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OPTIMUM INCLINATION FOR SHUTTLE RETRIEVAL OF INCLINATION NON-SENSITIVE SATELLITES

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16. ABSTRACT

This report presents the results of a study to identify the optimum inclination for a satellite when the satellite is inclination non-sensitive and is to be retrieved. This inclination is such that it provides an opportunity for a retrieval flight at least once each day with minimal on-orbit phasing requirements and minimal ascent performance losses.

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OPTIMUM INCLINATION FOR SHUTTLE RETRIEVAL OF INCLINATION NON-SENSITIVE SATELLITES

SUMMARY

Under current mission planning, the shuttle will be used for placement and retrieval of many different satellites in various orbits. Among these satellites are some which have biology experiments, ball bearing formation tests, etc., and which are not sensitive to the inclination of the orbit of the satellite. This report seeks to identify the inclination for placement of these satellites which provides an opportunity for a retrieval flight at least once each day with minimal on-orbit phasing and ascent performance requirements.

As pointed out in reference 1, which was a study of minimal energy phasing modes for rendezvous, extensive mission planning plays an important part in minimizing the on-orbit phasing requirements for a rendezvous regardless of the selected mode. Before launching his mission, the planner must consider if the satellite is to be available for rendezvous. This may place restrictions on the retrieval mission, such as requiring a launch on time on a particular day. If the launch, for some reason, fails to occur at the predetermined time, the shuttle would have to sit on the pad until the next favorable launch opportunity or would have to perform extensive on-orbit phasing. Both are expensive either in terms of mission time spent in non-productive phasing and/or in terms of OMS ΔV and net payload reduction. These extra factors may place such a constraint on the mission as to make it unfeasible. By employing a combination of proper mission planning and the optimal inclination solution as shown in this report, a versatile launch program with a minimal on-orbit phasing and ascent performance requirement is available. The selected inclination provides a 100 minute launch window, a 100 minute span of time over which launch can occur, with minimal performance penalty, and, as will be shown, assures the capability of the shuttle to launch on-time at least once every day in order to retrieve the satellite with minimal on-orbit phasing. The minimal phasing provides in return a maximum useful time on-orbit after retrieval for subsequent tasks. The minimal ascent performance penalty provides maximum payload capability; however, the capability is below the payload capability of the reference mission which is, in this case, the due east planar launch mission.

It should be noted that the launch window provided herein is provided to allow launch at the proper geometry for rendezvous independent of the actual satellite ephemeris, and is not provided for holds at launch. As the day of launch approaches and the emphemeris of the satellite becomes known with certainty, the actual launch time within the window to obtain proper geometry would also become known. If at this time, it were desired to provide a small operational launch window to account for launch holds, it can be provided if it were taken into account during the mission planning. Thus, we differentiate between the launch window for mission planning discussed in this report and the launch window used for operational launch holds.

I. STATEMENT OF PROBLEM

Within the range of missions which the shuttle will perform, there are missions from KSC which will require satellite placement and subsequent retrieval of the satellite. For the convenience of the shuttle and the mission planner, the satellites which have experiments which are not sensitive to the inclination of their orbit may be placed into an inclination which is convenient for launch and rendezvous-retrieval.

For rendezvous with a satellite, it is necessary that the shuttle be injected into the orbit plane of the target. If the shuttle must be injected inplane (no yaw steering during ascent), then there is only one (inclination equal to geocentric latitude of launch site) or two (inclination greater than about 28.5 degrees) times a day that launch can be effected. This occurs when the plane of the target orbit passes over the launch site. If the satellite is not at the proper position in the orbit to effect rendezvous directly, then the shuttle must inject into an orbit in the same plane, but with a different period in order to phase with the target until the proper phase angle with the target can be attained (reference 1). This time spent in phasing is frequently non-productive time and reduces the productive time on-orbit, currently limited to seven days. Even more significant for mission planning purposes is the fact that the actual ephemeris of the satellite is not well known until close to time of launch for retrieval. In planning a mission before launch for retrieval and even before launch for satellite placement, the mission planner has to build into his plan a time span which can be used for phasing and which is of variable length.

