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FIRST TOPSIDE SOUNDINGS OF THE IONOSPHERE

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SUMMARY

The first radio-pulse soundings of the topside of the ionosphere were obtained during two recent rocket flights at the NASA Wallops Island, Virginia, facility. These tests are part of the NASA topside sounder satellite program, whose primary objective is to investigate the ionosphere above the height of the F2 maximum.

On June 24, 1961, a two-frequency radio-pulse sounder was carried to an altitude of about 1060 km by a four-stage solid-propellant rocket. Reflections from the topside of the ionosphere were obtained on one or both frequencies during 13 of the 15 minutes the payload was above the maximum electron density level in the ionosphere. Unexpected effects were observed as the sounder passed through the levels in the ionosphere where the plasma frequency was equal to the sounding frequency; some evidence of ionization irregularities at altitudes between 700 and 950 km was obtained.

A second rocket-borne sounder was launched during disturbed ionospheric conditions on October 13, 1961, with the same type of vehicle. "Spread F" returns were obtained during the first portion of the flight, in addition to the normal topside echoes. This paper presents the results of the rocket tests and reviews the overall NASA topside sounder satellite program.

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INTRODUCTION

The tenuous gas in interplanetary space and in the vicinity of the planets is substantially ionized under the influence of radiation from the sun. The immediate objectives of the NASA ionosphere study program are concerned with ionization in the vicinity of the earth. NASA is presently supporting six projects designed to investigate the nature, dynamic behavior, and distribution in time and space of charged particles in the ionosphere. Four of the projects will use satellites, the fifth will use space probes, and the sixth will use sounding rockets. Two of the projects are topside ionospheric sounders that will examine the structure of the ionosphere from above, since the region above the F2 maximum (hmaxF2) cannot be explored by conventional ground-based stations.

The most important measurement that can be made above hmaxF2 is that of electron density distribution as a function of altitude; a density profile of this type can provide many clues concerning various ionospheric parameters. For example, the density profile in Figure 1 can be used to determine the temperature of the electron-ion gas and the composition and relative abundance of the ion species 0^+, H^+, and He^+ (Reference 1). Electron density data are also important in the study of the diffusion and recombination process.

Correlation of electron density distributions with data from other disciplines can provide very valuable information. By comparing the temperature of the ionized particles with the neutral gas temperature, the extent of thermal equilibrium in the ionosphere can be determined. By correlating observed ionization with the flux of incoming ionizing radiation, the ionization process itself can be investigated.

*A similar paper, "First Results in NASA Topside Sounder Satellite Program," was presented by the authors at the Eighth Annual National Meeting of the American Astronautical Society, January 16-18, 1962, Washington, D. C.
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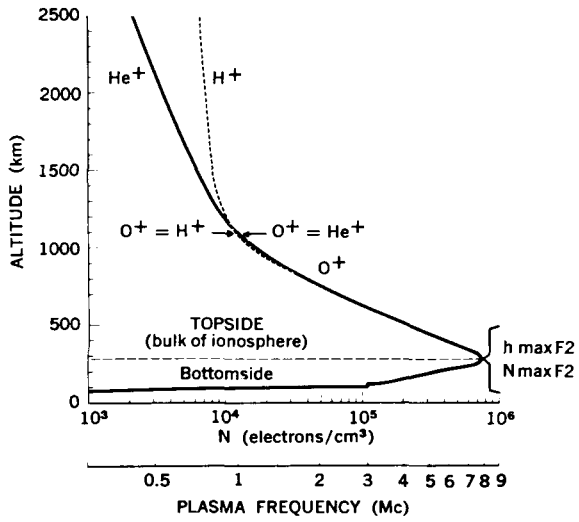

Figure 1—Average daytime electron density distribution in the ionosphere as a function of altitude for a temperature of 1350°K. The dashed curve is included to show the shape which would result if hydrogen were the main constituent above the O^+ region

The topside sounder technique is the only technique known that can provide electron density profiles synoptically above hmaxF2. Topside soundings should permit the investigation of the previously mentioned parameters as functions of time and geographical location. The anticipated data should be particularly valuable since the planned orbital inclination of 80 degrees is expected to provide data on the little-known and very complex polar and auroral zones. The profiles obtained in the equatorial regions will be of interest from another standpoint, since the distribution near the equator should be materially affected by the nearly horizontal direction of the earth's magnetic field.

The increased knowledge of the ionosphere also will be directly applicable to communications, tracking, and guidance. The importance of the ionosphere to terrestrial radio communication is well known. Predictions of ionospheric storms and disturbances are often unsatisfactory, because they are based on inadequate information.

The prediction of maximum usable frequencies for communication purposes is based upon observations from ground-based ionospheric stations. These observations were considered of sufficient importance to justify the establishment of about 150 ground-based ionospheric sounding stations throughout the world; and even that number of stations is not sufficient for accurate world-wide mapping of the bottomside ionosphere. Two of the most important observations obtained by these stations are the height and density of maximum ionization in the ionosphere. In principle, several topside sounders could provide this information synoptically and with better geographical coverage.

The ionosphere and the lower atmosphere both present severe problems in the design of precise tracking systems. Since the disturbing effects of the lower atmosphere (both refraction and absorption) become significant at frequencies below those at which the ionosphere is completely transparent, the problems presented by the ionosphere cannot be bypassed by raising the operating frequencies. High frequencies have other disadvantages, such as the necessity for complex antennas to maintain a large capture area. It is important to note that, in problems associated with the guiding and tracking of space vehicles, the entire ionosphere (both bottomside and topside) must be taken into account. In this respect, the need for an adequate topside observational program is crucial.

