NASr-21(09)

MEMORANDUM
RM-4451-NASA
APRIL 1965

INSTRUMENTATION TO MEASURE MARS' ATMOSPHERIC COMPOSITION, USING A SOFT-LANDED PROBE

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PREPARED FOR:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

The RAND Corporation
SANTA MONICA • CALIFORNIA

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PREFACE

This Memorandum surveys a variety of instrumental approaches to the identification and measurement of the constituents of the Martian atmosphere. The survey is intended to assist in selection of appropriate instruments to obtain Martian atmospheric data necessary to design a manned landing vehicle.

This Memorandum is one of two that support a more general study of measurement of the Martian environment, RM-4437-NASA, Mars Environmental Measurements in Support of Future Manned Landing Expeditions, by W. H. Krase, April 1965. The other is RM-4434-NASA, Use of Radiation Gauging Methods To Measure Atmosphere Density During Martian Entry, by J. W. Ranftl, April 1965.

All three Memoranda contribute to the Apollo Contingency Planning Study undertaken by The RAND Corporation for Headquarters, National Aeronautics and Space Administration, under Contract NASr-21(09).

The authors of the present Memorandum are consultants to the System Operations Department of The RAND Corporation.

SUMMARY

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This Memorandum seeks the most suitable method for determining the composition of the Martian atmosphere, using a soft-landed probe. The methods considered include optical spectroscopy, mass spectrometry, gas chromatography, and other means of gas analysis.

Of all the methods investigated, mass spectrometry appears best suited to Martian atmospheric analysis. Not only is the technique intrinsically well suited to the analysis of an unknown mixture of fixed gases, but the output can be telemetered with a minimum of processing.

The construction and power requirements of mass spectrometers are readily compatible with space-borne applications. It is estimated that such an instrument would weigh about 5 to 8 lb and require five to ten watts of power.

We suggest that in addition to its proposed functioning after landing, the instrument be used during the final low speed descent phase. This would supply additional information on the composition of the atmosphere and provide some data even in the event of accident and damage to the equipment during landing.

CONTENTS

I. INTRODUCTION

There are a number of tabulations of the probable composition and surface pressure of the Martian atmosphere. Based on these is a body of literature concerned with designing a vehicle for Mars atmosphere entry. Despite this abundance of literature, there remains much uncertainty as to which gases make up the bulk of the Martian atmosphere.[1,2]

The chief cause of this uncertainty is the interference of the Earth's atmosphere during spectroscopic observations. Except for an occasional small window, Earth's atmosphere is essentially opaque to radiation with a wavelength shorter than 3,000 Angstrom units. Unfortunately, this is the portion of the spectrum in which the gases thought to compose the bulk of the Martian atmosphere have absorption bands. Only carbon dioxide and water vapor, because of their absorption at longer wavelengths, have been positively detected. This is a very limited contribution toward characterization of the Martian atmosphere because, in most atmospheric models, these constituents make up only a fairly small part of the gases present. The balance is thought to be argon and nitrogen, plus various trace gases. This hypothetical composition was developed by eliminating those gases that should be detectable spectroscopically (but were not detected), those too chemically active to remain uncombined, and those whose molecular weight is too low for them to be retained by Mars' gravitational field. The widely published tabulations were compiled by using this purely inductive process, coupled with some assumptions regarding similarity between the Martian and terrestrial atmosphere.

In addition to the uncertainty as to atmospheric composition is the question of Martian surface pressure. Reference 2, published in January 1964, indicates that the surface pressure may be closer to 25 millibars than to the 85-mb figure previously accepted.

A number of attempts have been made to determine the total quantity of gas present in the Martian atmosphere, but with little consistency in results. This follows in part from the high degree of precision required with any technique yet devised, and in part from

the fact that measurements must be made against a high background in the Earth's atmosphere.

Although at present there seems to be enough information to permit the design of a vehicle capable of entering Mars' atmosphere and landing an instrument package, overdesign[*] is required because of the range of estimates of atmospheric parameters. The critical entry vehicle loading and launch vehicle requirements will require much better data before a manned vehicle or an optimized unmanned vehicle can be planned efficiently.

