BELLCOMM, INC.

III. 3

SUBJECT: The Influence of Apollo/Saturn V Launch Operations on Lunar Site Selection - Case 330

DATE: April 28, 1966

FROM: C. H. Eley III
H. E. Stephens

ABSTRACT

This paper presents some relationships between Apollo/Saturn V launch operations and multiple lunar landing sites, including the means by which site selection could facilitate launch operations.

A brief summary of the discussion is as follows:

a. A change in the lighting constraint to 7°-20° for a lunar landing reduces the Earth launch opportunity to about one launch window per month per site.

b. The highest probability for a successful countdown and launch occurs with launch windows spaced two days apart (considered as the 1st, 3rd, and 5th days). Included in this are the operational constraints presented in Reference 1.

c. From (b) above, it is apparent that lunar site selection could greatly facilitate Earth launch operations if lunar sites were situated such that launch windows fell two days apart.

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MEMORANDUM FOR FILE

1. INTRODUCTION

Until recently, the Apollo/Saturn V lunar mission was being planned for a single lunar landing site regardless of the day of launch. Reference 1 examined the ability of an Apollo/Saturn V to meet the Earth launch opportunity for a lunar mission with a sun angle of 10° to 45° from the eastern horizon at the landing site. The lunar landing window determined by this lighting constraint existed for 69 hours. In consideration of the astronauts' viewing conditions during a lunar approach, MSC is favoring a change in the lighting constraint from 10°-45° to 7°-20°. This change impacts both launch operations and lunar site selection. The purpose of this memorandum is to present the relationship between Apollo/Saturn V launch operations and multiple lunar landing sites, and the implications involved in site selection which could facilitate launch operations.

2. EARTH LAUNCH WINDOWS

Since a lunar site will now move through 13° of sun angle during the lunar landing window instead of 35°, the landing window is reduced from 69 hours to 25.6 hours ($13°/360 \times 29.5 \times 24 = 25.56$). The significance of this is that for one lunar site, on the average only two Earth launch windows per month exist--one for an "Atlantic" and one for a "Pacific" type of translunar injection. However, one of the mission rules states that only one type of translunar injection will be planned for each launch day. Thus, for a single lunar site only one launch window per month exists as far as launch operations are concerned. In view of the foregoing, it is obvious that multiple lunar sites are a requirement in order to provide more than one launch day per month.

Given that multiple lunar sites are available across the full range of longitudes within the "always-accessible" lunar region (see Figure 1), the maximum Earth launch opportunity in any one month is 8.4 days. This is directly related to the lunar landing opportunity which in turn is determined by the

7°-20° lighting constraint. Since the always-accessible lunar region moves through 103° of lunar rotation with respect to the sun each month (90° between longitude extremes and 13° between lighting extremes), and the solar month on the moon is 29.5 days, the total period per month that a landing can be made is 8.4 days (103°/360° x 29.5 = 8.44). This is in contrast to the 10.2 days per month which existed for the 10°-45° lighting constraint. Thus, given a 7°-20° lighting constraint and multiple lunar sites, the maximum number of Earth launch windows per month is (on the average) 16. However, since only one type of translunar injection will be planned for each day, then only 8 Earth launch windows per month will exist as far as launch operations are concerned.

3. LAUNCH CONSTRAINTS

a. General

The recycle requirements for an Apollo/Saturn V manned lunar landing mission were examined in Reference 1. In that memorandum, considering recycle operations but not excess repair time, it was concluded that:

(1) The space vehicle (SV) is capable of being recycled to meet a launch window one day later if a scrub occurs prior to T-6 hours in the countdown.

(2) The SV is capable of being recycled to meet a launch window two days later following a scrub at any point in the countdown.

(3) The SV is capable of holding for an extended period if the hold occurs prior to T-15 hours in the countdown.

