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MCDONNELL DOUGLAS TECHNICAL SERVICES COMPANY, INC.
HOUSTON ASTRONAUTICS DIVISION

SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT
DESIGN NOTE NO. 1.4-3-10
NAS 9-13970

SUBJECT: Nominal Profile Refinements Report: Target in 120 Nautical Mile Circular Orbit

DATE: 24 December 1974

1.0 SUMMARY

In this note the compatibility of the nominal rendezvous sequence with low target orbits is addressed. It was found that for targets in low earth orbits certain modifications of the nominal sequence are required to achieve a feasible anytime liftoff capability, notably the use of elliptical phasing orbits and the allowance of up to two days for rendezvous under certain phasing conditions.

2.0 INTRODUCTION

In Reference 1 the October 1973 Space Shuttle traffic model was analyzed and candidates for worst case flights were proposed based on their potential impact upon the nominal rendezvous sequence. For flights requiring a single rendezvous it was concluded that the parameter having the greatest probable impact upon the nominal sequence was target orbit altitude. According to the traffic model, the lowest target orbit altitude required for rendezvous will be 190 nautical miles (n. mi.). However, it was felt that for study

Enclosure

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purposes it would be more beneficial to investigate an even lower orbit altitude. (The target orbit altitude specified in Reference 2 for the Apollo Soyuz flight was 120 n. mi. and Department of Defense Shuttle missions at this altitude are being proposed.)

In the present study a target orbit altitude of 120 n. mi. was assumed and an analysis was conducted to 1) evaluate the effectiveness of the nominal sequence in accomplishing the rendezvous, 2) identify problem areas or incompatibilities with the nominal sequence, and 3) recommend solutions where possible.

3.0 DISCUSSION

A number of guidelines were adopted in the present analysis, namely:

A) The total ΔV requirement will be similar to that appearing in Reference 3 for Baseline Reference Mission 2 (BRM 2).

B) An anytime launch capability will be required (i.e. all insertion phase angles should be achievable).

C) The time spent in the phasing orbit will be multiples of 12 revolutions, which is about the maximum phasing duration specified in Reference 3 for BRM 2.

D) Elliptical phasing orbits having one apsis located at 100 n. mi. altitude will be used.

E) A 50 X 100 n. mi. insertion orbit will be assumed.

F) The nominal sequence will be preserved from the first coelliptic maneuver (NSR1) to final docking.

G) Only in-plane launches will be considered.

H) Use of phasing orbit perigee altitudes below 70 n. mi. will be avoided.

A portion of the modified nominal sequence trajectory profile for a 120 n. mi. target orbit is presented in Figure 1. The altitude labelled "H" was varied parametrically from 70 n. mi. to 500 n. mi. herein.

