The Shuttle Upper Atmosphere Mass Spectrometer Experiment

R. C. Blanchard,* Roy J. Duckett,† and Edwin W. Hinson‡
NASA Langley Research Center, Hampton, Virginia

A magnetic mass spectrometer currently is being adapted to the Space Shuttle Orbiter to provide repeated high-altitude atmosphere data to support in situ rarefied flow aerodynamics research, i.e., in the high-velocity, low-density flight regime. The experiment, called Shuttle Upper Atmosphere Mass Spectrometer (SUMS), is the first attempt to design mass spectrometer equipment for flight vehicle aerodynamic data extraction, and will make the measurement of aerodynamic coefficients of the Shuttle Orbiter possible in low-density flow. The SUMS experiment will provide freestream atmospheric properties, principally mass density, above altitudes at which conventional pressure measurements are valid. Experiment concepts, the expected flight profile, tradeoffs in the design of the total system, and flight data reduction plans are discussed. Development plans are based upon a SUMS first flight after the Orbiter initial development flights.

Introduction

THE SUMS experiment is being developed as part of the NASA Orbiter Experiments (OEX) Program, which will provide research quality instrumentation to study Shuttle Orbiter performance over the entire spectrum of atmospheric flight. The principal SUMS objective is to contribute to the development of a flight data base for winged entry vehicles. These flight data will aid the current and future development of computer programs which predict rarefied flow aerodynamic properties. The resulting improvements in prediction technology, with increased confidence based on actual flight data, will aid future studies such as aeromaneuvering and planetary atmosphere entry experiments. Beyond this application-oriented objective, however, is the need to expand basic knowledge of rarefied aerodynamics phenomena, to which SUMS will make a significant contribution. Additionally, SUMS will serve as the forerunner of possible future mass spectrometer applications for the study of shock formation and flight measurements of the changes in boundary-layer chemical composition during the transition from free-molecular flow to the continuum flow. Finally, it is possible that multiple flights of an airborne mass spectrometer over the altitude range of 130 km down to 80 km may also provide additional information on the Earth's atmosphere in regions below that traversed by Earth satellites and above that regularly assessed by ground-launched meteorological missions.

Flight mass spectrometers normally operate at low-pressure, high-altitude conditions where the molecular mean-free path is very large compared to some vehicle characterization dimension, i.e., large Knudsen numbers. There are several notable exceptions to this, for example, the PAET[1] and Pioneer Venus Sounder Probe[2] missions. In general, however, mass spectrometers operate under vacuum conditions only, and complexities are introduced to allow operation at high-pressure inlet conditions. The traditional avoidance of these complexities has resulted in the characteristic data gap between higher altitude mass spectrometry and lower altitude pressure and/or accelerometry as, for example, on both Project Viking[3] and Pioneer Venus[4] planetary missions. The SUMS experiment originates from past research with planetary flight data,[5] which attempted to obtain the rarefied flow drag coefficient of a 70 deg half-angle cone vehicle by interpolation through the data gap.

The SUMS experiment will obtain essential atmospheric information in the flight regime where the aerodynamic characteristics undergo significant changes when transitioning from free-molecular flow to continuum flow. Specifically, SUMS will provide freestream atmospheric parameters. The main atmospheric component of interest is total mass density (i.e., the sum of partials of the constituent species), a parameter which a mass spectrometer measures exceptionally well even though reactive species may not be readily separated (e.g., atomic oxygen will be measured as molecular oxygen). Until SUMS, the best available values of freestream density in the transition region come from atmosphere models which have very large uncertainties. Conventional atmospheric measurements from the current onboard development flight instrumentation (DFI), the future OEX Shuttle Entry Air Data System (SEADS), and the Shuttle meteorological system are made only at altitudes below the transition region. Therefore, SUMS will fill the need for reasonably accurate atmospheric measurements in the upper altitude region.

