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N70-18402	
(ACCESSION NUMBER)	(THRU)
57	1
(PAGES)	(CODE)
NASA CR-92387	30
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

SEATTLE, WASHINGTON

NASA CR 92387

THE BOEING COMPANY

REV LTR

CODE IDENT. NO. 81205

NUMBER D2-114040-3

TITLE: PARAMETRIC VISION SIMULATION STUDY - FINAL REPORT - PART II

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MODEL ________ CONTRACT NAS 9-7198

ISSUE NO. ________ ISSUED TO: ________

Prepared by N. N. Hansen
N. N. Hansen

Prepared by
D. C. Cunningham, Jr.

Prepared by
R. H. Ospess

PREPARED BY
F. E. Baird

SUPERVISED BY T. K. Maki
T. K. Maki

APPROVED BY
L. J. Mason

APPROVED BY ________

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ABSTRACT

This document is submitted in response to the requirement for a Final Report in the Statement of Work in the Contract NAS 9-7198, "Parametric Vision Simulation Study." The document describes in detail the second part of the subject study and an analysis of the data from the entire study. Part I of this report, document D2-114040-2, describes in detail the first part of the study including a description of simulation equipment and the results of the first part.

KEY WORDS

Manned Lunar Descent
Visual Simulation
Lunar Photometric Function
Lunar Models
Apollo
Illumination
TV Projector

1.0 SUMMARY

This document is an addendum to Document D2-114040-2, "Parametric Vision Simulation Study-Final Report - Part I." It contains a description of the Redesignation Study - an attempt to evaluate the effects of landing site redesignation on visibility during a manned landing on the moon -- and complete reduction of data from both the previous phase - the Trajectory Study - and this phase - the Redesignation Study.

Results indicate that the landing site look angle must be 12° (± 4°) below the sun angle to be "fairly visible" to the astronaut during a lunar landing, and that excessively high redesignation angles must be used to achieve "fair visibility" if the landing site look angle is substantially less than 12° below the sun angle. All data show a remarkable degree of consistency with photographic data of the moon from Lunar Orbiter V.

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2.0 INTRODUCTION

The Parametric Vision Simulation Study has been divided into two parts, (1) the Trajectory Study and (2) the Redesignation Study.

The Trajectory Study, reported in Reference 2, Document D2-114040-3, "Parametric Vision Simulation Study - Final Report - Part I," was originally designed to be a 20-hour simulation study of the effects of sun angle, flight path angles, and terrain roughness on visibility during a manned lunar landing. A projection lamp failure forced a delay at the end of 12 hours of simulation and while repairs were being made, it was mutually agreed between NASA/MSC and Boeing that the final 8 hours of simulation should be used to study the effect of redesignation angle (a heading change) on lunar visibility. This final phase has been termed the Redesignation Study to distinguish it from the previous phase which is now called the Trajectory Study. A different trajectory was used in the Redesignation Study.

Reference 2 contains a description of the Trajectory Study, the unreduced data from that study and a description of the simulator equipment used in both studies.

This present document contains a report on:

1) The Redesignation Study
2) An analysis of the data from both studies
3) The results of a separate analysis which show that the separate data packages from both studies are completely compatible with each other and with photographic data from Lunar Orbiter.

Figure 1 shows the terminology used in this report.

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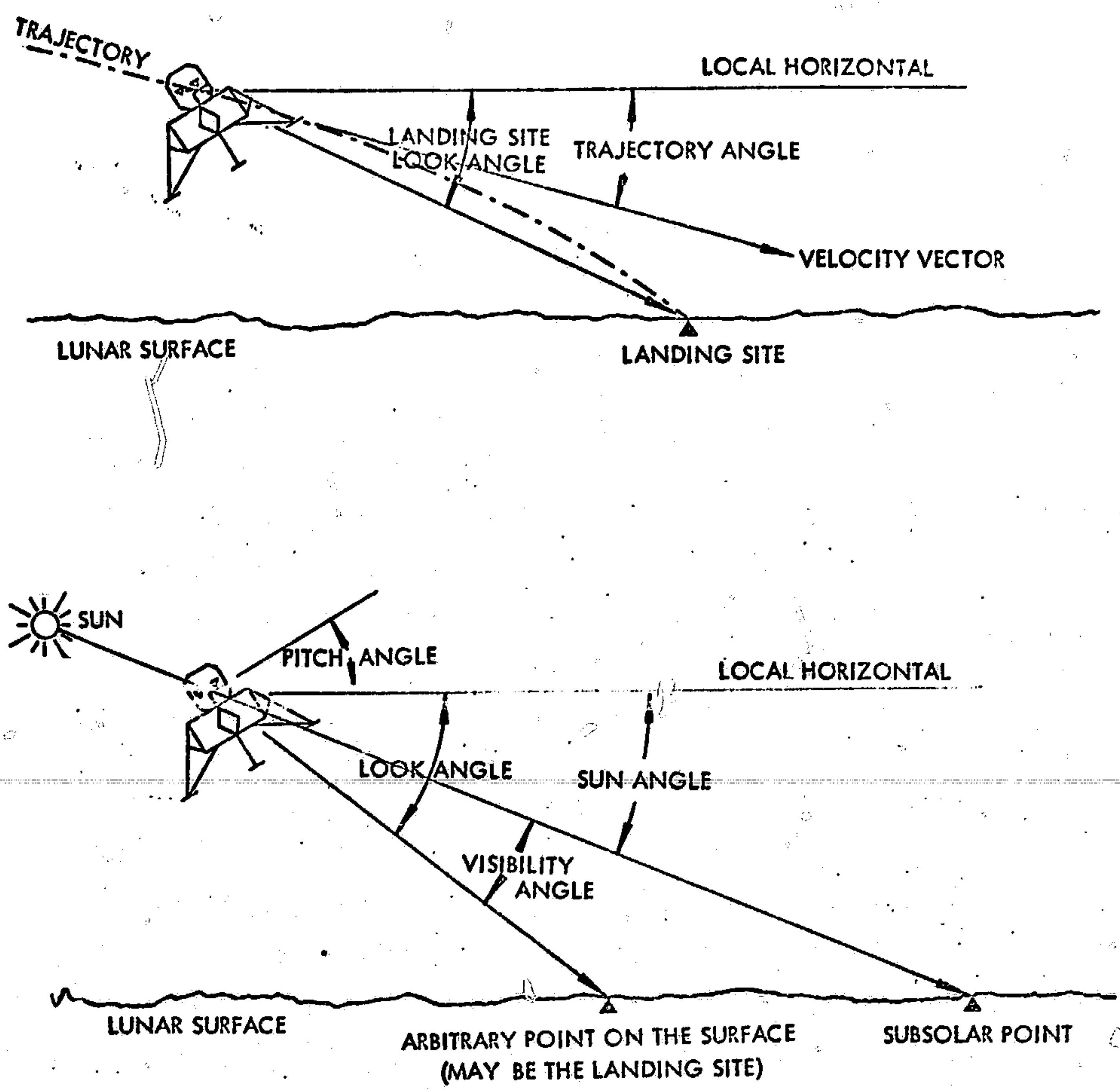

Figure 1 DESCRIPTION OF VARIOUS ANGLES USED IN THE REPORT

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3.0 THE REDESIGNATION STUDY

3.1 Study Description

The Redesignation Study was conducted using exactly the same simulation equipment used for the Trajectory Study described in Reference 2. However, a completely new trajectory was used for this study which differed from the previous three used in the Trajectory Study in that it: (1) had a lower pitch angle so that more of the lunar surface was visible in the lower part of the window thus providing somewhat better visibility, (2) had an almost straight-in approach to the landing site compared to the approach to a point 500 ft. above the landing site used previously, and (3) provided a choice of five separate redesignation angles up to 25° heading change in 5-degree increments in addition to a 0° redesignation angle.

Figure 2 shows the initial and final conditions for each of the three models and some dimensional data relating to the models. Trajectory data are given in Appendix II.

All runs were conducted over the rough series of models except for three runs over the smooth models that are included for comparison purposes.

Data were collected solely by voice recording. The questionnaire used previously was eliminated and subjects were not requested to estimate the vertical field of view, as had been done previously. It was felt that the recorded voice comments would contain all the information needed for data reduction for this phase of the simulation.

3.2 Simulation Results

Figure 3 is an abstract of the voice comments showing the subject's opinion as

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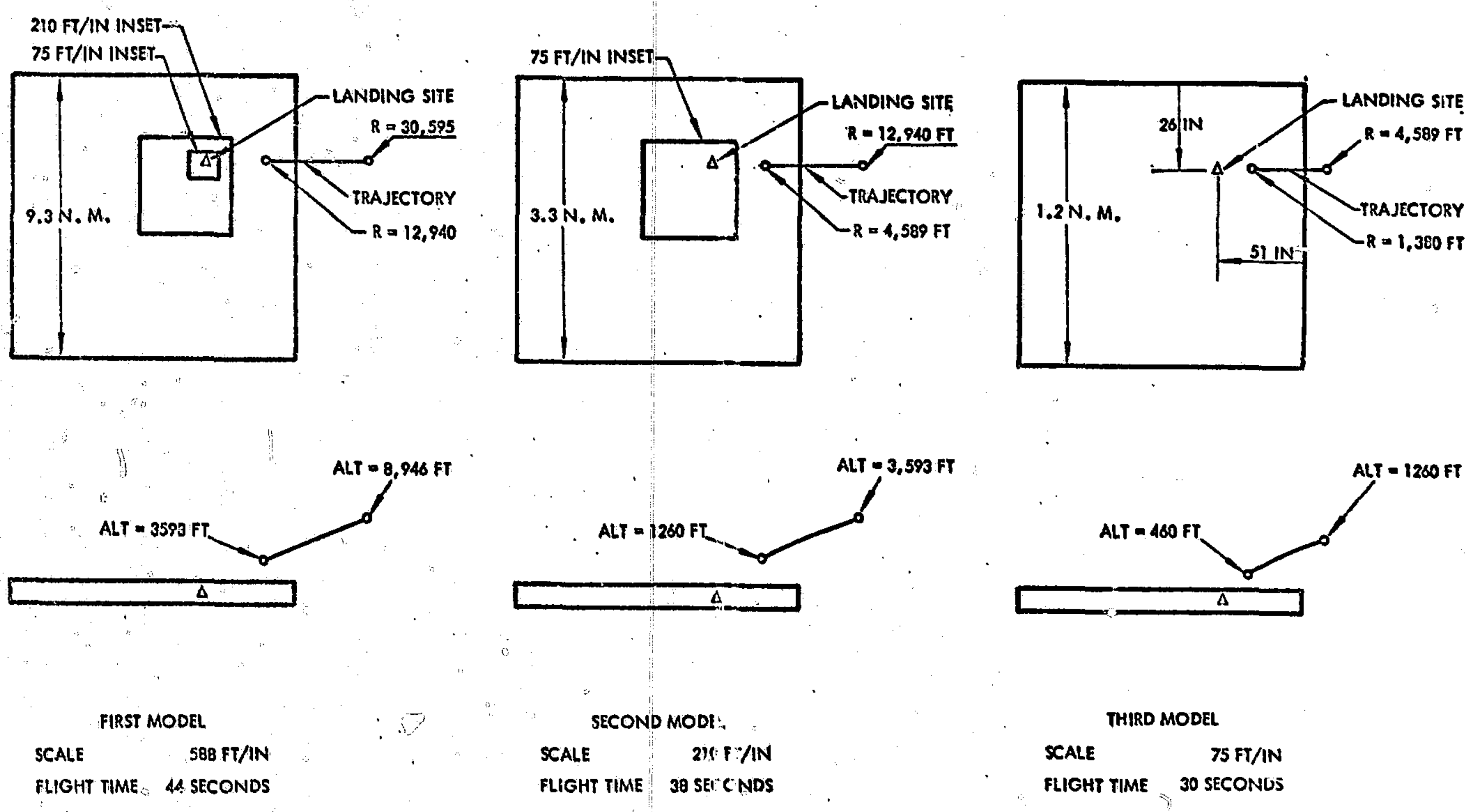

Figure 2 MODEL TRAJECTORIES — REDESIGNATION STUDY

REDESIGNATION STUDY

CONDITION		VISIBILITY			
SUN ANGLE	DOGLEG ANGLE	SUBJECT 5	SUBJECT 6	SUBJECT 7	AVERAGE
7°	0°	FAIR	FAIR	FAIR	FAIR
11°	0°	FAIR	BARELY	BARELY	BARELY
11°	5°	FAIR	FAIR	NOT FLOWN	FAIR
15°	0°	NONE	NONE	NONE	NONE
15°	5°	NONE	NONE	NOT FLOWN	NONE
15°	15°	BARELY	BARELY	NO COMMENT	BARELY
17°	0°	NONE	NONE	NONE	NONE
17°	10°	BARELY	NONE	NONE	NONE.
17°	20°	BARELY	BARELY	BARELY	BARELY
20°	0°	NONE	NONE	NOT FLOWN	NONE
20°	15°	NONE	NONE	NONE	NONE
20°	25°	BARELY	BARELY	NO COMMENT	BARELY
25°	0°	NONE	NOT FLOWN	NOT FLOWN	NONE
25°	25°	NONE	NOT FLOWN	NOT FLOWN	NONE

Figure 3 SUBJECTS' COMMENTS ON LANDING SITE VISIBILITY

to the relative visibility of the landing site. The entire transcript of the voice comments is given in Appendix I. "Barely visible" means the subject could detect something that looked like the landing site, but would not attempt a landing. "Fair visibility" means the subject could see well enough to attempt a landing although visibility was far from being "good."

From the data it may be concluded that:

(1) The 7° sun angles provide fair visibility without redesignation.

(2) A 15° redesignation is required to move the landing site from the "no visibility" region to the "barely visible" region when the sun angle is 15°.

(3) A 20-degree redesignation is required to move the landing site from the "no visibility" region to the "barely visible" region when the sun angle is 17°.

(4) A 25° redesignation is required to move the landing site from the "no visibility" region to the "barely visible" region when the sun angle is 20°.

(5) A 25° redesignation is not sufficient to change visibility when the sun angle is 25°.

