18p

N63 20196

CODE-1

GEORGE C. MARSHALL SPACE FLIGHT CENTER

HUNTSVILLE, ALABAMA

MSFC

February 20, 1961 MTP-M-S&M-F-61-2

RENDEZVOUS COMPATIBLE ORBITS

OTS PRICE

XEROX $ 1.60 ph

MICROFILM $ 0.80 mf.

[redacted]

FOR INTERNAL USE ONLY

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GEORGE C. MARSHALL SPACE FLIGHT CENTER

MTP-M-S&M-F-61-2

RENDEZVOUS COMPATIBLE ORBITS

By

W. R. Perry

20196

ABSTRACT

This material on rendezvous was prepared as part of a presentation to be given at the NASA Inter-Center Rendezvous Discussions at NASA Headquarters on February 27 through March 1, 1961.

The method of calculation is discussed and the results are presented in graphical form. The graphs show the available rendezvous compatible orbits in the 150 to 850 km altitude region. They give altitude as a continuous function of orbit inclination angle with number of revolutions between rendezvous points as a parameter.

TMX -50230

February 20, 1961 MTP-M-S&M-F-61-2

RENDEZVOUS COMPATIBLE ORBITS

By

W. R. Perry

ASTRONAUTICAL ENGINEERING SECTION
FUTURE PROJECTS DESIGN BRANCH
STRUCTURES AND MECHANICS DIVISION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

TABLE OF CONTENTS

LIST OF FIGURES

RENDEZVOUS COMPATIBLE ORBITS

SUMMARY

This material on rendezvous was prepared as part of a presentation to be given at the NASA Inter-Center Rendezvous Discussions at NASA Headquarters on February 27 through March 1, 1961.

The method of calculation is discussed and the results are presented in graphical form. The graphs show the available rendezvous compatible orbits in the 150 to 850 km altitude region. They give altitude as a continuous function of orbit inclination angle with number of revolutions between rendezvous points as a parameter.

INTRODUCTION

The synchronous or rendezvous compatible orbit has been discussed by Swanson and Petersen in References No. 4 and 5 and mentioned by Koelle in Reference No. 1. The rendezvous compatible orbit is so termed because the satellite returns to the initial injection point over the launch complex at predetermined intervals (References No. 4 and 5). Each time the satellite passes through this injection point it offers the possibility of a rendezvous from the ground via the same "standard" ascent trajectory.

The significant information to be added to the subject by this paper is the presentation of the possible rendezvous compatible orbits in graphical form showing all of the possible solutions within the interval that is presented. Even though the launch complex may pass through the target orbit plane twice each day, only one of these in-plane launch conditions is considered. This greatly simplifies the treatment of the problem and is justified in that it is not likely that a launch freqquency of more than one per day would be feasible. The types of orbits and procedures described here may be applicable to the following orbital operation missions;

1. Flights made for developing the rendezvous and orbital operations technique.

2. The first manned space stations which probably will be in low altitude orbits to avoid the Van Allen radiation and will require frequent supply and restaffing flights.

3. Assembly and refueling of lunar and interplanetary vehicles.

4. Assembly and refueling of orbital space stations that will later be put into higher orbits.

DISCUSSION

The requirements to be fulfilled in order to have a rendezvous compatible orbit are that the satellite be at the latitude of the desired Earth fixed reference point just as this reference point passes through the orbit plane (Figure I).

