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Flight Control Integration Support

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Design Note

Evaluation Of TILS For Use As The Orbiter Landing NAVAID

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Subject: Evaluation of TILS for Use as the Orbiter Landing NAVAID

1.0 Summary

An evaluation of the Tactical Instrument Landing System (TILS) for use in the Orbiter Autoland System has been made. It has been found that with certain modifications, the TILS can satisfy Orbiter Autoland requirements. These modifications, include (1) addition of DME equipment, (2) expansion of elevation coverage from 0-10° to 0-30°, and (3) expansion to redundant systems with associated ground monitors. Additional modifications that are not necessary to meet the Orbiter requirements, but that can enhance performance margin are (1) tightening of elevation antenna beam width from 1.3° to 0.5° and (2) Split site configuration to provide azimuth and range coverage through rollout.

2.0 Introduction

The baselined radio frequency ground-based navaid for the Shuttle approach and landing is the Microwave Scanning Beam Landing System (MSBLS). The function of the MSBLS is to provide the onboard receivers navigation information in the form of range, elevation, and azimuth data relative to the ground transmitter. The data is used to update the vehicle state vector which is in turn used to compute vehicle energy and position.

The presently accepted baseline MSBLS ground system is scheduled for delivery in December 1976, to support the Orbiter Approach and Landing Test (ALT). The present delivery requirement for MSBLS ground equipment to support the Shuttle Training Aircraft (STA) is December 1975. In the interest of commonality between the Orbiter and STA, and the delivery schedule conflict, it has become necessary to investigate the availability of other microwave scanning beam equipment that could satisfy the STA delivery date requirement and still be acceptable for use with Orbiter airborne MSBLS receivers. Of the available scanning beam systems, the most promising is the TILS.

It is the purpose of this memorandum to compare the performance of the TILS, a currently available production scanning beam system, to the baseline MSBLS.

3.0 Discussion

As previously stated, the basic requirement of the MSBLS ground system is to provide navigation information to the Orbiter during approach and landing. The autoland system touchdown requirements (Ref 1), are shown in Figure 1 which depicts the approach end of the runway, the nominal touchdown point ie., 2700 feet from threshold, the 3° Glideslope Intercept Point, and the 3 σ touchdown requirements footprint.

A pictorial description of the baseline MSBLS ground station is shown in Figure 2. This configuration is capable of providing an azimuth signal of $\pm 20°$ relative to the runway centerline and an elevation angle from 0° to 30°. The DME function will provide range from 12,000 feet altitude through touchdown and rollout. In the practical application, the elevation angle signal is not useable lower than one signal beam width to preclude masking and ground clutter. Thus, the baseline elevation signal is available down to 0.5°. The Level II requirement for autoland states that the automatic system shall be capable of executing fully automatic landings in "0-0" weather conditions with an all-up system (Category IIIC Requirement). The baseline design reflects an interpretation of these requirements to mean full MSBLS coverage through autoland and rollout. To provide this type coverage it was deemed necessary to split the scanner sites as shown in Figure 2. The elevation scanner is 200 feet normal to the centerline and 4000 feet down the runway from the approach end to provide unrestricted elevation coverage through touchdown. The azimuth scanner and DME antennas are located on the centerline beyond the stop end of the runway, approximately 12,000 feet from the elevation scanner, and provide coverage through rollout. In the split site configuration it is necessary to physically connect the two sites with a cable to provide a synchronizing link between the two antennas.

<u>TILS at the Baseline Position</u> - The standard TILS provides elevation and azimuth functions to airborne vehicles during final phases of landing and touchdown. A pictorial description of the TILS ground, station, at the baseline position, is shown in Figure 3. The con-

figuration is capable of providing an azimuth signal of $\pm 15^{\circ}$ relative to the runway centerline, and an elevation angle from 0 to 10°. In the practical application, the elevation angle signal is not useable below 1.3°.