The chart of Launch Ability by Hold or Recycle presented in Reference 1 is reproduced as Figure 5. That chart considered a single lunar landing site with launch windows on 2 or 3 consecutive days. With a concept of multiple sites of one launch window each, launch operations must be re-examined to determine the effect of landing site distribution on launch ability. Factors in addition to recycle operations which must be considered are:

(1) Probability of a scrub during the countdown

(2) T-time distribution of holds and scrubs

(3) Hold time prior to a scrub

(4) Cause of a scrub

(5) Repair time

(6) Launch crews.

b. Probability of Scrub

The probability of a successful launch for AS 504 was estimated in Reference 6 from historical data and by examining the factors parametrically. It was estimated that the probability of meeting a 2-1/2 hour launch window was 0.65 for a nominal countdown with a 2 hour built-in hold at T-7 hours, and 0.67 for a 4-hour window. Conversely, the probability of a scrub is 0.35 for a 2-1/2 hour launch window.

c. T-Time Distribution of Holds and Scrubs

As shown in Figure 5, the recycle time following a scrub rapidly increases as T-time decreases toward T-0. Thus, the point in the countdown at which a scrub is declared is important with respect to when a second launch attempt may be made. Historical data on 274 countdowns at Cape Kennedy (Atlas, Titan, and Saturn I) were examined in Reference 6. In those 274 countdowns, 169 were successful and 105 were scrubbed. Although specific information was not included on the T-time at which the 105 scrubs were declared, much qualitative information can be deduced. In the 169 successful countdowns, there were 442 holds distributed as follows:

T-time (Minutes)	Cumulative % of Holds
T-80	15
T-40	32
T-10	60

In the 10 Saturn I launches (also included in above figures), there were 18 holds distributed as follows:

T-time (Minutes)	Cumulative % of Holds
T-120	5
T-80	20
T-20	60

These figures show that the major portion of the holds occur very late in the countdown. In particular, only 5% of the Saturn I holds occurred prior to L/V cryogenics loading. This corresponds to the commencement of Saturn V L/V cryogenic loading at approximately T-6 hours. T-6 hours in the Saturn V countdown also represents the point at which recycle operations alone preclude a launch 24 hours later. Recognizing that

(1) the period of intense system operation is after commencement of L/V cryogenic loading, (2) most holds occur during this period, and (3) scrubs will normally be proceeded by a hold, it is postulated that most scrubs will occur after L/V cryogenic loading.

d. Hold Time Prior to Scrub

Historically, cumulative hold time prior to a scrub has ranged up to 5 hours (Reference 6). The cumulative hold time prior to 50% of the scrubs was greater than 1-1/2 hours. An estimate of the amount of hold time that will accumulate before a scrub of a MLL mission would be extremely difficult to make because of the many variables involved. However, there are certain factors that must be considered. For example, because of the complex nature of the Apollo/Saturn V space vehicle and limited launch windows, it is probable that a scrub will not be declared at the first indication of a malfunction. Rather, it is expected that every effort will be made to correct the malfunction and meet the scheduled launch window. Consequently, it is considered reasonable to add 1-1/2 hours to the recycle times as an allowance for cumulative hold time prior to the scrub. The inclusion of this cumulative hold time prior to the scrub changes the cutoff point in the countdown for a second launch attempt 24 hours later from about T-6 hours to about T-7 hours.

e. Cause of Scrub and Repair Time

Historically, of 98 scrubs (Reference 6), 54% were attributed to space vehicle malfunctions, 33% to GSE, and 13% to weather. This indicates that repairs have been involved in 87% of the scrubs. The repair time for an Apollo/Saturn V may vary from a few minutes to days. A detail treatment of repair time is beyond the scope of this memorandum. Any repairs that cannot be done in parallel with the recycle operations will add to the recycle time. As most of the scrubs are expected to occur so late in the countdown that recycle operations alone preclude a launch attempt 24 hours later, repair time is not necessarily a prime factor in ruling out a launch attempt on the second day. However, repair time is a factor that must be considered in planning for a launch attempt 48 hours after the scheduled window. The worst case occurs for a scrub at T-0 when, as shown in Figure 5, the recycle time is 41 hours. Including a 1-1/2 hour hold prior to the scrub (d above) reduces available excess repair time to 5-1/2 hours for a scrub at T-0 and a launch attempt 48 hours later.

f. Launch Success

As shown above, the T-time at which a scrub occurs is a prime factor in determining the ability to recycle for launch attempts on subsequent days. Scrubs after T-7 hours in the countdown preclude a launch attempt the next day. Although a quantitative estimate of the percentage of the scrubs that will occur prior to T-7 hours is not available, the effect can be examined by considering a range of values. The probability of a successful launch as a function of the percent of scrubs occurring prior to T-7 hours is shown in Figure 2 for five cases, which are:

(1) Launch window and launch attempt on 1st day only

(2) 1st and 2nd days (method of computation shown in Figure 3)

(3) 1st and 3rd days

(4) 1st, 2nd, and 3rd days (method of computation shown in Figure 4)

(5) 1st, 3rd, and 5th days.

