Bellcomm
955 L'Enfant Plaza North, S.W.
Washington, D. C. 20024

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from: I. I. Rosenblum

subject: Comparison of Measured LM/EVA Link Transmission Losses on Apollo 15 with Predicted Values - Case 320

MEMORANDUM FOR FILE

I. BACKGROUND

Prior to Apollo 15 calculations were made to predict VHF path losses for the EVA/LM link aimed at establishing the usefulness of the EVA/LM/EARTH relay as a backup to the EVA/LCRU/EARTH link.

Examination of the topography at the Hadley Rille north site, in relation to the traverses planned, (see Figure 1) led to the discarding of certain propagation models from consideration for signal prediction at this site. Among the models deemed inappropriate were: Bremmer Series,[1,2] Flat Terrain,[3] Geometric Optics[4] and Knife-edge,[5] illustrated in Figure 2. A prediction analysis was performed at MSC by TRW using the Bullington shadow loss model [6] (see Figures 2, 3 and 4) and at Bellcomm by the author using the Rounded Obstacle analysis method.[7,8,9] (See Figures 2, 5 and 6).

The VHF receiver "B" of the Apollo 15 Lunar Module was instrumented for telemetry to Earth of the received AGC level of the signal from the astronaut. Post-mission evaluation of this data, providing estimates of the actual transmission path loss between the astronaut and LM, was performed by TRW at MSC and reported in Reference 10. Based on these reported "measured" transmission losses, comparison with theoretical predictions has been made and the results are discussed below.

II. INITIAL ANALYSIS

An effort was undertaken to determine whether the LM VHF signal measurements on Apollo 15 were in agreement with values that could be or would be predicted using an appropriate prediction model.

The actual Apollo 15 LM landing site was offset from that targeted and the traverses actually undertaken deviated somewhat from those planned (see Figure 7). As a consequence many points for which pre-mission predictions were made were not visited and many points of instrumentated VHF signal strength were points without pre-mission loss prediction.

Our first post-flight analysis consisted of comparing the loss values obtained from AGC instrumentation, with loss values obtained by using the appropriate propagation prediction model for each identified traverse location actually reached as shown in Figure 7.

The elevation and distance data going into the prediction computations for the respective traverse points were taken from the scaled topographic map given in Reference 10 as was the measurement data. This map is the same as that map used in pre-mission analysis.

A. Traverse III

Figure 8, taken for a radial cut through points 29, 30 and 31 of Traverse III, shows the elevation profile for those points and that approximately applicable for points 28 and 32. The prediction for these points, along with measured (calculated from measured AGC data) loss values are shown in Figure 9. As seen the measured data shows progressively increasing loss in the path to the LM as the traverse goes further toward the rille. The Free Space, Knife-edge, and Flat Terrain appear to be inferior predictive models for the points of this traverse while the Rounded Obstacle, Bullington 50% and Bullington 90% models appear to provide reasonably close predictions. The actual quiescent value for point 31, it should be noted, is not known since the AGC data was off scale low at that point; therefore it is uncertain whether the Rounded Obstacle or the Bullington 90% model prediction is best here. It should be observed that the apparent quiescent levels of all points, including those for which estimates were made (indicated by dotted circles), are above the nominal threshold loss, 133 dB, for 70% word intelligibility (dotted line).

B. Traverse I

The elevation profile for Traverse I (nominally through points 3 and 5) is shown in Figure 10. The approximate elevation and distance values for points 2 and 4 are also indicated (in phantom) for convenience in this figure although the true profile for these points would be slightly different as they are somewhat off the radial to the LM through points 3 and 5.

Prediction and measured losses are shown in Figure 11. The true quiescent value for point 3 is not known because the measurement data was off-scale on the low side; so it was estimated. The range of measured loss values (between low and high readings) is small except for point 5. At point 5 the astronauts were on foot (on other points the astronauts were on the LRV) and the 2 minute data sampling interval was approximately 4 times that usually found at the other points. These factors which included the turning, twisting and bending of the astronauts and their antennas and proximity effects of the astronauts with each other and the LRV contributed to the greater signal variations at point 5.

Comparison of the predictions in Figure 11 with measured data indicates poor agreement for the Knife-edge and Free Space models. The Bullington 90% model predicts considerably greater losses than measured on three of the four points. The Flat Terrain, Bullington 50% and Rounded Obstacle model are each fair on 3 of the four points. At point 4, where the Rounded Obstacle and Bullington 90% loss predictions were quite high with respect to 2 measurements at essentially the same point, the Apollo 15 GOSS NET Technical Air-to-Ground voice transcript[11] indicates that the LM was sighted by one of the astronauts; this is in obvious conflict with the topographic profile calculated before the mission and used in making loss predictions for this point.

C. Traverse II

The points of Traverse II lie roughly on a straight line directed away from LM and the number of points is greater than on the other traverses. As a consequence a more consistent set of measurements and predictions would be expected with this traverse.

The elevation profile, applicable for a radial from the LM through points 14, 15, 16, 17, and 19, is shown in Figure 12. Many other points of Traverse II are shown on Figure 12 for convenience since the profile data would be very similar.

The measured transmission loss data for traverse II points and the corresponding prediction values for several models are shown in Figure 13. All measured data corresponds to the condition where the astronauts were seated on the lunar roving vehicle (LRV).

The Free Space and Bullington 90% models show poor agreement with measured values. The Knife-edge model (knife edge taken at same location as peak of rounded obstacle) shows poor agreement at all points closer to LM than 4200 meters, and fairly good agreement beyond that range.

The Bullington 50% model as well as the Flat Terrain model which forms the baseline loss for the Bullington prediction, show good agreement out to 4000 meters and then diverge considerably beyond that point. The Rounded Obstacle model shows fair agreement at all distances with an apparent tendency toward improved agreement at the longer ranges.

Four arrows at the top of Figure 13 indicate the approximate locations at which LM was sighted by the astronauts, according to the Air-to-Ground voice records. Except for point 19, such sightings are inconsistent with the preflight topographic base data as seen from Figure 12.

The inability to reconcile the measured results with the apparently appropriate prediction models in combination with the inconsistencies between the LM optical sightings and the pre-mission topography, raised serious questions as to the adequacy of any one model for lunar surface VHF prediction.

III. SECOND ANALYSIS

On the basis of the abovementioned analysis, the writer contacted Mr. R. E. Joosten, of the Mapping Sciences Laboratory, MSC and received from him a preliminary copy of the revised topography for the Apollo 15 area, which had been developed by the laboratory from pan camera photography. The new map, a 1:12,500 scale rendition, dated September 29, 1971 was based on pan frames 9809 and 9814 and provided revised contour lines at 10 meter intervals; the new map is shown in Figure 14.

The new data provided several clues toward a better understanding of the VHF measurements.

The resulting profiles for all three traverses were different from that given by the prior topography. In particular however the Traverse II profile was dramatically changed as shown in Figure 15. A new analysis of loss prediction was undertaken based on the new terrain data. The prediction models that were deemed appropriate were:

Geometric Optics

Bremmer Series

Flat Terrain

Rounded Obstacle (for negative angles of diffraction)

The results of this second prediction analysis using these models are shown in Figure 16, along with the measured data values.

In the region out to 4000 meters, where the terrain would be characterized as relatively level, several interesting results are noted. The Flat Terrain model and the Bremmer Series provide a relatively good match to the observed data. The Geometric Optics model departs from the measured values as range increases; this is related to the inclusion of the divergence factor in this version of the prediction model (geometric optics without divergence closely parallels the Bremmer Series curve).

In the region near 4000 meters and beyond, where the terrain is a steep hillside rising from a relatively level plain, models applicable to line-of-sight conditions are used. These are:

1. Rounded Obstacle model (using negative angles of diffraction).

2. Geometric Optics (representing the elevation of terrain above nominal level plain as height value for Antenna #2).

3. Flat Terrain (representing elevation of terrain as above)

4. Bremmer Series (representing elevation of terrain as above)

Of these, the Geometric Optics model predictions provided the best fit to the measurement data, with Bremmer Series and Flat Terrain models providing almost the same predictions, while the Rounded Obstacle model values showed a poor fit except for points fairly close to zero grazing angle geometry.

The measured loss values in the region beyond 4000 meters are about 10 dB greater than predicted by any of the within line-of-sight models. Fortunately, the available signal here is well above that nominally required, so that a 10 dB error in prediction is not consequential.