Experiment Concepts

Technical Objective

The principal objective of the SUMS experiment is to support full-scale flight measurements of the rarefied flow aerodynamic force coefficients. For example, Fig. 1 shows the anticipated variation of the rarefied flow drag coefficient of the Orbiter as a function of altitude. This curve results from trajectory computer simulations using preflight Orbiter aerodynamic data.[6] Indicated on the figure are the approximate locations of the three major flow regimes encompassed by the experiment, namely, the hypersonic continuum, the transition, and the free-molecular flow flight regimes. It is anticipated that the Orbiter drag coefficient will undergo a significant change while traversing these regimes, as shown on the figure, although the variation and magnitude shown are based solely upon theoretical computation and empirical bridging formulas in the transition flow regime. The lower graph on this figure shows the corresponding approximate variation in the two representative parameters required to measure the aerodynamic force coefficients; that is, acceleration and surface pressure. In principle, two types of measurements are required to uniquely separate the force coefficient in the force equation; one is the aerodynamic accelerations and the other is the state properties of the

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*Entry Data Group Leader, Aerothermodynamics Branch, Space Systems Division. Member AIAA.

†Aerospace Engineer, Aerothermodynamics Branch, Space Systems Division.

‡Project Manager, Systems and Applied Sciences Corp., Hampton, Va. Member AIAA.

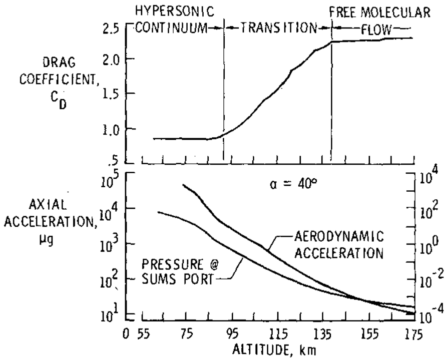

Fig. 1 Orbiter altitude profiles of rarefied drag coefficient, acceleration, and surface pressure.

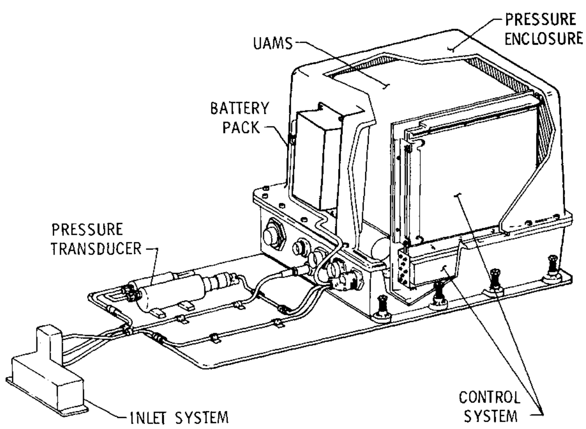

Fig. 2 SUMS instrument components.

ambient atmosphere at that time. The SUMS provides the required information to determine freestream properties which, given the system temperatures, can be represented as surface pressure, as shown on the figure. The surface pressure is directly proportional to dynamic pressure for the SUMS port location and for a given angle of attack. Further, from the force equation, the dynamic pressure is directly proportional to acceleration, which results in the force coefficients being directly proportional to the ratio of the measurements shown on the figure. Namely, for drag,

$$C_D \simeq a_m / P_m$$

where a_m is the acceleration measurement, which for this experiment is obtained by a sensitive accelerometer system called High Resolution Accelerometer Package (HiRAP) currently under development, and P_m is the total surface pressure, which is obtained by summing the partial pressures provided by the SUMS system.

Hardware Implementation

An operational spare flight unit of the Viking Project Upper Atmosphere Mass Spectrometer (UAMS) experiment[7] was modified for this application. The major modifications are: 1) a pressurized enclosed mounting fixture which serves the dual purpose of preventing corona and arcing and providing the mechanical interface between the existing UAMS and the Orbiter, 2) the design of an inlet system to control the flow of gas in order to increase the operating altitude range, and 3) an electronic control system to provide the necessary data interface with the Orbiter, as well as to provide autonomous control of the operation of the experiment during flight. Figure 2 is an artist's conception of the current SUMS physical system, showing its main components.