Subjects felt they could probably land under conditions of "fair visibility," but would not attempt a landing under "barely visible" conditions. Since none of the redesignations changed visibility from "barely" to "fair," (except for the 11° case) it is impossible to estimate on the basis of the data, what redesignation angles would be required to produce "fair" visibility. However, when these data are compared with the data from the Trajectory Study later in Section 5, it will be shown that they provide a basis for estimating the redesignation angles required for "fair" visibility.

4.0 DATA ANALYSIS OF BOTH THE TRAJECTORY STUDY AND THE REDESIGNATION STUDY

Data from both phases of the study contain much useful information when examined closely. The three data packages from the Trajectory Study - the voice comments, the estimated vertical field, and the de-briefing comments - and the voice comments from the Redesignation Study have been examined both individually and together. Results of the examination are presented in this section.

4.1 Washout Phenomonology

The washout phenomenon is caused by the high back scatter photometric property of the moon. Light coming from the sun is reflected backward toward the sun more intensely than in any other direction. This high back scatter is caused by a thin layer of fine loosely compacted rock dust particles on the order of 10-micron average diameter. The particles are stacked against each other to produce a fairy-castle packing which is about 90% voids by volume (Ref. 5, Document D2-114040-2). Light entering this porous material penetrates several tens of microns below the surface and is scattered by each particle in a general lambert fashion. If one looks into the surface along the line of illumination, he will see illuminated particles well below the surface. If he looks at the same point from any other angle, he will see fewer particles because the lower particles lie in the shadows of particles closer to the surface. The spot will appear less bright because he is seeing more shadowed area than before. As the look angle increases, the percent of shadowed area increases and brightness decreases.

On the basis of this phenomonology one would expect that:

1) The amount of light back-scattered should be independent of terrain slope. This has already been proved since the existence of the washout effect has been well established.

2) Terrain visibility in the vertical plane should depend primarily on the

visibility angle (see Figure 1 for a definition of terms) and be reasonably independent of sun angle and trajectory angle.

3) An observer should find it difficult to judge terrain slope in the vicinity of the washout area.

4) An observer should find it difficult to judge vehicle motion when terrain features are washed out.

In the data analysis that follows, each of these hypotheses is tested for validity.

4.2 Trajectory Study Voice Comments Analysis

Recorded voice comments made during the Trajectory Study runs were examined for data on landing site visibility. It was found that, in most cases the subjects commented when the landing site became "barely" visible and later when it appeared to have "fair" visibility. These two events seemed to be sufficiently distinguishable and subject's comments appeared to be sufficiently consistent from run to run and generally from subject to subject to warrant investigation.

According to hypothesis 2 above, terrain visibility should depend primarily upon the visibility angle in the vertical plane. The visibility angle (see Figure 1) is defined as positive in the downward direction so that an increase in the visibility angle corresponds to an increase in visibility on the lunar surface. In order to test this hypothesis, the landing site look angle was first calculated for each of the three trajectories from computer readout shown in Figure 4.*

The times at which subjects commented that the landing site was (1) "barely" visible, and (2) "fairly" visible were noted and the landing site look-angle read off the look angle vs. time curves. These angles are shown in Table 1. Sun angles were then subtracted from these readings to obtain the visibility angles which are shown in Table 2. It was noted in examining the results in Table 2 that data from Subject 3 differed considerably from that of the other subjects. A re-examination of recorded comments revealed that the subject was looking at general visibility over the entire lunar model surface and not concentrating specifically on the landing site. On the basis of this, it was decided to eliminate this data from subsequent analyses. Table III gives the average visibility angles for "bare" visibility and "fair" for all subjects except Subject 3.

We are now in a position to examine Hypothesis 2 above, i.e., whether visibility depends on visibility angle only. The data were plotted across trajectory angles in Figure 5 and across sun angles in Figure 6. There appears to be a tendency to estimate smaller visibility angles at higher sun angles which on the basis of this data seems to contradict the hypothesis. The subjects almost unanimous preference for the higher trajectories (Ref. 2, p. I-3 ff), does not necessarily tend to support the hypothesis since there is another factor that may have influenced their performance. Figure 7 shows a plot of the lower limit of the LM window (top

*The curve showed an unexpected deviation from smoothness over to the last model which, it was conjectured, could have been caused by inability to read the original curves accurately. It will be recalled that the trajectory and attitude were programmed into the computer by reading points from a set of curves and calculating polynomial coefficients for these points. The effect of a 100' curve-reading error on the calculated value of the landing site look angle was calculated to determine the reasonableness of this assumption. The calculations showed that the ±100 foot curve reading error would cause a ±7°, angular error at the end of the trajectory which easily could have caused the deviation. Fortunately, the deviation does not affect study results, since the only important thing is the actual value of the landing site look angle, not what it should have been.

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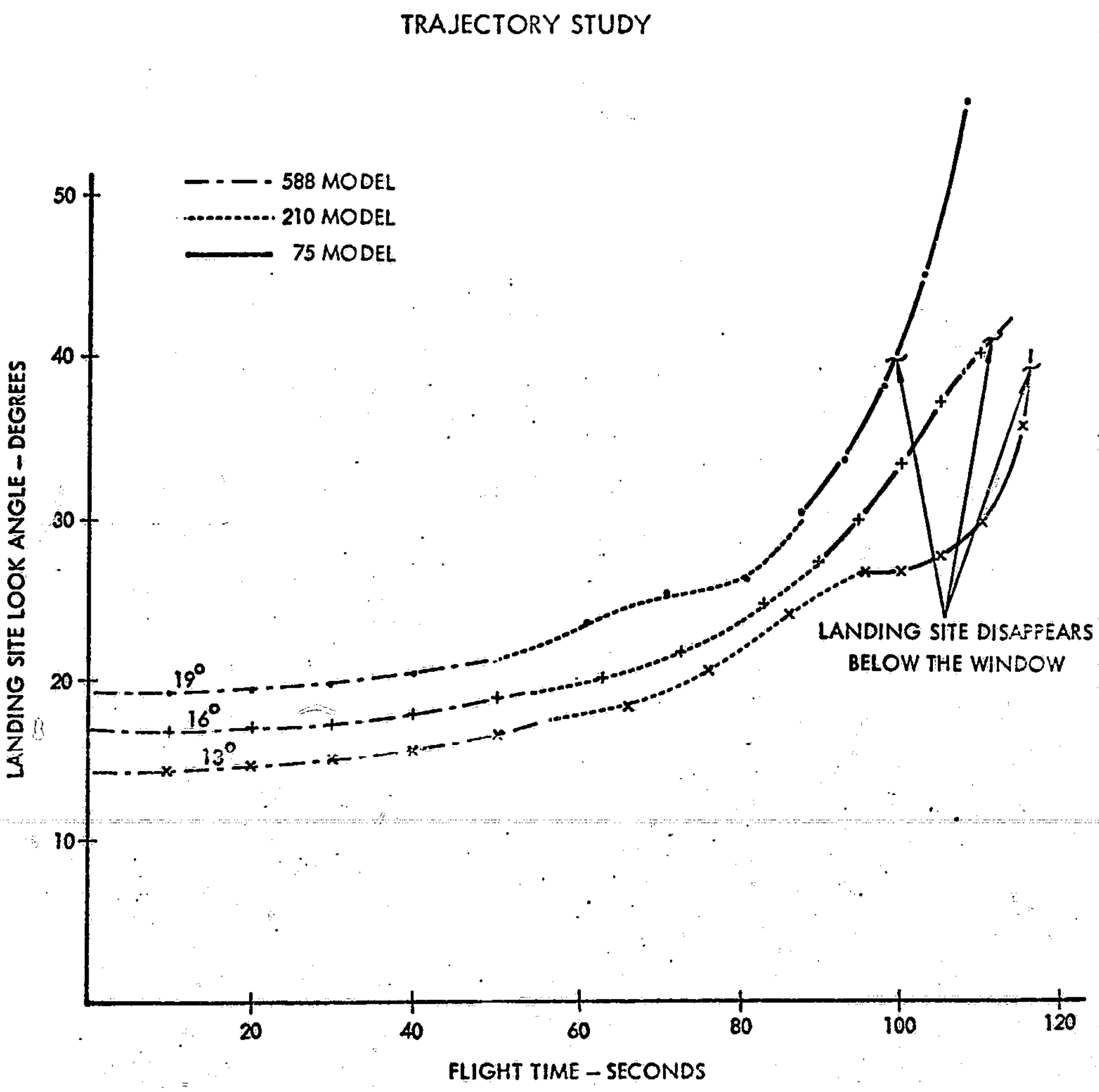

Figure 4 LOOK ANGLE TO LANDING SITE vs FLIGHT TIME

TABLE I

TRAJECTORY STUDY

LANDING SITE LOOK ANGLE FOR "BARE" AND "FAIR" VISIBILITY AT THE LANDING SITE

		SUN ANGLE DEGREES																	
		7			11			15			20			25			30		
FLIGHT PATH ANGLE DEGREES		13	16	19	13	16	19	13	16	19	13	16	19	13	16	19	13	16	19
VISIBILITY ANGLE																			
	ROUGH MODELS	SUBJECT 1																	
"BARELY"		NC	NC	NC	NC	NC	NC	NC	21	22	∞	27	29	∞	∞	∞	∞	∞	∞
"FAIR"		NC	NC	NC	NC	NC	NC	27	27	25	∞	35	∞	∞	∞	∞	∞	∞	∞
		SUBJECT 2																	
"BARELY"		19	16	19	14	19	20	18	19	21	NC	NC	NC	NC	NC	NC	NC	NC	NC
"FAIR"		27	19	25	19	21	21	∞	∞	∞	NC	NC	NC	NC	NC	NC	NC	NC	NC
		SUBJECT 3																	
"BARELY"		NC	NC	26	24	NC	20	27	27	34	∞	36	40	NC	NC	∞	NC	NC	
"FAIR"		NC	28	NC	27	32	33	∞	∞	∞	∞	∞	∞	NC	NC	∞	NC	NC	
		SUBJECT 4																	
"BARELY"		NC	17	19	17	19	20	22	∞	25	∞	∞	∞	∞	∞	∞	∞	∞	∞
"FAIR"		NC	∞	42	22	22	23	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
	SMOOTH MODELS	SUBJECT 1																	
"BARELY"		15	NC	NC	NC	NC	NC	NC	NC	NC	∞	33	∞	NC	NC	NC	∞	∞	∞
"FAIR"		NC	NC	NC	NC	NC	NC	NC	NC	NC	∞	∞	∞	NC	NC	NC	∞	∞	∞
		SUBJECT 2																	
"BARELY"		NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
"FAIR"		NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
		SUBJECT 3																	
"BARELY"		21	28	NC	25	27	29	25	31	42	∞	∞	42	∞	∞	∞	∞	∞	∞
"FAIR"		27	NC	NC	27	30	35	NC	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
		SUBJECT 4																	
"BARELY"		NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
"FAIR"		NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC

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TABLE II

TRAJECTORY STUDY

VISIBILITY ANGLES FOR "BARE" AND "FAIR" VISIBILITY AT THE LANDING SITE

		SUN ANGLE DEGREES: 7			11			15			20		
FLIGHT PATH ANGLE DEGREES		13	16	19	13	16	19	13	16	19	13	16	19
VISIBILITY ANGLE													
ROUGH MODELS	SUBJECT 1												
	"BARELY"	NC	NC	NC	NC	NC	NC	NC	6	7	∞	7	9
	"FAIR"	NC	NC	NC	NC	NC	NC	12	12	10	∞	15	∞
	SUBJECT 2												
	"BARELY"	12	9	12	3	8	9	3	4	6	NC	NC	NC
	"FAIR"	20	12	18	8	10	10	∞	∞	∞	NC	NC	NC
	SUBJECT 3												
	"BARELY"	NC	NC	19	13	NC	9	12	12	19	∞	16	20
	"FAIR"	NC	21	NC	16	21	22	∞	∞	∞	∞	∞	∞
	SUBJECT 4												
	"BARELY"	NC	10	12	6	8	9	7	∞	10	∞	∞	∞
	"FAIR"	NC	∞	NC	11	11	12	∞	∞	∞	∞	∞	∞
SMOOTH MODELS	SUBJECT 1												
	"BARELY"	8	NC	NC	NC	NC	NC	NC	NC	NC	∞	13	∞
	"FAIR"	NC	NC	NC	NC	NC	NC	NC	NC	NC	∞	∞	∞
	SUBJECT 2												
	"BARELY"	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	"FAIR"	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	SUBJECT 3												
	"BARELY"	14	21	NC	14	16	18	10	16	27	∞	∞	27
	"FAIR"	20	NC	NC	16	19	24	NC	NC	NC	∞	∞	∞
	SUBJECT 4												
	"BARELY"	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	"FAIR"	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC

TRAJECTORY STUDY

TABLE III

AVERAGE VISIBILITY ANGLES FOR "BARE" AND "FAIR" VISIBILITY AT THE LANDING SITE

"BARELY VISIBLE" AVERAGE:

ROUGH MODELS; $7.8 \pm 2.7^{\circ}$

SMOOTH MODELS; $10.5 \pm 3.5^{\circ}$

"FAIR VISIBILITY" AVERAGE:

ROUGH MODELS; $12.4 \pm 3.9^{\circ}$

SMOOTH MODELS; NO DATA

$$\text{AVERAGE} = \frac{\sum_{n=1}^{K} X_n}{K}$$

$$\text{DEVIATION} = \sqrt{\frac{\sum_{n=1}^{K} \left(\delta X_n\right)^2}{K-1}}$$

