79

P. Kruger

GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : James Baker
ATS F&G Project

DATE: October 5, 1971

FROM : W. F. Hardgrove
Test and Evaluation Division

SUBJECT: ATS-G Mass Spectrometer Monitor Proposal

Attached is an updated copy of the Technical and Management proposal for the ATS-G Mass Spectrometer Monitor. Cost and schedule has been changed slightly to reflect current estimates.

The ATS Project's estimate for Fairchild Industries integration/systems work and the Test Operations Tax for T&E project labor are in addition to the instrument cost shown on page 15 of attachment 1. The estimated T&E labor shown by attachment 2 is expected to average 1.3 MY/Y or 6.5 man years total. The tax rate for this period is estimated at 25K per man year.

William F. Hardgrove

William F. Hardgrove
Thermodynamics Branch

Attachment 1 - Mass Spectrometer Monitor Proposal
Attachment 2 - Manpower Estimate for Civil Service -
Test and Evaluation Division Personnel

322/WFH:bds

cc:
300/H. E. LaGow
320/J. C. New
322/H. Maurer
322/R. Kruger
460/H. Gerwin
460/J. Corrigan
460/J. Woodruff

Attachment 1

PROPOSAL TO
PROJECT OFFICE, ADVANCED TECHNOLOGY SATELLITE F&G
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER

MASS SPECTROMETER MONITOR FOR ATS-G

Submitted by

Matthew P. Thekaekara, Principal Investigator

and

William F. Hardgrove, Project Engineer
Thermodynamics Branch, Test and Evaluation Division

Goddard Space Flight Center
Greenbelt, Maryland

August 1971

TECHNICAL SECTION

SUMMARY

A proposal is made to install a mass spectrometer monitor (MSM) on board the ATS-G satellite. The purpose of the MSM is to identify and forestall sources of contamination and causes of failure of the experiments on board. The MSM is a sensitive instrument to measure the mass number and flux density of the atoms and molecules in the vicinity of the spacecraft. Such measurements are considered highly necessary for ATS-G spacecraft, partly because of several major experiment components such as radiation coolers, optical surfaces and infrared sensors, which are sensitive to contamination and partly because the satellite configuration with its dish antenna, solar arrays, hydrazine thrusters, thermal insulation material, etc. is such as to generate contamination hazards. Mass spectrometers may be made as relatively small, lightweight instruments and have been flown successfully on earlier satellites with low requirements of power and telemetry. A major requirement is that sufficient lead time will be available for building, testing and calibration of a mass spectrometer which incorporates the best state-of-the-art features in sensitivity and reliability, at reasonable cost and specifically designed for the satellite environment of ATS-G.

OBJECTIVES AND MAJOR REQUIREMENTS

The objective of the mass spectrometer monitor is to obtain measurements in the vicinity of the ATS-G spacecraft of what are basically spacecraft generated molecular fluxes which may degrade the mission. The measurements of flux density (in particles/cm^2/sec) and the atomic mass information will permit the identification of quantity and species of the flux with a high degree of certainty in many cases and with lower probabilities in some. This identification will be correlated to events occurring on the spacecraft such as firing of the hydrazine thrustor, turning off or on of major experiments, power dissipation near critical areas of desorptive material, diurnal and seasonal changes of exposure to sunlight, temperature changes on the earth viewing module, the parabolic antenna and the solar panels. Thus, it would be possible to determine the chemical composition and density of the contaminating material which the spacecraft generates and carries along with it.

Some of the satellite effluents are such as to affect significantly the long term reliability and stable performance of the experiments on board. Thus, for example, the reflectance of highly polished surfaces, optical mirrors and radiation cooler cones will be lessened by overcoating with foreign material. Thermal and optical detectors which operate at very low temperatures, say, -100 or -200°C, may fail totally on account of an ice-cap or other opaque film deposited over them. Infrared sensors and photo-cathodes suffer deterioration due to contamination.

Data supplied by the mass spectrometer monitor will in certain cases permit the experimenters to forestall harmful effects on their on-board instrumentation. In other cases, it will be possible to determine the causes of partial failure or inadequate performance. New calibration factors may have to be computed or new parameters will have to be included in the analysis of data. Valuable information will be obtained on the outgassing properties of the spacecraft materials and vulnerability to degradation of optical materials and detector surfaces.

