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National Aeronautics and Space Administration

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SHUTTLE PROGRAM

POTENTIAL PROBLEMS RELATIVE TO TDRS/IUS TILT TABLE ELEVATION WITH FAILED VRCS

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CONTENTS

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FIGURES

1.0 SUMMARY

This report presents a potential problem - the associated operational concerns and preliminary solution alternatives related to elevating the inertial upper stage/tracking and data relay satellite (IUS/TDRS) with a failed Orbiter vernier reaction control system (VRCS). This problem arises from the combination of TDRS thermal constraints and tilt table constraints (the primary reaction control system (PRCS) cannot be used to hold attitude while the tilt table is being elevated), and the problem is compounded by the minimum PRCS attitude deadband. The potential solution options appear to affect and/or be affected by the launch window, flight profile, crew procedures, vehicle (IUS, TDRS, Orbiter) capability and constraints, flight rules, etc.; therefore, if the solution to this problem is to be anything other than to abort the mission, it appears that the selection of the implementation method cannot be made unilaterally but will require the consensus of all elements.

The preliminary assessment and evaluation as described in this document was made within the present knowledge and visibility of the author. It is acknowledged that some facts used in this assessment may not be current; that other considerations and information, of which the author is unaware, may exist that significantly affect the magnitude of the problem and/or the conclusions drawn; and finally, that other (and better) solutions may exist. Therefore, comments and inputs are solicited. Questions related to this document should be referred to Jerome Bell, mail code FM2, extension 4346.

2.0 INTRODUCTION

Current Space Transportation System (STS) guidelines appear to be directed towards designing deployable payloads to be compatible with the PRCS operation in the event of a failure of the nonredundant VRCS. This capability, then, would not preclude mission success in the event of the single-point VRCS failure; to this end, previous and present flight planning activities have provided for VRCS failure contingency in the propellant budget. With respect to the TDRS/IUS (STS-5), such a failure also has a potential timeline impact when considered in relation to the TDRS/IUS current understood design constraints and the operational timeline developed to date. The purpose of this document is to identify potential problems associated with tilt-table elevation in case of VRCS failure, potential impacts to the present STS-5 timeline, and options for flight design solution.

3.0 SYMBOLS AND ACRONYMS

ASE	airborne support equipment
AGO	Santiago Ground Station
AOS	acquisition of signal
CIR	cargo integration review

GET	ground elapsed time
GMT	Greenwich mean time
GMTLO	Greenwich mean time of lift-off
GN&C	guidance, navigation, and control
GSTDN	ground spaceflight tracking and data network
IOS	Indian Ocean Ground Station
IUS	inertial upper stage
LOS	loss-of-signal
MPAD	Mission Planning and Analysis Division
PI	payload integrator
PIP	payload integration plan
PRCS	primary reaction control system
RF	radio frequency
RTS	remote tracking site
SRM	solid rocket motor
STDN	spaceflight tracking and data network
STS	Space Transportation System
TDRS-A	tracking and data relay satellite - first flight
VRCS	vernier reaction control system
ZLV	Z local vertical, payload bay along radius vector toward center of Earth, Orbiter nose parallel to the velocity vector

4.0 REQUIREMENTS AND CONSTRAINTS

The following requirements and constraints are understood to apply during elevation of the IUS/TDRS from the payload bay:

a. While the tilt table is in motion, the Orbiter may either be under VRCS control or in free drift. Active attitude control using the PRCS while the tilt table is in motion is not permitted.

b. When the TDRS is elevated in the Orbiter, it shall be shadowed from the Sun by the Orbiter or be in the eclipse of the Earth.

c. With the tilt table up, the Orbiter is to avoid attitudes that permit Orbiter radiators to reflect solar radiation onto the IUS.

d. The airborne support equipment (ASE) erects at approximately 0.1 deg/sec. Total time is approximately 280 seconds for 29 degrees of travel.

In addition, the following operations requirements were derived from the flight planning activity:

a. The nominal ground elapsed time (GET) to elevate the TDRS/IUS 29 degrees out of the payload bay is about 9 hours.

b. The TDRS is to be elevated for activation of its transmitter over the ground spacecraft tracking and data networks (GSTDN).

c. Launch window constraints dictate that 9 hours GET be a daylight environment.

5.0 NOMINAL TIMELINE

In order to investigate what adverse effects, if any, result from having to elevate the TDRS/IUS without VRCS control, the nominal (baseline) TDRS timeline was utilized. This timeline calls for the Orbiter to maneuver from Z local vertical (ZLV) to deployment attitude just after 8 hours 50 minutes GET, which establishes a solar protection (Orbiter-shadowing) attitude for TDRS. This attitude maneuver is then followed by elevation of the TDRS/IUS configuration to 29 degrees. Predicated on using the Hawaii GSTDN pass at 9 hours 15 minutes GET to activate the TDRS transmitter and based on the present constraint that the TDRS must be elevated prior to turning on the transmitter, the 9-hour GET reflects approximately the latest time to plan elevation to 29 degrees. Additionally, in the interest of minimizing the time the TDRS spacecraft must be exposed to the environment during elevation, and also with consideration given to initializing and verifying the activation of the IUS guidance computer prior to elevation, the 8-hour 50-minute GET is approximately the earliest time for elevation. This allows the Indian Ocean ground station (IOS) (with Hawaii as a backup) to uplink the ground-determined state vector to the Orbiter, which in turn will be transferred to the IUS.

With regard to maneuvering the TDRS/IUS from 29 degrees to the ejection position of 58 degrees, the IUS power budget must be considered; this budget is based on switching to internal IUS power no later than 10 minutes prior to ejection. Since the umbilical is pulled during this phase of the erection process, dictating that the IUS be on internal power prior to final elevation sequence, the elevation to 58 degrees should nominally not be planned earlier than 10 minutes prior to deployment.

Based on the TDRS launch window, the above tilt-table elevation activities - both from 0 to 29 degrees and from 29 to 58 degrees - will occur during daylight, which will necessitate protection from the Sun during elevation.

6.0 ANALYSIS

The position of the Sun relative to the Orbiter was generated assuming that the Orbiter will be in deployment attitude under PRCS control prior to elevation of the tilt table, and also that the PRCS is inhibited and the Orbiter placed in free drift at the time elevation is initiated. Figures 1(a) through 1(e) illustrate a typical time history of Sun location relative to the Orbiter body for various assumed initial drift rates, positions, and orientations of the TDRS. For this assessment, the PRCS deadband residual rates at inhibition of the PRCS were assumed to be 0.1 deg/sec/axis, although it is recognized that the current guaranteed minimum rate is 0.2 deg/sec/axis. The 0.1 deg/sec/axis rate was ascertained to be adequate to establish trends and to identify concerns. There also appears to be a feeling that the Orbiter would potentially stabilize at a deadband rate less than 0.2 deg/sec/axis, given sufficient time. Therefore, the 0.1 deg/sec/axis was investigated in order to avoid being overly pessimistic at the outset with knowledge that the higher deadband rate of 0.2 deg/sec/axis would tend to make the results even worse.

It should be noted that the simulation only considered an initial attitude and a set of attitude rates, which then were acted on by gravity gradient torques. The fact was not considered that as the tilt table is being raised the Orbiter will experience an attitude excursion. It is estimated that for the case where the Orbiter begins with an inertial rate of zero deg/sec/axis, the Orbiter attitude would only be changed on the order of about 1 to 2 degrees during the time period that the IUS/TDRS is elevated through a 58-degree angle. Moving the tilt table at 0.1 deg/sec/axis would induce an Orbiter pitch rate of less than 0.01 deg/sec, which is an order of magnitude less than the assumed initial rate.

Four sets of initial attitude rates were investigated. Case A in figures 1(a) through 1(e) reflects the ideal situation of beginning with a zero deg/sec/axis deadband at the time the Orbiter initiates free drift. Case B reflects a positive pitch rate of 0.1 deg/sec with zero deg/sec in yaw and roll at the time free drift is initiated. Inasmuch as the deployment attitude requires the Sun to be behind and below the Orbiter at an angle of 58 degrees relative to the Orbiter X-axis, a positive pitch would result in the payload bay being exposed to the Sun in the shortest amount of time. An initial negative (nose down) pitch rate would require the Orbiter to rotate through an additional 64 degrees to have the Orbiter payload bay facing in the same direction relative to the Sun as a positive (nose up) pitch. Case C assumes initial attitude rates of 0.1 deg/sec in all axes while case D assumes a deadband rate of 0.1 deg/sec existing in yaw and roll only.

The Sun trajectories, with respect to the Orbiter body axis for each of the four initial conditions described above, are plotted in figures 1(a) through 1(e); they are the same in each figure. The difference between figures 1(a) and 1(e) is the blockage provided by the Orbiter for reference points on the TDRS at various elevated positions.

Despite the fact that the body blockage is dynamic while the TDRS/IUS is being elevated, and in the absence of the availability of a model to predict the instantaneous body blockage relative to the solar vector, figures 1(a) through 1(e) assume that the body blockage remains static for the time interval under consideration.

