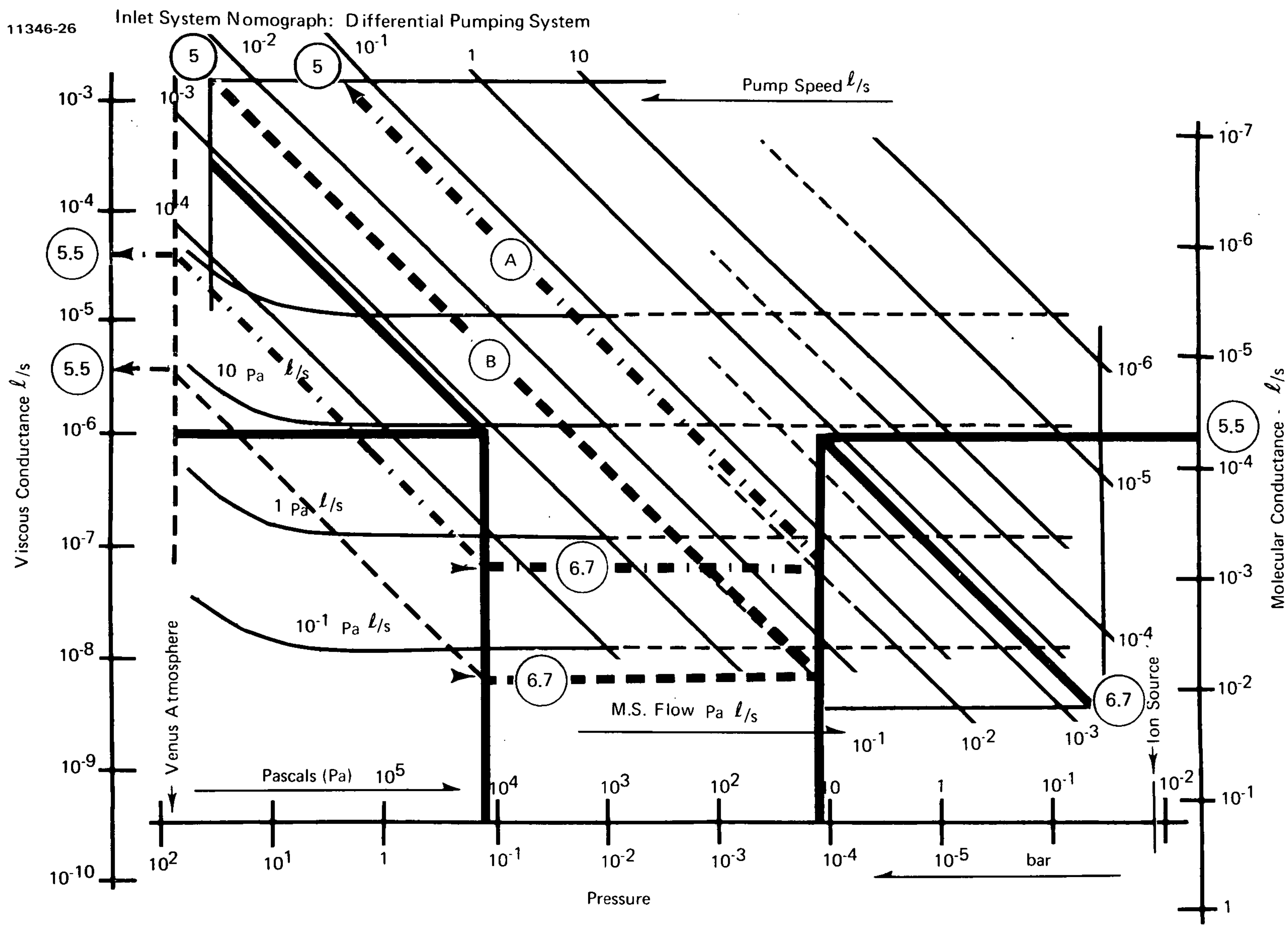


Figure 7-4 Nomograph—Differential Pumping System

Disadvantages of the approach are:

- It cannot be used as in a molecular beam system.
- It does not change the C_1 conductance value unless a higher flow can be tolerated.
- It may increase weight and power requirements by a factor of two over other approaches.

Unknowns relative to the approach are:

- The second stage pump type.
- System performance vs. tradeoff—especially second stage flow, q_2.

The differentially pumped inlet system requires more systems study and is not within the scope of the present study.

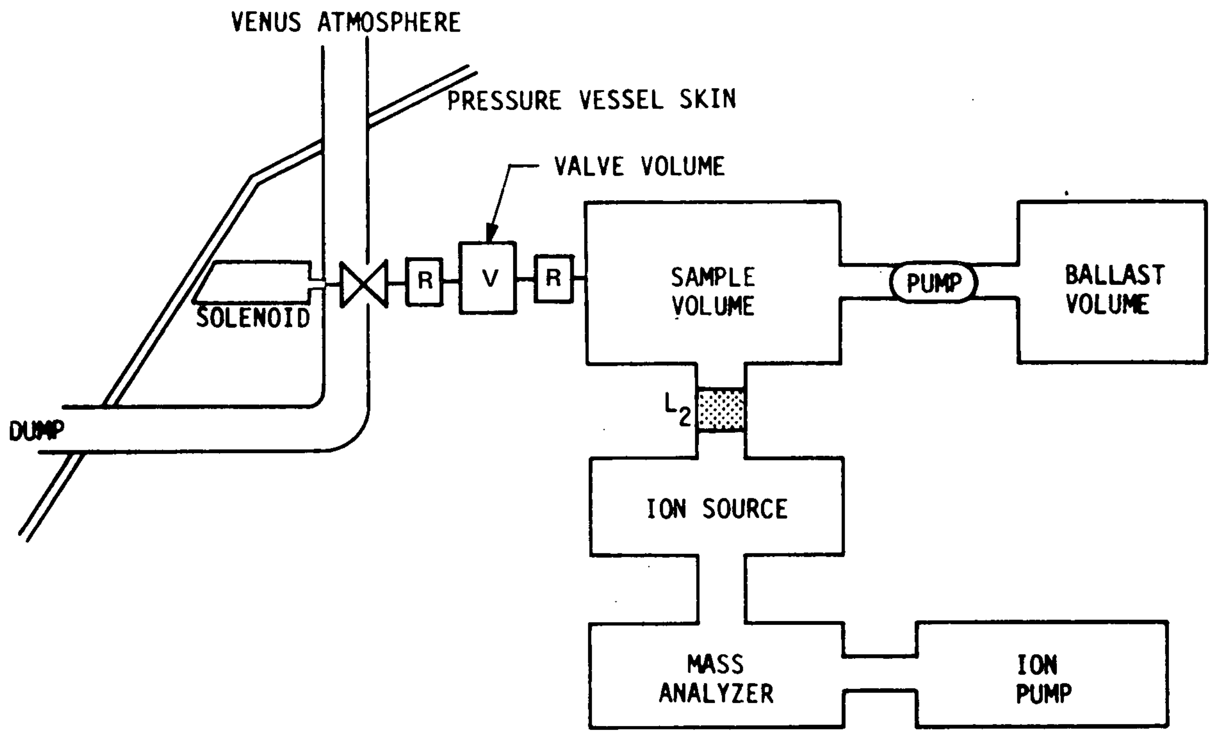
7.2 BATCH SAMPLE INLET SYSTEM

A third approach for the Pioneer-Venus inlet system is shown in Figure 7-5. The manifold consists of a single stage, one-inlet restrictor preceded by a valve with a specific, known volume. The valve would be a multicycle unit.

This "sampling valve," as it might be called, acts as a variable restrictor: the greater the duty cycle, the greater the conductance and the smaller the duty cycle, the less the conductance. The extremes are obvious: completely closed there is no gas flow, and fully open over a long span of time there is a maximum flow permitted by the inherent conductance of the valve. Conductance L_1 can be considered part of the valve; however, it should be recognized that L_1 may actually consist of two parallel conductances separated by a small volume.

Figure 7-6 shows one possible schematic representation of the valve. It is designed so that when the valve is closed, all the trapped volumes are on the downstream side of the seat.

The conductance values of C_1 and C_2 will be arbitrarily assumed to be equal and their sum equivalent to the restrictor value used in the first stage of the three-restrictor-constant flow system as calculated in Table A-3 of



11346-27

Figure 7-5 Schematic of Batch Sample - Cyclic Valve Inlet System

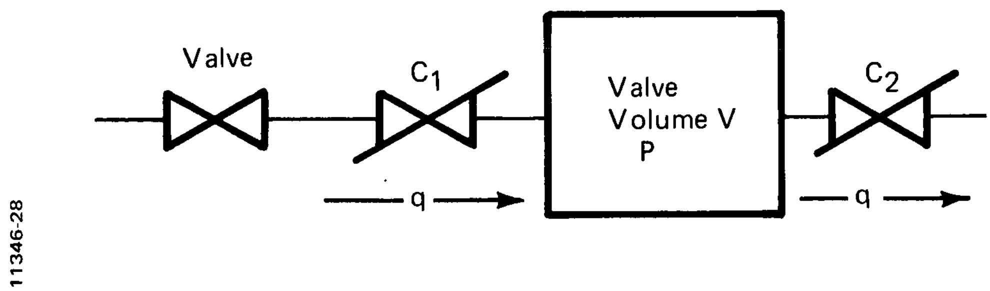


Figure 7-6 Simplified Schematic of Batch Sample System

Appendix A. That value was 1.92×10^{-4} ℓ/s; and from $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$, each restrictor will have a value of 3.84×10^{-4} ℓ/s. Thus, if the valve were opened during the first 18 minutes, the pressure profile would be identical to the Model III approach ignoring transient conditions due to the valve volume.

At T = 18 minutes, the pressure in the valve volume would be about one half the Venus ambient or 47,000 Pascals (0.47 bar). If the valve were closed at this pressure level, the valve volume pressure would drop to 10% of its value in

$$T = 2.3\,\tau \log 10 = 59.8 \text{ sec} \tag{7-1}$$

where τ, the time constant, is determined by the volume divided by the pumping speed on that volume. Assuming the volume to be 10 cubic centimeters,

$$\tau = \frac{V}{S} = \frac{10 \text{ cc}}{3.84 \times 10^{-4}\ \ell/s} = 26 \text{ sec} \tag{7-2}$$

(The pumping speed is essentially the second conductance.)