The curves shown for Flat Terrain, Bremmer Series and Geometric Optics predictions (for level terrain) were all developed for an antenna height combination of:

27 feet for LM

6 feet for EVA.

For the case with the astronauts seated on the LRV, the actual antenna height is probably closer to 4 feet; the use of this value would shift the prediction down by a few dB, bringing the theoretical predictions even more in agreement with the measured data. The influence of strictly local terrain features at the LM touchdown site and LM inclination should also be taken into account (in assigning a value for LM antenna height) in detail comparisons of actual and predicted loss values. In addition, antenna pattern values for the EVA backpack antenna with astronauts seated on the LRV may be drastically different from that assumed (the average standing EVA case).

III. CONCLUSIONS

On the basis of this comparison of measured and predicted transmission losses of the Apollo 15 EVA/LM VHF link, it is concluded that:

1. The measured path losses are not accurately predicted by any model, using actual traverses and pre-mission topographic data.

2. There were serious inaccuracies in pre-mission topographic data.

3. The pan camera topographic data, used with appropriate propagation models, gives a reasonable prediction of observed results. The best terrain/model matches appear to be:

TERRAIN	APPLICABLE MODEL
Level	Flat Terrain/Bremmer Series
Hilly	Rounded Obstacle/Bullington 50%
Hill on plain	Geometric Optics

4. Loss prediction is very sensitive to details of topography. A sizeable safety margin of perhaps 5-10 dB should be allowed on future missions at key traverse points if topographic data is questionable.

2034-IIR-vh

I. I. Rosenblum

Attachments
Figures 1 - 16

REFERENCES

1. Bremmer, H., Terrestrial Radio Waves, Elsevier Publishing Company, 1949.

2. Lindsey, Jefferson F., III, "Lunar Surface Transmission Loss for the Apollo Astronaut," NASA TN D-4915, NASA, Washington, D. C., December 1968.

3. Bullington, K., "Radio Propagation Variations at VHF and UHF," Proceedings of the I.R.E., January 1950.

4. Schroeder, N. W., "Path Loss Expressions for a Radio Link on a Rough Spherical Surface," Bellcomm TM-70-2034-5, June 30, 1970.

5. Rosenblum, I. I., "Screening of Line of Sight to LM by Craters at Apollo Site 2 - Mission G," Bellcomm Memorandum for File, June 30, 1969.

6. Lee, P. H., "Apollo 15 Mission EVCS-LM VHF Coverage," TRW Systems Group, Project Technical Report No. 17618-H168-R0-00, June 11, 1971. Prepared for NASA, MSC, Houston, Texas.

7. Rosenblum, I. I., "EVA VHF Communications with LM on Apollo 15 Traverses." Bellcomm TM-71-2034-2, August 16, 1971.

8. Dougherty, H. T., and Maloney, L. J., "Application of Diffraction by Convex Surfaces to Irregular Terrain Situations," Radio Science Journal of Research, NBS/USNC - URSI Vo.. 68D, No. 2, February 1964.

9. Rice, P. L., et al, "Transmission Loss Predictions for Tropospheric Communication Circuits," NBS Technical Note No. 101 (revised) Volumes I and II, U. S. Department of Commerce, NBS CPRL, Boulder, Colorado, Volume I (revised) January 1, 1967; Volume II (original issue) May 7, 1965.

10. Lee, P. H., "Apollo 15 Extravehicular Communications System Postflight Analysis," TRW Systems Group, Project Technical Report No. 17618-H213-R0-00, September 17, 1971. Prepared for NASA, MSC, Houston, Texas.

11. "Apollo 15 Technical Air-to-Ground Voice Transcription," MSC-04558, prepared by Test Division, Apollo Spacecraft Program Office, MSC, Houston, Texas.

