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FINAL TECHNICAL REPORT

For

Support Activities to Maintain SUMS
Flight Readiness

Contract No. NAS1-17399

Volume 1 of 9
Project Report

submitted to

National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia 23665-5225

by

The University of Texas at Dallas
P.O. Box 830688
Richardson, Texas 75083-0688

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May 19, 1992

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Abstract

The Shuttle Upper Atmosphere Mass Spectrometer (SUMS), a component experiment of the NASA Orbital Experiments Program (OEX), was flown aboard the shuttle Columbia (OV102) mounted at the forward end of the nose landing gear well with an atmospheric gas inlet system fitted to the lower fuselage (chin panel) surface. The SUMS was designed to provide atmospheric data in flow regimes inaccessible prior to the development of the Space Transportation System (STS). The experiment mission operation began about one hour prior to shuttle de-orbit entry maneuver and continued until reaching 1.6 torr (about 86 km altitude).

The SUMS mass spectrometer consisted of the spare unit from the Viking mission to Mars. Bendix Aerospace under contract to NASA LaRC incorporated the Viking mass spectrometer, a microprocessor based logic card, a pressurized instrument case, and a University of Texas at Dallas provided gas inlet system into a configuration suited to interface with the shuttle Columbia. The SUMS was built by the Bendix Aerospace Division. After completion the SUMS experiment supporting activities were transferred to UTD under the direction of NASA LaRC.

The SUMS experiment underwent static and dynamic calibration as well as vacuum maintenance before and after STS 40 shuttle flight. The SUMS flew a total of 3 times on the space shuttle Columbia. Between flights the SUMS was maintained in flight ready status at the physics laboratory of UTD. The flight data has been analyzed by the NASA LaRC Aerothermodynamics Branch. Flight data spectrum plots and reports are presented in the Appendices to the Final Technical Report for NAS1-17399.

1.0 Introduction

The shuttle Upper-Atmosphere Mass Spectrometer (SUMS) was developed as a part of the NASA-Orbiter Experiments (OEX) Program. The OEX Program objective was to provide research quality instrumentation to study shuttle Orbiter performance over the entire spectrum of atmospheric flight. Flight data from the OEX program experiments are being used by various NASA groups in support of the development of flight performance prediction technology for future space transportation systems as well as to provide flight data in regimes which are difficult to simulate with ground based laboratory facilities. The SUMS instrument provided measurements of in situ rarefied flow aerodynamics and measurements of high altitude atmospheric parameters for aerodynamic calculations.

The SUMS instrument was designed around an existing proven airborne mass spectrometer which was modified to meet the experiment objectives. Two NASA Viking Program upper aatmosphere mass spectrometer (UAMS) back-up mass spectrometers were used by Bendix Aerospace under the direction of NASA Langley Research Center (LaRC) and NASA Johnson Space Center (JSC) to form the core of the NASA OEX SUMS instrument. The Viking UAMS spare mass spectrometer was packaged along with a Bendix single board microcomputer and power supplies into a pressurized case suitable for the shuttle space environment. A gas micro leak inlet system derived from the proven NASA Pioneer Venus Large Probe Mass Spectrometer (LNMS) was provided by the University of Texas at Dallas (UTD) to interface between the shuttle entry atmosphere and the UAMS ion source entrance. The OEX program provided a data handling and command system to interface the SUMS to the shuttle power command and data recording systems.

The SUMS instrument flew aboard the shuttle Columbia (OV102) three times. The atmospheric flow regime data was obtained on Flight STS 35. Flight STS 61C failed to obtain data due to a "sticking" protection valve, Flight STS 40 lost data due to water accumulated in the entrance tube. No further flights are planned due to the scheduled refurbishment of the shuttle Columbia vehicle.

2.0 History of the SUMS Instrument

In order to assess the heritage of the SUMS instrument components some history of the Viking Project Mass Spectrometer is included. Viking Project hardware development began in 1971 and was completed in 1974. The SUMS Mass Spectrometers (Viking spares) were built at Bendix-Ann Arbor under the supervision of Dr. A.O.C. Nier of Minnesota, the Viking Entry Science Principal Investigator. The two spare Viking mass spectrometers (MS) units along with the appropriate Ground support Equipment (GSE) were made available to the OEX Project for use in the SUMS instrument program in 1979.

The Bendix Aerospace Operation of Ann Arbor was selected to fabricate the SUMS instrument under contract NAS1-16073. The NASA Johnson Space Center, Orbiter Experiments Office provided support in interfacing the SUMS to the shuttle vehicle and general support throughout the experiment development by a contract with Lockheed (Contract No. NAS9-15588).

While the SUMS was at Bendix Aerospace the instrument went through initial calibration, performance testing, and an environmental qualification test program. At the same time the required shuttle Program Safety and Interface Reviews were accomplished.

After completion of the effort at Bendix, the SUMS was moved to UTD to be kept flight ready until time to install the instrument aboard the shuttle for a flight opportunity. The SUMS GSE consisted of a microprocessor controlled test set, an HP computer, a vacuum maintenance station, and a static gas calibration station. The inlet system was developed by UTD under subcontract to Bendix Aerospace (SC 1663). Support for SUMS Flight Readiness and Vacuum Maintenance was contract NAS1-17399 from NASA LaRC to UTD.

2.1   Major Events in SUMS Activities

SUMS Shipped from Bendix	3-3-82
OEX - Integrated Systems Test	1-25-84
Columbia Fit Check at Palmdale	3-27-84
Microprocessor Failure	6-13-84
Emission Regulator Failure	7-26-84

STS 61C Flight Event
Pre-Ship Functional at UTD	9-4-85
Ship to KSC for Installation	9-6-85
Completion of KSC Testing	9-18-85
Installation	10-1-85
KSC Launch	1-12-86
Flight	1-12 thru 1-18-86
Edwards Landing	1-18-86
Protection Value Failure Investigation	2-27-86

STS 35 Flight Event
Shipped to KSC	2-01-90
Moved to OPF	2-19-90
Orbiter Flight (10 days)	12-1 thru 12-11-90
Edwards AFB Landing	12-11-90

STS 40 Flight Events
Shipped to KSC	12-14-90
Installed Flight Battery	1-04-91
Functional Test	2-24-91
Launch	6-5-91

Orbiter Flight	6-5 thru 6-12-91
SUMS Removal	6-29-91
SUMS Return to UTD	7-8-91
SUMS Evaluation	7-15-91
SUMS Vacuum Maintenance	7-20-91

3.0 Theory of Operation of the SUMS Instrument

The initial prototype Viking Upper Atmosphere Mass Spectrometer (UAMS) instrument was built by A.O. Nier of University of Minnesota for the Martin Marieta Corp. The flight UAMS instruments were built by the Bendix Corporation Aerospace Operation.

The UAMS had been designed to have its ion source interface at the surface of the Viking aeroshell as shown by Figure 1. This interface was modified to receive gas by way of an inline protection valve from a .25 in. diameter stainless steel (ss) tube. Figure 2 is a block schematic of the SUMS inlet system. The ss tube couples the ion source to the inlet system which is mounted to within about 4 inches of the entrance tube which samples the atmosphere in the vicinity of the shuttle orbiter chin panel. Gas flows from the entrance tube by way of a SEADS port tee connection to the SUMS inlet system. In the inlet system the gas flows by one path to a Tavis pressure transducer and by a second path to an inlet valve. Under control of the stored logic program of the SUMS microcomputer the inlet valve is open to allow gas to flow to the two parallel micro leaks. Gas flowing through the parallel leaks feed the ion source from on-orbit pressure of about 1×10^{-6} torr until 5×10^{-3} torr pressure atmosphere. During this period of time the mass spectrometer gas measurement data is monitored by the SUMS computer to determine if any 3 consecutive gas measurements read greater than 1.0×10^{-9} amperes. As the SUMS computer senses the 1×10^{-9} ampere threshold it issues a command to operate the range valve. The range valve closes off the large leak leaving the gas flow through the small leak only to feed gas to the ion source. The SUMS computer continues to monitor the mass spectrometer until the 1×10^{-9} ampere threshold is sensed for the second time, the computer then sends a command to close the inlet valve and the protection valve. The Tavis pressure transducer output signal and the ion current are monitored by the SUMS computer to prevent SUMS operation at too high a pressure and provide an overlapping pressure measurement at the 1.0 torr region.

The SUMS experiment is controlled in flight by the shuttle Orbiter General Purpose Computer (GPC) software after the forward fuselage Load Control Assembly has furnished the proper SUMS power up commands. SUMS measurements are stored on digital magnetic tape by the OEX PCM tape recorders. After landing the data tapes are sent to NASA/JSC. JSC processes the OEX Data to Produce a SUMS Computer Compatable Tape (CCT). The CCT is sent to LaRC for data processing and analysis by the Aerothermodynamics Group.