Referring to figures 1(a) and 1(b) (stowed cargo configuration), which typify the maximum shadowing afforded by the Orbiter, it is seen that the cargo element will be exposed to a Sun environment for no longer than approximately 5 minutes (case C), which is the approximate nominal length of time required to raise the tilt table. Figures 1(c) and 1(d) show that the payload could be exposed to the Sun in about 4 minutes. Assuming that for short-term intervals the attitude time history can be scaled by the initial attitude rate, it appears then that a 0.2 deg/sec/axis deadband rate would result in violation of the solar constraints from 2 to 2.5 minutes after the Orbiter is placed in free drift. Assuming that the elevation was initiated immediately, this time would equate to about midway through the process of elevating to 29 degrees.

Figure 1(e) shows the potential Sun shadow that exists when the TDRS/IUS is elevated to the ejection position at 58 degrees. It is seen for this configuration that case C results in daylight exposure in about 2.5 minutes; the higher 0.2 deg/sec rate could be expected to result in solar exposure in about 1 minute.

Figure 2 shows, for information purposes, the time history of the Sun position relative to the stowed thermal constraints of the TDRS. (These constraints are the current constraints contained in the TDRS payload integration plan (PIP) and are mapped as a pitch/yaw rather than roll/pitch). Since these solar exposure constraints apply to a stowed configuration, and since the present constraint is for no solar impingement when elevated, it appears reasonable to assume that the limits during the elevation process (at least from 0 to 29 degrees) will either be zero or between zero and the time limits shown in figure 2. From figure 2, the following observations can be made:

a. Independent of whether the tilt table is being elevated or in fact remains stowed, the TDRS thermal constraints appear to limit the time in an uncontrolled free drift. Case D illustrates that less than 15 minutes of free drift time is available; for 0.2 deg/sec/axis rate, it is reasonable to expect a significant decrease in available time. (Since case C traverses many thermal constraints boundaries, it is difficult to assess exactly when the thermal constraint is violated, although perhaps the limit is 10 minutes after free drift is initiated).

b. Past discussions have implied the possibility that the tilt table is moving at a rate slower than 0.1 deg/sec. It seems unlikely that the TDRS (and perhaps even the IUS) can tolerate elevation time longer than 5 minutes, which results from elevation rates slower than about 0.1 deg/sec, without active attitude control.

In fact, at 0.1 deg/sec elevation rate, the STS also loses the flexibility to elevate from a stowed configuration directly to 58 degrees (without stopping).

7.0 ASSESSMENT

From the previous discussion, it appears that the STS may not be able to support elevating the TDRS/IUS under the conditions of a failed VRCS and a 0.2 deg/sec/axis PRCS deadband without impact to procedures and/or timeline. This section attempts to identify and assess some potential options for solving the problem of elevating the TDRS/IUS with failed verniers.

7.1 OPTION 1: ELEVATE DURING DARKNESS

The obvious candidate solution for elevation of the TDRS/IUS when the VRCS has failed is to utilize a darkness pass for elevation. In a generic sense (totally separated from any other integrated operational consideration), this strategy would allow the elevation to occur without need of concern for violating the TDRS or IUS thermal constraints and would impose no constraint on Orbiter attitude prior to or during elevation; it then follows that the initial drift rates resulting from PRCS deadband would not be of concern. (This observation presupposes that the elevation process can be accomplished within one darkness pass - approximately 33 to 36 minutes. There is no information that indicates otherwise.) This implementation concept must be evaluated in context of the integrated set of activities that must be supported and the trajectory/ environment opportunities that occur for this flight.

7.1.1 Elevation to 29 Degrees

If the VRCS fails early in the flight (prior to nominal time of elevation), there is potentially some flexibility (and its associated implications) as to when the tilt table can be raised to 29 degrees. Based upon the fact that the IUS must be in a stowed configuration for the star scan, the star scan must essentially occur during darkness for TDRS thermal protection; the realistic time of launch for TDRS-A will occur in the afternoon (19:35 GMT). The opportunities associated with nighttime elevation of the tilt table prior to nominal deployment opportunity are approximately 6:20 to 6:35 GET, 7:50 to 8:25 GET, and 9:20 to 9:55 GET. In addition, the opportunity associated with the ascending node, taking into consideration a second star scan and the crew work/rest schedule, would be 22:55 to 23:25 GET.

7.1.1.1 6:20 to 6:55 GET Opportunity

The 6:20 to 6:55 GET darkness pass for elevation to 29 degrees is not recommended when the VRCS fails. This time period occurs in the midst of the groundtracking activity for orbit determination; since an attitude maneuver would be required to achieve a thermal protection attitude after elevation and prior to sunrise, degradation in the accuracy of the state vector would be expected to occur. While the exact effect of this maneuver has not been evaluated relative to state vector accuracy (to a limited degree the amount of PRCS thrusting can be controlled by maneuvering at the slowest possible rates, i.e., nontime-critical), it is undesirable to be maneuvering during this period of gathering data. A quiescent Orbiter (in terms of maneuvering) is preferred in order not to corrupt the tracking measurements made prior to the maneuver. There appears to be no advantage to elevating the TDRS/IUS at this opportunity other than that it provides enough time so as not to interfere with other mandatory activities; hence, the capability for nominal deployment is retained. On the other hand, utilization of the nighttime elevation opportunity suggests the following:

a. Assuming that the tilt table has no capability for multiple erection, commitment to a descending node opportunity will be required without the IUS state vector transfer having been made and verified. (Currently this activity is planned to nominally occur over IUS at above 8:35 GET). In other words, the flexibility for utilizing the ascending deployment opportunity would be sacrificed with a major checkout operation outstanding that is over and above the requirement for the nominal plan. (Currently TDRS/IUS design requires that the TDRS/IUS be elevated for turning on the TDRS transmitter and for transferring the TDRS to IUS internal power.

b. To support the total set of descending node opportunities, the IUS/TDRS would need to remain elevated for between 6 and 7 hours (in deployment attitude). Taking the proposed TDRS revision to the thermal constraints (presented at the April 1980 STS/TDRS Interface Working Group) as 130 minutes of deep space viewing and 5.5 hours in deployment attitude for a 24.5-hour stay in the Orbiter, it appears (subject to TDRS verification) that the 7-hour elevation time can be attained at the expense of an estimated 2-hour reduction in Orbiter stay time (22.5-hour maximum), a 1-hour reduction in deep space viewing (70-minute maximum) or some combination of the above, such as a resultant capability of 24 hours in the bay and 85 minutes of deep space facing. The multiple erection problem presently makes this concern a moot point since the ascending node capability is not required after the TDRS/IUS is once elevated. If the multiple erection capability were available, all deployment opportunities in all likelihood still could not be achieved; the ascending node would require an additional 1 hour (minimum) of time in the elevated position, which further reduces the Orbiter stay time and deep space capability. Preserving the deep space capability would decrease the stay time by an additional 1.3 hours, and the optimum deployment would need to be one orbit early.

c. A 2- to 2.5-hour gap would exist in the nominal timeline that could not be supported with this elevation opportunity. (This represents 22 to 28 percent of the time to nominal elevation.) It would then appear reasonable to assume that this gap is large enough to warrant designing the contingency strategy to handle a VRCS failure during this last 2- to 2.5-hour timeframe on an equal probability with earlier failure occurrences (this assumption is certainly debatable). Since the foregoing assumption leads to designing for a later failure occurrence, there is no identified reason to hurry elevation.

7.1.1.2 7:50 to 8:25 GET Opportunity

The 7:50 to 8:25 GET darkness pass for elevation to 29 degrees is the last opportunity to elevate to 29 degrees in darkness prior to the nominal elevation time; consequently, this may be the last opportunity to elevate the IUS/TDRS in darkness and still meet the nominal deployment time. The same considerations apply to this opportunity as discussed for the 6:20 to 6:55 GET opportunity, although in some instances the significance of the particular implication may be altered.

a. First and foremost, elevation at this time requires a commitment to the descending mode with the same reservations and implications as previously discussed for the 6:20 to 6:55 GET opportunity; i.e., no state vector transfer check. It appears that the risk associated with committment to a descending node opportunity without the state vector transfer can be reduced by nominally planning to check out the capability for state vector transfer early in the flight (this strategy also would be available for the 6:20 to 6:55 opportunity). By doing this check early, confidence that the system is working is gained and, therefore, all that remains prior to deployment is an uplink of the actual state vector to be used by the IUS guidance, navigation, and control (GN&C). This early check does not have any impact because the present flight profile concept entails performing orbit trim maneuvers that also require ground tracking and orbit determination processing.

b. Similar to the discussion pertaining to the earlier darkness opportunity, an attitude maneuver is required to achieve the deployment attitude after elevation and prior to orbital sunrise. The difference between this opportunity and the 6:20 to 6:55 GET opportunity is that this maneuver occurs after the tracking has been completed rather than in the middle of the tracking period. Since the nominal timeline also requires an attitude maneuver after the state vector has been generated, the additional degradation in state vector accuracy at deployment time is attributable to an additional 25 to 60 minutes of propagation. In the past a star scan had originally been planned during this timeframe to satisfy the then thought-to-be requirements. In spite of the fact that the star scan entailed significantly more maneuvering than would be required to simply reach the deployment attitude in a leisurely fashion (as proposed here), it is logical to expect that the ability to meet geosynchronous orbit insertion conditions are not compromised for the nominal deployment opportunity. This is based on the fact that the state vector accuracy associated with the aforementioned star scan was determined by Boeing to be acceptable. The effect of the one-orbit deployment delay on accuracy needs to be assessed; the two-orbit deployment delay is not necessarily affected since present plans depend on additional tracking and another state vector uplink.

c. To support the complete set of descending node deployment opportunities, it is necessary to elevate the tilt table for approximately 5 hours; an additional hour of elevation time is required to support a sequential ascending node deployment. Although the multiple erection capability currently poses a problem for the ascending node deployment (as previously discussed) this elevation opportunity at the very worst should be on the margin of thermal capability to satisfy the ascending deployment opportunity.

d. A 30- to 60-minute gap exists in the nominal timeline during which, if the VRCS failed, this elevation opportunity could not support. This represents only 6 to 11 percent of the time to elevation. The probability of a failure occurring in this last 30 to 60 minutes is small, perhaps to the point that consideration of failure during the last hour prior to nominal elevation is not preplanned but treated on a real time basis.