Baseline MSBLS/TILS Elevation Coverage - Figures 4 & 5 graphically depict both MSBLS and TILS elevation coverage from the baseline position for the final and initial flare ranges respectively. The basic MSBLS elevation coverage is from 0.5° to 30° as opposed to the TILS elevation coverage of 1.3° to 10°. The three orbiter trajectories shown in Figure 5 were obtained from Ref 1 and represent trajectories with headwind, no wind, and tailwind conditions. As shown in Figures 4&5, the present TILS configuration located at the baseline position will not provide full elevation coverage during the steep glide slope approach and prior to the final flare for the headwind trajectory. Figure 6 shows the planview of both elevation coverages in the baseline position. It is apparent that elevation coverage is not provided to touchdown in all cases described by the touchdown requirements.

In order that TILS satisfies the elevation requirements, the elevation coverage must be raised from 10° to 30° and the elevation scanner must be located 2500 feet from the approach end and 200 feet normal to the centerline of the runway as shown in Figure 7. This move is made necessary by the 1.3° elevation restriction imposed by the standard TILS elevation scan. Figure 8 shows the planview coverage of the modified TILS at 2500 feet from threshold and indicates that 15° width of the elevation scan causes loss of signal in most cases described by the touchdown requirements ellipse. However, for the headwind, nominal, and tail-wind trajectories described in Figure 7, the data dropout occured at 3, 4, and 5 seconds prior to touchdown. These times-to-go correspond to 25, 32.5, and 40 feet in altitude respectively and elevation coverage below these altitudes would not be provided. However, elevation to touchdown is not a necessity since altitude information from 400 to 100 feet altitude is a blend of MSBLS and Radar Altimeter data and below 100 feet altitude, the information is provided entirely by the Radar Altimeter. Furthermore, the IMU could provide the necessary azimuth and altitude information required for final flare, touchdown, and rollout.

The other change that must be implemented, is the addition of the DME function to the TILS. This is necessary in order that range measuring capability accurate enough to meet the autoland requirements is available for state vector update. The only other navaid which provides range information is the TACAN, which has an accuracy of $\pm$ 400 feet. The $\pm$ 400 ft accuracy provided by the TACAN is equivalent to the 1σ tolerance of the autoland requirements which is the tolerance for the <u>total</u> GN&C system. Thus it is obvious that a more accurate DME than is provided by TACAN is necessary (Ref 3). With the above mentioned changes, and the addition of DME, the modified TILS will be able to satisfy the basic Orbiter ground navaid requirements with only a small amount of system degradation.

Rollout Coverage - As noted in Figure 3, the TILS is a colocated scanning beam system. Given that the elevation scanning beam must be located 2500 feet from threshold, a colocated system provides azimuth and DME coverage to the Orbiter down to approximately 0-5 seconds prior to touchdown. The tradeoff implied is that of cost savings of a colocated site versus the necessity of azimuth and DME data during touchdown and rollout. Analysis indicates that rollout guidance can be provided by using inertial data from the IMU.

Figure 9 shows a comparison of the touchdown and rollout accuracies of the baseline MSBLS and modified TILS.

The touchdown errors are shown both with and without Radar Altimeter to indicate the difference between the all-up system and the failed Radar Altimeter case, which requires altitude to be derived from MSBLS range and elevation angle.

The inertial contributions represent a 0.5 ft/sec velocity error in each axis. This is based on a previously performed analysis (Ref 4).

The final set of errors shown in Figure 9, represents the total error at full stop in the baseline MSBLS due to MSBLS system accuracy, and the TILS which includes both system accuracy and the error contirbutions from the inertial system during touchdown and rollout.

4.0 Conclusion

From the described analysis, it can be concluded that the TILS can satisfy Orbiter Autoland system requirements with the following requirements:

1. Addition of DME equipment.
2. Expansion of the elevation coverage from 0-10° to 0-30°.
3. Expansion to redundant systems with associated monitors.