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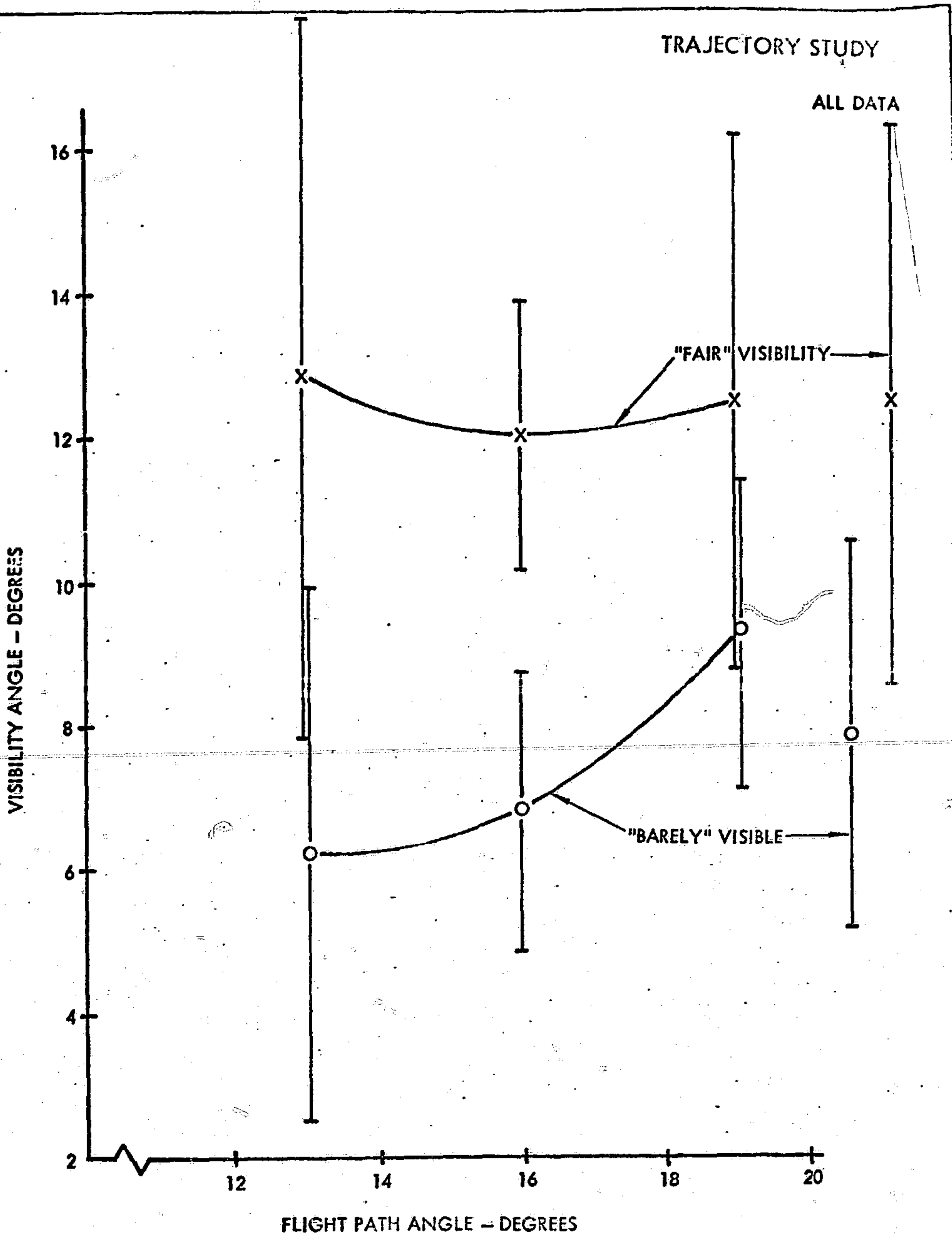

Figure 5 VISIBILITY ANGLE PLOTTED AGAINST TRAJECTORY ANGLE

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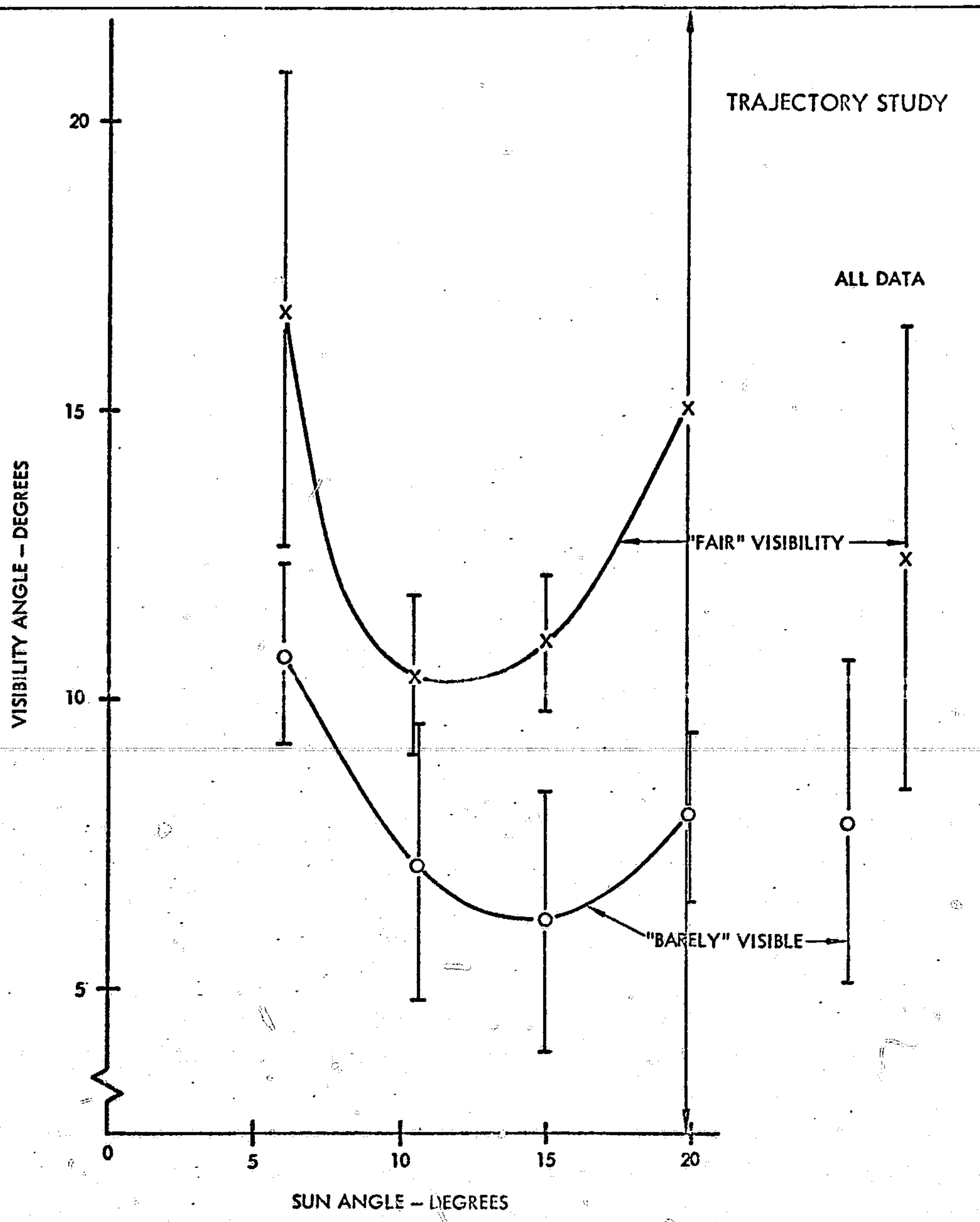

Figure 6 VISIBILITY ANGLE PLOTTED AGAINST SUN ANGLE

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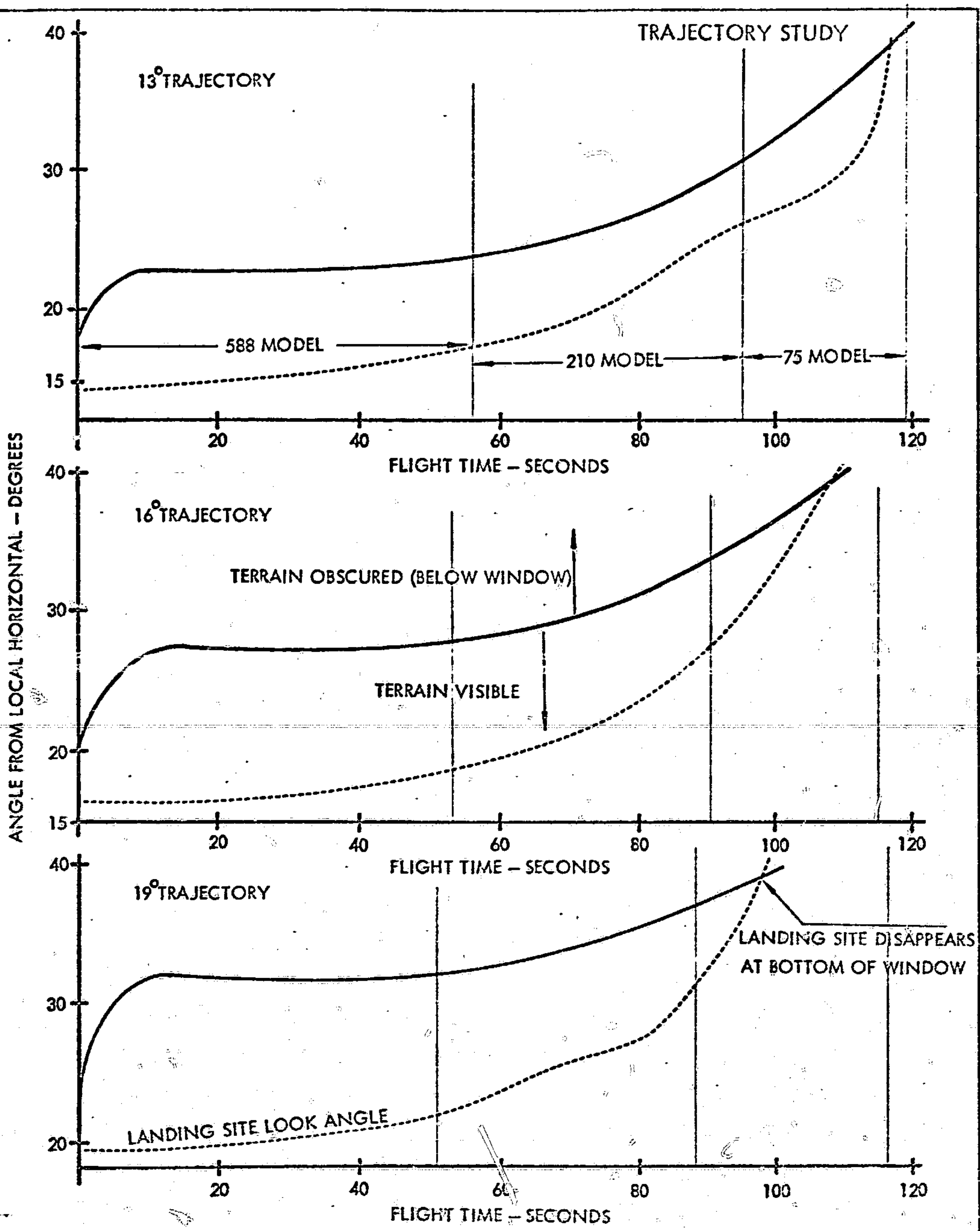

Figure 7 LANDING SITE LOOK ANGLE AND LOWER WINDOW LIMIT vs FLIGHT TIME

curve in each case) superimposed on look angle curves (bottom curve in each case) for the three trajectories. More shadowed terrain at larger angular distance from the landing site is visible at the high flight path angles. This does not affect the visibility at the landing site, but does give a possible basis for the reported preference of the subjects for the higher flight path angles, since overall visibility was better.

It seems more likely that the tendency to estimate lower visibility angles at higher sun angles could have been caused by the fact that a slight improvement in overall visibility would be much more noticeable when visibility is near zero. When visibility is not so near zero, as at the lower sun angles, visibility changes would not be quite so important and subjects would probably tend to estimate larger visibility angles just to be on the safe side. If this is true, the tendency is subjective in nature and would not affect the hypothesis.

Judgement of the visibility of small slopes, hypotheses 3, was not an objective of this study. However, a specific comment on slope visibility was made by one subject (p. 1-6, D2-114040-2) and all subjects remarked during the debriefing sessions that they could not judge the terrain slope during the simulated descent. This important observation not only identifies a potentially dangerous situation but also raises the question of whether or not the only safe sun angle for a landing might be one that produces shadows where terrain slopes are too great for a safe landing and no shadows where terrain slopes are low enough to be safe for landing. It is worth noting here that the shadows on the moon, while they are blacker than on earth, are not totally black and the contrast of the shadow area as defined by the equation:

$$C = \frac{Bs - Bav}{Bav}$$

Where: C = Contrast

Bs = Brightness of the shadow

Bav = Brightness of average terrain

is definitely not -1, even when there is no starlight and no earthshine illuminating the shadowed areas. The light that illuminates the shadowed part of a crater is light back-scattered by the sunlit part of the same crater. Under certain conditions, contrasts as small as -.2 are obtained. The dynamic range of the human eye, being considerably greater than the vidicon camera used in Ranger & Surveyor and the SO 243 film used in the Lunar Orbiter, should make it possible for the astronauts to see clearly enough in the shadowed areas to traverse them in complete safety on foot. Whether or not they can see well enough to land the LM in the shadow areas safely is another question.

The subjects' lack of ability to identify debris piles is consistent with Hypothesis 3 above (see p. I-3 and ff, D2-114040-2). Their small size and low silhouette makes them appear like small low hills which cast almost no shadows at the higher sun angles. Since the subjects could not estimate slope, slope could not be expected to give visual cues which might otherwise improve debris visibility. This leads to the conclusion that lunar debris will probably not be visible until the spacecraft is very near the landing site and then only when the sun angle is low enough to form shadows.

Hypothesis 4 above is established by the subjects direct comments. Subjects reported a lack of ability to judge motion when terrain features were washed out, which again leads to the conclusion that sun angles low enough to form shadows must be used.

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4.3 Trajectory Study Estimated Vertical Field Data Analysis

Table 1 of Document D2-114040-2 gives the vertical field estimated by each of the subjects during a pause in the 19° trajectory. The pause occurred at the 83 second point, i.e., 5 seconds before the end of the second model. At this point the lower limit of the windows was 36° down from the horizon. Subjects were asked to estimate the visible field in degrees from the bottom of the window using the LPD. The visibility angle was obtained by subtracting the sun angle and the window limit angle from these visible field estimates. Results are shown in Table 4.

Comparison of Table 4 with Table 3 shows a remarkable consistency. Whereas the average "fair" visibility angle from the voice data was 12.4° ± 3.9° the average from the vertical field estimates is 12.4° ± 2.4°. No doubt such close agreement is fortuitous considering the deviations.