The mode of operation can take one of several forms. It would be convenient if either the "open time" or the "closed time" was constant throughout the operation of the valve. Assuming the first, that the valve would be cycled with a constant open time, then immediately after T = 18 minutes, the valve would begin frequent but brief closures in order to maintain the average flow into the system at the T = 18-minute level. If the open time is assumed to be constant at 0.300 sec, then at T = 21 sec, the valve closes at a rate of 160 cycles/sec for a period of 0.74 sec per cycle. As the Venus ambient pressure increases, the rate decreases and the "closed time" increases. Near the surface, at T = 72 minutes, the valve closes only 1.8 cycles/minute, but the closed time has increased to almost 30 sec each cycle. Details of this approach are found in Table A-4, Appendix A.

This mode produces ever-increasing fluctuations in the sample volume pressure. The rapid cycle rate early in the mission would result in very small pressure variations. By the end of the mission, the pressure would be changing approximately one-third between the open and closed periods of the valve.

The second approach would be one with a constant "closed time." Table A-5 of Appendix A details this approach with 6 sec as the "closed time" constant. Several advantages are realized with a constant closed time. There are fewer fluctuations during lower atmospheric analysis where the data are most important. This is at some sacrifice in increased variations at the T = 18 sec-plus time interval. Fewer total cycles are required and the cycle rate starts slowly and increases with time. This places the most probable time of failure later in the mission.

The constant "closed time" system can be used in a somewhat different mode of operation. The valve could be cycled once or twice for each measurement period rather than semi-continuously. The valve would be opened by a timing clock; it would be held open either, again, by a timing scheme which would be adjusted to the increasing ambient pressure (approximately equal to Column 7, Table A-5), or by a signal generated from the ion source. If the latter method is used, the ambient pressure can be calculated from the time required for the pressure rise in the ion source. The mass scan would begin almost immediately after the valve closed. If the scan took 60 seconds, the total pressure would have dropped by the end of the scan to 10% of the initial value. Considerably less drop would be realized with a 10-sec scan.

This technique would require some sort of buffer storage to compensate between the fast scan time and the slower transmission rate. However, the quantity of gas pumped by one cycle of the valve per measurement period, compared to semi-continuous operation to maintain a constant flow, is two decades less. This has a major impact on the ballast used.

Many variations are possible with the batch inlet system; however, it is not within the scope of this investigation to study them all. What has been shown is that such a manifold could be used with the mechanical pump to maintain a nearly constant flow into the mass spectrometer. Certainly the design must be such that pressure bursts are at a minimum and that they cause no difficulty with the mechanical pump. From the science return point of view, the pressure variations must be known so that the mass spectral data can be properly corrected at a later time by computer programming.

7.3 RARE GAS ANALYSIS

The incorporation of a mechanical pump together with an active gas chemical pump offers a unique approach to a better analysis of the inert gases through enrichment. If the mechanical pump was backed by a chemical sorption pump which would effectively remove the active gases, especially the CO_2 (95 to 97% of the ambient), then, as the mission progresses, the ratio of inerts to active gases and the partial pressure of these gases would steadily increase. This could be sampled at the very end of the mission by the addition of two or three components, as shown in Figure 7-7. The valve, which

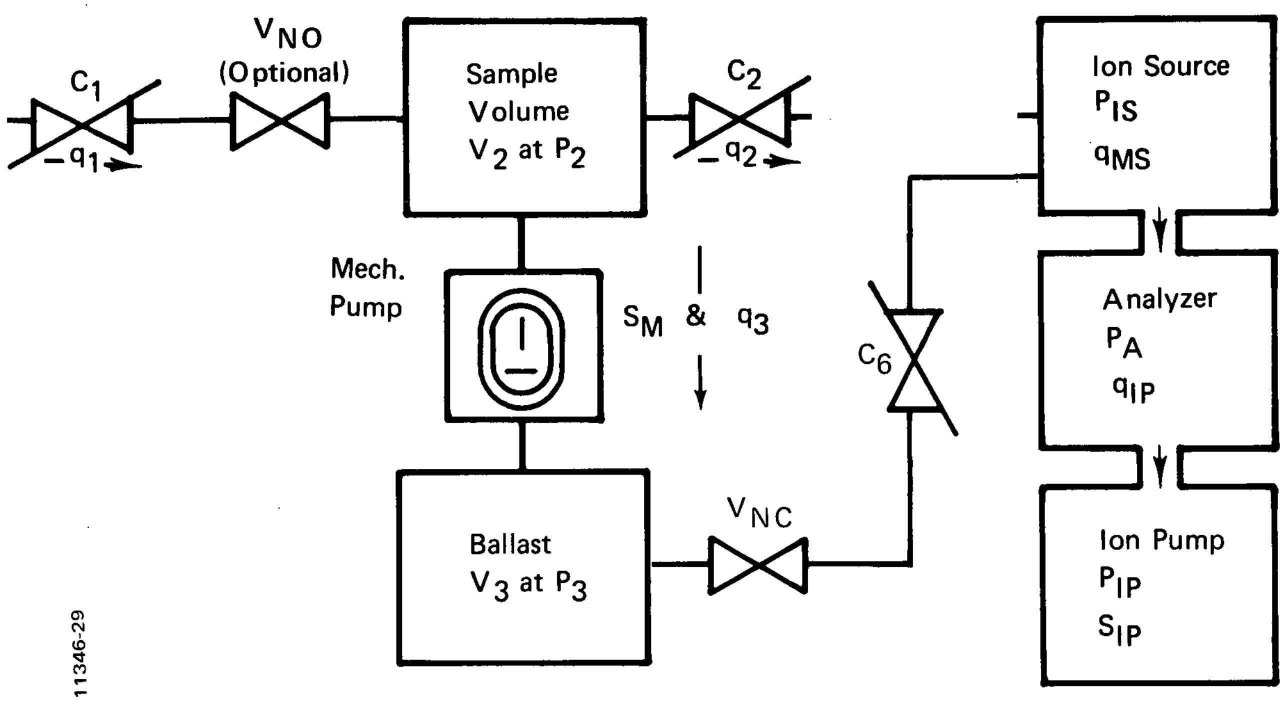


Figure 7-7 Rare Gas Analysis Schematic

normally would be open during the earlier part of the mission V_{NO}, would close and a valve connecting the ballast volume to the ion source, V_{NC}, would open. Restrictor C_6 would provide the required pressure drop in order to maintain the ion source at 10^{-2} Pascals (about 10^{-4} torr). The value of C_6 would not be critical in terms of catastrophic failure of the ion source filament. A chemical pump without the mechanical pump could be used in exactly the same way. However, there would be no capability to compress the inerts during the major portion of the mission and hold them for the later analysis. A chemical pump alone would continuously backstream the rare gases.

There should be little need for more than one analysis. The ambient temperature of Venus during most of the sampling time is above the boiling temperature of the inerts; thus, the relative composition of these gases would remain essentially constant. Less hardware and logic is required for a single analysis; and by performing the "inert scan" during the last time interval, less total ambient gas is required for the mission, easing the design requirements by from 12% (Table A-1, Appendix A) to 18% (Tables A-2 and A-3, Appendix A).

SECTION 8

ENGINEERING DESIGN REQUIREMENTS

The design requirements for the mechanical pump can be established through considerations of overall inlet system allocations and the characteristics of available pumps. The SSG and NASA/ARC have allocated 9 kg (20 pounds) and 12 watts (Reference 2) for the probe neutral mass spectrometer system. The orbiter neutral MS allocation is 4.5 kg (10 pounds) and 10 watts (Reference 2). The Viking Upper Atmosphere MS unit has approximately these same characteristics. Therefore, it can be assumed that the remainder, or 4.5 kg (10 pounds) and 2 watts, has been allocated to the inlet system. We have arbitrarily allocated 2.5 kg and 5 watts to the mechanical pump. Pfeiffer presently has an operating pump weighing 2.5 kg and using 9 watts. The company projects a weight of 1.4 kg and power of 5 watts. From these figures it can be seen that the power allocation of 2 watts for the inlet system is a low estimate if a mechanical pump is utilized. Including heaters, chemical pump, valving, and control electronics required in the system, a more realistic estimate might be on the order of 7.5 to 10 watts.

The remainder of the design requirements must be consistent with the actual or projected inlet system configuration. Pfeiffer presently has an envelope of about 10 cm diameter and 10 cm long, but has projected a much smaller envelope based on tailoring the external housing to the pump.

In addition, the pump should be able to operate from the unregulated 28-Vdc power supply of the probe and should be compatible with the probe environmental characteristics and inlet system configuration.

Figure 8-1 shows a cutaway view of the three-stage Roots pump as proposed by Arthur Pfeiffer Co. of Wetzlar, Germany. The specifications of this pump as well as its mechanical interfacing characteristics are shown in Figure 8-2.

A mass spectrometer inlet system concept utilizing the mechanical pump and mounted in a Pioneer-Venus probe is shown in Figure 8-3. The system is a mechanization of the constant flow inlet described in Section 4.