3
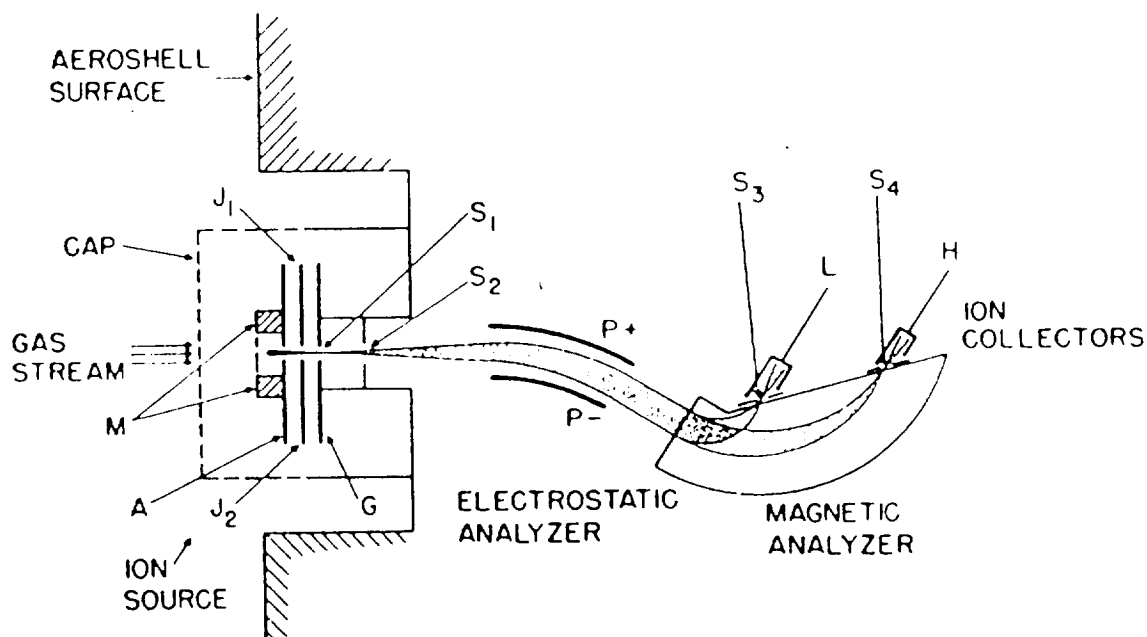
Figure 1

Schematic diagram of the Viking UAMS mounted on the aeroshell of the Viking lander spacecraft. The OEX-SUMS instrument utilized a replacement for the cap which interfaced with the Sums inlet via 1/4 inch diameter stainless steel tubes. The schematic shows the ion flow for the 2 channel Mattauch-Herzog double focussing mass spectrometer.
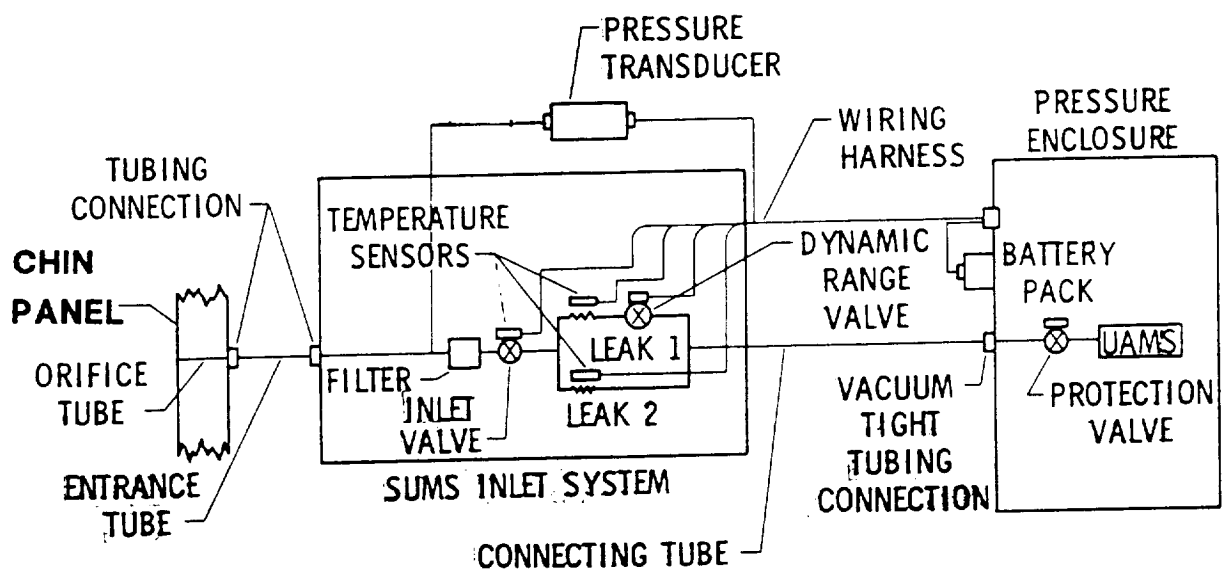
Figure 2
SUMS Inlet System Component Schematic

SUMS Instrument Specification

The SUMS instrument may be generally described by the following instrument specification.

Mass Range:
low channel   1 to 7 amu
high channel   7 to 50 amu

Current Resolution: 3%

Mass Resolution   1% valley of adj. peaks at M/E 28

Scan Rate: 5 seconds per scan

Emission: 100 μA

Ionization Potential: 75 volts

Ion Source Sensitivity: 10^{-5}A/torr

Measurement Range:
Minimum Orifice Pressure 10^{-6} torr
Maximum Orifice Pressure   1.5 torr

Large Leak (#1) Range 10^{-6} torr to 5×10^{-3} torr

Small Leak (#2) Range 5×10^{-3} torr to 1.6 torr

Weight: 89 lbs

Power: 28 Vdc, 2A maximum

Commands: a)   SUMS Instrument On/Off
            b)   SUMS Ion Pump Power On/Off
            c)   SUMS Maintenance Pump Power On/Off

Temperature On-Orbit
            Maximum   +100° F
            Minimum   -40° F

SUMS DATA AND DATA CONTROL

The SUMS spectrometer data is 16 bit parallel digital synchronized by a 64 kHz TTL clock and a read data strobe. The SUMS housekeeping data is high level analog (0-5 volts). The read data strobe must have a period somewhere between 5.0 msec. and 11.2 msec. with 7.0 msec. being the preferred period. The duration of the strobe should be 16 periods of the 64 kHz (250 µsec.) The logic of the strobe is active low. The SUMS experiment is allotted a data rate of 1600 bps. The science measurements are output from the UAMS at 800 bps. The mass range is scanned in four scans of interlaced measurements. The SUMS data is read by the OEX Pulse Code Modulator (PCM data format consists of: (1) A frame which consists of 0 to 63, 8 bit words and (2) a major frame which consists of 0 to 63 frames. The time for a major frame is 0.08875 seconds. SUMS science data was allocated word 47 and word 48 of each frame of data. The SUMS 12 housekeeping data words were interleaved in word 49 and appear once each major frame. Since the PCM over samples the mass spectrometer data, if a mass spectrometer data word is not available the SUMS inserts a status word in the data stream. The science data from the mass spectrometer consists of 12 engineering words, 72 low mass words, and 360 high mass words each scan. A scan is completed every 5 seconds at a rate of 13.2 millisec per step. The details of the SUMS data may be found in Appendix A and in Appendix D.

SUMS POWER MODES

Mission phase	SUMS Mode	POWER
Prelaunch	ION PUMP MAINTENANCE	2 WATTS
Orbit	SUMS ION PUMP (SIP)	30 WATTS
Entry	SIP AND INSTRUMENT POWER	45 WATTS
Landing	ION PUMP MAINTENANCE	2 WATTS

Flight Power Profile

During a shuttle Orbiter flight the SUMS experiment typical power profile will be as follows:

Prelaunch - Ion Pump Maintenance Power - 2.0 watts
Orbit Insertion + 1 hour - SUMS Ion Pump On for 3 hours - 30.0 watts
De-orbit Burn - 2 hours - Ion Pump and Instrument On for Entry + 20 min.-45.0
    watts
Shuttle landing - Ion Pump Maintenance Power - 2.0 watts

3.1   Magnetic Analyzer

A double focussing mass analyzer containing tandem electric and magnetic field sectors covers the mass range 1-50 amu. The mass range is divided into two outputs in parallel. The magnetic sector focusses the two outputs in the ratio 1:7. The ions are collected on faraday cups placed at the proper radius to receive the ions. In the magnetic analyzer ion trajectories are determined by the relationship

$$m/e = kR^2B^2/V$$

where m/e is the mass to charge ratio of the ion, R is the trajectory radius in cm (2.54 cm for high mass channel), V is the ion acceleration voltage in volts (177 Vdc for ions of mass 44 amu), k is a constant (4.824×10^{-5}) and B_g is the field strength of the magnet in gauss.

The magnetic analyzer has a field of approximately 5000 gauss. The mass of an ion entering the high mass collector is given by m/e =7780/V. For the low mass collector the mass collected is 1/7 that for the high mass collector.

The high mass exit slit has a width of 0.063 cm and the low mass exits slit has a width of 0.038 cm.

The magnetic analyzer magnet poles cover the collector slits completely rather than end abruptly at the focal plane. This virtually eliminates the variation in magnetic fields at the exits. The air gap is 0.42 cm, and the pole faces are 0.09 cm thick. The magnets are 2.54 cm thick Alnico V material. The yoke was 0.5 cm thick soft iron.

A .3 liter/sec sputter ion pump keeps the instrument clean while sealed off. With 100 μA emission current and the 0.3 liter sputter ion pump pumping the analyzer section, the response of the instrument is nearly linear up to ion source pressures of 3×10^{-4} torr (to 5 $\times 10^{-5}$ torr without the sputter ion pump).