The data shows no dependence on subject, which is again consistent with the voice data. It is interesting to note that while voice data from Subject 3 was considerably different from the other subjects, his vertical field estimates are quite consistent with the others.

There appears to be a slight tendency in the vertical field data to estimate a smaller visibility angle at the 15° sun angle than at lower sun angles. As previously noted, this trend also appears in the voice data. However, the opposite trend occurs in the Redesignation Study data showing that it probably is subjective in nature as noted in Section 4.2. Thus, the total data package tends to support Hypothesis 2, that visibility depends primarily on the visibility angle.

TRAJECTORY STUDY

TABLE IV

VISIBILITY ANGLE FROM ESTIMATED VERTICAL FIELD OF VIEW AT THE 19° TRAJECTORY

SUBJECT	SUN ANGLE 7°	11°	15°
1	14°		9°
2	14°	13°	9°
3	15°	15°	
4	15°		9°
1	11°		11°
2	11°		12°
AVERAGE	13.3° ± 2.4°	14.0° ± 1.4°	10.0° ± 1.4°

OVERALL AVERAGE:

12.43° ± 2.35°

4.4 Redesignation Study Voice Comments Analysis

In order to analyze the Redesignation Study voice comments properly, it was necessary to combine the summary comments shown in Figure 3 with the data from the Trajectory Study given in Tables III & IV. The method chosen was to display the data from both studies on an actual photograph of the moon.

This display not only shows the compatibility of data between both parts of the simulation but, significantly, the compatibility of the simulation data and visual conditions on the lunar surface as indicated by Lunar Orbiter photographs.

The moon photo selected was Frame 42 from Lunar Orbiter V, taken down sun of the western horizon when the spacecraft was at 48.47° East Longitude and 0.96° South Latitude and at an altitude of 97.26 km. The development of this visual correlation with the Lunar Orbiter photograph is accomplished with construction of three transparent overlays.

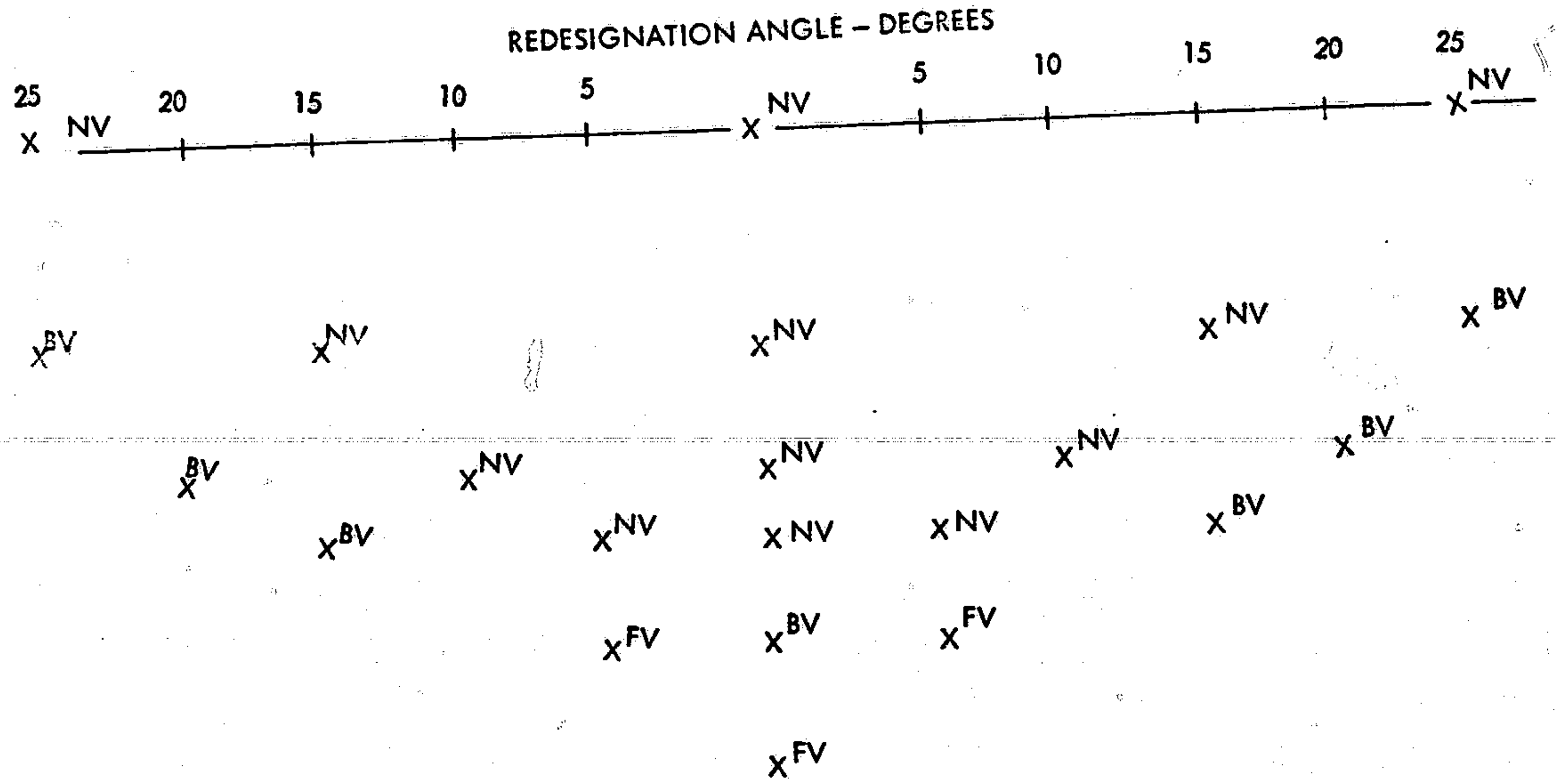
The data from the Trajectory Study are plotted on the first overlay transparency. The subsolar point was calculated from Lunar Orbiter V data. Next, the 7.8° visibility angle corresponding to "barely visible" and the 12.4° visibility angle corresponding to "fairly visible," from Tables III and IV, were located along the ground track. Finally the two arcs were drawn from a common center through these two visibility points to generate a locus of apparent equal visibility to the left and right of the ground track.

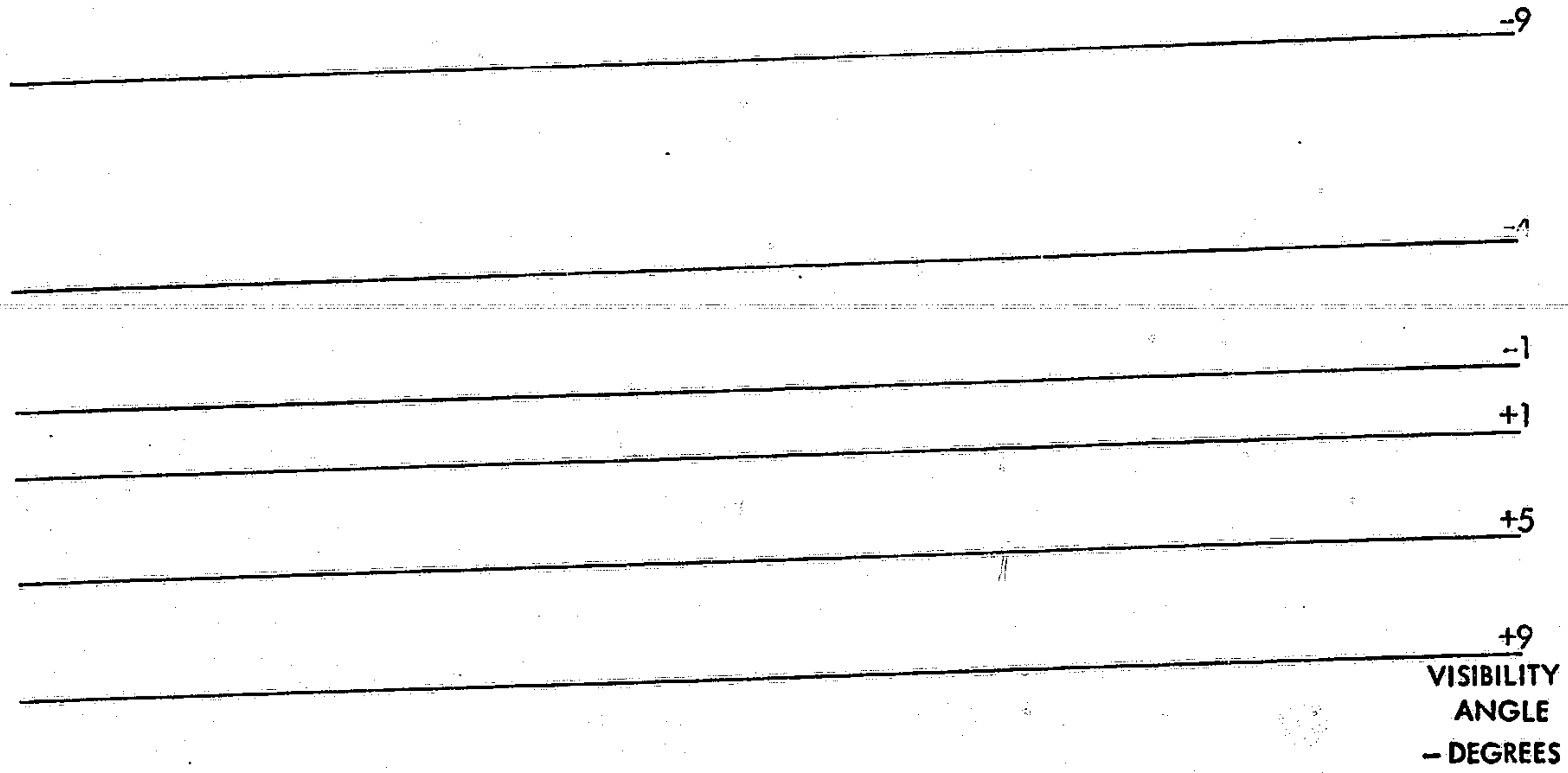
A grid of constant visibility angles (i.e. the look angle minus the sun angle) is plotted on the second overlay. Note that the zero visibility angle passes through the subsolar point and the lower visibility angles lie higher in the photograph. This grid of visibility overlayed with the lunar orbiter photograph can be used to illustrate visibility conditions for various combinations of sun

NV = NO VISIBILITY

BV = "BARELY" VISIBLE

FV = "FAIR" VISIBILITY

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-4
-1
+1
+5
+9
VISIBILITY
ANGLE
– DEGREES