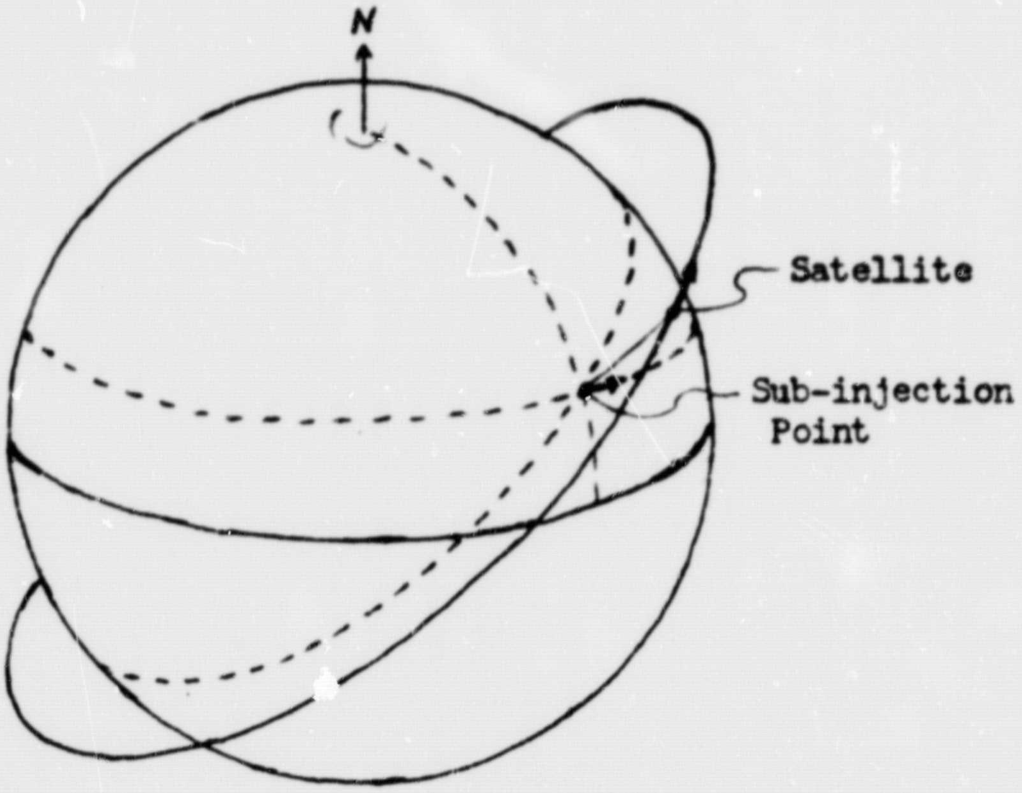


Figure 1. Orbit Track Over Earth

One revolution of the satellite relative to a latitude circle is a nodical period. It follows that there must be an integral number of nodical periods between consecutive passes of the reference point through the same portion of the orbit plane. Secular perturbations of the orbit due to the Earth's oblateness (References 2 and 3) cause the orbit to precess along the equator in a direction opposite to the Earth's rotation for satellites in direct orbits. This results in the nodical period being slightly shorter than the sidereal period. For the same reason the reference point on the Earth takes less than 24 hours to complete a revolution relative to the orbit plane.

Now, since there are an integral number of nodical periods in a revolution of the Earth relative to the orbit plane, the change in longitude per nodical period (taking into account regression of the nodes) must be contained an integral number of times, N, in some multiple, M, of 360 degrees. This change in longitude per nodical period, $\Delta\lambda$, (Figure 2) can easily be computed by the following equations.

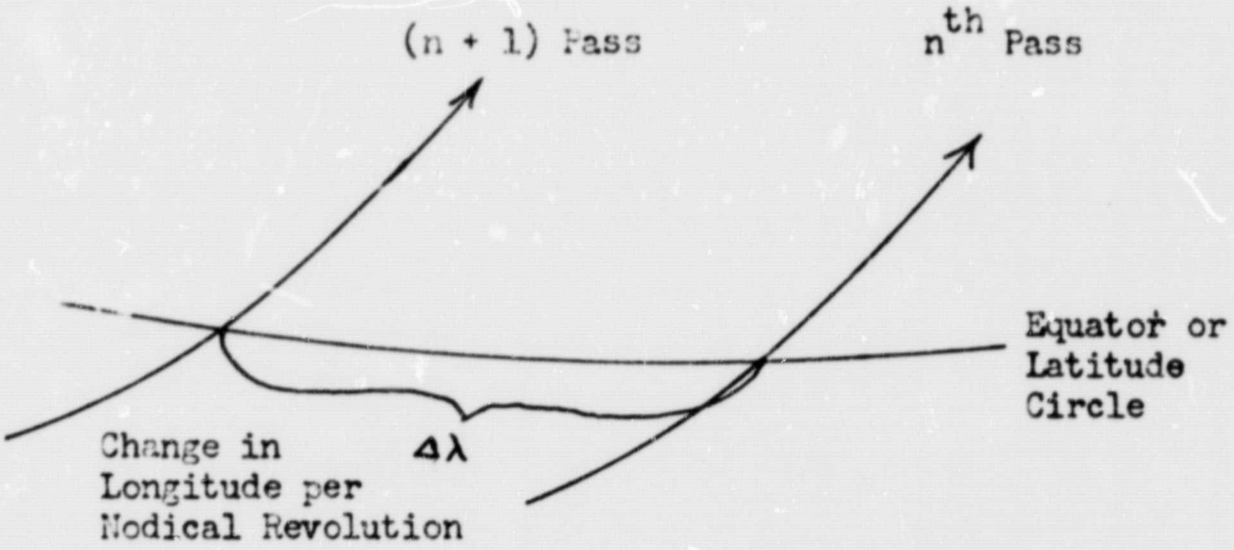


Figure 2. Change in Longitude per Nodical Period

(1) $\Delta\lambda = (\omega_{\bullet} - \dot{\alpha}_{\Omega})\, P_n$ [deg]

$\Delta\lambda$ = change in longitude per nodical period [deg]

$\omega_{\bullet}$ = rotational velocity of the Earth [deg/min]

$\dot{\alpha}_{\Omega}$ = nodal regression rate of the orbit [deg/min]

P_n = nodical period of the satellite [min]

(2) $P_n = 2\pi/(n_s - \dot{\alpha}_{\Omega})$

$n_s = 2\pi/P_s$

P_s = sidereal period of the satellite [min]