7.1.1.3 9:20 to 9:55 GET Opportunity

This darkness pass represents both the last opportunity to elevate the tilt table prior to nominal deployment and the first opportunity to elevate (or complete the elevation) if the VRCS fails between sunrise of the orbit on which a 29-degree elevation is to occur and nominal completion of the elevation process. As the requirements and constraints are presently defined, a concern evolves as to whether the nominal deployment time can be met while using this elevation opportunity. However, if the TDRS/IUS system has more capability than has previously been assumed, there are some potential advantages to using this 9:20 to 9:55 GET darkness period, not only for the failed VRCS situation but also for the nominal timeline. This opportunity is assessed as follows.

a. Under the present constraint that the TDRS must be elevated prior to turning on the transmitter, delaying elevation to 9:20 GET (darkness) could in general mean essentially missing the Hawaii pass for turning on the transmitter as is now nominally planned. This would necessitate relying solely on Santiago if activation has to be performed over a station; consequently, the operations for activation of the transmitter and making a go/no-go decision for nominal deployment become vulnerable to a station pass (Santiago) that may be subject to potential reduced coverage and communications dropout because of a combination of trajectory dispersions, stationmasking, and keyhole effects. Therefore, to maximize the TDRS antenna coverage over Santiago (in the event of PIP failure), prudence would dictate that the Orbiter fly the landmark tracking attitude mode. This activity, in turn, leads one to question whether the remainder of the deployment operations can indeed be performed in time to meet the nominal opportunity. With less than an absolute maximum of 20 minutes available between Santiago loss-of-signal and IUS deployment, this is considered extremely risky. It therefore appears extremely undesirable (if not infeasible) to plan for the 9:20 to 9:55 GET darkness period for elevating the tilt table, followed in succession by turning on the transmitter, elevation to 58 degrees, and subsequent nominal deployment. With the above factors, deployment is felt to require at least a one-orbit slip.

b. Even if the nominal deployment opportunity could be met, the plan associated with ensuring radio frequency (RF) coverage between GSTDN (Santiago) and the TDRS omni introduces potential velocity increments to the actual state vector. Depending on the capability of performance of the IUS navigation system, additional inaccuracies of the initialized IUS state vector may be experienced. Results from previous parking orbit state vector accuracy analyses did not consider this landmark tracking hypothesis prior to deployment. Therefore, it is not desirable to intentionally create degraded

IUS guidance data as dictated by using this darkness pass for elevation under the current constraints.

c. This opportunity imposes no impact upon the TDRS thermal capability; in fact, the time during elevation decreases by about 20 to 30 minutes.

d. Elevation during this 9:20 to 9:55 GET darkness pass covers VRCS failure occurring up to essentially the nominal deployment opportunity. This, in turn, allows the IUS G&N state vector initialization function to be performed and verified before elevation and before committing to the descending node deployment opportunity.

e. In reviewing the above advantages and disadvantages associated with this opportunity, it is evident that thermal and station coverage requirements for turning on the TDRS transmitter is the driving factor that makes this opportunity unattractive. If, on the other hand, the TDRS had the capability to tolerate the transmitter operating while in the stowed configuration for a period of about 10 to 15 minutes, this opportunity for elevation would be recommended - not only for a failed VRCS but also for the nominal timeline.

The Hawaii pass acquisition where the transmitter is nominally planned to be turned on occurs at about 9:15 GET. A proposed plan is to turn on the transmitter while it is stowed during this pass. After loss of signal at the Hawaii station or sunset - whichever is latest - elevation of the tilt table is initiated. Preliminary analysis (to be published at a later date) indicates that Hawaii will appear in the TDRS omni field of view for 1 to 2 minutes in the stowed configuration and in ZLV attitude. Therefore, a GSTDN to TDRS omni RF link is also available as well as the PI-to-TDRS link. Also, continuous coverage with the IUS omni is for contingency RF commanding available to the IUS. This contrasts a maximum of approximately 30 seconds TDRS omni coverage with the current scheme of elevating before turning on the transmitter. This contrast is caused by the differences in the required Orbiter attitude for each implementation scheme. Thus, all checkout activities (except the switching of TDRS source power from the Orbiter to IUS, which is performed onboard) are performed prior to elevation of the tilt table.

7.1.1.4 <u>22:55 to 23:30 GET Opportunity</u>

For the ascending node deployment opportunity, constraining elevation of the tilt table (occurring during this darkness pass) should have minimal impact to the present conceived timeline. The present timeline envisions elevation to 29 degrees about 1 hour prior to deployment; i.e., 23:00 GET (essentially the end of the darkness). To ensure elevation during darkness with sufficient time thereafter to attain deployment attitude prior to sunrise, the conservative approach is to begin elevation at sunset, or 35 minutes earlier than is currently being employed. It does not appear that this plan would conflict with any presently identified trajectory-constrained activity. In real time, a determination would have to be made as to whether TDRS thermal constraints are violated as a result of this increased 35 minutes of elevation time.

7.1.2 Elevation to 58 Degrees

The time to elevate from the 29- to 58-degree position is primarily governed by the battery life of the IUS and the fact that the umbilicals will be pulled as the TDRS/IUS configuration rotates through this 29 degrees. Hence, the only option available in selection of a time to elevate to 58 degrees for obtaining compatibility with a darkness pass is potentially small timing changes relative to deployment. The parking orbit can be assumed to be stationary with respect to the Sun for purposes of assessing the daylight/darkness occurrence relative to the deployment opportunities. Therefore, the feasibility of employing nightside passes for elevation to 58 degrees need only be assessed in terms of whether the deployment opportunity is for a descending or ascending node. The current Boeing submittal to the flight planning annex indicates a maximum capability of 438 minutes from the time the power is transferred to IUS/TDRS Stage I batteries until TDRS separation from the IUS; the December 6, 1979 Flight Operations Summary indicates that the nominal deployment opportunity (transfer to internal power at 9:54 GET) requires about 428 minutes of battery capability. For present discussion purposes this implies that an approximately 10-minute margin exists for capability to control the elevation time relative to darkness. The time indicated above is not meant to imply that this is the current IUS power margin nor that it is necessarily a margin at all; that problem will be for Boeing to define. It is only included to establish a rough order of magnitude of the capability/constraint limit that should be considered.

7.1.2.1 Descending Node Deployment Opportunity

For the nominal deployment opportunity, the present 51-minute coast time dictates that ejection occur at about 10:04 GET, that power be switched from the Orbiter to IUS internal power 10 minutes prior (9:54 GET), and that the tilt table elevation to 58 degrees be initiated at about 9:57 GET.

In order to use darkness for elevation of the tilt table to 58 degrees, the switching to IUS internal power, the physical elevation from 29 degrees to 58 degrees, configuring the tilt table for PRCS operations, and finally using the PRCS to maneuver back to deployment attitude must all occur before sunrise. It then becomes evident that, in general, the capability to elevate in darkness to 58 degrees will depend on three major parameters - the launch time (window), the time required to do the preceding activities, and the potential additional IUS power requirements and existing IUS capabilities. Figures 3(a) and 3(b) illustrate the variation in sunrise time as a function of lift-off time and time of year. (While the indicated GET addresses sunset/sunrise relative to the nominal deployment opportunity, the data could have been shown as time prior to solid rocket motor (SRM)-1 ignition and would have applied to all the approved descending node deployment opportunities).

To cover what is felt to be the probable TDRS launch window that is independent of the day of the year (1900 to 2100 GMT), sunrise could vary between 9:49 and 10:02 GET (66 minutes to 53 minutes prior to SRM-1 ignition, respectively); the current recommended lift-off time of 1935 GMT would result in sunrise occurring between about 9:55 and 10:00 GET or between 55 and 60 minutes prior to SRM-1. If it is assumed that (a) the nominal relative time between switching to

IUS internal power and initiation of tilt table elevation to 58 degrees is to be retained at 3 minutes, (b) the maximum time to elevate the tilt table from 29 to 58 degrees in the worst case will not exceed 5 minutes, and (c) if approximately 7 minutes were to be budgeted to secure the tilt table at 58 degrees and maneuver to deployment attitude (1 minute configuration activities plus a 180-degree maneuver at 0.5 deg/sec), the worst case (2100 GMT) would require about 81 minutes on IUS internal power prior to deployment. (If the option exists to constrain the launch window closing to no later than 2000 GMT, the worst case time would decrease to 76 minutes on IUS power). For the preferred 1935 GMT lift-off time, between 70 and 75 minutes would be required. It has previously been identified at the TDRS cargo integration review (CIR) that 67 minutes between deployment and SRM-1 ignition was needed due to Orbiter performance considerations for the ascending node opportunity, which would translate into being on IUS internal power for 77 minutes prior to SRM-1 ignition. At the time, IUS engineers concurred that this capability was available, and at present the Mission Planning and Analysis Division (MPAD) has submitted a change to the IUS addendum that establishes that the time between deployment and SRM-1 ignition be between 46 and 67 minutes.