Besides the components previously discussed, there also is a pressure transducer used to provide information for the operation of the valves within the inlet system and a battery pack which provides power to maintain proper vacuum levels within the UAMS during periods when external power is unavailable.

The mounting location of the SUMS instrument package on the Orbiter is in the forward nose wheel well against the forward bulkhead, as depicted in Fig. 3. This location provides relatively easy access to the instrument for postflight removal, if necessary. Figure 4 is a detailed conception of the SUMS installed in the forward bulkhead of the wheel well (the view is facing forward looking up into the wheel well). The SUMS inlet system is remotely located from the mass spectrometer to be as near as possible to an existing Orbiter pressure orifice. The shape of the inlet system shown in Figs. 2 and 4 is peculiar because of the volume envelope required to fit the system under the lip of the edge of the wheel-well door frame, adjacent to the forward bulkhead. The connection to the port is on the opposite side of the bulkhead, approximately 15 cm away. This particular port, about 10 cm behind the nose cap, is near the stagnation point for high angles of attack ($\alpha = 40$ deg), which is the nominal Orbiter reentry attitude at high altitudes. At 40 deg angle of attack, the line normal to the surface at the port is at an angle to the velocity vector of about 29 deg. In addition, the port is located such that at this attitude, real gas effects on pressure are negligible in the continuum flow regime.

The major addition to the Viking UAMS for SUMS is the inlet system, which effectively creates a "closed-source" mass spectrometer system from the existing "open-source" system. The inlet system provides three functions: 1) establishing a gas flow path from the pressure port to the UAMS, 2) protecting the instrument in a high-pressure environment, and 3) expanding the dynamic measurement range. 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 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 port of 10^{-6} to 50 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-molecule flow above transition and hypersonic continuum below transition, with overlapping coverage of the conventional low-range pressure transducer. The pressure transducer is full-scale when SUMS reaches its cutoff pressure of 50 Torr, which provides an overlap of approximately 30 km in terms of altitude.

The current inlet system design is shown schematically in Fig. 5. (Other SUMS elements are included in the figure for completeness.) With all valves open on orbit, the pressure drops across the inlet system by a factor of about 20. During entry, closure of the range valve blocks the high conductance path through leak 1, forcing the flow through leak 2 with the drop across the system increasing to 2×10^5. The ratio of these pressure drops is 10^4, which represents the increase in dynamic range realized by addition of the dual-leak system.

Other elements of the inlet system include a filter to keep out particulate size matter and an inlet valve to stop the gas flow during nonoperating periods. A separate remote protection valve is used in the SUMS system to prohibit inadvertent damage to the mass spectrometer itself.

Experiment Flight Profile

The current plan is to fly the SUMS experiment on the Shuttle Orbiter-102 vehicle. The measurements from the

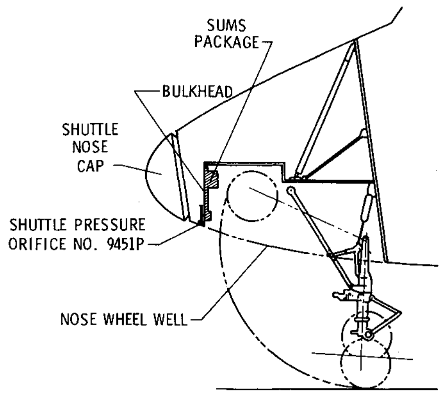

Fig. 3 Location of SUMS on the Shuttle Orbiter.

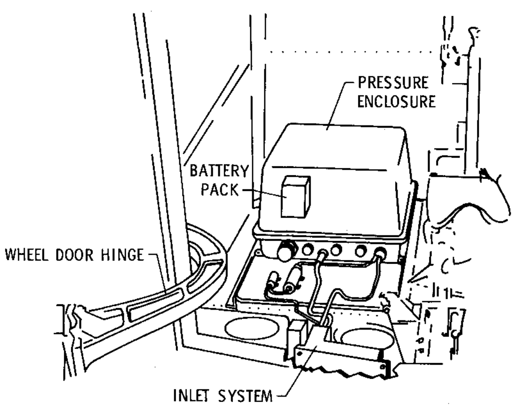

Fig. 4 SUMS installed in Shuttle Orbiter wheel well.