The major requirement is that mass spectrometer monitor has adequate mass range, sensitivity and resolving power. The quadrupole mass spectrometer is preferred to other types of instrumentation because of its advantages for spacecraft application. The instrument has been flown on several satellites such as the Orbiting Geophysical Observatory II, IV and VI, the Atmospheric Explorer XVII, and a large number of sub-orbital rockets. Most of our current detailed knowledge about the upper atmosphere of the earth, its composition and variations with time and latitude, have been obtained through the quadrupole mass spectrometers. In earlier years, prior to 1960, mass spectrometers of different types, e.g., Bennet tubes and magnetic sectors, were flown in one of the USSR Sputniks, Sputnik III, and many of the early rockets of both USA and USSR. The quadrupole mass spectrometer (QMS) has since been developed to a high degree of reliability and accuracy. Quadrupole mass spectrometers are being planned to be flown on the Skylab by Marshall Space Flight Center and on several of the scientific satellites.

A major difference between the QMS flown on earlier satellites and rockets and the one now proposed is that the earlier ones were designed to study the atmosphere of the earth and our objective is to study the atmosphere or "cloud" generated by the satellite. In the earlier models, a small orifice was provided in the direction of the velocity vector of the satellite or on certain cases, the mass spectrometer was deployed to a distance away from the body of the spacecraft.

In the synchronous orbit, the atmosphere of the earth vanishes to the particle density of the solar ecliptic plane and the effluents of the satellite are of major importance.

The MSM has a sensor unit assembly projecting partially outside the skin of the Earth Viewing Module and behind it at a short distance a control electronic package. The sensor unit assembly consists essentially of an ion source, the quadrupole mass analyzer and a detector. The ion source generates positively charged ions from the neutral particles which traverse the space between a hot filament grid and an accelerating cathode. The ions traverse the space between the four rods of the quadrupole electric field due to an adjustable direct current voltage and an alternating radio frequency voltage. The motion of the ions is governed by the well-known Mathieu's differential equations, so that ions of only a single atomic mass determined by the changing parameters of d.c. and r.f. traverse the length of the quadrupole and reach the ion detector, while ions of all other masses are neutralized by impingement on the rods. The detector may be an ion counter which counts and totals single events or an ion multiplier with an analog current output. Charged ions rather than neutral particles can be detected by the QMS by adding a bias voltage to the ion source.

The QMS can be operated in a scanning mode or the stepping mode. In the scanning mode, the d.c. voltage sweeps through a given range, thus focussing ions of different masses in succession on the detector. In the stepping mode, the QMS is set to step successively through a certain number of values of mass number, remain at each value for a sufficiently long time to give a measure of ambient ions of that mass. This mode of operation increases the sensitivity of the QMS by three decades. The QMS can also be operated with a cold cathode source. In this mode of operation, no heated filament is required for the production of ions, thus reducing the power input and heat dissipation and also avoiding any interference of the light from the filament with any of the other experiments on-board such as the startracker. However, the cold cathode source requires a magnet, and the problem of possible interference with the magnetometer at the hub of the antenna should not be ignored. It may well be that the distance of about 25 feet between QMS magnet and the magnetometer makes the problem of vanishing significance.

The control electronic unit supplies the necessary electrical power for the ion source, the quadrupole mass filter and the detector unit, receives and executes command signals, and converts the output of the detector to a format compatible with the spacecraft telemetry.

BACKGROUND AND JUSTIFICATION

Spacecraft project offices have long considered the necessity of monitoring the contamination on-board satellites.

A proposal to install mass spectrometer monitors on satellites was made in 1966 to NASA Headquarters by Dr. Richard J. Leite of the High Altitude Engineering Laboratory, University of Michigan, Ann Arbor, Michigan. Dr. Leite's proposal (NASA control No. 23-005-206) was studied by the NASA Contamination Review Board under the charimanship of Maurice Dubin and was unanimously recommended for flight. Many types of spacecraft were considered as suitable vehicles for the experiment, the Earth Resources Technology Satellite, the Mariner-Mars Probe, the Mariner Mercury Venus Probe, the Viking Orbiter, the Skylab and satellites of the Nimbus series. While the problem was considered to be one that called for an urgent solution, no definite decisions were taken to implement the contamination monitor program.