From Reference 2,

$$(3)\quad \dot{\alpha}_{\Omega} = -\, n \cos \gamma \left[3\,\frac{k_2}{p^2} + 10\,\frac{k_4}{p^4}\,\left(1 + \frac{3}{2}\,e^2\right)\left(1 - \frac{7}{4}\sin^2 \gamma\right) + \ldots \right]$$

n = mean motion of the satellite $\approx n_s$ $\left[\text{deg/min}\right]$

γ = inclination of orbit to equator $\left[\text{deg}\right]$

e = eccentricity of the orbit

$k_2 = \frac{C - A}{2\,M} = 2.14684 \times 10^4$ $\left[\text{km}^2\right]$

$k_4 = \frac{16}{5}\,k_2^2$ $\left[\text{km}^4\right]$

A = moment of inertia of the Earth about an equatorial axis

C = moment of inertia of the Earth about the axis of rotation

M = Earth's mass

$p = a(1 - e^2)$ $\left[\text{km}\right]$

a = semi-major axis of the orbit $\left[\text{km}\right]$

Equation (2) for the nodical period could be replaced by refined equations given in Reference 3, however, Equation (2) was used for this analysis so it is given here.

The equations mentioned above were used to compute $\Delta\lambda$ per nodical period as a function of inclination angle, γ, for various altitudes (for circular orbits). This was then plotted (Figure 3) as $\Delta\lambda$ vs γ with altitude, y, as a parameter. A cross plot was then made of the values of $\Delta\lambda$ that gave an integral number of "nodical revolutions" of the satellite within an integral number of Earth rotations relative to the orbit. These cross plots are shown in Figures 4 - 8. Where;

N = number of nodical revolutions of the satellite between rendezvous times. (A nodical revolution could be measured relative to any latitude circle).

M = number of Earth rotations relative to the orbit plane.

T = time for M Earth rotations relative to the orbit plane.

So that, for any given number of revolutions of the satellite between rendezvous points, these graphs give the required altitude as a continuous function of inclination angle.

Figure 9 as is indicated on the diagram gives orbital lifetime for various mass to area ratios and is based on the 1959 ARDC atmosphere.

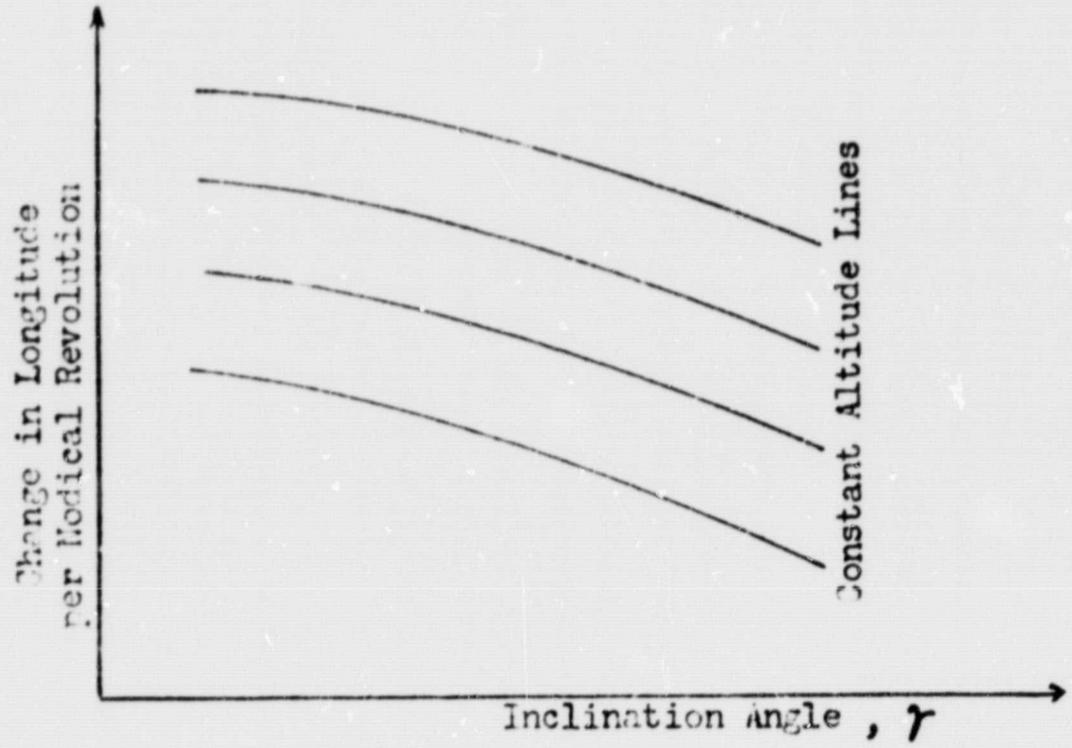


Figure 3. Change in Longitude vs Inclination Angle

Example

Suppose it is desired to establish an orbit that will offer favorable chances for rendezvous at four day intervals. This means that we take M = 4 and would look at Figure 6 which is drawn for the case M = 4.

From Figure 6 it is seen that, within the altitude interval presented, it is possible to get orbits that have 56 through 64 revolutions in the M = 4 interval. Next we can assume that we are looking for an orbit with an inclination angle of 30 degrees and an altitude of 500 - 600 km. Figure 6 shows a solution of 560 km that would have 59 revolutions and about 94 hours, 4 minutes between rendezvous points. From Figure 9, this orbit has a sidereal period of about 95.7 minutes.

