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AN INTEGRATED NASA TRACKING NETWORK FOR APOLLO

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Summary

This is a preliminary report on an integrated network in support of the Apollo mission. It proposes a method for the utilization of existing Jet Propulsion Laboratory and Goddard Space Flight Center large antenna facilities for the support of the Apollo mission from near Earth through the lunar phases and return (see Fig. 1). The use of a single* range and range rate transponder (see Fig. 2a, 2b and references 1, 2, 3 and 4) in the Apollo spacecraft utilizing a common rf-channel will allow the application of approximately ten geographically dispersed large NASA antenna facilities to this mission, with the resulting redundancy to cover emergency situations and to provide scheduling flexibility - an important consideration in view of the long duration of the Apollo mission.

The application of the rf-portions of this transponder to the transmission of the PCM-telemetry-voice-television signals and the reception of PCM-commands is also considered, thus making the proposed system applicable to all of the Apollo tracking and communications requirements.

A complete report on the implementation of an integrated Apollo Tracking Network is in preparation.

*In all references to a single unit, two identical spacecraft units are meant to provide system redundance.

CONTENTS

INTRODUCTION

Tracking of the Apollo spacecraft at lunar distance will require the use of large ground antennas to minimize the spacecraft transmitter power requirements (see Appendix A and reference 5). Both the Jet Propulsion Laboratory and the Goddard Space Flight Center have installed tracking networks utilizing large tracking antennas.

The Jet Propulsion Laboratory Deep Space Instrumentation Facility Network presently has 85 foot antennas at Goldstone, Johannesburg and Woomera, and will be augmented by additional facilities in southern Europe by the time of the Apollo mission.

The Goddard Network will have 85 foot diameter antennas at Rosman, Australia, Alaska, and Canada and 40 foot diameter antennas in South America, South Africa and the United States.

Either of these networks would provide the necessary minimum coverage for the lunar phase of the mission. However, using both networks, the required back-up or redundant coverage is provided to ensure continuous contact with the spacecraft even though one of the ground stations might fail. The redundant coverage is important when considering the long duration of the mission. This would allow any of the stations to be closed down for repair or maintenance or used to support other programs without affecting the coverage for the Apollo mission.

Both the JPL DSIF Network and the Goddard large antenna facilities utilize range and range rate tracking systems. In this system, coherent modulation is transmitted from the ground via a controlled carrier, re-transmitted with strict phase coherence by a transponder in the space-craft, and received back at the ground where both the received carrier and the modulation are compared in phase with the transmitted signals, providing both range and range rate information. Both systems can uitlize a common spacecraft transponder operating on the same rf-channel, (although not simultaneously) so that either system could track the spacecraft independently of the other, with no sacrifice in system performance. Transponder power level requirements are similar for each system, amounting to less than a watt of transmitted power (at lunar distance), using a four foot spacecraft antenna and a 40 to 85 foot ground antenna. An operating frequency in the 2200-2300 Mc band appears most likely, based on transponder and ground antenna considerations.

Present concepts of the Apollo mission require the spacecraft to carry different equipment to support each of the various phases of the mission. It must carry separate tracking beacons for the near earth phase (C-band radar), the lunar phase (R+$\dot{R}$ beacon), the rendezvous and the re-entry phase. In addition separate transmitters, receivers and antenna systems are required to provide for the several rf-links between the spacecraft and the ground.

In this report, it is proposed that:

1. A single range and range rate transponder in the spacecraft should be used to track during the parking orbit, injection lunar transfer, lunar orbit, lunar rendezvous, earth return, re-entry, and land phases. For the parking orbit, re-entry and landing phases, on early Apollo flights, the presently utilized radar tracking systems would be used to qualify the range and range rate system for these phases. In addition, the use of the range and range rate system for rendezvous tracking (spacecraft to spacecraft) would be qualified during these same flights.

2. The combination of the JPL DSIF Network and the Goddard large antenna facilities should be utilized cooperatively for the transfer, lunar and return phases of the mission.

3. Selected existing and augmented stations of the present Mercury and Satellite Instrumentation Networks and tracking ships should be equipped with the necessary range and range rate ground equipment to support the Earth orbital, injection and re-entry phases.

4. Simple range and range rate stations should provide landing data during final re-entry. (See Ref. 5, p 13, Fig. 9 and 10)

5. The spacecraft range and range rate transponder should include provision for the transmission of PCM–telemetry, PCM–voice, PCM–television and for the reception of PCM–commands.

I. The Range and Range Rate System

A. Description

All Range and Range Rate Systems operate on the principle that an electromagnetic wave propagated through space experiences a phase delay proportional to the distance traveled. Therefore, by measuring the phase differences between the transmitted and received signals, it is possible to determine the distance between the ground station and the spacecraft transponder. In the Goddard system, several different ranging frequencies (tones) are used to resolve ambiguities in the range measurement. The range rate of radial velocity of the spacecraft is determined by measuring the Doppler shift of the carrier frequency. This requires that the spacecraft transponder maintain phase coherence between its received and transmitted signals.

The Goddard System is designed to measure range with a resolution of $\approx \pm 15$ meters. It measures range rate with the resolution of $\approx \pm 0.1$ meters/second. This system is described in detail in references 1, 2, 3 and 4.

The system presently operates in the microwave region (1700-2200 Mc) and uses self-tracking ground based antennas. Since these antennas track the spacecraft, azimuth and elevation angle data is obtained form the pedestals. The angle data are expected to be accurate to approximately 2.10^{-3} radians. The angle data are a secondary feature of the system which allows each station to determine the position of the spacecraft. The present system has the unique feature that three stations may operate with the transponder simultaneously if required, as for instance for injection tracking. (See reference 2)

The Range and Range Rate System development was initiated by Goddard to improve the accuracy of the satellite tracking networks. It was designed as a universal tracking system which could be utilized with both the scientific satellites and the manned spacecraft. Particular attention was given to the compatibility with the JPL ranging system in the design of the transponder. The transponders in the Goddard System were designed with a wide band channel especially for passing the JPL pseudo-random noise code signals. No difficulty is anticipated in converting the system to any rf-channel designed for use by JPL or Goddard in support of Apollo.

The narrow bandwidths used in the Goddard System make it simple for other data (television, telemetry and voice) to be combined with the ranging data for transmission to earth. All of these data can be transmitted simultaneously while making ranging measurements.

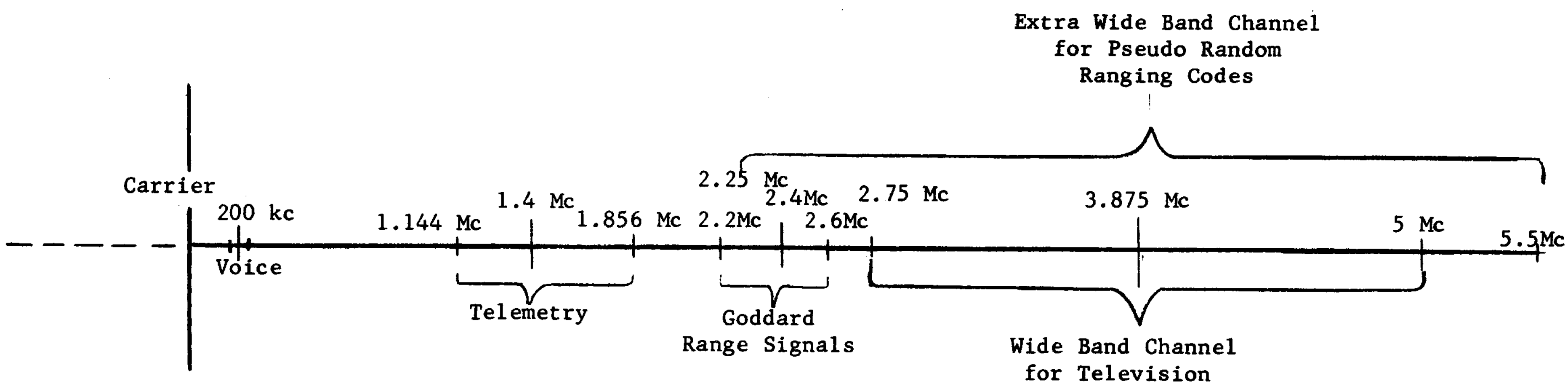
As shown in Appendix A the Goddard Range and Range Rate System can operate at lunar distance with an airborne transmitted power of only 2 watts, utilizing a 4 foot diameter spacecraft antenna and a 14 foot diameter ground antenna.

In keeping with the universal tracking and communication system concept, Appendix A also shows the required transmitter power when the 85 foot diameter antennas are used instead of the 14 foot diameter antennas. This reduces the power for the ranging system to only 0.1 watt. The telemetry, voice and television signals will modulate the same carrier as the ranging data. The voice channel will need approximately 0.7 watt, and the PCM telemetry channel will require approximately 5 watts. It is also shown that transmission of a near-commercial quality television, but using 8 frames per second instead of the normal 30 frames per second, would require a transmitter power of 126 watts. A total transmitter power of approximately 132 watts would therefore be needed. This would reduce to approximately 20 watts if the JPL 210 foot dishes were used for television reception. (See also Table I)

Power Allocation for 20 Watt Transmitter

Carrier	0.1 Watts
Voice	0.7 Watts
Telemetry	5.0 Watts
Goddard Range Signals	0.1 Watts
Television or Pseudo Range Signals	14 Watts

Calculations Based on
4' Spacecraft Antenna
85' Ground Antenna



A METHOD OF TRANSMITTING ALL
SPACECRAFT DATA THROUGH THE
GODDARD RANGE AND RANGE RATE
TRANSPONDER

Table I

Note: Only one sideband shown for simplicity.

B. The Proposed Spacecraft Transponder

The spacecraft transponder is the essential element in the system which will tie the Goddard Space Flight Center and Jet Propulsion Laboratory facilities together. It will have a wide band channel capable of accepting the JPL pseudo-random code ranging signals and a narrow band channel for passing the ranging tones of the Goddard System. It could also contain the necessary modulators to add the voice, telemetry and television signals to the carrier.