Information regarding the composition of the Martian atmosphere can be gathered from three vantage points--from outside that atmosphere, during entry, or from the Martian surface. This Memorandum specifically considers both instrumental methods suitable for a soft-landed package and selection of the most suitable method for surface measurements. To complete the discussion, mention is also made of the possibility of use of the other modes. For example, the sort of data that might be gathered by a satellite or fly-by vehicle is discussed in Sec. II. Such methods offer the opportunity to refine observations that have long been made from the Earth's surface, but with avoidance of interference from the terrestrial atmosphere. The completeness and accuracy of such analysis will depend, in part at least, on the transmission characteristics of the Martian atmosphere in the ultraviolet range, currently not well known. Furthermore, any such remote measurements give average or total values over the entire path length and do not afford the specific point by point analysis that can be gained by other methods.[**]

In order to avoid the uncertainties involved in a landing, provision might be made to analyze the atmosphere during entry. An ingenious method of doing this (in part) has been suggested in Ref. 3. Such a mode would have the additional advantage of giving information regarding the variation of atmospheric properties with altitude. On the other hand, if data were to be transmitted in real time, or otherwise, before the possibly destructive impact, one would have to maintain communication

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[*] If the surface pressure is extremely low, even landing an instrument package without damage could be difficult.

[**] The data discussed in Ref. 2 typify the difficulties of making spectral analyses with remote instruments.

during entry, a limiting condition.[4] More serious than the communication problem, however, is the likelihood of obtaining spurious readings of the composition of the atmosphere resulting from ablation products and composition changes due to the shock layer. Unless a means can be found that would avoid such problems,[*] composition measurement during early phases of high speed entry presents formidable difficulties. Some measurements of other parameters during entry do seem appropriate, and these are discussed in Ref. 4.

In the present Memorandum, Sec. II discusses possible methods of atmospheric analysis. Section III considers the relative merits of methods applicable to analysis of the Martian atmosphere from a surface landed probe. Section IV examines the advantages of using instrumentation during the final descent phase as well. The final section presents conclusions.

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[*]X-ray spectrometry is suggested as a possibility in Ref. 5.

II. METHODS OF ATMOSPHERIC ANALYSIS

OPTICAL SPECTROSCOPY

To date only optical methods have been available for investigating the Martian atmosphere. The most familiar optical technique is spectrometric analysis of light reflected from the planet's surface in order to detect absorption bands characteristic of individual atmospheric constituents. Other analyses seek to determine the abundance or pressure of the atmosphere by investigating properties such as the polarization of light. The latter technique involves the prediction of the degree of polarization of light reflected from the planet's surface and comparison with observed values. The disparity between them is attributed to an intervening atmosphere.

Unfortunately, efforts to identify chemical elements and compounds in the Martian atmosphere have yielded few positive results because of terrestrial atmospheric interference. For this reason, a process of elimination has been used to limit the field to those constituents that are undetectable spectroscopically and whose presence cannot be ruled out on some other basis. According to arguments presented in Ref. 6, only nitrogen and the rare gases have any likelihood of being present in significant quantities. These gases have not been detected spectroscopically because their absorption bands at normal temperatures are below the cutoff wavelength of the ozone layer[1,7] in the Earth's atmosphere.

In addition to being opaque in certain regions of the spectrum, Earth's atmosphere serves to create a high background in measuring the band structure of the Martian atmosphere. For example, the presence of O_2 in Earth's atmosphere has hindered the detection of the same species in the atmosphere of Mars. While O_2 has not been detected, it has been possible to establish on a signal-to-noise basis a (small) upper limit to the quantity that might be present on Mars.[8]

To separate the effects of absorption in the two atmospheres, Kaplan[2] made use of the doppler shift in the Martian spectrum as occasioned by a high relative velocity between the planets. This work

has indicated the presence of water vapor. An attempt was also made
to measure surface pressure by investigating, for the first time, the
pressure broadening of the CO_2 bands. Unfortunately, all conclusions
were based upon analysis of a single photographic plate,[*] reducing the
the reliability of the results. In addition, an assumption had to
be made regarding the composition of the undetectable remainder
of the atmosphere. The data indicated a surface pressure of 25 mb, $\pm$ 15
mb, in contrast to the 85 mb cited in Ref. 1.