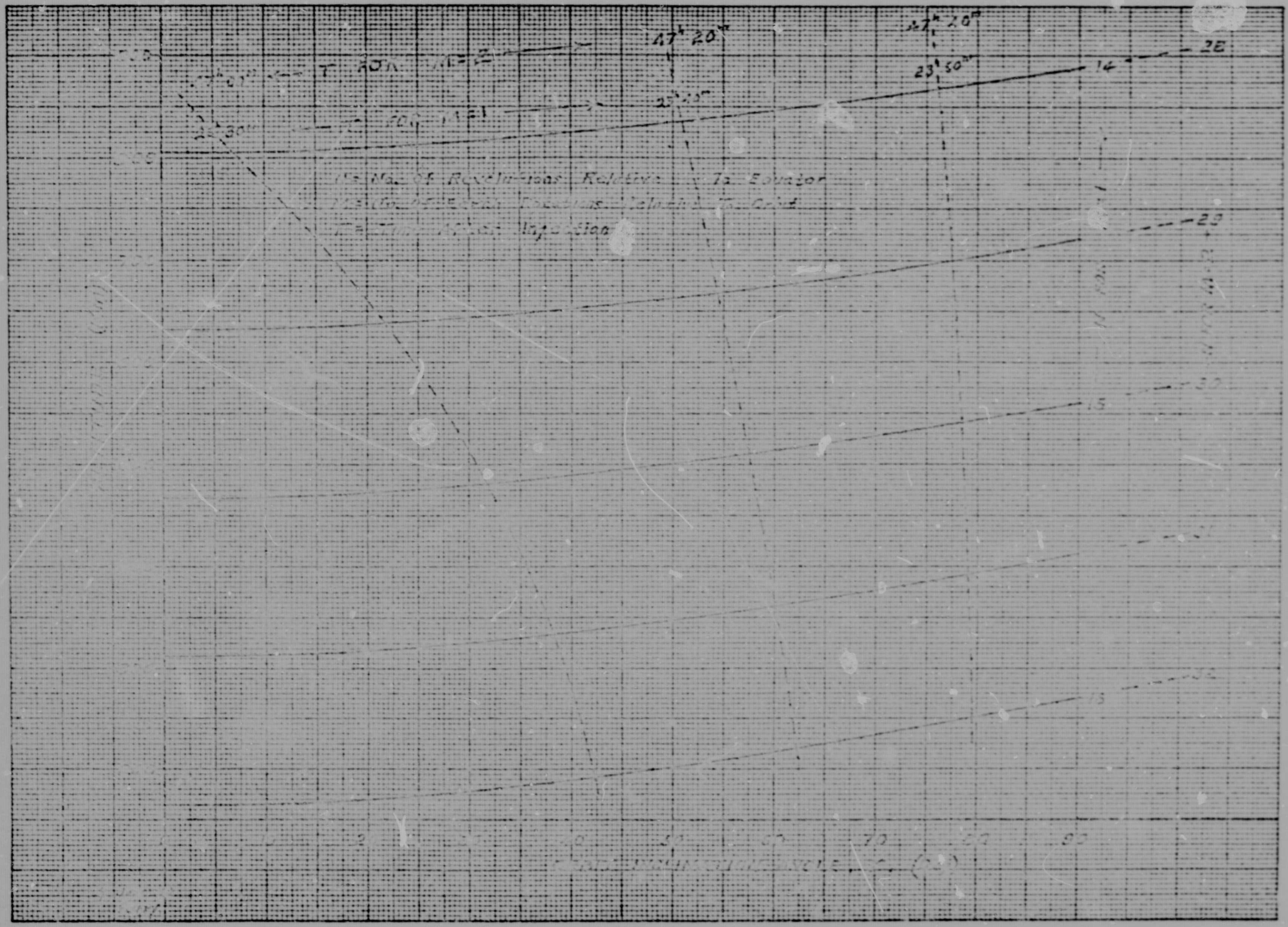


Figure 4. Rendezvous Compatible Orbits for M = 1, M = 2