NASA TOPSIDE SOUNDER PROGRAM

Consideration of satellite-borne topside sounding experiments was already under way early in 1958. On July 3, 1958, the Space Science Board of the National Academy of Sciences sent out requests

for ideas on satellite experiments; several organizations replied with proposals for topside sounding experiments. Further support was provided by the Space Science Board's Working Group on Satellite Ionosphere Measurements at a meeting in Boulder, Colorado, in September 1958. At a special, independent meeting in October 1958 at Ithaca, New York, held to consider the topside sounder experiment in detail, at least seven groups expressed interest in this type of experiment. In particular, this meeting stimulated a proposal from the Canadian Defence Research Telecommunications Establishment (DRTE), which approached NASA in late 1958. NASA was pleased to accept DRTE's cooperation on the topside sounder program, and it was agreed that this scientific undertaking would be a joint effort of Canada and the United States. This was the first international agreement for cooperative research with a space vehicle; a joint announcement of the arrangement was made by both countries on April 20, 1959.

Concurrently, the NASA had requested that the Central Radio Propagation Laboratory (CRPL) of the National Bureau of Standards examine the topside sounder proposals received by the NASA for scientific merit and engineering feasibility, and recommend immediate and long-range approaches for this area of research. In June 1959 CRPL recommended the fixed-frequency system as a first-generation experiment and suggested that the DRTE of Ottawa, Canada, be encouraged to develop its swept-frequency system as a second-generation experiment. This second recommendation was, in fact, a concurrence by CRPL with the decision already reached between the NASA and DRTE. The topside sounder effort, which began in Canada early in 1959, is known within the NASA as the S-27 project. The NASA and CRPL discussed the development of the simpler first-generation fixed-frequency system as a parallel effort, in view of its complementary features. The NASA received a joint proposal from CRPL and Airborne Instruments Laboratory (AIL) in January 1960. CRPL was to provide scientific supervision of a fixed-frequency experiment and analyze the resulting data; AIL was to design, construct, and test the satellite payload. The CRPL-AIL topside sounder experiment is now known as the S-48 project. Work began at AIL on May 9, 1960.

Since the S-27 and S-48 projects are under the same project manager at Goddard Space Flight Center, and in view of the similarity of objectives and techniques in the two projects, a joint working group was set up early in 1960. The United Kingdom then expressed interest in participating in the topside sounder program. Under the present agreement, the United Kingdom supports the program by operating a telemetry station in the South Atlantic. In return for the use of this station, Canada and the United States will provide topside soundings over the United Kingdom stations at Singapore and Winkfield, England. Data from all three United Kingdom stations will be used in ionospheric research in England. Figure 2 is a chart of the responsibility and data distribution for the program.

Although the S-27 and S-48 projects are similar in objectives and techniques, the emphasis and instrumentation used in the two experiments are quite different. The Canadian experiment is designed primarily to investigate polar, arctic, and auroral effects which produce the very complex ionospheric conditions existing over Canada. For this purpose DRTE has established telemetry stations at Resolute Bay, Northwest Territory, Prince Albert, Saskatchewan, and Ottawa, Ontario. The S-48 project, however, will emphasize the study of meridional cross-sections through the ionosphere using Canadian and United States telemetry stations along the 75°W meridian. Figure 3 shows the S-27 and S-48 telemetry stations. The United States experiment has a low resolution and a fast profile acquisition rate, whereas

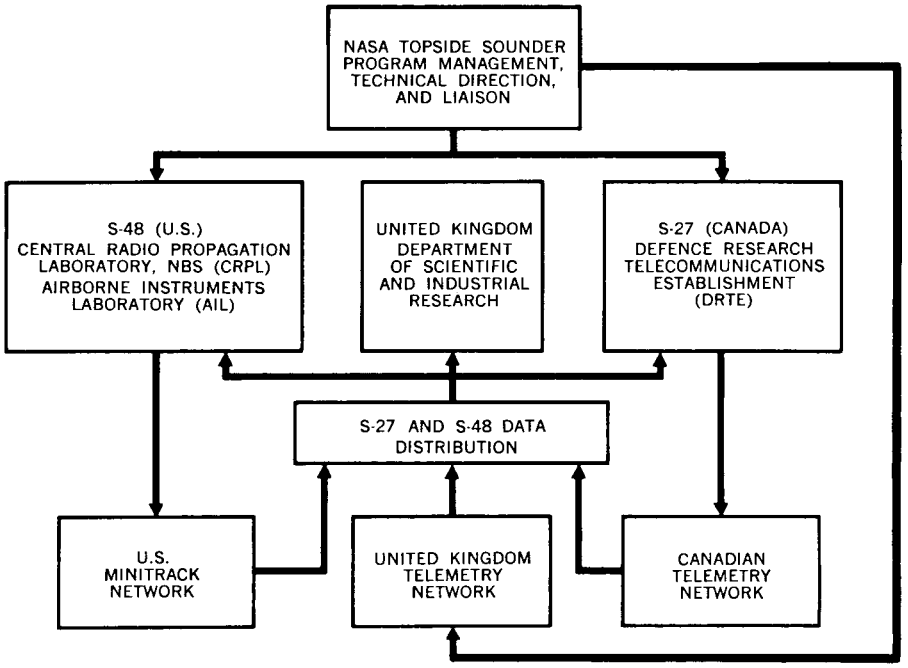

Figure 2—Chart of responsibility and data distribution for ionospheric topside sounding