The transponder in the spacecraft can be used to make independent range and range rate measurements with the rendezvous vehicle. In this mode of operation the transponder responds only to the rendezvous vehicle independently of the earth tracking network. The necessary range tone generators and phase measuring circuity would have to be added to the spacecraft to allow it to operate in a manner similar to a ground station measuring the range and range-rate to the transponder in the rendezvous vehicle. The angle data (unit position vector from one spacecraft to the other) between the two spacecraft would be determined by an interferometer operating on the transponder carrier frequency. This system is described in detail in reference 6.

A transponder which would operate simultaneously with both systems would be hard to build. However, a transponder to be used alternately by either system sould require only a slight increase in complexity over either unit. Present operational concepts do not require simultaneous operation.

The modifications to both the Goddard and the JPL transponders required to produce a transponder compatible with both systems have been considered.

The Goddard transponder could be made compatible with the JPL transponder (assuming proper frequency changes) by the addition of a phase locked loop to make the transmitted carrier frequency coherent with the received carrier frequency. The required change in multiplication ratio would be resolved during the frequency change. A block diagram of the modification required on the Goddard transponder is given in Fig. 2a.

The JPL transponder could be made compatible with the Goddard system by the addition of the Goddard ranging channels. These channels consist of filters and amplifiers to isolate and process the ranging signals from the individual Goddard stations. The Goddard rf-carrier could be offset slightly ($\approx$1.4 Mc) with respect to the JPL carrier so that the received frequency enters the proper ranging channel. Since the carrier frequency is a multiple of the local oscillation frequency it would be possible for the Goddard system to measure range rate as presently designed. A block diagram of the modified JPL transponder is shown if Fig. 2b.

A factor pertinent to the selection of the form of the spacecraft transponder is the choice of the operating frequencies. Ground antenna considerations also affect this choice. The JPL antenna design philosophy utilizes a feed system at a single operating frequency band, 2200 to 2300 Mc, without provision for rapid feed interchange, whereas the Goddard philosophy has been to provide multiple frequency feeds at both 1700 and 2200-2300 Mc with rapid switchover.

The present trend toward the assignment of an Apollo operational frequency adjacent to the 2200 and 2300 Mc band is therefore supported. This is also desirable since it requires less modification to the basic transponder. A modulation summing unit has to be added in both cases. (See Fig. 2a and 2b)

II. Development of the NASA Integrated Network for Apollo

A. Manned Space Flight Network

The Manned Space Flight Network was installed to support the three orbit Mercury Missions. This net is presently augmented to support the "18 Orbit Mercury Missions" (see Fig. 3a and 3b).

The Gemini spacecraft is more complex than the Mercury spacecraft, requiring larger amounts of data to be transmitted to and from the spacecraft during the mission. This necessitates the original FM/FM telemetry links to be replaced with digital data links. PCM telemetry systems are being procured for the sites indicated in Fig. 3c for installation by late CY 1963. Since the Gemini spacecraft has a digital computer; the present analogue command links are being replaced with digital command links to allow direct entry of the commands and data into the spacecraft computer. Present indications are that these stations will also require a ground computer because of the complexity and amount of the data transmitted. The manned spacecraft network presently utilizes radar tracking at C and S-band. Gemini is being instrumented only for radar tracking, although it is felt that the inclusion of the range and range rate system would be desirable for pre-Apollo qualification testing.

B. Goddard Large Antenna Facilities

The following Goddard 40 to 85 foot antenna facilities are expected to be in operation, equipped with range and range rate systems in time to support the Apollo Mission.

Site	Facility
Fairbanks, Alaska*	85 foot (one)
Rosman, North Carolina**	85 foot (two)
Australia (East Coast)	85 foot (one)
Mojave (Goldstone), California**	40 foot (one)
Quito, Ecuador**	40 foot (one)
Santiago or Antofagasta, Chile**	40 foot (one)
Johannesburg, South Africa**	40 foot (one)

In addition to the above facilities, Goddard will have three mobile range and range rate ground equipments, utilizing fourteen foot antennas, suitable for tracking to lunar distances with a 2 watt transmitter (Appendix A). They will be available for disposition as selected sites for tracking and parking orbit and lunar phases of the Apollo mission, as for instance United States, Africa and Australia (Fig. 5a thru 5d and Fig. 6). These locations make possible the tracking of the parking orbit (Fig. 5a thru 5d) as well as the entire lunar phase (Fig. 6 and 7).

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* Now operational.
** To be operational by third quarter CY 1963.

All of the facilities mentioned previously are provided for general satellite tracking and data acquisition support. Their application, on a scheduled basis, in support of the Apollo Mission is being planned. In addition to these facilities, the following Goddard Stations are to be established in support of specific application satellite programs.

Site	Program	Facility
Fairbanks, Alaska	NOS	85 foot (one)
Nova Scotia, Canada	NOS	85 foot (one)
Northern Europe (Probable)	NOS	85 foot (one)
Eastern U. S. (California)	Communications	85 foot (one)
Hawaii (Probable)	Communications	85 foot (one)

Additional tracking coverage will be available from the Goddard tracking ships, three of which are assumed to be available in time for Project Apollo as follows:

Atlantic Ocean . . . . 58°W, 27°N
(Mandatory, see Fig. 4)
Indian Ocean . . . . 65°E, 25°S

Pacific Ocean. . . . . .135°W, 25°N

These ship locations cover parking orbits 1, 2, 3 and 4 for launch azimuths from 80° to 110° (see Fig. 5d, shaded areas).

C. Jet Propulsion Laboratory DSIF

It is understood that JPL will have the following large antenna facilities in operation and available on a schedulable basis for support of the Apollo Mission.

Site	Facility
Goldstone, California	85 foot (two)
	210 foot (one)
Woomera, Australia	85 foot (one)
Eastern Australia	85 foot (one)
	110 foot (one)
Johannesburg, South Africa	85 foot (one)
Southern Europe (probable)	85 foot (one)
	210 foot (one)
Japan (possible)	? (one)

In addition to these permanent facilities, JPL may also have one or more mobile facilities suitable for ranging to lunar distances.

It is understood that each of the above facilities will be equipped with the JPL Range and Range Rate System.

D. The Proposed Apollo Network

The Apollo Network will be developed from the existing and planned JPL and Goddard Facilities just mentioned. Elements from the Goddard Manned Space Flight and Satellite Instrumentation Networks will be used to cover the parking orbit, injection, Earth approach and re-entry phases. These elements will include both land and ship stations, probable as follows:

Site	Tracking System
Bermuda	Radar (early missions)
	R and $\dot{R}$ (final missions)
Johannesburg, South Africa	R and $\dot{R}$ (early missions)
Carnarvon, Australia	Radar (early missions)
	R and $\dot{R}$ (early missions)
Kauai, Hawaii	Radar (early missions)
	R and $\dot{R}$ (final missions)
Guaymas, Mexico	Radar (early missions)
	R and $\dot{R}$ (final missions)
Cape Canaveral	Radar (early missions)
	R and $\dot{R}$ (final missions)
Atlantic Ocean Ship	Radar (early missions)
(58° W, 27° N)	R and $\dot{R}$ (final missions)
Indian Ocean Ship	Radar (early missions)
(65° E, 25° S)	R and $\dot{R}$ (final missions)
Pacific Ocean Ship	Radar (early missions)
(135°W, 25° N)	R and $\dot{R}$ (final missions)

The following JPL and Goddard facilities will be available on a schedulable basis to cover the lunar transfer, lunar orbital and Earth return phases of the Apollo mission:

Site	Antenna
Goldstone, California	JPL 85 and 210 foot
Johannesburg, South Africa	JPL 85 foot
Southern Europe	JPL 85 and 210 foot
Eastern Australia	JPL 85 and 210 foot
Rosman, North Carolina	GSFC 85 foot
Johannesburg, South Africa	GSFC 40 foot
Eastern Australia	GSFC 85 foot
Fairbanks, Alaska	GSFC 85 foot
Quito, Ecuador	GSFC 40 foot
Antofagasta or Santiago, Chile	GSFC 40 foot

The range and range rate stations at Johannesburg, Carnarvon and Hawaii, listed on page 14, in support of the parking orbit, injection, near Earth, and re-entry phases utilizing 14 foot antennas, will also provide a tracking-only capability out to lunar distances. It is assumed that the mobile JPL stations will also have this capability.

The suggested layout of stations will provide ten large antenna facilities, all of which should have range and range rate capability at the Apollo frequencies, and all of which would be capable of full tracking and communications coverage for Apollo to lunar distances including lunar orbits. (See reference 5, p A1)

The addition of the three mobil 14 foot antenna range and range rate stations provide a total of thirteen stations for tracking. It is considered that from this number and dispersion of stations, any conditions of program scheduling and operational emergency would still provide complete tracking and communications coverage during the entire Apollo mission.

At the time of the Apollo mission, many of the Goddard stations selected for the integrated network will have been equipped with range and range rate systems in support of the basic scientific and application satellite programs. These stations will require augmentation to permit their use at the Apollo frequencies*. (No programs other than

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*The communications bandwidth being considered for the final Apollo mission is 1.34 Mc for the television PCM and 150 kc for telemetry PCM (see Appendix A).

Apollo will utilize these frequencies.) The Rosman, Fairbanks, Eastern Australia, Carnarvon, Johannesburg, Quito, Chile, Mojave stations and the three ships will be so augmented.

Several stations will be equipped with Range and Range Rate Systems solely for Apollo: Bermuda, Hawaii, Guaymas and Cape Canaveral.

The JPL stations presumably will also require augmentation to operate at the Apollo frequencies.

E. Proposed Network Operation

Launch phase tracking will be accomplished using radar beacons on the booster rocket with normal tracking procedures. Contributing stations for this phase are shown on Fig. 4.