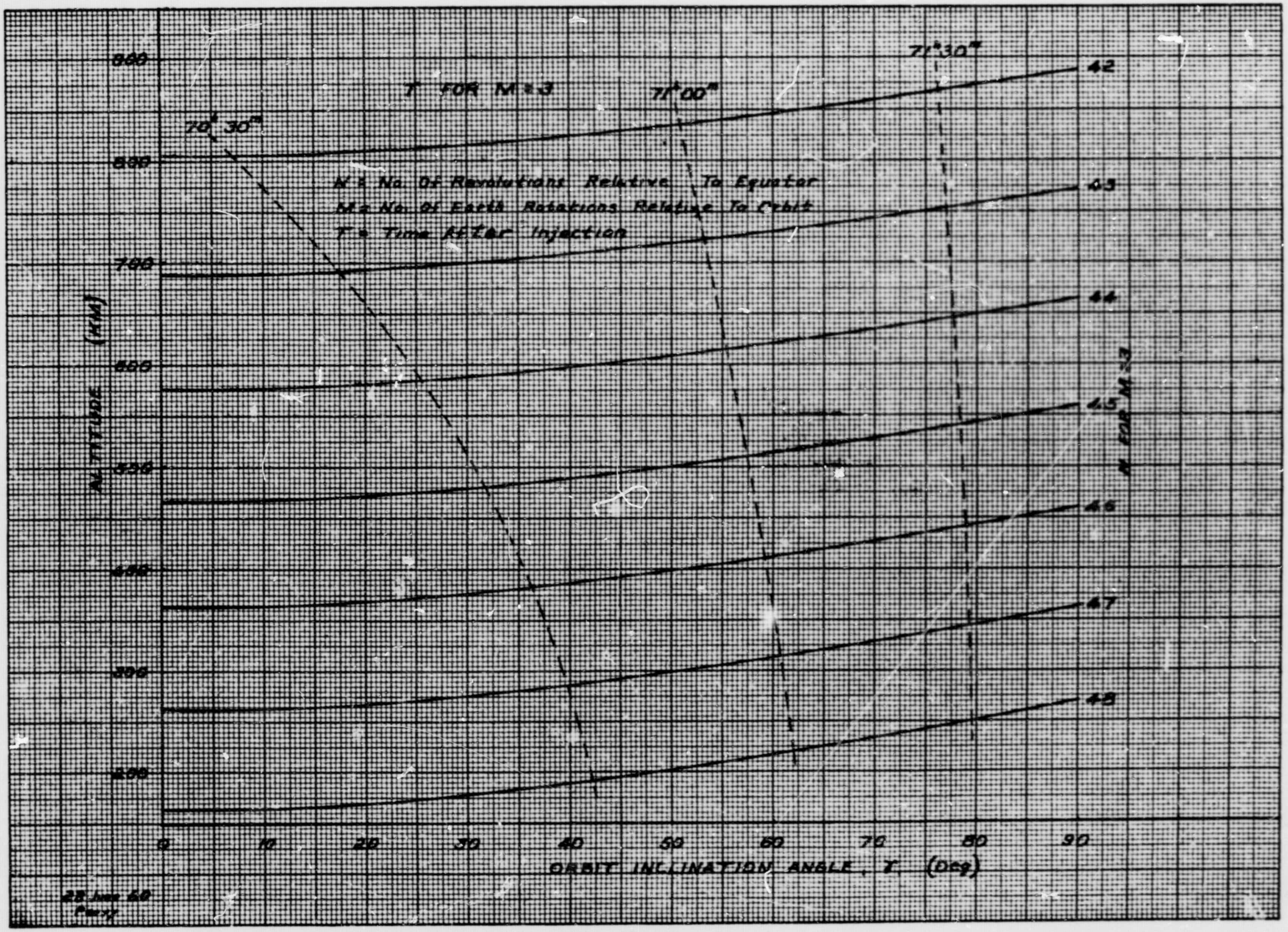


Figure 5. Rendezvous Compatible Orbits for M = 3

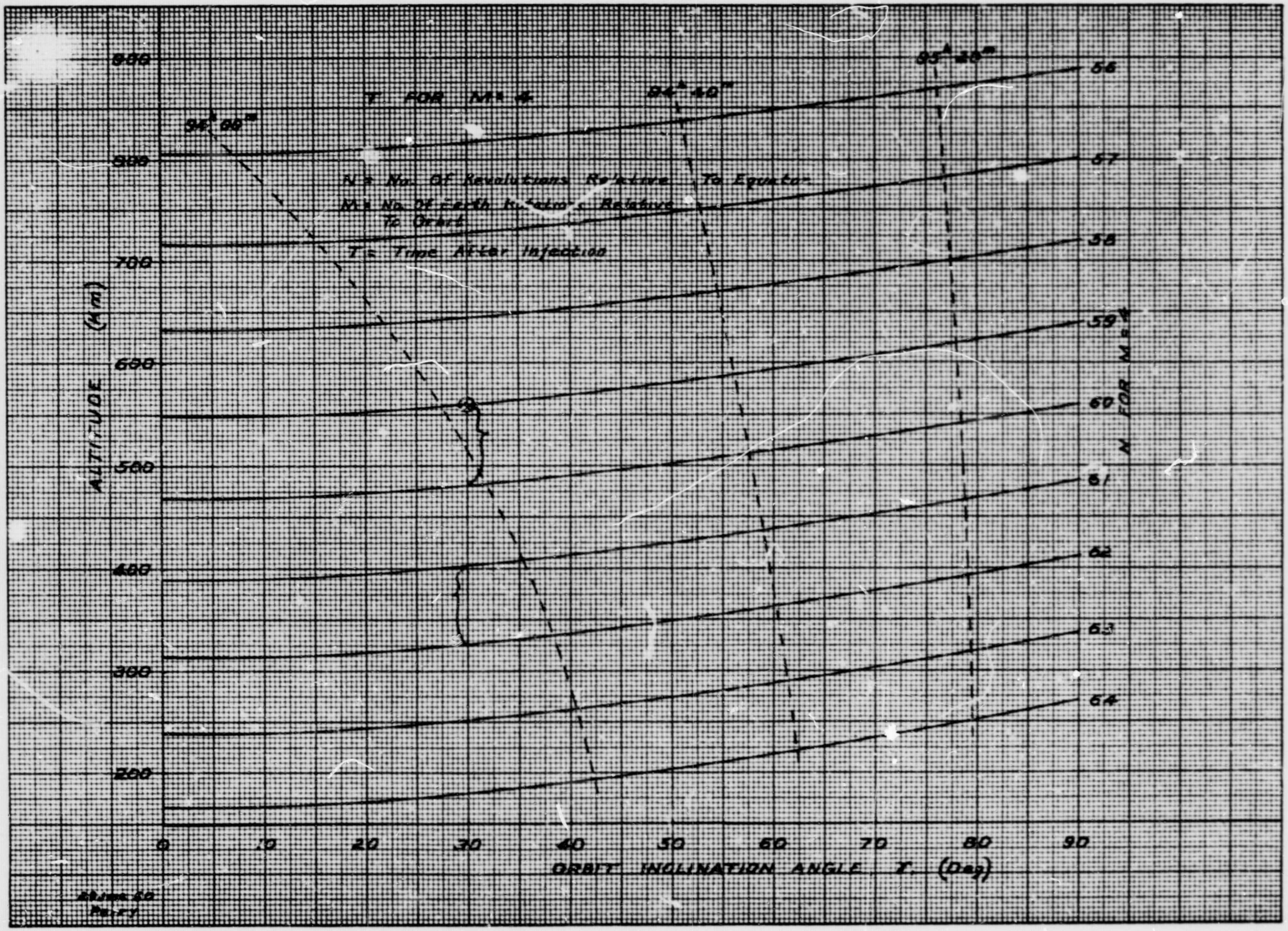