Based on the previous facts, the following observations are presented:

a. If the IUS capability to support 67 minutes between deployment and SRM-1 ignition exists or can be obtained - either nominally or by contingency procedures and flight rules - darkness passes can be used to elevate the tilt table for descending node deployment opportunities.

b. To meet the nominal deployment opportunity under failed VRCS conditions, operations associated with elevating to 58 degrees would likely preclude the use of Santiago for TDRS transmitter activation or as a go/no-go site for deployment prior to elevating to 58 degrees.

   Under the timing assumptions previously made for activities such as switching to internal power, physically elevating the tilt table etc., the initialization of the elevation to 58 degrees could occur as early as 9:37 GET; this time is based on a 2100 GMT and occurs 3 to 5 minutes prior to Santiago acquisition of signal (AOS). For a 1935 GMT launch, this time could be between 9:43 and 9:48 GET, which would occur somewhere between AOS and loss-of-signal (LOS). It seems reasonable to visualize that the go/no-go for nominal deployment should be given over Hawaii. If for some reason that decision has not been made, then the deployment would be delayed.

c. There is some flexibility in controlling the minimum time from switching to internal power to the time the IUS/TDRS can be ejected. Basically, 6 minutes have been budgeted to maneuver to deployment attitude. This was based on a 180 deg/0.5 deg/sec/maneuver rate. If the required maneuver angle is smaller or a larger maneuver rate is employed, the time can be reduced. It should be cautioned, however, that the larger maneuver rate may produce more degradation in the IUS state vector accuracy and will require additional propellant.

d. Elevation from 29 to 58 degrees would have to be compatible with elevation from the stowed configuration to 29 degrees if it is determined that elevation to 29 degrees should occur during the 9:20 to 9:55 GET opportunity. In effect, one darkness pass would need to support both elevation phases. Assuming the latest time to begin elevation to 29 degrees would occur at 9:25 GET (Hawaii AOS + 10 minutes) and 5 minutes to actually elevate to 29 degrees, the earliest that the switch to internal power can occur is 9:30 GET. Considering elevation to 29 degrees and elevation to 58 degrees together, it appears that an operational launch constraint of between 1900 and 2200 GMT is derived.

7.1.2.2 Ascending Node Deployment Opportunity

For the current TDRS-A launch window, elevating the tilt table to 58 degrees during darkness is not feasible without significant impact to the IUS power requirements. SRM-1 ignition for the ascending node deployment opportunity will occur in the neighborhood of 25:10 GET. Ejection time will then be between 24:03 GET (for a 67-minute coast between deployment and SRM-1 ignition) and 24:24 GET (for the absolute minimum 46-minute coast time). Assuming the 15-minute predeployment activities previously discussed, switching to IUS internal power would be initiated at 23:48 to 24:00 GET with 23:51 to 24:12 GET being the latest time that elevation to 58 degrees could be initiated. Figure 4(b) shows the variation in sunrise/sunset time as a function of lift-off time and time of year. It is seen that for the expected TDRS launch window and the recommended 1935 GMT lift-off time, the above GET's occur in a daylight environment. To achieve a nightside pass would require elevation to 58 degrees at a minimum of 12 minutes prior to the preceding sunrise, which could necessitate being on IUS internal power as long as 2 hours prior to SRM-1 ignition. This is considered to be an unacceptable demand. In addition, were this to be a viable option, it would require that the initial elevation to 29 degrees occur early during this same darkness pass, as both elevation phases appear to be competing for the same darkness opportunity. Thus, it is concluded that nighttime elevation for the ascending node deployment is not a feasible solution to the problem of loss of VRCS capability.

7.2 OPTION 2: CONTROL ORBITER ATTITUDE EXCURSION WITH INTERRUPTIONS DURING THE ELEVATION SEQUENCE

A second option theoretically available for elevating the tilt table with failed VRCS is to control the Orbiter attitude excursion during the elevation process by interrupting the tilt-table sequence and performing maneuvers to re-establish the desired (solar protection) attitude. Conceptually, this might be accomplished by monitoring the Orbiter attitude errors during the free-drift elevation process; whenever these attitude errors reached a pre-established limit, the crew would stop the tilt table at the current position, apply the "brakes" or otherwise configure the tilt table for PRCS operation, and then, using the PRCS, maneuver back to the original attitude. Figure 4 illustrates this concept. Disregarding the tilt-table acceleration/deceleration phase, the tilt-table elevation angle time history is shown for the 0.1 deg/sec rate. Nominally, this is a continuous event from the time that elevation is initiated until it travels 29 degrees. It is seen from figure 4 how typically the time history of the tilt table would be affected by having to periodically readjust the Orbiter attitude. The frequency of the attitude corrections will be governed by the dynamics of the Orbiter/tilt-table system, Sun position and related Orbiter attitude, Orbiter shadowing, and by the attitude deadband rates existing at the time of PRCS inhibition prior to each elevation segment. The required attitude maneuver(s) would occur each time the Orbiter attitude error limit is reached, and the duration of the pause between tilt table elevation activities will be dependent upon the attitude error that needs to be corrected and the rate at which the maneuver is performed. The following observations are made relative to this option:

a. The time required to complete elevation through a total rotation angle of 29 degrees may be increased significantly above the nominal time to elevate. Of equal or even greater significance is the fact that the total time is unpredictable due to the present uncertain and random nature of the contributing sources. To realistically implement this concept, a statistical analysis and simulation is required to determine the expected time variation (typically σ). The initiation of the elevation process is then scheduled at a time which ensures no interference (under the worst credible situation to be considered) with activities following the elevation process. It is impossible to assess the impact of this operation in a generic sense other than the obvious potential power impact if the elevation time requires longer than 10 minutes (from 29 to 58 degrees) and timeline impact to the current nominal if the duration requires more than about 15 minutes, i.e., elevating to 29 degrees in time to meet the Hawaii pass at 9:15 GET.

b. Significant quantity of additional RCS propellant would be required to be budgeted. The precise RCS usage would be based on the frequency of corrections, the maneuver rate and timing requirements and constraints. The time required to perform these operations can be reduced at the expense of additional propellant. It should be noted that these maneuvers would require the PRCS for both starting and stopping the attitude rates. Under the worst possible conditions, a maximum of two 29-degree elevation phases would be required.

c. The state vector accuracy is likely to be significantly degraded by virtue of the maneuvering required. Again, it is impossible at present to quantify the impact in a generic sense. An important item to remember is that there is no additional groundtracking that will improve the accuracy for the nominal and one-orbit late deployment opportunity.

d. An analysis would have to be performed to determine these preflight attitude error limits.

e. It is understood that in the manual direct rotation pulse command mode, a capability may exist to control rates to within 0.04 to 0.06 deg/sec with the PRCS. Therefore, before the elevation is initiated, it would seem prudent to plan to trim the attitude rates to within this capability. If the initial rate can be reduced to about 0.05 deg/sec (a reduction factor of four in the advertised 0.2 deg/sec deadband) the number of subsequent corrections may very likely be reduced by virtue of the fact that the attitude error limit would take longer time to exceed initially. Subsequent analysis may even show that under 3σ conditions, elevation through a 29-degree angle would require no interruption. Procedures would need to be developed and simulations performed to establish the minimum limit to which the Orbiter attitude rates could be controlled and the time required to achieve these conditions. It is assumed that the timeline would be biased to accommodate this attitude rate trim prior to elevation. If residual attitude deadband rates in the vicinity of 0.04 to 0.06 deg/sec can be achieved rapidly by using manual procedures, it may very well be performed after each interruption for attitude maneuvers; otherwise, timing considerations may make this procedure only applicable immediately prior to initiation of each elevation phase; i.e., 0 to 29 degrees and 29 to 58 degrees.

7.3 OPTION 3 - CONTROL ORBITER ATTITUDE RATES DURING ELEVATION

This option basically assumes that the Orbiter attitude and attitude rates are controlled during the elevation process. Conceptually, it is assumed that the PRCS could be configured to fire selected jets in the manual direct rotation pulse mode as discussed in section 7.2. Strict interpretation of the constraint that the PRCS not be fired during elevation would exclude this alternative; however, being unaware of the PRCS operational model and the hypothetical conditions that went into defining the above constraint, this option is offered in the event that it has not been previously considered or evaluated for feasibility. Intuitively, this concept would seem to be simpler than option 2, have more complex procedures than option 1 although potentially it would possess less timeline and flight design impact and have no more of an IUS/TDRS system impact than either of the other two. However, man-in-loop simulations involving the dynamics of elevating the tilt table appear to be required for assessment of this option.