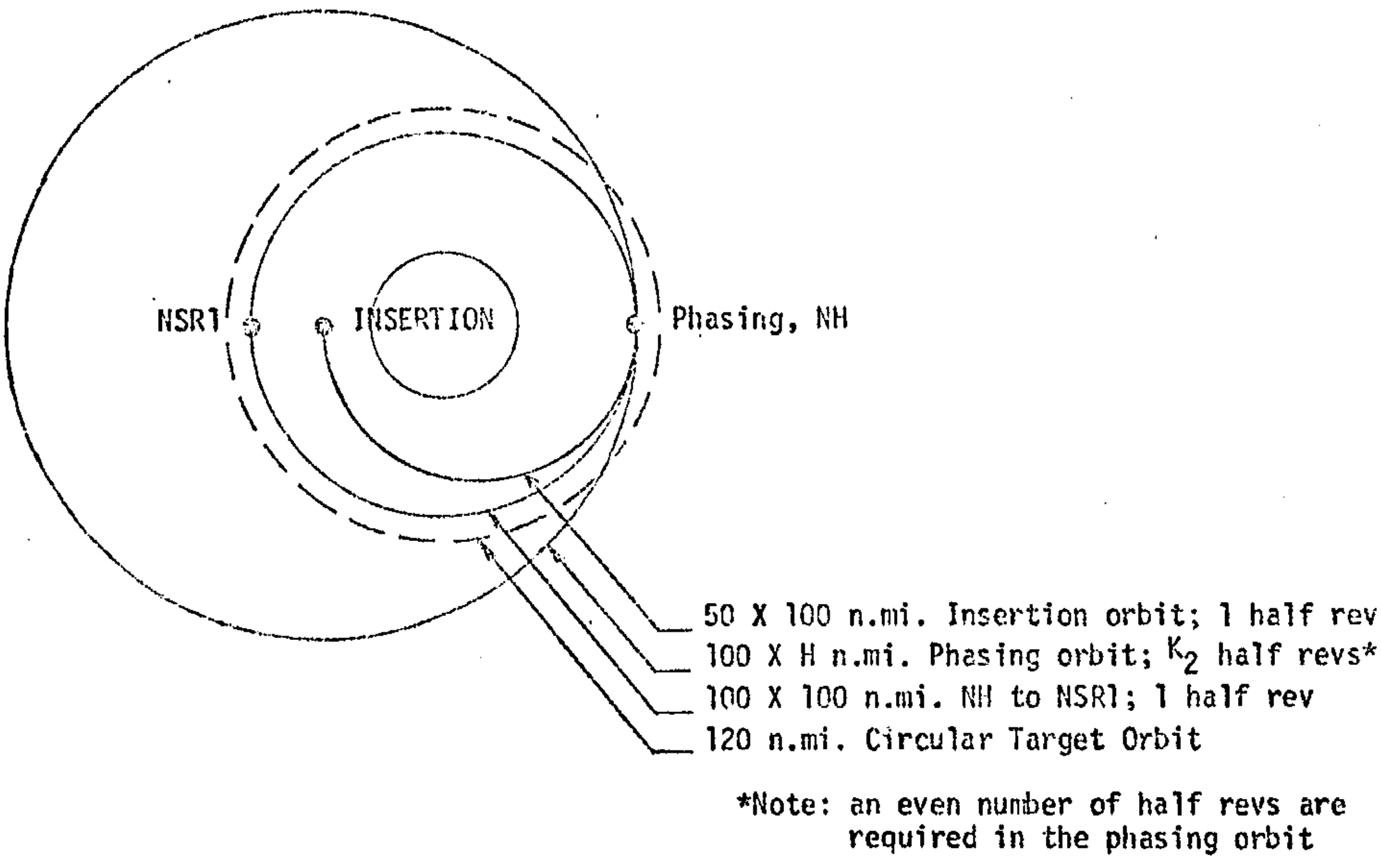


FIGURE 1 - MODIFIED NOMINAL PROFILE FROM INSERTION THROUGH NSR1

The phasing equation used to determine insertion phase angle as a function of the number of half revs in the phasing orbit is:

$$\theta_i = \theta_c - (\eta_T \frac{P_1}{2} - 180)\ K_1 - (\eta_T \frac{P_2}{2} - 180)\ K_2 - (\eta_T \frac{P_3}{2} - 180)\ K_3$$

where

θ_i = insertion phase angle (dependent variable)

θ_c = phase angle at NSR1, 6.5 degrees (assumed to be a constant, but in reality varies to obtain appropriate terminal rendezvous phase lighting)

η_T = mean motion of a target in a 120 n. mi. circular orbit = 4.048 deg/min.

P_1 = period of the 50 X 100 n. mi. insertion orbit = 87.264 minutes.

P_2 = period of the 100 X H n. mi. phasing orbit (a function of altitude.)

P_3 = period of the 100 X 100 n. mi. orbit to NSR1 = 88.196 minutes.

K_1 = number of half revs in the insertion orbit = 1

K_2 = number of half revs in the phasing orbit (the independent variable)

K_3 = number of half revs in the height-to-NSR1 orbit (assumed to be 1)

It might be noted that the height maneuver, NH, is effectively a circularization at nominally 100 n. mi. altitude, and NSR1, which is assumed to occur 1/2 revolution later, will likewise occur at 100 n. mi., but will nominally require no velocity increment. Compensation for orbital decay, phasing discrepancies, etc. could conceivably be performed at either of these times.

Data were generated via digital computer using the standard two-body conic equations for mean motion and orbital periods. It should be noted that the empirical equations for mean motion and period presented in Reference 4 were programmed for the Hewlitt Packard 9820 computer for comparison purposes. Agreement to within one or two degrees was observed when the number of half revs (K_2) was small. However, when a sizeable number of half revs was specified, the insertion phase angle obtained empirically differed from the two-body value by several degrees. Table 1 presents some comparisons.