Figure 6. Rendezvous Compatible Orbits for M = 4

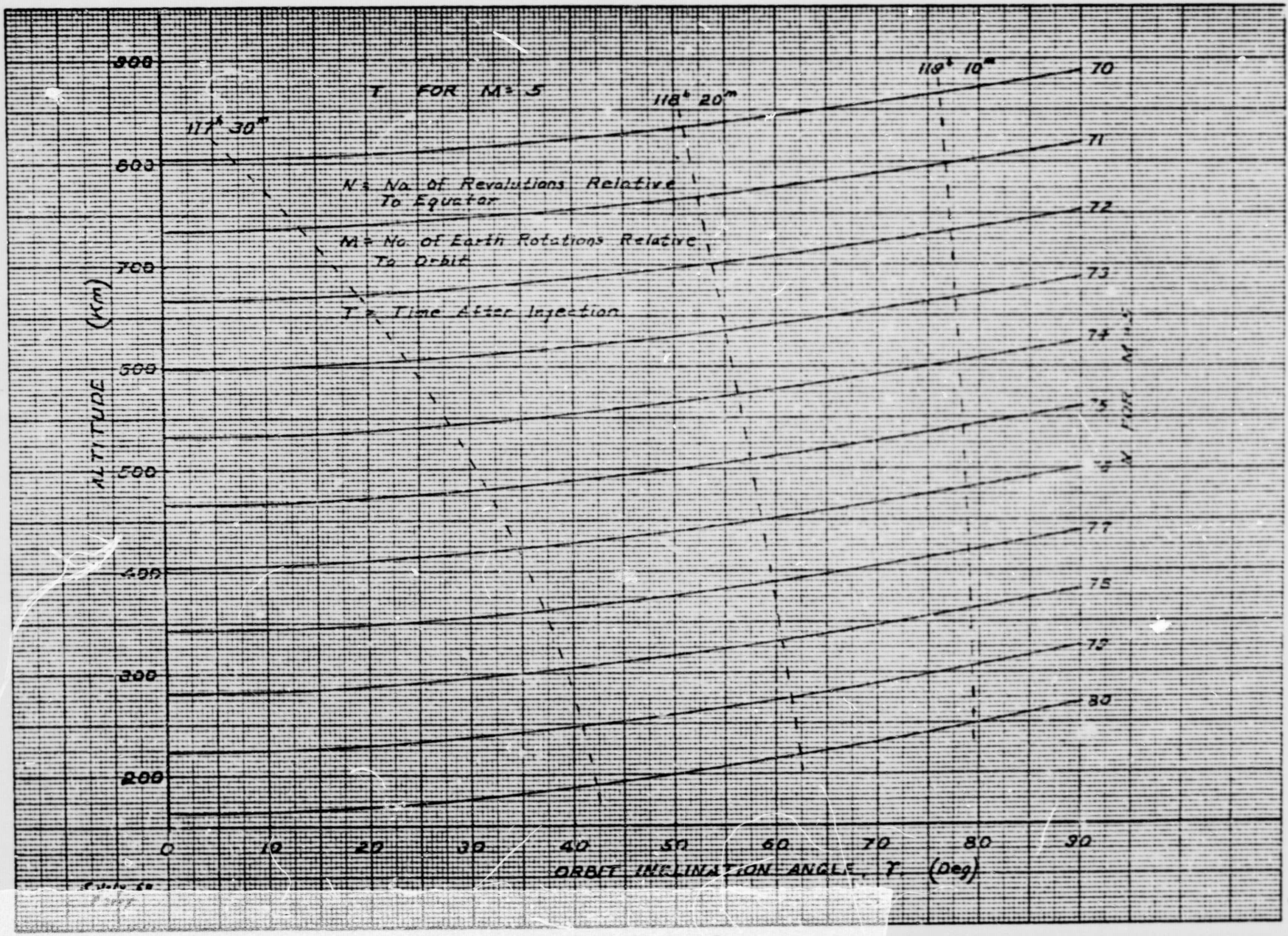


Figure 7. - Rendezvous