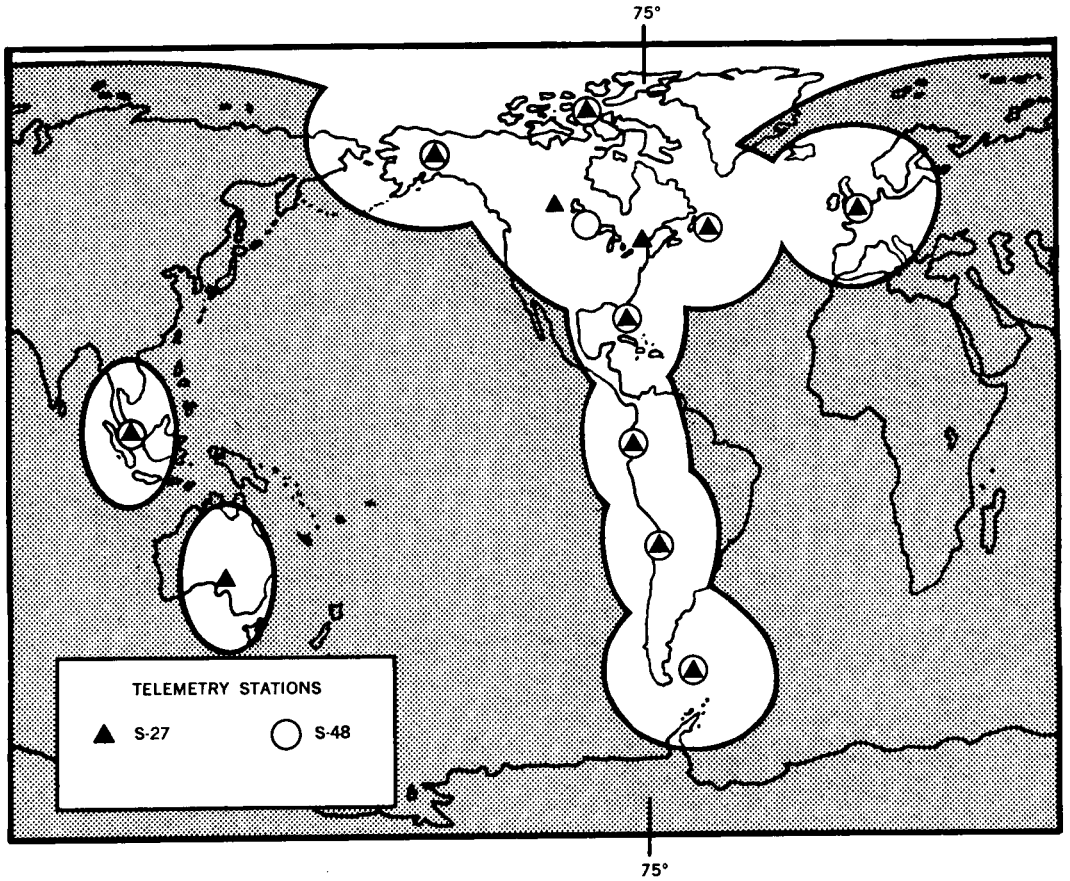

Figure 3—S-27 and S-48 telemetry stations and the areas of coverage

the Canadian experiment has a high resolution and a slow profile acquisition rate. In the S-48 project, six fixed frequencies will provide downward pulse transmissions and echo receptions in the 3 to 9 Mc range. The S-48 payload, weighing about 105 pounds, is scheduled for launch, in 1962, by a Scout vehicle into a nearly circular orbit of 1000 km (620 miles) altitude with an 80 degree inclination.

ROCKET TESTS

Since previous rocket experimentation provides no precedents for the topside sounder program, an important part of the CRPL-AIL effort has been rocket testing of a simplified topside sounder. The original plan, which called for a single daytime firing to a height of about 1000 km during undisturbed ionospheric conditions, had the following principal objectives:

1. To obtain a measure of the effective reflection coefficient of the topside of the F-layer, and to provide an indication of the required transmitter power and the appropriate level of receiver gain necessary to obtain optimum ionospheric echoes with satellite sounders;
2. To determine whether the topside of the F-layer is smooth or rough under quiet daytime conditions. It is important, for instance, to know if the topside is predominantly horizontally stratified, or if irregularities such as blobs of ionization or large-scale ripples are common;
3. To obtain an experimental determination of the separation of the ordinary and extraordinary components of reflected signals under sample experimental conditions;
4. To obtain an indication of the possible importance of the field-ducted echoes, as discussed, for instance, by Gallet and Utlaut (Reference 2). This is crucial in the preparation for the reception of complex and possibly confusing echo returns in the satellite experiment;
5. To obtain information on the type and degree of antenna detuning that will take place;
6. To test the adequacy of the data telemetry link, including provisions for synchronization, bandwidth, etc.;
7. To obtain a qualitative measurement of the level of the cosmic noise background (Reference 3) at two frequencies—a useful repetition of and supplement to the results obtained by the DRTE group at 3.85 Mc in satellite Transit II-A.

In June 1960 it was decided that it would be scientifically inadvisable to adjust the parameters of the satellite topside sounders on the basis of a single "quiet" daytime rocket observation. It was felt that a nighttime firing under disturbed conditions was highly desirable. The final plan, therefore, included a second rocket test to study topside reflection characteristics at a time when spread F echoes indicative of disturbed ionospheric conditions were being observed on bottomside soundings. (Spread F is the name of a phenomenon involving the reflection of radio waves from the F region of the ionosphere. Under certain conditions, for periods lasting from a few minutes to several hours, the radio wave echo ceases to be well-defined over a relatively narrow interval and, instead, a large number of scattered returns at various ranges are observed.) Because of the prevalence of spread F echoes in polar and arctic regions, i.e., in the Canadian ionosphere at high latitudes, a foreknowledge of the degree to which topside echoes will be degraded during this condition is of considerable importance in the planning of the DRTE experiment. Since spread F is regularly

observed in the equatorial region, the results will be very useful in the final planning of the CRPL-AIL satellite experiment.

EXPERIMENT DESIGN CONSIDERATIONS

Selection of Sounding Frequencies

On the basis of predictions of the F2 layer's maximum electron density and the likely shape of the topside profile, sounding frequencies of 4.07 and 5.97 Mc were decided upon for the rocket experiment. The use of frequencies less than about 4 Mc was prevented by limitations on antenna size. The selected frequencies minimized interference from ground broadcast stations. These frequencies and several near them were monitored continuously at the National Bureau of Standards field station at Fort Belvoir, Virginia, for about one month to confirm their suitability.

It was later decided to include only the 4.07 Mc sounding frequency in the second rocket payload. For a nighttime firing during disturbed conditions, it was estimated that there would be less than a 10 percent chance of obtaining echoes at 5.97 Mc. In order to facilitate interpretation of the results and to evaluate the success of the test, it was decided to include an ion trap in the second rocket, in place of the 5.97 Mc transmitter, which would provide a local measurement of ion density during the ascent portion of the rocket trajectory. In a previous flight an ion trap had measured ion densities that were in excellent agreement with electron densities deduced from bottomside ionograms taken at the same time and place (Reference 4).