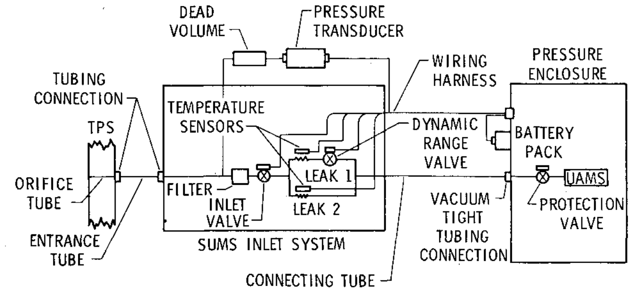

Fig. 5 SUMS inlet system component schematic.

Table 1 SUMS design specifications

Mass range	1-50 amu
Scan rate	5 s
Measurement range	Minimum orifice pressure, 10^{-6} Torr Maximum orifice pressure, 50 Torr
Leak 1 range	$+5\times10^{-4}$ Torr 10^{-6} to 4×10^{-3} Torr -0 Torr
Leak 2 range	$+0$ Torr 4×10^{-3} to 50 Torr -5 Torr
Signal resolution	±3%
Absolute accuracy limits	±10% free molecular flow ±20% transition flow and lower altitudes

SUMS will be initiated by Orbiter command approximately 1 h prior to the deorbit maneuver. During re-entry, mass density measurements will be taken for approximately 35 min, 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. A prelaunch checkout is planned, during which all valves remain closed, with power being supplied to the ion pump. The instrument is cycled on to gather system performance data. During the high-vibration launch environment all power to the SUMS system is off. Approximately 1-2 h after orbit insertion, the inlet valve is 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 1-2 h prior to deorbit burn, the instrument is 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 1 h). During re-entry, at about 4×10^{-3} Torr orifice pressure (about 130 km), the valve in series with leak 1 is closed, effectively switching the dynamic range of the instrument by forcing the gas sample to flow through leak 2 only. At 50 Torr surface pressure (about 57 km) all valves are automatically closed, stopping the external gas flow into the system. Beyond this time, the instrument and ion pump remain powered to gather data on the pump-down of the system. During the terminal landing phase, the instrument is turned off coincident with other OEX instrument systems. The ion pump remains powered for the remainder of time in the flight 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. The above flight profile is planned for each of the six SUMS experiment development flights.

System Design Constraints

Several design constraints have been considered in the development of the SUMS experiment. The first was to use an existing proven airborne mass spectrometer which could be minimally modified to meet experiment objectives. This eliminated the need for costly development of a major component of the system, but necessitated using dated instrument technology. This constraint imposed mostly a system complexity compromise into the system design, but did not compromise proof of concept (i.e., using mass spectrometry for aerodynamic extraction purposes). Second, the system was to be mounted and flown on the Orbiter, an existing vehicle with multimission goals. Further, development of the system will be through repeated return flights of the equipment. This necessitated a location on the vehicle for quick removal for potential laboratory examinations and/or servicing between flights. The current design location is optimum, considering all possibilities. The third major constraint in the design is the use of an existing orifice for obtaining external gas samples. This and the previous mounting location constraint obviously are related. Several alternatives were considered in the design but were rejected early, mostly because of the complexities introduced in installation and removal of the equipment. In general, these constraints have introduced tradeoffs in the SUMS design and its subsequent performance, as well as complexities in the calibration, data reduction, and data analysis systems.