TABLE 1

COMPARISON OF TWO-BODY AND EMPIRICAL RESULTS FOR A 100 X 250 N. MI. PHASING ORBIT

Half-revs in Phasing Orbit	θ_i, Insertion Phase Angle (deg.) Via Two-Body P,n	Via Empirical P,n *	Difference (deg.)
3	358.863	357.537	1.326
21	283.573	277.369	6.204
51	158.090	143.757	14.333

NOTE: Target orbit = 120 n. mi. circular; Insertion orbit = 50 X 100 n. mi.; $K_1 = K_3 = 1$; $\theta_c = 6.5°$.

* $P = 84.4511836 + .036848172\ h + .000002499\ h^2$ (P in minutes; h in n. mi.)

$n = 4.262817696 - .001783366\ h + .000000429\ h^2$ (n in degrees/min; h in n. mi.)

4.0 RESULTS

The data presented herein were derived by using two-body conic values for period and mean orbital motion. Although the curves depicting insertion phase angle are plotted as if they were continuous functions, it should be noted that in actuality they are step functions because integral numbers of half revs were assumed in generating the data. Minor phase angle adjustments may therefore be required in practice.

Figure 2 presents half revs of phasing as a function of insertion phase angle for various elliptical phasing orbits; All orbits have an apsis altitude equal to 100 n. mi. Note that for a 100 X 140 n. mi. phasing orbit, only a single insertion phase angle (i.e., 11.4 degrees) may be accomodated. This is because the semi major axis of the phasing orbit is identical to the semi major axis of the target orbit and hence their periods are the same. The maximum phasing orbit apsis altitude presented is 500 n. mi., and the minimum is 70 n. mi.