Orbiting astronomical observatories may contribute greatly to
analysis of the Martian atmosphere. Such vehicles, equipped with
ultraviolet spectrometers and operating beyond the interference of the
Earth's atmosphere, presumably could detect gases that cannot be observed
from Earth. This is not certain, however, because the Martian atmosphere
may have absorption bands that overlap to such an extent that the
individual constituents cannot be identified. It is also questionable
whether data of sufficient refinement can be telemetered to permit
measurement of pressure broadening effects. Observation of the plates
reproduced in Refs. 2 and 9 will give some idea of the subtlety required.
Also important is the fact that the spectra of fixed gases are character-
ized by broad bands that are not easily adapted to telemetry.

Absorption spectroscopy can use other light than that reflected
from the surface in order to reduce interference among bands of different
elements or compounds. Even if the Martian atmosphere were to prove
opaque, at certain wavelengths, to light passing radially through its
entire depth, there would exist some altitude above which a ray passing
tangentially would not encounter a sufficient mass of the atmosphere
to be totally absorbed. Such rays may be observed when the planet
occults a star. Unfortunately for the Earth-bound observer, such
occultations visible from Earth and involving stars of sufficient
brightness are very rare.[10] Reference 11 shows, however, that such
events would occur frequently for a spacecraft in the vicinity of the
planet. By observing the time variation in the intensity of light
from a star as it is occulted, information can be gathered about

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[*]Additional observations are being made during the 1965 opposition.

atmospheric density at the same time that spectral data regarding its composition are being recorded. The density computations are dependent upon assumptions regarding the distribution of temperature and composition[11] and hence involve a degree of uncertainty, but results should be of value for preliminary reconnaissance. A variation of the occultation technique, based upon an analysis of the frequency shift in a transmitted signal as a fly-by vehicle disappears behind the planet, is scheduled to be performed during the Mariner C mission.

As a last example of the possibilities of optical spectroscopy, we consider what might be accomplished by soft-landing equipment on the surface. Analyzing sunlight as it reached the surface after being filtered through the atmosphere would give little better results than those obtained by an analysis of reflected sunlight using an orbiter.* Alternatively, one could consider landing an emission spectrometer to analyze the light from a sample of atmosphere excited by an RF source. Reference 6 indicates that, at best, only about a dozen elements and compounds could be detected and the reliability of the data is questionable. Because of limited application and high data transmission requirements, the landing of optical spectroscopic equipment is not attractive.

MASS SPECTROMETRY

Individual types of mass spectrometers are generally similar in operating principle. All have some provision for introducing a specimen of the unknown--in gaseous form--into a vacuum system and ionizing it. The ions are then acted upon by electrical or combined electrical and magnetic fields to separate them according to their respective discrete values of mass over charge (m/e).[12] It is in this mechanism of separation that the types vary. Once separated, the ions are commonly detected by some form of electrometer. The output, being in the form of discrete peaks at different values of m/e, is particularly well suited to data compression and telemetry.

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*An optical spectrometer might be used during the descent phase to give information on composition as a function of altitude, but such application must be considered in perspective with the high data requirements and the amount of analytical information thus obtainable.

In the "drift tube" or "time-of-flight" type of instrument, ions are accelerated along the axis of a linear array of electrodes. By varying the frequency with which the array is excited, ions with specific values of m/e can be selected. The remainder, being out of phase, are scattered. A plot of current versus frequency thus becomes a mass spectrum of the mixture being analyzed. A typical time-of-flight instrument is the Bennett RF mass spectrometer.[13] This instrument was developed for atmospheric analysis, and has been flown in Aerobee and Iris sounding rockets, sweeping the m/e ranges 1 to 5 or 0 to 50 once a second.

Another general type of mass spectrometer is the "quadrupole" or "massenfilter." This is based upon a fairly new concept, having first been described in 1958.[14] The instrument underwent rapid development, and has been flown in Nike-Cajun vehicles. The one described in Reference 15 scanned the m/e range 11 through 44 plus several specific lower values every two seconds. In principle, the massenfilter is similar to the time-of-flight instrument. In construction, the massen-filter has electrodes in the form of four parallel bars arranged at the corners of a square. Ions are admitted near the axis at one end of the array and, under the influence of alternating voltages applied to the electrodes, follow a convoluted path toward the other end. At a given frequency, only particles with a given m/e reach the detector; the remainder are scattered.