Specifications

Table 1 lists pertinent specifications of the SUMS system. Meaningful analysis of SUMS absolute accuracy depends upon such factors as the "as-built" equipment and the calibration station. The values in Table 1 are rough estimates which are somewhat qualitative and judgmental, based upon

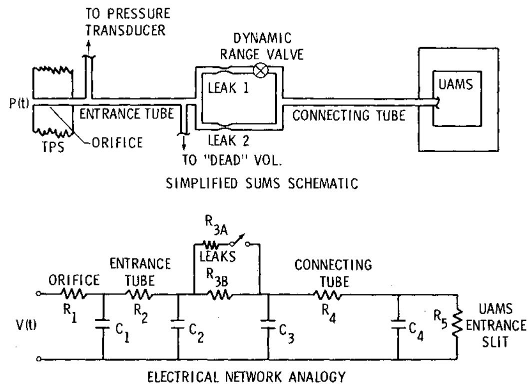

Fig. 6 **SUMS electrical analogy for pressure response analysis.**

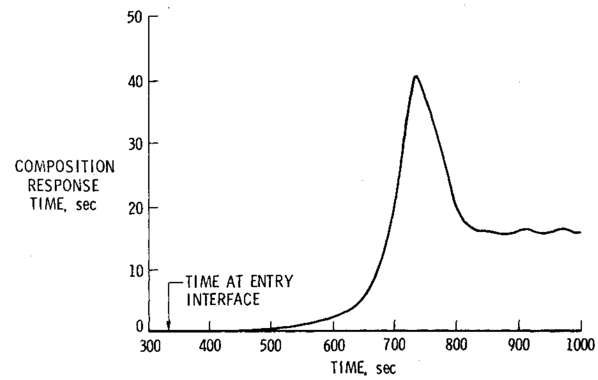

Fig. 8 Predicted composition response time history.

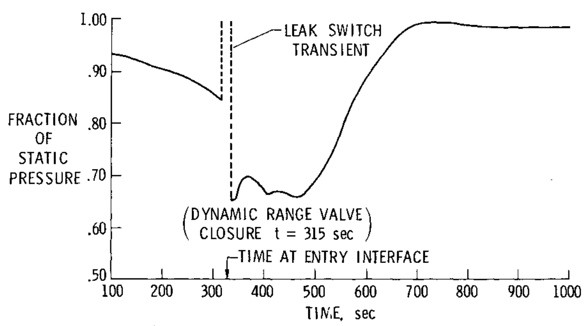

Fig. 7 Predicted fraction of static pressure.

worst-case criteria. Other factors which contribute to the accuracy are: 1) fidelity of calibration tests in simulating flight parameters, 2) inlet system data reduction algorithm, 3) flowfield data reduction algorithms, 4) accuracy of trajectory and ancillary data, and 5) assessment of gas sample "sources" and "sinks." In addition, the dynamic measurement range of the instrument is quite wide (i.e., from orbital altitudes down to 57 km) covering a wide range of both atmospheric and trajectory conditions. Thus, it is not anticipated that the final accuracy will be defined with single values.

In addition to the specifications presented in Table 1, certain design goals have been identified which relate to the inlet system. This system is a principal component which affects the experiment outcome directly and, effectively, the only major degree of freedom in the design (i.e., the mass spectrometer was already built). The inlet design goals were: 1) minimize the dynamic pressure lag of the system, 2) minimize the time delay in detection of changes in gas composition at the orifice location, and 3) avoid leak switch during the transitional flow flight regime. These goals are mutually conflicting and required design tradeoffs, which will be discussed next.

Inlet System Analysis

Analysis Technique

The SUMS system can be represented by an electrical analog consisting of a four-node R-C network described in Fig. 6. 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_{3A} and 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 parallel, which represent the UAMS entrance slit (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 programed to provide the network output, representing the UAMS ion source pressure, as a function of time.

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 determined solely by the molecular conductances of the system elements. The static drop is defined as

$$\sum_{1}^{4} R_i / R_5$$

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 ion source pressure to the static ion source pressure that would exist at a constant orifice pressure equal to the instantaneous dynamic value. A design goal for SUMS was to hold this ratio as close to 1.0 as possible, to minimize the introduction of error in flight data interpretation.

The predicted dynamic response history for the SUMS design is shown in Fig. 7. The minimum value of the fraction of static pressure (maximum drop) of 0.66 occurs just after the dynamic range valve closes and coincides with the maximum dP/dt to P ratio. This relatively low value results from a design tradeoff involving an intentional increase in volume prior to the leaks to improve the system response to changes in gas composition at the orifice.