Contamination to a greater or less extent had been observed by many experimenters from the beginning of the space program. V. G. Istomin reported at the CSAGI General Assembly, Moscow in 1958 that a Bennet type mass spectrometer detected water vapor in the vicinity of Sputnik III. The amount of water vapor which was quite high in the first revolution decreased to one-sixth in the third revolution and became still less in subsequent revolutions. In the first revolution, the ion current due to H_2O, Mass 18, was 230 times the ion current due to O, Mass 16.

From the rate of decrease with respect to time of the amount of H_2O, Istomin concluded that this was a contaminant and not a natural constituent of the atmosphere. The decrease was rapid probably because it was a small satellite with few outgassing materials. J. W. Townsend commenting on Istomin's report observed that he and his colleagues had obtained similar mass spectra.

The persistence of water vapor over a long period of time was reported by Hinton, Leite and Mason[2]. Their data were based on quadrupole mass spectrometers flown on Orbiting Geophysical Observatory II and IV. At the beginning of the satellite life, the amount of water vapor generated by the satellite increased the local density of H_2O to about 10^5 times the ambient H_2O density at the OGO altitude. Three months later, the ratio was about 10^3 and six months later, about 10^2. That even after six months the satellite was outgassing water vapor was a surprising conclusion.

Contamination of surfaces by outgassing on OGO-VI was reported by McKeown and Corbin[3]. The detectors were quartz crystal microbalances which can measure the total amount of material deposited on a given surface without, however, an accurate identification of species. The primary source of outgassing on the satellite was the solar panels baking out in the sun. The change in mass of the crystal was considerably greater when the solar panels were in view than when the crystal was directed away from the solar panels. The mass deposited on the crystal reached a maximum when the satellite was 5 months in orbit and amounted to 9.6 $\mu g/cm^2$ for an aluminum coated crystal and 5.2 $\mu g/cm^2$ for a gold coated crystal. From the desorption activation energy of the accreted mass, the authors conclude that the outgassing contamination from the panels was most probably epoxy assembly materials of the panels and diffusion pump oil adsorbed during prelaunch tests. While this identification of species may be open to further study, the fact that effluents from the solar panels reached the spacecraft and gave it a thin film coating cannot be questioned. Under these circumstances, a mass spectrometer may have identified the material in question.

Several examples might be given from past experience of satellites of contamination and consequent degradation or failure of on-board experiments. The effect is obvious, the cause is a matter of conjecture and educated guess. An example which has received a great deal of attention in NASA Centers and contracting laboratories is the failure of the filter wedge spectrometer (FWS) on Nimbus IV. The FWS was designed to measure radiance of the earth in the wavelength bands 1.2 to 2.4 μm and 3.2 to 6.4 μm. The spacecraft was launched on April 8, 1970. When the FWS was turned on in orbit 5, it was found that the 1.2 to 2.4 μm band was degraded and the 3.2 to 6.4 μm band was totally obscured. The presence of ice absorption bands in the 1.2 to 2.4 μm range showed clearly that an ice cap had been formed over the low temperature (176K) detector by the condensation of water vapor. As stated in a memorandum dated May 18, 1970, originated by Dr. J. F. Clark, Director, GSFC, this might be a generic problem common to the upcoming generation of radiation coolers. In accordance with the directives of that memorandum, a Radiation Cooler Task Group[4] was formed under the chairmanship of H. E. LaGow, Director of Systems Reliability, to investigate the FWS failure. The formation of the ice cap could readily be explained; but why it did not sublimate shortly afterwards was puzzling. One hypothesis which has been advanced is that other foreign materials of low volatility such as oils, adhesives or plasticizers condensed over the ice cap, thus effectively sealing it off.

