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DEPARTMENT OF ASTRONOMY

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INVESTIGATION OF GALACTIC AND PLANETARY RADIO ASTRONOMY

Status Report
January 1965 thru June 1965
NASA Grant NSG 572

Submitted by Fred T. Haddock
January 1966

The University of Michigan
Radio Astronomy Observatory

Department of Astronomy
Department of Electrical Engineering

STATUS REPORT

NASA GRANT

INTRODUCTION

This is the third semi-annual status report on NSG-572, initiated in October 1963.

NSG-572 is a three year, step-funded grant which continues investigation previously carried on under NASw54 and NSG-181-61.

The organization of the following sections reflect the two tasks of the grant (I) Galactic Radio Astronomy and (II) Planetary Radio Astronomy Investigation.

I. Galactic Radio Astronomy

A. 11.03 Rocket Experiment

1. General

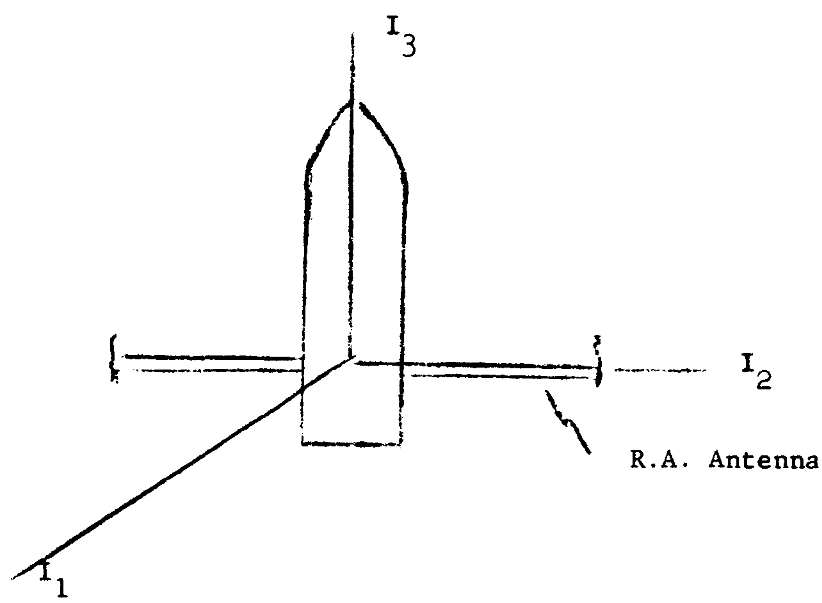
This period was devoted almost entirely to the final phases of the preparation of the 11.03 rocket payload, culminating, appropriately, with its successful launching on the last day of the reported period. Following is a description of the major tasks:

2. Mechanical Problems

a. Dr. J. L. Steinberg (Meudon Observatory) was responsible for a study carried out by Sud Aviation on vibrations and mechanical stresses in De Havilland antennas during the erection process. This indicated vibrations with growing amplitude, and much greater (possibly catastrophic) bending moments than predicted on the rigid-boom approximation. The results of this study were largely numerical results of digital integration of very complex equations derived from a Hamiltonian formulation. These numerical results were not directly applicable to our case, but nonetheless disturbing. J. Greene and D. Walsh studied this problem. Although a conclusive solution could not be obtained, they formed a strong opinion that this was probably not dangerous to our particular experiment. This was partly by examining some of the results of Sud, and partly on the basis of studying simpler but related problems which yielded solutions. A resumé of their results, sent by Steinberg, showed that in their calculations angular momentum was apparently not conserved. This was not a minor effect, accountable for by digital round-off or some such explanation, but an order of magnitude error. Its sense was such to exaggerate greatly the bending moments. There were other criticisms of the Sud approach, but this one, to our mind, rendered their results valueless.

This problem, therefore, did not influence our payload design.

b. A consideration which resulted in our reducing the length of our antennas from the original design figure of 60 feet to 35 feet was that of moments of inertia.