Compatible Orbits for M = 5

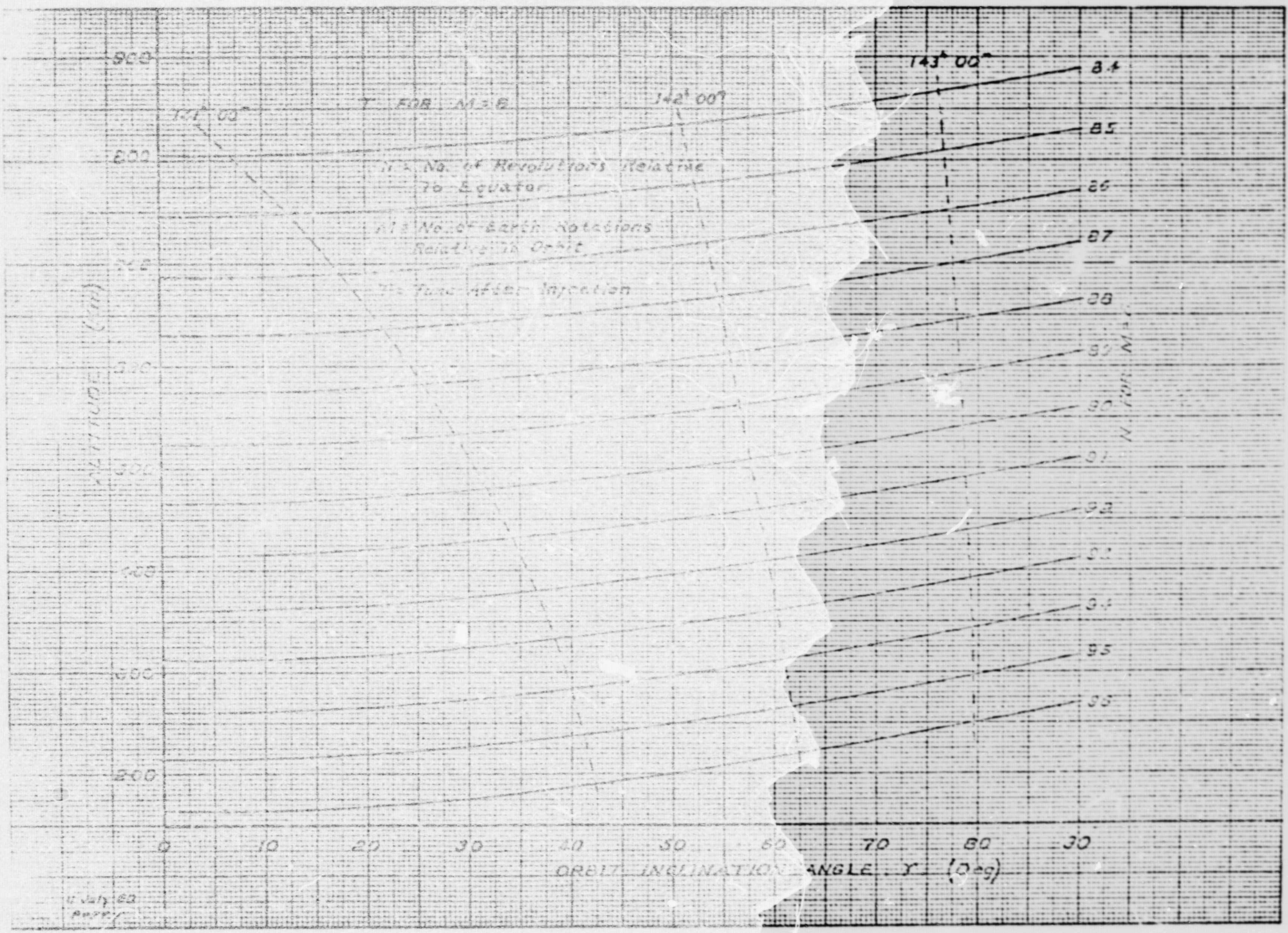
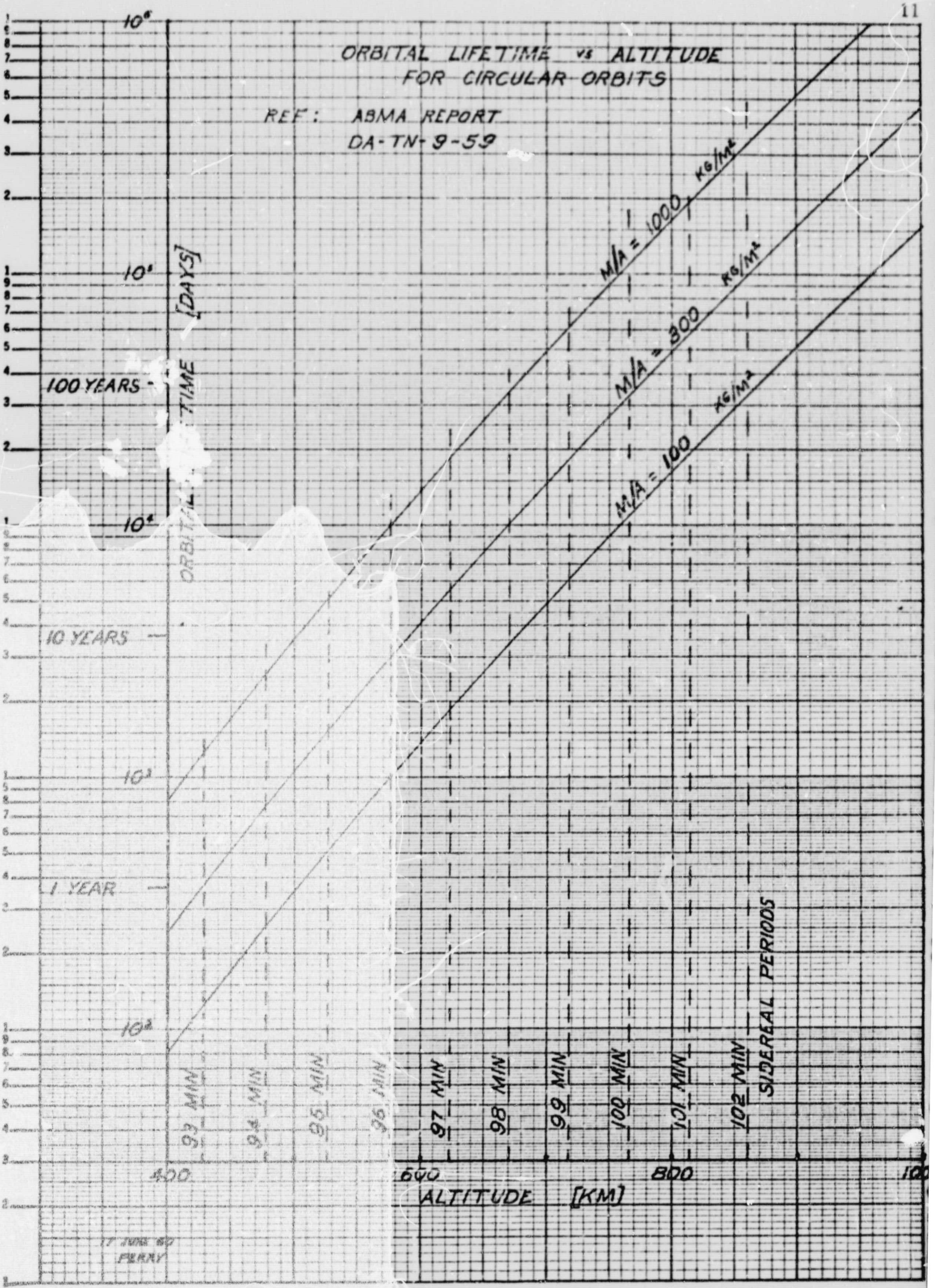