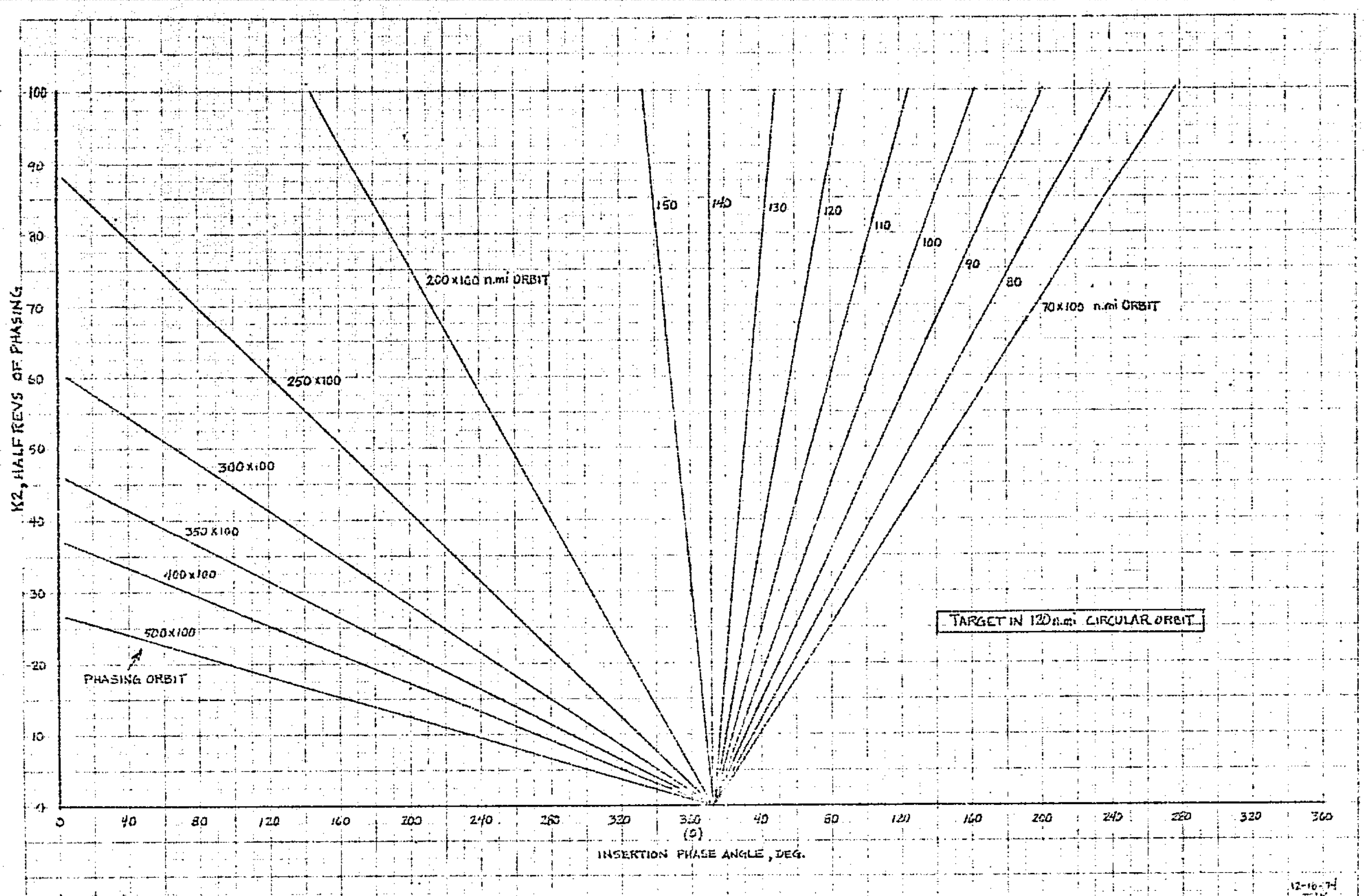
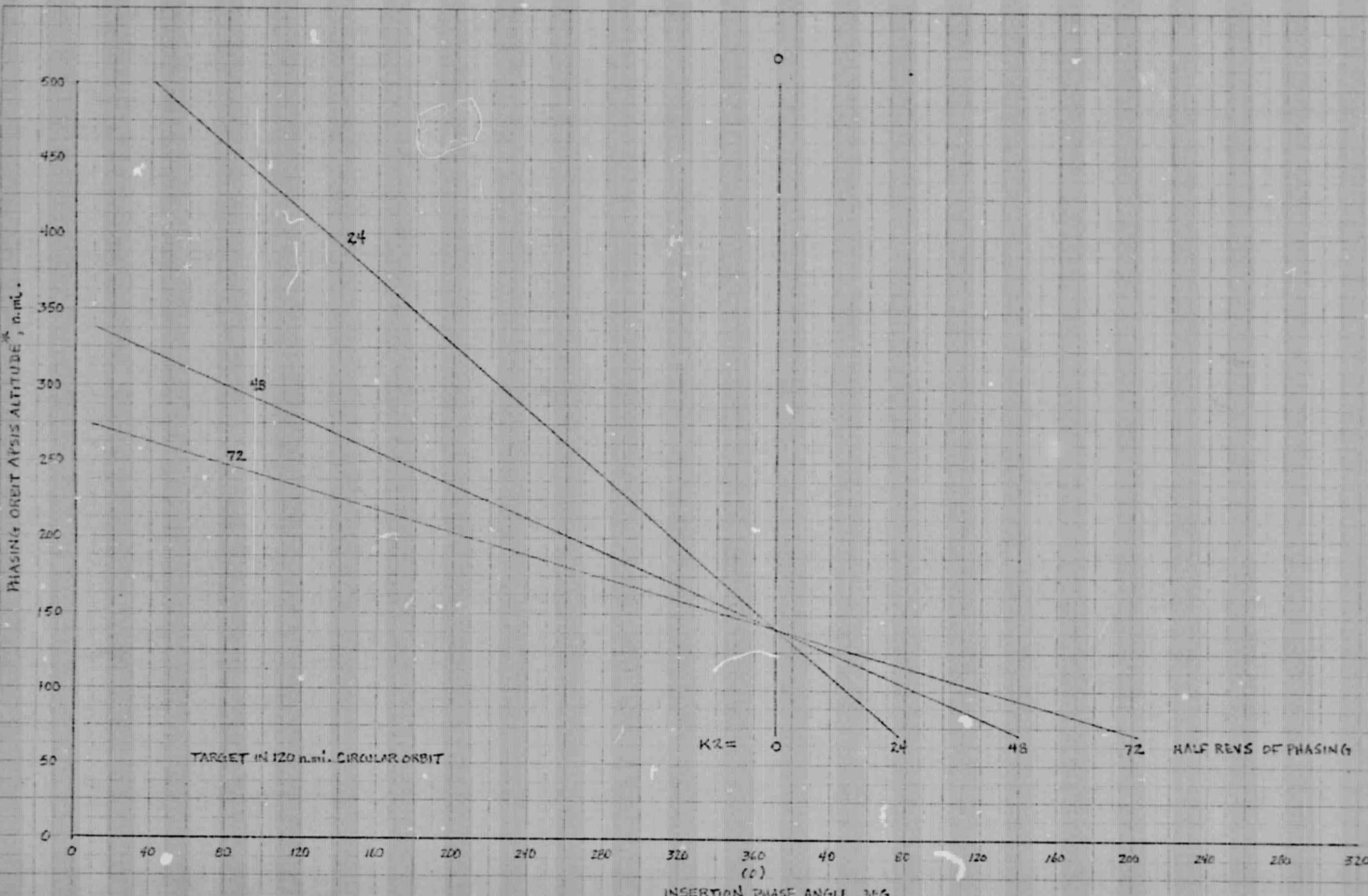