Decreasing V in the above equation causes ions of increasing mass to be focussed on each of the ion collectors forming a series of mass peaks, the amplitudes of which are proportional to the concentration of each gas species in the ion source. Figure 3 shows a SUMS high channel mass spectrum. In this instance, mass abundance in ion current is plotted on a log scale of 4 decades against time, which is equivalent to mass number in amu and ion acceleration voltage. Major peaks are identified by amu or ion acceleration voltage steps. The detector is a linear auto-ranging electrometer amplifier. A 4 bit digital word determines the measurement range and a 5 Bit digital word determines the signal level within the range.
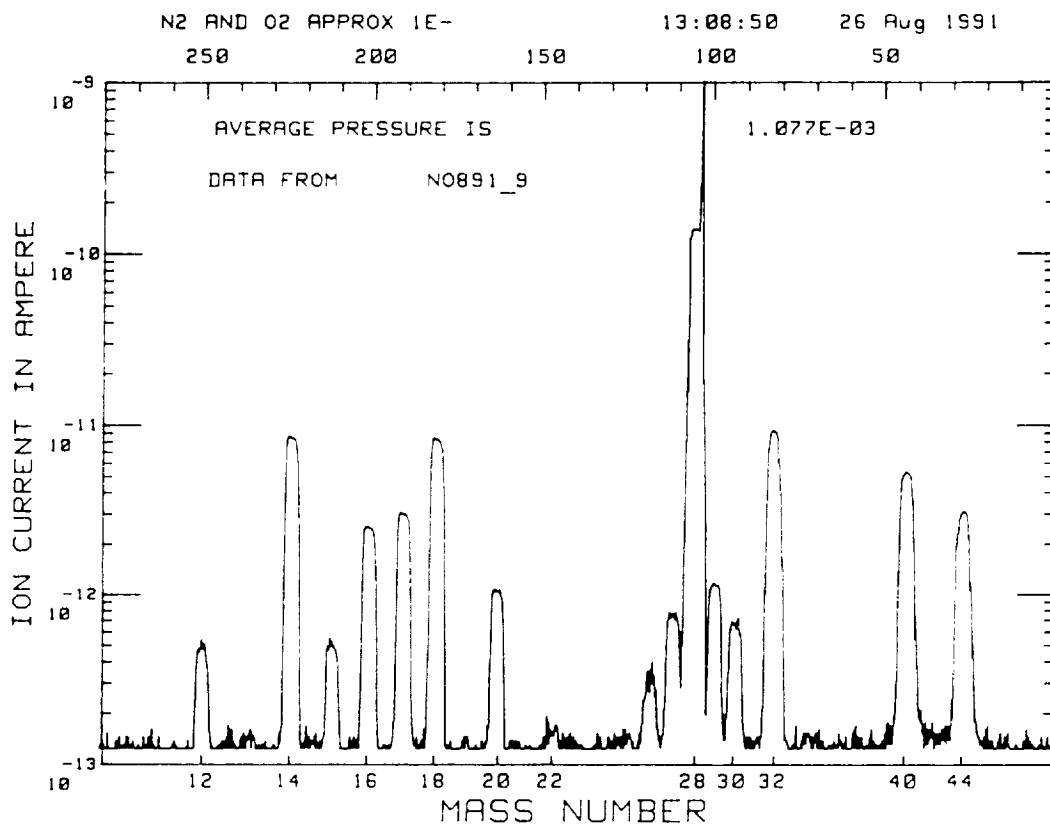
N2 AND O2 APPROX 1E-   13:08:50   26 Aug 1991

Figure 3
A Typical Mass Spectrum Plot of $N_2/0_2$ Mixture on the High Mass Channel
of the SUMS Instrument

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3.2 Ion Source

The ion source is located in the cavity into which the inlet system passes the atmospheric gas samples. Gas molecules having entered the ion source cavity are bombarded by an electron beam as they pass through the beam volume. The ion source consist of a heated 1 mil diameter tungsten-rhenium (98%W, 3%Re) hairpin-shaped wire filament. A small magnet of Alnico bars provide 300 gauss of focus to the electron beam. Emission is regulated by the emission control electronics to 100 μA. Approximately 90% of the electron beam is collimated by the magnetic field to enter the trap box opposite the filament. Some of the redundancy of the Viking instrument was removed to simplify the SUMS instrument. The ionization potential was set to a single level, (75 volts) and the filament selection was fixed hard wired to the selected filament. Ions formed by electron bombardment are drawn out of the source cavity by a large negative accelerating potential resulting from the ion chamber being at 330 to 1200 Vdc positive and the collimating slits being at ground potential. The J-plates, alpha and object slits focus the beam toward the analyzer tube.

3.3 Electrostatic Analyzer

Following the ion source the ions are passed through a set of parallel curved plates whose potential vary proportionately to the ion acceleration voltage. The ion beam that emerges from the curved plate analyzer section has the same distribution independent of the mass of the ion. Potentials on the plates are set to track the ion acceleration voltage at a constant ratio, the outer plate being positive and the inner plate negative. Ions having a small difference in energy, ΔE, from the central beam will follow trajectories through the electric sector having different radii, thereby being focussed in energy.

3.4 Gas Inlet System

The major addition to the Viking UAMS for SUMS is the gas inlet system which effectively creates a "closed-source" mass spectrometer system from the existing "open-source" system. The inlet system provides three functions; establishing a gas flow path from the pressure port to the UAMS, protecting the instrument in a high pressure environment, and expanding the dynamic measurement range. Figure 4 diagrams the relationship of the gas entrance tube to the Shuttle vehicle. The latter function is accomplished by the use of two flow restrictors or "leaks" in parallel. Leak #1 has a large conductance and establishes the system pressure drop at high altitudes. Leak #2 has a very small conductance and allows the instrument to operate at lower altitudes and higher pressures. A "dynamic range" valve is inserted in a series with Leak #1 so that closure of this valve forces the gas to flow through Leak #2. Such a system is required on SUMS because the range of UAMS ion source pressures for which measurements are valid is 10^{-8} to 10^{-4} torr, which is inadequate to span the required surface pressure range at the SUMS gas entrance port of 10^{-6} to 1.6 torr with a single leak. This surface pressure range arises from the requirement to cover the entire transitional flight regime, with substantial coverage of free-molecular flow above transition and of the hypersonic continuum below transition with overlapping coverage of
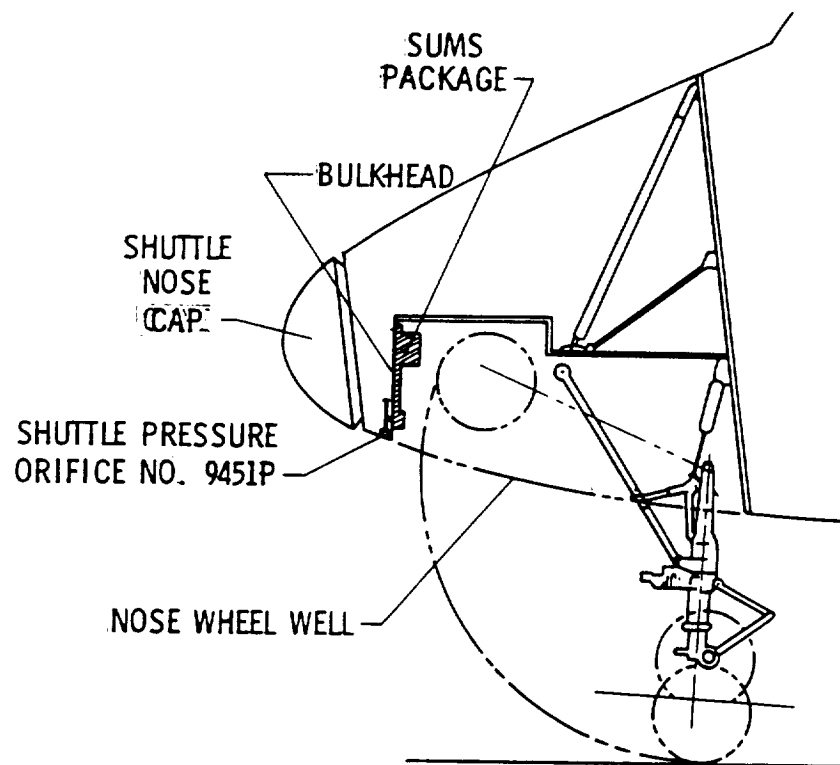
SUMS
PACKAGE ⌐

BULKHEAD

SHUTTLE
NOSE
CAP

SHUTTLE PRESSURE
ORIFICE NO. 9451P

NOSE WHEEL WELL

Figure 4
The SUMS Instrument Location in the Shuttle Nose Wheel Well.

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the conventional low range pressure transducer. Figure 5 gives a summary of the shuttle predicted Orbiter altitude profiles for surface pressure.

The basic feature of the inlet system is its simplicity. A pressed tube micro leak with a very low surface to volume ratio admits gases directly into the ion source without passing through other leaks or pumping stages. This feature minimizes any reactions the gases may undergo with the walls of the systems. Other advantages of the micro leak are its extremely small dead volume, its inertness to reactive gases, and its fine adjustability to any desired leak rate. The fine leak (leak #2) was formed from 1/8 in OD, .049 in wall thickness stainless steel tubing. The coarse leak (leak #1) was formed from 1/8 in OD, .020 in wall thickness stainless steel tubing.

The micro leak is a gas permeation device which can provide controlled gas flows of extremely small magnitudes with good accuracy, stability and reproducibility. The SUMS fine leak was built to provide a fixed conductance of 1.2×10^{-3} std cc/sec. The atmospheric gases permeate between two parallel oxide or nitride thin films formed by controlled passivation of the parent metal tubing. The tubing is forged into a flat plate at a point midway between two miniature flanges. The conductance of the leak is determined by the thickness of the submicron gap formed by the controlled degree of forging between the interior walls of the tube.

3.5   SUMS Electronics

The UAMS was modified to operate in the SUMS mode by the addition of a microprocessor computer control board, a power module, and a valve operation circuit. The microprocessor board used an INTEL 8085 chip and discrete logic to provide the interfaces between the shuttle data handling and command systems. The power module accommodated the shuttle power bus to the SUMS requirements. A uv erasable PROM stored the program which controlled the SUMS computer operations during the shuttle mission. A pressurized container filled with SF_6 gas housed the total instrument at atmospheric pressure to prevent corona problems from the high voltage circuits as the shuttle re-entered the earth's atmosphere passing through the corona pressure region. The pressure case also provided thermal isolation from the expected heating of the nose area of the shuttle. The SUMS packaging concept is shown by Figure 6. The instrument electronics and inlet system are located in the Shuttle nose wheel well during flight as shown by Figure 7.