In order to effect the rendezvous without phasing, it is necessary that the shuttle be injected with the proper phase angle with respect to the target to initiate terminal rendezvous immediately. If the shuttle could adequately yaw steer during ascent in order to inject into the plane of the orbit of the satellite, then the launch could be planned at the time when the phase angle is correct and not worry about the orbit plane. This can eliminate the expensive, on-orbit "catchup" phasing requirements. The mission planner can plan the mission from ground elapsed time with certainty; the only uncertainty would be when to launch to get the proper phasing. As the launch date for rendezvous approaches, the target ephemeris becomes known and the time for launch is fixed.

It turns out that if the shuttle can be launched over a 100 minute span of time about the inplane launch opportunity (which occurs at least once daily), then launch can be assured with the proper phase angle to effect rendezvous without the use of a phasing orbit. Thus with this capability, one can be assured of the opportunity of launching once daily without needing a phasing orbit.

Since four minutes of launch window time is equal to a variation of one degree of node, this corresponds to asking the shuttle to be able to launch into an orbit of specified inclination but with a freedom of twenty-five degrees in the descending node. Reference 2 shows that nodal control for other than the inplane launch is very expensive in payload for inclinations much above due east (28.5°) from KSC. However, a large launch window can be achieved from KSC for inclinations corresponding to "near" due east launch. The task of this report is to find the inclination achieving the 100 minutes at minimum performance penalty compared to the inplane, due east launch.

II. GENERAL DISCUSSION

The identification of the inclination for placement of the satellite which provides a minimum performance loss across a 100 minute launch window for retrieval is the focal point of this study. The launch window provided in this study is a means of reducing the on-orbit phasing required to achieve rendezvous and retrieval with a satellite on its orbit about the earth. The method of developing the launch window for retrieval is by biasing the descending node of the orbital insertion point of the orbiter relative to the optimum value of the descending node for an in-plane launch. The launch relative descending node is defined as the angle measured from the launch meridian along the equatorial plane to the orbital plane intersection with the equator. Since a variation of descending node of one degree is equal to about four minutes of launch window time, 100 minutes of variation implies a change of about 25 degrees of node. A variation in the descending node about the optimum node developed by a planar flight trajectory produces a non-linear reduction in injection weight capability. The minimization of this reduction across the 100 minute launch window is our goal. Since the injection weight reduction is due to the yaw steering requirements during ascent to achieve the desired variation in the descending node, the selection of an optimal flight azimuth will reduce these payload losses. The azimuth is optimized such that part of the orbiter steering loss penalty is negated by aiming the booster in the proper direction to minimize the steering requirement to meet the desired insertion or main engine cutoff target conditions.

Inclinations ranging from due east to 29° were examined for ascent performance losses across the 100 minute launch window using both northerly and southerly flight azimuths. The orbit inclination of 28.8° was selected, as its launch window has a maximum of 204 Kg (450 lbs) of injection weight penalty compared to the optimum planar due east case. This is divided between 91 Kg (200 lbs) due to a higher inclination and 113 Kg (250 lbs) due to providing the 100 minutes of launch window. It is noted that this payload loss figure will be changed with more refined study as the shuttle configuration matures and the trajectory shaping criteria become better defined.

A discussion of the shuttle configuration, the ascent trajectory simulation, and the selection of the launch window is presented.

A. Shuttle Configuration Description

The preliminary space shuttle performance presented in this analysis was compiled for the RI shuttle configuration with an orbiter weighing 68,039 Kg (150,000 lbs) of dry weight and dated January 12, 1973. This configuration has a delta-wing orbiter, an 8.22m (324 inch) diameter external propellant tank, and two 3.6 meter (142 inch) diameter solid rocket motors. The solid rocket motors fire in parallel with the orbiter main engines during the boost phase. The solid rocket motors have thrust vector control capability. The motors are staged after boost and drop into the ocean to be recovered by recovery ships.