FIGURE 2 – HALF REVS OF PHASING AS FUNCTION OF INSERTION PHASE ANGLE FOR VARIOUS ELLIPTICAL PHASING ORBITS

On Figure 3 phasing orbit apsis altitude is shown as a function of insertion phase angle for half revs of 0, 24, 48 and 72. The curves are terminated at 70 n. mi. altitude because atmospheric drag becomes a serious problem in this region according to Reference 5.

In general, two solutions exist for an insertion phase angle. For example, by assuming 24 half revs of phasing it can be seen from Figure 3 that an insertion phase angle of 60 degrees may be accommodated by using either a 100 X 90 n. mi. or a 100 X 465 n. mi. phasing orbit. In the former case (100 X 90 n. mi.) the orbiter chases the target, and in the latter case (100 X 465 n. mi.) the target chases the orbiter. Because of atmospheric drag and heating considerations, the orbiter-chase solution will not handle all insertion phase angles. Assuming a minimum apsis altitude of 70 n. mi., the maximum achievable insertion phase angle for the 24 half rev case is about 76 degrees. To accomodate greater angles and maintain 24 half revs of phasing the target-chase solution typified by the higher orbit altitudes would have to be used.



* ONE APSIS ALTITUDE IS ASSUMED TO BE AT 100 n.mi.