3.6   Calibration Procedure

The SUMS instrument underwent a functional test and a static and dynamic calibration run prior to being shipped from UTD to KSC for installation into the Space Shuttle Columbia. A manually operated valve and special AN fittings were attached to the SUMS inlet entrance tube so that after calibration and functional testing are completed, the valve may be closed to maintain the SUMS vacuum integrity. The instrument, with exposed
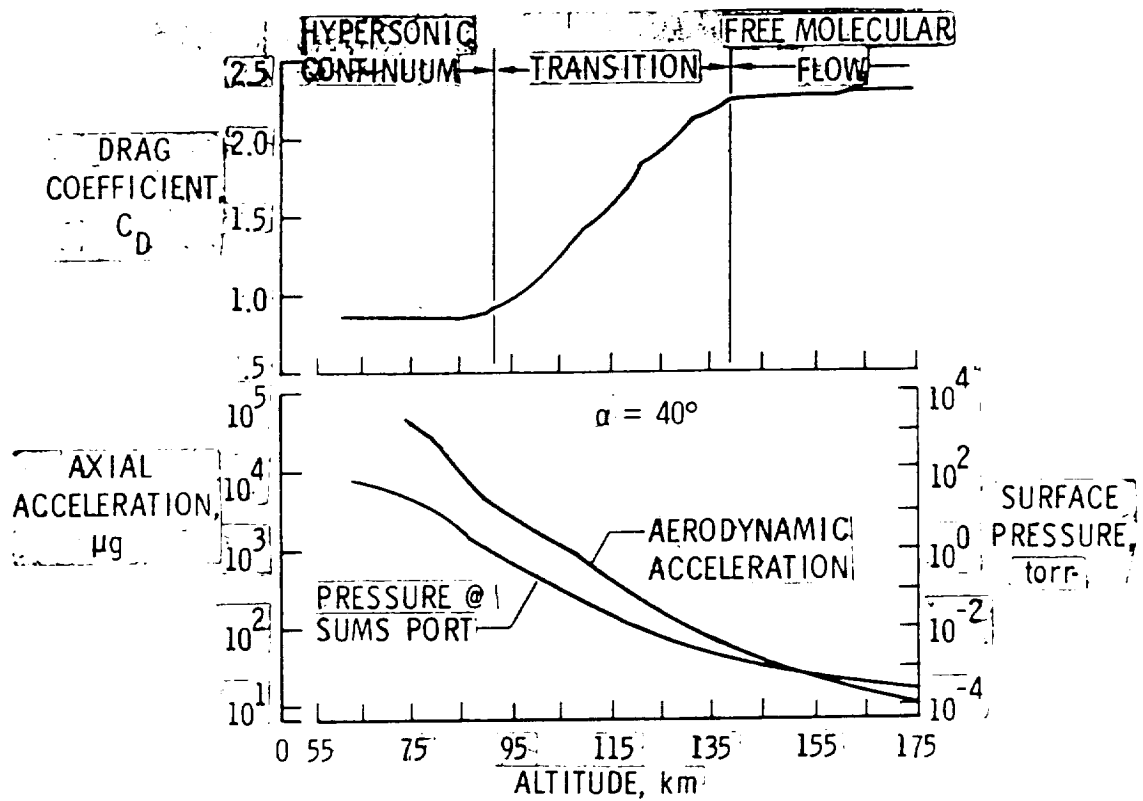
Figure 5
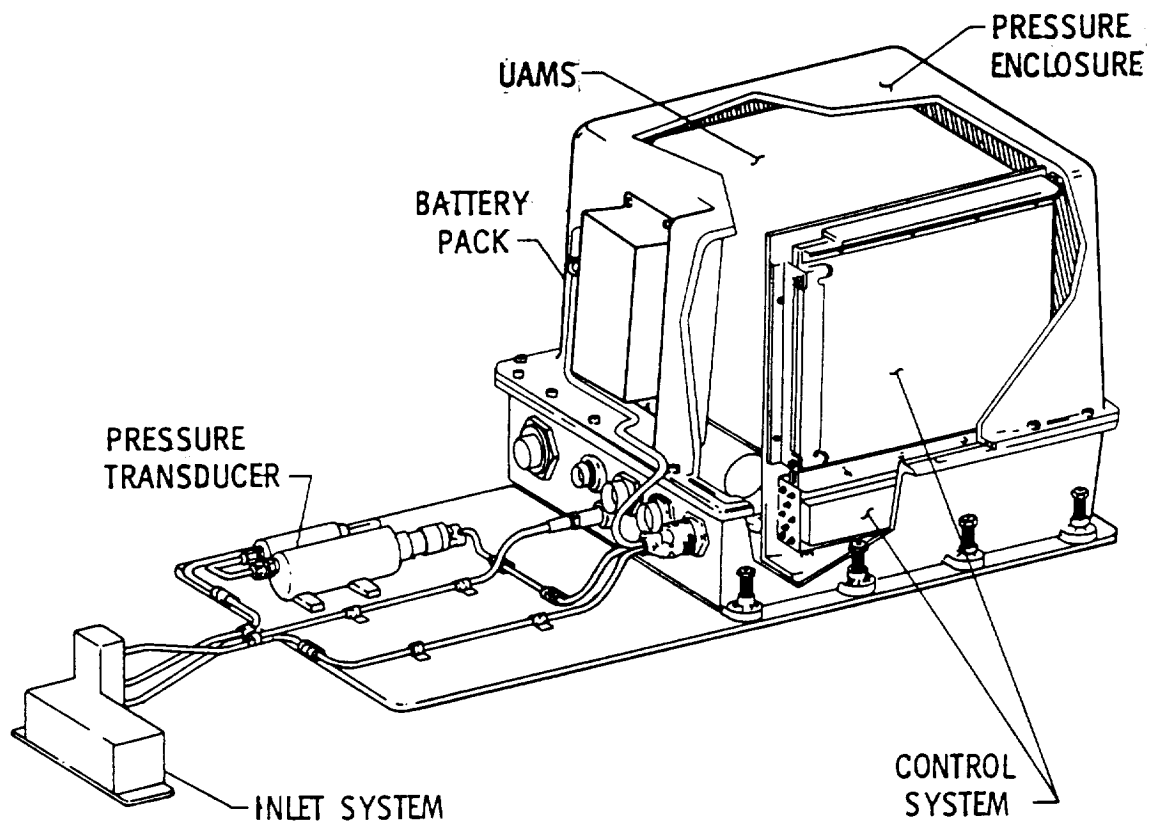The Shuttle Orbiter Predicted Altitude Profiles of Drag, Acceleration, and Surface Pressure.

PRESSURE
ENCLOSURE

UAMS

BATTERY
PACK

PRESSURE
TRANSDUCER

INLET SYSTEM

CONTROL
SYSTEM

Figure 6
SUMS Instrument Components and Their Interconnection.

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PRESSURE
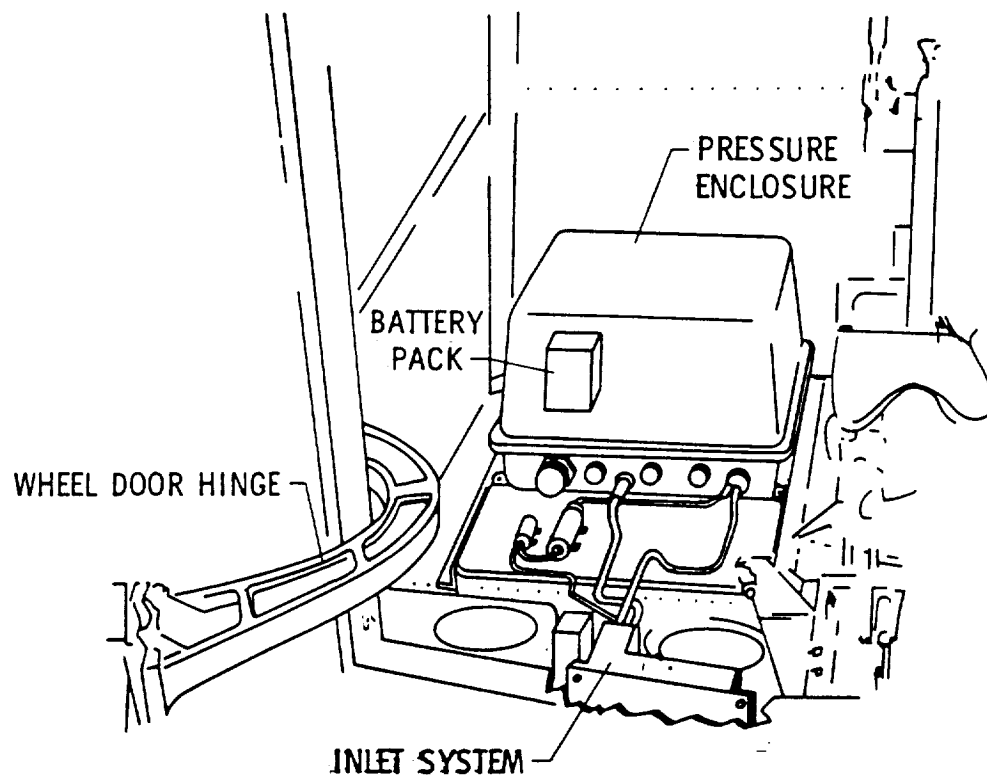ENCLOSURE

BATTERY
PACK

WHEEL DOOR HINGE

INLET SYSTEM

Figure 7
SUMS Installation into the Shuttle Nose Wheel Well.

gas inlet entrance tube, was attached to a vacuum chamber pumped by a sputter ion pump. The vacuum chamber has a variable orifice to the sputter ion pump. The orifice is adjusted such that for the dynamic calibration the slope of the pumping speed can be set to approximate the predicted shuttle entry profile. The vacuum chamber is equipped with suitable gauges to permit monitoring of the gas pressure from about 100 torr to 10^{-8} torr. The principal gases used for calibration were CO_2, N_2, and O_2.