The three orbiter engines thrust at the "emergency" power level (EPL) setting from liftoff until the last Return-To-Launch Site (RTLS) point which occurs during the orbiter alone phase of flight. At this point, if there has been an orbiter engine-out, the two operating engines remain at the EPL setting until main engine cutoff (MECO). In addition, the OMS and RCS engines fire for a specified length of time prior to MECO. If an engine-out has not occured, all three main engines are set at the ascent normal power level until MECO. The RCS and OMS engines are not used for nominal flight. The target orbit is 56 x 105 n. mi. at MECO for the nominal flight case and 40 x 153 n.m. for the abort MECO.

The weight breakdown for this configuration is shown on Table 1. Some of the pertinent trajectory parameters are also shown for the RI configuration. This configuration has been updated; however, the results should remain essentially constant unless a major redesign occurs. The trajectory simulation employed herein is the most rigorous description of the launch vehicle performance available at this time. The design groundrules and data used for the trajectory and configuration design are shown on Table 2. The thrust trace delivered by one SRM in the SRB is a saddle shaped trace and is shown on Figure 1.

The due east mission from KSC nominally carries 65,000 pounds of payload into orbit. The payloads shown in this report will be referenced to this baseline payload. The OMS ΔV budget for the due east mission is currently 198 MPS (650 fps) and the RCS translation ΔV budget is 30.5 MPS (100 FPS).

B. Shuttle Ascent Performance Description

The performance analyses used to develop the 100 minutes launch window for the various satellite inclinations were accomplished using the RAGMOP program. This program was developed by MSFC and is documented in reference 3. This program is for parametric ascent trajectory optimization. It computes the optimum, polynomial form, attitude control histories, the optimum engine burn times and the optimum launch azimuths using a search-accelerated, gradient-projection, parameter optimization technique. The trajectory model includes a rotating, oblate earth model, a scheme for the continuous throttling of the orbiter engines to limit thrust acceleration during the orbiter phase of flight, and a lofting scheme to constrain the maximum ascent dynamic pressure.

The major trajectory effects which were taken into account during the performance analysis are as follows:

1. The aerodynamic and orbiter thrust moments are balanced by solid rocket motor gimbal deflection during boost and by SSME gimbal deflection during the orbiter alone flight phase.

2. The orbiter is yaw steered from SRB staging to main engine cutoff to obtain node variations across the launch window.

3. The launch vehicle flight azimuth is optimized to minimize the yaw steering losses by the orbiter.

4. The launch vehicle is rolled to the optimum flight azimuth at five seconds after liftoff. The launch vehicle is initially positioned with the orbiter tail fin set to the due south direction.

5. The launch vehicle is pitched over at five seconds after liftoff in an orbiter "heads down" flight attitude.

6. The usable propellant in the external tank is constrained to 700,656 Kg.

The baseline trajectory for the booster phase and the orbiter-alone phase until the last RTLS point is shaped as the "abort" flight mode which assumes an orbiter engine-out at the last RTLS point. The abort trajectory is shaped to assure a once-around flight back to the landing site in case of an engine-out on the orbiter. The trajectory for the nominal case is shaped from the last RTLS point on the abort trajectory to the nominal main engine cutoff point. The specified inclination and descending node at main engine cutoff for the launch window analysis are achieved in both the abort and nominal flight modes.

C. The Launch Window Inclination Selection

The selection of the proper 100 minute launch window for satellite rendezvous and retrieval is based on an analysis of the near due east orbit inclinations. Previous studies have shown that except for the due east inclinations, the descending node variations with ascent yaw steering are very expensive with respect to performance penalties even with optimum flight azimuths. This is shown by the increase in performance penalties across the window as the inclinations are increased from the due east mission as displayed from a prior unpublished study by the author on Figure 2 using a general launch site in the KSC area. Thus the intent of the trajectory analysis is to minimize the yaw steering penalties and associated injection weight penalties with a judicious selection of orbit inclination near due east.