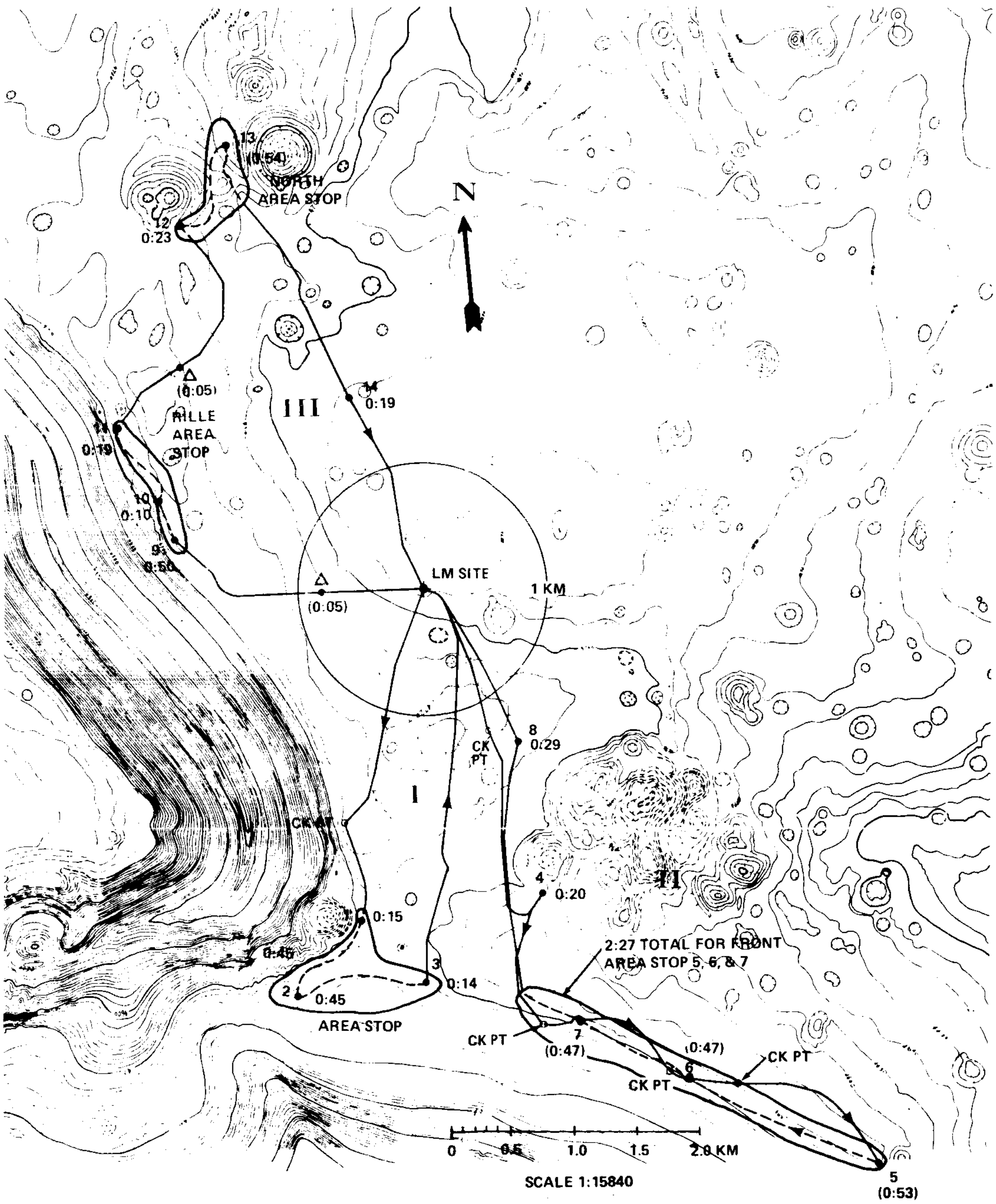

FIGURE 1 - APOLLO 15 LRV TRAVERSES

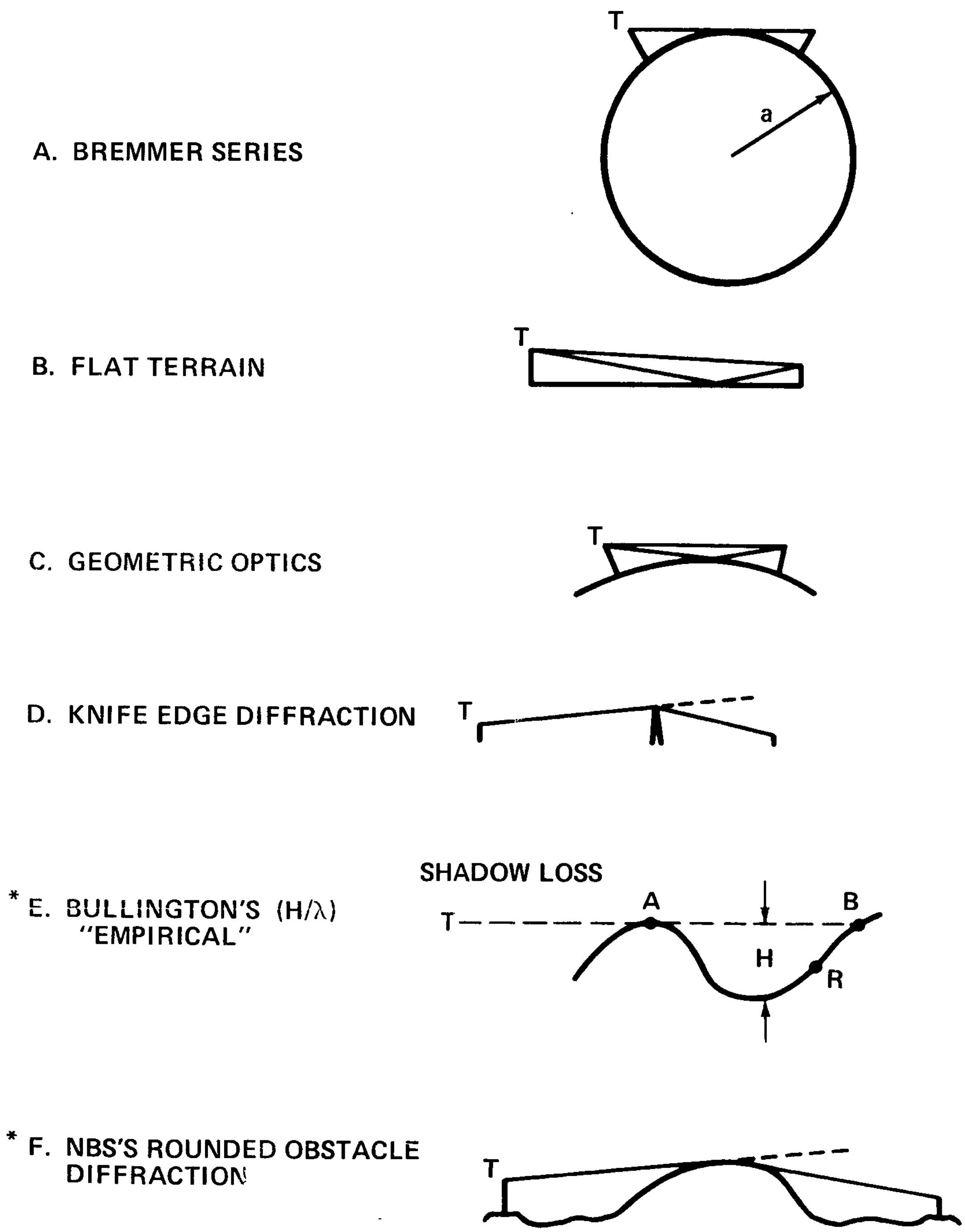

FIGURE 2 - VHF PROPAGATION LOSS MODELS

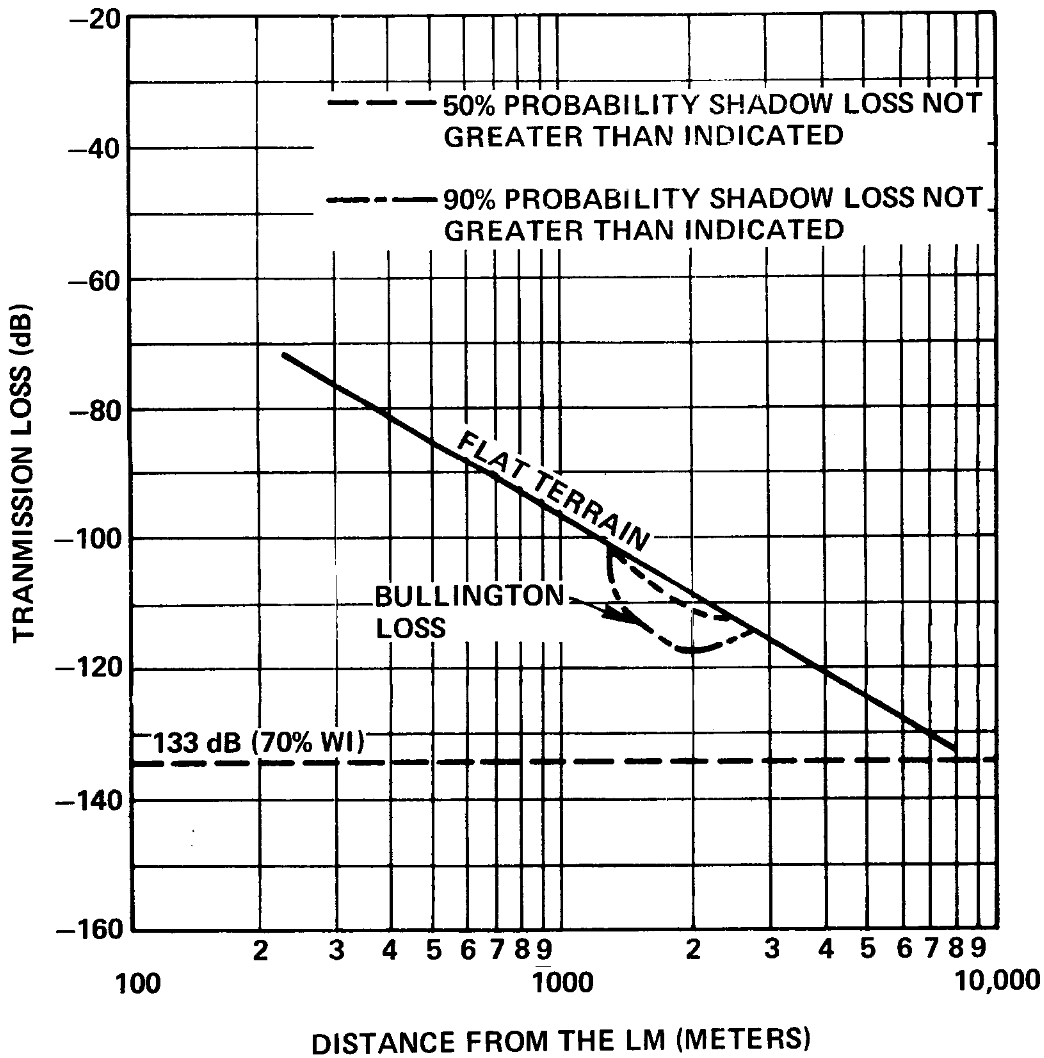

FIGURE 3 - BULLINGTON LOSS PREDICTIONS