Two types of calibration tests were performed on the completed SUMS hardware; static pressure response, and dynamic pressure response. The static tests were performed over an inlet pressure range of 10^{-5} to 1.6 torr for nitrogen and oxygen gas mixtures and for a mixture of nitrogen, oxygen and carbon dioxide. These tests provided data for determination of static sensitivity coefficients, external pressure at range valve closure, external pressure at shutdown, and the ratio of pressure drops for the two leaks. Dynamic calibration tests were run with typical flight inlet pressure profiles. The known time, pressure and time, currents will be used to verify the SUMS analytic model of the instrument response for flight data reduction.

Figure 8 shows a typical result from a static calibration test for a nitrogen/oxygen mixture with the range value closed. These data from the flight instrument were obtained to check the laboratory procedures, to provide data on the behavior of the automatic electronic logic circuitry and total system, as well as to provide tests on the calibration data reduction software system. Figure 3 presented earlier shows as a typical result from the static calibration test for nitrogen/oxygen mixture with the range value open. The calibration data and analysis is included in attachment Appendix B.

3.7   Inlet System Analysis

The SUMS system can be represented by an electrical analog consisting of a four-node R-C network described on Figure 9. The following equivalences hold in the analogy: voltage to pressure, current to volumetric flow rate, and resistance to the reciprocal of molecular conductance. Resistances R_1, R_2, and R_4 represent connecting tubing while R_{3B} represent the selectable leaks. Capacitors C_1, C_2, and C_3 represent volumes associated with R_1, R_2, and R_4. The network is terminated by R_5 and C_4 in (R_5) and the UAMS ion source volume (C_4). The applied forcing function, $V(t)$, represents the surface pressure time history expected at the orifice. A system of four nonhomogeneous linear differential equations was formulated by applying Kirchoff's current law at each of the four nodes. The solution for this system yields the voltages (pressures) as a function of time at the nodes. A computer code was written for the solution and was programmed to provide the network output, representing the UAMS ion source pressure, as a function of time. This procedure is detailed in Appendix A.
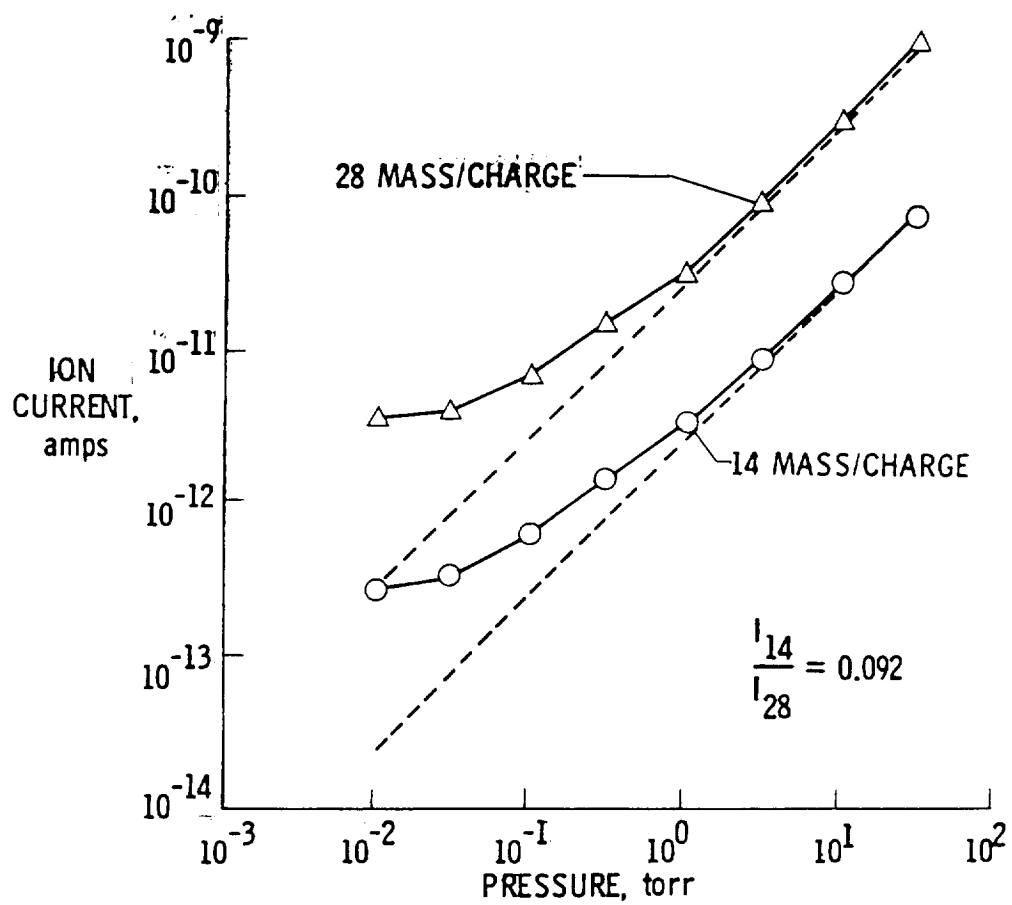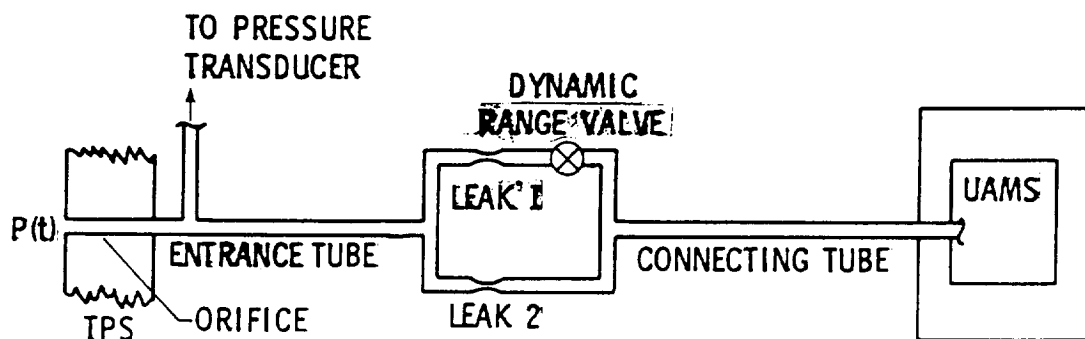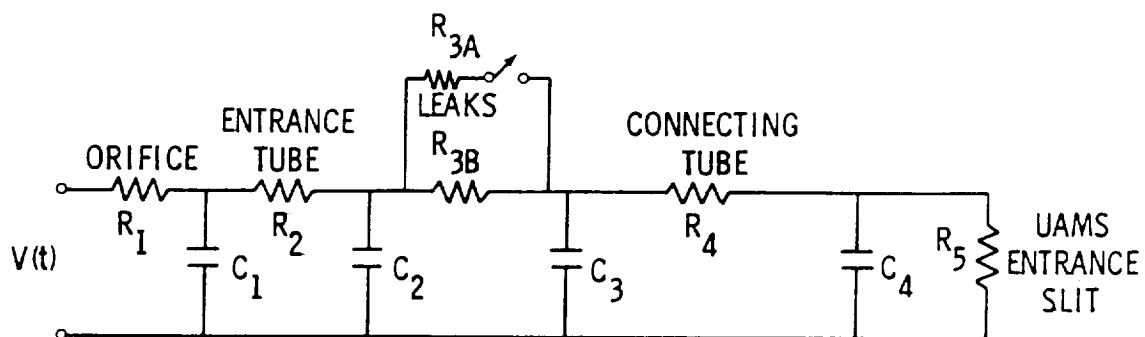
Figure 8
Initial Static Calibration Data for N_2 at High Pressure
(Range Valve Closed)

17

TO PRESSURE
TRANSDUCER

DYNAMIC
RANGE VALVE

LEAK 1

P(t)

ENTRANCE TUBE

TPS   ORIFICE

LEAK 2

CONNECTING TUBE

UAMS

SIMPLIFIED SUMS SCHEMATIC

R_{3A}

LEAKS

R_{3B}

ENTRANCE
TUBE

ORIFICE

CONNECTING
TUBE

V(t)

R_1

C_1

R_2

C_2

C_3

R_4

C_4

R_5

UAMS
ENTRANCE
SLIT

ELECTRICAL NETWORK ANALOGY

Figure 9
Inlet System Math Model for Analysis of Conductance

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3.8 System Pressure Response

The SUMS dynamic system response to a rapidly increasing orifice pressure was a major concern in the design phase. The static pressure drop across the inlet system tubing is simple to predict and calibrate and is solely determined by the molecular conductances of the system elements. The static drop is defined as $R_s/\Sigma R_i$ and is independent of the system volume. The "dynamic" drop is more difficult to predict since it is affected by the presence of finite volumes of the tubing and by the ratio of dP/dt to P at the orifice. A suitable parameter for analysis of the dynamic pressure response is the ratio of actual drop to the static drop that would exist at a constant pressure equal to the instantaneous dynamic value. A design goal for SUMS was to hold this ratio as close to 1.0 as possible, in order to minimize the introduction of error in flight data interpretation.