The initial moments of inertia are:

Yaw M. I. (I_1) = Pitch M. I. $(I_2) \simeq 18.10$ slug-ft^2
Roll M.I. (I_3) = 1.47 slug-ft^2 (not final values)

The roll M.I. is initially much smaller than either the yaw or pitch M.I., which are nearly equal. The vehicle will spin stably about the axis of smallest M.I., in the sense that a small perturbation will result in a precessional motion of the roll axis about the invariable direction (i.e. the angular momentum vector). As the antenna extends the pitch M.I., I_2, does not change, but both I_1 and I_3 increase by equal amounts. I_1 will always be the greatest, but eventually I_3 will exceed I_2. This situation is unstable in the sense that the vehicle will not spin about the axis of intermediate M.I.; a perturbation, no matter how small, will cause this axis to precess about one of the others. That is, the roll axis will describe a conical motion about one of the others. That is, the roll axis will describe a conical motion about one of the other two. This "tumbling" motion is very undesirable, and the antenna length was reduced so that I_3 would not exceed I_2 with the antennas fully erected. The fully erected M.I. were:

$$\left.\begin{array}{l} I_1 \simeq 31.0 \text{ slug-ft}^2 \\ I_2 \simeq 18.1 \text{ slug-ft}^2 \end{array}\right\} \quad \text{(not final values)}$$
$$I_3 = 14.33 \text{ slug-ft}^2$$

3. <u>Completion of Payload and Testing</u>

The construction of the payload was completed in this period, and considerable effort spent to ensure that the characteristics of the radiometer system were satisfactory. The shortening of the antenna length put a much greater burden on the preamplifier input characteristics, particularly at 0.75 Mc/s. Redesign of the input transformer was necessary. The problem was to adjust the input impedance and noise parameters so that (i) the effective receiver temperature was low enough for satisfactory sensitivity, and (ii) the variations with antenna impedance of the receiver output due to receiver noise (that is, the effective baseline above which cosmic noise must be measured) were sufficiently small. While the main effort was directed at 0.75 Mc/s, it was necessary to ensure that the performance at 1.225 and 2.0 Mc/s would not be unduly compromised. The solution reached empirically was acceptable but probably far from optimum. If further payloads of this type are constructed, this design could probably be investigated much more thoroughly with profit.

Other modifications required, largely due to the change in antenna length, included adjusting the receiver gains so that with the expected signal levels the outputs would be in satisfactory regions of the dynamic response curve. Similarly the flight noise generator output level required adjusting and tailoring to give satisfactory receiver outputs.

These payload modifications were carried out largely by H. Estry, in close cooperation with D. Walsh.

The payload was delivered to Building No. 7 at Goddard Space Flight Center on 5/17 for the beginning of flight level environmental tests. The payload was weighed, dynamically balanced at 400rpm and the moment of inertia around three axes was measured. The thermal vacuum test was started next. During the first run, power to the payload was inadvertently switched on in a partial vacuum. An arc formed at the receiver turn on Ledex which burned off the wiper contact of the switch. The switch wafers were replaced and the thermal vacuum test was successfully completed.

Various vibration tests of the payload were conducted from 5/26 to 6/3. These tests revealed that the Hoffman Zener diode type 1N1737A employed in several of our voltage regulators were not suitable for flight. They were replaced with acceptable 1N1737A units manufactured by the Dickson Corporation. The vibration tests also caused the filament of the 2nd stage preamp tube (type GE7462) to open. This problem was resolved by changing the mounting configuration of the tube and socket as suggested by a NASA vibration specialist.

The payload was delivered to Wallops Island personnel on 6/15. The post T and E check of the payload calibration was worked in between various spin tests, mating checks and nose cone ejection tests. The count down procedure was revised. Final ground station set up and data recording format was reviewed with NASA Telemetry Station Operators. A final check of all payload systems was performed including a full deployment test of the radio astronomy antenna.

The final 11.03 pre-launch meeting was held in W. Lord's office on 6/17. Representatives from all groups participating in the launch or the recording of data were present.

The 11.03 payload was launched June 30 at 1:33 a.m. Wallops Island time. The flight lasted 25.4 minutes and an altitude of 1,700 km was achieved. Good telemetry records were obtained throughout the flight from ground tracking stations at Wallops Island and Bermuda.

4. Calibration

Considerable effort was devoted to calibration of the radiometers. This was done in two main phases: (1) in the laboratory prior to T and E; (2) at Wallops Island in the two weeks prior to launch. In addition a short check of certain key characteristics was made at GSFC immediately following T and E and prior to departure for Wallops Island.