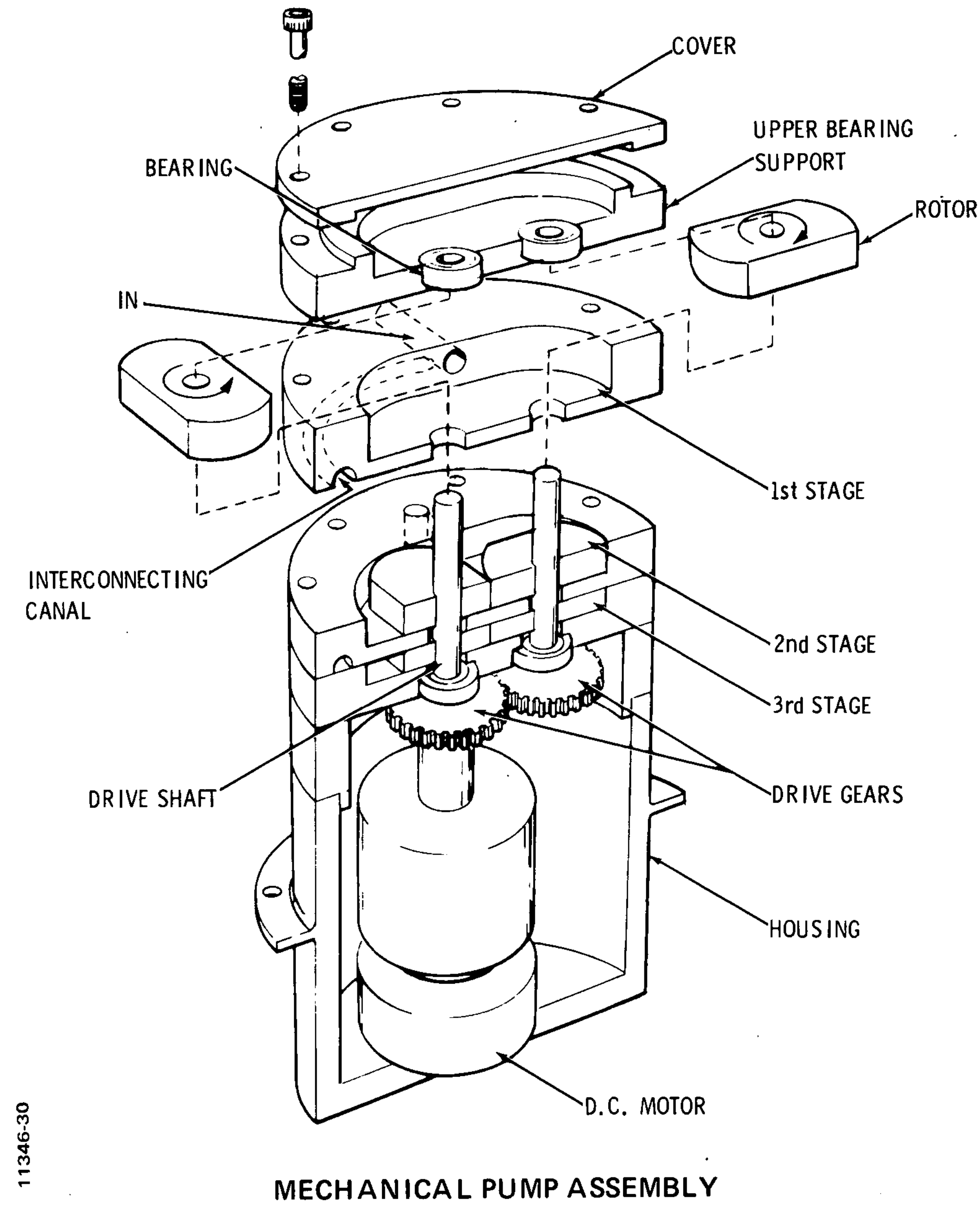


Figure 8-1 Roots Blower Assembly Drawing

PUMP SPECIFICATIONS:

TYPE: ROOTS

STAGES: 3

CHAMBER VOLUME
1ST STAGE 5.8 CM^3
2ND STAGE 3.8 CM^3
3RD STAGE 2.9 CM^3

PUMPING SPEED:

.95 ℓ/SEC @ 8000 RPM

PRESSURE:

@ 8000 RPM BACKING PRESSURE = 10 TORR
@ 8000 RPM SUCTION PRESSURE = .1 TORR

WEIGHT:

2.5 KG MAX

POWER:

5W

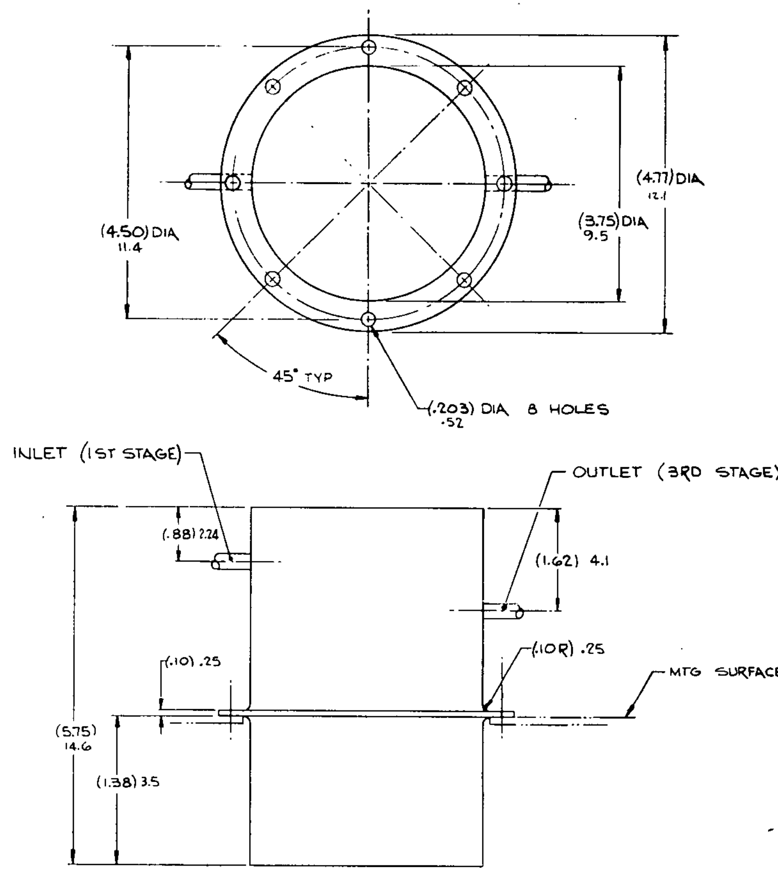


Figure 8-2 Mechanical Interface and Specifications

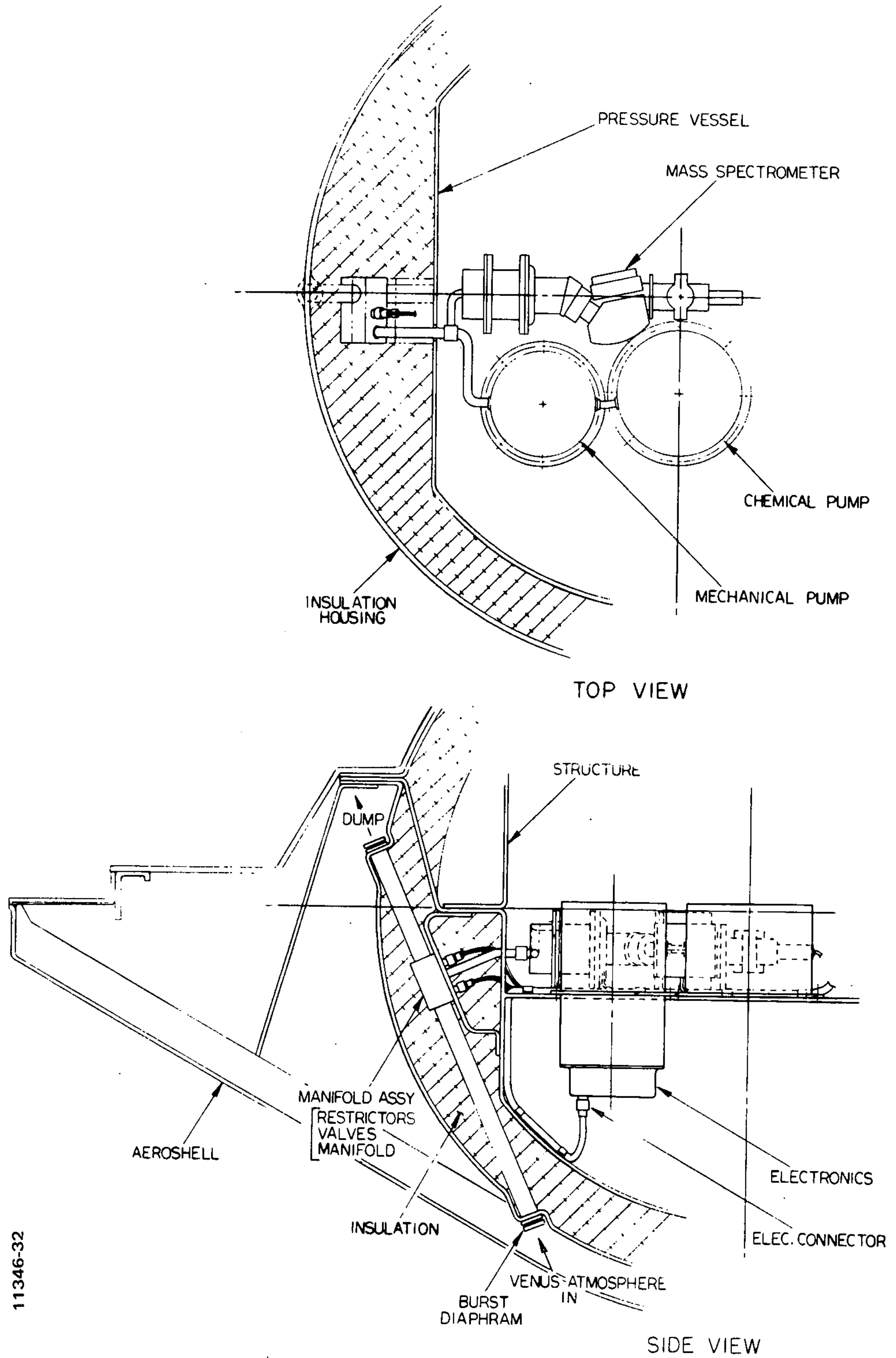


Figure 8-3 Inlet System Concept with Mechanical Pump

Venus atmosphere enters through the orifice created when the burst diaphragm is ruptured. This orifice is located on the lower end of the probe with the dump orifice above, creating a pressure differential and a resulting gas flow. The manifold assembly contains the restrictors and valves necessary for the flow control as well as most of the sample volume. The manifold, sample volume, MS inlet line, and ion source all must be heated so that they are maintained at a temperature a few degrees above the Venus ambient atmosphere to prevent possible condensation of the gas. The mechanical pump ballast is created by a 500-cc chemical pump operating at 1, 333 Pascals.

The primary environmental constraints on the pump design result from acceleration and temperatures. Peak acceleration resulting during entry into the Venus atmosphere may exceed 300 Earth g's (Reference 3). The pump's most sensitive axis is transverse to the drive shaft axis. Actual loads to be experienced have not been applied to a pump of this type, and a detailed loads analysis has not been conducted.

Since the pump is operated off the main sample stream and condensation is not serious, it is not necessary to heat it as high as the remaining components. However, in order to reduce selective pumping or gettering by the materials of the pump, a vacuum bakeout at 150-250°C is desirable. This involves primarily the bearing lubricant applied in the pump. Extensive study of the bearings and lubricant utilized was not undertaken during this study, but there are methods for accomplishing bearing seals and lubrication for this application.