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. While measurement of composition is not of major interest, reasonably accurate determination of composition, if feasible, would certainly add to the scientific value of the experiment. The time delay for sensing composition changes 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

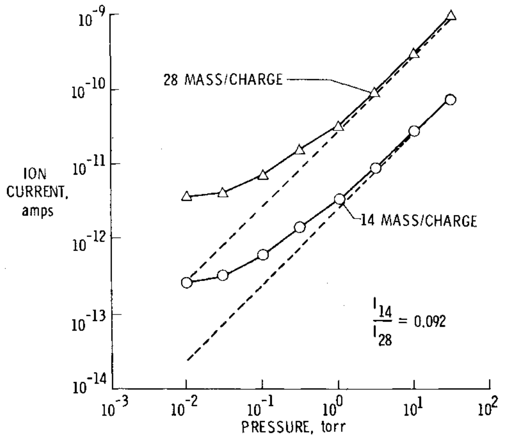

Fig. 9 Initial test results of N_2 static calibration (high pressure).

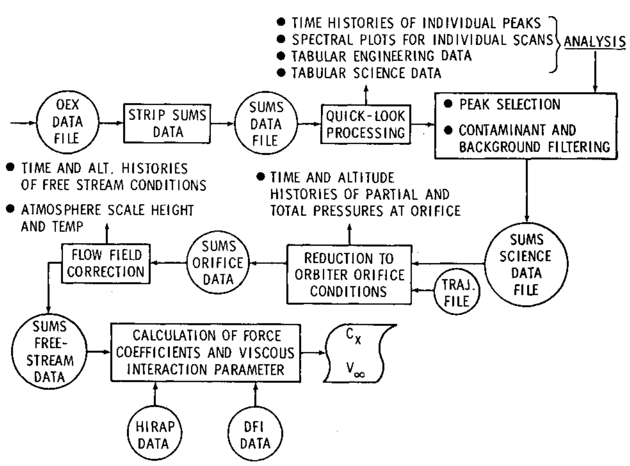

Fig. 10 SUMS flight data reduction flow.

maximization of the gas flow velocity. Flow velocity is affected by tubing diameters and the presence of volume just ahead of the leaks. Obviously, too, the tubing lengths affect the delay. Adding volume has the effect of creating a "semi-flow through" system which increases the flow velocity as the outside pressure increases, but has the undesirable effect of increasing the dynamic pressure drop or pressure lag. The inlet system design took these factors into account to the extent possible within constraints discussed earlier. Studies during the preliminary design showed that the addition of a significant dead volume (about 30 cm^3) could reduce the delay to acceptable values, while not affecting the dynamic pressure drop adversely. Composition response lag times are predicted as shown on Fig. 8. The delay is predicted to be as much as 40 s for a short period of time, falling back to about 16 s until instrument cutoff. The beginning of this region of relatively long composition response times corresponds to an altitude of about 80 km.

Dynamic Range Valve Closure

Another design goal for SUMS was to avoid closure of the dynamic range valve (to switch leaks) during the vehicle's transition from free-molecule flow to continuum flow. This is a primary region of interest to SUMS and it is, therefore, desirable to avoid the risk of data degradation during the leak switch transient. This goal must be considered together with other concerns; specifically the requirement to overlap pressure measurements and the desire to maintain the ion source measurement signal-to-noise ratio at an acceptable value after switching. Maintaining a 50-Torr maximum orifice pressure to overlap the low-range pressure transducers and a signal-to-noise ratio of 10 after the leak switch puts the dynamic range valve closure at freestream conditions which give a Knudsen number of slightly less than 1.0, which is just within the classical definition of the onset of vehicle transitional flow.