The predicted pressure drop history for the SUMS design is shown on Figure 10. The minimum value of the fraction of static pressure drop (maximum drop) of 0.66 occurs just after the dynamic range valve closes and coincides with the maximum dP/dt to P ratio.

3.9 Response to Changes in Gas Composition

A design goal for SUMS was to minimize time lag between the occurrence of changes in gas composition at the orifice and the sensing of those changes at the UAMS ion source. This time delay is determined by two processes; molecular diffusion and bulk transport. Molecular diffusion rates decrease rapidly as pressure increases, such that the delay is controlled almost solely by flow velocity through the system at pressures above 1 torr. This led to a design approach which called for maximization of the gas flow velocity. Flow velocity is affected by tubing diameters and by the presence of volume just ahead of the leaks. Obviously, too, the tubing lengths affect the delay. The inlet system design took these factors into account to the extent possible. Composition response lag times are predicted as shown on Figure 11. The delay is predicted to be as much as 40 seconds for a short period of time falling back to about 16 seconds until instrument cutoff. The beginning of this region of relatively long composition response times corresponds to an altitude of about 80 km.

4.0 Problems and Solutions

During the course of the SUMS activities several failures and design changes have been processed. The failures included valve operation, high voltage components, and microprocessor chips. The design changes included modifying the housing of both the inlet box and the instrument case, adding filters and changing the inlet configuration, and change out of the pressure sensor to meet the range of measurement required. The configuration change included adapting to the carbon-carbon chin panel re-design.
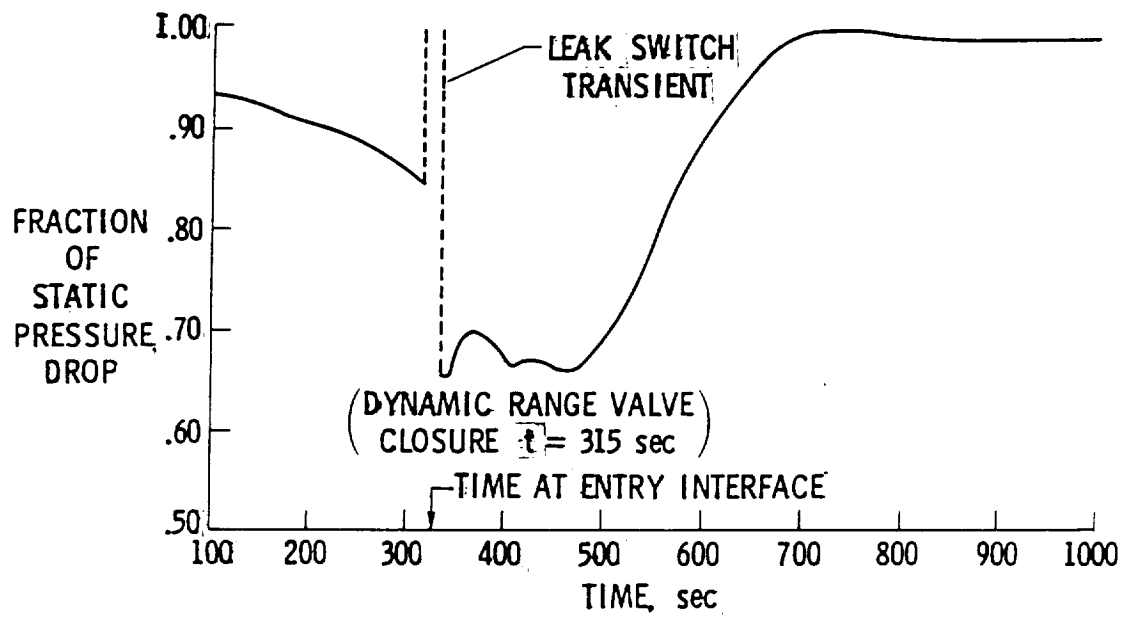
19

Figure 10
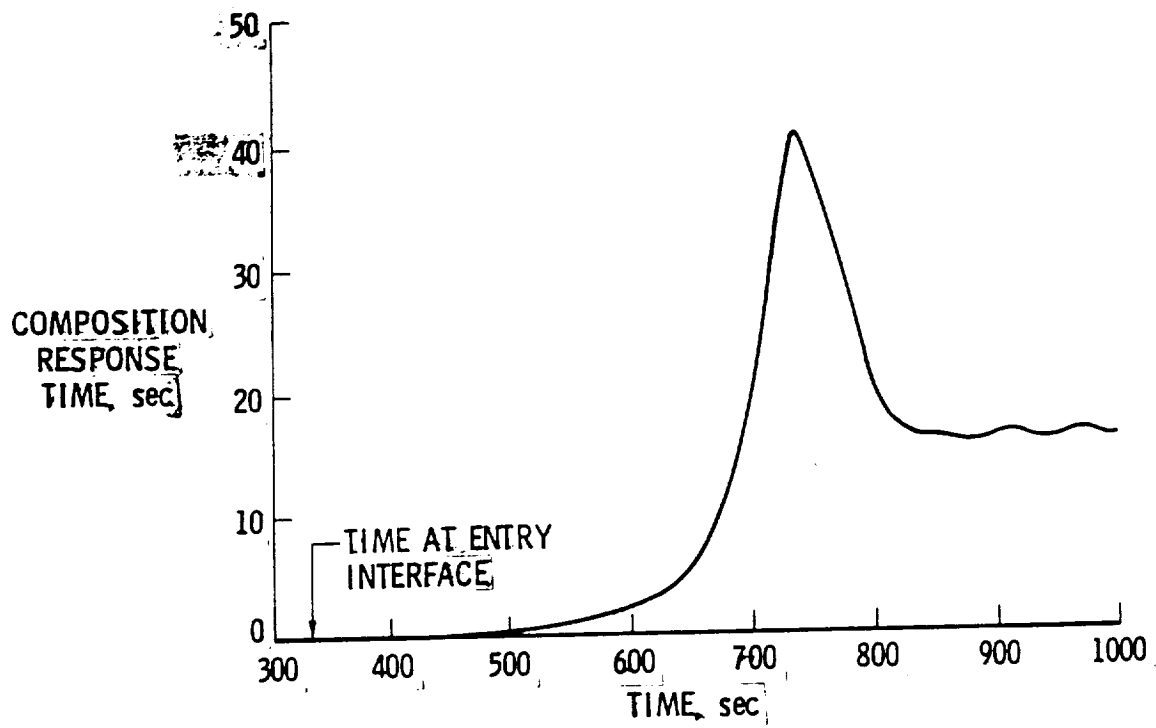Predicted Fraction of Static Pressure Drags

20

Figure 11
Predicted Composition Response Time History

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4.1 Valve Problems

The SUMS atmospheric sample control valves, a miniature magnetic latching type, proved troublesome to the SUMS performance throughout the program.

Initially the required leak rate of 1 X 10^{-10} torr cc/sec air proved to be difficult to achieve. Only one vendor was willing to accept this requirement. In order to meet the leak rate a soft seat configuration of valve was chosen. The soft seat proved to be prone to "sticking" if left in the closed position too long. A special technique of sending multiple operate pulses under microprocessor control improved the reliability of operation of the valve. A further hindrance to predicting valve operation came about due to the uncertainty of the shuttle launch schedule. The valves could not be properly cycled after installation into the shuttle.

At other times it appeared that the vulcanized viton seats may have secreted or sublimated a material which collected or condensed on the valve body causing sticking in the open condition. Although it is very possible that unknown contaminants entered the valve by way of the ports either from the instrument or from the calibration systems.

A technique for monitoring and storing the current waveform of the valve operate pulse in a digital form enabled the test operator to recognize a tendency to "stick". This technique was incorporated into the test and checkout procedures used during the KSC SUMS installation activity.

4.2 Crushed Ion Source

While conducting the static and dynamic calibration a marked decrease in the sensitivity of the ion source with time was detected. The usual cause of loss of sensitivity for an ion source is contamination of the surfaces allowing the build up of charge to defocus the ion beam. While attempting to disassemble the source for cleaning it was found that the sapphire spacers were crushed causing the elements to be misaligned. A weld ring inside the source cover interfered with the source when installed. SN 7 UAMS was used to replace the crushed SN 6 UAMS. The SN7 UAMS was used for all SUMS flights. Repairs were made to the SN 6 UAMS source, but the sensitivity remained degraded. Apparently some problem of alignment remains to be corrected.

4.3 High Voltage Breakdown

During a functional test a malfunction was indicated by abnormally high instrument current. The problem was isolated to the emission control circuit. A transformer was found to be faulty. A spare unit from the SUMS spare parts kit was used to replace the faulty unit.

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4.4   Sputter Ion Pump Linearity

It was found during calibration that the pumping speed of the ion pump was nonlinear. Further testing showed that the pump became linear if the high voltage was reduced from 3000 Vdc to 1800 Vdc. the power supply was modified to incorporate the lower voltage.

5.0   Flight Operations

The SUMS experiment was flown onboard the Shuttle Orbiter-102 vehicle. The measurements from the SUMS was be initiated by Orbiter command approximately 1 hour prior to the de-orbit maneuver. During reentry, mass density measurements were taken for approximately 35 minutes with the data recorded on a separate OEX tape recorder located remotely from the instrument system.