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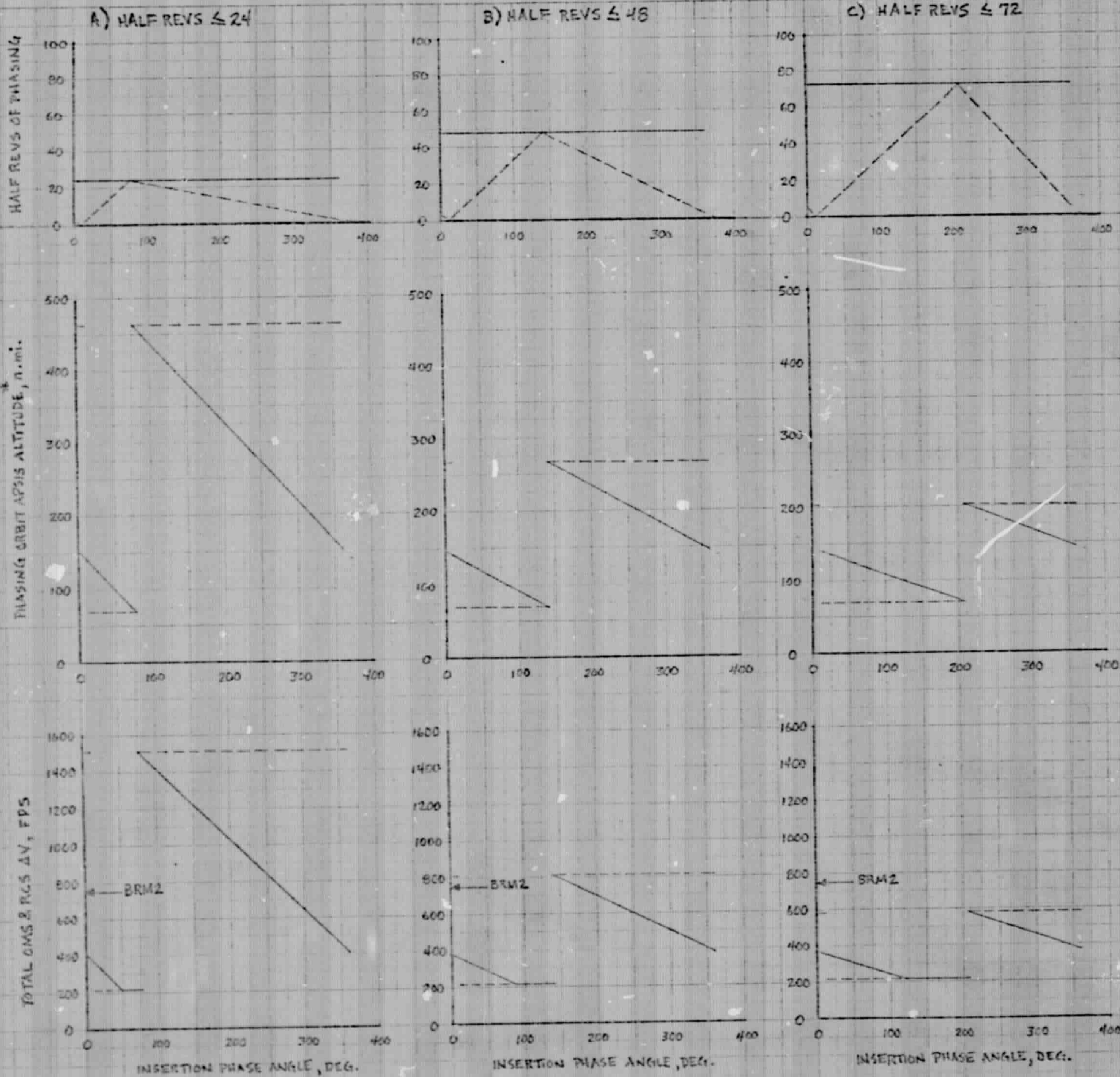
FIGURE 3 – PHASING ORBIT APSIS ALTITUDE AS FUNCTION OF INSERTION PHASE ANGLE FOR 0, 24, 48 AND 72 HALF REVS OF PHASING

Figures 4a, 4b and 4c present half rev, altitude and impulsive velocity requirements as functions of insertion phase angle for missions employing 24, 48 and 72 half revs of phasing. These may be considered to represent one, two and three day rendezvous situations, respectively. The BRM 2 ΔV of about 750 fps is indicated on each of the figures. No ΔV allotments have been made herein for orbital maintenance.

Referring to the 70 X 100 n. mi. curve on Figure 2, the limiting insertion phase angles for 24, 48 and 72 half rev phasing orbits are seen to be about 76°, 140° and 203° respectively. The discontinuities appearing on Figures 4a, 4b and 4c appear at these three locations. The segments (excluding the 0 to 11.4° phase angle sector) to the left of the discontinuities represent orbiter-chase solutions, and the segments to the right represent target-chase solutions.

Observe from Figure 4a which represents a 24 half rev mission that the ΔV's required to accomodate phase angles in the vicinity of 76° to 273° exceed the BRM 2 ΔV requirement. Moreover at one point (76+ degrees) they are nearly twice as high. Note, however, that for the 48 half rev case shown on Figure 4b the ΔV requirements for the entire insertion phase angle region are less than or nearly equivalent to the BRM 2 ΔV.



* ONE APSIS IS ASSUMED TO BE AT 100 n.mi.