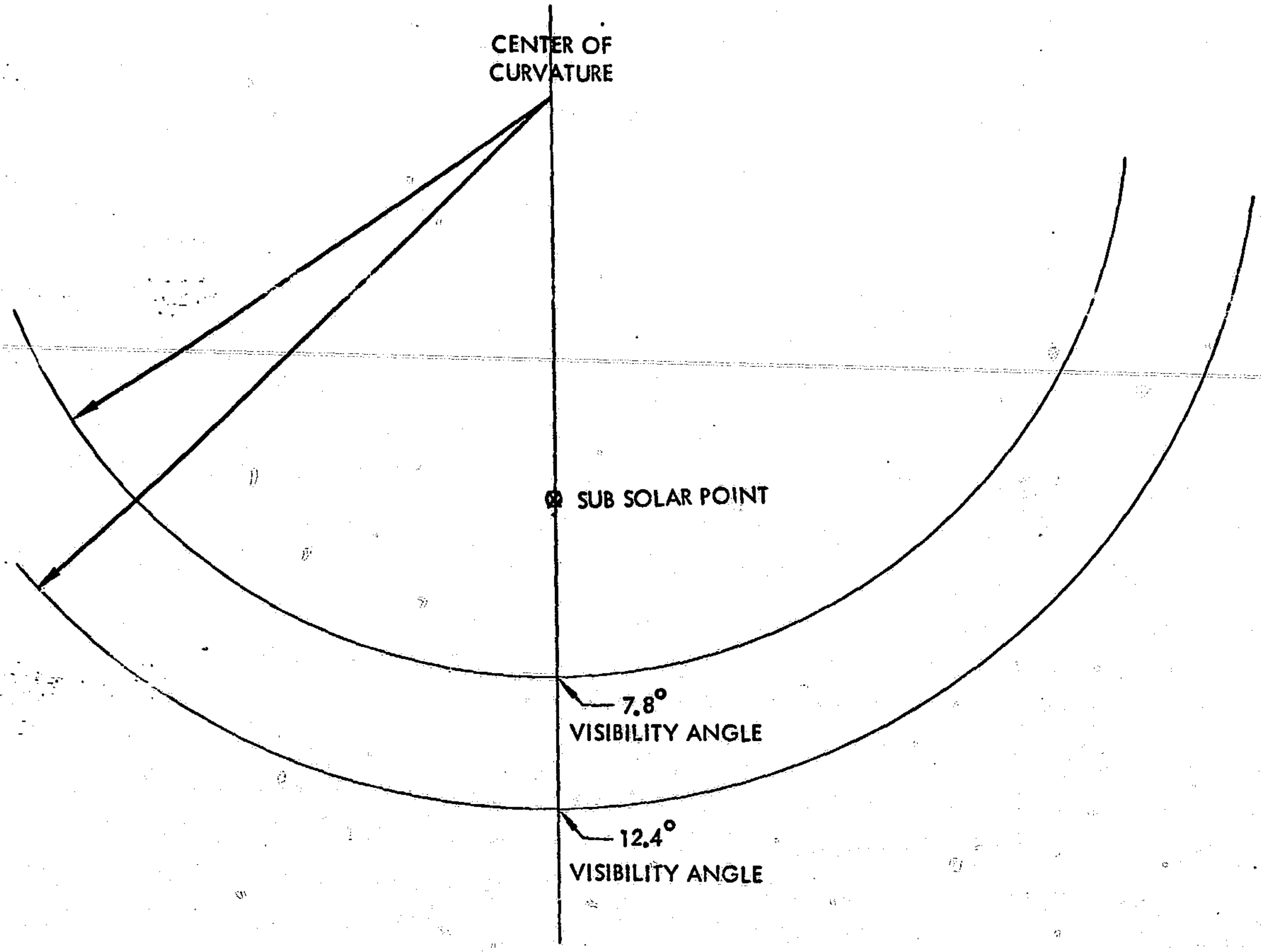
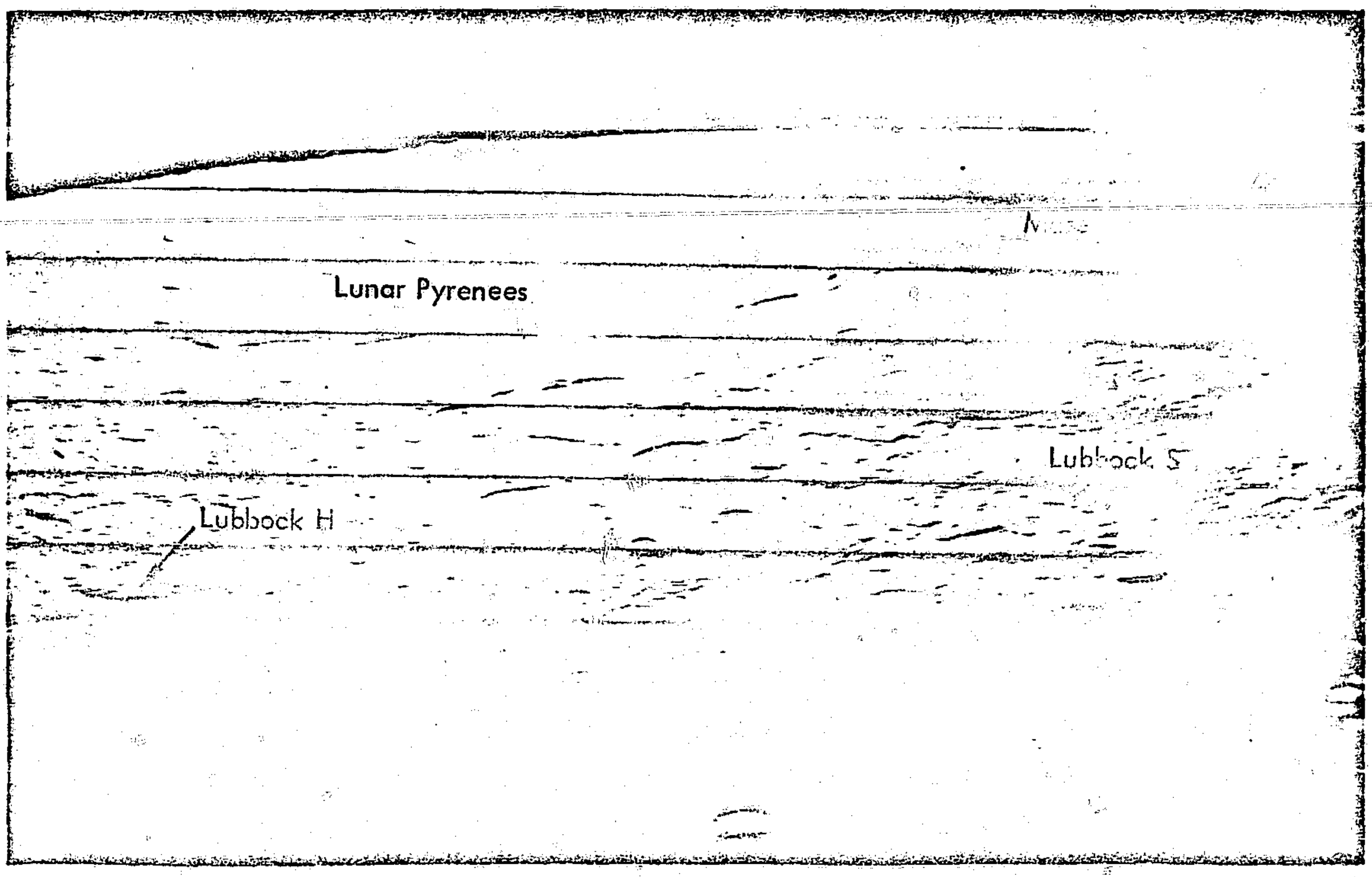

CENTER OF
CURVATURE
SUB SOLAR POINT
7.8°
VISIBILITY ANGLE
12.4°
VISIBILITY ANGLE

Figure 8 DOWN-SUN PHOTO OF THE MOON WITH OVERLAYS

•OVERLAY REGISTER MARKS

OVERLAY REGISTER MARKS •



angles and look angles. For example, when the landing site look angle (equivalent to the trajectory angle approximately) is 16 degrees and the sun angle is 7 degrees, the amount of washout at the landing site is shown along the 9 degree visibility angle grid on the photograph.

Finally, the subjects' comments on landing site visibility from the Redesignation Study (Figure 3) were plotted on the third overlay. Redesignations were always toward the left of the reference straight-in ground track because of LM window geometry. The points plotted on the third overlay represent majority opinion of the test subjects concerning visibility for the stated conditions (see Figure 3). Points to the left of the ground track represent actual points, while points to the right represent a "mirror image" of the actual points. This was done to illustrate the symetrical nature of the LO photograph.

The specific data points from the Redesignation Study (third overlay) are generally quite consistent with the visibility boundaries corresponding to "barely" and fairly visible conditions from the Trajectory Study as extended to points off the ground track (first overlay). Larger redesignation angles would have provided improved data in the "fair" visibility region, but this was not evident prior to the simulation.

Note that one point (and its mirror image) plotted on the +5° visibility angle line indicates "fair" visibility although it lies inside the 12.4° circle on the overlay. These points are still within the 12.4 ± 3.9° tolerance band and, therefore, do not present any inconsistency.

It is evident by looking at Figure 8 with its overlays that the points marked "NV" for "no visibility" falling within the 7.8° visibility angle curve certainly do correspond to points of no visibility on the photograph. On the other hand, the area outside the 12.4° curve contains quite a bit of detail and one might consider visibility to be "fair" in this region. Figure 8 with its overlays shows that the simulation did duplicate visibility conditions on the moon, and that simulation data are quite compatible with actual conditions to be encountered during a manned lunar landing.

5.0 RESULTS AND CONCLUSIONS

Figure 8, the down-sun photograph of the moon taken by Lunar Orbiter V, shows that the data obtained in both the Trajectory Study and the Redesignation Study phases of the Parametric Vision Simulation are completely compatible with visual conditions on the moon. While there has been no attempt to derive a figure of merit for the simulation, it is felt, on the basis of a simple visual inspection of Figure 8, that the simulation accurately reflects the gross visual conditions on the moon.

A number of conclusions may be drawn from this simulation:

1. The visibility angle for "fair" visibility must be at least 12.4° ± 3.9°.
2. A redesignation, that is a heading change, may be used to improve visibility. Figure 9, which is based on information in Figure 8, estimates the redesignation angle required to improve visibility from "barely visible" to "fairly visible" when the visibility angle is less than 12.4°.
3. The required redesignation angle rises very rapidly with higher sun angle.
4. Landing sites on the moon should contain a small number of features which stand out from the background to give the astronauts landmarks which will provide visual cues. Rills are preferred, but large craters may also be used. Small craters, low hills and debris piles are generally not acceptable as landmarks. (See Table I-1, D2-114040-2).
5. Astronauts should make simulated landings on models of actual landing sites prior to the mission to familiarize them with visual conditions on those landing sites. (See p. I-4 and ff, D2-114040-2)

USE FOR DRAWING AND HANDPRINTING — NO TYPEWRITTEN MATERIAL

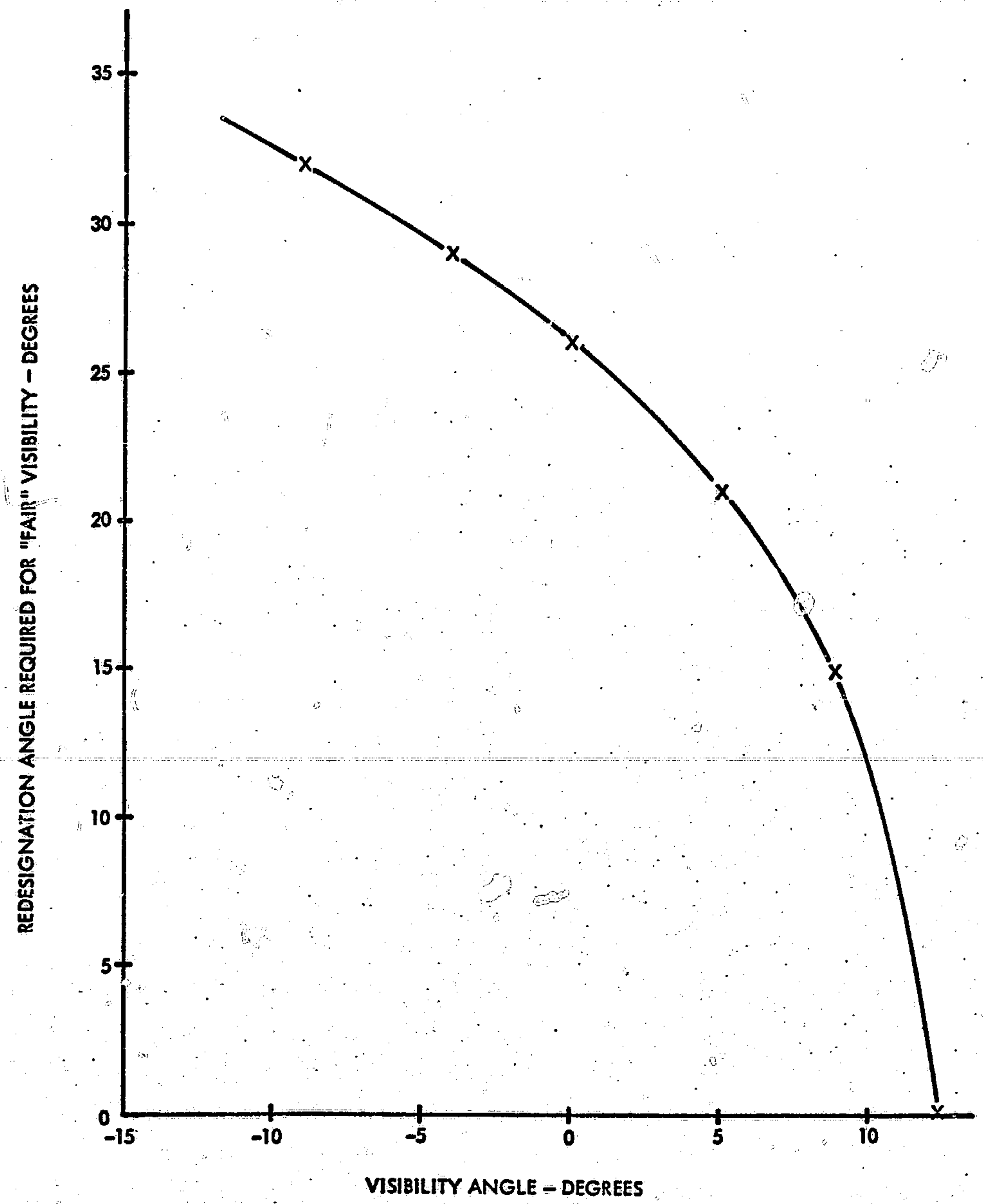


Figure 9 REQUIRED REDESIGNATION ANGLE vs VISIBILITY ANGLE

6.0 REFERENCES

1.0 Boeing Document D2-114040-1, Parametric Vision Simulation Study - Presimulation Report.

2.0 Boeing Document D2-114040-2, Parametric Vision Simulation Study - Final Report - Part I.

3.0 Boeing Document D2-113372-1, Description of the Boeing Space Flight Simulator and Assorted Simulation Facilities.

APPENDIX I

REDESIGNATION STUDY VOICE COMMENTS

As was mentioned in the body of this report, each subject was invited to make verbal comments during the runs. At the completion of the simulation, these verbal comments were extracted and typed for inclusion in this report. Those comments are given in the following pages of this Appendix.

TEST SUBJECT: COL. FRANK BORMAN

7° Sun Angle - No redesignation - Rough Models

14 seconds - I can't identify anything that looks like a landing site at this time.

36 seconds - I still can't identify any landing area.

50 seconds - I have target.

60 seconds - Pretty good definition.

64 seconds - I can see the rill and the crater.

72 seconds - Very good definition now.

- I'll tell you one thing, your head movement sure makes a lot of difference on this LPD. You can move it just a little bit and the landing site will move 2° without any problem at all.

86 seconds - Very good definition still.

100 seconds - The landing site has come down to 40°. (Editor's note: Calculated value is 39° at this point in the trajectory).

105 seconds - I am loosing some of the definition of the crater.

11° Sun Angle - No redesignation

10 seconds - It's very difficult to pick out any detail down range where the target would be.

17 seconds - The details underneath are very distinct.

28 seconds - Down range is still washed out very badly.

37 seconds - The only detail I'm getting is around 55°.

48 seconds - I think I have it now.

68 seconds - Very good definition underneath.

76 seconds - I can see it well enough.

85 seconds - The landing site is very clear.

95 seconds - Details are good the rill is very distinct.

100 seconds - Still good detail.

- I could see really not much difference between 7 and 11° as far as sun angles go. They had about the same amount of definition. I feel both of them were adequate.

5° Redesignation

9 seconds - The redesignator has not moved over very far.

19 seconds - The definition is just about the same as the last time.

15° Sun Angle - No redesignation

15 seconds - Things beneath you and along the LPD line are not very well defined.

22 seconds - I have no idea where the landing site is.

40 seconds - Anything above 58° on the LPD is very badly washed out.

52 seconds - Anything above 52° is washed out.

60 seconds - I can pick up the big crater, but I still don't see the rill.

65 seconds - The landing site is washed out.

72 seconds - Areas above 50° are coming into view. I still don't see the rill.

78 seconds - The rill is just becoming visible.

85 seconds - I can see the big crater now. The other one I saw before was not it.

92 seconds - The landing point is still not very well defined.

95 seconds - The rill is visible.

105 seconds - The rill is visible, but nothing else is very visible. Now things are starting to become visible.

- I didn't get very good definition until right at the end of that run.

5° Redesignation

8 seconds - I see the crater now.

15 seconds - The definition is better on this run than the last one.