The inclinations greater than 28.8° shown in Figure 2 suffer substantial losses in injection weight capability across the window for both the abort and nominal missions. The critical design weight is the abort mission injection weight as it is the maximum weight which can be carried into orbit and safely returned in case of an abort. This weight, together with the OMS and RCS propellant weights burned during the abort trajectory, provide the maximum weight loading aboard the shuttle which can be successfully flown on the nominal mission and maintain an intact abort capability in case of a main engine failure at the last return-to-launch site point in the trajectory. This specifies that the choice of inclination be made with respect to the abort injection weights across the launch window. From Figure 2, it can be seen that the inclinations in the range from 28.6 to 28.8 have the near-minimum injection weight penalties across the 100 minute launch window for the launch site used. As can be seen, an inclination of 28.6 has larger losses at the edge of the window than at the center while 28.8 has larger losses at the center than at the edge for the launch site used in the previous study. It is clear that an intermediate inclination for any selected launch site could be found that has smaller losses at the center than 28.8 and has smaller losses at the edge of the window than 28.6, resulting in a smaller maximum injection weight loss across the window. Further reflection would indicate that the smallest maximum performance loss across the window would occur when the losses at the edge and the center are balanced.

The purpose of this study is to determine the unique inclination having balanced losses across the launch window for the current shuttle launch site, Pad 39A, (39B is only .0189° north, so the results are sufficiently applicable).

The final results of the current study are shown on the Figure 3. The selected inclination of 28.8° has a 100 minute launch window which has payload losses on the ends which equal the payload losses in the middle of the window. This inclination has a 100 minute launch window which has a maximum injection weight penalty of 204 Kg (450 lbs) compared to the planar due east mission. This penalty is divided between 91 Kg (200 lbs) due to the higher orbit inclination and 113 Kg (250 lbs) due to provision for the launch window. This payload penalty of 204 Kg (450 lbs) is the amount of payload which must be offloaded by the mission planner from the 29,484 Kg (65,000 lbs) payload capability of the shuttle for a due east planar mission. This assures that the shuttle can inject successfully for all flights within this 100 minute launch window and retain intact abort capability. The optimum flight azimuth for each target descending node is shown on Figure 3.

It should be noted that the trajectory shaping criteria and vehicle configuration are not firm at this time and will change with the maturity of the shuttle program. Thus it appears suitable to recommend that the inclination of 28.8° be selected as the inclination for the inclination-insensitive satellites for which retrieval is planned. Subsequent studies will be performed in the future to redefine more closely the penalties and orbit inclination for the selected launch site location at KSC.

III. CONCLUSIONS

This report deals with the selection of an inclination for placement of a satellite such that a daily, on-time launch for retrieval can be achieved with minimal on-orbit phasing requirements on the shuttle. These satellites to be placed into orbit are not sensitive to the inclination of their orbit about the earth. This allows the mission planner to place the satellite in such an inclination that the satellite may be visited and/or retrieved on any day in the future and retain almost full capability (except for payload bay volume in the case of retrieval) to execute a different mission. It may eliminate the need for further on-orbit phasing and extends the useful mission lifetime.

The study has established that the inclination of about 28.8° is suitable for satellite placement. It satisfies the criteria for selection as it has a maximum penalty of 204 Kg (450 lbs) of injection weight to provide the 100 minute launch window.