A range of values from 0 to 30% for the percentage of scrubs and extended holds occurring prior to T-7 hours was used in Figure 2. If the experience from Saturn I is indicative of Saturn V, the number of scrubs occurring prior to T-7 hours will be on the low side of this range, say less than 10%.

Figure 2 shows that:

(1) The probability of a successful launch with launch windows on the 1st and 2nd days only is not significantly greater than for a single launch window.

(2) The probability for a successful launch with windows on the 1st and 3rd days is significantly greater than for windows on the 1st and 2nd days only.

(3) The probability of a successful launch with windows on the 1st, 2nd, and 3rd days is practically the same as for windows on the 1st and 3rd days only.

(4) The probability for a successful launch with windows on the 1st, 3rd, and 5th days is significantly greater than for windows on the 1st, 2nd, and 3rd days.

g. Launch Crews

In addition to improving the probability of a successful launch, scheduling launch windows on the 1st, 3rd, and 5th days instead of the 1st, 2nd, and 3rd days will reduce the launch crew availability and fatigue problems.

4. CONSTRAINING FACTORS AND SITE SELECTION

In order to discuss the principal relationships between Earth launch operations and lunar site selection, it might be appropriate to first enumerate some of the principal conclusions brought out in the preceding sections.

a. A change in the lighting constraint to 7°-20° would:

(1) Reduce the Earth launch opportunities to about one day per month for a particular lunar site.

(2) Necessitate multiple lunar sites be selected in order to increase the length of the launch opportunity.

(3) Reduce the Earth opportunity for multiple lunar sites on the accessible part of the lunar surface to 8.4 days per month.

b. Assuming a 7°-20° lighting constraint is used, only one Earth launch window per month exists for Earth launch operations for each particular lunar site.

c. The highest probability of a successful launch for a given number of sites occurs with Earth launch windows two days apart; for example, on the 1st, 3rd, and 5th days.

From the above, which includes the operational constraints presented in Reference 1, it is apparent that lunar site selection could greatly facilitate Earth launch operations if site selection were such that launch windows were two days apart (or "1-3-5"). Since the lunar landing site must move 13° to the west for each succeeding Earth launch window, then site selection could proceed in those promising lunar regions which are 26° apart.

Figure 1 shows the always-accessible lunar region which lies within the Standard Apollo Block. One fortunate facet of the lunar topography is that those areas currently considered the most promising for site selection easily accommodate a 26° separation. The three areas--Mare Tranquillitatis, Sinus Medii, and Oceanus Procellarum--include many site possibilities both above and below the lunar equator. The choice of selecting sites only above or only below the lunar equator also merits consideration because of their association with the type of translunar injection involved. Generally speaking, "Pacific" injections favor sites above the lunar equator while "Atlantic" injections favor those sites below the lunar equator. (This may vary slightly, however, depending on the time of year.) A selection of sites for the 8.4 day launch opportunity all of which favor the same ocean injection would facilitate mission planning.*

Within the Standard Apollo Block, the "1-3-5" concept of site selection is dependent, of course, on a sufficient number of sites being approved as a result of the lunar data analysis. Since the Lunar Orbiter program is nearing its operational phase, consideration should be given to targeting those areas for site investigation which favor a 1-3-5 separation. This would apply specifically to Orbiter "B" which, to date, has not been targeted.

5. ACKNOWLEDGMENT

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*This is predicated on a decision to conduct Apollo/Saturn V launches at night as well as day.