A major recommendation of the Radiation Cooler Task Group was a flight test to define the gas environment in the vicinity of a spacecraft. Experiments to determine the atomic and ionic species in space and their relative abundances have been flown on several satellites, but in general, they were so designed as to avoid as completely as possible any interference from the effluents of the satellites. When such interference occurred, they were ignored because they were of no value to the experimenter. An experiment specifically designed to monitor the contamination due to the outgassing materials on the satellite is highly desirable for the upcoming generation of radiation coolers which will operate at lower temperatures than the one on Nimbus IV.

Though such an experiment would be considered useful for many types of satellites, it would seem uniquely necessary for the ATS-G satellite. There are three radiation coolers on-board the ATS-G, two for the MET package Sounder-Imager and one for the CO_2 laser. These two are among the major experiments onboard. There are also large optical surfaces, one of 8" diameter, probably another of 16" diameter, which are vulnerable to contamination. The shape and size of the spacecraft is another major consideration. The 30' dish antenna with its 48 radial ribs and copper coated dacron mesh presents a large area to the earth viewing module at a distance of 23 feet. There are also the two large semi-cylindrical solar panels at either end of a 52' boom. Both the solar panels and the antenna can give rise to effluents in the process of baking out. They can also reflect towards the EVM the outgassing particles of the EVM itself.

The EVM is a major source of outgassing. It is basically a 54" cube with many components and compartments, layers of insulation, polymeric materials, and other sources of vapor. It may be expected to persist in evolving significant quantities of material which may contaminate sensitive experiments. Many hypotheses exist as to how these may leave the surface and then return to some other area where they form a contaminating substance. These include such considerations as molecule-molecule interactions, electrostatic attractions, and fluxes from incompletely expanded thrusters.

Another area of concern for all satellites and especially for the ATS is the exhaust from the thruster engines themselves. The engines are fired periodically to maintain the position and attitude of the spacecraft. The effects of the thruster exhausts have been discussed by W. C. Lyon[5] and by Mayer, Taylor and Schieler[6]. As Lyon has shown, in addition to the collimated primary beam which moves away from the spacecraft along the axis of the thruster, there are uncollimated ions and neutrals which travel obliquely and impinge on the spacecraft. Mayer, Taylor and Schieler have shown the possibility of contamination from pre-ignition products of restartable thruster engines. It is also well known that most propulsion nozzles do not fully expand the fuel within the thruster and considerable expansion takes place outside the nozzle. The gases due to the delayed expansion do not travel away from the spacecraft along the thruster axis, but radially in all directions from the point where the expansion takes place. These gases constitute a major source of contamination for the north and south faces of the EVM where the hydrazine thrusters are located.

During the preliminary discussions at Fairchild Industries on July 25, 1971, the F. I. spokesman, M. Titland, suggested the north face of the EVM between the two radiation cooler cones as a possible location for the mass spectrometer monitor. This location affords a good view of the dish antenna, the solar paddle and the hydrazine thruster. It permits particles to be deflected to the MSM from the cooler cones. While it is recognized that problems of spacecraft integration for the larger experiments of ATS-G may make this location unavailable to the MSM, in view of the small volume, weight and power requirements of the MSM, it is certain that a suitable location can be found where the MSM can be of maximum benefit to the overall performance of the ATS-G and each of its experiments.

In a memorandum dated June 15, 1971 to H. L. Gerwin, ATS-F and G Project Manager, J. L. Baker, Deputy Project Manager discussed the advantages and disadvantages of three contaminant detectors for ATS-F, Quartz Crystal Microbalance, Quadrupole Mass Spectrometer, and Tungsten Catalyzed Cesium Detector. Among the advantages of the QMS was that it can identify the species, has high sensitivity, and is an item that is already well developed. The main disadvantage was that it could not meet the ATS-F schedule. Hence, the QCM was recommended, and is to be flown on ATS-F. The Quadrupole Mass Spectrometer can meet the schedule of ATS-G. A QCM also will probably be flown on ATS-G, in a location close to the one suggested for the MSM. The two instruments are complementary to each other and their combined output will give a high level of confidence to the final data analysis.