Power Radiated and Transmission Loss

Consideration of the peak pulse power required for sounding was based on a calculation of the probable transmission loss and on the best available information concerning the cosmic noise level at the two sounding frequencies. Transmission loss is principally caused by path attenuation and by magneto-ionic splitting into the ordinary (o) and extraordinary (x) components. Path attenuation depends on the effective distance to the reflecting layer at which the electron density corresponds to a plasma frequency equal to the radiated frequency.*

The path attenuation is

$$\alpha = 33 + 20 \log f_{Mc} + 20 \log 2d_{km} , \tag{1}$$

where

α = path attenuation in db,
f_{Mc} = frequency radiated in Mc,
d_{km} = apparent distance to the reflecting layer in km.

*The transmitted signals reflect from the ionosphere when they reach an electron density $N = f^2/80.5$, in electrons/cm^3, where f is the transmitted frequency in kc. This frequency is known as the plasma frequency corresponding to the density N.

Note that d_{km} is not the true distance to the layer where reflection takes place because the ionosphere acts as a dielectric, producing a divergence of radiation. This can be considered an additional transmission loss due to an increased distance to a reflecting layer. On the assumption of an altitude of 1000 km for the sounder and a representative topside electron density profile, the values of d_{km} for 4.07 and 5.97 Mc were calculated to be 650 and 750 km, respectively.

Magneto-ionic splitting results in a loss of as much as 6 db: up to 3 db in splitting, and another 3 db because the returned wave is elliptically or circularly polarized, whereas the antenna is linearly polarized. Antenna orientation loss was not considered because a favorable orientation of the sounding antenna with respect to the ionosphere is provided by the spin-stabilized vehicle.

The total losses are listed in Table 1. Cosmic noise was computed from the empirical relation $T_{eff} = 500(100/f)^{2.3}$. Values for a 20-kc RF bandwidth are included in the table. The 20 kc bandwidth was determined on the basis that a range resolution of 5 to 8 km was desirable. The minimum detectable signal was considered to be 10 db above noise. From this the required radiated power was determined. The signal-to-noise ratio and minimum detectable signal do not take into account beneficial integration from film presentation of the data.

Table 1
Power Calculations

Frequency (Mc)	Minimum Total Loss (db)	Cosmic Noise (dbm)	Minimum Detectable Signal (dbm)	Required Radiated Power (watts)
4.07	113.5	-96.6	-86.6	0.49
5.97	118.0	-100.8	-90.8	0.53

ROCKET PAYLOAD

The sounder payload was designed to mate with a four-stage solid-propellant vehicle, Argo D-4 (Javelin). To obtain a trajectory that would exceed an altitude of 1000 km, it was necessary to limit the payload weight to about 50 pounds. The radio sounder consisted primarily of two pulsed transmitters, a single receiver for both frequencies, two 16-foot telescoping antennas, antenna matching networks, and an electronic programmer. Figure 4 is a block diagram of the payload used for the quiet ionosphere test. The transmitted RF pulses have a duration of 100 microseconds and a 15-millisecond repetition period, the longest anticipated delay time for an ionospheric return. The sounder was programmed for a transmit and receive interval first at 4.07 Mc and then at 5.97 Mc, followed by a period for synchronization. This cycle was repetitive at a 22.2/sec rate.

An RF peak pulse power of 40 watts was obtained from the completely transistorized transceiver. Losses in the dual-frequency reactive matching networks operating into a 32 foot dipole antenna reduced the radiated power to between 2 and 3 watts for each frequency. For each frequency the echo

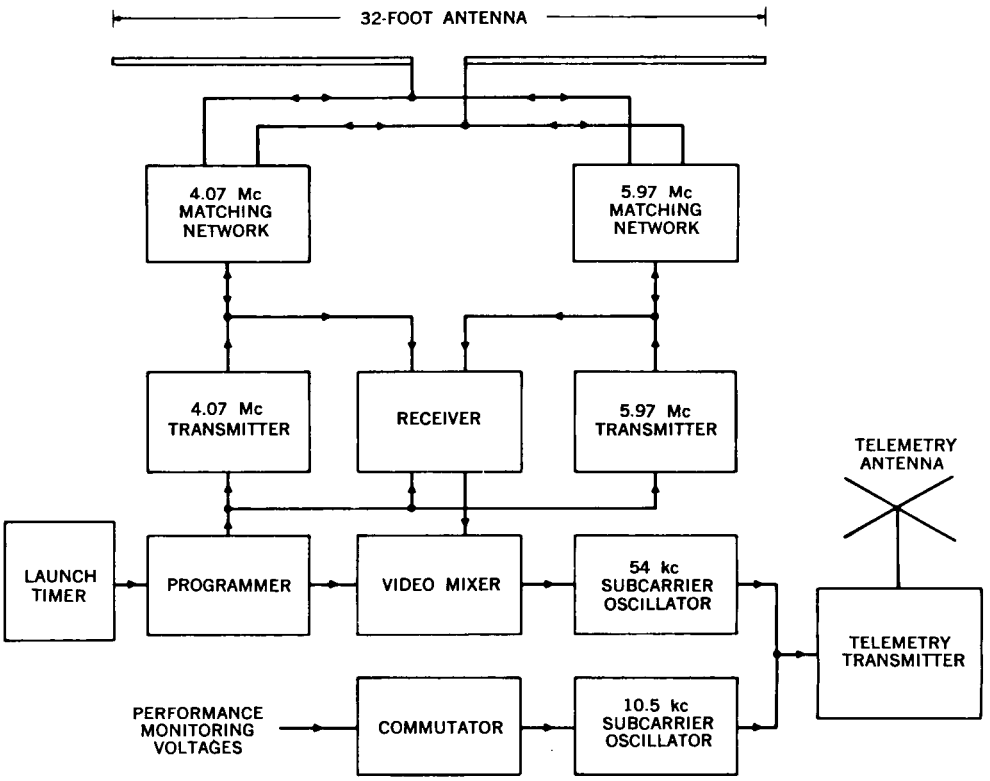

Figure 4—Block diagram of the S-48 rocket payload for the quiet ionosphere test

signals received and the output of the transmitter, combined with suitable synchronization signals, were telemetered via a standard FM/FM VHF radio link to several ground stations.