8.0 CONCLUDING REMARKS

The following summarizes the observations resulting from the analysis and assessment of elevating the tilt table with the VRCS failed:

a. The PRCS deadband of 0.2 deg/sec appears incompatible with preserving the TDRS thermal constraints when elevating in daylight without special flight procedures development. This may also apply to a 0.1 deg/sec deadband. The feasibility of developing such procedures and the attendant flight design and timeline ramifications would need to be assessed.

b. PRCS attitude deadband and TDRS thermal constraints are not a consideration if elevation can be planned to occur during darkness.

c. Elevation to the 29-degree position can be scheduled to occur during darkness.

d. Elevation to the 58-degree position to support a descending node deployment opportunity during darkness is feasible if the launch can be constrained between 1900 and 2100 GMT, and the IUS can support being on internal power for

77 to 80 minutes prior to SRM-1 ignition. The launch window implication is not believed to be a factor for TDRS-A, and the power implication may be borderline.

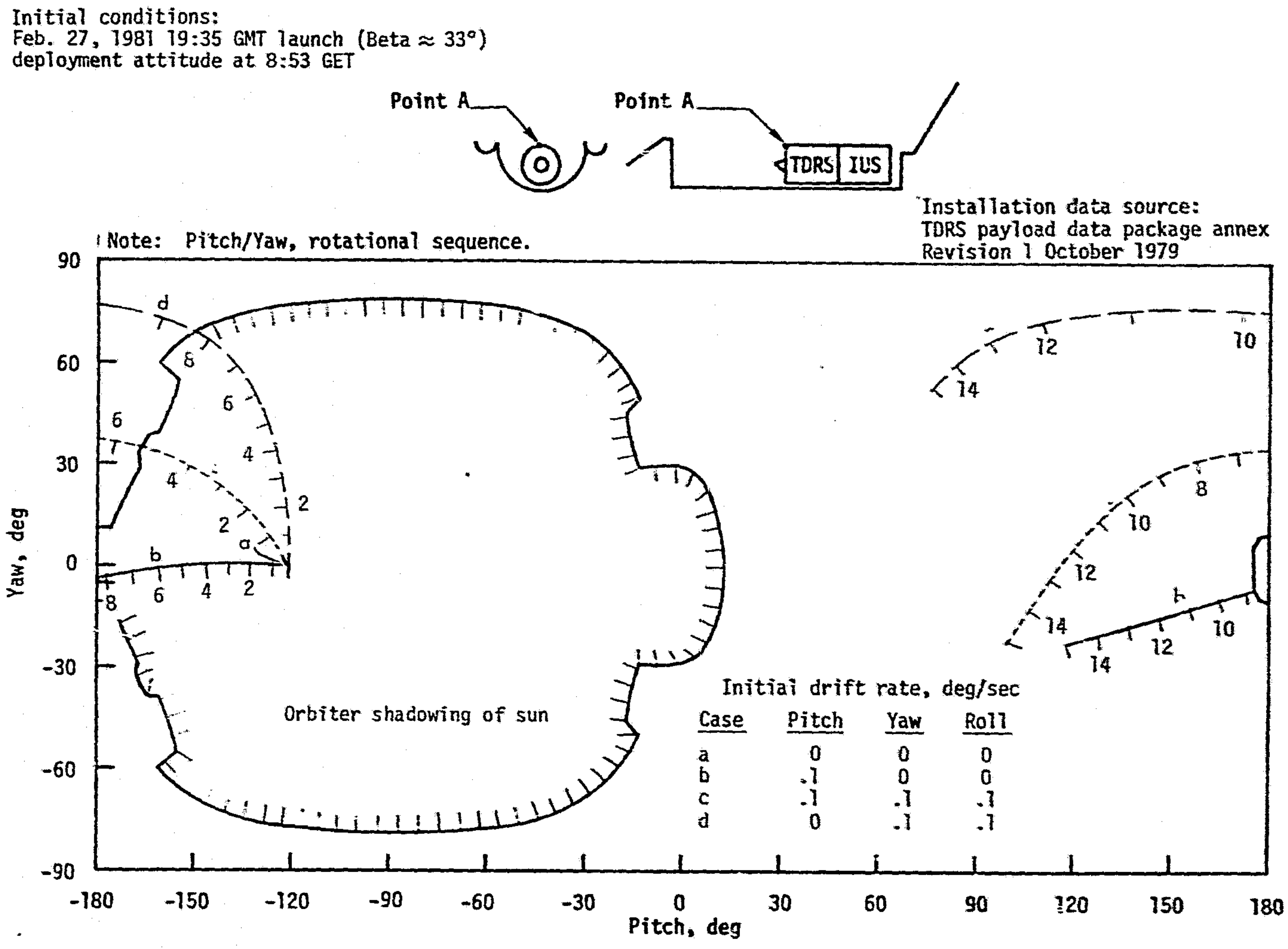
e. Elevation to 58 degrees during darkness to support the ascending node deployment is not believed a viable alternative. Special procedures will need to be developed or a program directive issued that eliminates the ascending node opportunity if the VRCS fails.

f. Whether or not special procedures are developed to support the TDRS specifically, the principle of controlling Orbiter attitude and rate deadband with failed VRCS may have other applications and may be worthwhile to develop as a generic capability. This is obviously a Flight Operation Directorate decision.

g. For the descending node deployment opportunity, it is recommended that the present timeline be changed so as not to initiate elevation of the tilt table to 29 degrees earlier than 9:25 GET (approximately darkness for the time of day of launch being considered). The details of this proposed timeline change will be documented in a forthcoming memorandum with the associated proposed PIP changes.

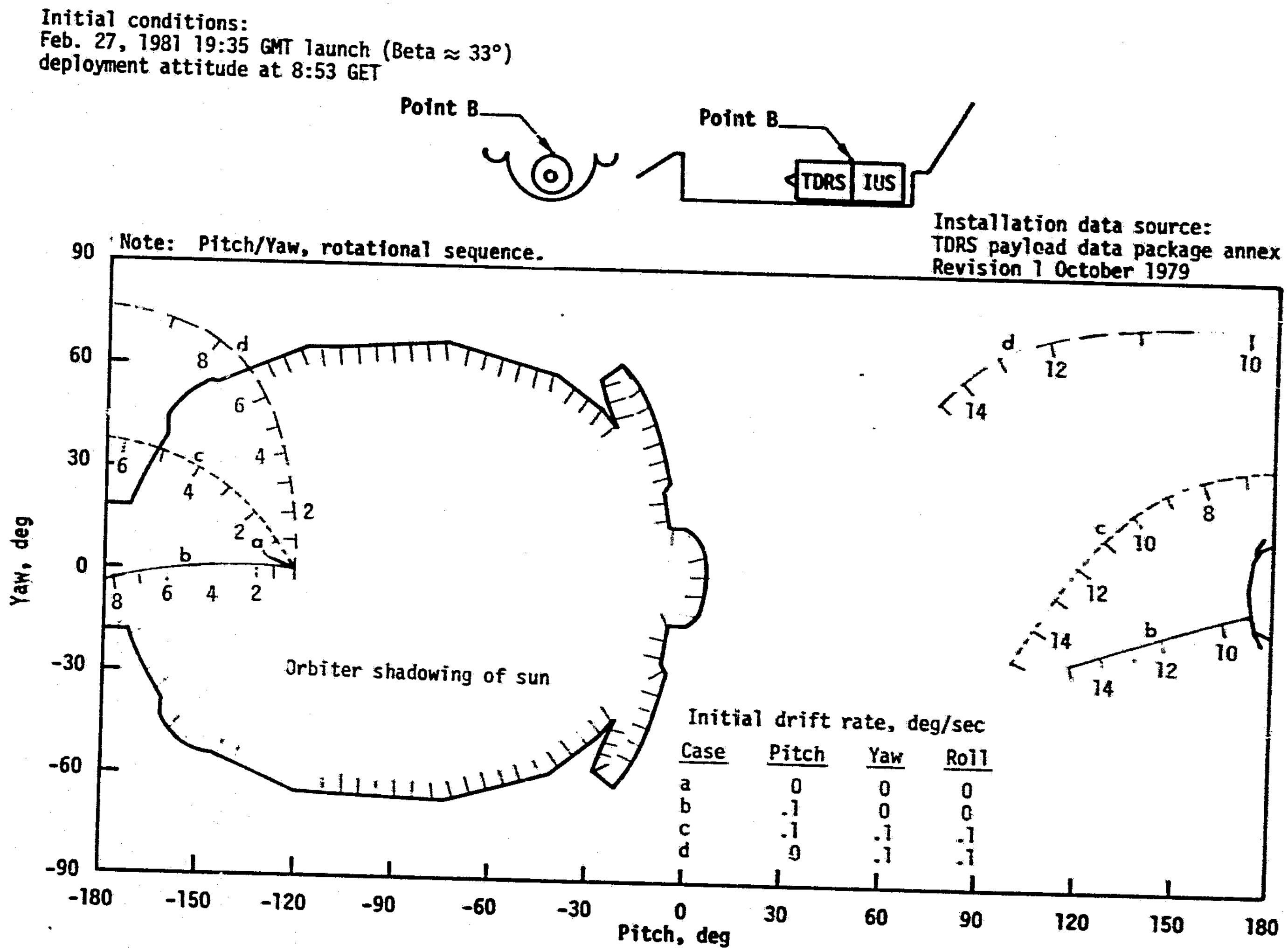
h. As a result of this assessment, it is recommended that all plans be oriented towards making a go/no-go decision during the Hawaii pass at 9:15 GET and that consideration be given to delaying elevation of the tilt table and delaying deployment, if such a decision is not received.

i. In concurrence with item (g) above, the state vector transfer function assessment should be performed well before to the IOS uplink of the final state vector for IUS flight execution. Planning should be developed which minimizes IUS real time assessment requirements for the IOS pass and later passes.