SECTION 9

RECOMMENDATIONS

The results of this study are positive in that two mechanical pump approaches have been identified for pumping quantities of Venus ambient gas from 1,000 to 10,000 times that required by the mass spectrometer. Unanswered questions and unknown parameters exist in both approaches. At present, the Pfeiffer Roots blower appears superior to the bellows pump; however, development work preceded this study for many months. No such work has been performed on the bellows type pump, and the simplicity of the latter could outweigh the advantages of the Roots.

It is recommended, therefore, that work be continued in both areas, but with special emphasis on the Roots design. A number of different tasks have been outlined as separate projects. Many must eventually be accomplished before a total inlet system can be designed. This separation offers both a choice in the approaches presented and an opportunity to schedule such work consistent with the Pioneer-Venus program.

9.1 VERIFICATION OF THE PERFORMANCE OF THE PFEIFFER ROOTS BLOWER

- Purchase an improved model of the Roots pump from Pfeiffer consistent with the specifications of Appendix B.
- Obtain one week's engineering assistance from Pfeiffer for operational instruction.
- Test the pumps for:

  speed

  throughput

  compression ratio.
- During the tests, monitor the pump for:

  temperature rise

  power dissipated.

- Examine the pump for design strengths and weaknesses as they would apply to a flight model.

- Extrapolate the necessary changes to arrive at a flight design.

- Identify remaining development necessary to produce a flight type model.

The American Vacuum Society (AVS) Testing Standards will be followed wherever possible. However, for expediency, certain exceptions will be taken. Thermocouple gages will be used in place of the McLeod gage; calibrated and correlated Gilmont "floating ball" flow meters will be substituted for the recommended positive displacement (liquid) type; stability will be defined as three measurements, 3 minutes apart, all to within ± 5%. Since precision measurements are not a goal of the test program, such changes should not affect the overall quality of the results.

Figure 9-1 is a schematic of the test configuration which will be used for measuring the ultimate pressure capability of the pump as a function of back pressure.

The cold trap is recommended by AVS to eliminate measurement errors due to oil backstreaming of the mechanical pump. Dry nitrogen will be used as the test gas because carbon dioxide would freeze out on the trap. An outline of the testing procedure is as follows:

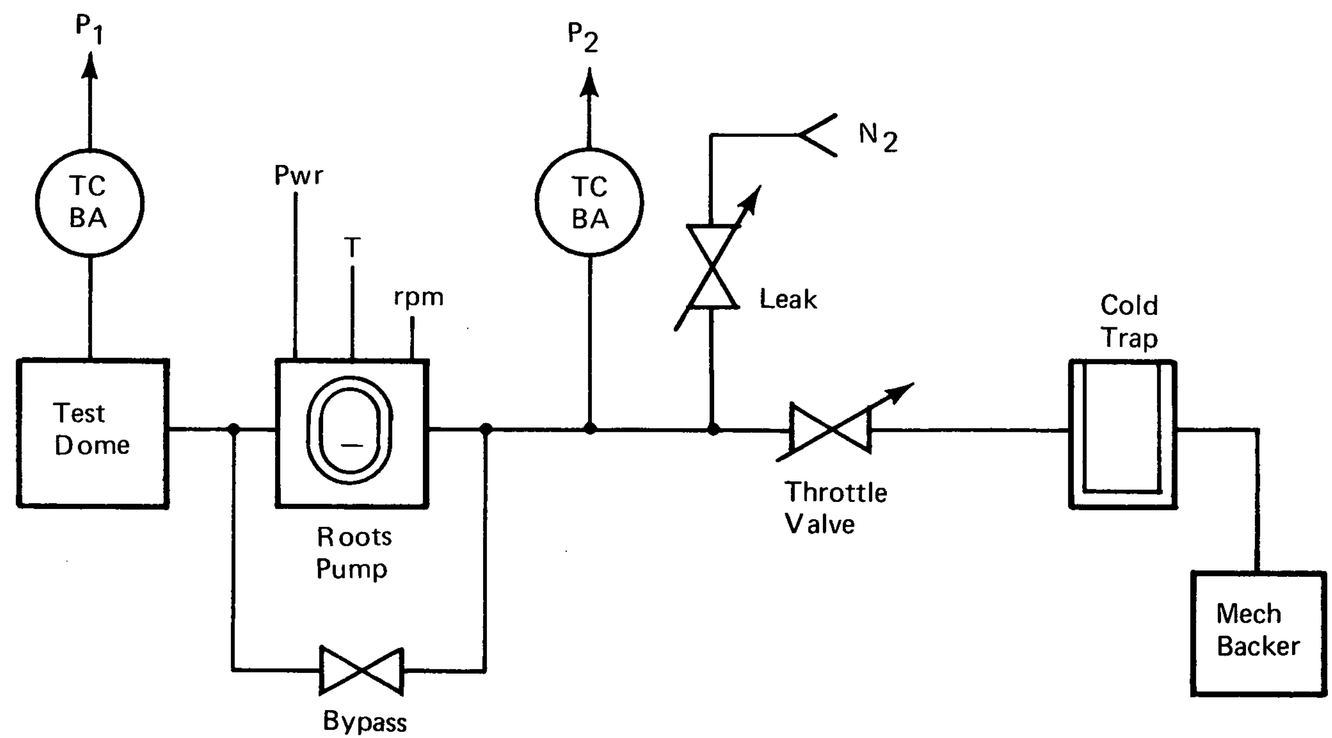
1. With the bypass open, the entire system is pumped down with the mechanical pump and purged with nitrogen. The cold trap is filled during the pump-down.

2. After purging, the system is stabilized at the desired backing pressure with the leak and throttle valves.

3. The pump is started; then the bypass is closed and pressures are again allowed to stabilize.

This test will be repeated for a series of pressure ranges from 10^3 Pascals down and for different pump speeds. Higher pressure operation will be considered after consultation with the Pfeiffer engineer; but care must be exercised to prevent catastrophic failure of the pump, especially early in the test program.

11346-33



Zero Flow P_1 Vs. P_2 → { Compression, Temp Rise, Power } → As a Function of: Pressure (P_2), rpm

Figure 9-1 Testing of Mechanical Pump — Ultimate Pressure

Figure 9-2 is a schematic of the manifold configuration for testing pumping speed. The procedure is similar to that above. As before, the by-pass valve offers protection to the pump by permitting the conditions to be established before starting the pump. Inadvertent pressure or flow "bursts" are thus eliminated.

9.2 RESIDUAL GAS ANALYSIS ON THE PUMP

The purpose of this test is to determine the extent of selective back-streaming and sample contamination by bearing lubrication.

- Using a mass spectrometer, measure the relative change in composition of a special gas mixture as a function of Roots pumping.
- With a cold-trapped mass spectrometer, measure the amount of lubricant backstreaming from the pump.
- Perform the necessary mass spectral analysis to show lubricant is not from test manifold.

For the selective pumping tests, a gas mixture of different mass ratios would be used, such as:

up to 5%	H_2	-	1 AMU
not more than 1%	He	-	4 AMU
not more than 1%	Ne	-	20 AMU
about 5%	N_2	-	28 AMU
not more than 1%	Ar	-	40 AMU
not more than 1%	Kr	-	83 AMU
not more than 1%	Xe	-	13 AMU
remainder (85%)	CO_2	-	44 AMU

Not all of the above are necessary, but three or four should be used to cover the mass range of interest (1-140 AMU).

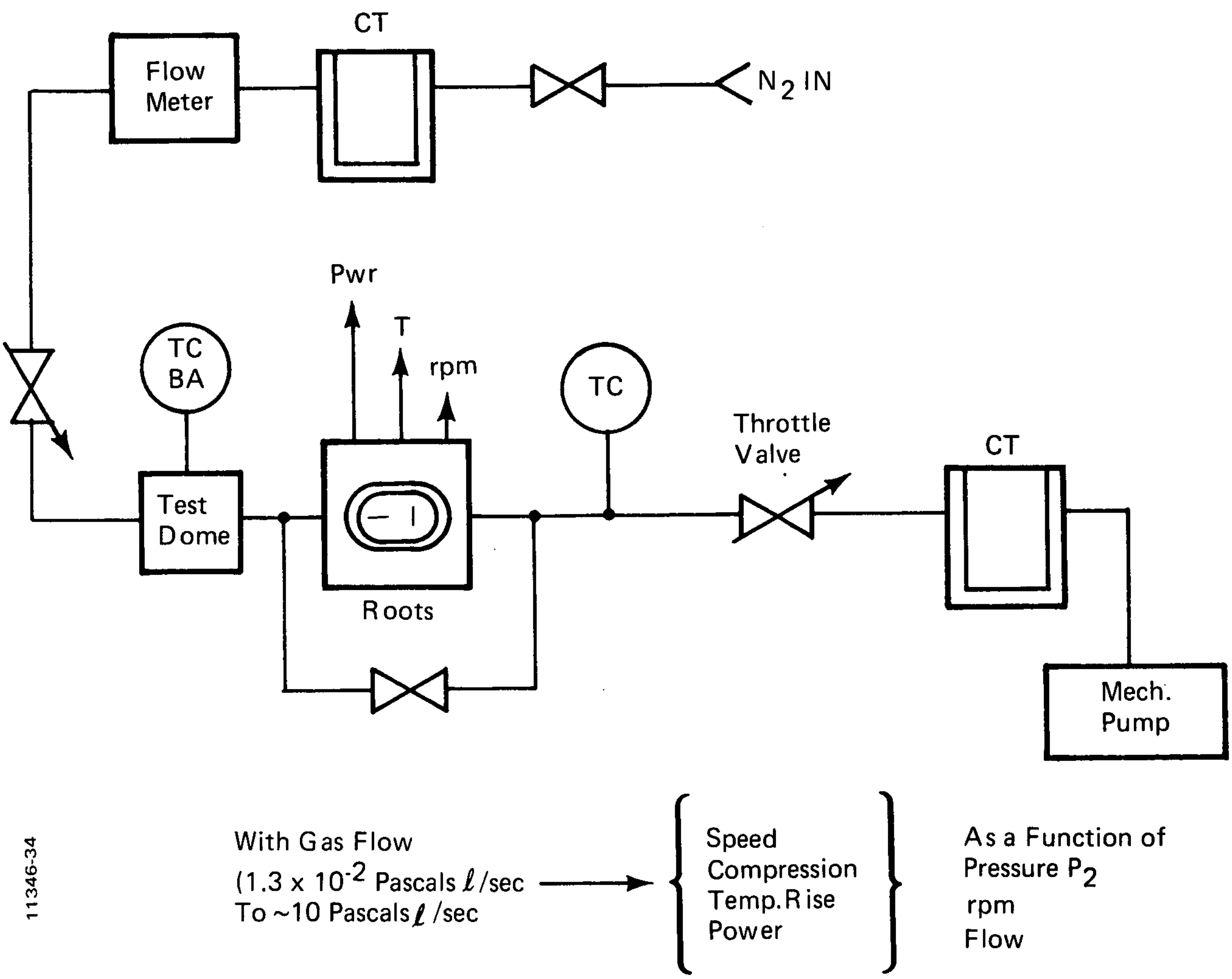


Figure 9-2 Testing of Mechanical Pump — Throughput

The selective pumping test would be performed on a test set, as shown in Figure 9-3, according to the following steps:

1. Evacuate and flush manifold and pump with test gas.

2. Close the throttle valve and fill the manifold with the test gas to the desired pressure level, about 10 Pascals. Close the line valve.