Figure 5 shows the first flight payload. The telescoping sounder antennas are shown collapsed and folded forward in the position that permits a protective nose cone to surround the payload. Shortly after ejection of the nose cone, the antennas unfold into a plane normal to the vehicle axis. As the antennas approach this position, explosive charges in the base of each antenna pole are fired, extending each antenna to its 16 foot length. When the antennas are unfolded completely and locked into position, power is applied to the ionospheric sounder and the sounding experiment begins.

QUIET IONOSPHERE TEST

The first of the two scheduled firings took place at 1817 EST on June 24, 1961, at Wallops Island, Virginia (Reference 4). Topside echoes on one or both frequencies were received during 13 of the 15 minutes the payload was above the F2 maximum. Except for the fact that the 4.07 Mc echoes were somewhat weaker than expected, the experiment proceeded as planned and was a complete success. The preliminary results were:

1. It was confirmed that a peak radiated power of about 2 to 3 watts is sufficient for topside sounding of the quiet ionosphere from altitudes of about 1000 km;

2. The fixed-frequency sounding system proposed for the S-48 program was shown to operate successfully;
3. Unexpected effects occurred as the sounder left and re-entered the overdense ionosphere;
4. Some evidence was obtained of ionization irregularities in the 700 to 1000 km height range (maximum effect in the 850 to 950 km range).

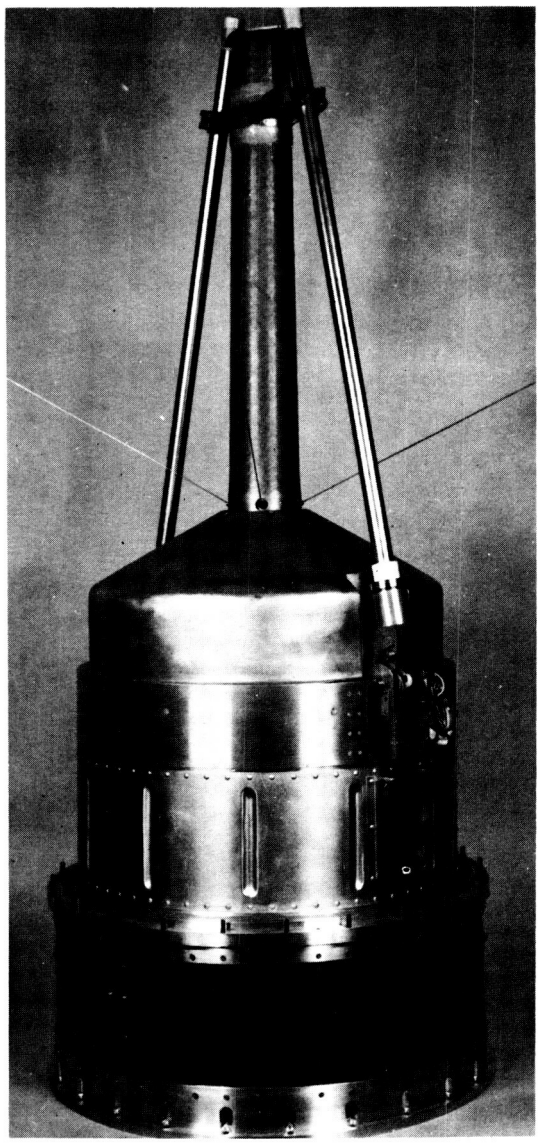

Figure 5—Payload for NASA flight 8.15

The flight was affected somewhat by the vehicle de-spin operation, which reduced the spin rate to less than 6 rpm rather than the desired 60 to 90 rpm. Consequently, the vehicle was no longer spin stabilized and began to tumble, as was indicated by a periodic fading of both the ionospheric echo returns and the telemetry signal.

A possible effect on the experiment—which cannot be verified—might have been caused by failure of the last section of one or both sounder antennas to extend fully, lacking the aid of centrifugal force. This would have caused a slight detuning of the antenna system. The effect is suggested by the noticeably lower echo signal strengths observed at 4.07 Mc as compared with the 5.97 Mc echoes. Since the loaded Q of the antenna system at 4.07 Mc was about three times higher than at 5.97 Mc, any change in antenna pole length would degrade the antenna efficiency much more at 4.07 Mc.

Figure 6 shows film records of data taken at both frequencies. The ordinate on the film records is the "virtual depth" of the reflection level below the rocket sounder; this is obtained by multiplying one-half of the echo delay time by the speed of light in a vacuum. The virtual depth was expected to be zero at the points where the sounder emerged from the reflection levels for a particular frequency and magneto-ionic component, and then increase to a maximum value at the time when the sounder was farthest from the reflection levels—this occurs near the apogee of the trajectory. The virtual depth was expected to be symmetrical on the downward part of the trajectory. On good film records the topside echoes conform rather well to these expected patterns. But on the films reproduced in Figure 6, which have a compressed time scale, the weaker 4.07 Mc trace is only barely discernible. A better presentation is obtained by using an expanded time scale (Figure 7). The double return on the 4.07 Mc record is due to the presence of two magneto-ionic components.