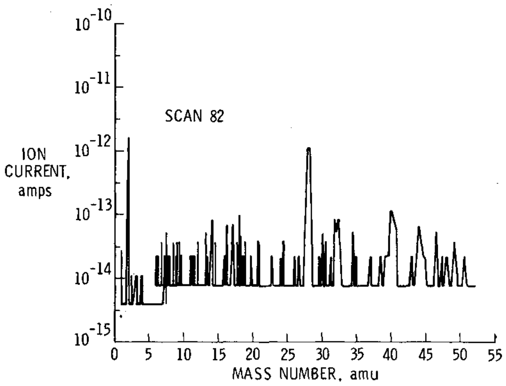

Fig. 11 Typical test case spectra from SUMS flight hardware.

SUMS Preflight Tests

Three types of calibration tests have initially been performed on the completed SUMS hardware: static pressure, dynamic pressure, and gas composition change responses. The static tests were performed over an inlet pressure range of 10^{-6} to 50 Torr for separate nitrogen and oxygen gas samples and a mixture of nitrogen and oxygen. 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 to determine the instrument pressure lag due to a rising inlet pressure. The known pressure lag will be used to compensate the SUMS analytic model of the instrument response for flight data reduction. The composition change response was tested at several pressures and pressure rise rates to determine the lag between time of gas composition changes at the inlet and the time at which the instrument senses such changes. This will allow closer estimates of composition change times, which will be of concern during interpretation of flight data.

Figure 9 shows a typical result from the initial static calibration test for nitrogen after closure of the range valve. These initial data from the flight instrument were obtained to check the laboratory procedures, to provide preliminary data on the behavior of the automatic electronic logic circuitry and total system, as well as to provide tests of the calibration data reduction software system. These data were taken prior to a bakeout and, thus, are somewhat limited by the presence of a significant background level in the SUMS analyzer. This results in a limit to meaningful calibration data over the low-pressure end of the analyzer pressure range. (Note the flattening of the curves.) However, the test plan includes a final bakeout, and additional calibration testing will be done prior to flight. Some initial information on the SUMS system does, however, emerge from this preliminary data. For instance, after correction for the background (indicated by the dotted line) the initial value of the sensitivity for N_2^+ is found to be about 2.73×10^{-11} A/Torr and for N_2^{++} about 2.52×10^{-12} A/Torr. This indicates a nitrogen fractionization ratio (i.e., 14:28) of about 9%, which is within tolerance of what is anticipated for the 75-eV ionization potential source and given instrument geometry.

In addition, an integration test was performed with SUMS connected to a flight data system, which provided actual flight format data files. These files have been used in the subsequent

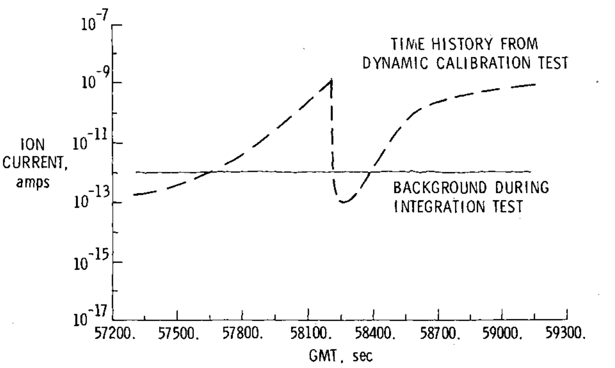

Fig. 12 Time history of N_2 peak from integration and initial dynamic calibration tests.

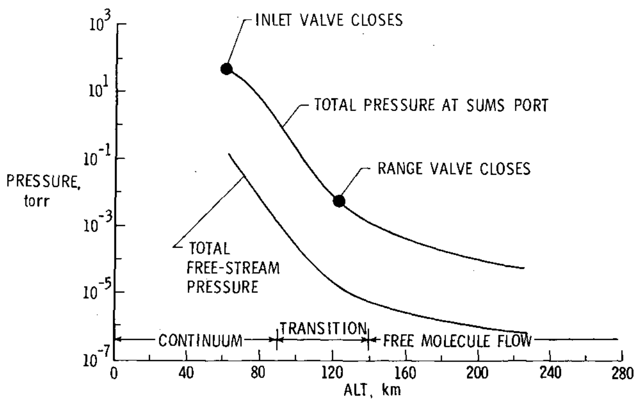

Fig. 13 Predicted altitude profiles of SUMS port surface and freestream pressures.

development of software data interfaces and data reduction programs.