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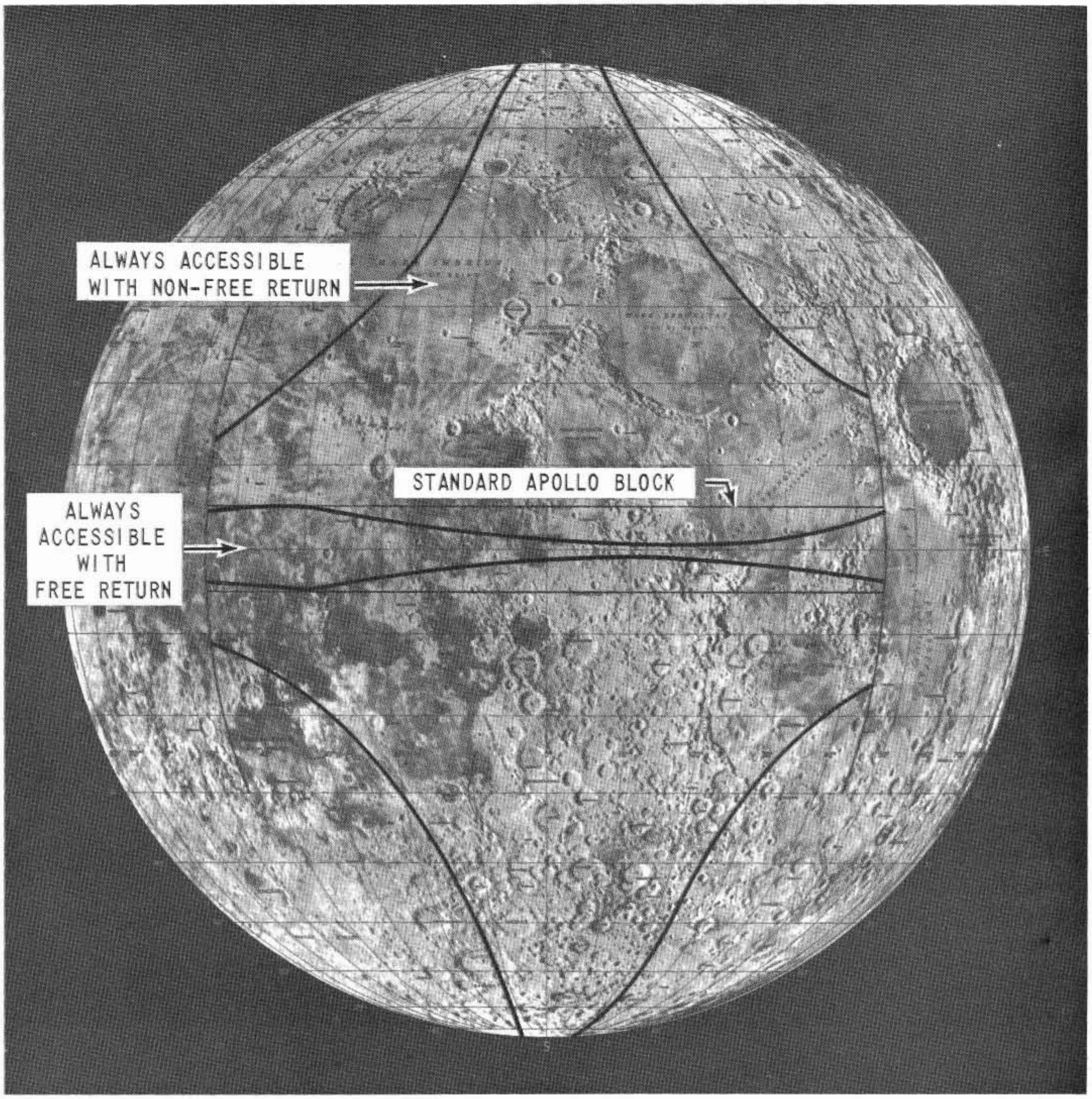
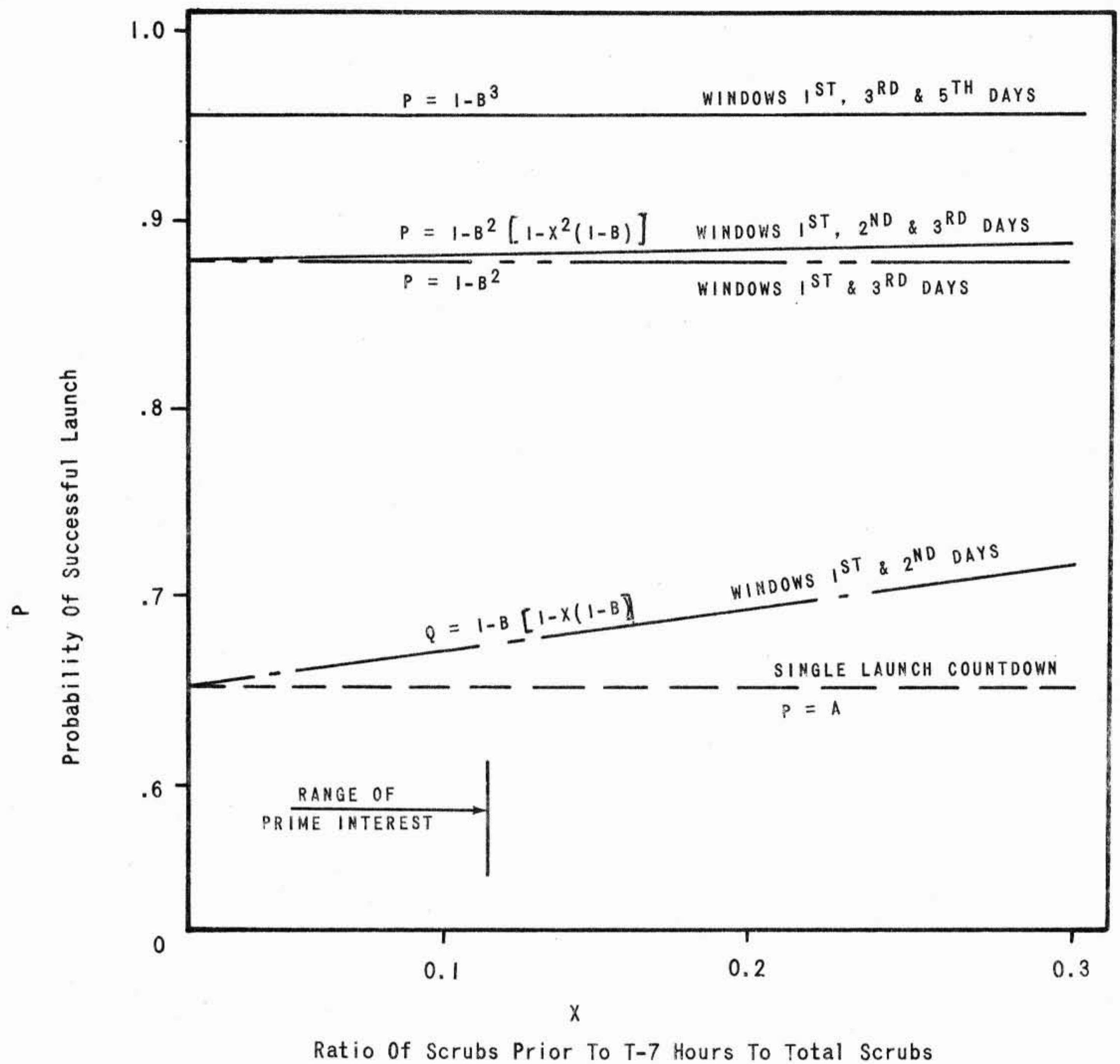