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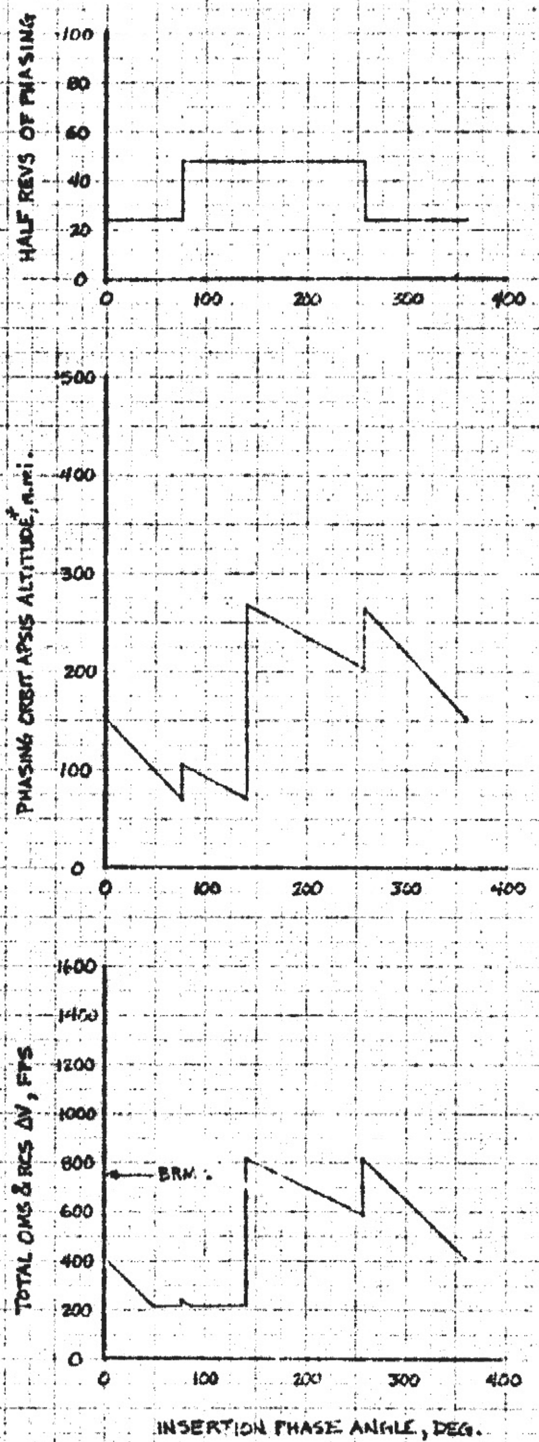
FIGURE 4 – HALF REVS, APSIS ALTITUDE AND ΔV REQUIREMENTS FOR RENDEZVOUS WITH A TARGET IN A 120 n.mi. CIRCULAR ORBIT

The dashed lines on Figure 4 represent minimum phasing time solutions. To the left of the discontinuities the lowest permissible phasing orbit was assumed (100 X 70 n. mi.) for all insertion phase angles in that sector, and to the right of the discontinuity (through 371.4° insertion phase angle) the highest required phasing orbit was assumed. The rationale for the latter was, "if a given propellant loading is required for one particular phasing geometry, why not use it to advantage to accomplish the rendezvous in a shorter time period when possible?" For the 24 half rev or less case (dashed lines on Figure 4a) a ΔV requirement of about twice the BRM 2 value would be required for insertion phase angles in the rightmost sector. For the 48 half rev or less case (dashed lines on Figure 4b) the ΔV requirement for the rightmost sector would be nearly equal to that of BRM 2. If this technique were used,both the apogee and perigee altitude of the phasing orbit and the mission ΔV requirement would remain fairly constant within a given insertion phase angle sector. Mission duration, however, could vary considerably, and such a variation might be objectionable from a crew duty cycle standpoint.

The recommended approach therefore is to utilize one day phasing (24 half revs) for those insertion phase angles exhibiting ΔV's less than BRM 2: otherwise employ two day phasing (48 half revs).

Figure 5 presents half revs, phasing orbit apsis altitude, and impulsive velocity requirements for the recommended solution. It can be seen from the apsis altitude profile on Figure 5 that the 24 half rev orbiter-chase solution has been employed for insertion phase angles between about 11.4° and 76°. From about 76° to 140° a 48 half rev orbiter-chase solution was used. For angles between about 140° and 257° a 48 half rev, target-chase solution was chosen, and from about 257° to 371°, a 24 half rev, target-chase solution.

Table 2 presents modified nominal sequence data for a typical rendezvous mission having a target in a 120 n. mi. circular orbit. An insertion phase angle of 0° and a phasing duration of 24 half revs were assumed in developing Table 2.



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* ONE APSIS IS ASSUMED TO BE AT 100 n.mi.