22 seconds - I can see the landing site now.

<u>15° Redesignation</u>

7 seconds - Definition is better on this run than it was on the last one. I can see the landing site now.

19 seconds - Visibility on this run is better than on the last two.

- That one is much better.

<u>17° Sun Angle - No redesignation</u>

10 seconds - Everything is washed out, the lunar surface is completely washed out except off to the left.

15 seconds - If I move my head forward and look off to the left I can see terrain details.

21 seconds - Ahead I see nothing, I have no idea where the landing site is.

28 seconds - Still nothing unless I look off to the periphery on the left.

30 seconds - Everything is washed out, I can't even pick up the big crater.

51 seconds - I start to pick up the big crater, but I cannot yet see the rill.

61 seconds - The only things visible are off to the left and underneath.

75 seconds - It's all washed out, a white blob.

85 seconds - I just begin to pick up the big crater.

92 seconds - The target area is still washed out. I can see the crater, but I still can't pick up the rill.

107 seconds - I still can't see the landing area.

End of run - I never did see the rill at all on that segment.

<u>10° Redesignation</u>

8 seconds - There's better visibility on this run, I can just about pick up the area that I think would be the landing site.

20 seconds - There is much better visibility in the landing area.

End of Run - A dramatic difference in target visibility for a 10° redesignation.

- Part of the increase in visibility was due to an adjustment to the light valve projector.

30' Redesignation

10 seconds - I can see the large crater to the left.

19 seconds - The target area is visible, but there is much better visibility below the target area.

End of Run - The target area is much better defined. I would say this is acceptable.

<u>20° Sun Angle - No redesignation</u>

5 seconds - Just completely washed out.

9 seconds - The only place I can see is looking off to the left.

15 seconds - Any place where the target might be is completely undefinable.

21 seconds - Still completely washed out.

30 seconds - I still have no idea of any terrain features except for looking off to the left.

40 seconds - No definition there at all.

50 seconds - Still nothing except by looking off to the left.

56 seconds - Nothing in the landing area, it's all white.

63 seconds - Above 54° there is nothing on the LPD.

76 seconds - I'm starting to get definition around 54° now.

<u>15° Redesignation</u>

- Still quite washed out. I'm amazed at it.

90 seconds - Can still pick up some targets off to the left.

95 seconds - The area to the right is completely washed out. I can see the large crater now.

105 seconds - Now I can see the target.

25° Redesignation

6 seconds - The area underneath me is very well defined.

8 seconds - There's the large crater.

12 seconds - I still cannot define the target area.

19 seconds - I can see the two small craters.

- That still wasn't very good.

25° Sun Angle - No redesignation

5 seconds - Everything is washed out.

10 seconds - I can see some features by looking way over to the left.

15 seconds - Everything ahead of me is washed out.

22 seconds - Completely unacceptable.

35 seconds - Even off to the left is not very well defined.

50 seconds - Very, very washed out, nothing at all in the target area.

60 seconds - No terrain features except off to the extreme left of the window.

70 seconds - Very, very poor.

75 seconds - I just start to see a crater at the very bottom of the window down around 60°.

25° Redesignation

95 seconds - Still washed out badly.

95 seconds - I can see terrain features to the left and low.

100 seconds - I can just pick up the left side of the big crater.

110 seconds - The right side is completely washed out.

- I can see no sense in going to the 30° sun angle the trend has been to become worse all the way along at the higher sun angle.

End of Run - This is the first real visual simulation I've seen of this problem. We've all been speculating and there's a continual effort to allow the sun angle to get larger and larger because it relieves the launch time constraint, but it seems to me that you really couldn't use anything much greater than 15°.

15° Sun Angle - No redesignation - Smooth models

10 seconds - Things are still pretty well washed out to the right.

40 seconds - It's pretty well washed out.

43 seconds - Visibility to the left is pretty good.

50 seconds - Pretty badly washed out still.

70 seconds - Visibility on this smooth model seems worse than on the rough models.

84 seconds - I just started to see things in the landing area.

104 seconds - Target definition is fairly good, I don't see the rill.

7° Sun Angle - No redesignation - Smooth models

- This has been very valuable to me being able to see this, now when somebody says we'll use a 30° sun angle we will be able to tell the it's not possible.

10 seconds - This is much better.

15 seconds - There's a dramatic improvement. You can see things much further down range.

46 seconds - I see a large crater out there.

57 seconds - Very much better definition than the last run.

75 seconds - Definition in the 42° to 50° area is very good.

90 seconds - Very good definition in the 42° area.

100 seconds - I can see well up to about 32°.

105 seconds - Definition is good.

25° Redesignation

- The redesignation at these lower sun angles does not provide the dramatic improvement that it does at the higher sun angles.

TEST SUBJECT: MAJ. BILL ANDERS

7° Sun Angle - No redesignation - Rough models

44 seconds - Reasonably good definition.

54 seconds - There is good definition.

64 seconds - Looks good.

82 seconds - I was just able to pick up the triad of craters at the landing site.

86 seconds - Definition is good.

11° Sun Angle - No redesignation

44 seconds - There is considerably more wash out.

50 seconds - There's a lot more wash out on this run.

57 seconds - I'd say we're approaching the unacceptable angle between the line of sight and the sun angle.

72 seconds - There's a little definition at 47°. None at 46°.

Repeat of the 7° Sun Angle - No redesignation

- I have the landing point in sight.
- The area between the bottom of the washout and the bottom of the window is okay for altitude reference.
- The landing site is still on the limit of the indistinguishable detailed area.
- The foreground is good for altitude estimation.

5° Redesignation

- You get a lot better detail forward.

End of Run - It seems like if you're going to redesignate, the later you redesignate the more it's going to help you.

15° Sun Angle - No redesignation

- Very poor detail for altitude control.

30 seconds - Still very poor detail, I can't even see the rill.

51 seconds - Very poor visual cues.

59 seconds - There's some detail at about 25° yaw.

89 seconds - Very poor detail.

100 seconds - I can see nothing but gross features. I can see hardly anything in the landing area.

<u>5° Redesignation</u>

99 seconds - There's still poor detail.

108 seconds - Very poor detail.

<u>15° Redesignation</u>

- This is not as good as the lower sun angle final phase, but it's better than the 5° redesignation.
- I can do a little bit better at picking out a possible landing site. For trajectory control you need a little bit better detail.

<u>17° Sun Angle - No redesignation</u>

- This is terrible.
- Hit the eject and bail out. This is like landing on a salt flat.

39 seconds - We're in bad trouble. It looks like we're landing on a big sand dune now. No detail at all to speak of. Down range past the target is zero detail. You can probably get some help in altitude control by looking off to the left side. There's no detail in the landing area. There is some detail low in the window. It would be impossible to evaluate the landing area.

<u>10° Redesignation</u>

- Very little detail. There's more detail now for trajectory control but I still cannot evaluate the landing area. I don't think you could reasonably make an LPD dog-leg evaluation because you can't see the landing area good enough to tell you what values to crank

- into the computer.

- You can't see any better in the area after the redesignation than you could before the redesignation.

20° Redesignation

100 seconds - You still can't evaluate the terrain good enough to make an intelligent dog leg.

20° Sun Angle - No redesignation

13 seconds - No detail.

- No detail in the landing area.

59 seconds - No detail.

15° Redesignation

- There is not enough detail at all.

End of Run - The dog-leg was not sufficient.

25° Redesignation

- This gives me pretty good side detail at about 20° yaw, but I still cannot evaluate the landing site at all.

- My conclusion is that the dog-leg is improving the situation from a completely unacceptable one to a half acceptable one. You might as well save your fuel and not do it early, but wait until you get down and do it all at once.

- Absolutely no detail early in the flight. Limited visibility off to the left for trajectory control.

39 seconds - There's absolutely nothing.

- At this sun angle it appears the dog-leg is useless because you can't look at the terrain and say, "I'll do this dog-leg," because there's no place to go. You can't see anything in the area. It would be much better to go on down to your hover point and yaw around, and then look for an acceptable area to land.

End of Run - This is really an eye opener. Here we are looking for what was a complete non-detailed area to an almost non-completely-detailed area. The only thing the dog-leg does is to give you a little more capability of controlling your trajectory.

TEST SUBJECT: JAY MONTGOMERY

7° Sun Angle - No redesignation - Rough Models

30 seconds - Looks like we might be off as much as 1 1/2° on the LPD.

72 seconds - Good visibility here.

- Visibility was good all the way down, you have good contrast, no problem, the LPD indication is as stable as one would expect flying down it drifts a little bit, but this one would expect to see flying over terrain.

11° Sun Angle - No Redesignation

21 seconds - There is a large degradation in the picture.

26 seconds - I am starting to see the rill or a feature that I can define as the rill.

41 seconds - Definition is improving all the way in.

- You begin to get this foggy effect here where you don't have the resolution and the terrain definition at the outset, but as your range is closing and you get closer to the objects they begin to come out of the fog and washed out area and define themselves. Where with the 7° sun angle I could see that rill almost from the time we pitched over and stabilized, here I had to wait for quite awhile before I could see anything that even looked like the Y shaped rill.

96 seconds - You get good definition in this phase.

5° Redesignation

24 seconds - 600' altitude we have good definition.

- It looks like we're not going to have a big problem here. Again its going to be a problem of sitting back and waiting for features

- to develop. The large features are picked up early enough.
- Probably with the normal Apollo landing site and what I can see here you wouldn't want a sun angle much higher than 11°.

15° Sun Angle - No Redesignation

20 seconds - A wash out extends all the way back to at least 56° and the shape of it would be a large oval.

33 seconds - The large crater at the foot of the Y rill is coming out now.

44 seconds - I don't have any definition where the LPD indicator is telling me I should be looking.
- All good definition was short of where the landing site is. Everything in the area of the landing site and above is obliterated by the wash out.

58 seconds - Some large features are beginning to peak through in the area of the landing site.

66 seconds - I still can't see the landing site. It is at the bottom edge of the wash out.

78 seconds - We're still at the front edge of the wash out.
- It looks like almost exactly what the LPD is giving us for an indication is right at the forward edge of the wash out and that's bad, because procedurely our redesignation should be down range, but we couldn't do that in this type of situation.

92 seconds - I can see the large crater feature.

105 seconds - I am still chasing the landing area back. I can see the landing area though.

I only get definition of the landing area at the very last portion of the trajectory which would be so low that it would be almost prohibitive to permit redesignation.

15° Redesignation

9 seconds - I can't see a large feature down there.

- With this much wash out you would have to start the redesignation much earlier.

17° Sun Angle - No Redesignation

20 seconds - Only large features are visible at 56° about.

35 seconds - The wash out has now extended over the landing point and to the left.

- The wash out looks like it is about a degree of two degrees short of the indicated landing site. Whereas before the landing site was right on the edge of the washed out area.

- Because we have such distinct craters we have better visibility up range anywhere from 3° to 6° short of the indicated landing site which I don't think we will have with the smoother models which are more representative of the landing area.

96 seconds - It's still washed out short of the landing site.

102 seconds - I can't see the crater that's short of the Y rill any longer.

10° Redesignation

18 seconds - At this low down you're too late to clean up the problem.

30 seconds - You can see the features in the area, but you're so low now that it's irrelevent.

End of Run - If the sun angle is higher you're going to have to take corrective action earlier in the trajectory to get out of this washed out area.

20° Redesignation

13 seconds - There are some small features in that area that are just starting

to peek through.

- The crater size can cause you problems. The 30' to 50' diameter craters could tip you over, you still can't see till you're right down on the deck and even the bigger features are quite difficult to see.
- At this sun angle there is almost nothing to see down the LPD. The only thing that can be seen is way out to the far left.

<u>20° Sun Angle - 15° Redesignation</u>

16 seconds - I'm looking up along the LPD and can't define anything along the flight path.

25 seconds - Some small craters are peeking through at the very bottom of the window.

40 seconds - We have almost 10° below the landing site that is washed out.

55 seconds - There is a wash out at least 10° up-range of the landing site.

70 seconds - There are features within 5° of the indicated landing site.

86 seconds - There is a large crater up there that I should be able to see, but I can only see the rim of it after the redesignation.

105 seconds - I'm just starting to pick up pictures now.

<u>25° Redesignation</u>

- No comments on that run.

<u>15° Sun Angle - No Redesignation - Smooth Models</u>

14 seconds - There is poor definition in the landing site area.

20 seconds - The features are small enough, but I can't see them.

- This is what we expected with the smoother models. The features are smaller, and the wash out, together with the fact that you can't see the features because they're smaller, really presents a problem.

52 seconds - With this size feature I just cannot pick out enough.

73 seconds - The features I am able to define are moderately large.

[illegible].

90 seconds - I cannot see small features at the landing site or beyond down range.

96 seconds - There's a large feature there.

- The rill beyond the landing site I almost could not see it. It just defined itself the very last phases of the trajectory.

<u>25° Redesignation</u>

13 seconds - Still not that much improvement we're right on the edge of the wash out.

23 seconds - Were too late.

30 seconds - Starting to pick up the small features.

<u>11° Sun Angle - No Redesignation</u>

10 seconds - I still can't see the landing area.

15 seconds - Down range from the landing area is washed out.

- I can see the rill beyond the landing area now plus a good definition of the features around the landing area.

52 seconds - I would say that this is just barely acceptable.

55 seconds - I have 2° to 5° of visible craters beyond the landing site.

81 seconds - Still good definition at this point.

- No comment on the last model.

APPENDIX II

REDESIGNATION STUDY TRAJECTORY PARAMETERS

As was mentioned in the body of this report, the trajectories used for the Redesignation Study were completely different from the three trajectories used for the Trajectory Study. Trajectory parameters for the Redesignation Study trajectories are given in the following pages of this Appendix.

Figure II-1 shows the look angle to the landing site and the depression angle to the lower limit of the LM window. It may be compared to Figure 7 in the body of the report. Figure II-2 shows the complete trajectory for the 0° redesignation angle. The remaining figures show only the trajectory parameters for flights over the last model, the parameters for the first two models being identical with the parameters shown in the first two-thirds of Figure II-2.