The laboratory calibration was lengthy and intensive, and investigated the effects of variation of temperature and supply voltages. The Wallops

Island calibration did not include such variations; it was at ambient temperature and with normal supply voltages, and was the final pre-flight calibration and check on changes subsequent to laboratory calibration. Such changes were partly due to T and E and partly due to certain modifications subsequent to laboratory calibration (for example, the second stage tube in the preamplifier was changed during T and E).

Efforts were taken to achieve the highest possible accuracy of measurement; for example, the radiometer output voltage was fed to a voltage-to-frequency converter, the output of which was read from a cycle-counter with 10 sec true integration. During the reduction of the results it was attempted to preserve this accuracy by taking into account many small factors commonly neglected; for example, a change of 3 db was not assumed to be a ratio of 2, but the more accurate value of 1.995.

The calibration had three principal parts:

(1) Determination of preamp input impedance $R_L + jK_L$, at each frequency. This is necessay to correct for changes with antenna impedance in the antenna-preamp signal transfer.

(2) Determination of noise parameters, F_m, R_n, G_o, B_o, at each frequency. This is necessary to correct for changes with antenna impedance in the contribution of receiver noise to the output.

(3) Radiometer input-output characteristics ("dynamic response"). The most important feature here is the dependence of this characteristic on variations in temperature and supply voltages. It appeared that the response curve was not reproducible under apparently identical conditions on different occasions. However, it was found that over a wide range of conditions, the variations could be accounted for by (i) a change ΔG in the pre-detector gain, (ii) a D.C. offset ΔV in the radiometer output. These two parameters can be determined by our two-point ("no-noise" and "noise") flight calibration procedure. Thus reduction of output voltages to input signals requires a single response curve, plus two parameters measured directly in flight. The full range of validity of this method of corrections requires further analysis of calibration data.

The data processing for each radiometer will now be reduced by the use of a single empirical characteristic curve, plus a small number of accurately determined parameters which permit all necessary corrections by means of simple formulae. This is a great improvement on the use of large numbers of empirical curves which require the interpolation of many parameters.

During the analysis of this calibration data, considerable assistance was given by the Applied Analysis Group. Some of the products of this cooperative effort should have wider application to other projects. In particular, programs were developed for determination of input impedance of noise parameters by means of least square methods. This results in a great improvement of accuracy and efficiency of utilization of data compared with hand reduction, which uses relatively crude graphical methods. It is also faster and more economical both in money and man-hours. The programs are arranged to accept data in as "raw" a form as possible with a minimum of hand processing; for example, attenuator readings are entered directly in decibels instead of first converting them to ratios by means of tables. The value of the rapid reduction possible by this means was particularly well-illustrated by experience at Wallops Island. It was feasible to devote time to obtaining as much data as possible rather than spend precious time on reduction. By telephoning the data back to Ann Arbor, the reduced results were available within hours, confirming that the measurements had good internal accuracy and permitting small changes from pre-T and E calibrations to be detected rapidly. This reduction would otherwise not have been available until after launch, and any faults could not have been detected before launch.

As a result of the pains taken, the typical error in antenna-preamp transfer is 0.03 db, and in effective receiver noise temperature 0.05 db. These are the r.m.s. deviations of a single measurement from the least-squares determined curve over a range of antenna impedances which is wide and exceeds that over which we expect to obtain useful astronomical data in flight.

B. Kilometer Wave Orbiting Telescope Studies

Some preliminary work has been done on definition of the problem for the KWOT system. Among the areas considered are the following:

1. The practical problem of making antenna pattern measurements, i.e., the size of the antenna range required, the advantages and disadvantages of developing our own antenna test site, etc.

2. Attempts to determine the effects of current distribution, RF

resistance of the antenna elements, and distortion of the shape on the radiation pattern of the rhombic.

3. Development of computer programs to investigate the effects of current distribution and distortion of shape on the radiation pattern of a rhombic (or long wire).

4. Continuing investigation into the choice of an antenna system, losses in the antenna, environmental effects on the antenna and the possible limitation on the size of space structures for radio astronomy.

5. Consideration of the interrelationship of tasks and time in order to obtain Pert-type program schedules.

C. Papers and Publications

1. A paper "Antenna Impedance in a Plasma: Problems Relevant to Radio Astronomy Measurements from Space Vehicles", co-authored by D. Walsh and F. T. Haddock, was written in this period. It was originally presented in abbreviated form at I. A. U. Symposium No. 23 at Liège in August 1964, and has been published in Annales d'Astrophysique, 28 (3), 605, 1965.