The third general type of mass spectrometer utilizes magnetic deflection. In this instrument, the ions are accelerated and shaped into a beam passing through (normal to) a magnetic field. The radius of curvature of the resulting trajectory is proportional to the individual value of m/e for each ion. A heterogeneous beam can thus be spread into a fan shape, where each ion's transverse position depends on its m/e. Several detectors, or a position sensitive detector would serve to register the effect. Alternatively, the entire pattern can be swept across a single detector by varying the magnetic field strength or more commonly, by varying the accelerating potential that drives the beam. Output thus becomes a plot of current against voltage.

A rugged, lightweight mass spectrometer is not difficult to build. A great deal of developmental work has already been done and is discussed in the literature. It is now possible to build such an instrument, suitable for soft landing and analyzing the Martian atmosphere. The instrument could detect all gases present in significant quantity (above 0.1%), and present the data in a form well suited for telemetry. An appropriate magnetic deflection or massenfilter spectrometer would weigh about five to eight lb. The massenfilter would require about eight or nine watts of power, whereas the magnetic deflection type would require four to five.

GAS CHROMATOGRAPHY

Gas chromatography has developed from inception to widespread industrial application in little more than 25 years.[16] In one of its original forms, chromatography involved flowing the liquid to be analyzed through a tube or column that contained a granular substance chosen for its varying affinity for the different chemical constituents composing the mixture. During this process the constituent most readily absorbed by the stationary solid phase would displace all others at the entrance to the column, forming a more or less well-defined band. After some time, the column would be found to contain a number of such bands, each containing a different substance. (If flow were to continue for too long a time, the substance most readily absorbed would displace all others.) Because this technique was originally applied to mixtures of organic dyes, it became known as "chromatography."

A variation on the form of chromatography described above has been found well suited to automatic analysis. Instead of flowing a large volume of unknown through the column in order to build up a band structure, the unknown is introduced in the form of a slug into an inert carrier that is in continuous flow through the column. Separation takes place by the same mechanism already mentioned, but instead of being allowed to reach equilibrium, the unknown is flushed from the column by the continuing flow of carrier. With this technique of "elution analysis" the components of the unknown are separated in the column and appear at the exit

according to affinity for the stationary phase. Thus, time of appearance and not location in the column becomes the indicator of the constituents.

In 1941, the suggestion was made that elution analysis might be applied to gases as well as liquids. This proved to be feasible and many instruments have since been made for such application. The technique has proven particularly valuable for hydrocarbon analysis where constituents often have m/e values so close together that separation by mass spectrometry is difficult. The constituents can be separated easily through use of a judiciously chosen column packing material.[17]

Since in elution chromatography the time at which a component appears at the column exit is an indication of its identity, the instrument must provide for detection of admixtures in the eluent gas. This may be accomplished by sensing variations in any of a number of physical properties.[18] For a completely automatic system, one would prefer a property that is easily sensed electronically. One successful form of detector passes the column exhaust through a cell containing a pair of electrodes and, by continually sweeping the impressed voltage, measures breakdown potential. Output format thus becomes a series of voltage peaks above or below the breakdown voltage of the carrier gas. Such peaks normally resemble skewed error functions. By integrating the area between a curve and the axis, it is possible to compute the abundance of the corresponding constituents. This can be done to within 10 per cent even with fairly crude chromatographic equipment. By refining the technique, it is possible to obtain accuracies within one per cent.[19]

Because of its advantages for hydrocarbon analysis, gas chromatography lends itself particularly well to a search for organic compounds. Reference 20 describes an instrument developed for Jet Propulsion Laboratory (JPL) in 1962 as part of the instrumentation for the Surveyor lunar mission. It comprises an oven to distill samples of the lunar crust and a gas chromatograph to analyze any volatile products. This particular chromatograph is capable of resolving 22

components (mostly organic compounds) with a very low limit of detectability (3×10^{-10} mole).