REDESIGNATION STUDY

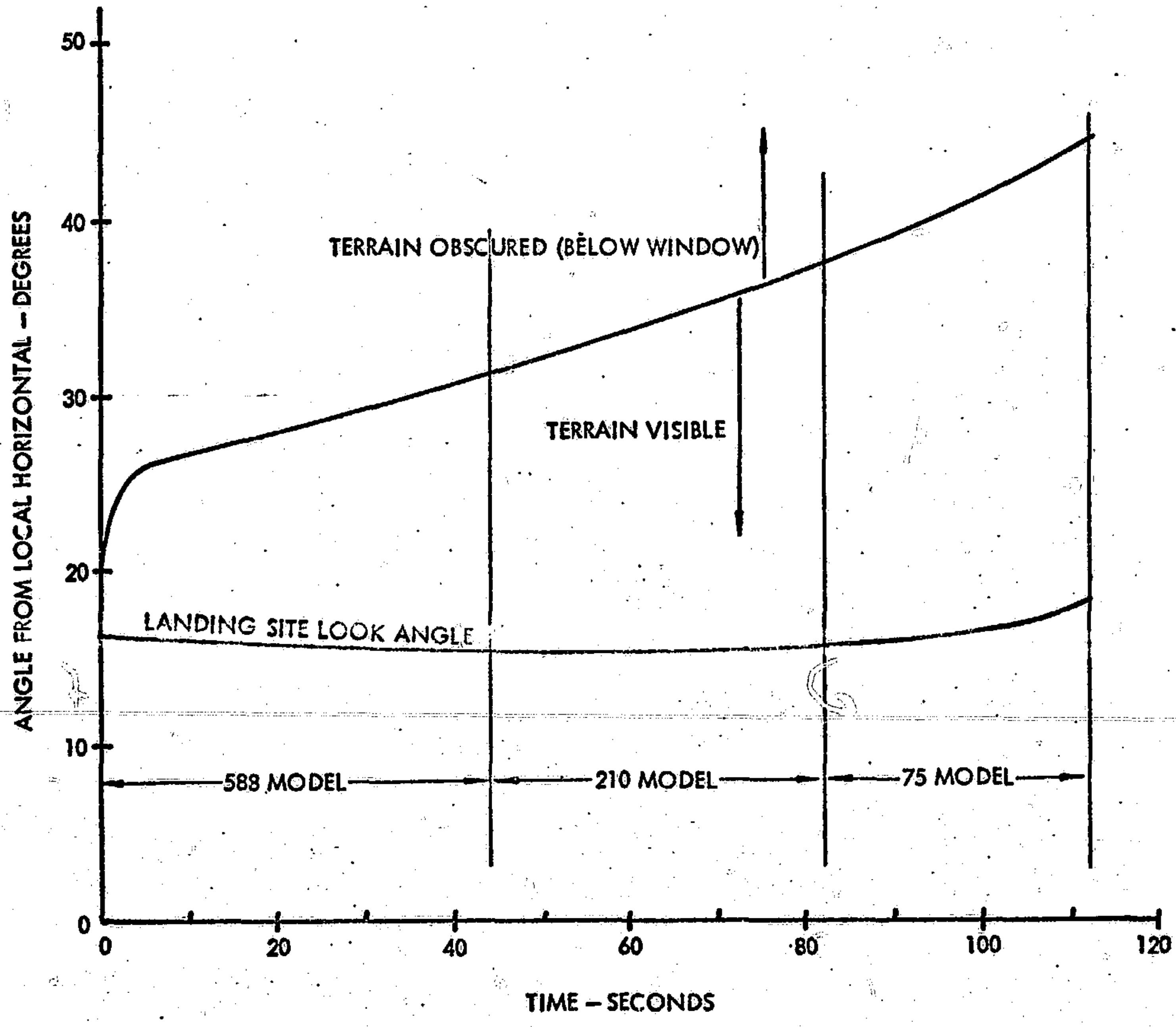
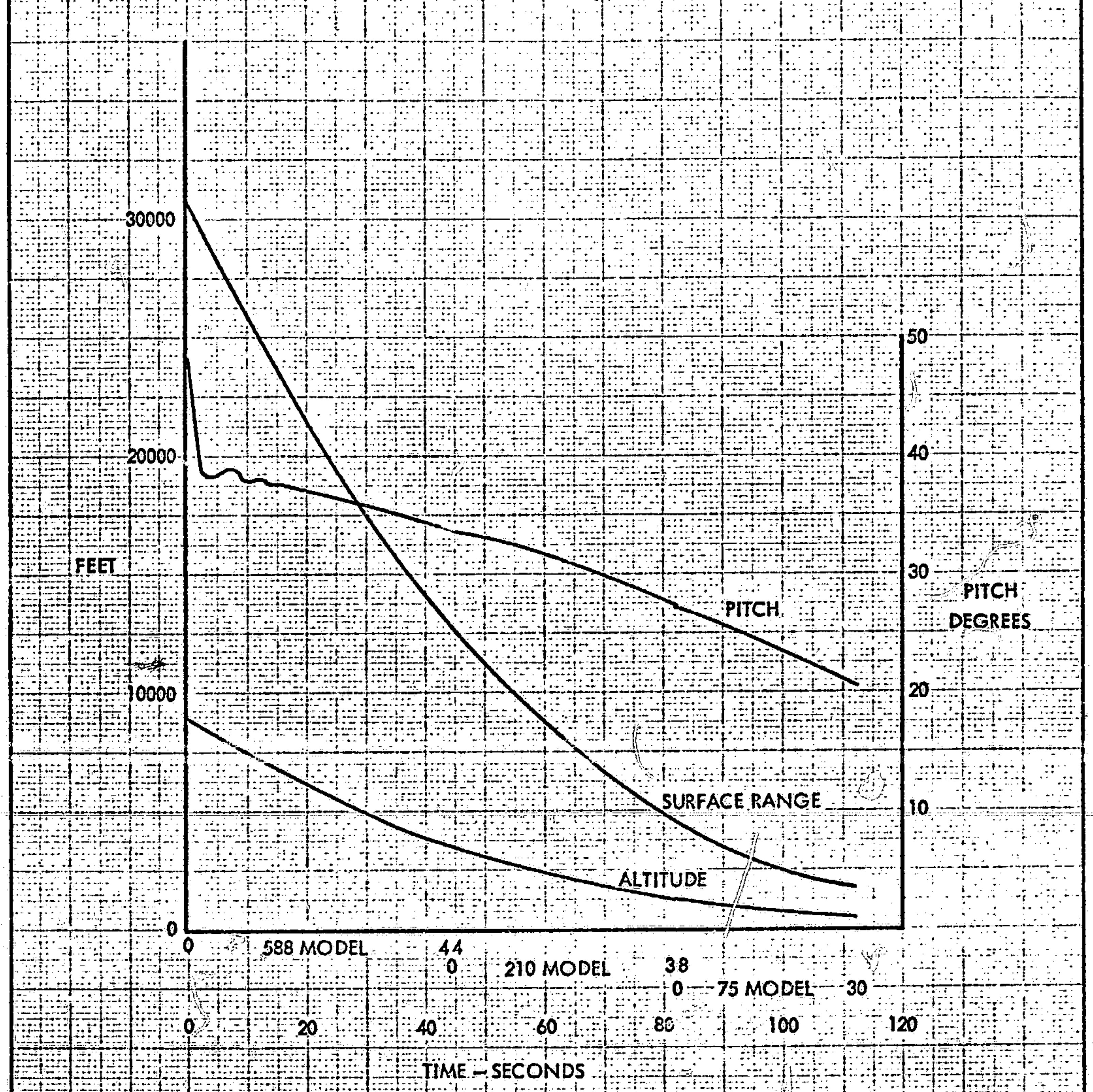


Figure II-1

LANDING SITE LOOK ANGLE AND LOWER WINDOW LIMIT ANGLE vs FLIGHT TIME



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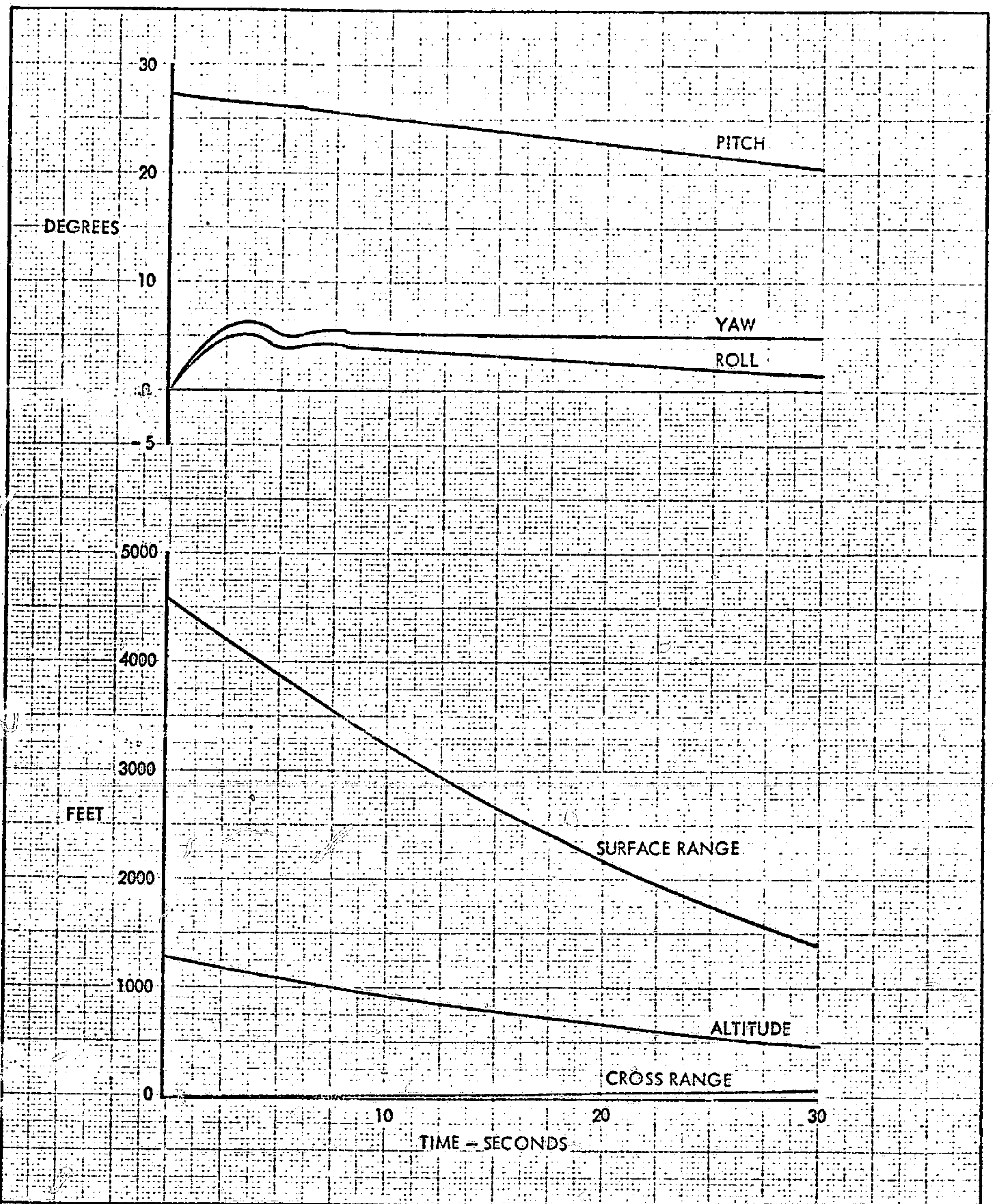
CALC					Figure II-2 TRAJECTORY DATA FOR REDESIGNATION STUDY – 0° REDESIGNATION	
CHECK						
APPD.						
APPD.						

U3 4013 8000 REV. 1/66

REV LTR



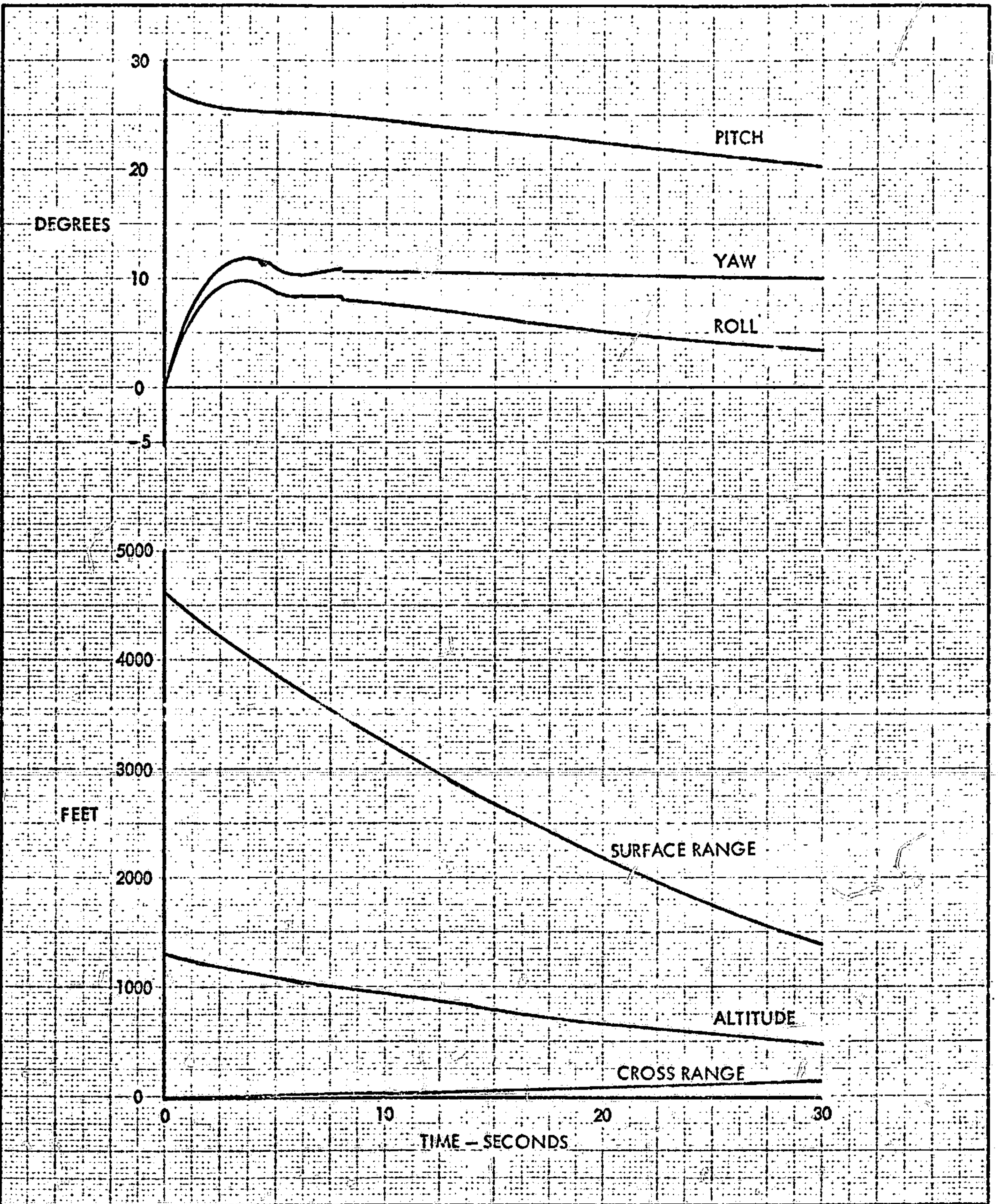
	INITIALS	DATE	REV BY INITIAL	DATE	TITLE	MODEL
CALC					Figure II-3 TRAJECTORY DATA FOR REDESIGNATION STUDY 5° REDESIGNATION	
CHECK						
APPD.						
APPD.						