Parking orbit tracking will utilize the stations listed on page 14 and shown on Fig. 5a thru 5d. These stations will utilize radar tracking during the early Apollo mission flights, shifting over to range and range rate tracking for the final Apollo mission. These stations will also be used to cover the injection phase into the transfer orbit, depending on their location. As discussed in reference 5, page 8, this disposition of stations provides from 20 to 30% probability of coverage for this maneuver.

Transfer orbit tracking will initially be accomplished by the same stations used to cover the parking orbit. At approximately 12 minutes after the start of injection these stations provide 80%

probability of coverage as shown on Fig. 5d (large circles) 6, and 7. After the spacecraft reaches an altitude of 10,000 km (approximately 45 minutes after injection) primary reliance will be put on the large antenna stations of JPL and Goddard as listed on page 14. The coverage for these stations is shown on Fig. 6*. These stations will also be used to track the lunar orbiting and Earth return phases. They will be applied on a scheduled basis depending on their operational readiness, other program requirements and geographic location. Either JPL or Goddard stations will be scheduled interchangeably.

Re-entry tracking will utilize those stations of the group used to track the parking orbit situated along the approach path. For a landing in the United States, these stations would include Australia, Hawaii, Pacific Ocean Ship and Guaymas, assuming approximately 32^{o} approach plane inclination.

Final re-entry landing phase tracking will utilize simple mobile range and range rate/interferometer stations utilizing the onboard transponder as shown in reference 5, Fig. 9 and 10. Studies on the blackout problem and the prevention are underway. (See reference 7 and 8)

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*Please note that the visibility for the DSIF station within the "lunar band" indicated is roughly the same as shown in this figure. The curves of Rosman have to be shifted eastward to Goldstone, the curves of Carnarvon have to be shifted to Woomera.

This network will provide the Manned Spacecraft Center with all tracking telemetry and communications necessary to fully support the Apollo mission. Spacecraft position and velocity will be provided continuously from the onboard guidance system (via the PCM telemetry) and from both the JPL computed trajectory and the Goddard computed trajectory. Telemetry and voice communications will be provided directly to Manned Spacecraft Center via the network communications system.

CONCLUSION

As shown in this rather short report, the "Integrated NASA Apollo Comminications and Tracking Network" will utilize a combination of all applicable NASA facilities to support the complete Apollo Lunar Mission, including rendezvous. Existing or planned facilities are used whenever possible to provide a network which will fulfill all of the Apollo requirements with a maximum use of NASA resources and a minimum investment in new equipments and facilities.

Full operational capability of the major elements of the proposed network will be able to be tested utilizing presently scheduled flight programs. For example, all elements of the Manned Space Flight Support Network will be checked and evaluated by the late Mercury and Gemini programs. The JPL elements will be evaluated using presently scheduled lunar and planetary probes. The Goddard facilities will be particularly subject to detailed testing, evaluation and modification if indicated by means of the several highly eccentric satellite programs now scheduled which will utilize the Range and Range Rate System and the large antenna facilities for instance, the Interplanetary Monitoring Probe, (S-74 IMP), and the Eccentric Orbiting Geophysical Observatory (S-49 EOGO). The repetitive nature of these eccentric satellites will be particularly valuable to check actual systems performance and orbital computation programs on an orbit to orbit basis.

It is considered that the proposed cooperative operation using both JPL and Goddard facilities is a mandatory requirement for adequate coverage of the Apollo mission.

REFERENCES

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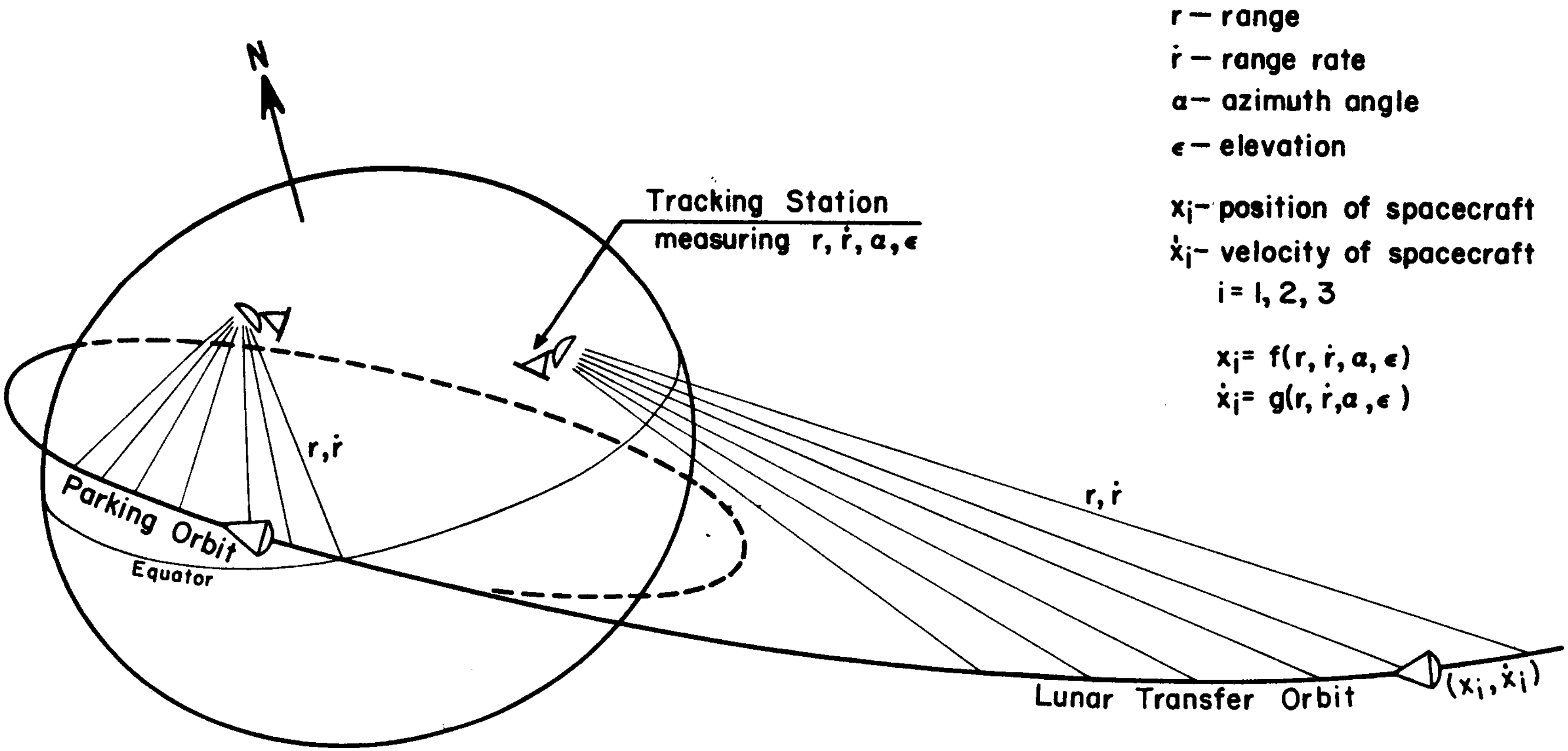
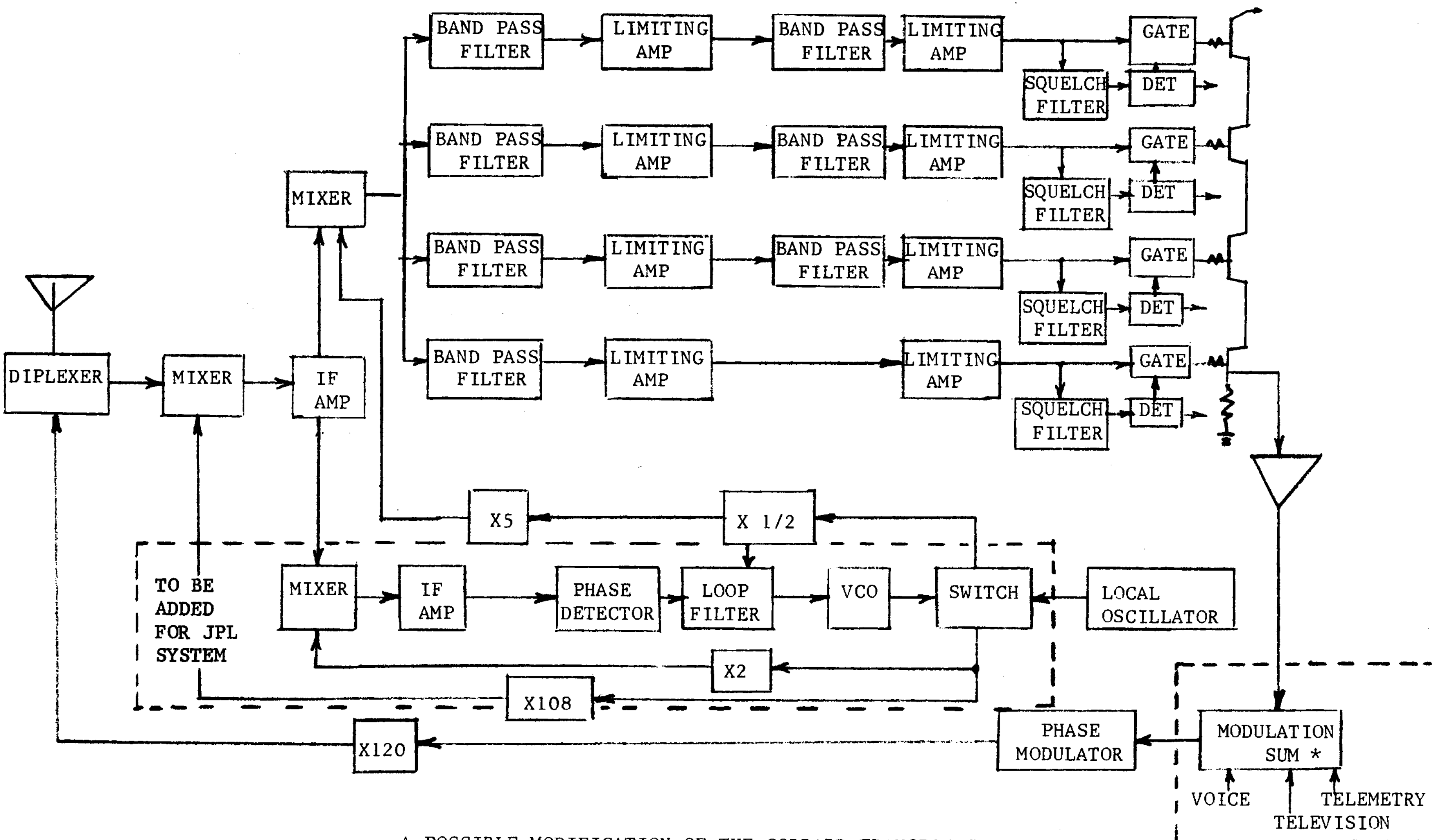