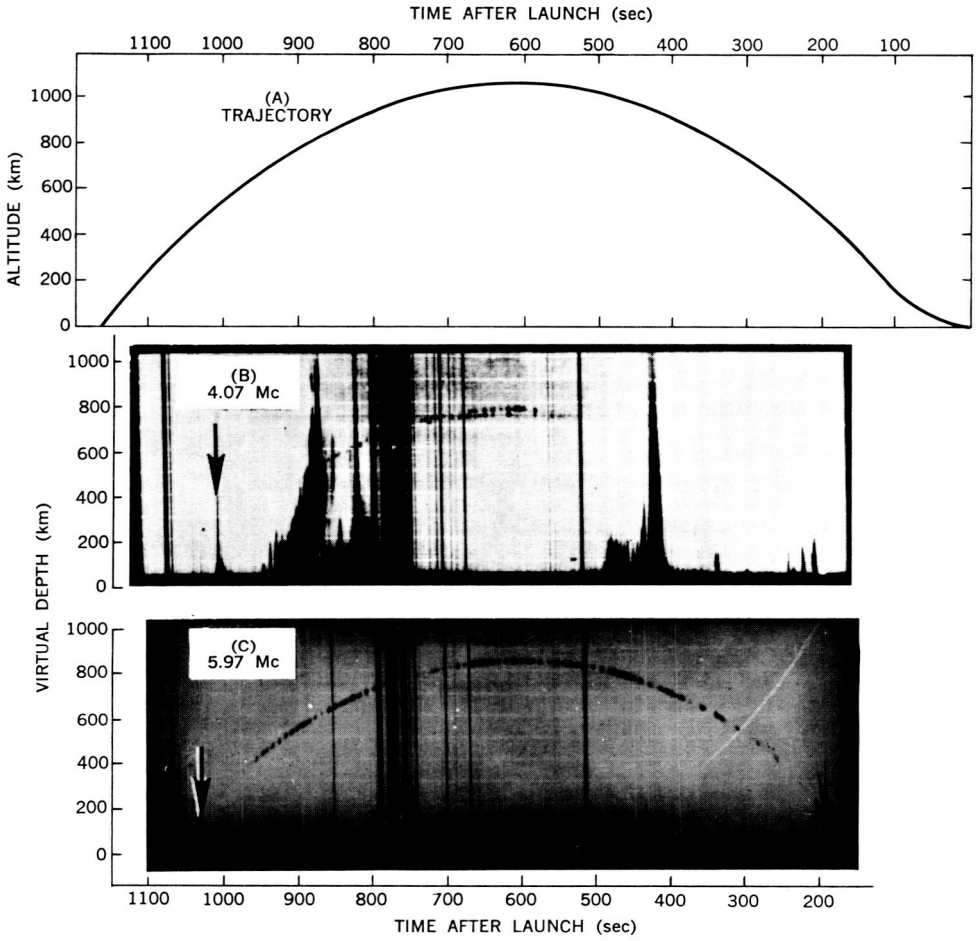

Figure 6—Sounding records of the quiet ionosphere obtained during NASA flight 8.15, Wallops Island, Virginia, June 24, 1961

Unusual effects on both frequencies ("splashes," which may be a kind of plasma resonance effect) occurred as the sounder emerged from the topside of the ionosphere and passed through the three reflection levels–the ordinary level, o($X = 1$), the extraordinary level, x($X = 1 - Y$), and the z level ($X = 1 + Y$)*. Also, on the 5.97-Mc x-component (and to a much lesser extent on the 4.07-Mc z-component), several traces that are almost exactly harmonically related in virtual depth occurred during the first 10 seconds after topside exit. Because of the relatively small radar cross section of the antenna, it is remarkable if these are, in fact, multiple echoes (indicating up to three round trips between the sounder and the ionospheric reflection level). Figure 8 shows enlarged views of these topside "exit" phenomena.

The echoes were weak or missing entirely during the time when the sounder was within 100 to 150 km of the reflection level. This undoubtedly was due to detuning of the system by the relatively high electron density in this region. Prominent effects can be observed on the 4.07 Mc record between

* $X = (f_N/f)^2$ and $Y = f_H/f$, where f_N = plasma frequency, f_H = gyro frequency, f = sampling frequency.

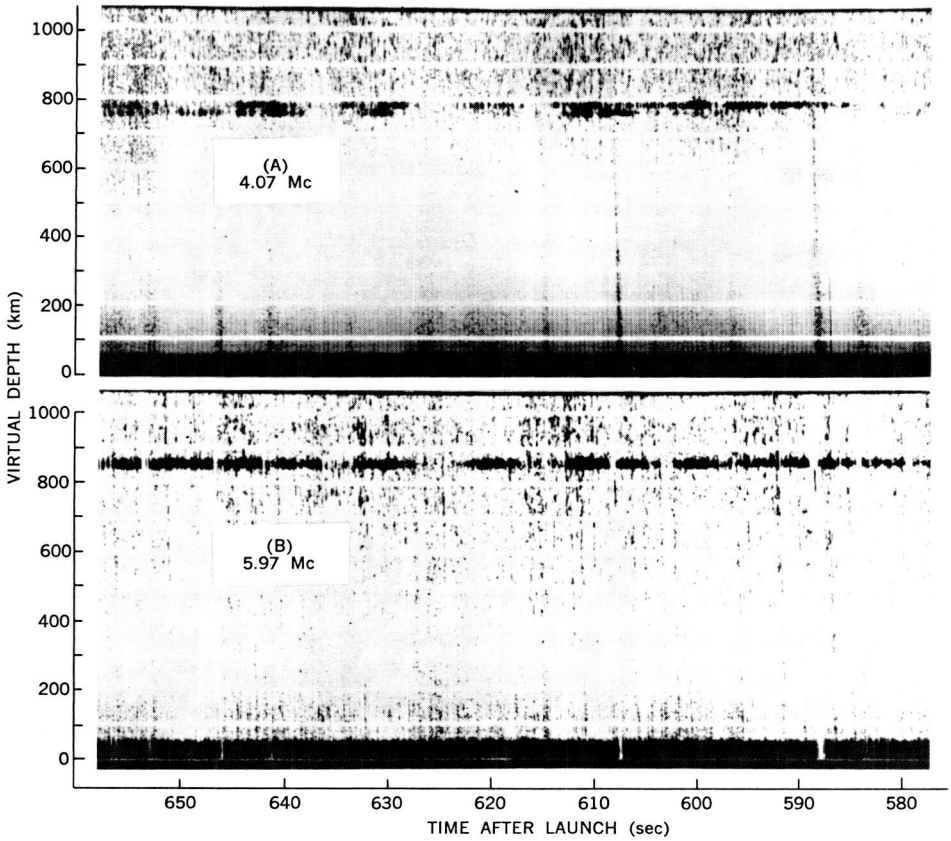

Figure 7—Expanded record of apogee portion of NASA flight 8.15 sounding experiment

about 400 to 480 seconds (910 to 1000 km) and between about 780 and 940 seconds (960 to 700 km). It can be seen that large effects occurred in the 910- and 950-km regions on both upward and downward legs of the trajectory; however, the "disturbance" lasted over a much wider height range on the down portion and a second large effect occurred as the sounder passed through the 840-km level. The causes of these effects are not understood but it seems likely that they indicate the presence of scattering irregularities in the 700 to 1000 km range. The occasional vertical gaps in the records are due to telemetry outages caused by tumbling. An increase in noise background, probably due to cosmic noise, is also evident during the higher parts of the flight.