Work has also been done at JPL on the development of a gas chromatograph for Martian atmospheric analysis. We estimate, on the basis of JPL experience, that an instrument capable of analyzing for A, N_2, and CO_2 would weigh between four and five lb and require three and one-half watts input power. A similar instrument capable of analyzing organic compounds as well would weigh approximately ten lb and require six watts.

OTHER METHODS

In addition to the methods discussed above, which are directly useful for investigation of planetary atmospheres, there does exist a wide range of analytical procedures that have been used for the study of gases. These include simple and fundamental methods of chemical analysis and extend to modern studies of atomic and molecular structure and motion.

Microwave Spectroscopy. This is a relatively new technique that has been considered for atmospheric analysis. However, microwave spectroscopy has an inherent limitation that rules it out as the primary means of analyzing the Martian atmosphere. This is the fact that in order to be detected by microwave techniques, a molecule must have a dipole moment.[21] This rules out H_2, N_2, CO_2, CH_4, and all of the rare gases. Since these include most of the gases we might expect to find in significant quantity in the Martian atmosphere, the microwave techniques would not have direct application. Because the method has been used in other space studies, it is discussed more fully in the Appendix.

Nuclear Magnetic Resonance Spectrometry. This has been reviewed and does not appear suitable for the problem at hand because of the complexity of the equipment and the indirect relation of the information obtained to gas composition. The technique measures spin properties of nuclei under the combined influence of magnetic and RF fields and yields limited information on molecular structure or composition.

Direct Chemical Methods. These are generally not well suited for the remote analysis considered here. Automation of such methods is tedious and in the case of a multicomponent sample, several parallel or serial procedures would be involved.

Indirect Gas Analysis. Many types of instruments have been designed for specialized determinations in control applications. These, however, typically require advance knowledge of the constituents and the composition range. They are very indirect in characterization since analysis depends upon measuring only related effects such as thermal properties or other physical parameters. Such methods are not well suited to analysis of an unknown atmosphere of widely varying possible composition and would not likely be used as primary methods. Some of the simpler methods may be used in backup of other analytical equipment.

Alpha Scattering. This method[22] is one example of auxiliary equipment that might be included to confirm an analysis. In principle, a source of alpha radiation is directed at the atmospheric sample. This causes proton production from nitrogen nuclei and alpha-particle scatter from the gas components. Analysis of particle type and energy is used as a measure of composition. The weight of appropriate equipment is estimated to be about 2.5 lb and power requirements at 0.8 watt. Data requirements would be low, of the order of 3 bits per second for one selected mode of operation. Successful use of the method in the simplified mode described would depend on the Martian atmosphere's actually being the argon-nitrogen-carbon dioxide system for which the equipment was designed.

III. SELECTION OF A METHOD FOR MARTIAN ATMOSPHERIC ANALYSIS

Section II suggested that mass spectrometry and gas chromatography are the two most promising general methods of measuring Martian atmospheric composition from a soft-landed instrumentation package. Next we will compare specific techniques within these methods.

Optical spectrometry is not as attractive as the above two more fully automated methods of gas analysis. It is limited in application and the equipment more likely to be damaged on impact. Further, evaluation of the data would be far from straightforward as it would involve investigating the shape and intensity of a number of diffuse and possibly overlapping bands. The other methods would have lower data rate requirements, being more adaptable to a digital format. Therefore, for a remotely operated, soft-landed package, optical spectroscopy equipment is not likely to be as dependable, as simple in operation, as positive in identification, nor as informative for given data transmission rates as mass spectrometry and gas chromatography.

GAS CHROMATOGRAPHY VERSUS MASS SPECTROMETRY

The choice of the primary method for Martian atmospheric analysis after landing in a soft-landed probe has been narrowed to a selection between gas chromatography and mass spectrometry. Prototype instruments have been constructed for each method of analysis. Instruments for either method could be constructed in a weight range of 5 to 8 lb and with power requirements of not more than 10 watts. Our investigation favors mass spectrometry for the following reasons: (1) The technique is more adaptable to a preliminary investigation since no knowledge of species or abundance is necessary to design the apparatus. All gases within the range of the instrument are detected in the same manner. This is not the case with gas chromatography, where certain combinations of gases must be treated on a special basis if they are to be separated. (2) The output data are particularly adaptable to the digital format required for telemetering. (3) The equipment senses a fundamental physical property of the species, and not a derived characteristic such as its interaction with a chromatograph column.