This proposal is being made by a group in the Test and Evaluation Division of GSFC which is engaged in fundamental research in space simulation and high vacuum. A basic problem in the production and measurement of high vacuum is the study of residual gases and contamination in the vacuum chambers. Considerable experience has been gained over the last ten years in the development and use of mass spectrometers, especially quadrupoles. We currently operate six different types of mass spectrometers with widely varying characteristics of resolution, mass range, sensitivity, etc. We have developed a highly automated computer technique for analysis of the quadrupole mass spectrometer output. The experimental and analytical skills which have been gained over the years in the prelaunch testing of satellites and contamination studies in high vacuum test chambers can be put to effective use in monitoring, with a quadrupole mass spectrometer, the possible contaminants on-board a complex satellite like the ATS-G.

APPROACH

a. General

A quadrupole mass spectrometer will be used to monitor the ambient atoms and molecules surrounding the ATS-G satellite in order to identify and remedy possible sources of contamination. Molecular and atomic species, both neutral and ions, will be identified and their absolute densities will be measured.

The quadrupole mass spectrometer is a proven instrument and several models made by different manufacturers have been flown previously on scientific satellites and rockets.

b. Configuration

The mass spectrometer monitor consists of two parts, the sensor assembly weighing about 3 pounds and the electronic control box weighing about 6½ pounds. The sensor assembly is cylindrical in shape, 3" in diameter and 10" in length. It is located on the north face of earth viewing module, with one end which is the ion source projecting outside the surface of the spacecraft. The electronic control box which occupies a volume of about 800 cubic inches is located close to the sensor assembly within the body of the spacecraft.

The sensor assembly will be a sealed unit so as to protect it from contaminants during spacecraft integration and launch phase. All testing and calibration will be done prior to sealing it. The seal will be broken on command from ground after the spacecraft is in orbit.

c. Data Requirement

There are two major analog experiment outputs, ramp voltage 0-5V and mass spectrum. Bandwidth is between 1 Hz and 250 KHz. Seven channels of housekeeping data are required. Range analog is 0 to 5.12 volts. Sampling rate is 1 per 3 seconds. Accuracy is ±1%.

d. Command Requirements

Nine commands are used, namely, 2 redundant ordnance commands to open the mass spectrometer monitor to the ambient, 2 power commands to furnish power to the entire system and to the filament, 5 impulse commands for filament selection, for operational configurations and reset.

e. Data Reduction and Analysis will be done in-house.

f. Results

Results expected are as stated under Section 1, Objectives. The sources of contamination on-board the spacecraft will be identified by species and density flux. Data will be available to study the correlation between variations in the satellite "cloud" and satellite "events," changes in satellite environment, long term changes in performance of individual experiment packages, efficiency of radiation coolers, etc. Valuable information will thus be generated which cannot be obtained from laboratory experiments.

REFERENCES

1. Istomin, V. G., "Investigations of the Ion Composition of the Earth's Atmosphere by Rockets and Satellites," Annals of the I.G.Y., Vol. XII, Part I, pp 444-448, Pergamon Press, London, 1960.

2. Hinton, B. B., Leite, R. J., and Mason, C. J., "Comparison of Water Vapor Measurements from Two Similar Spacecraft," Trans. American Geophysical Union, Vol. 50, No. 4, pp 267, April 1969.

3. McKeown, D. and Corbin, W. E., Jr., "Space Measurements of the Contamination of Surfaces by OGO-6 Outgassing and their Cleaning by Sputtering and Deabsorption," ASTM/IES/AIAA Space Simulation Conference, 14-16 September, 1960, Space Simulation, NBS Special Publication, 336, pp. 113-123.

4. LaGow, Herman E., Chairman, "Report of the Findings of the Radiation Cooler Task Group," DIRS 02273-I-2-TR-239-032-215, September 11, 1970, Goddard Space Flight Center, Greenbelt, Maryland 1970.

5. Lyon, Warren C., "Thruster Exhaust Effects on Spacecrafts," AIAA 8th Electric Propulsion Conference, Stanford, Calif., Aug. 31 - September 2, 1970.

6. Meyer, S. W., Taylor, D., and Schieler, L., "Preignition Products from Propellants at Simulated High Altitude Conditions," Combustion Science and Technology, Vol. I., No. 2, pp 119-129, 1969.

MANAGEMENT SECTION

I. Work Plan

A Mass Spectrometer Monitor to determine the spacecraft molecular environment during flight and to establish whether or not contaminants are present is proposed.