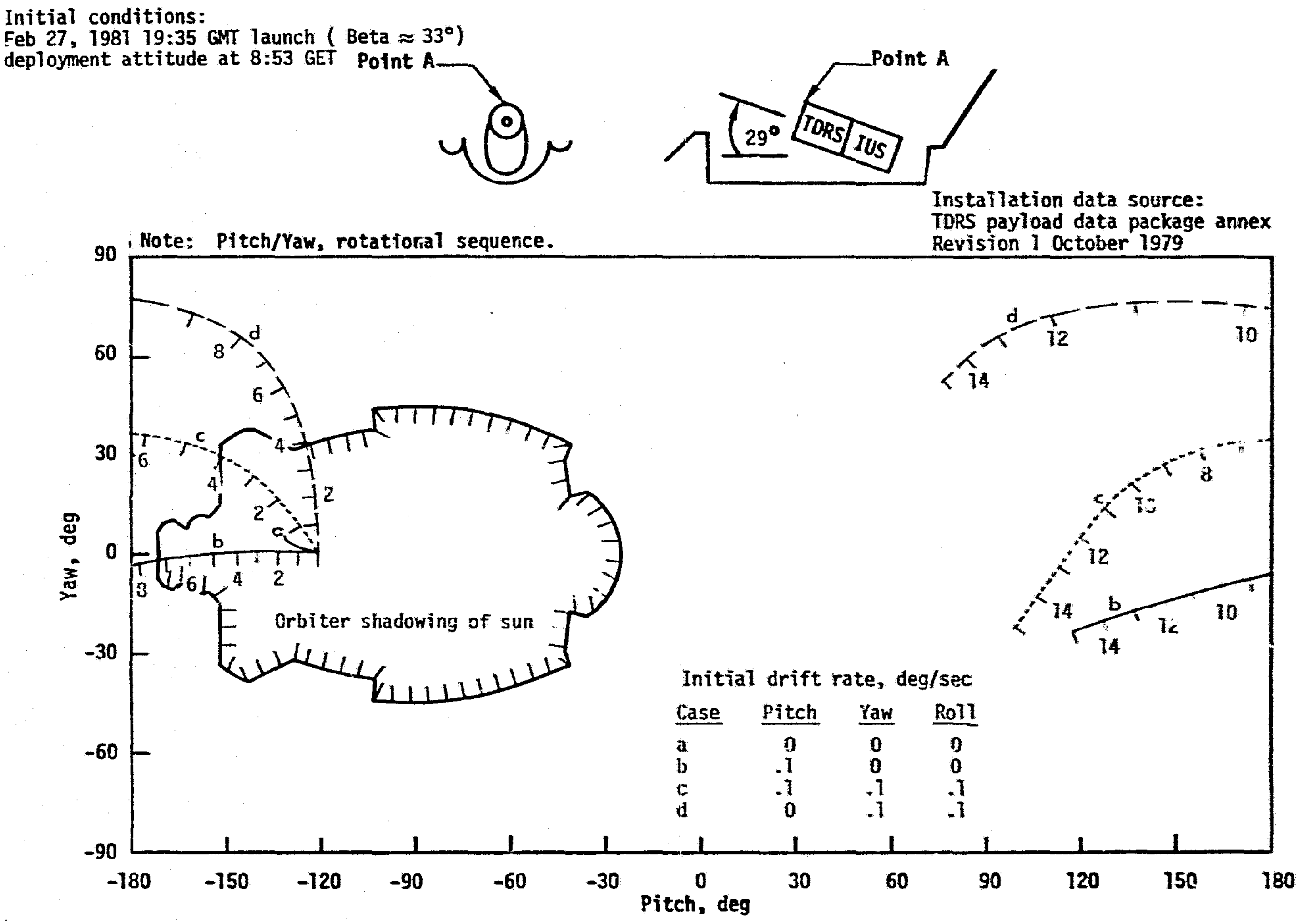
(a) Point A stowed.

Figure 1.- Time history of Sun relative to Orbiter body for Orbiter initially in deployment attitude and free drift.



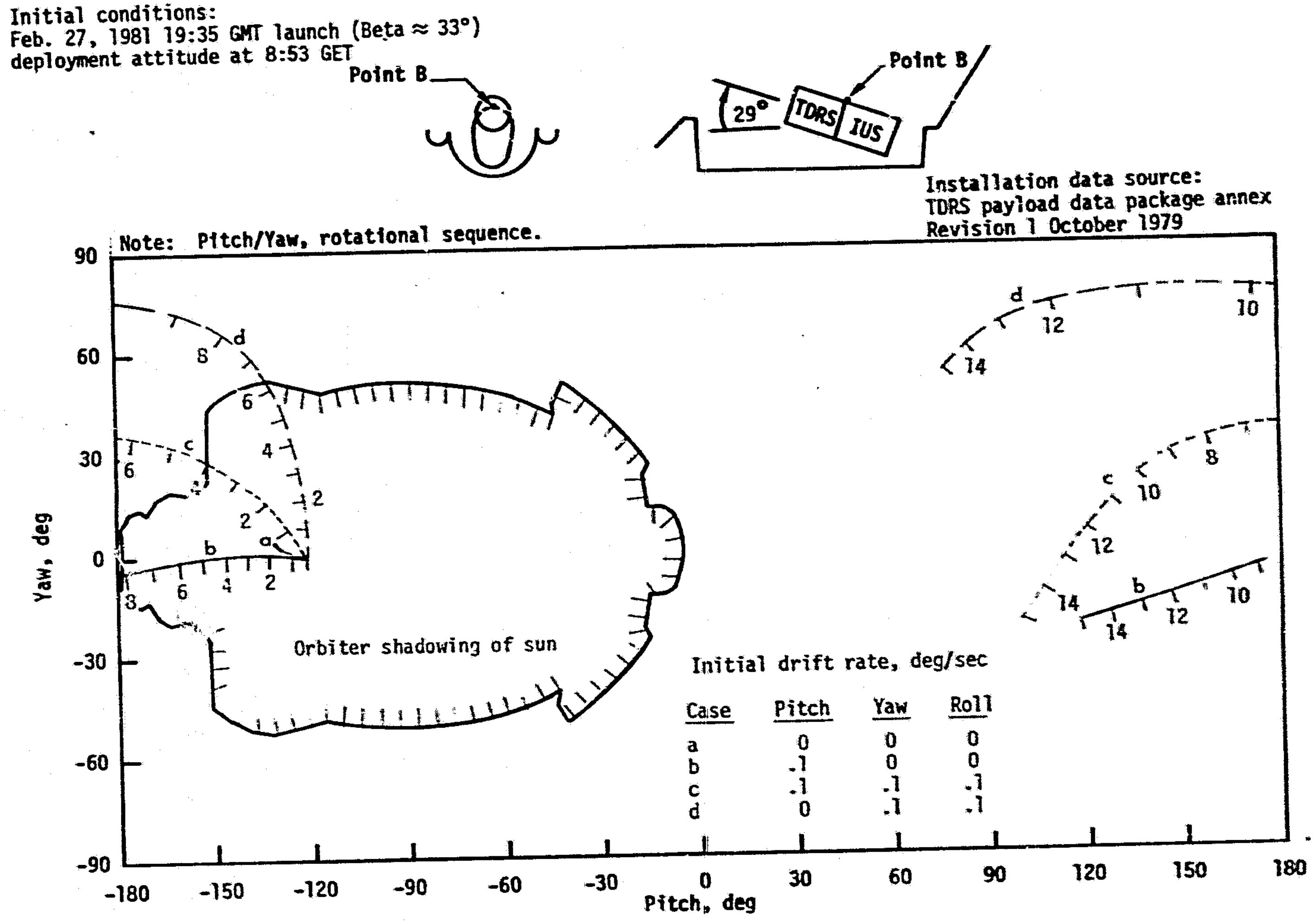
(b) Point B stowed.

Figure 1.- Continued.