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TABLE 1

ROCKWELL INTERNATIONAL BASELINE CONFIGURATION

	Metric	English
GROSS LIFTOFF WEIGHT	1,860,400 kg**	4,101,483 lbs**
SRM LIFTOFF WEIGHT	1,024,560 kg	2,258,777 lbs
SRM PROPELLANT	879,260 kg	1,938,444 lbs
SRM INERT WEIGHT	145,300 kg	320,333 lbs
ORBITER LIFTOFF WEIGHT	835,837 kg**	1,842,706 lbs**
PROPELLANT MAINSTAGE	700,656 kg	1,544,684 lbs
OMS (ASCENT)*	2,310 kg	5,095 lbs
ACPS (ASCENT)*	907 kg	2,000 lbs
TOTAL INJECTED WEIGHT	131,960 kg**	290,927 lbs**
WET TANK WEIGHT	40,857 kg	90,076 lbs
FPR	2,385 kg	5,260 lbs
RESIDUALS	4,792 kg	10,566 lbs
DRY TANK	33,680 kg	74,250 lbs
ORBITER INJECTED WEIGHT	91,104 kg**	200,851 lbs**
OMS	0	0
ACPS	1,181 kg	2,605 lbs
EXPENDABLES	1,622 kg	3,578 lbs
PAYLOAD	18,160 kg**	40,037 lbs**
ORBITER LANDED WEIGHT (LESS PAYLOAD)	70,140 kg	154,631 lbs
ORBITER DRY WEIGHT	68,039 kg	150,000 lbs
STAGING		
REL VELOCITY	1,368 mps	4,483 fps
FLIGHT PATH ANGLE	29.015 deg	29.015 deg
ALTITUDE	41,424 m	135,904 ft
MAXIMUM DYNAMIC PRESSURE	3,173 ksm	650 psf
TIME AT MAXIMUM Q	55 sec	55 sec
VELOCITY AT LAST RTLS POINT	2,700 mps	8,860 fps

* CONSUMED DURING ABORT-TO-ORBIT

** SOUTH POLAR MISSION FROM WTR

TABLE 2

CONFIGURATION DESIGN CHARACTERISTICS

SYSTEM	
LAUNCH SITE	KSC
PARALLEL BURN	YES
T/W AT LIFTOFF	1.7
MAX G	3.0
MAX Q (CONSTRAINED BY LOFTING)	3,173 KSM (650 psf)
FIXED ET PROPELLANT (W/O FPR)	700,656 kg (1,544,684 lbs)
ET DIAMETER	8.22 m (324 inches)
LAUNCH SITE LATITUDE (PAD 39A)	28.608422 deg
LAUNCH SITE LONGITUDE (PAD 39A)	80.604133 deg
ROLL INITIATION TIME	5 sec
SRB	
PROPELLANT	PBAN
NOZZLE EXPANSION RATIO	11:1
DIAMETER OF SRM	3.60 m (142 inches)
THRUST SHAPE	Saddle
CANT ANGLE	0^{o}
SRM EXIT AREA	10.05 m^2 (108.2 ft^2)
SRM VACUUM ISP	266.3 sec
THRUST VECTOR CONTROL	Yes
ORBITER	
RELATIVE VELOCITY AT LAST RTLS POINT	2,700 mps (8860 fps)
SSME THROTTLE DURING BOOST	No
SSME VACUUM THRUST (EPL)	232,786 kg (513,200 lbs)
SSME VACUUM THRUST (NPL)	213,191 kg (470,000 lbs)
SSME VACUUM ISP	455.2 sec
OMS VACUUM THRUST	2,721.6 kg (6,000 lbs)
OMS VACUUM ISP	313.2 sec
NUMBER OF OMS PODS	2
RCS VACUUM THRUST	431 kg (950 lbs)
RCS VACUUM ISP	230 sec
NUMBER OF RCS MOTORS	4