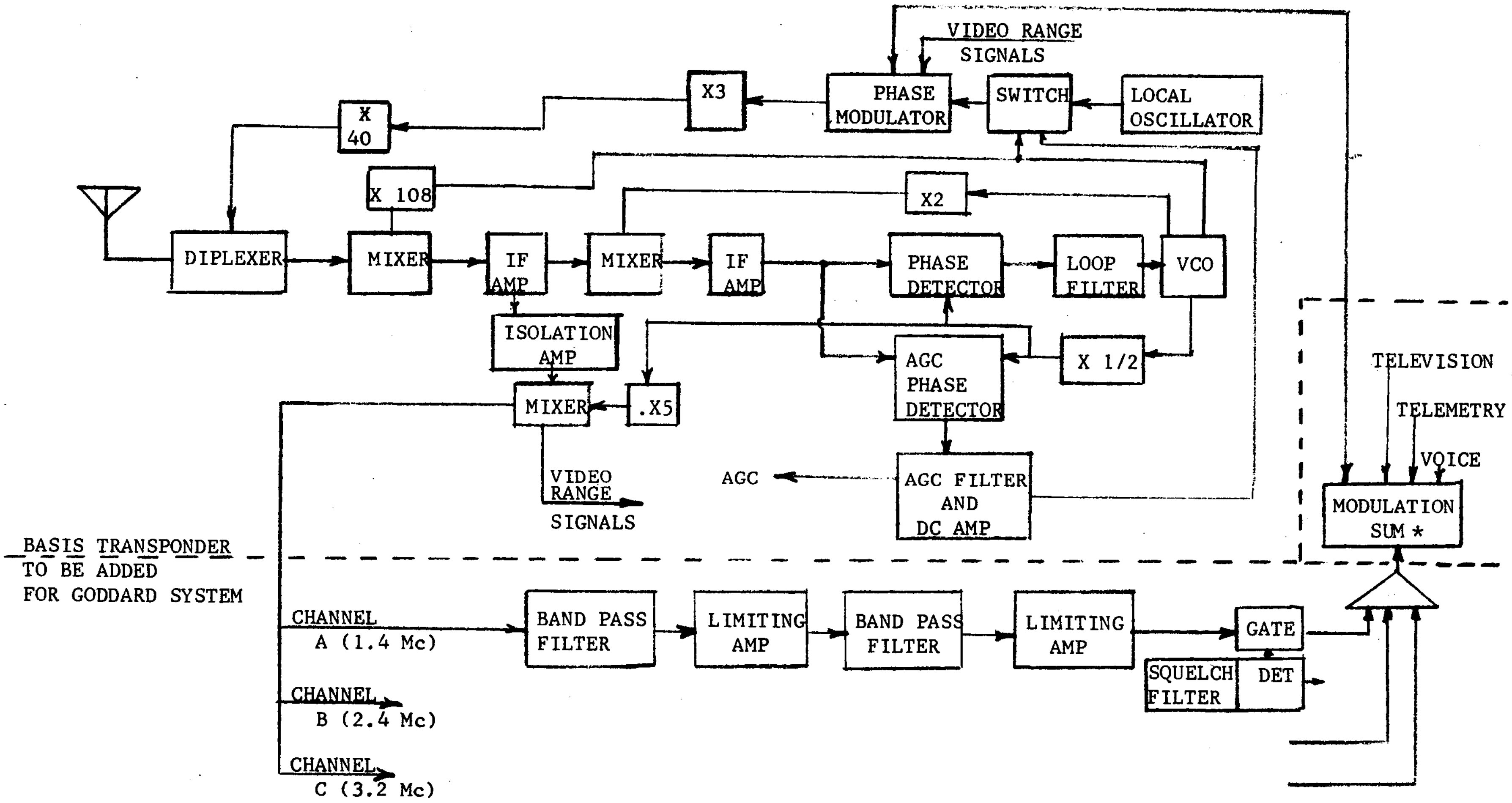
Figure 1 (R&$\dot{R}$) - Tracking of Parking and Lunar Transfer Orbits



A POSSIBLE MODIFICATION OF THE GODDARD TRANSPONDER

FIGURE 2A

* MUST BE ADDED TO
EITHER TRANSPONDER



A POSSIBLE MODIFICATION OF THE JPL TRANSPONDER

FIGURE 2B

* MUST BE ADDED TO EITHER TRANSPONDER

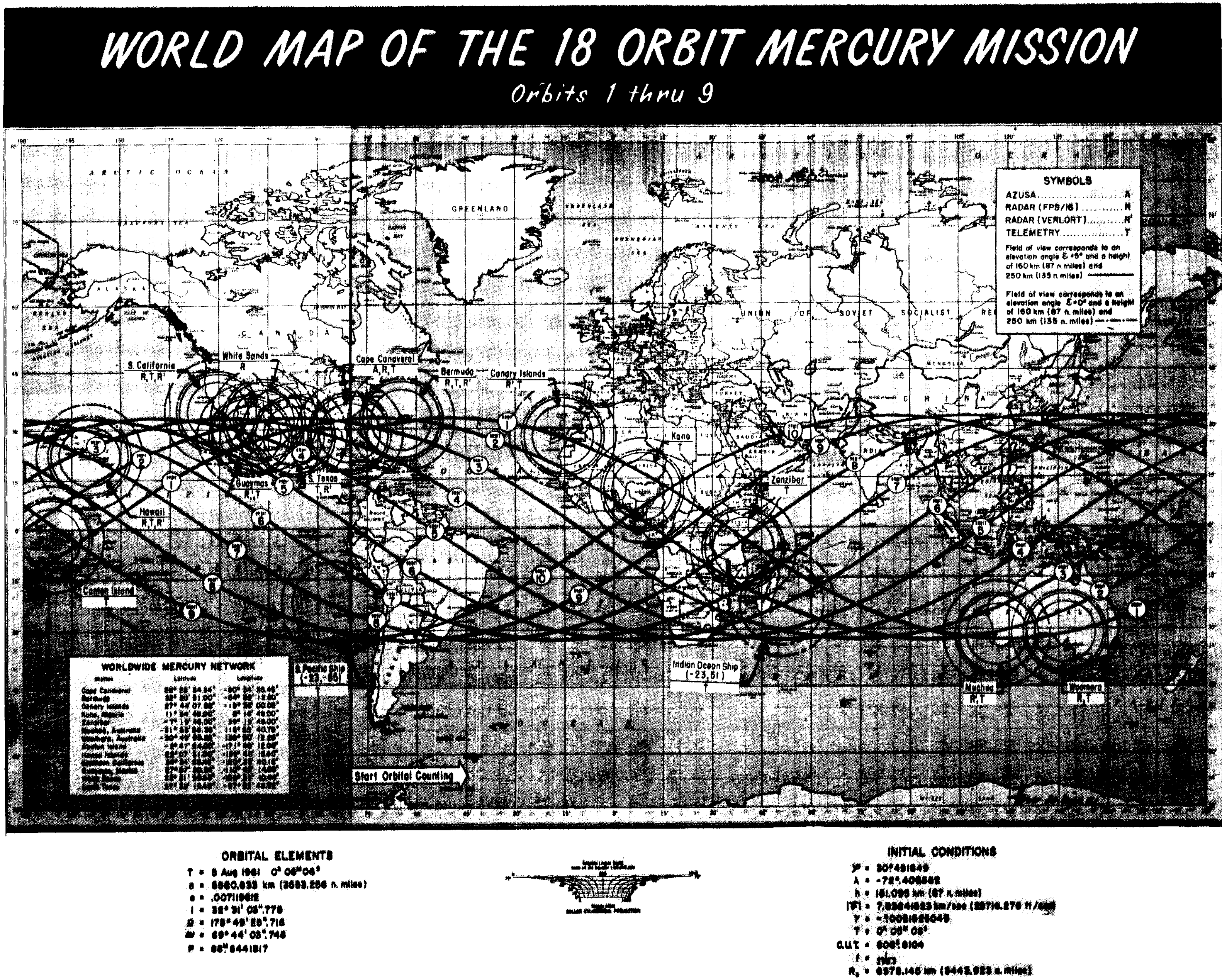
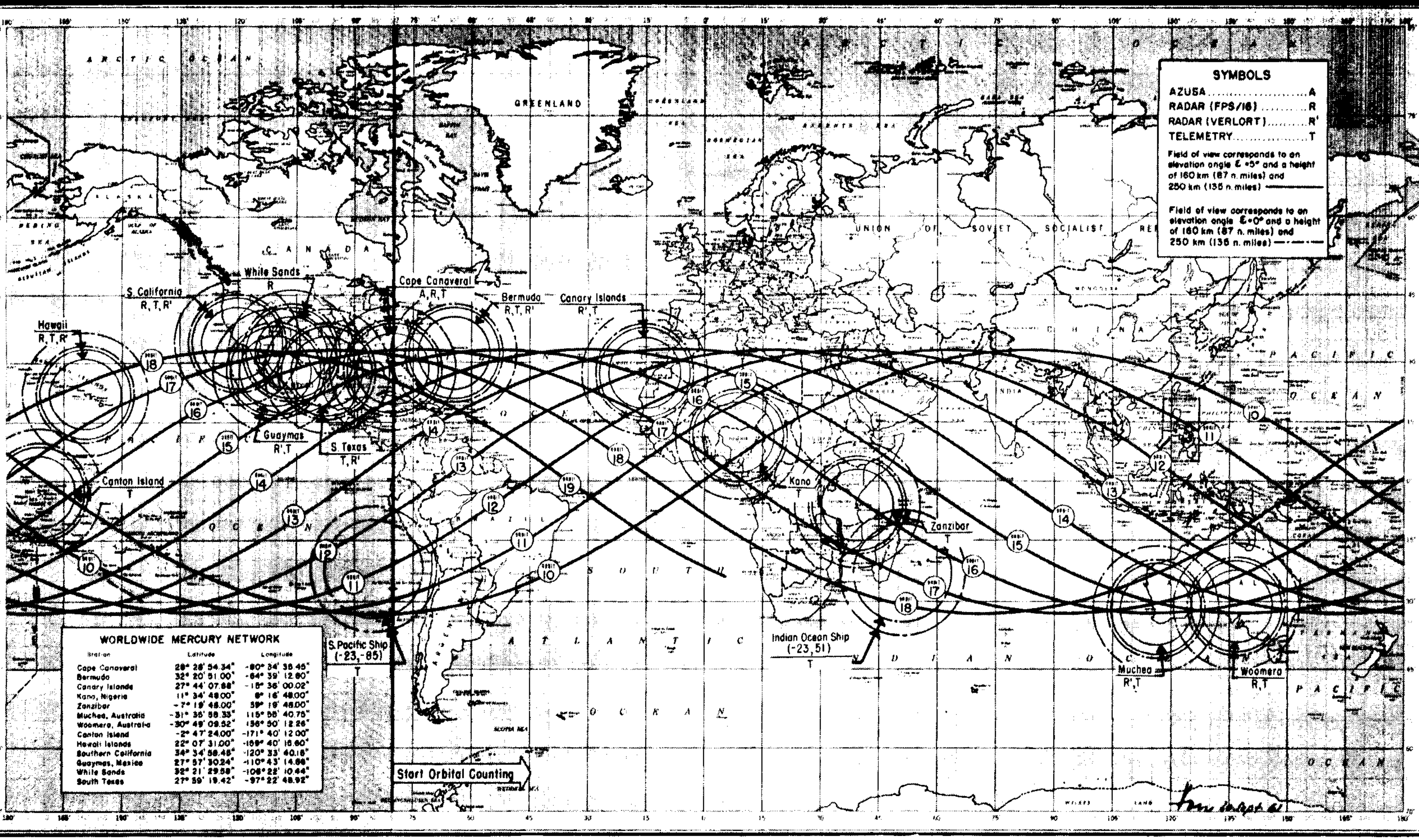