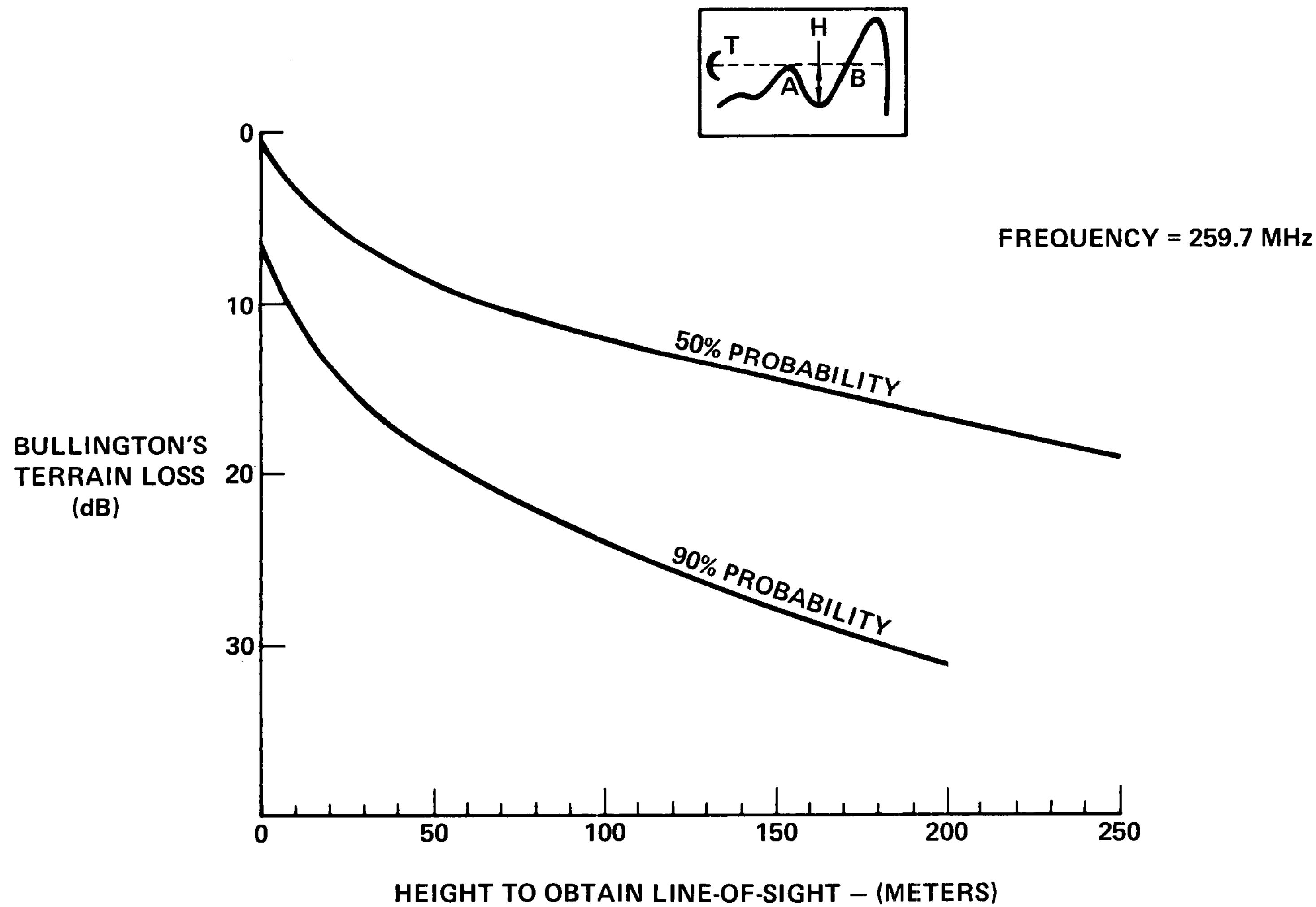

FIGURE 4 - BULLINGTON TERRAIN LOSS VS. HEIGHT

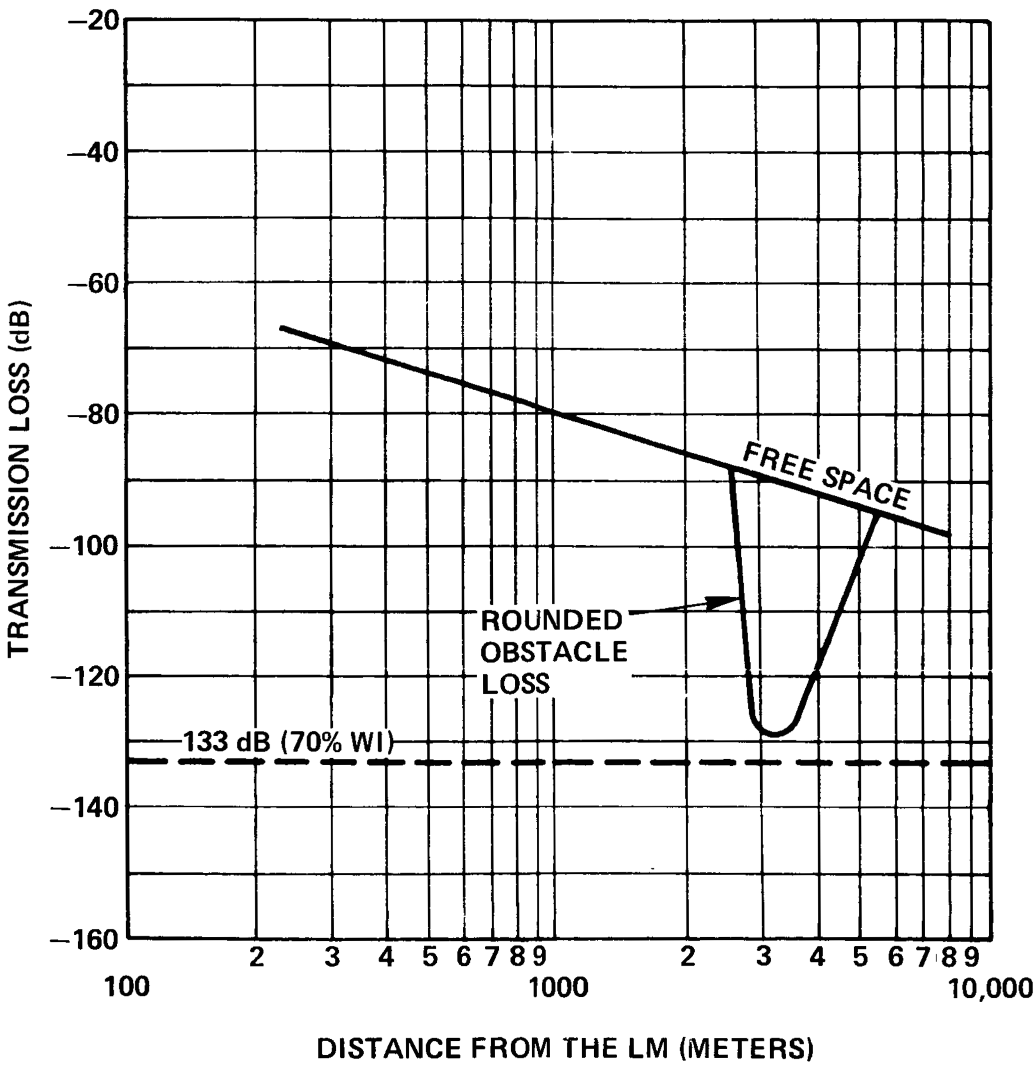

FIGURE 5 - ROUNDED OBSTACLE PREDICTIONS

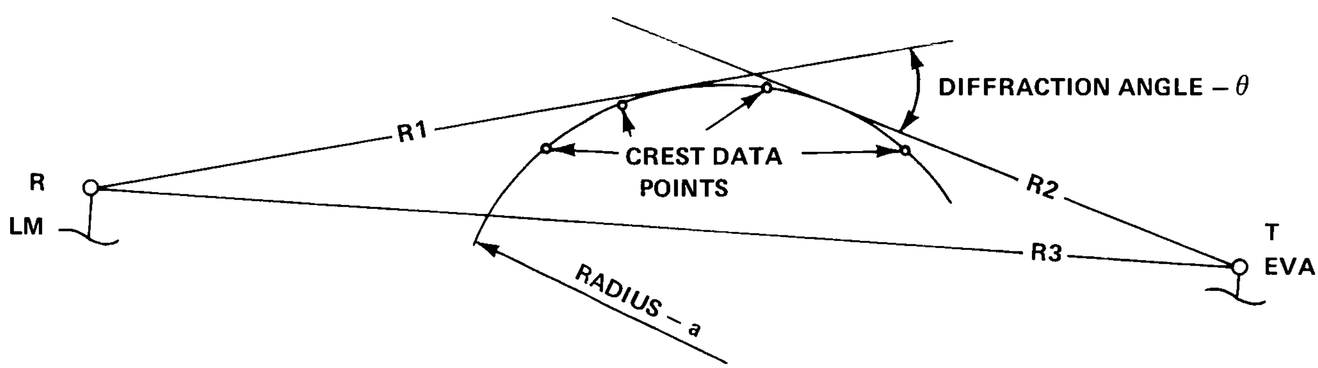