- THE FREE RETURN AREA CONTAINS APPROXIMATELY 50% OF THE STANDARD APOLLO BLOCK.
- THE NON-FREE RETURN AREA IS APPROXIMATELY 15 TIMES AS LARGE AND INCLUDES THE ENTIRE APOLLO BLOCK.

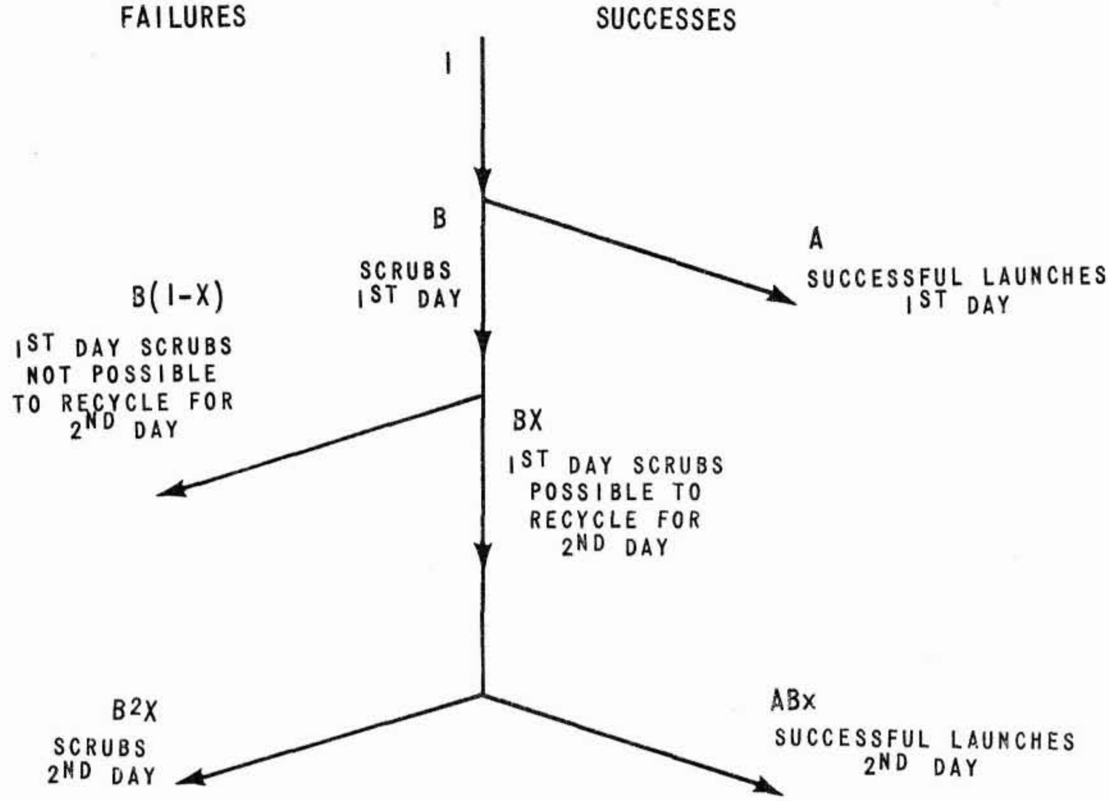
FIGURE 1 - AREAS ALWAYS ACCESSIBLE WITH FREE RETURN AND NON-FREE RETURN BETWEEN 1968 AND 1987.



NOTES:

1. A = PROBABILITY OF SUCCESSFUL LAUNCH IN SINGLE ATTEMPT (0.65 FOR MLL).
2. B = PROBABILITY OF SCRUB IN SINGLE COUNTDOWN (0.35 FOR MLL).
3. X = RATIO OF SCRUBS PRIOR TO T-7 HOURS TO TOTAL SCRUBS. (INCLUDES EXTENDED HOLDS TO NEXT WINDOW PRIOR TO T-15 HOURS).
4. AN EFFORT TO LAUNCH IN ALL WINDOWS ASSUMED.