WORLD MAP OF THE 18 ORBIT MERCURY MISSION
Orbits 1 thru 9
SYMBOLS
AZUSA .... A
RADAR (FPS/16) .... R
RADAR (VERLORT) .... R'
TELEMETRY .... T
Field of view corresponds to an elevation angle E = 5° and a height of 160 km (87 n. miles) and 250 km (135 n. miles)
Field of view corresponds to an elevation angle E = 0° and a height of 160 km (87 n. miles) and 250 km (135 n. miles)
GREENLAND
ARCTIC OCEAN
CANADA
UNION OF SOVIET SOCIALIST RE
S. California
R, T, R'
White Sands
R
Cape Canaveral
A, R, T
Bermuda
R, T, R'
Canary Islands
R' T
Kano
T
Zanzibar
T
Guaymas
R, T
S. Texas
T, R'
Hawaii
R, T, R'
Canton Island
T
S. Pacific Ship
(-23, -80)
Indian Ocean Ship
(-23, 61)
Muchea
R, T
Woomera
R, T
Start Orbital Counting
WORLDWIDE MERCURY NETWORK
ORBITAL ELEMENTS
INITIAL CONDITIONS

Fig. 3a

WORLD MAP OF THE 18 ORBIT MERCURY MISSION

Orbits 10 thru 18

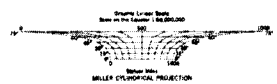


WORLDWIDE MERCURY NETWORK

Station	Latitude	Longitude
Cape Canaveral	28° 28' 54.34"	-80° 34' 35.45"
Bermuda	32° 20' 51.00"	-64° 39' 12.80"
Canary Islands	27° 44' 07.68"	-15° 36' 00.02"
Kano, Nigeria	11° 34' 48.00"	8° 16' 48.00"
Zanzibar	-7° 19' 48.00"	39° 19' 48.00"
Muchea, Australia	-31° 35' 58.33"	115° 58' 40.75"
Woomera, Australia	-30° 49' 09.52"	136° 50' 12.26"
Canton Island	-2° 47' 24.00"	-171° 40' 12.00"
Hawaii Islands	22° 07' 31.00"	-159° 40' 16.60"
Southern California	34° 34' 58.48"	-120° 33' 40.18"
Guaymas, Mexico	27° 57' 30.24"	-110° 43' 14.88"
White Sands	32° 21' 29.58"	-106° 22' 10.44"
South Texas	27° 39' 19.42"	-97° 22' 48.92"

ORBITAL ELEMENTS

T = 5 Aug 1961 $0^h\,05^M\,06^S$
a = 6580.633 km (3553.258 n. miles)
e = .007119612
i = 32°31'03".778
Ω = 175°49'25".716
ω = 69°44'03".746
P = $88^M.5441617$



INITIAL CONDITIONS

φ = 30°.451649
λ = -72°.406562
h = 161.095 km (87 n. miles)
$|\vec{v}|$ = 7.83841623 km/sec (25716.276 ft/sec)
γ = -°.0021525049
T = $0^h\,05^M\,06^S$
C.U.T. = 806^s.8104
f = $\frac{1}{298.3}$
R_e = 6378.145 km (3443.923 n. miles)