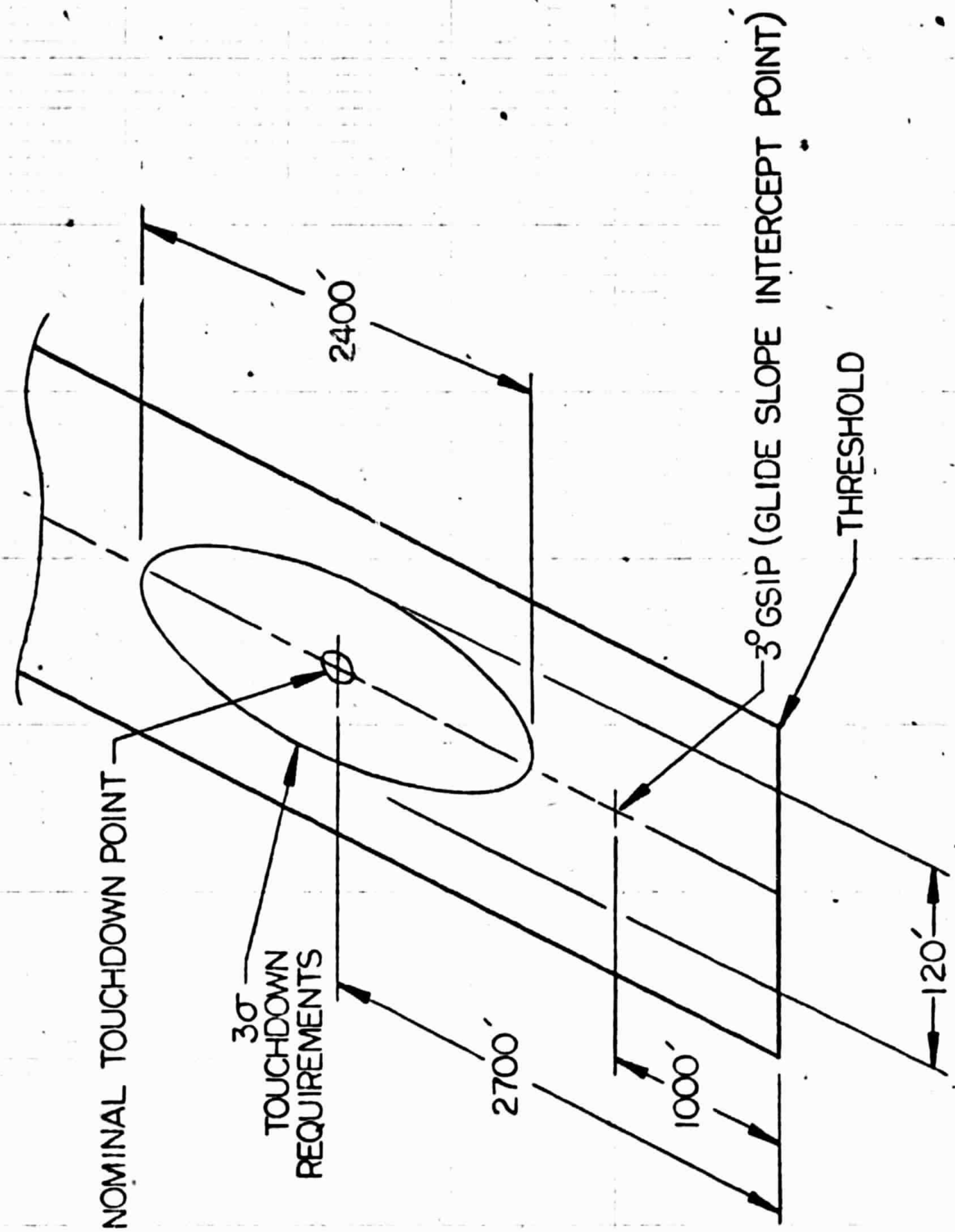
Additional modifications that would not be necessary to meet the Orbiter requirements, but would contribute to the margin of performance are tightening the elevation antenna beam width from 1.3° to o.5° and a split site configuration to provide azimuth and range information coverage through completion of rollout.