In interviews with people who are developing mass spectrometers
and gas chromatographs, those most closely involved with gas chromatography
did not indicate that it offers any particular advantage over mass
spectrometry for the Mars atmospheric analysis mission in weight,
reliability, or power consumption. While it would be possible to
build a laboratory gas chromatograph able to resolve all fixed gases
that might be present, the separation difficulties mentioned above
are apt to be present in an instrument practical for flight to Mars.

SELECTION OF A MASS SPECTROMETRIC METHOD

Mass spectrometry therefore appears to be the preferred method
for measuring the composition of the Martian atmosphere from a soft-
landed package. A great deal of developmental work pertinent to the
Mars mission has already been done on the massenfilter and magnetic
deflection types of instrument. Similar instruments have also been
constructed and flown in Earth atmospheric analysis. There is little
question about constructing an effective instrument according to either
principle of mass separation.

Selection of one method over the other can be influenced by
technological developments at a particular time. The selection also
may be mission-related. In any case, a number of tradeoffs will be
involved. For example, a permanent magnet type of mass spectrometer
might recommend itself because, in addition to any conceptual advantages,
a practical advantage might accrue from the ease with which pumping
could be accomplished by integrating an ion pump into the existing
magnet. But on the other hand, additional experiments in the same
vehicle might involve the measurement of magnetic fields, in which
case the presence of a permanent magnet could easily be a serious
liability. We cite this example only to point out the fact that
selection of a specific instrument cannot be accomplished without
regard for the mission as a whole, and must involve factors far
removed from the fundamentals of the experiment.

We suggest the massenfilter type of mass spectrometer as the primary instrument for atmospheric analysis from the Martian surface after soft landing. The following advantages are pertinent: (1) It is possible to construct the instrument without permanent magnets so as to permit certain other types of experiment. (2) Weight requirements are low. (3) Less critical conditions are required for producing the ionized sample source. (4) Data collection is easier because of flatter peak output, which permits the use of stepwise peak reading rather than integration of peaks.

For later flights, when refined analysis is appropriate, a combined preparative chromatographic column to separate the gases and a mass spectrometer (as a detector) could be used effectively. Such an assembly would make possible a more exact analysis of mixtures than either instrument alone. For example, it is difficult to separate A and O_2 or H_2 and Ne chromatographically, and a mass spectrometer of resolution that is high even for laboratory apparatus is required to separate C_2H_4, N_2, and CO. By choosing chromatograph columns that complement the mass spectrometer, it would be possible to avoid the blind spots in either instrument.

DATA REQUIREMENTS

As an estimate of data requirements, we will consider that the instrument is programmed to read H_2O, N_2, O_2, A, and CO_2 peaks. For a range of detectability of 0.1 to 100 per cent it is likely that at least 10 bits of information will be required per peak. Additional readings of background and no-ion current values will require a total of 8 readings or 80 bits. Current techniques indicate that each reading can be made in 1/2 second, or a total of 4 seconds for the determination. However, data transmission rates may dictate that a less frequent sampling rate be used. For example, an 80-second cycle could result in an average bit rate of 1 bit per second.

IV. ANALYSIS DURING THE DESCENT PHASE

Besides analyzing the near-surface atmosphere after landing, the same soft-landed instrument package might possibly be used also during the descent phase. Such an application would have two principal benefits: (1) additional information could be obtained on the composition of the atmosphere at various altitudes; and (2) in the event of an accident during the landing, an otherwise useless experiment might yield useful data from the pre-landing operational phase.

The opportunity for obtaining useful information during the initial high-speed entry phase of descent would be minimal because the shock wave conditions in the immediate vicinity of the vehicle probably would adversely affect the atmospheric composition and state. Further, communication capability probably would be severely hampered or nullified during the high-speed phase of entry.

For a soft-landed package, the vehicle would need means for slowing its descent. At lower altitudes, the shock layer should not materially affect the sampling process, and additional data on atmospheric composition may be gathered.