Shortly after the topside echoes ceased, because of detuning on the downward part of the flight, splashes, which are believed to indicate ionospheric re-entry, occurred on both frequencies (arrows in Figures 6B and 6C). It is not yet clear why the three magneto-ionic components are not observed individually as in the topside exit. After an interval during which the payload was passing through the overdense region, it broke through the bottomside of the F-layer and sharp increases in interference took place almost simultaneously on both frequencies. Prior to bottomside exit, the ionosphere shielded the sounder from interfering terrestrial signals. The relatively large time difference between 4.07 and 5.97 Mc topside re-entry together with the almost simultaneous bottomside exit is a graphic indication of the substantial difference between the topside and bottomside

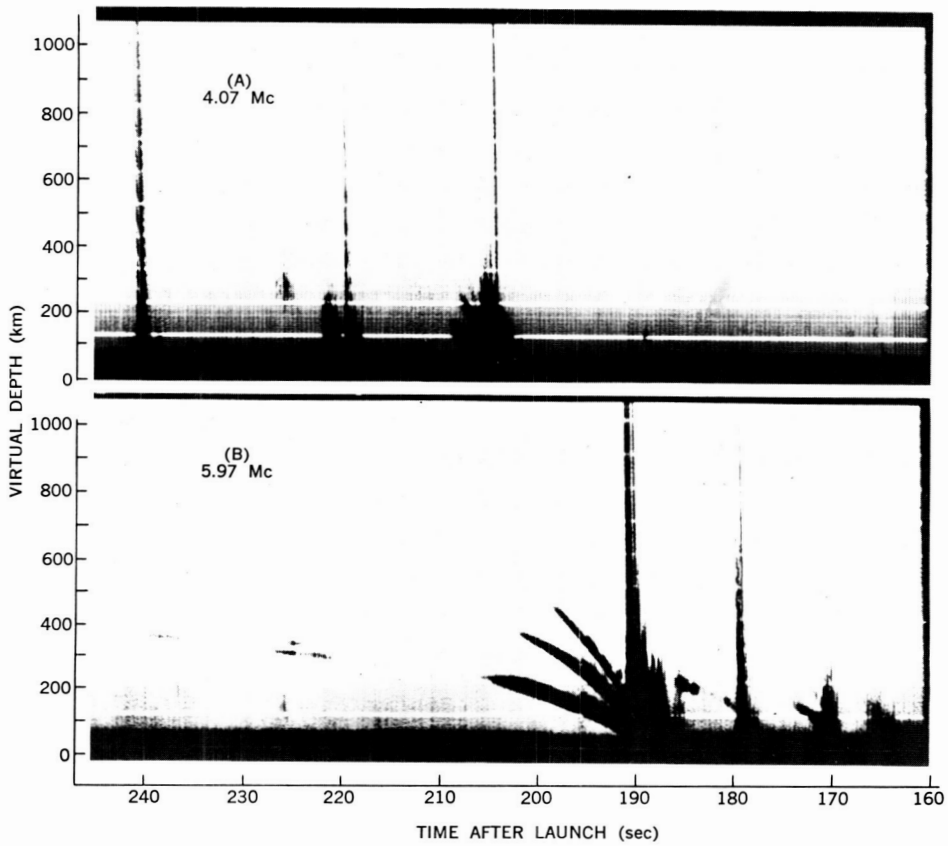

Figure 8—Topside exit effects observed during the NASA 8.15 flight

electron-density gradients. On the basis of the exit heights alone, it can be seen that the topside electron density distribution was nearly exponential and the neutral atmosphere scale height between 400 and 600 km was about 72 km at the time of the experiment (Figure 9). This indicates a temperature of about 1200°K if we assume an atomic oxygen atmosphere. At the time of the firing, the F2 layer maximum penetration frequency was 7.8 Mc, and the height of the F2 peak electron-density level about 305 km, as determined by the Wallops Island bottomside sounder.

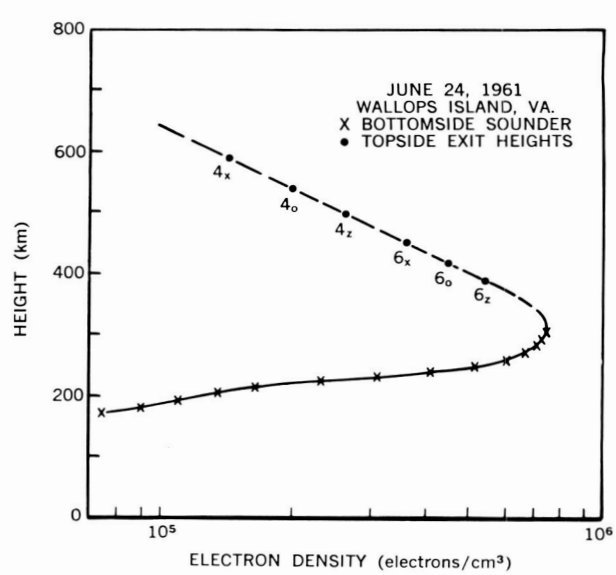

Figure 9—Topside profile obtained from z, ordinary (o), and extraordinary (x) exit points at 4.07 (symbol 4) and 5.97 (symbol 6) Mc together with the profile derived from ground-based soundings

DISTURBED IONOSPHERE TEST

To satisfy the objectives of the experiment, the second firing was delayed until a time when

observations made with the Wallops Island bottomside sounder indicated that suitable spread F was present. In temperate latitudes, spread F tends to be associated with magnetic disturbances. Unfortunately, however, during a magnetic storm, the F2 penetration frequency usually decreases very substantially. Therefore, though a considerable amount of spread F is often present, the maximum electron density in the ionosphere is frequently less than that required for topside reflections on the 4.07 Mc sounding frequency. It was found that either periods following magnetic storms or nights during which moderate magnetic-bay-type disturbances were observed were most likely to meet both of the required conditions – spread F present and a sufficiently high F2 layer penetration frequency. About 4-1/2 weeks of readiness passed before the ionospheric conditions were satisfied and, at the same time, the proper weather conditions and a clear firing range existed. Finally, on the night of October 13, 1961, the conditions were favorable. Mild spread F had begun at about 2240 EST during the occurrence of a small magnetic bay. By 2326 EST the "spreading" was deemed sufficient and the rocket was fired.