5.0 References

1. Space Shuttle Automatic Landing Support Program PDRL No. UA 01 DTD June 1974; Sperry Flight Systems.
2. Microwave Scanning Beam Landing System (MSBLS) Navigation Set for Space Shuttle Orbiter Vehicle; Presentation Handout, H. Erwin, Aug. 1974.

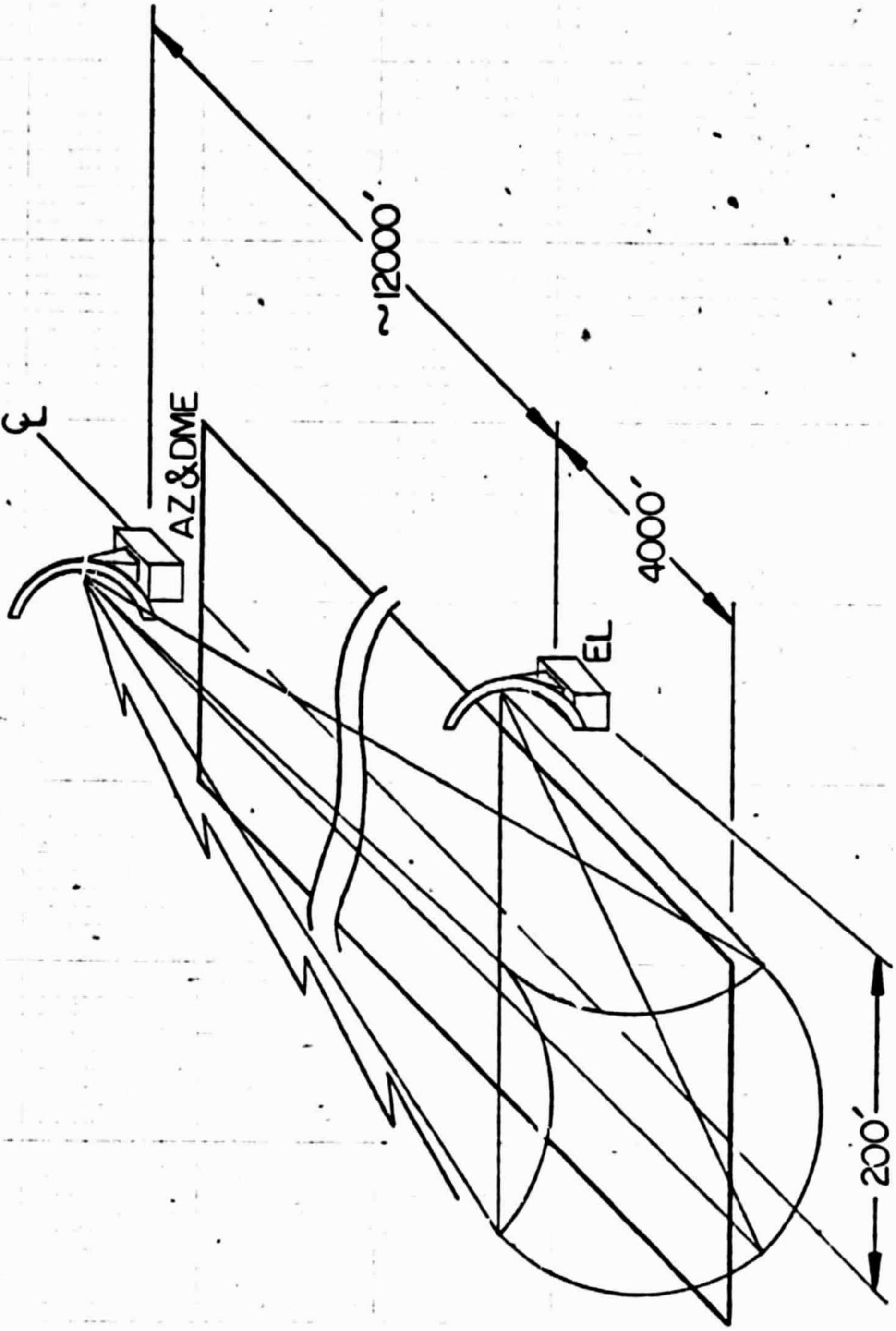
3. Space Shuttle Guidance, Navigation and Flight Control Accuracy Control Document, DTD June 1974; Rockwell International.