The type of mass spectrometer suggested would be capable of atmospheric analysis every four seconds or less. However, it is not positive that the communication capacity would be adequate to relay such rapid readings. Storage of data for later transmission would defeat the "insurance" motive of analysis during flight. Consequently, determinations should more likely be initiated every 10 to 15 seconds during the final descent phase.

V. CONCLUSIONS

Of the instruments investigated for a soft-landed device to analyze the Martian atmosphere, mass spectrometers appear to be the most feasible. Of the types of mass spectrometers considered, the massen-filter seems preferable for the task.

The mass spectrometric technique is well suited to the analysis of an unknown mixture of fixed gases. Mass spectrometers have already been used in space and have demonstrated their ruggedness and adaptability to the Martian mission. Further, since the output is in the form of a limited number of peak or line effects, the amount of output information required for an analysis cycle is minimal.

It is estimated that a mass spectrometer for soft landing on the Martian surface could be constructed at an approximate weight of five to eight lb. (This weight would include the basic instrument and its output signal circuits, but not the telemetry equipment.) Power requirements for the basic instrument are in the range of five to ten watts.

The instrument could complete an analysis in four seconds or less, but for increased accuracy and operation within conservative data transmission rates, would more likely take 10 to 15 seconds. The equipment is capable of repeat analysis.

We suggest that the instrument be constructed and utilized for analysis during the descent period as well (subsequent to the initial high-speed entry phase and before landing). This would yield additional data on the upper atmosphere composition and would increase the probability of a successful mission since some data would be available despite a failure during landing.

Appendix

MICROWAVE SPECTROSCOPY

Microwave spectroscopy is an extension of the classic method of optical spectral analysis into the region of wavelengths greater than those of the infrared, i.e., longer than 1 mm. As with spectroscopy at shorter wavelengths, microwave spectroscopy can be performed in either the emission or absorption modes. In the laboratory, implementing the technique commonly involves containing a low pressure sample of the gas within a waveguide, usually at least a meter long, that has a microwave source at one end and a detector at the other. The frequency is varied, and a spectrum of absorption within the gas is plotted as a function of frequency. As indicated in Ref. 12, a number of circuit parameters have to be well stabilized or manually compensated in order to obtain an accurate spectrum.

Microwave emission spectroscopy has been used for space applications other than composition analysis. In the Mariner Venus mission[23,24] microwave receivers tuned to 13.5 and 19.0 mm radiation were used to measure the surface temperature of the planet. This experiment was based upon the atmosphere penetrating properties of radiation at centimeter wavelengths.[25]

Microwave emission spectroscopy could be used only to a limited extent for remote analysis of planetary atmospheres. One would need to develop a space-borne receiver of exceedingly high sensitivity, capable of being tuned across a wide band in the microwave region. This instrument would necessarily be based in a spacecraft because of the interference from Earth's atmosphere in this portion of the spectrum.

The microwave spectrum of a gas exhibits a sharp line structure, rather than the band structure common to gases in the UV and visible portions of the spectrum. Because the lines are sharply defined and overlapping of lines of different species rarely occurs,[21] it is usually possible to identify any one of the currently catalogued gases by detecting a single line. This requires an instrument capable of being calibrated to better than 0.1 mc in

25,000 mc, an accuracy long attainable in the laboratory. However, when one attempts to analyze a mixture of unknown gases rather than simply to establish the presence of some particular one, it becomes necessary to sweep a portion of the spectrum rather than merely to make measurements at a single frequency. Because of the large number of spectral lines that characterize each gas, the bandwidth swept can be fairly narrow (say 20,000 to 30,000 mc), but because of the accuracy and sensitivity required, the sweep must be made rather slowly. Times of the order of an hour are not unusual.[21] It is also possible to make abundance measurements by using microwave spectroscopy, although such measurements require instruments of even greater refinement.[21]

Unfortunately, microwave spectroscopy has an inherent limitation that rules it out as the primary means of analyzing the Martian atmosphere: in order to be detected by microwave techniques, a molecule must have a dipole moment.[26] This rules out H_2, N_2, CO_2, CH_4, and all of the rare gases, which include most of the gases we might expect to find in significant quantities in the Martian atmosphere. Thus microwave spectroscopy could have a very limited use in Martian atmospheric analysis, and would be of no use for a preliminary survey.

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