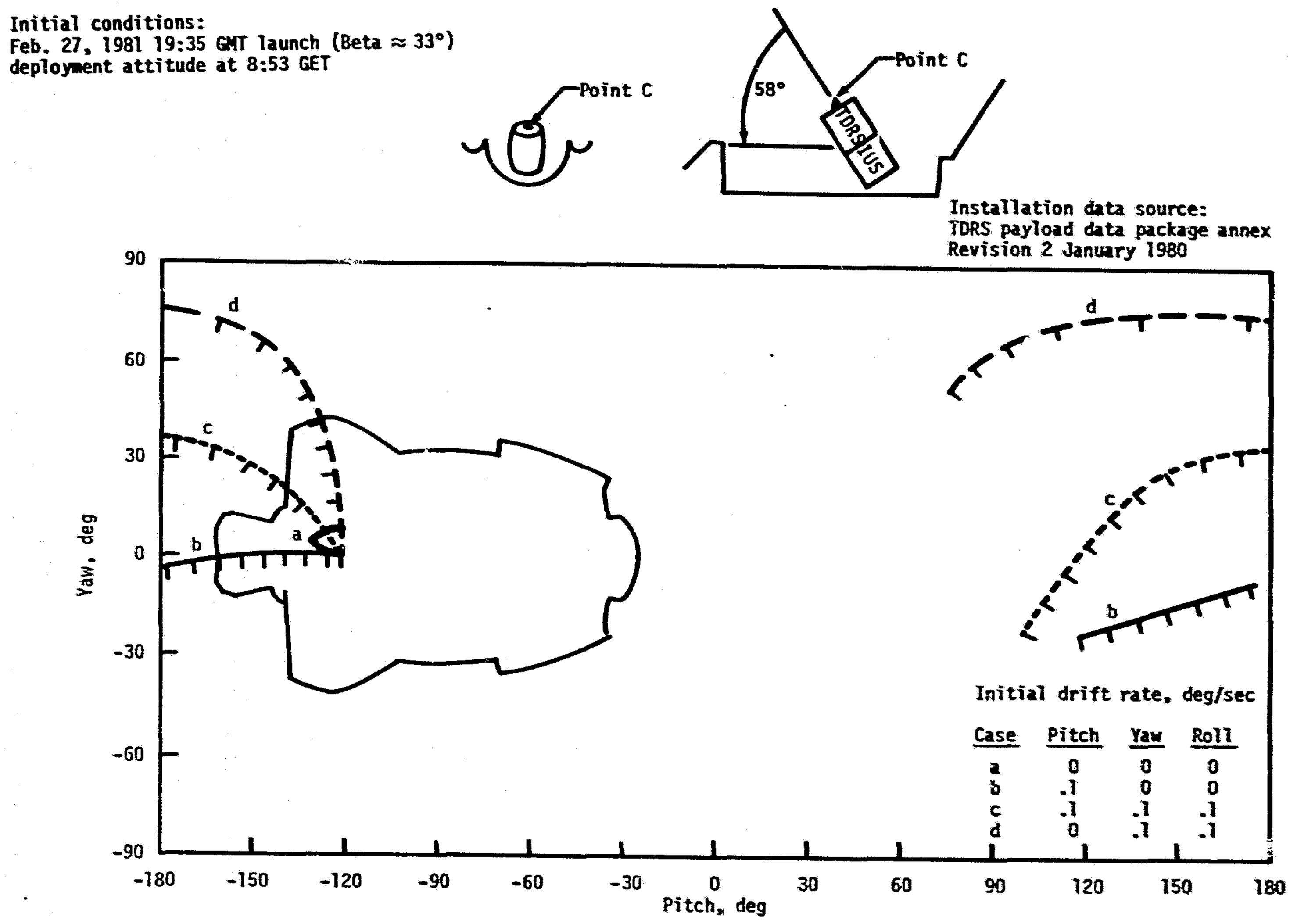
(c) Point A elevated.

Figure 1. - Continued.



(d) Point B elevated..

Figure 1.- Concluded.



(e) Point C elevated to 58 degrees.

Figure 1.- Concluded.

In.ctal conditions:
Feb 27, 1981 19:35 GMT launch (Beta ≈ 33°)
deployment attitude at 8:53 GET

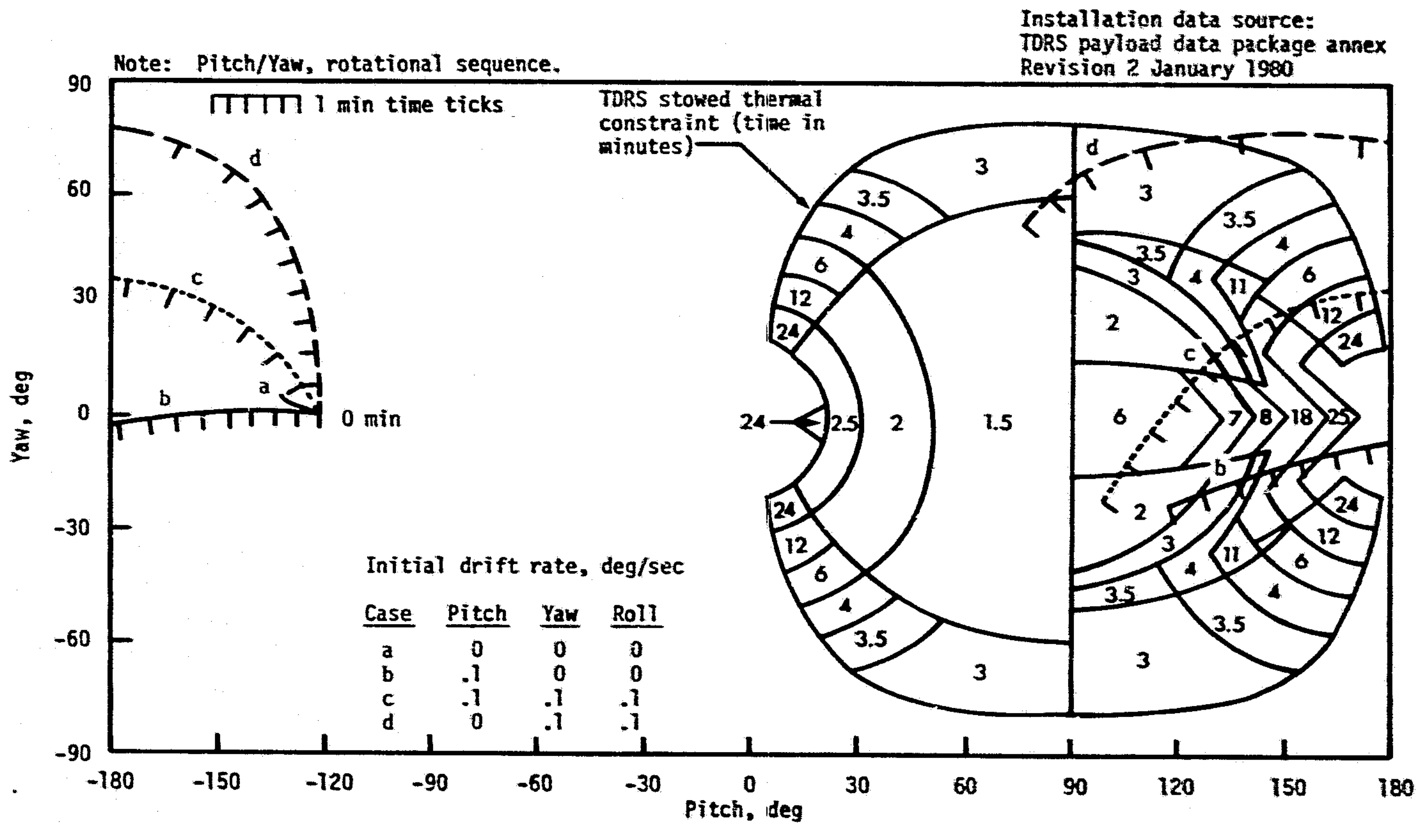
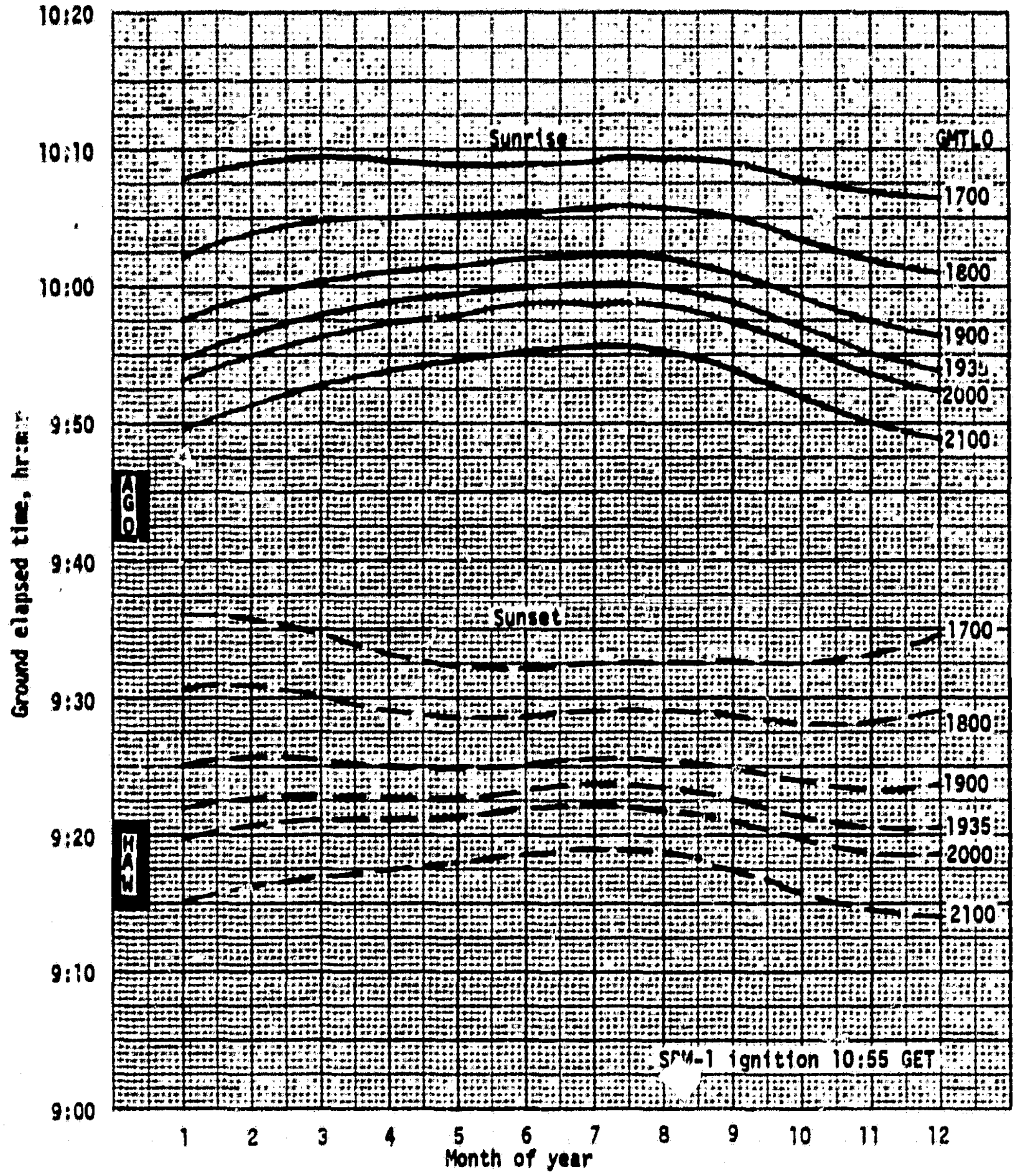
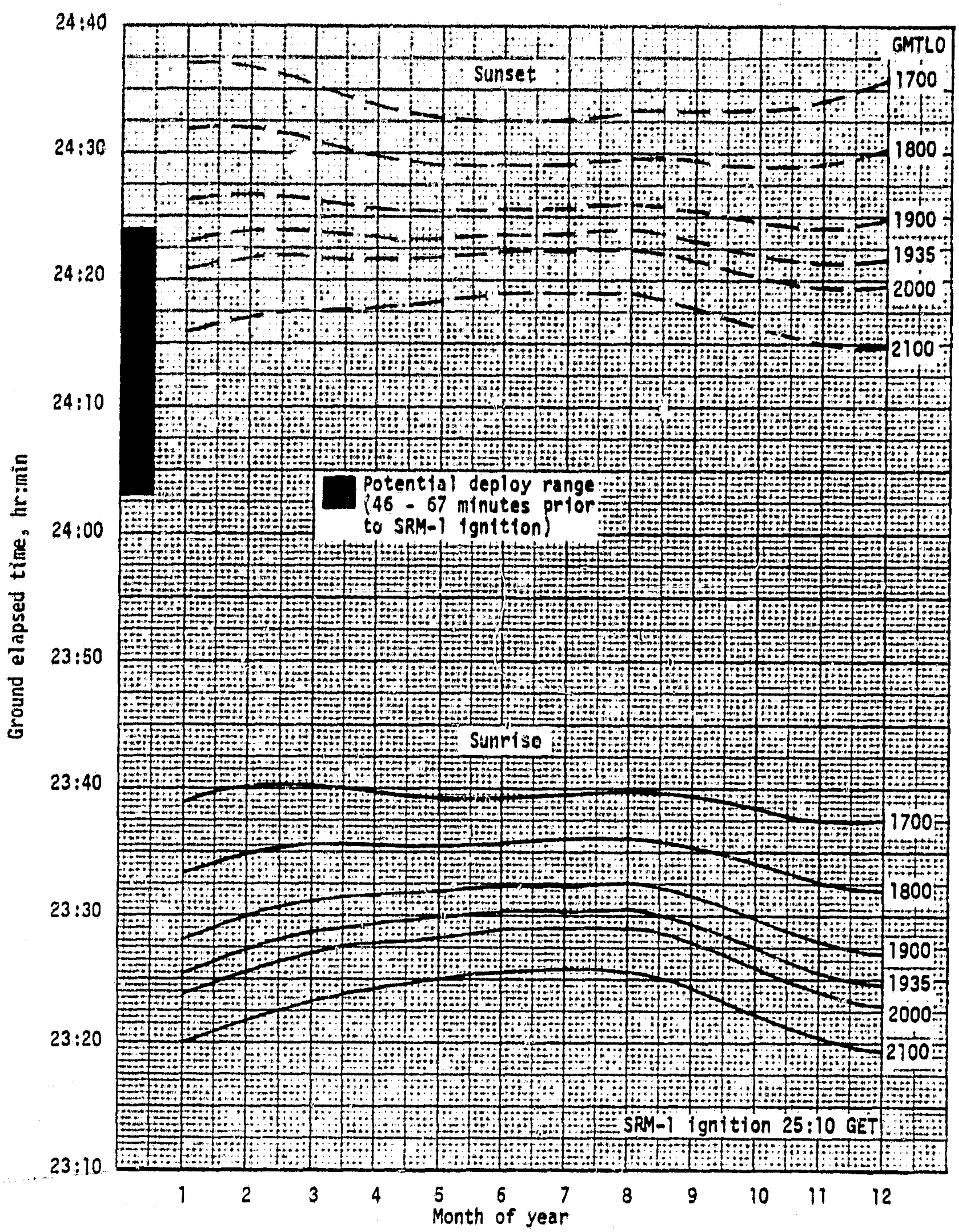