The principal investigator is Dr. Matthew P. Thekaekara. The Mass Spectrometer Monitor is planned for flight on ATS-G scheduled to be launched in May 1975.

The design, construction, testing, and calibration of the instrumentation will be the responsibility of an outside contractor. Requirements to be written into the specifications for the mass spectrometer and for analyzing the data as well as evaluation of the satellite data will be developed by Dr. Thekaekara.

II. Personnel

The following personnel of the Space Simulation Research Section in Thermodynamics Branch of the Test and Evaluation Division will be directly involved in the Mass Spectrometer Monitor project.

Dr. Matthew P. Thekaekara - Principal Investigator
Mr. Harold Shapiro - Consultant
Mr. William F. Hardgrove - Project Engineer

Resumes are attached.

PRINCIPAL INVESTIGATOR: DR. MATTHEW P. THEKAEKARA

Dr. Thekaekara has been associated with the Space Simulation Research Section, Test and Evaluation Division, Goddard Space Flight Center, since 1962. Among the major research activities of this Section are the production and measurement of high vacuum and the study of contamination in the space simulation chambers which are used for prelaunch testing of spacecraft and their experiments. Previous to his joining GSFC, he was Chairman of the Physics Department in Georgetown University. He took his Ph.D. in physics from Johns Hopkins University. Dr. Thekaekara received the Exceptional Performance Award of Goddard Space Flight Center in 1970 and the Space Environment Award of the Institute of Environmental Sciences in 1971. He is the author of two textbooks in physics and of over 50 technical publications.

CONSULTANT: HAROLD SHAPIRO

B. S. Physical Chemistry, graduate work towards the master's degree. Past ten years working with the mass spectrometers and residual gas analyzers in the Test and Evaluation Division. Introduced the quadrupole mass spectrometer into GSFC as a better working instrument than the magnetic deflection types used before. Designed and built a three-dimensional quadrupole spectrometer. Of prime importance in the construction and use of the automatic reduction of mass spectral data by computer.

PROJECT ENGINEER: WILLIAM F. HARDGROVE

Mr. Hardgrove has extensive experience in the measurement and analysis of ultra-high vacuum. He has been responsible for the development of an ultra-high vacuum capability at GSFC utilizing cryosorption as the pumping technique. He has developed several sets of specifications for environmental research facilities. He has served as technical representative and monitored major development contracts. The engineering and management knowledge of this experience will be utilized during the procurement of the mass spectrometer instrumentation, environmental testing, and integration into the spacecraft.

III.

Project Schedule

Mass Spectrometer Monitor

Event		Date	Lapsed Time Months
Project Approval	Assumed	Aug. 71	
Award of MSM Contract		30 July 72	
Engineering Model Delivery		31 May 73	10
Prototype Delivery		1 March 74	9
Flight Model Delivery		1 July 74	4
Launch		July 75	12
Data Confirmation Period		Sept. 75	2
		Total	37

IV. Cost Estimate

Design Engineering & Fab.			
Engineering Model	150		
Prototype	135		
Flight Model	130		
		415	
Purchased Parts	36		
Support Equipment			
Calibration System	10		
GSE { Power Supply Monitor	15		
Environmental Tests	12		
Drawings	40		
Travel	15		
Contingency	55		
		183	
Project Costs (Excluding Spacecraft Integration & T&E Manpower)			
Ground Operating Software	15		
Ground Operation Equip. (Tape)	2		
Ground Operation Contractor Per.	30		
Data Reduction & Analysis			
Fiscal Year 74	30		
75	30		
76	40		
		147	
Total: Mass Spectrometer Instrument			745K

Attachment 2

Mass Spectrometer Monitor
Manpower Estimate
for
Civil Service - Test & Evaluation Division Personnel

Fiscal Year	1972	1973	1974	1975	1976	Total MY
Principal Investigator	.6	.75	.75	1.0	.5	3.6
Consultant	.1	.1				0.2
Project Engineer	.7	.7	.8	.1	0	2.3
Electronic Engineer Mechanical Engineer	.1	.2	.1	0	0	.4
						6.5