Fig. 3b

NETWORK MODIFICATION FOR GEMINI PCM-STATION LOCATIONS

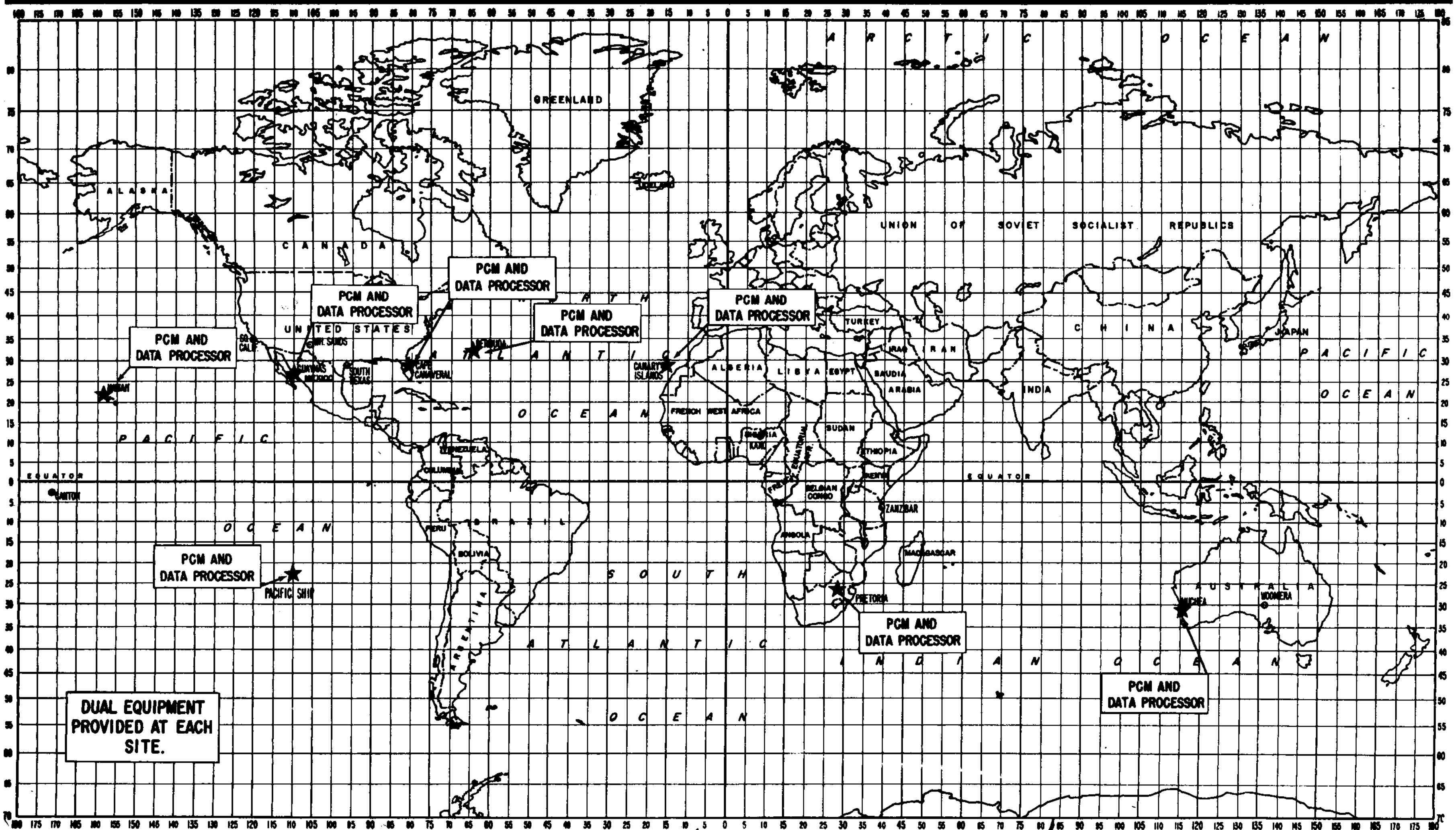
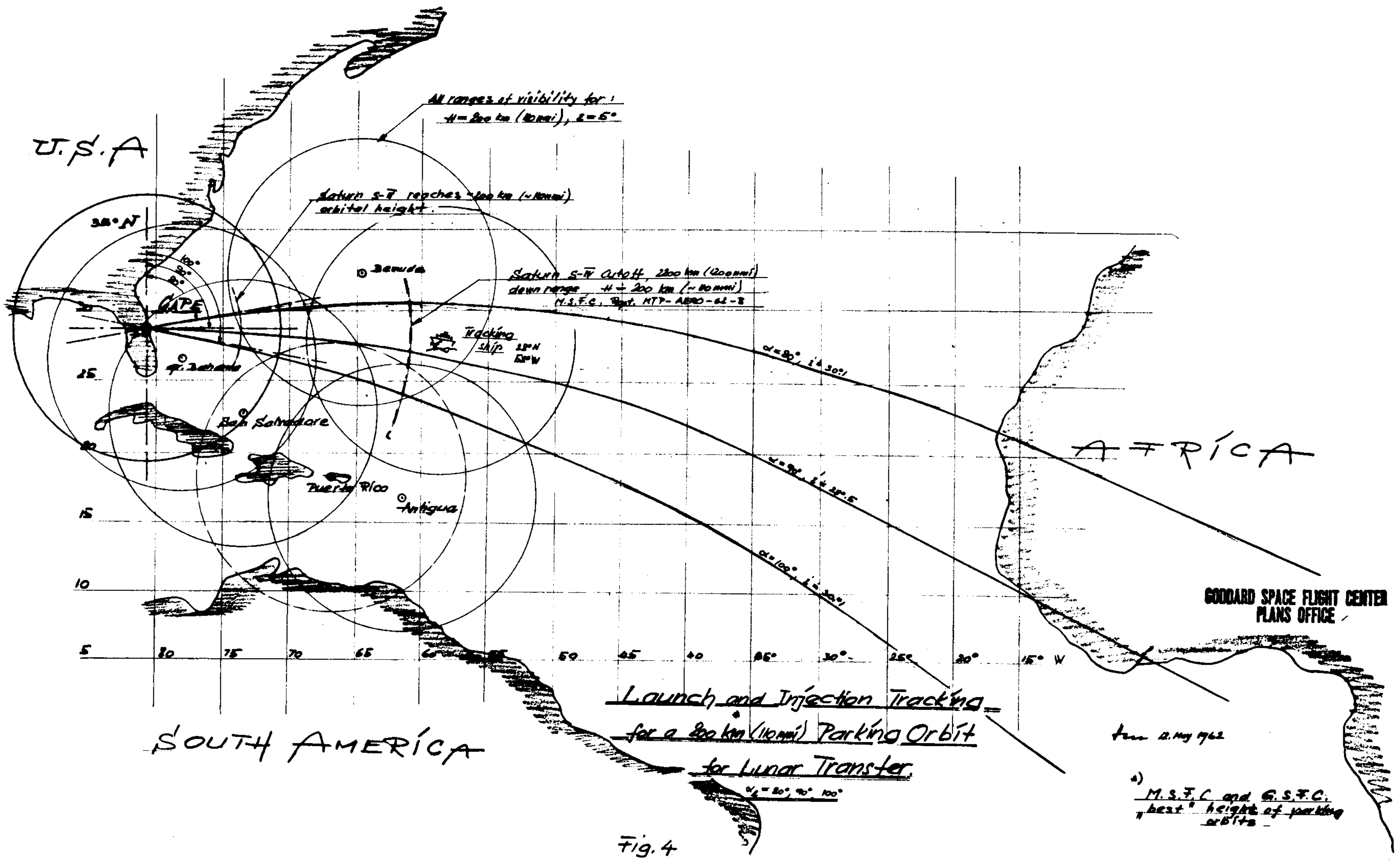


Fig. 3c

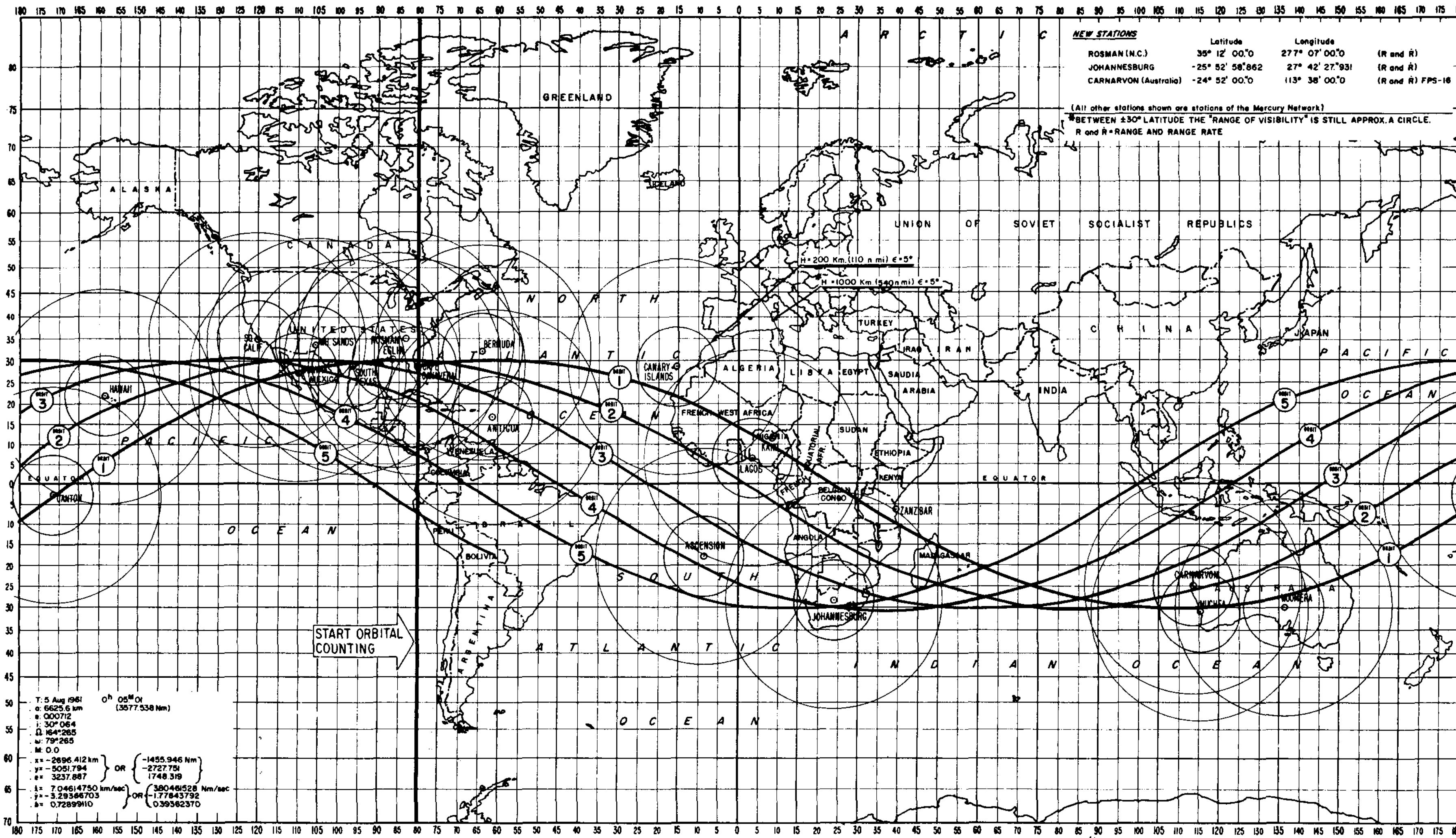
[handwritten initials] 10 Aug. 62 GODDARD SPACE FLIGHT CENTER-*PLANS OFFICE*



Launch and Injection Tracking for a 200 km (110 nmi) Parking Orbit for Lunar Transfer