Contamination and Flowfield Analyses

In addition to the calibration test data analysis, serious attention is being given to modeling the flowfield about the Orbiter and the study of possible contamination of the ambient atmosphere sample by outgassing from the vehicle surfaces.

Samples of the Orbiter tiles are being studied in laboratory simulations of flight conditions expected for temperature and pressure. These tests will provide data on the molecular content of contaminants, their fractional products at high temperatures, and the levels to be expected. One known potential source of contamination is the tile waterproofing applied before launch, but questions remain regarding how flight conditioning in orbit may affect it before re-entry. In the actual flight data, the time history of the contamination peaks, a function of outgassing, will be significantly different from the atmospheric peaks.

Monte Carlo techniques[8] are being applied to the characterization of the flowfield about the Orbiter in order to obtain freestream atmospheric properties from the actual SUMS measurement at the inlet orifice location on the Orbiter surface. This procedure is analogous to using hypersonic continuum theoretical pressure coefficients from a flowfield computer code in order to interpret freestream conditions from pressure transducer measurements.

Flight Data Reduction Process

The block diagram of the SUMS flight data reduction process is shown in Fig. 10. Digital data from the SUMS instrument will be recorded in flight on the onboard OEX recorder. The flight tapes will be taken to NASA Johnson Space Center (JSC) for processing and generation of experiment user tapes.

Raw data for SUMS only will be stripped at the NASA Langley Research Center and will be input to quick-look processing programs which produce output on the operation of the instrument and science data display for preliminary analysis. Two examples of the types of data display are shown on Figs. 11 and 12 as actually processed by the software from the SUMS integration test data. Figure 11 is a spectral plot obtained during scan number 82 of that test 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. Some 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 12 shows the mass 28 peak time history during the entire integration test run. This peak is constant because it is from the residual trapped gas inside the closed instrument. Also shown in Fig. 12 is the result for mass 28 (corrected for residual background) from the dynamic calibration test. In this test, molecular nitrogen was introduced to the instrument with pressure increasing with time as expected in flight. The internal instrument pressure reached a maximum at 58,195 s GMT, at which time the range valve closed, as indicated by the sharp four-decade drop in ion current.

Analysis of the quick-look data will provide information to determine the background and contaminant filtering necessary to separate the peak contributions from atmospheric gases only. The resultant filtered science data file then will be input to a succession of programs which correct for the pressure drop across the inlet system and the freestream to surface pressure ratio in the flowfield about the Orbiter. Time and altitude histories of the orifice (partial and total pressures) and freestream parameters (partial/total pressures, partial/total densities, pressure scale height, and temperature) will be obtained. Figure 13 shows the expected altitude history for the SUMS orifice pressure and the total freestream pressure for the first SUMS flight. These curves are based on best postflight estimates for atmosphere and trajectory from the STS-1 flight.

The final step in the data reduction occurs when the SUMS freestream data, reduced acceleration data from HiRAP, and reduced wall temperature from the DFI are brought together to calculate the force coefficients and the viscous interaction parameter.

Conclusions

An experiment, called Shuttle Upper Atmosphere Mass Spectrometer (SUMS), is being conducted to develop mass spectrometer technology for application to support rarefied flow aerodynamics flight research. The equipment consists of a closed source mass spectrometer system which is designed purposely to operate in flight below classical vacuum pressure limits into the fringes of the hypersonic continuum flow regime. This experiment is the first attempt at adapting mass spectrometry for purposes of obtaining full-scale flight information for aerodynamic research. The focus of the investigations is the free molecular flow and transition flight regimes, which are typically difficult to simulate in current ground facilities, particularly for winged entry vehicles like the Orbiter. The Orbiter's repeated entries into the Earth's atmosphere and subsequent return of the equipment provide a unique development approach, unlike expendable equipment in the past. The experiment design takes full advantage of the opportunity to develop the SUMS equipment through actual flight experience. Current plans include an initial flight after the development flights on Orbiter 102.

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