There are several instrument control functions to be performed throughout the flight profile of the Orbiter. These are done autonomously by the SUMS logic circuitry within the control system. Prior to launch, a prelaunch checkout was performed. During this time, all valves remain closed with power being supplied to the ion pump. The instrument is cycled on to gather system performance and condition data. This instrument cycling occurs prior to the vehicle prelaunch operation. During the high vibration launch environment, all power to the SUMS system is off. Approximately 1 to 2 hours after orbit insertion, the inlet valve was commanded open to allow the trapped volume of gas behind the leaks to escape. At this time, the ion pump power is also applied. About 1 to 2 hours prior to de-orbit burn, the instrument was turned on to gather data on background levels as well as to allow time for the system to warm up to operating temperature (warmup duration is about an hour). During reentry, at about 5×10^{-3} torr orifice pressure, the range valve in series with Leak #1 was closed, effectively switching the dynamic range of the instrument by forcing the gas sample to flow through Leak #2 only. At 1.6 torr surface pressure (about 86 km), all valves are automatically closed, effectively stopping the external gas flow into the system. Beyond this time, the instrument and ion pump remain powered on in order to gather data on the pump-down of the system. During the terminal landing phase, the instrument was turned off coincident with other OEX instrument systems. The ion pump remains powered for the remainder of time in the entry profile and during ground operations so that vacuum conditions within the UAMS can be maintained during periods of high external pressure for reflight and instrument safety.

6.0   Data Analysis

6.1   Response to Changes in Gas Composition

A design goal for SUMS was to minimize time lag between the occurrence of changes

in gas composition at the orifice and the sensing of those changes at the UAMS ion source. this time delay is determined by two processes; molecular diffusion and bulk transport. Molecular diffusion rates decrease rapidly as pressure increases, such that the delay is controlled almost solely by flow velocity through the system at pressures above 1 torr. This led to a design approach which called for maximization of the gas flow velocity. Flow velocity is affected by tubing diameters and by the presence of volume just ahead of the leaks. Obviously, too, the tubing lengths affect the delay. The inlet system design took these factors into account to the extent possible within constraints discussed earlier. Composition response lag times are predicted as shown on Figure 11. The delay is predicted to be as much as 40 seconds for a short period of time falling back to about 16 seconds until instrument cutoff.

6.2   Flight Data Reduction

6.2.1   Quick-look Analysis

The block diagram of the SUMS flight data reduction process is shown on Figure 12. digital data from the SUMS instrument was be recorded in flight on the onboard OEX recorder. The flight tapes were taken to the National Aeronautics and Space Administration (NASA) Johnson Space Center (JSC) for processing and generation of experiment user tapes.

Raw data for SUMS only was stripped at the NASA Langley Research Center and will be input to quick-look processing programs which give information on the operation of the instrument and science data display for preliminary analysis. Two examples of the types of data display are shown on Figures 13 and 14 as actually processed by the software from the SUMS STS 35 Flight Data. Figure 13 is a spectral plot obtained during the flight and shows the measured ion currents for each of the mass numbers. Several significant peaks which were caused by residual gases in the instrument are clearly evident. The large mass 28 peak is mostly molecular nitrogen since the 14 peak is consistent with the expected 14:28 ratio for nitrogen. Molecular oxygen shows at mass 32, argon at mass 40, and carbon dioxide at mass 44. A small amount of water vapor is evident at mass 18 and the results of fractionization of molecular nitrogen and oxygen show at masses 14 and 16. Figure 14 shows the mass 28 peak time history during part of the flight. This peak varies because it is driven by the external pressure. The internal instrument pressure reached a maximum at $t_0 + 985$ seconds, at which time the range valve closed as indicated by the sharp drop in ion current.

Analysis of the quick-look data provided information to determine the background and filtering necessary to separate the peak contributions from background gases. The resultant filtered science data file was then used in a succession of programs which correct for the pressure drop across the inlet system and for the $P_\infty/P_{surface}$ ratio in the flowfield about the Orbiter. Time and altitude histories of the orifice parameters (partial and total pressures) and the freestream parameters (partial/total pressures, partial/total densities were
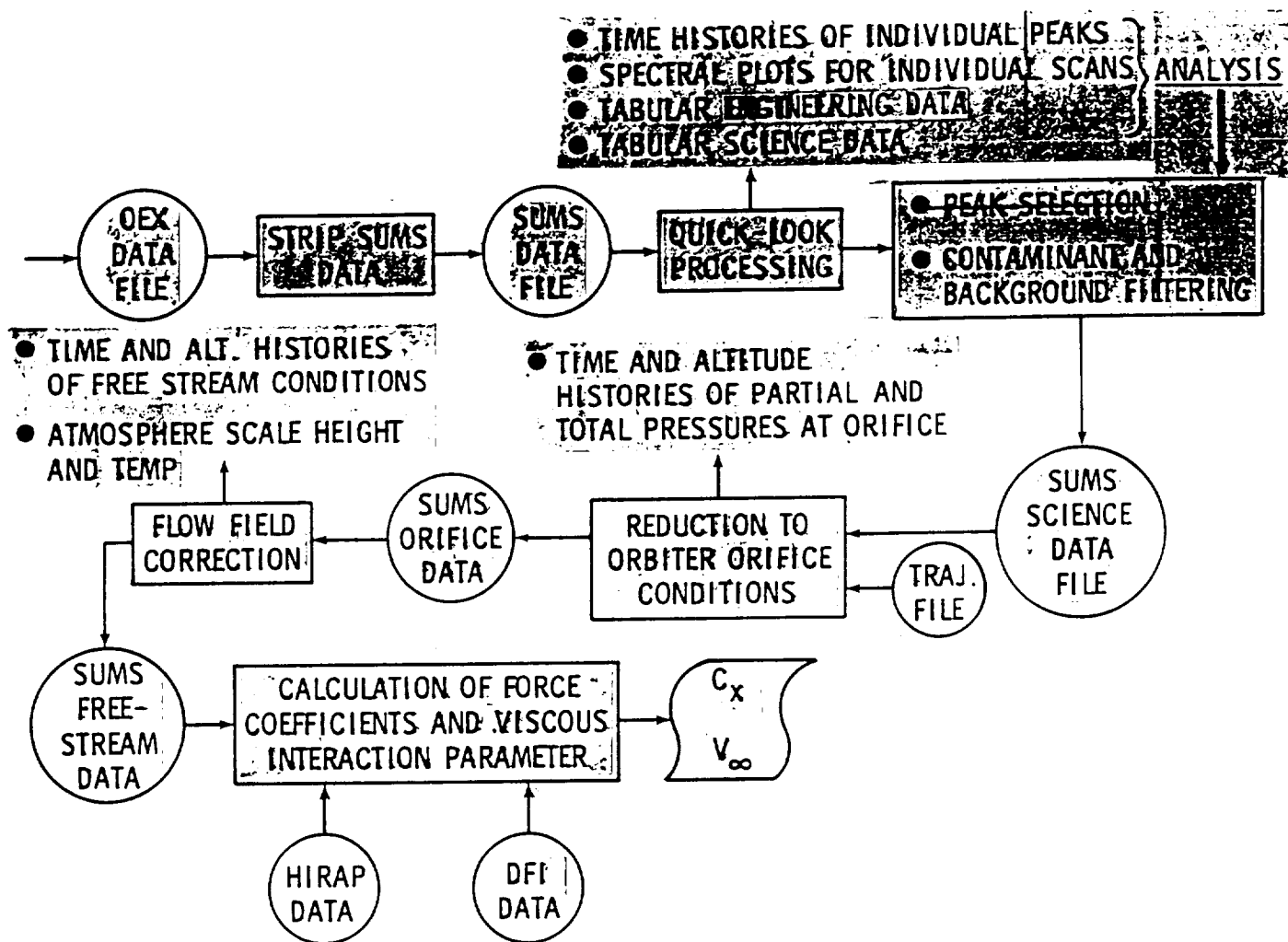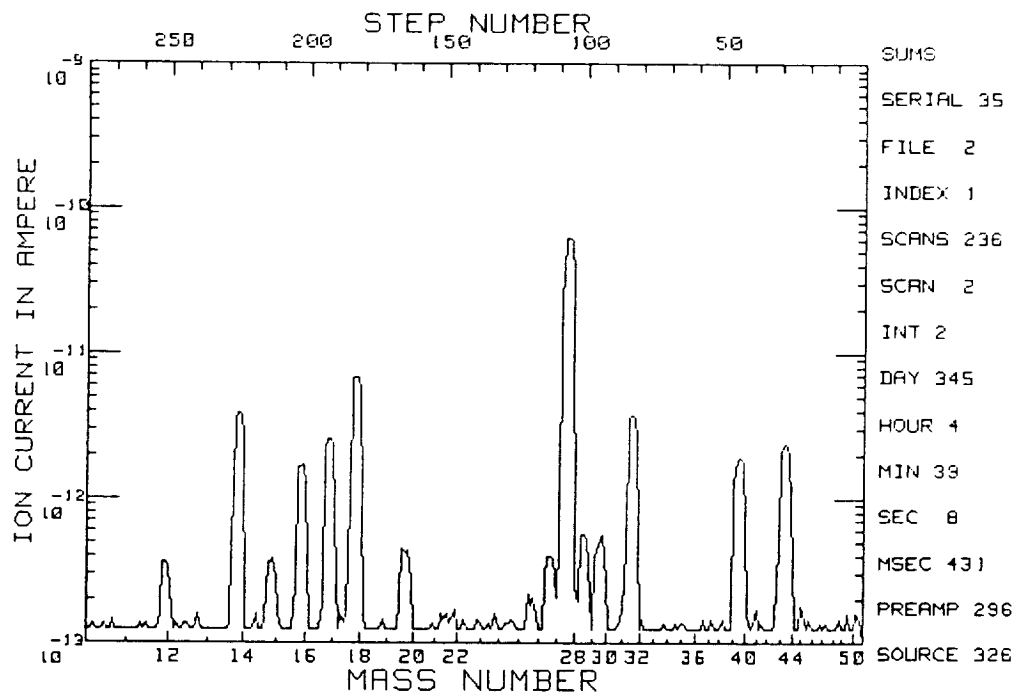
Figure 12
SUMS Flight Data Reduction Flow