4. Kriegsman, B., Mahar, K, "Entry and Landing Navigation System Performance with New Navaid Error Models", CSDL Shuttle Memo 10E-74-49, 10 September 1974.



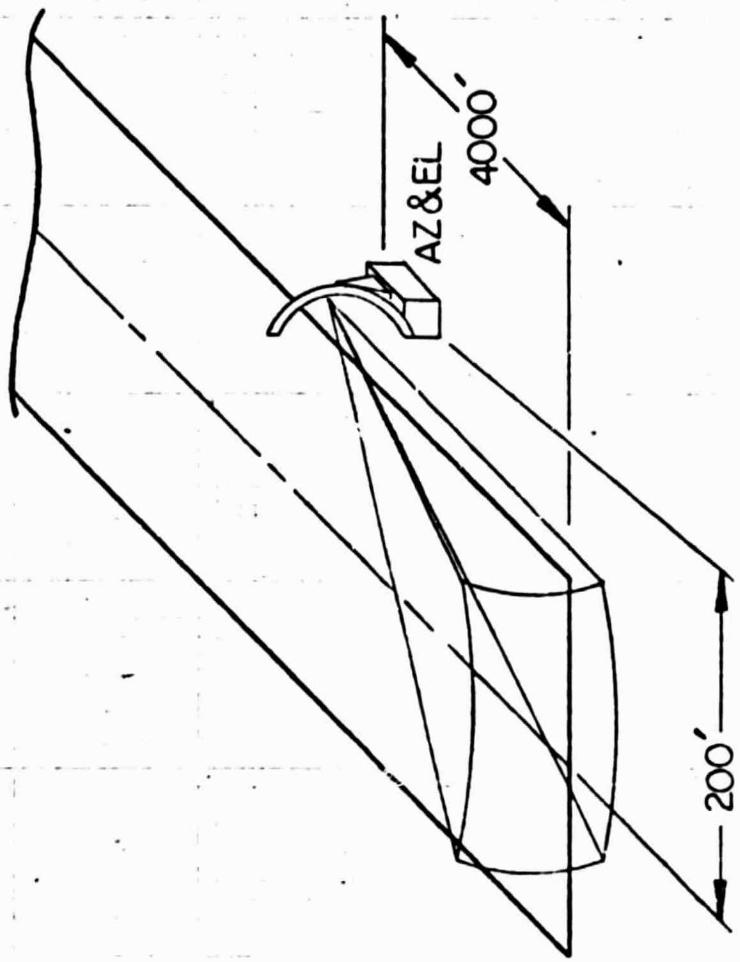