Figure 2.- Time history of Sun relative to TDRS stowed thermal constraint.



(a) Nominal descending node deployment opportunity.

Figure 3.- Sunrise/sunset time variations throughout the year as a function of lift-off time.



(b) Ascending node deployment opportunity.

Figure 3.- Concluded.

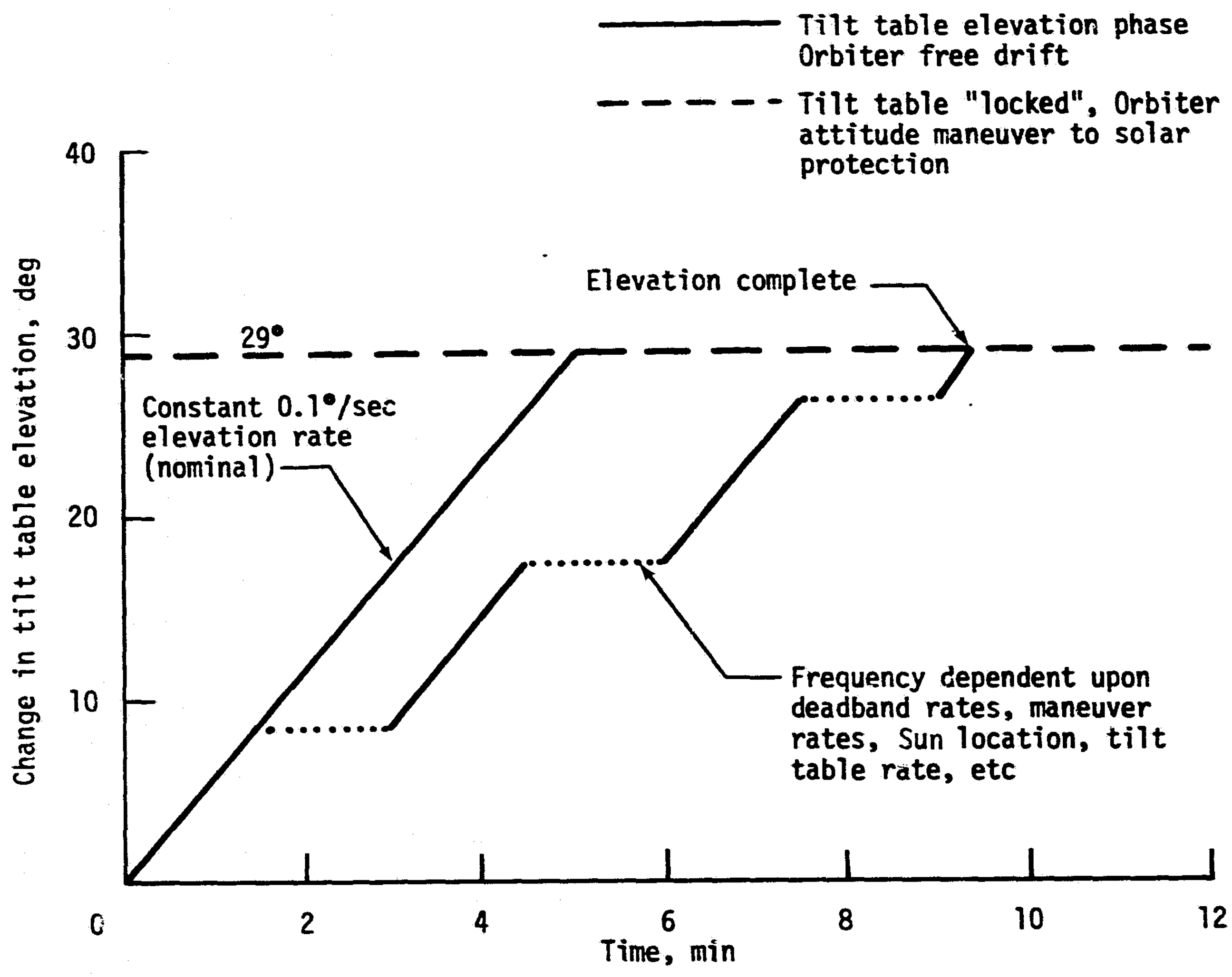


Figure 4.- Illustrative control concept for elevation of tilt table in daylight and providing solar protection.

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