Figure 13
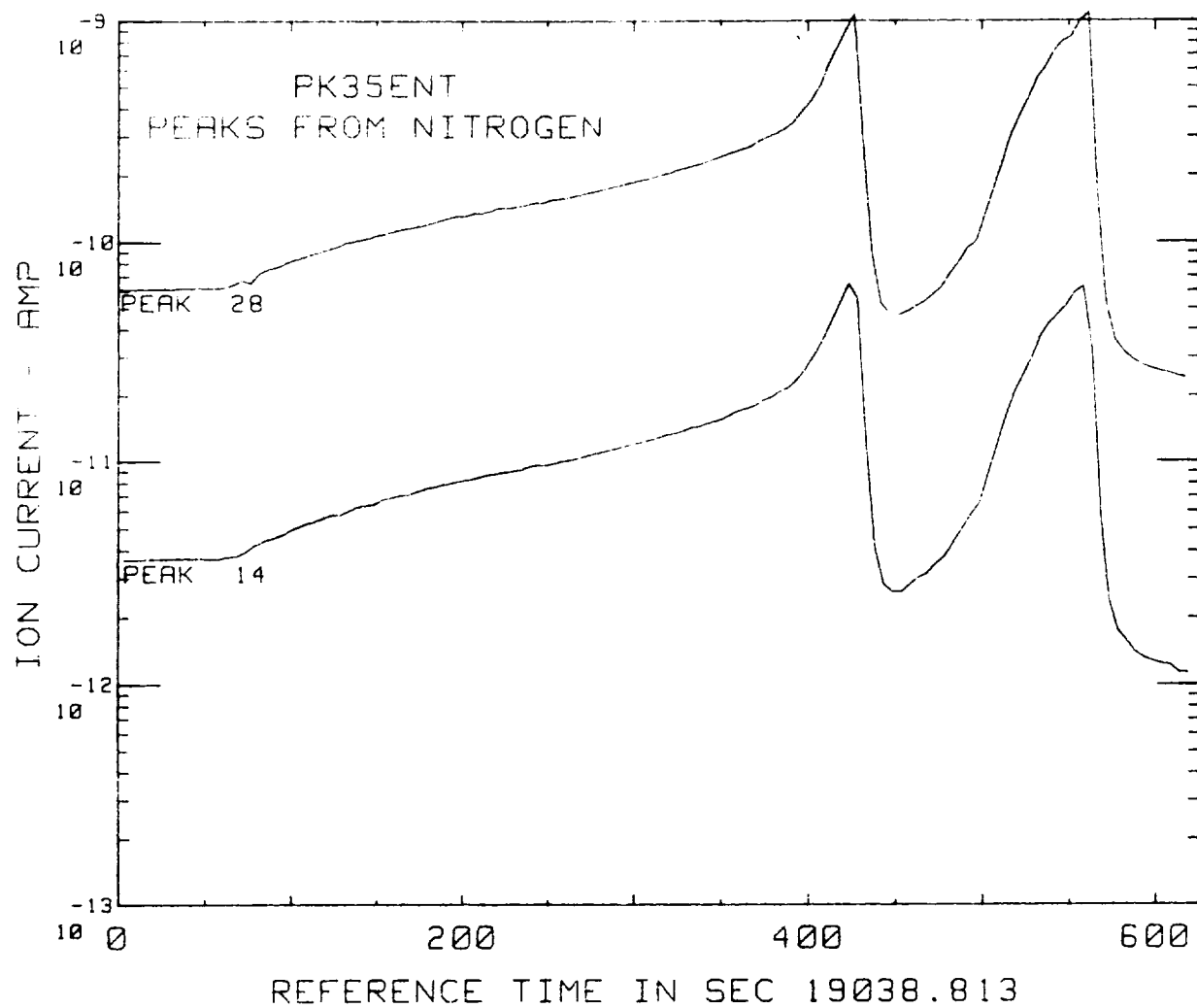Typical Test Mass Spectra from the SUMS Flight Instrument

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Figure 14
Time History of the N_2 Peak from Integration and Initial Dynamic Calibration Tests

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obtained. Figure 15 shows the predicted altitude history for the SUMS orifice pressure the STS-35 SUMS flight.

6.2.2 Final Analysis

The final step in the data reduction occurs when the SUMS freestream data, reduced acceleration data from HiRAP, and reduced wall temperature from the Development Flight Instrumentation (DFI) are brought together to calculate the force coefficients and the viscous interaction parameter. This work is in process.

Several separate development analyses go into constructing the data base which is used in the final data reduction and analysis of the flight data. These include: (1) the contaminant analysis which consists of laboratory simulations of flight conditions for spectral analysis of outgassing properties of the materials which may affect the gas sample, (2) the calibration analyses which produce the calibration factors, and (3) the flowfield development which uses a Monte-Carlo technique to describe the rarefied flow properties about the Orbiter so that freestream properties can be obtained, a procedure which is analogous to using hypersonic continuum theoretical pressure coefficients from a flowfield computer code in order to interpret freestream conditions from pressure transducers.
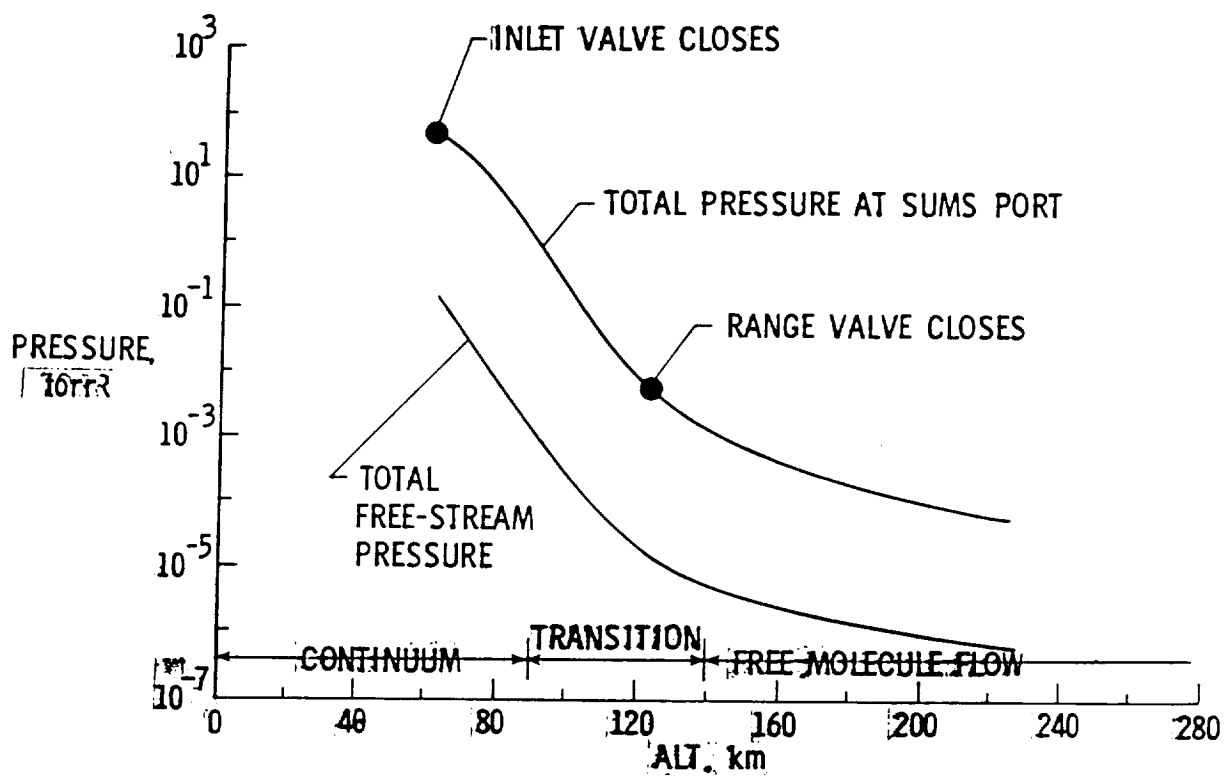
Figure 15
Altitude Profile of Predicted SUMS Port and Free-Stream Pressures

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13. ABSTRACT (Maximum 200 words)

The Shuttle Upper Atmosphere Mass Spectrometer (SUMS), a component experiment of the NASA Orbital Experiments Program (OEX), was flown aboard the shuttle Columbia (OV102) mounted at the forward end of the nose landing gear well with an atmospheric gas inlet system fitted to the lower fuselage (chin panel) surface. The SUMS was designed to provide atmospheric data in flow regimes inaccessible prior to the development of the Space Transportation System (STS).

The experiment mission operation begins about 1 hour prior to shuttle de-orbit entry maneuver and continues until reaching 1.6 torr (about 86 km altitude). The SUMS flew a total of three missions, 61C, STS-35, and STS-40. Between flights, the SUMS was maintained in flight ready status at the physics laboratory of UTD. The flight data has been analyzed by the NASA LaRC Aerothermodynamics Branch. Flight data spectrum plots and reports are presented in the Appendices to the Final Technical Report for NAS1-17399 as follows:

Attachment A: Flight 61-C Report (Vol. 2)   Attachment C: Flight STS-40 Report (Vol. 9)
Attachment B: Flight STS-35 Report (Vol. 3, Vol. 4,   Attachment D: SUMS Software Listing (Vol. 9)
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