U3 4013 8000 REV. 1/66

REV LTR________

BOEING NO. D2-114040-3

SH. II-3



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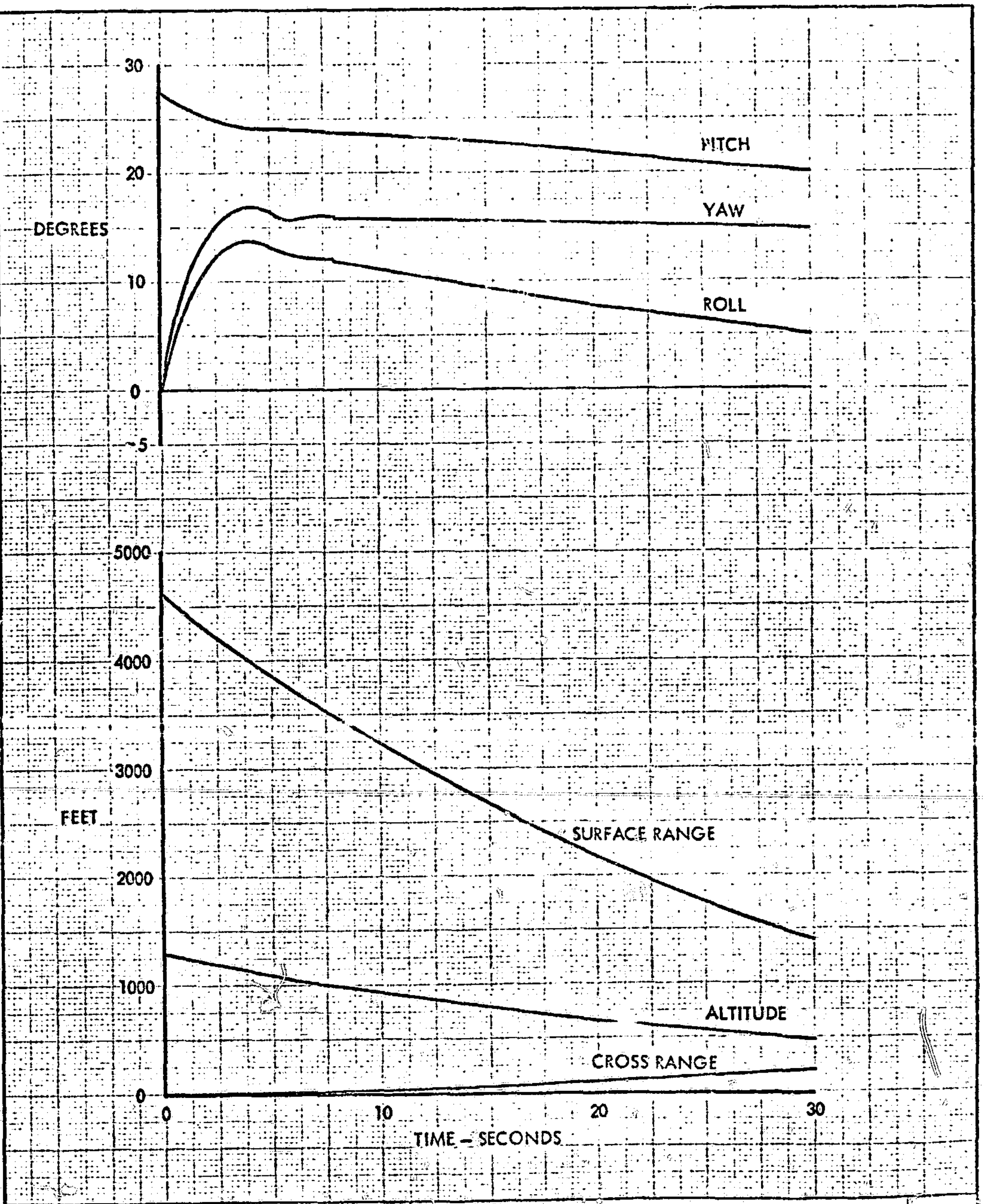
CALC					Figure II-4	
CHECK					TRAJECTORY DATA FOR REDESIGNATION STUDY	
APPD.					10° REDESIGNATION	
APPD.						

U3 4013 8000 REV. 1/66

REV LTR



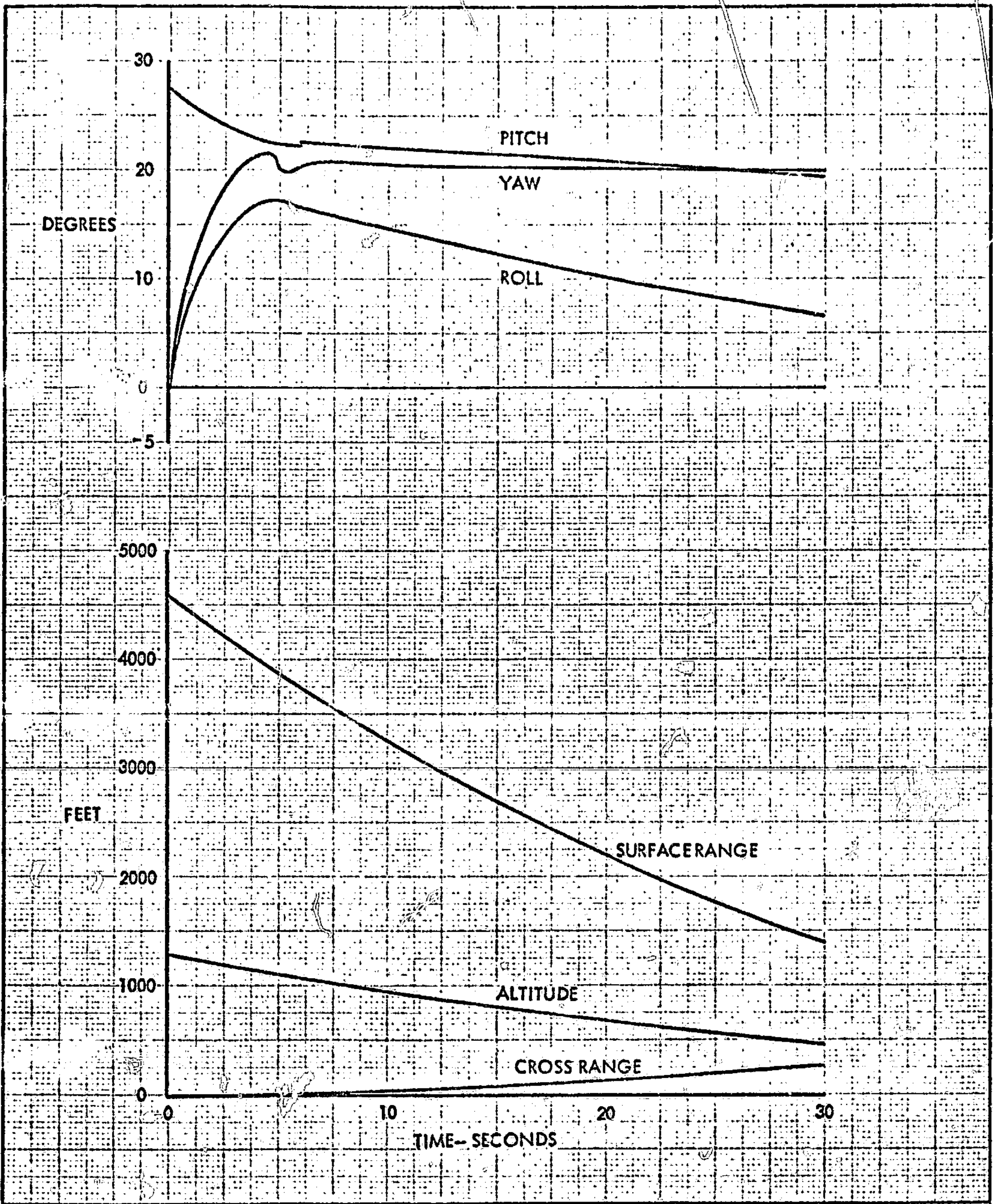
	INITIALS	DATE	REV BY INITIAL	DATE	TITLE	MODEL
CALC					Figure II-5	
CHECK					TRAJECTORY DATA FOR REDESIGNATION STUDY	
APPD.					15° REDESIGNATION	
APPD.						

U3 4013 8000 REV. 1/66

REV LTR

BOEING NO. D2-1[illegible]4040-3

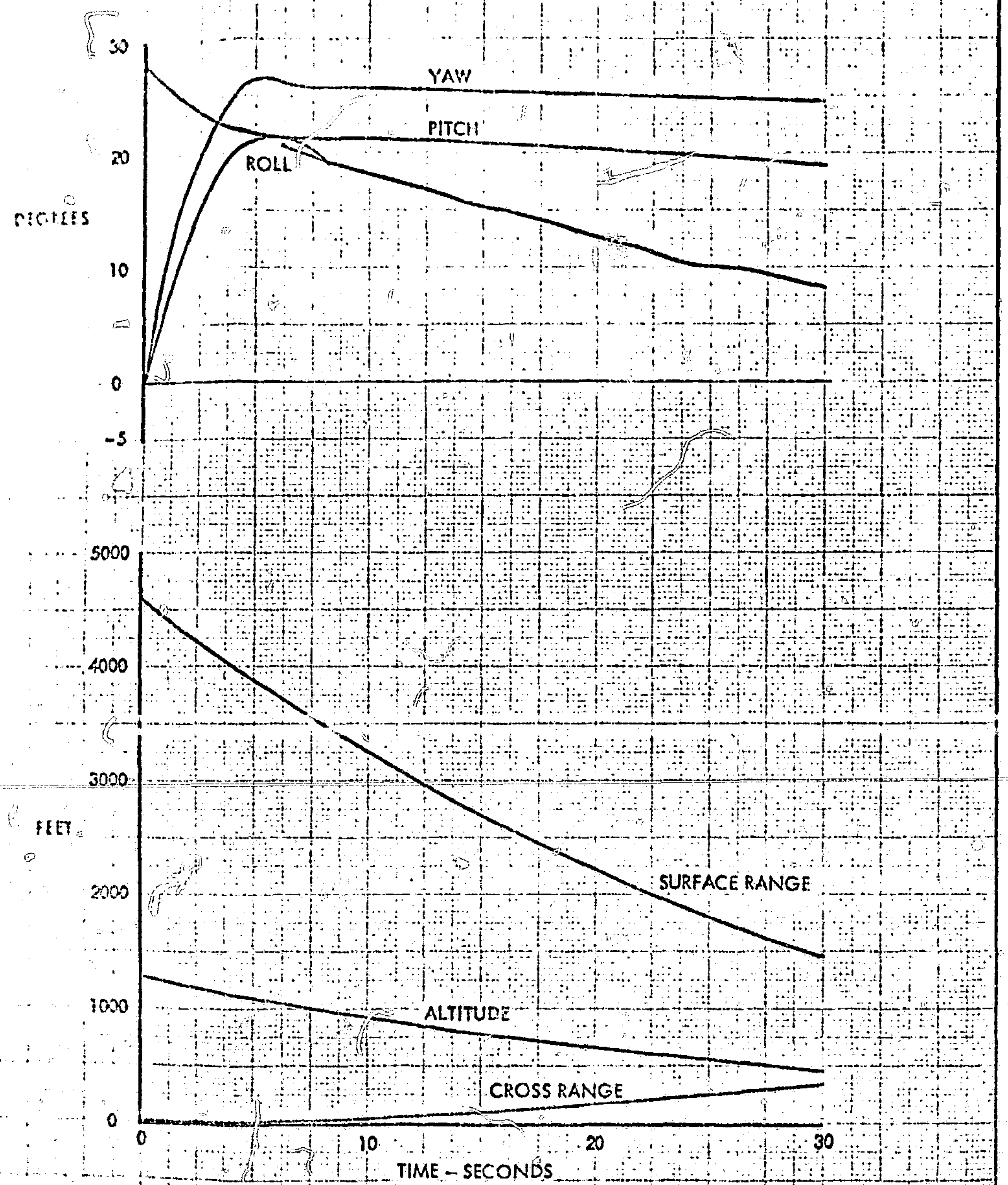
SH. II-5



	INITIALS	DATE	REV BY INITIAL	DATE	TITLE	MODEL
CALC					Figure II-6 TRAJECTORY DATA FOR REDESIGNATION STUDY 20° REDESIGNATION	
CHECK						
APPD.						
APPD.						

U3 4013 8000 REV. 1/66

REV LTR______



	INITIALS	DATE	REV BY INITIAL	DATE	TITLE	MODEL
CALC					Figure II-7 TRAJECTORY DATA FOR REDESIGNATION STUDY 25° REDESIGNATION	
CHECK						
APPD						
APPD						

REV LTR