FIGURE 5 – RECOMMENDED HALF REV, APSIS ALTITUDE, AND ΔV PROFILES FOR RENDEZVOUS WITH A TARGET IN A 120 N.MI CIRCULAR ORBIT

TABLE 2

MODIFIED NOMINAL SEQUENCE FOR 120 N. MI. CIRCULAR TARGET ORBIT

Maneuver	h_a/h_p, n. mi.	ΔV, fps
1. MECO	-	-
2. Insertion *	100/50	136.1
3. Phasing	152.5/100	87+94=181
4. Height	100/100	94
5. First Coelliptic	100/100	0
6. Corrective Comb.	110/100	23
7. Second Coelliptic	110/110	22
8. TPI	120/110	20
9. TPF	120/120	55
10. Docking	-	10

* Insertion ΔV not included on Figures 4 and 5

The maneuvers appearing in Table 2 are identified on Figure 6.

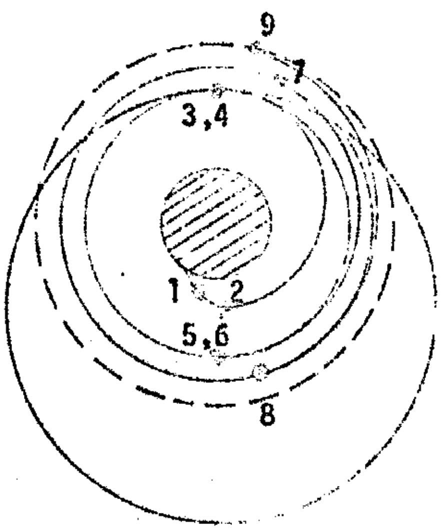

FIGURE 6 - SCHEMATIC OF RENDEZVOUS PROFILE

A study of this type usually generates more questions than answers and the present effort was no exception. Some questions which may be posed as a result of this study are:

- Rather than spending 2 days in a phasing orbit, can launch be delayed 1 or 2 days to improve the insertion phase angle? What is the daily variation of phase angle with inclination, altitude?
- Are special attitudes required to minimize drag when low elliptical phasing orbits are employed?
- What is the minimum practical altitude for a phasing orbit and what are the exact ΔV costs?
- If altitude maintenance is performed during phasing, exactly how should it be done?
- What are the effects of differential nodal rotation for the altitudes and phasing conditions required? How do you target these in OMDAP?
- When (if ever) is it desirable to add payload bay kits to increase ΔV capability and thereby reduce phasing times?
- Does the sequence conflict or interfere with any other shuttle operations? (rest periods, etc.)
- What additional ΔV's are required to develop launch windows? How do these ΔV requirements vary with orbit inclination?
- What special star tracker horizon interference problems arise for low orbit rendezvous?

- What peculiar tracking requirements are associated with low target orbits?
- What measures should be taken to guarantee proper lighting? What is the effect of orbit inclination?

5.0 CONCLUSIONS

In conclusion it may be stated that the nominal BRM 2 rendezvous sequence appears applicable for low target orbits with the following modifications:

A) Employ elliptical phasing orbits to allow the option of either orbiter-chase or target-chase.

B) Extend time-to-rendezvous to about two days under certain phasing conditions.

Follow on action is planned to:

A) Generate similar data for circular target orbit altitudes of 150 and 190 n. mi., assuming 10, 24, 48, and 72 half revs of phasing.

B) Determine orbit maintenance requirements for low phasing orbits, giving particular attention to:

i) identifying problem areas

ii) developing techniques

C) Investigate the nature of the star tracker problems for low orbit rendezvous.

6.0 REFERENCES

1. SSEOS Design Note No. 1.4-3-8, "Rendezvous Requirements and Candidate Worst Case Flights from the October 1973 Space

Shuttle Traffic Model," McDonnell Douglas Technical Services Company, Inc., dated 9 December 1974.

2. JSC Internal Note No. 72-FM-295, "Rendezvous Dispersion Analysis of the Apollo-Soyuz Test Project," Johnson Space Center, dated 15 January 1973.

3. JSC Internal Note No. 73-FM-47, "Space Shuttle Baseline Reference Missions-Volume II-Mission 2 Revision 1," Johnson Space Center, dated 29 May 1974.

4. Class Notes, MAB Rendezvous Class/E. Lineberry, given at Johnson Space Center, September 1974.

5. SSEOS Design Note No. 1.4-3-9, "Orbital Lifetime Studies in Support of Atmospheric, Magnetospheric, and Plasmas-in-Space Missions," McDonnell Douglas Technical Services Company, Inc., dated 9 December 1974.

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