Fig. 4

APOLLO PARKING ORBITS
H=200 Km (110 nmi) α=80°



SCALE AT EQUATOR 1:60,000,000
FROM ARMY MAP SERVICE SERIES 1107 - EDITION 2-AMS

Fig. 5a

7 June 1962 GODDARD SPACE FLIGHT CENTER - *PLANS OFFICE*

APOLLO PARKING ORBITS
H = 200 Km (110 n mi) α = 90°

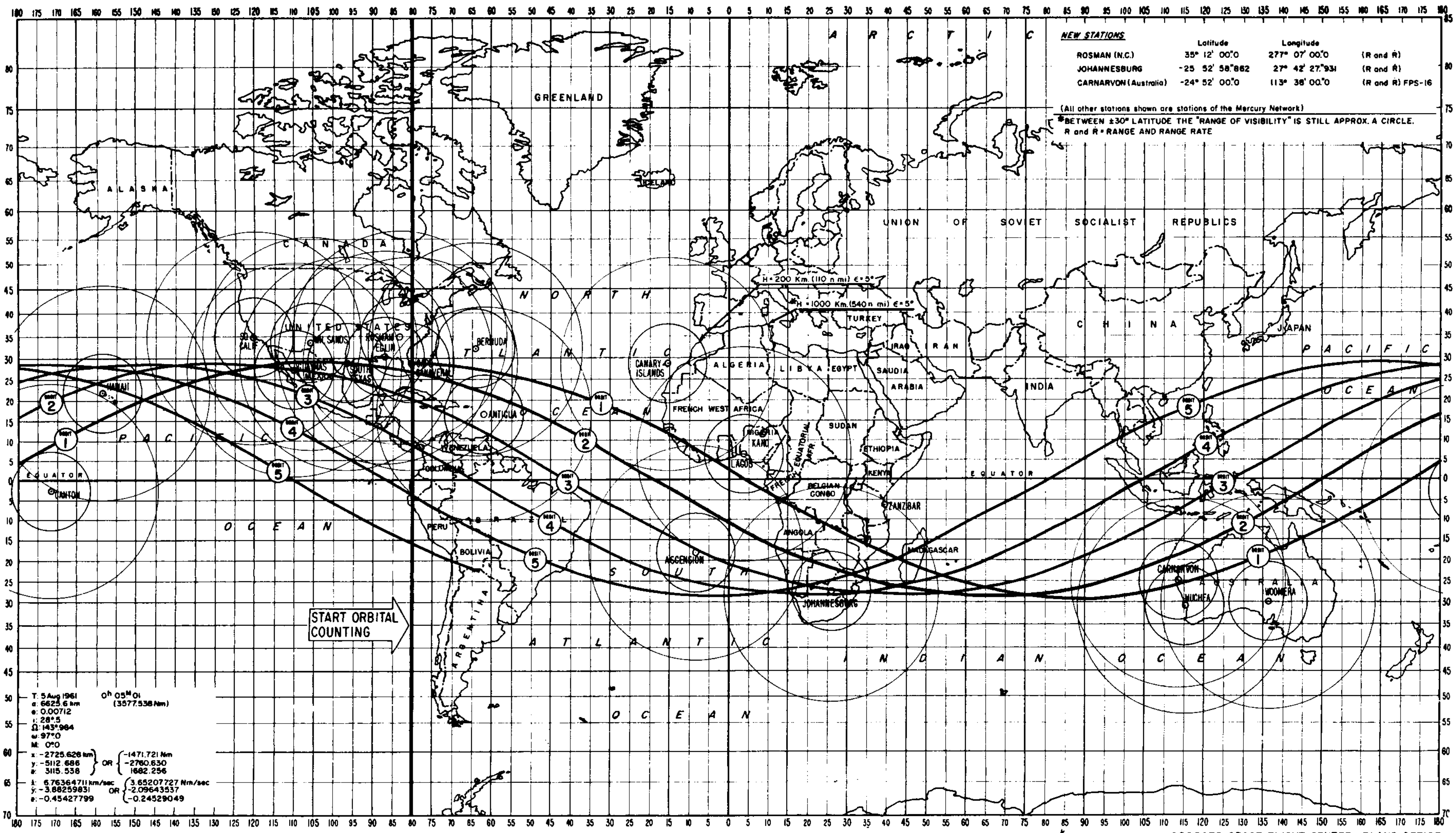
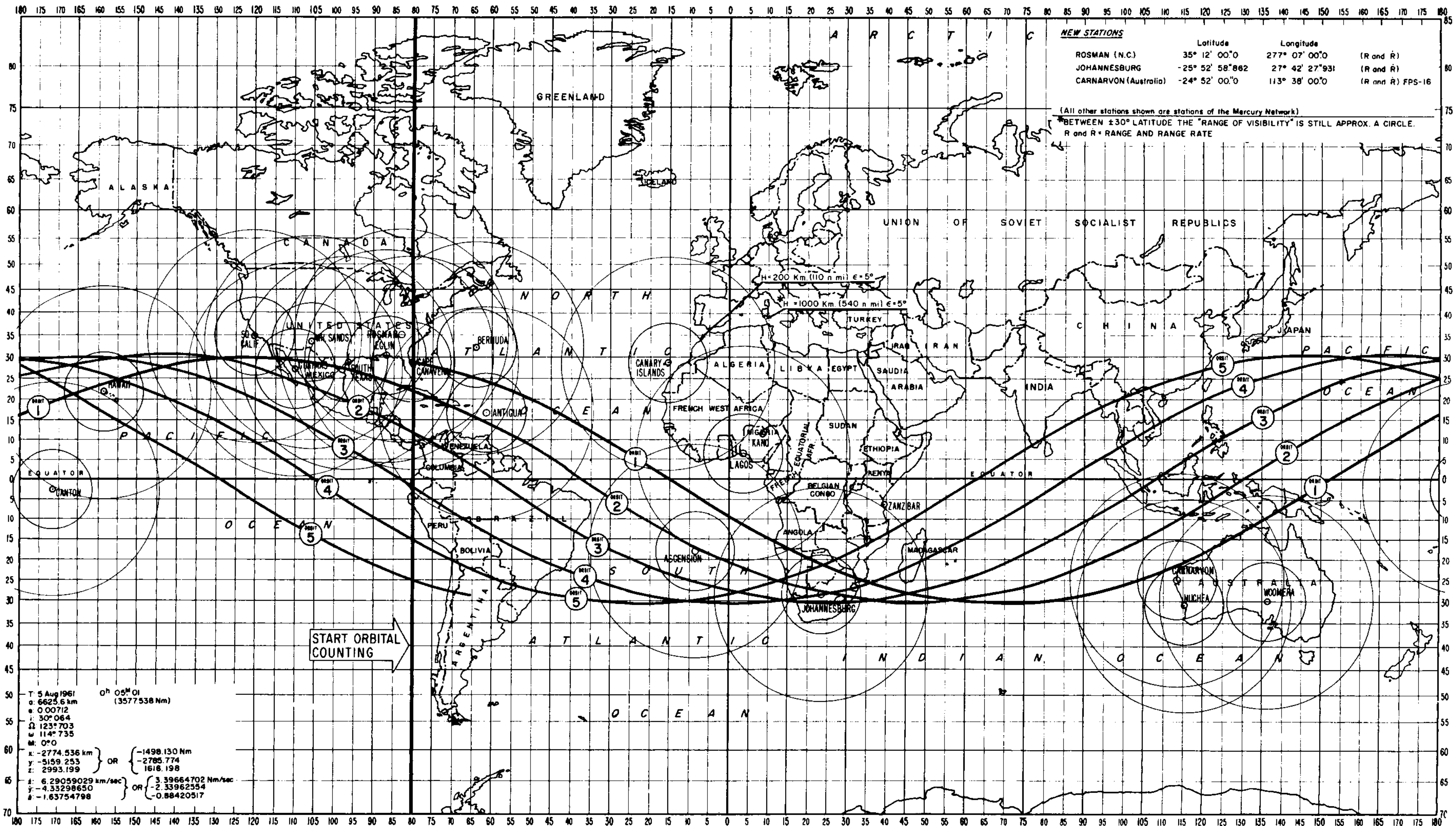


Fig. 5b

Fen 7 June 1962 GODDARD SPACE FLIGHT CENTER - *PLANS OFFICE*

APOLLO PARKING ORBITS
H = 200 Km (110 n mi) α = 100°

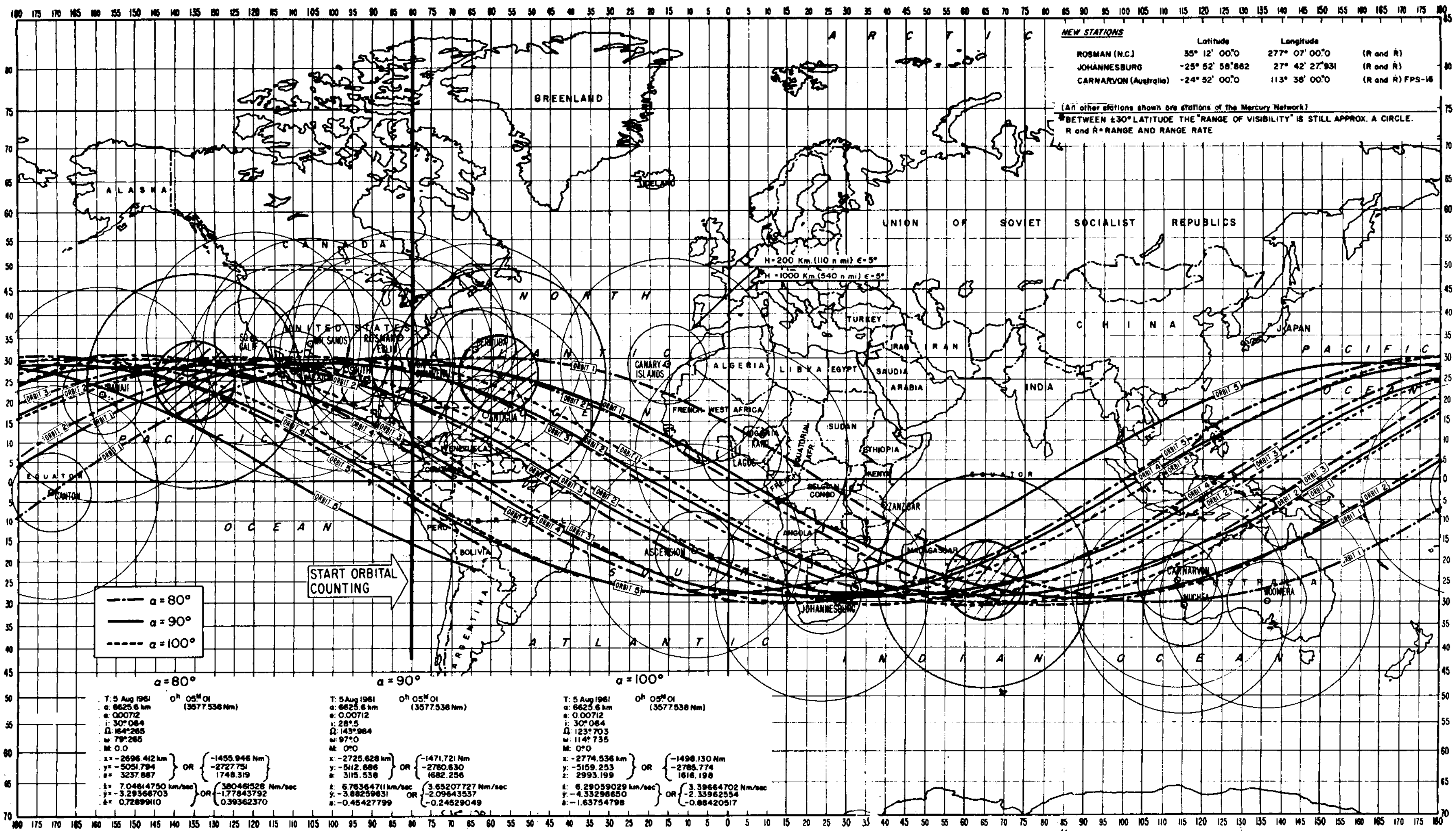


SCALE AT EQUATOR 1:80,000,000
FROM ARMY MAP SERVICE SERIES 1107 - EDITION 2-AMS

Fig 5c

7 June 62 GODDARD SPACE FLIGHT CENTER - *PLANS OFFICE*

APOLLO PARKING ORBITS WITH VARIABLE LAUNCH AZIMUTHS(α) H=200 Km(110 n mi)