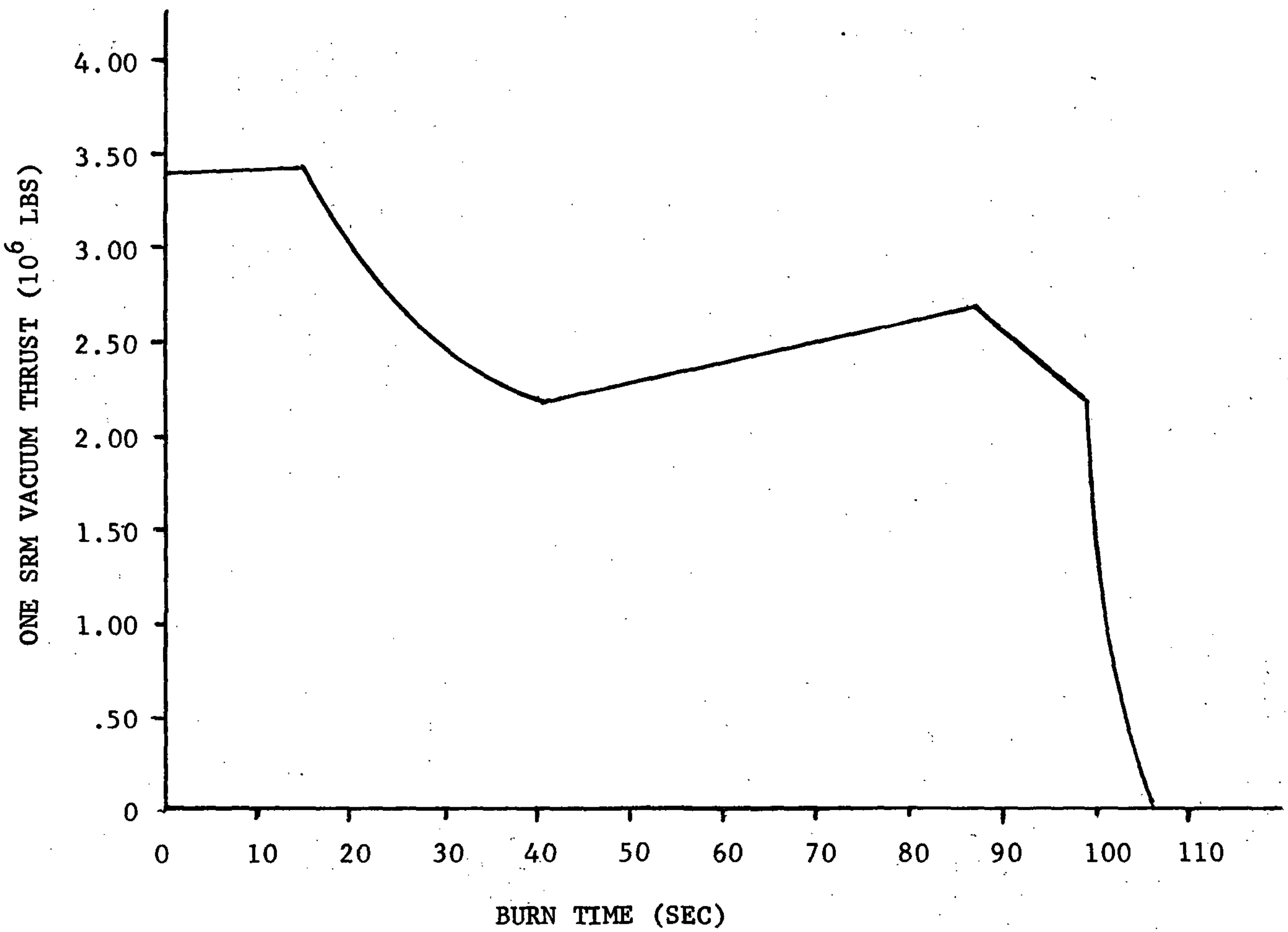

FIGURE 1. SRM VACUUM THRUST PROFILE

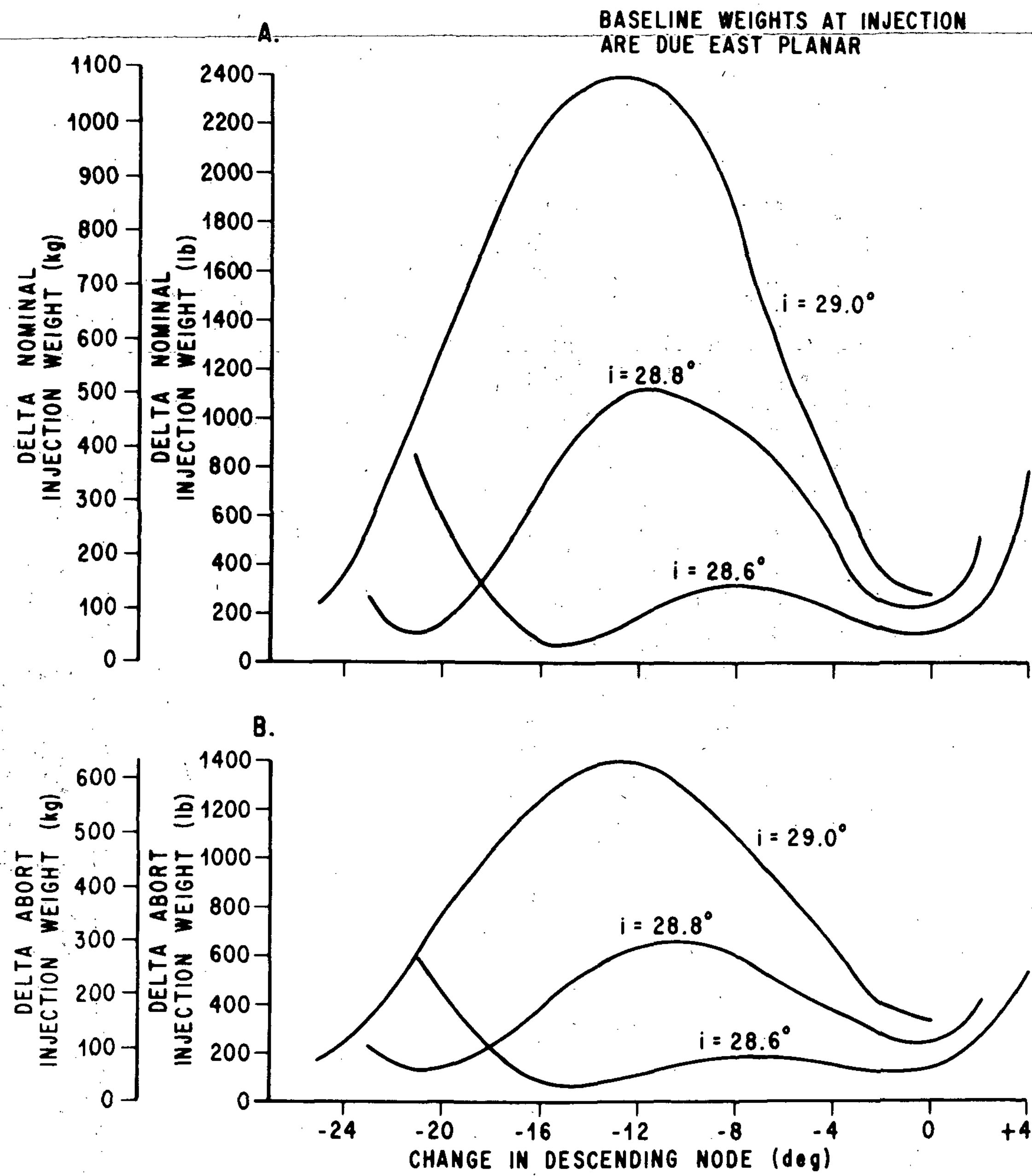

FIGURE 2. COMPARISON OF INJECTION WEIGHTS FOR THE ABORT AND NOMINAL DESIGN MISSIONS FOR VARIATION OF ORBIT INCLINATION