3. Run a mass spectral scan on the gas in the system.

4. Start the pump and close the bypass valve.

5. Open the valve to the mass spectrometer as needed to maintain a constant ion source pressure. It could be that the mass spectrometer pump should be throttled, especially if it is of the sputter ion variety.

6. Make periodic mass scans of the residual gas at the pump inlet.

7. After the run, close the valve to the mass spectrometer and continue to make mass scans to determine effect of mass spectrometer pump.

The analysis of lubrication backstreaming is best performed by adding a fractionating cold trap, Figure 9-4. This trap consists of about 15 centimeters of 1 millimeter ID stainless tubing placed between the Roots blower and the mass spectrometer. The operational sequence varies slightly:

1. Evacuate and flush with a test gas. One hundred percent nitrogen would be sufficient.

2. Fill manifold to about 10 Pascals. Close the line valve, and the valve to the mass spectrometer and to the mechanical pump and its cold trap.

3. Start the pump and close the bypass valve.

4. Chill the cold trap and hold at liquid nitrogen temperature.

5. Continue to operate in this manner for an hour or so.

6. Close the valve between the fractionating cold trap and the Roots pump and open the valve to the mass spectrometer.

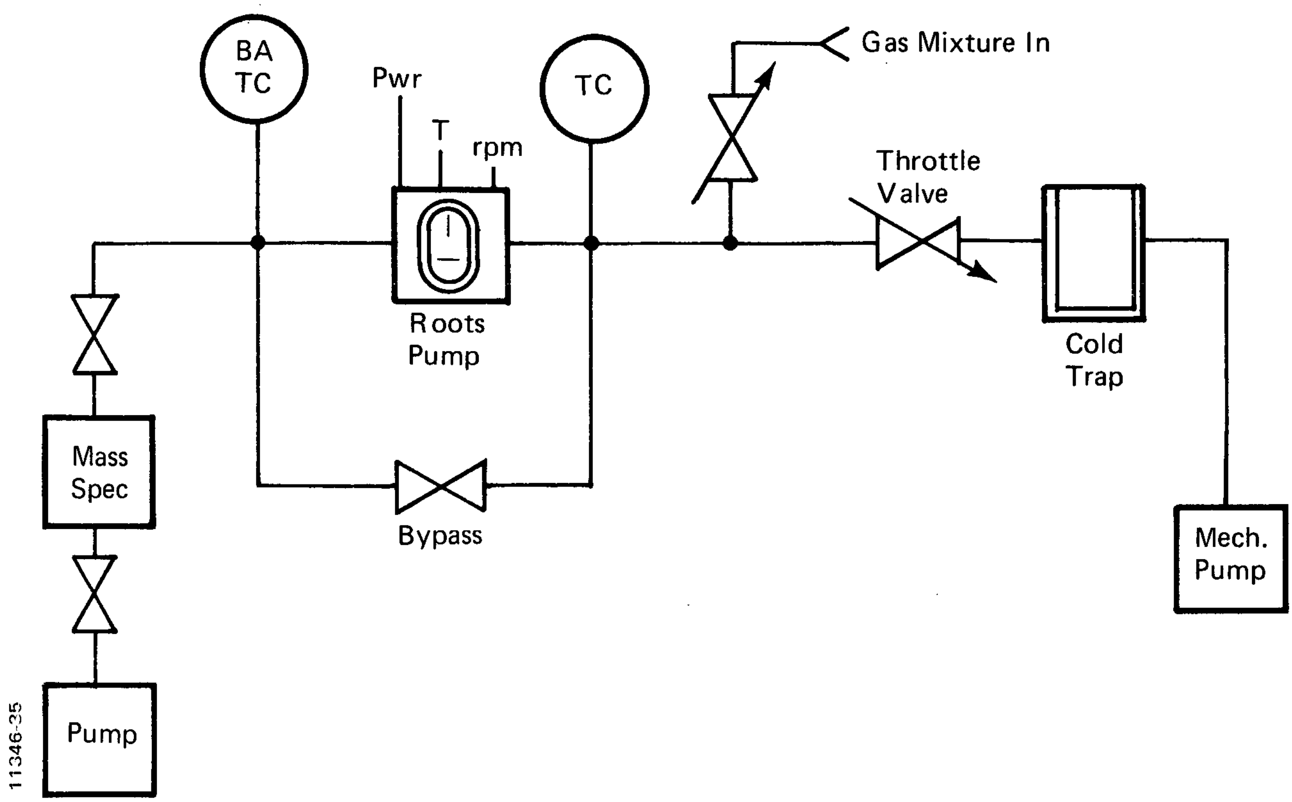


Figure 9-3 Testing of Mechanical Pump — Selective Pumping

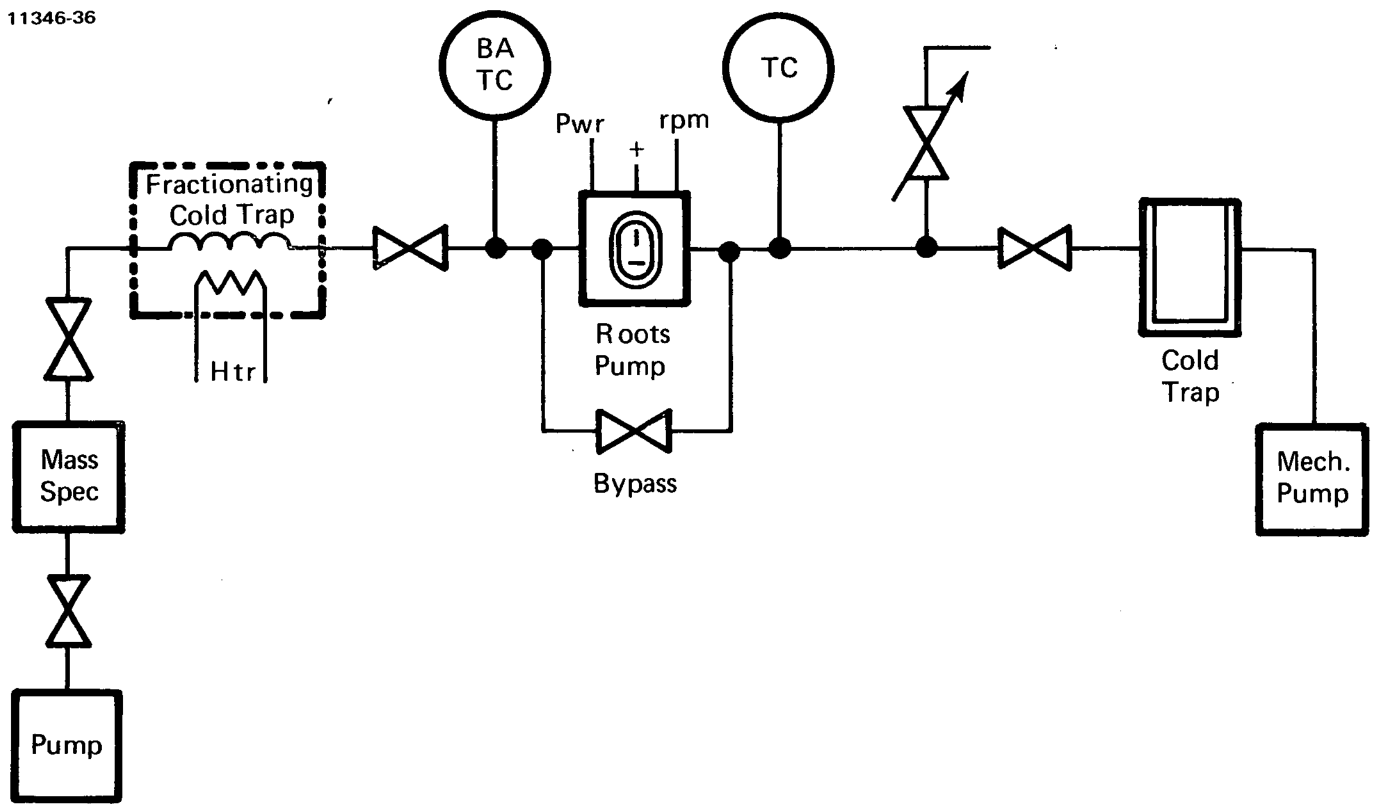


Figure 9-4 Testing of Mechanical Pump—Lubrication Backstreaming

7. Heat the fractionating cold trap at about 10°C per minute and monitor the effluent with the mass spectrometer.

If hydrocarbons are detected, a sample of the oil from the mechanical pump may be analyzed in the mass spectrometer to cover that possibility.

9.3 CAPABILITY FOR CONTROLLED ROTOR SPEED

- Determine the necessary controlling parameters of the electronic circuit.
- Breadboard a feedback circuit.
- Test the Breadboard with the pump under descending probe pressure profile conditions.

The three-restrictor constant flow schematic shown in Figure 7-1 does not provide actual constant flow conditions with a constant speed mechanical pump. Figure 9-5 shows a simplified pressure profile for the ion source, sample volume, and vacuum ballast for the mission. With three restrictors, the pressure varies over a decade three different times. More restrictors in parallel would decrease the pressure fluctuations but would add to the complexity of the valving system.