FIGURE 2 - PROBABILITY OF SUCCESSFUL LAUNCH AS FUNCTION OF % SCRUBS PRIOR TO T-7 HOURS APOLLO/SATURN V MLL MISSION



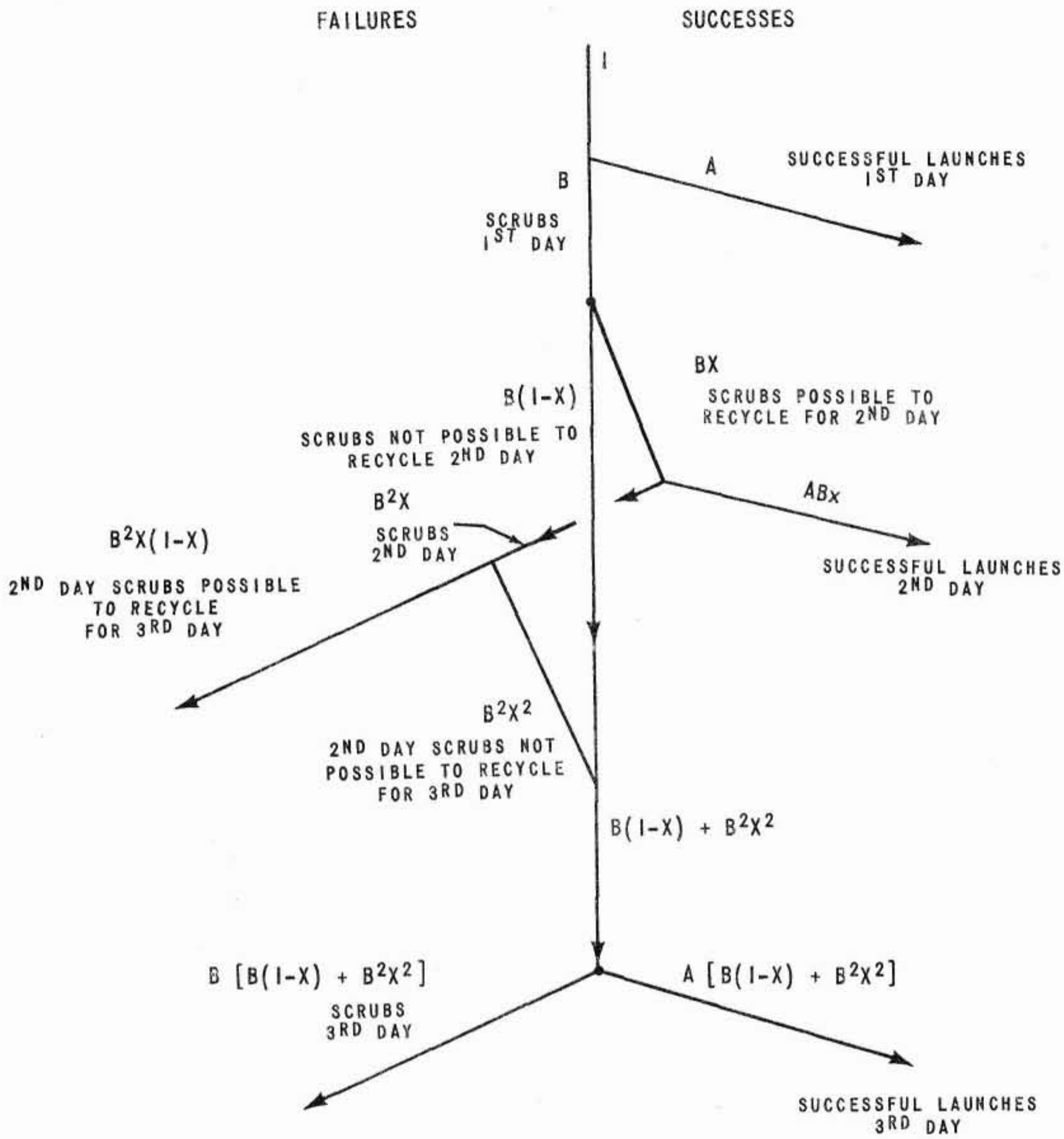
PROBABILITY OF SUCCESSFUL LAUNCH IS:

$$1-B\ [1-X(1-B)]$$

NOTES:

1. A = PROBABILITY OF SUCCESSFUL LAUNCH IN SINGLE COUNTDOWN (0.65 FOR MLL)
2. B = PROBABILITY OF SCRUB IN SINGLE COUNTDOWN (0.35 FOR MLL)
3. RATIO OF SCRUBS PRIOR TO T-7 HOURS TO TOTAL SCRUBS (INCLUDES EXTENDED HOLDS TO NEXT WINDOW PRIOR TO T-15 HOURS)
4. AN EFFORT TO LAUNCH IN EACH WINDOW ASSUMED

FIGURE 3 - PROBABILITY OF SUCCESSFUL LAUNCH WITH LAUNCH WINDOWS ON TWO CONSECUTIVE DAYS. APOLLO/SATURN V MLL MISSION



PROBABILITY OF SUCCESSFUL LAUNCH IS:

$$1-B^2\left[1-X^2(1-B)\right]$$

NOTES:

1. A = PROBABILITY OF SUCCESSFUL LAUNCH IN SINGLE COUNTDOWN (0.65 FOR MLL)
2. B = PROBABILITY OF SCRUB IN SINGLE COUNTDOWN (0.35 FOR MLL)
3. X = RATIO OF SCRUBS PRIOR TO T-7 HOURS TO TOTAL SCRUBS (INCLUDES EXTENDED HOLDS TO NEXT WINDOW PRIOR TO T-15 HOURS)
4. AN EFFORT TO LAUNCH IN EACH WINDOW ASSUMED