2. Work continued on the draft of a paper dealing with thermal radiation fields and antennas in anisotropic plasmas. This is being written jointly with H. Weil, and his temporary absence in Paris slowed progress considerably.

II. Planetary Radio Astronomy Investigation

A. Photochemical Studies of the C-O Complex

The behaviour of CO_2 under dissociating and ionizing radiation was studied with special reference to two-body processes which will predominate in a tenuous CO_2 atmosphere. The four pertinent equilibrium equations for dissociation and association of CO_2, CO, O_2 and O are readily solved for the equilibrium value of [O] and hence for the other constituents. For an initial isothermal height distribution of [CO_2] there appear maxima for [O] [CO] and [O_2] at about the height where the optical thickness of the initial CO_2 is unity for the dissociating flux. At the higher levels O and CO dominate, in nearly equal numbers.

The photoionization equilibrium equations are more complicated because of a number of possible charge exchange and rearrangement reactions, all of low negative activation energy. These may, however, be solved systematically for the various ion densities.

Using the above formulation for a level where the optical depth for dissociation was about 0.06 and the corresponding optical depth for photoionization was about 0.8 and using reasonable values of the flux densities, O_2^+ turns out to be the predominant ion, and $[CO_2^+]$ is very small -- two orders of magnitude less.

B. Martian Ionospheric Studies

Previous Martian atmosphere models have been based on a mixture of CO_2 with at least as much, and generally much more N_2. As a result of Kaplan, et al (1964), it appeared at least possible that CO_2 might be the dominant, if not the only significant constituent. Consequently studies were initiated to construct a model atmosphere and ionosphere using a surface pressure of only 6 millibars and pure CO_2, with a subsolar atmospheric temperature of 230 deg K near the surface. Summarized results, neglecting any formation of ozone are:

Tropopause at 16 km, temperature 168 deg K.

Vibrational relaxation at 60 km, temperature 151 deg K.

Beginning of dissociation at 75 km, temperature 93 deg K.

Radiation by CO_2 of heat released by dissociation complete below 85 km.

Beginning of diffusive equilibrium for neutral constituents at 100-110 km.

Predominant species at bottom of diffusion region, CO and O (in about equal amounts).

Solution of the dissociation equilibrium equations included shielding by the O_2 present above a given level.

A preliminary study of the photoionization processes resulted in O_2^+ as the dominant ion in the lower ionosphere -- the end product of a number of charge interchange and rearrangement reactions. Consideration of the thermal balance in the photoionization region indicated that a temperature much greater than about 300 deg K in the upper ionosphere was unlikely, and that the peak electron density would be around 10^5 cm^{-3} at 130 km.

The preliminary conclusions of this analysis received some subsequent support in the observations made during the Mariner flyby; the observed scale height of 25 km at a solar zenith angle of 70°, is consistent with the scale height for the C_2^+ ion at a temperature of about 180 deg K, corresponding about 250 deg K in the subsolar region.

C. Topside Electron Density Profiles

Considerable analysis of Alouette topside ionospheric data was done in preparation for the Journeyman probe experiment launched at the end of June, 1965. Arrangements were made for special soundings by both the S-27 and S-48 satellites, and optimum launch windows were calculated for the shot. A visit to DRTE, Ottawa, was planned following the shot for detailed analysis of individual topside soundings pertinent to the location and local time of the shot. Arrangements were also made to obtain topside information rapidly in connection with the expected POGO experiment to be launched in October.

In the general area bounded by 30°N, 40°N, 50°W and 100°W, and for local time between 2100 and 0300 during June and July 1963, the f^xF at the satellite altitude did not significantly depend on longtitude, latitude, magnetic latitude, local time, the K_p magnetic character or the 10 cm solar flux. This does not rule out possible compensating dependences on local time and the day of the month, for example, or local time and latitude of the satellite.

D. Forces on Non Rigid Bodies in Space

The formulation of Roche's limit usually found in the literature is quite erroneous for orbiting bodies since it is based merely on the gravitational gradient and not on the differential acceleration of the components of the body. Using the latter criterion the critical distance becomes 2.29 planetary radii for touching spheres and 1.44 radii for a small particle on the surface of a large sphere, rather than the usually-quoted value of 2.9 radii. The latter would apply to touching spheres which have a density just half that of the planet.