FIGURE 6 - GEOMETRY FOR CALCULATION OF DIFFRACTION LOSS FOR ROUNDED OBSTACLE

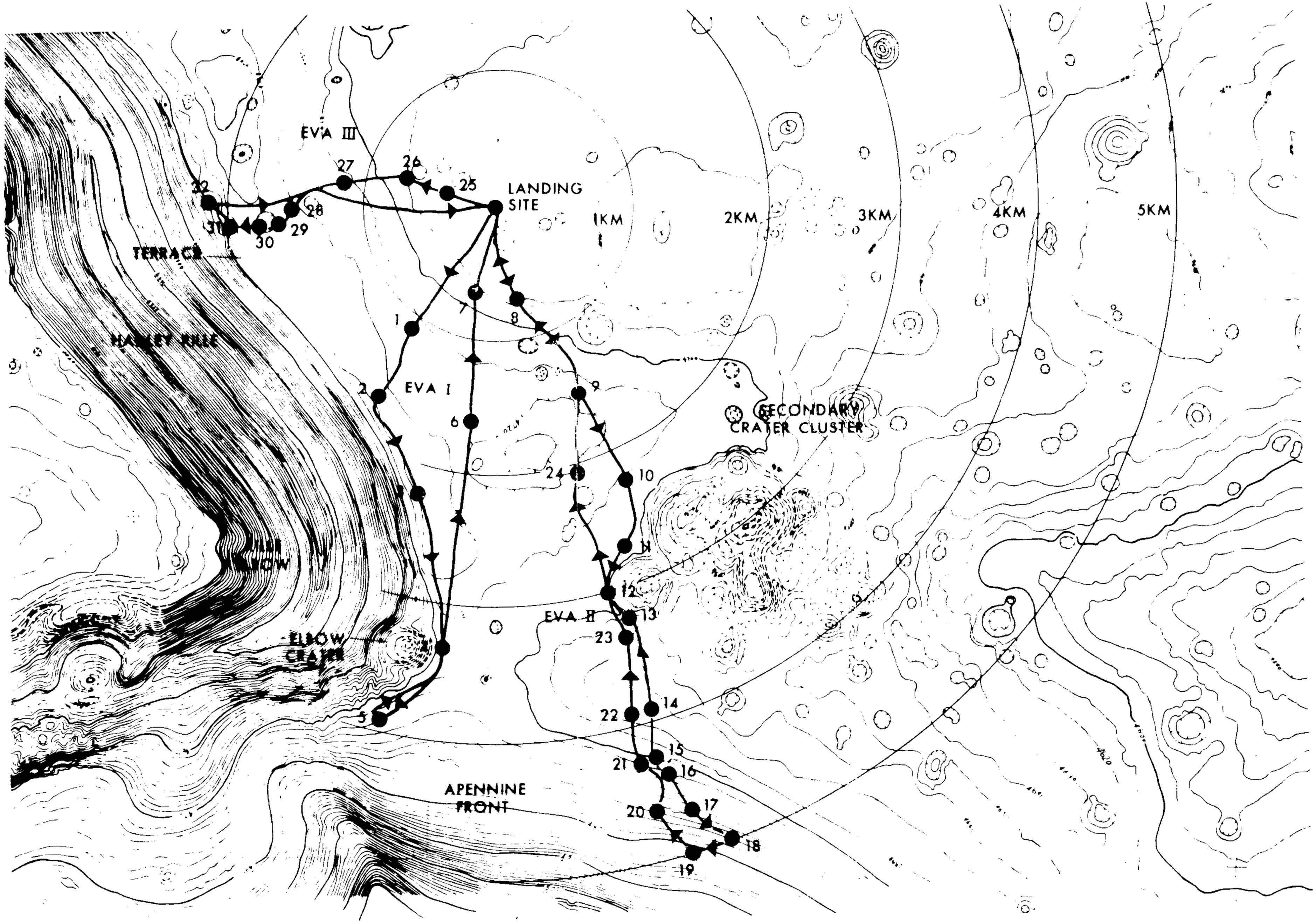

FIGURE 7 - ACTUAL EVA TRAVERSE ROUTES FOR APOLLO 15 ON A TEN METER CONTOUR INTERVAL MAP
(FROM TRW RPT 71:7151. EVT-29 17 SEPT 1971)