If the pump can be controlled to have a variable pumping speed, then it may be possible to establish a constant ion source pressure as depicted in Figure 9-6. This pressure would be set at the maximum allowable level, thus providing maximum sensitivity in the mass spectrometer.

Figure 9-6 may be an oversimplification of the situation since more power would be required to maintain a constant sample volume late in the mission than earlier. As the ballast volume pressure increases more power would be required. The purpose of this test is to determine the nature of the circuitry required to provide a constant ion source pressure.

9.4 EVALUATE THE ANNULAR RESTRICTOR

- Make four restrictors of different conductance value in the range of 10^{-7} to 10^{-4} ℓ/s.
- Test each restrictor for both viscous and molecular flow.
- Design a flight type annular restrictor.

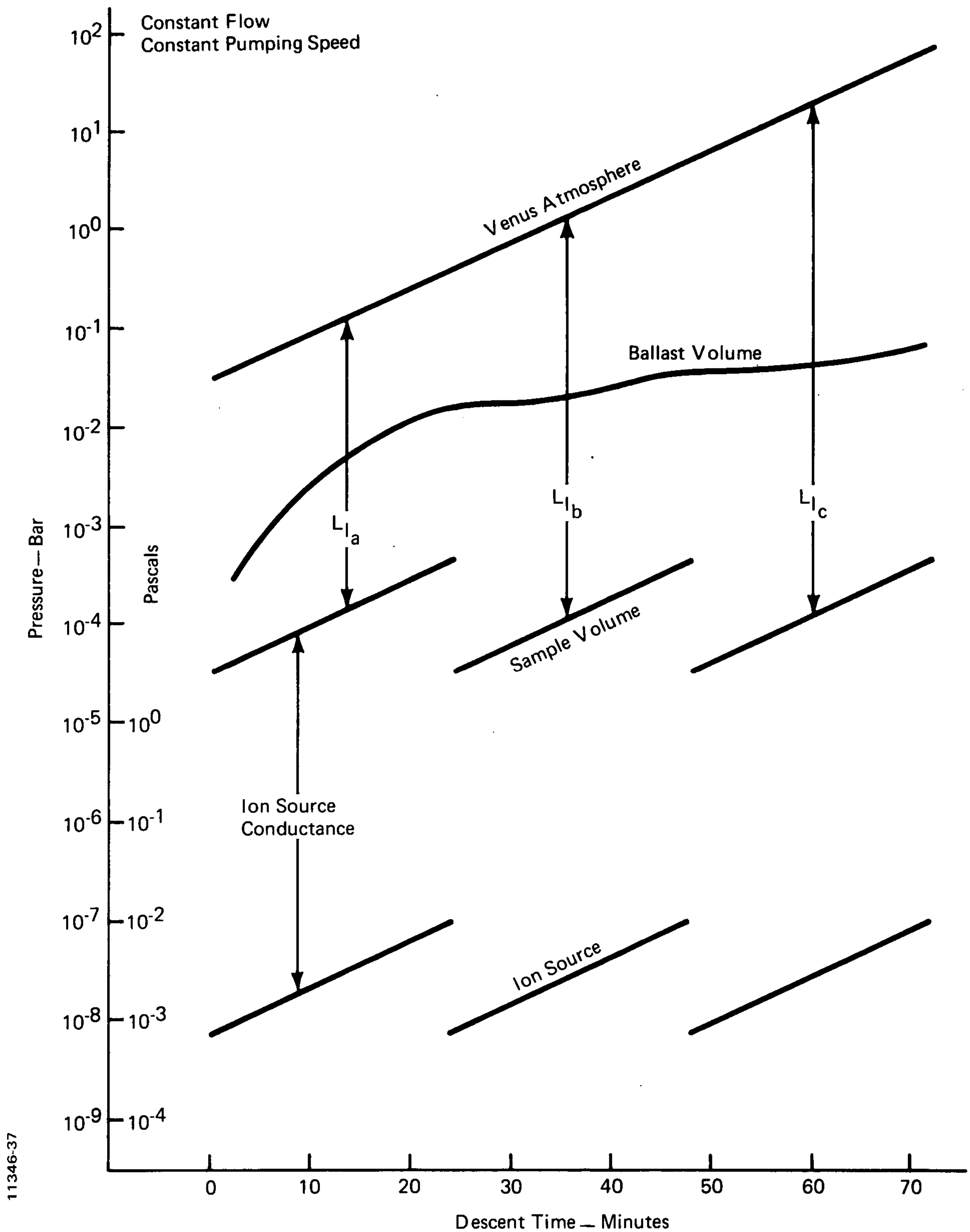


Figure 9-5 Time-Pressure Profile, Constant Pumping Speed

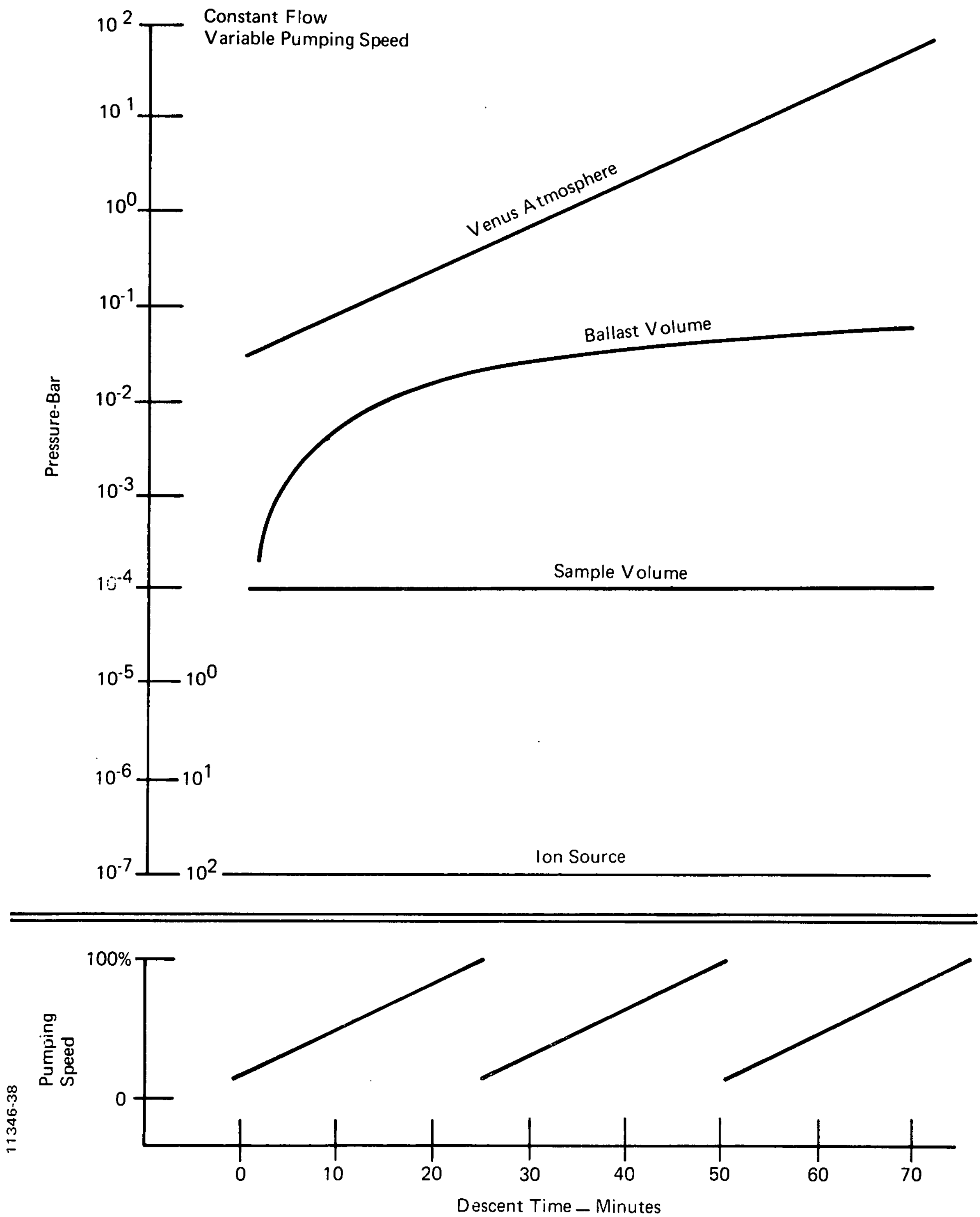


Figure 9-6 Time-Pressure Profile, Variable Pumping Speed

Figure 9-7 shows the test setup for such an evaluation. The same flow meter as the positive displacement type would be used for both tests if possible. In the viscous test, if the inlet pressure is about 10^7 Pascal (100 bar), then exhausting to atmosphere 10^5 Pascal (1 bar) creates a pressure drop sufficiently great to use the approximate formula. Likewise, in the molecular tests, if the inlet pressure is two orders of magnitude or greater than the output, the approximation formula is valid. To ensure molecular flow, the input pressure would be about 1 Pascal.

9.5 INLET ENGINEERING MODEL

This effort is recommended in order to achieve the objective of an inlet system preliminary design:

- Build engineering breadboard model complete with vacuum or chemical ballast, restrictors, etc.
- Test over the entire operating range with a Venus model test gas.
- Make mass spectrometric measurements to determine extent of chemical pump or lubrication problems.
- Analyze and test system for worst-case conditions and single-point failure possibilities.
- Provide an inlet system preliminary design.