Figure 8. Rendezvous Compatible Orbits M = 6



ORBITAL LIFETIME vs ALTITUDE
FOR CIRCULAR ORBITS

REF: ABMA REPORT
DA-TN-9-59

REFERENCES

1. Koelle, H. H., Engler, E. E., and Massey, J. W.: Design Criteria and their Applications to Economical Manned Satellites. Proceedings of the Manned Space Stations Symposium, Los Angeles, California, April 1960.

2. Krause, H. G. L.: The Secular and Periodic Perturbations of the Orbit of an Artificial Earth Satellite. Paper presented at the VII Internation Astronautic Congress, Rome, September 1956.

3. Krause, H. G. L. and DeWitt, R. N.: Comparison of Precalculated Orbital Elements of the Army Explorer Satellites with Actual Elements Derived from Observations. Report No DSP-TR-2-60, Army Ballistic Missile Agency, Redstone Arsenal, Alabama, June 20, 1960.

4. Petersen, N. V. and Swanson, R. S.: Rendezvous in Space - Effects of Launch Conditions. Proceedings of the Manned Space Stations Symposium, Los Angeles, California, April 1960.

5. Swanson, R. S. and Petersen, N. V.: The Influence of Launch Conditions on the Friendly Rendezvous of Astro-vehicles. Proceedings of the AAS - 2nd Western National Meeting, Los Angeles, California, August 1959.