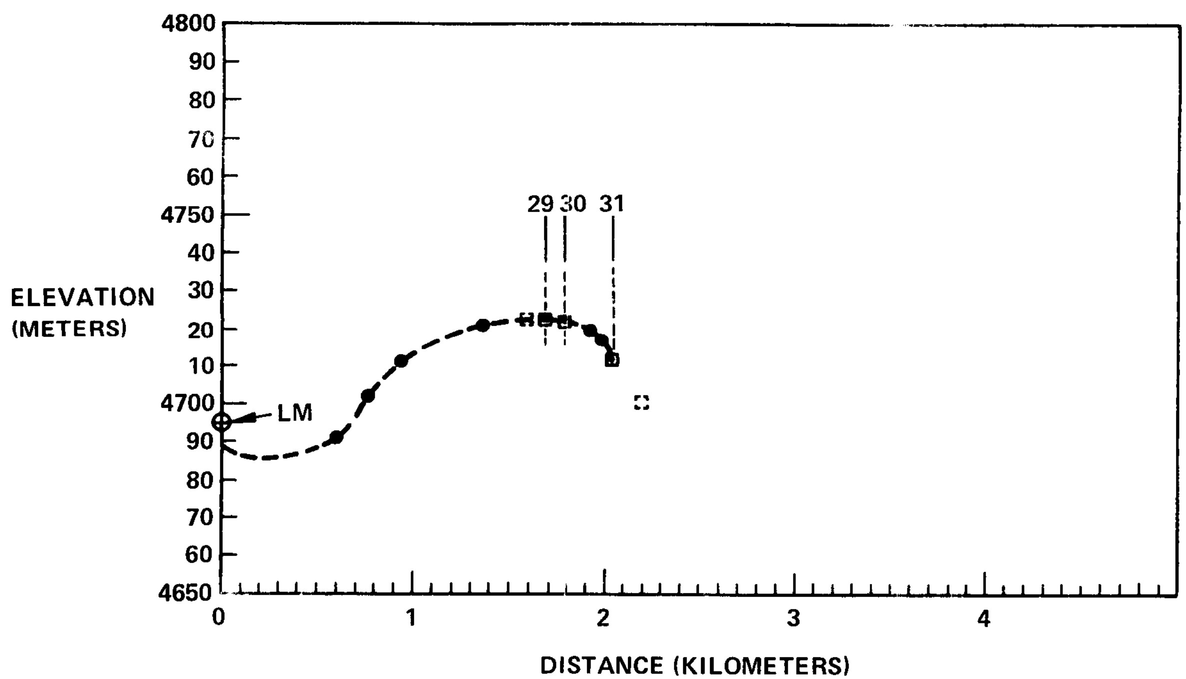

FIGURE 8 - ELEVATION PROFILE FOR POINTS 29, 30, & 31 -- TRAVERSE III

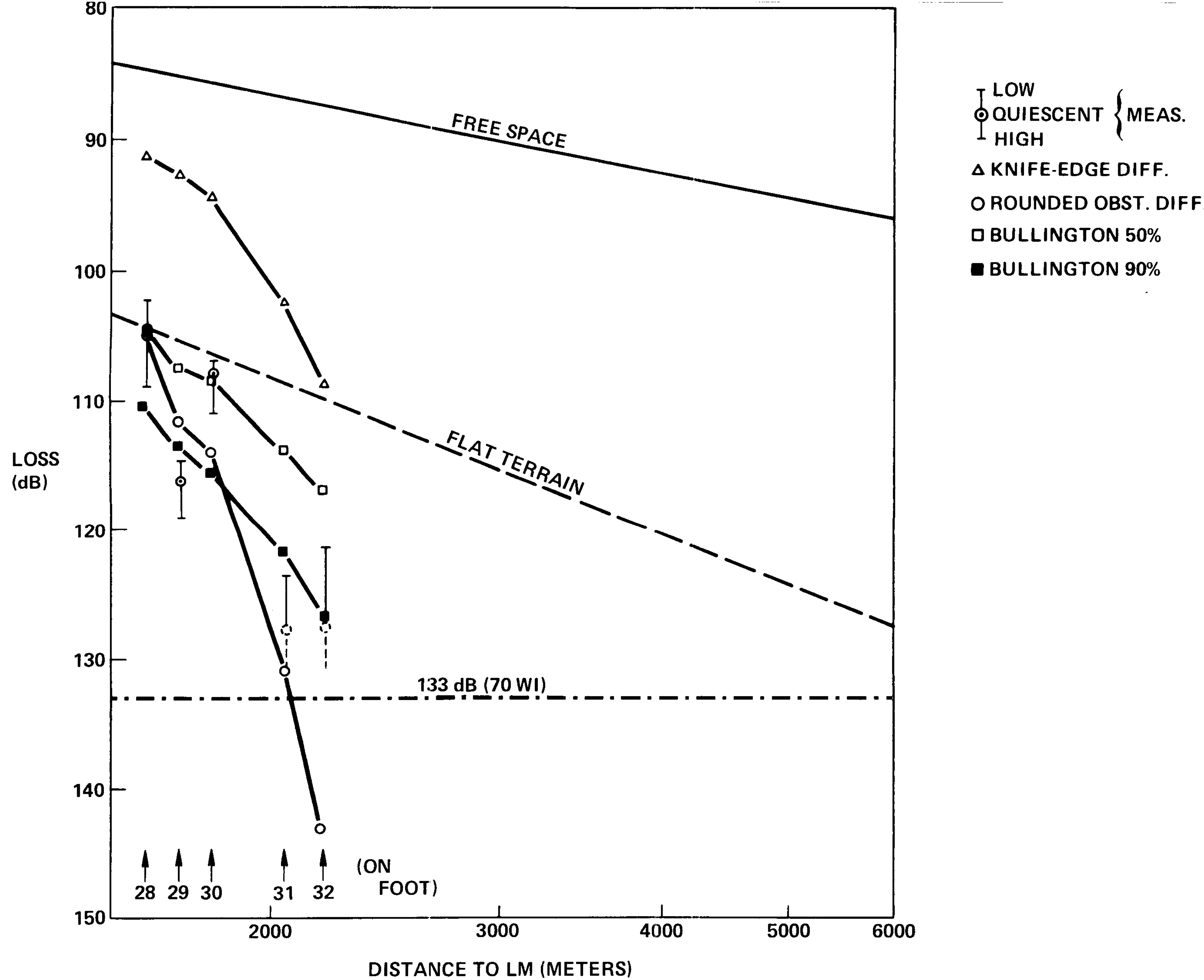

FIGURE 9 - TRAVERSE III – MEASURED AND PREDICTED VHF TRANSMISSION LOSS EVA – LM
(EVAS ON LRV EXCEPT @ POINT 31)

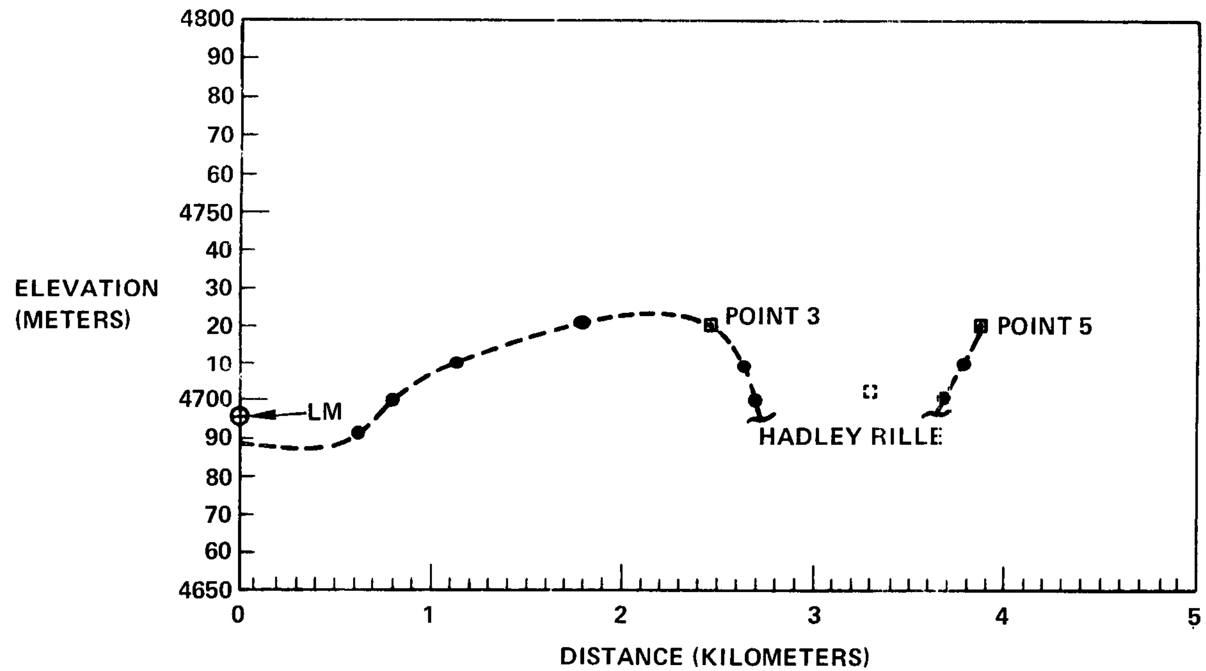

FIGURE 10 - ELEVATION PROFILE FOR POINT 5 — TRAVERSE I

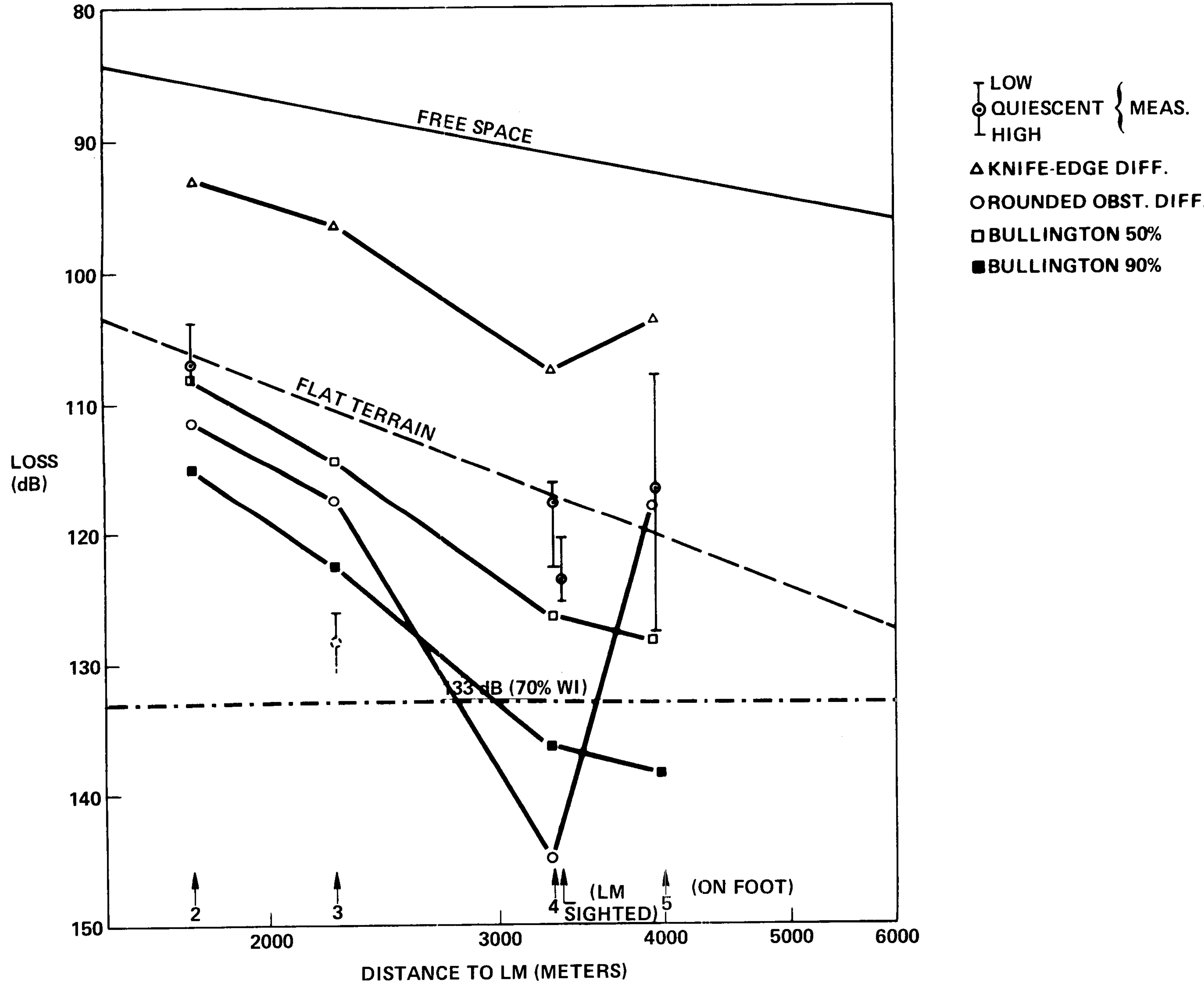

FIGURE 11 · TRAVERSE I – MEASURED AND PREDICTED VHF TRANSMISSION EVA – LM
(EVAS ON LRV EXCEPT @ POINT 5)