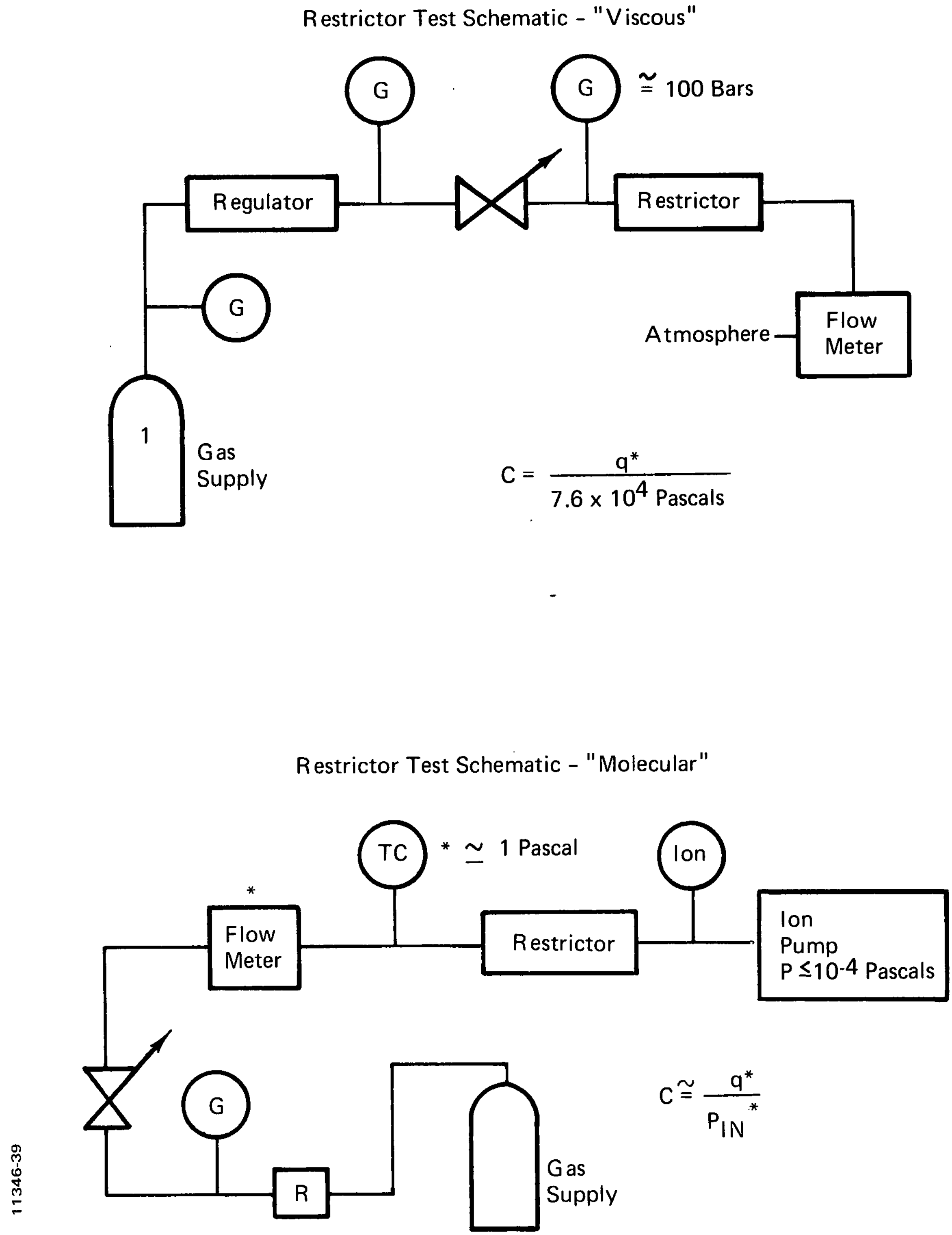


Figure 9-7 Restrictor Test Schematics

SECTION 10

REFERENCES

1. NASA ARC Document PV-1003, "Atmospheric Inlet System for the Pioneer-Venus Probe Mission Mass Spectrometer," August 1972.

2. NASA ARC Document, "Pioneer-Venus: Report of a Study by the Science Steering Group," June 1972.

3. NASA ARC Document PV-1002.00A, "Pioneer-Venus Baseline System Design," July 1972.

APPENDIX A

INLET MODEL PRESSURE AND FLOW COMPUTATIONS

TABLE A-1 - MODEL I

Sample Time, Min	Mean Pressure m bar		Integrated Mean Pressure bar sec		Quantity bar ℓ		Quantity bar ℓ	Flow Pa ℓ/s	Pa ω/ 1 ℓ/s P_m	Accum. Bar ℓ
3	61	3-min or 180-sec Sample Times	11	Mult. by × ℓ/s	11 X	Mult. Intg. Mean Press. by 2.59×10^{-4} ℓ/s	28×10^{-4}	1.6	1.6	28
6	157		28		28		73	4.1	4.1	101
9	285		51		51		132	7.4	7.4	233
12	465		84		84		218	12.2	12.2	451
15	645		116		116		300	16.8	16.8	751
18	815		146		146		378	21.2	21.2	1,129
			T $\boxed{436}$		$\boxed{436 \text{ X}}$		$\boxed{1,129 \times 10^{-4}}$			
21	1,010		182	Mult. by 0.05 × ℓ/s	9 X	by 1.3×10^{-5}	24×10^{-4}	1.3	1.3	1,153
24	1,235		222		11		29	1.6	1.6	1,182
27	1,500		270		14		35	2.0	2.0	1,217
30	1,762		317		16		41	2.3	2.3	1,258
33	2,050		369		18		48	2.7	2.7	1,306
36	3,062		551		28		72	4.0	4.0	1,378
39	5,850		1,053		53		137	7.7	7.7	1,515
42	9,900		1,782		89		232	13.0	13.0	1,747
45	15,000		2,700		135		351	19.6	19.6	2,098
			T $\boxed{7,446}$		$\boxed{372 \text{ X}}$		$\boxed{968 \times 10^{-4}}$			
48	21,125	6-min or 360-sec Sample	3,802	Mult. by 0.005 × ℓ/s	19 X	by 1.3×10^{-6}	49	2.7	2.7	2,147
			T $\boxed{3,802}$		$\boxed{19 \text{ X}}$					
54	31,175		11,223		56 X		146	4.1	4.1	2,293
60	46,750		16,830		84		219	6.1	6.1	2,512
66	64,825		23,337		117		303	8.5	8.5	2,815
72	84,550		30,420		152		395	11.6	11.6	3,210
			$\boxed{85,612}$		$\boxed{428 \text{ X}}$		$\boxed{1,113 \times 10^{-4}}$			
			93,494		1,236 X		$3,209 \times 10^{-4}$	Flow Model		

TABLE A-2 - MODEL II

Sample Time, Min	Mean Pressure m bar		Integrated Mean Pressure bar sec		Quantity bar ℓ		Quantity bar ℓ	Flow Pa ℓ/s	Pa ω/ 1 ℓ/s P_m	Accum. bar ℓ
3	61	3-min or 180-sec Sample Times	11	Mult. by × ℓ/s	11 X	Mult. Intg. Mean Press. by 2.59 × 10^{-4} ℓ/s	28 x 10^{-4}	1.6	1.6	28
6	157		28		28		73	4.1	4.1	101
9	285		51		51		132	7.4	7.4	233
12	465		84		84		218	12.2	12.2	451
15	645		116		116		300	16.8	16.8	751
18	815		146		146		378	21.2	21.2	1,129
			T $\boxed{436}$		$\boxed{436\ X}$		$\boxed{1,129 \times 10^{-4}}$			
21	1,010		182	Mult. by 0.05 × ℓ/s	9 X	by 1.3 × 10^{-5}	24 x 10^{-4}	1.3	1.3	1,153
24	1,235		222		11		29	1.6	1.6	1,182
27	1,500		270		14		35	2.0	2.0	1,217
30	1,762		317		16		41	2.3	2.3	1,258
33	2,050		369		18		48	2.7	2.7	1,306
36	3,062		551		28		72	4.0	4.0	1,378
39	5,850		1,053		53		137	7.7	7.7	1,515
42	9,900		1,782		89		232	13.0	13.0	1,747
45	15,000		2,700		135		351	19.6	19.6	2,098
			T $\boxed{7,446}$		$\boxed{372\ X}$		$\boxed{968 \times 10^{-4}}$			
48	21,125		3,802	Mult. by 0.010	38 X	by 2.59 × 10^{-4} ℓ/s	98 x 10^{-4}	5.4	5.4	2,196
		6-min or 360-sec Sample	T $\boxed{3,802}$		$\boxed{38\ X}$					
54	31,175		11,223		112 X		290	8.2	8.2	1,486
60	46,750		16,830		168		436	12.2	12.2	2,922
66	64,825		23,337		234		604	17.0	17.0	2,526
72	84,550		30,420		304		787	22.6	22.6	4,313
			$\boxed{85,612}$		856		$\boxed{2,215}$	Pressure Model		
			93,494		1,664		4,312			

TABLE A-3 - MODEL III

Sample Time, Min	Mean Pressure m bar		Integrated Mean Pressure bar sec		Quantity bar ℓ		Quantity bar ℓ	0.00555 Pa ℓ/s	Pa ω/ 1ℓ/s	Accum. bar ℓ from 5
3	61	3-min or 180-sec Sample Times	11	Mult. by χ ℓ/s	11 χ	Mult. Intg. Mean Press. by 1.92 × 10⁻⁴ ℓ/s	21 x 10^{-4}	1.2	1.2	21
6	157		28		28		54	3.0	3.0	75
9	285		51		51		98	5.4	5.4	173
12	465		84		84		161	8.9	8.9	334
15	645		116		116		223	12.4	12.4	557
18	815		146		146		280	15.6	15.6	837
			T $\boxed{436}$		$\boxed{436\ \chi}$		$\boxed{837 \times 10^{-4}}$			
21	1,010		182	Mult. by 0.05 χ ℓ/s	9 χ	by 0.96 x 10^{-5}	17 x 10^{-4}	0.9	0.9	854
24	1,235		222		11		21	1.2	1.2	875
27	1,500		270		14		26	1.4	1.4	901
30	1,762		317		16		30	1.7	1.7	931
33	2,050		369		18		35	1.9	1.9	966
36	3,062		551		28		53	2.9	2.9	1,019
39	5,850		1,053		53		101	5.6	5.6	1,120
42	9,900		1,782		89		171	9.5	9.5	1,291
45	15,000		2,700		135		259	14.4	14.4	1,550
			T $\boxed{7,446}$		$\boxed{372\ \chi}$		$\boxed{714 \times 10^{-4}}$			
48	21,125		3,802	Mult. by 0.010	38 χ	by 1.92 x 10^{-6}	73 x 10^{-4}	4.1	4.1	1,623
		6-min or 360-sec Sample	T $\boxed{3,802}$		$\boxed{38\ \chi}$		$\boxed{73 \times 10^{-4}}$			
54	31,175		11,223		112 χ		215	6.0	6.0	1,838
60	46,750		16,830		168		323	8.9	8.9	2,161
66	64,825		23,337		234		448	12.4	12.4	2,609
72	84,550		30,420		304		584	16.2	16.2	3,193
			$\boxed{85,612}$		$\boxed{856}$		$\boxed{1,644 \times 10^{-1}}$			
			93,494		1,664		$\boxed{3,194 \times 10^{-4}}$			