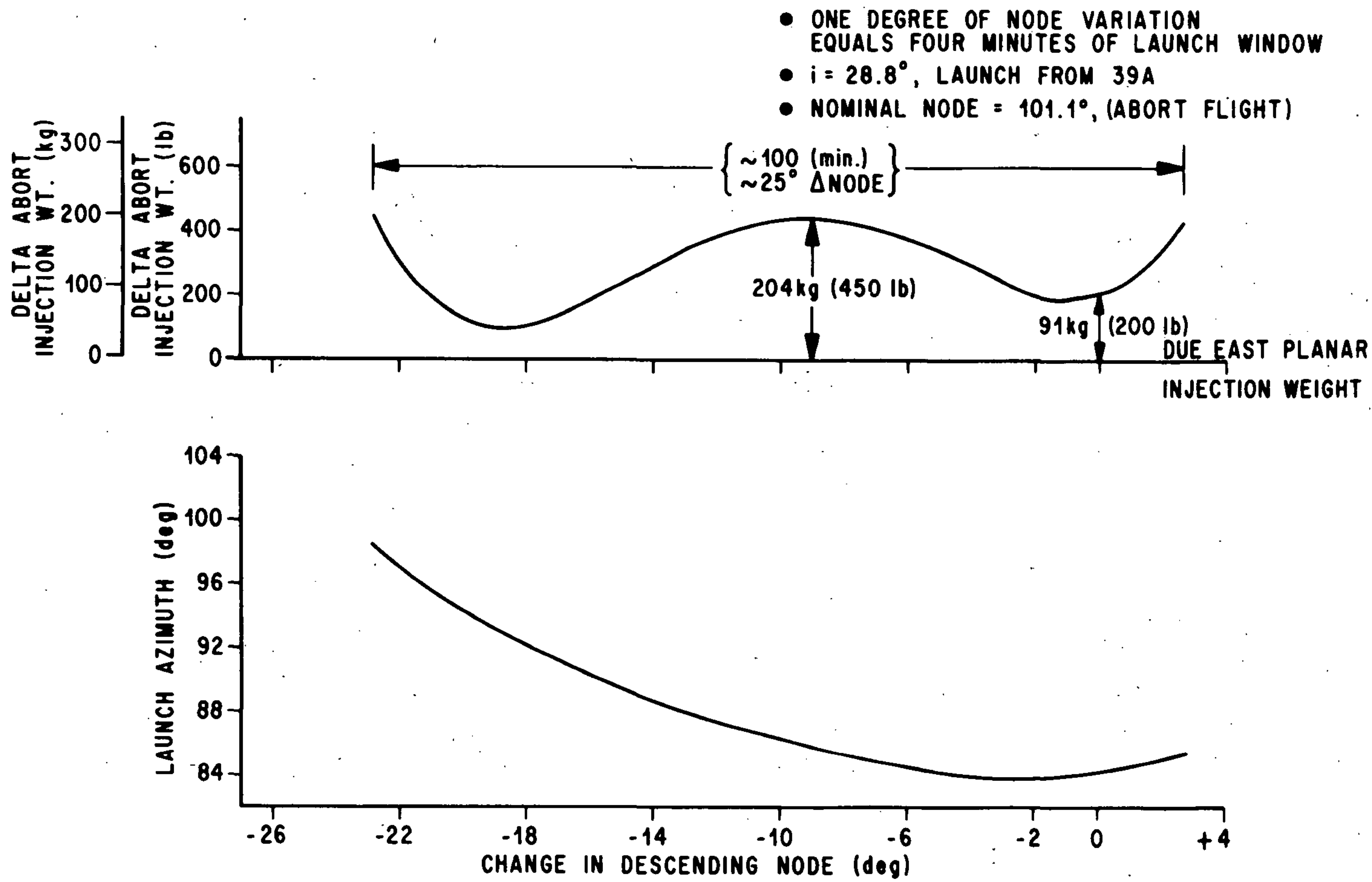

FIGURE 3. LAUNCH WINDOW INJECTION WEIGHT VARIATION AND OPTIMAL FLIGHT AZIMUTH

APPROVAL

OPTIMUM INCLINATION FOR SHUTTLE RETRIEVAL OF INCLINATION NON-SENSITIVE SATELLITES

by D. L. Blackwell

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

for H. J. Horn

E. D. Geissler, Director
Aero-Astrodynamics Laboratory

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