FIGURE 4 - PROBABILITY OF SUCCESSFUL LAUNCH WITH LAUNCH WINDOWS ON THREE CONSECUTIVE DAYS. APOLLO/SATURN V MLL

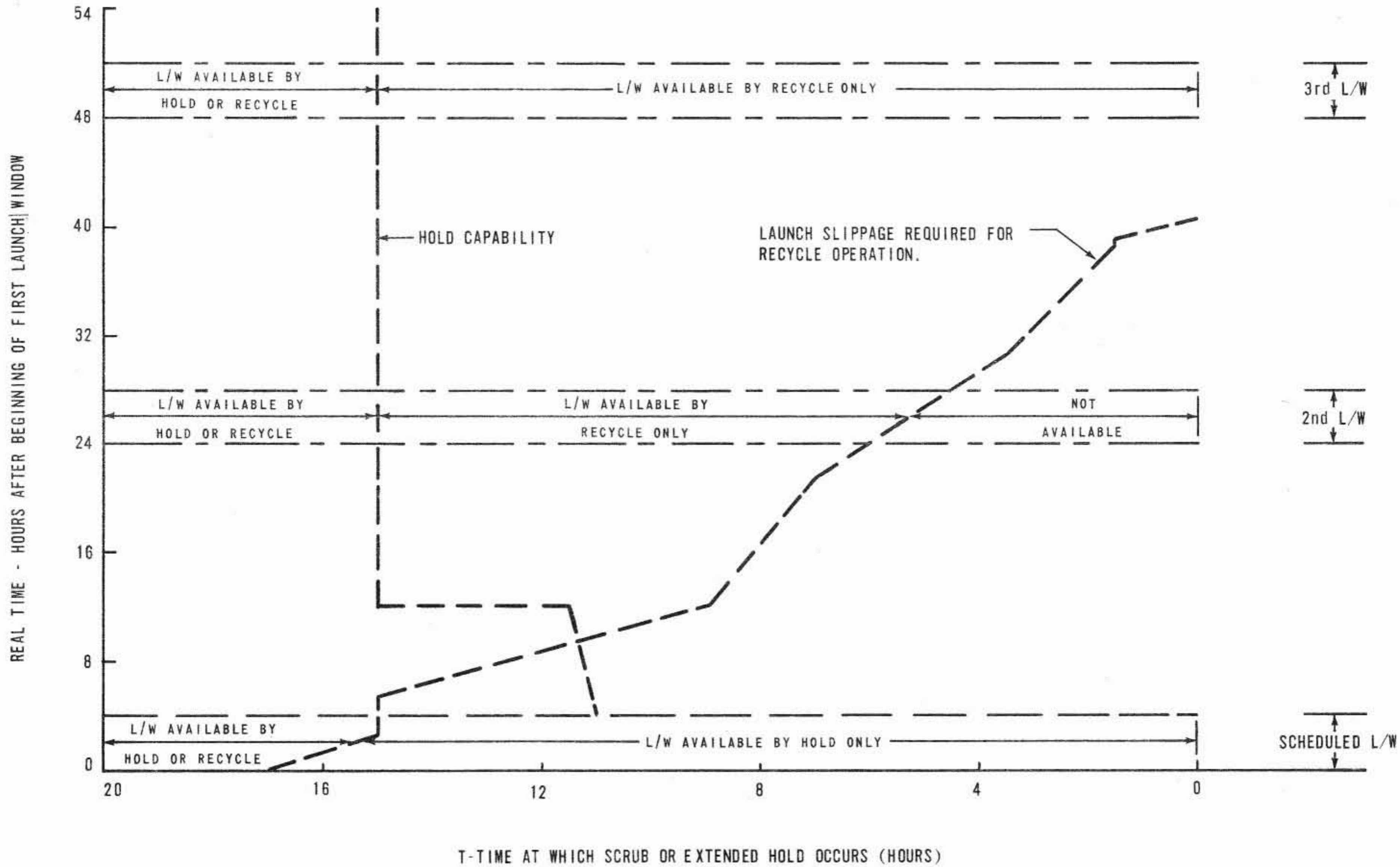


FIGURE 5 LAUNCH ABILITY BY HOLD OR RECYCLE