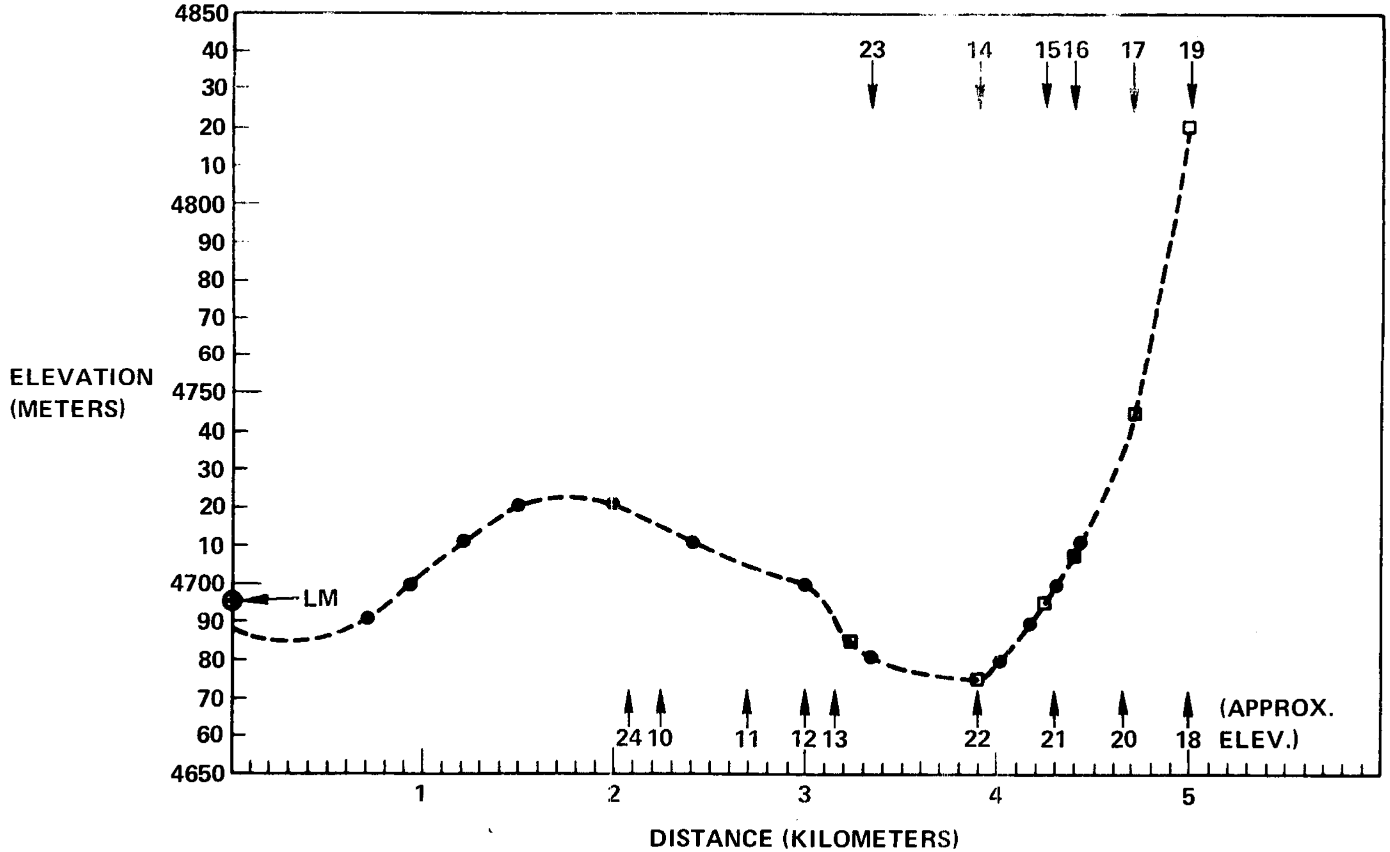

FIGURE 12 - ELEVATION PROFILE FOR POINTS 23, 14, 15, 16, 17, 19 – TRAVERSE II

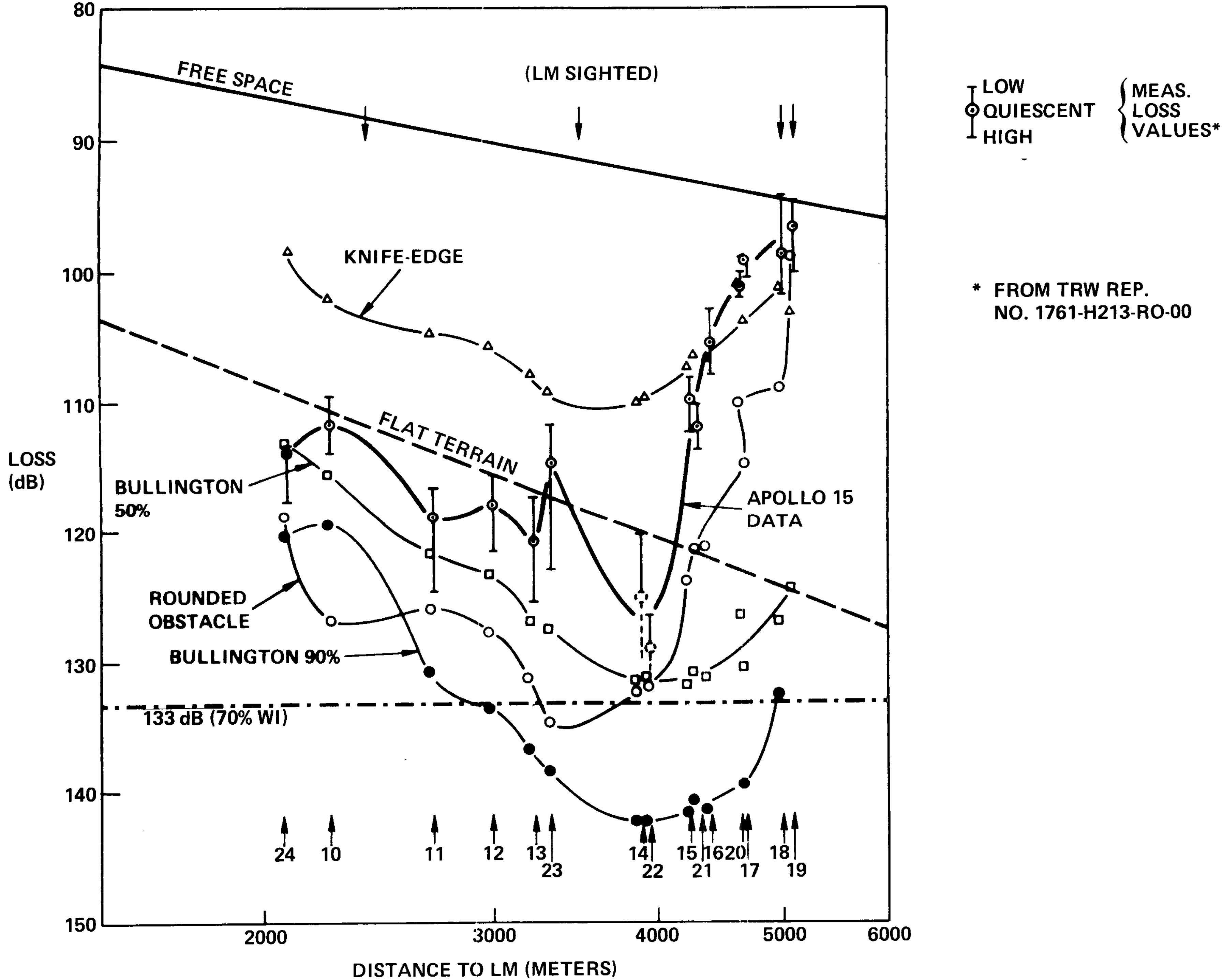

FIGURE 13 - TRAVERSE II – MEASURED AND PREDICTED VHF TRANSMISSION LOSSES APOLLO 15 – EVA/LM (EVAS ON LRV)