SCALE AT EQUATOR 1:60,000,000
FROM ARMY MAP SERVICE SERIES 1107 - EDITION 2-AMS

Fig. 5d

7 June 1962 GODDARD SPACE FLIGHT CENTER - *PLANS OFFICE*

CONTOURS OF VISIBILITY FOR X-Y MOUNTED DISHES

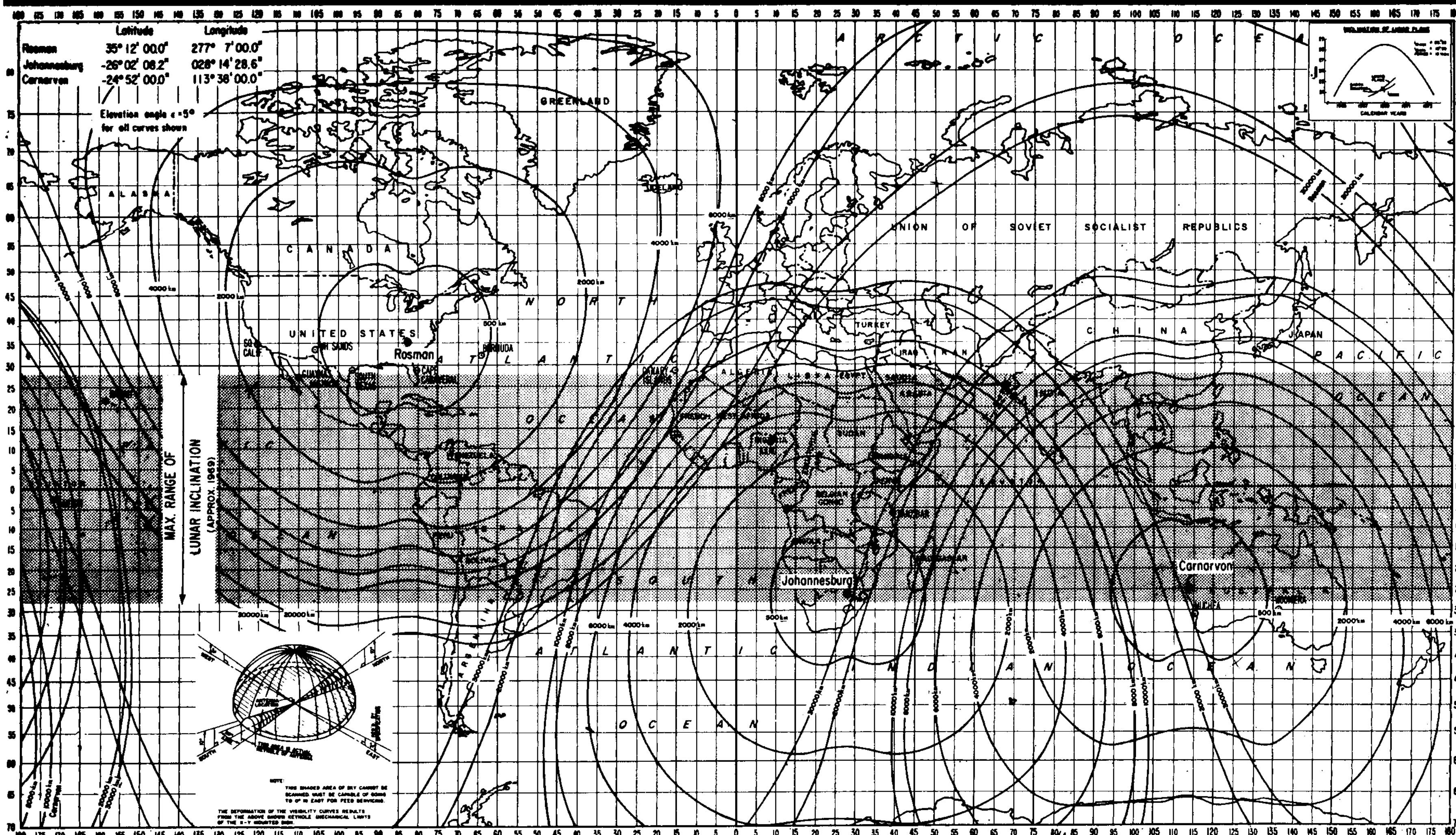


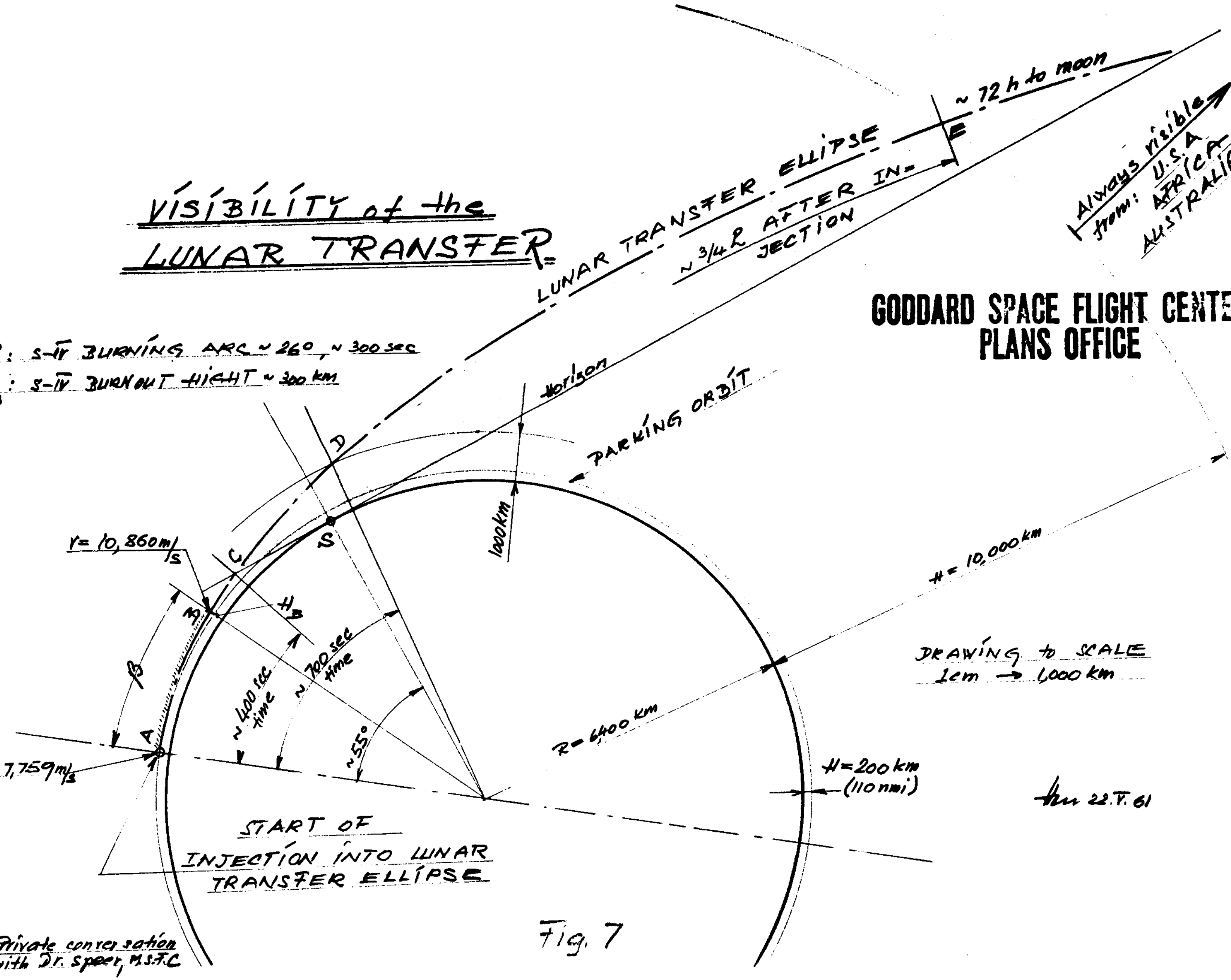
Fig. 6

SCALE AT EQUATOR 1:60,000,000
FROM ARMY MAP SERVICE SERIES 1107 - EDITION 2-AMS

10 Aug 62 GODDARD SPACE FLIGHT CENTER - PLANS OFFICE

VISIBILITY of the LUNAR TRANSFER

GODDARD SPACE FLIGHT CENTER
PLANS OFFICE



* β : S-IV BURNING ARC ~ 26°, ~ 300 sec
H_3 : S-IV BURNOUT HIGHT ~ 300 km

DRAWING to SCALE
1 cm → 1,000 km

Hm 22.V.61

Fig. 7

*) Private conversation with Dr. Speer, M.S.F.C