TABLE A-4 - MODEL IV

Sample Time, Min	Mean Pressure m bar		Integrated Mean Pressure bar sec		Quantity bar ℓ	qω/ 1.92×10^{-4} ℓ/s bar ℓ	Open Time (To Maintain 280×10^{-4} bar ℓ 13 min)		0.300 sec Open Time		Closed Time per Cycle
							%	Sec/Period	Cycles/Period	Cycles/Min.	Sec/Cycle
3	61	3-min or 180-sec Sample Times	11	Mult. by x ℓ/s	11 x	21×10^{4}					
6	157		28		20	54					
9	285		51		51	98					
12	465		84		84	161	100%	Full Open	NA	NA	NA
15	645		116		116	223					
18	815		146		146	280					
			T $\boxed{436}$		$\boxed{436\ x}$						
21	1,010		182	Mult. by 0.05 x ℓ/s	9 x	349×10^{-4}	80.2	144	481	160	0.074
24	1,235		222		11	426	65.7	118	394	131	0.157
27	1,500		270		14	518	54.0	97	324	108	0.256
30	1,762		317		16	608	46.1	83	277	92	0.350
33	2,050		369		18	708	39.5	71	237	79	0.460
36	3,062		551		28	1,057	26.5	48	154	53	0.832
39	5,850		1,053		53	2,022	13.8	25	82.7	28	1.87
42	9,900		1,782		89	3,421	8.1	15	49.3	16	3.35
45	15,000		2,700		135	5,184	5.4	9.7	32.3	11	5.27
			T $\boxed{7,446}$		$\boxed{372\ x}$						
48	21,125		3,802	Mult. by 0.010	38 x	$7,300 \times 10^{4}$	3.8	6.8	22.7	7.6	7.63
		6-min or 360-sec Sample	T $\boxed{3,802}$		$\boxed{38\ x}$						
54	31,175		11,223		112 x	21,548	2.6	9.4	31.3	5.2	11.2
60	46,750		16,830		168	32,314	1.7	6.1	20.3	3.4	17.5
66	64,825		23,337		234	44,807	1.2	4.3	14.3	2.4	24.8
72	84,550		30,420		304	58,406	0.9	3.2	10.7	1.8	29.7
			$\boxed{85,612}$		$\boxed{856}$						
			93,494		1,664						

TABLE A-5 - MODEL V

Sample Time, Min.	Mean Pressure m bar		Integrated Mean Pressure bar sec		Quantity bar ℓ	qω/ 1.92×10^{-4} ℓ/s bar ℓ	Closed Time (To Maintain 280×10^{-4} bar ℓ) %		6-sec Closed Time		Open Time
							%	Sec/ Period	Cycle/ Period	Cycle/ Min.	Sec/Cycle
3	61	3-min. or 180-sec Sample Times	11	Mult. by x ℓ/s	11 x	21×10^4	↑	↑	↑	↑	↑
6	157		28		20	54					
9	285		51		51	98	0%	Full Open	NA	NA	NA
12	465		84		84	161					
15	645		116		116	223					
18	815		146		146	280	↓	↓	↓	↓	↓
			T $\boxed{436}$		$\boxed{436 \text{ x}}$						
21	1,010		182	Mult. by 0.05 x ℓ/s	9 x	349×10^{-4}	19.8	36	6.0	2	24.0
24	1,235		222		11	426	34.3	62	10.4	3.5	11.3
27	1,500		270		14	518	46.0	83	13.7	4.6	7.08
30	1,762		317		16	608	53.9	97	16.2	5.4	5.12
33	2,050		369		18	708	60.5	109	18.2	6.1	3.90
36	3,062		551		28	1,057	73.5	132	22.0	7.3	2.18
39	5,850		1,053		53	2,022	86.2	155	25.9	8.6	0.965
42	9,900		1,782		89	3,421	91.9	165	27.5	9.16	0.545
45	15,000		2,700		135	5,184	94.6	170.3	28.4	9.46	0.341
			T $\boxed{7,446}$		$\boxed{372 \text{ x}}$						
48	21,125		$\boxed{3,802}$	Mult. by 0.010	38 x	$7,300 \times 10^4$	96.2	173.2	28.9	9.62	0.235
		6-min. or 360-sec Sample	T 3,802		38 x						
54	31,175		11,223		112 x	21,548	97.4	350	58.3	9.74	0.172
60	46,750		16,830		168	32,314	98.3	354	59.0	9.85	0.102
66	64,825		23,337		234	44,807	98.8	356	59.3	9.90	0.067
72	84,550		30,420		304	58,406	99.1	357	59.5	9.94	0.050
			$\boxed{85,612}$		$\boxed{856}$						
			93,494		1,664						

APPENDIX B

MECHANICAL PUMP SPECIFICATION

SPECIFICATION
MECHANICAL PUMP

1. SCOPE

The purpose of this specification is to determine the developmental requirements for a mechanical vacuum pump for possible use as a component in the mass spectrometer inlet system of the Pioneer-Venus atmospheric entry probe. The response obtained to this specification will be utilized to identify specific sources for pump development and the development cost and schedule requirements.

2. APPLICABLE DOCUMENTS

None.

3. REQUIREMENTS

There are two types of requirements to be met: (1) the performance requirements of the pump and (2) the design requirements for a flight type pump. The second set of requirements should be recognized as design goals only at this time.

3.1 PERFORMANCE REQUIREMENTS

The pump shall have the following operational characteristics insofar as possible. Any exception must be clearly stated.

3.1.1 Throughput

The pump shall have a minimum throughput of 1 torr liter per second at an input pressure of 1 torr.

3.1.2 Speed

From 3.1.1 above, the pump speed can be determined to be 1 liter per sec at 1 torr. This speed shall remain approximately constant with input pressures up to 10 torr. A requirement goal would be to have a 1 liter per second capability from 10 torr to 0.1 torr.

3.1.3 Compression Ratio

Items 3.1.1 and 3.1.2 shall hold true with a backing pressure of at least 50 torr.

3.1.4 Contamination

Backstreaming from the pump at the inlet shall not include any species foreign to the gas being pumped in excess of 1 part in 10^8.

3.1.5 Selective Pumping

Selective pumping of gas species of atomic mass units from 1 to 140 is allowed, but not greater than $(1/\text{mass})^{1/2}$. If selective pumping is present it must be constant and determinable.

3.1.6 Pump Life

The pump shall be capable of 90 minutes of operation at full speed when pumping the expected Venus atmosphere (attached). This would follow 15 hours of preflight testing using a CO_2/N_2 test mixture.

3.2 DESIGN REQUIREMENTS

The pump should be designed within the following constraints or design goals. These should be considered as target goals only and may be sacrificed in terms of pump performance. The drive motor shall be considered part of the pump.

3.2.1 Weight

Pump weight should not exceed 5 pounds including the drive motor.

3.2.2 Power

Input power shall be unregulated 28 Vdc ± 10%. Power shall not exceed 10 watts maximum during the operational modes.

3.2.3 Size

The pump size shall be a minimum consistent with the performance requirements.

3.2.4 Environment

The design will be chiefly dictated by the inertial loads during entry where peak acceleration may exceed 350 Earth g's. Primary sensitive axes of the pump to these loads should be indicated.

The pump must be capable of satisfactory start-up and operation after being in a weightless, non-operating condition for approximately six months.

The gases to be pumped will consist primarily of carbon dioxide at temperatures from -38°C to 480°C.

The pump must also be capable of a vacuum bakeout with the inlet system for 48 hours at 200°C.

3.2.5 Control

As a requirement goal the motor shall be of a type which permits speed as rpm control.

COMPOSITION OF THE VENUS ATMOSPHERE

Component	Estimated Percent by Volume
CO_2	97, +3, -4
N_2	< 2
O_2	$< 10^{-3}$
H_2O	$10^{-2} - 10^{-1}$
	$10^{-4} - 10^{-2}$
HCl	$10^{-4.2}$
HF	$10^{-6.2}$
CH_4	$< 10^{-4}$
CO	$10^{-2.34}$
COS	$< 10^{-6} - 10^{-4}$
NH_3	$< 10^{-5.5}$
N_2O	$< 5 \times 10^{-5}$
He	$\approx 10^{-2}$
CH_3Cl	$< 10^{-4}$
C_2H_2	$< 10^{-4}$
HCN	$< 10^{-4}$
O_3	$< 10^{-6}$
C_3O_2	$< 10^{-4.3}$
H_2S	$< 10^{-1.7}$
SO_2	$< 10^{-5.5}$
CH_3F	$< 10^{-4}$

APPENDIX C

MECHANICAL PUMP SURVEY

RFP Letter No.	Pump Vendor Contacts	Response	Remarks
0260	Edward High Vacuum	Neg	Does not have the technology
0261	Beach-Russ Company	None	
0262	Sargent-Welch Company	Neg	No time to estimate
0263	Linco Instrument Company	Neg	Cannot spare personnel or time
0264	Airco-Timescal	None	
0265	Leybold-Heraeus	None	
0266	Kinney Vacuum	Neg	Responded but with power and weight exceptions due to friction
0267	Metal Bellows Corp.	None	Did consider (verbally)
0268	Dresser Industries	Neg	Nothing to offer
0269	Gust Mfg. Company	None	
0270	Norton Vacuum Engineering	Neg	Work schedule limitations
0271	Ultek Division, Perkin-Elmer	None	
0272	Barkly & Dexter Laboratories	Neg	No time to quote; they do make a Roots circulating pump
None	Precision Scientific Company		
↓	Leiman Bros.		

RFP Letter No.	Pump Vendor Contacts	Response	Remarks
None	Alcatel		
	Servometer		
	SLAC		
	MD Pneumatics		
	Roots Connersville		
	Nash Engineering		
	Stokes Vacuum		
	AIRSERCO		
	Aero Vac Corp.		
	Ace Pump		
	Bendix Automation & Measurements		
	Conde Pump		
	Cooke Vacuum Products		
	Granville Phillips		
	Nelson Pumps		

APPENDIX D

NEW TECHNOLOGY

A negative report is submitted.

The work performed was conceptual preliminary design and state-of-the-art survey. Detailed design or invention of new components was not undertaken. Since the subject program did not enter hardware detailed design or development, no new tools, processes, methods, or techniques were conceived which are reportable under the provisions of the New Technology Clause.