FIGURE 14 - APOLLO 15 EVA AREA BASED ON PAN CAMERA PHOTOGRAPHS

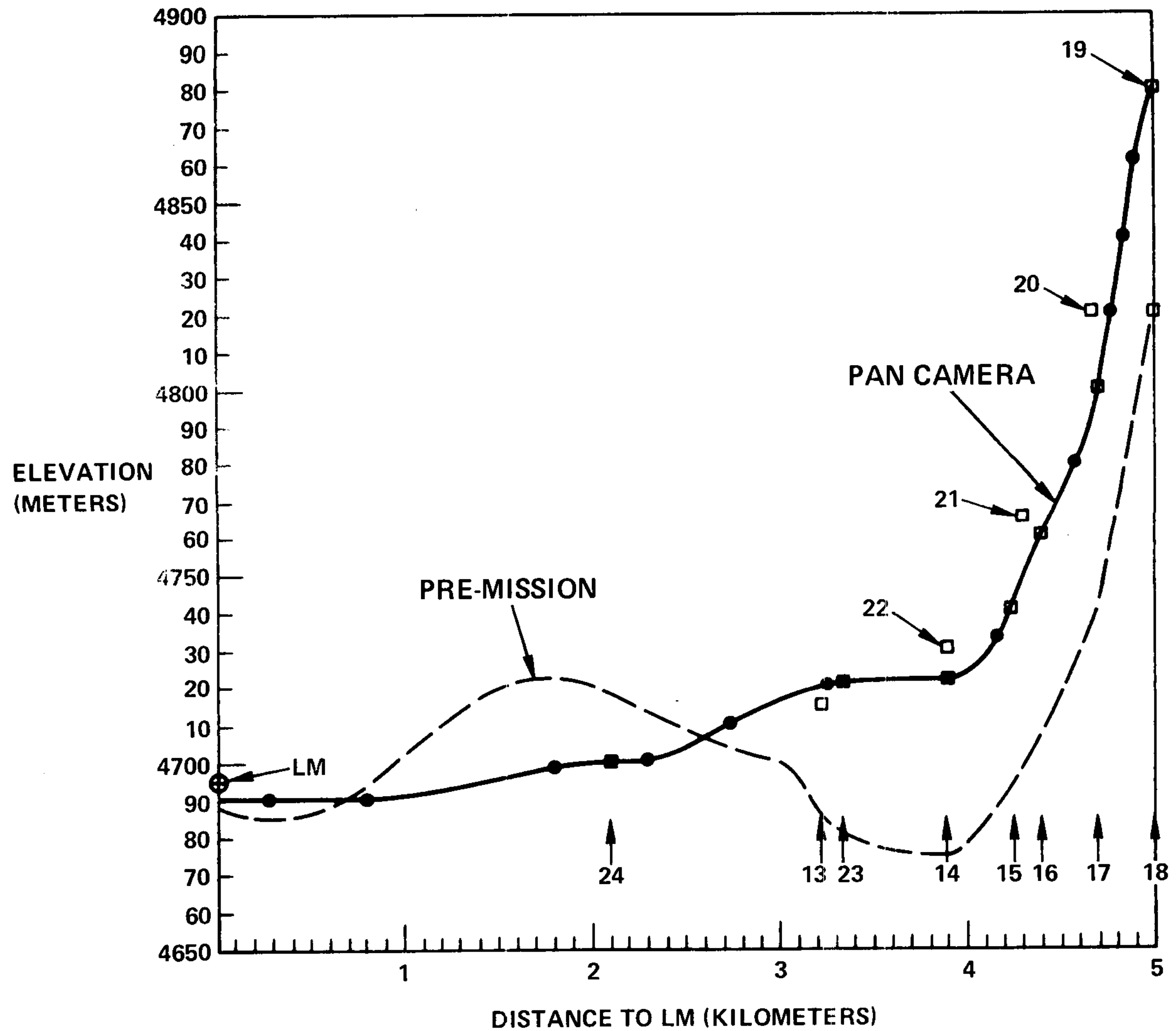

FIGURE 15 - ELEVATION PROFILE FOR POINTS 23, 14, 15, 16, 17, 19 — TRAVERSE II
(BASED ON PAN CAMERA TOPOGRAPHIC DATA)

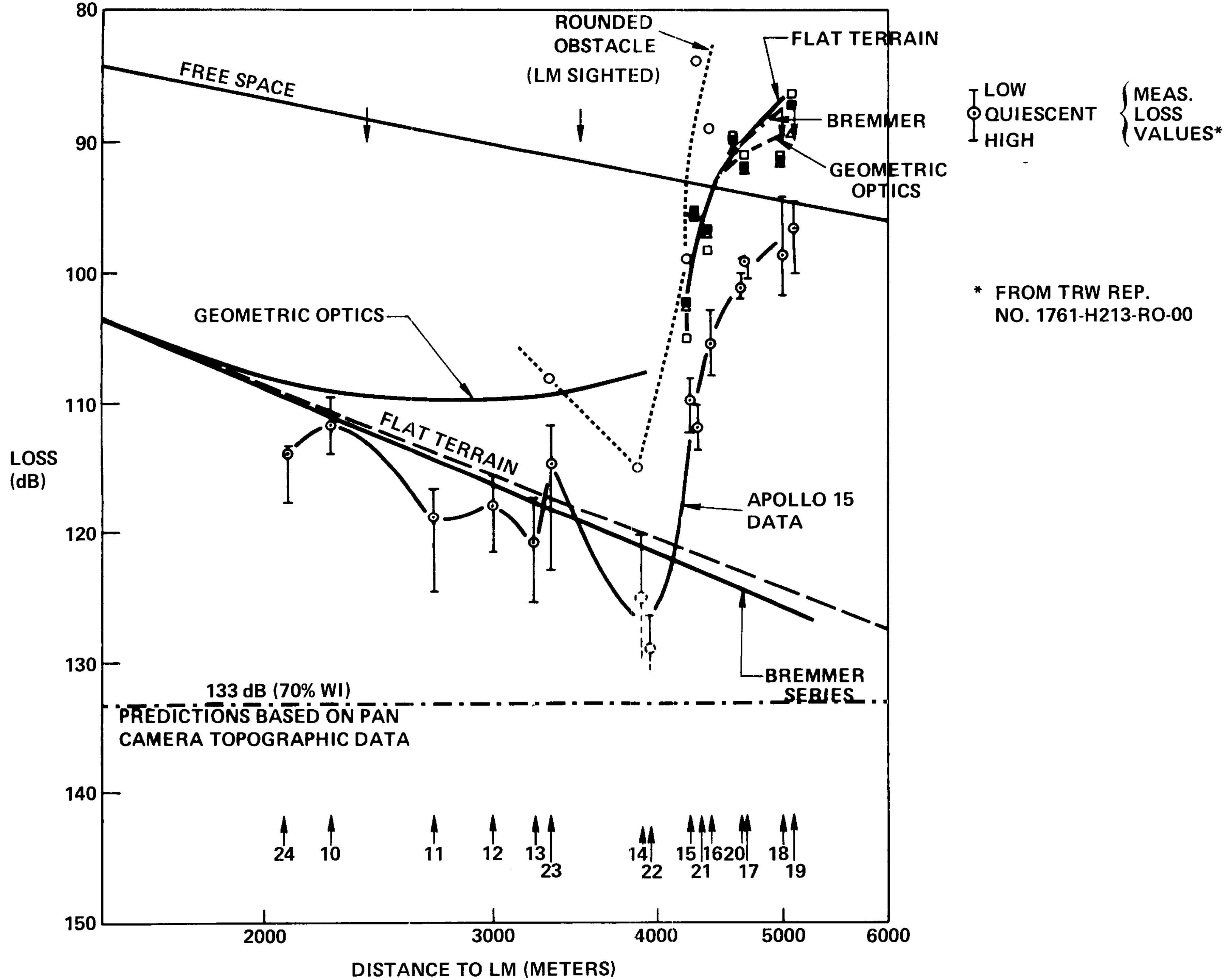

FIGURE 16 - PREDICTIONS BASED ON PAN CAMERA TOPOGRAPHIC DATA (BASE DATA SAME AS FIGURE 13)

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From: I. I. Rosenblum

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