The trajectory was very similar to that of the earlier firing. Peak altitude, about 1070 km, was reached in 610 seconds. The 4.07-Mc sounder was automatically turned on 132 seconds after launch, when the payload's altitude was about 270 km. Figure 10 shows the film record of the 4.07 Mc topside sounding data obtained during the flight. The returns are of two types – a clean, relatively well-defined echo observed throughout the flight and, over the first half of the flight, a broader, more diffuse return occurring at a slightly greater range. The well-defined trace is thought to be the "normal" topside reflection composed of overlapping ordinary and extraordinary echoes. Near ionospheric re-entry on the downward part of the flight (beginning at about 1040 seconds on Figure 10) the two magneto-ionic components can be seen to separate. The more diffuse returns are believed to be associated with the ionization irregularities responsible for the bottomside spread F conditions. Calculations suggest that these returns represent signals that are propagated obliquely along magnetic field lines between the sounder and the reflection level. Given a magnetic dip between 68 and 70 degrees and using a simple geometric analysis, we would expect the virtual depth or range of the "field-guided" echoes to be about 6 to 8 percent greater than vertically incident topside echoes. At apogee the observed separation appears to be about 60 km, the range of the diffuse returns being about 7 percent greater than the well-defined trace. Also, at times during the flight the spread echo

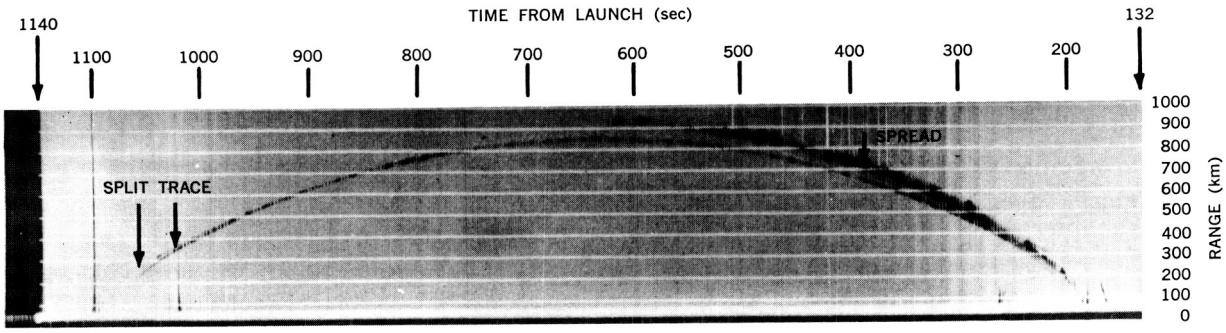

Figure 10—Sounding data from the disturbed ionosphere test, NASA flight 8.17

signal strength was great enough to saturate the receiver (40 to 50 db above cosmic noise). Signal strengths of these magnitudes were as much as 30 db above expected levels (calculated on the basis of isotropic radiation).

These results seem to suggest that field-guided ducting along magnetic-field-aligned irregularities was occurring from the time that the sounder emerged from the topside of the ionosphere until apogee was reached. Beyond apogee only the clean echo trace is observed. One of the possible explanations for the termination of the diffuse returns at the midpoint of the flight involves the azimuth on which the flight took place. The azimuth was about 8 degrees south of east, and the sounder traveled progressively into regions of lower magnetic dip. Consequently, it would be reasonable to assume that the region in which the ionization irregularities existed did not extend beyond the midpoint of the trajectory, since bottomside sounding stations in the Bahamas observed no spread F during the night of the firing.

As in the first flight, plasma-resonance effects appear to be observed as the sounder passes through the levels in the ionosphere corresponding to several reflection conditions. However, in this experiment, only resonances associated with the extraordinary and z levels seem to be observed on topside exit, with the resonance corresponding to passage through the ordinary level very weak or missing. Effects similar to those on the earlier flight also occurred on topside re-entry to and bottomside exit from the ionosphere.

On the basis of the heights of the resonance effects, the topside electron density distribution was determined to be approximately exponential with a neutral atmosphere scale height of about 50 km. Values of virtual depth computed on the basis of a 50-km scale height for both the normal and ducted echoes are in substantial agreement with the observations. If we assume an atomic oxygen atmosphere, this scale height would imply a temperature of about 800°K.

CONCLUSIONS

The successful tests of the topside ionospheric sounders are significant since they demonstrate the feasibility of an important technique for future ionospheric research. At the same time they have provided valuable and, in some cases, unexpected geophysical data.

Specific examples of the influence of the rocket-test results upon the satellite program are:

1. Weak echoes received during the first rocket topside sounding showed that the satellite receiver gain characteristic should be revised to provide a better quality of telemetry data at times when weak ionospheric echoes are being received by the satellite and the received telemetry signal-to-noise ratio is poor.

2. The second rocket topside sounding showed a completely unexpected situation—echoes, possibly field-ducted, were received with signal strengths much greater than expected, and caused saturation and blocking of the receiver. This required further examination of the satellite receiver design to provide protection against a saturating signal.

3. Quite unexpected and not entirely understood phenomena have been observed in both rocket flights, indicating that the data analysis will require a large amount of personal judgment and hand processing prior to automatic machine reduction.

The information gained from the two experiments provides a substantial background for the extensive topside sounding program that will begin in the latter part of 1962 with the launching of the Canadian S-27 and United States S-48 topside sounder satellites.

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