AUTOLAND REQUIREMENTS

FIGURE 1



MSBLS BASELINE

FIGURE 2



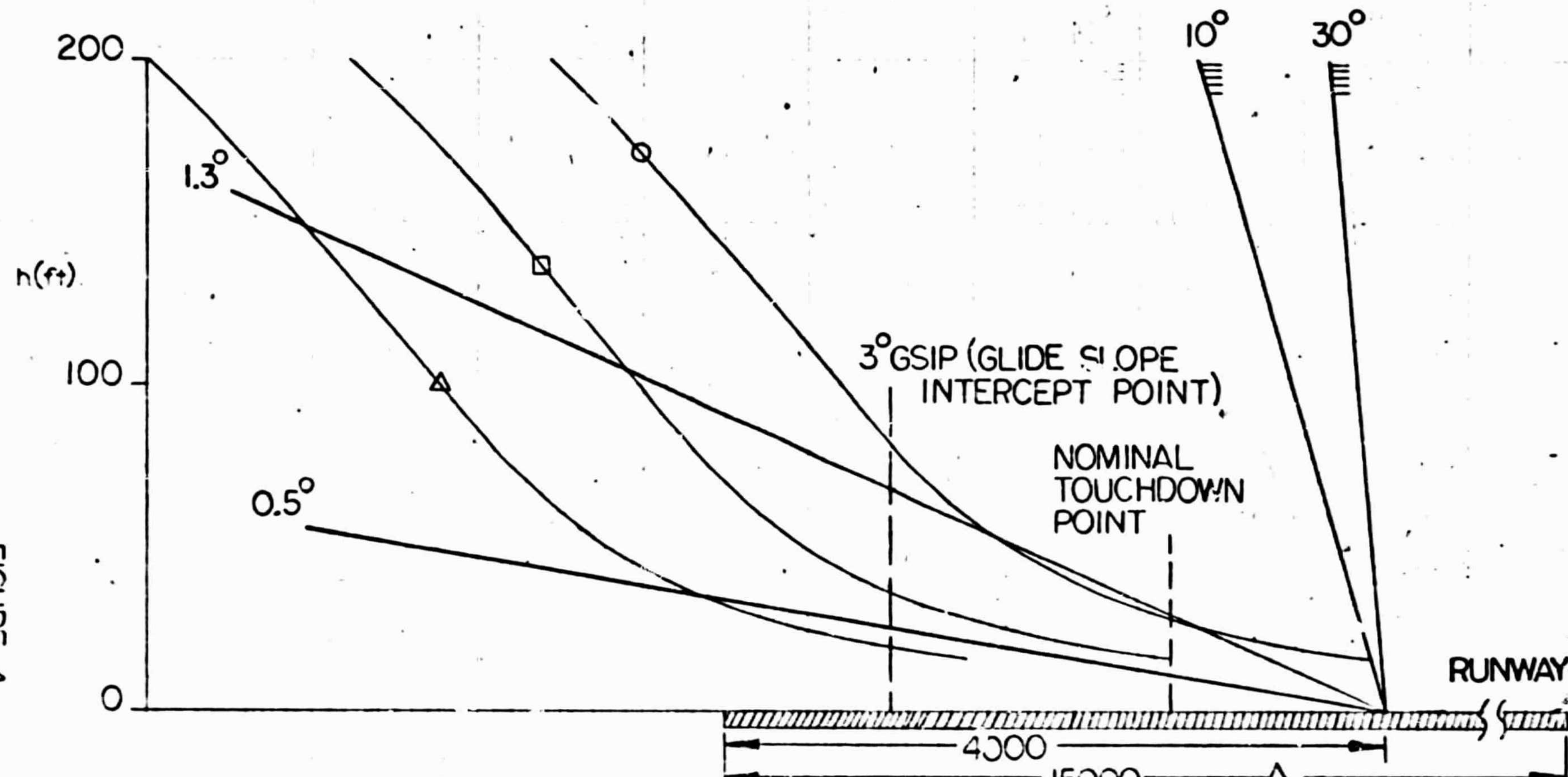
TILS BASELINE

FIGURE 3

NOTES:
1. MSBLS EL COVERAGE 0.25°-30°
2. TILS EL COVERAGE 0.65°-10°

LEGEND:

○ - TRAJECTORY W/ TAILWIND
□ - TRAJECTORY W/ NO WIND
△ - TRAJECTORY W/ HEADWIND



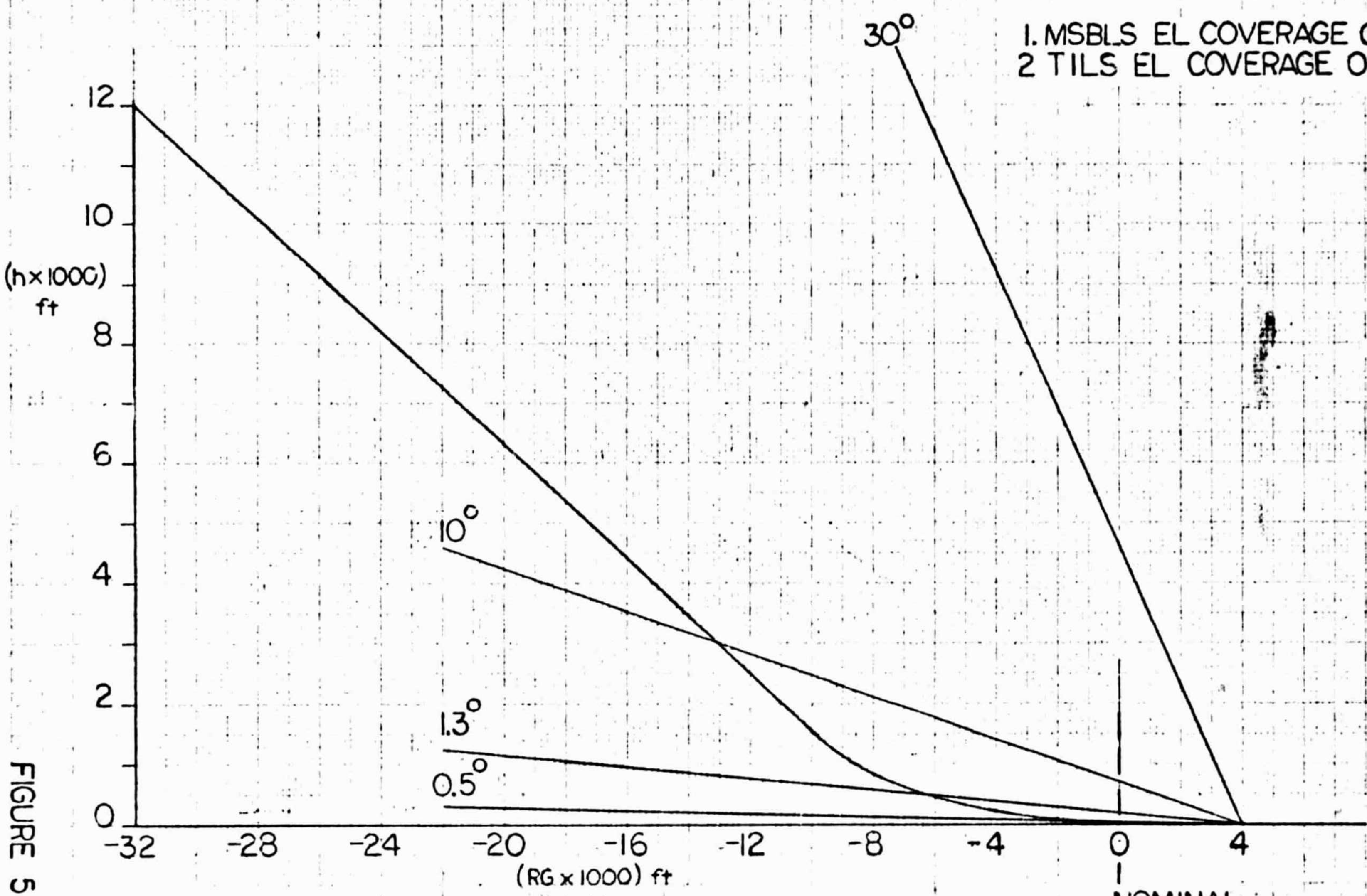
BASELINE - MSBLS/TILS
ELEVATION COVERAGE

FIGURE 4

JMT
10-25-74

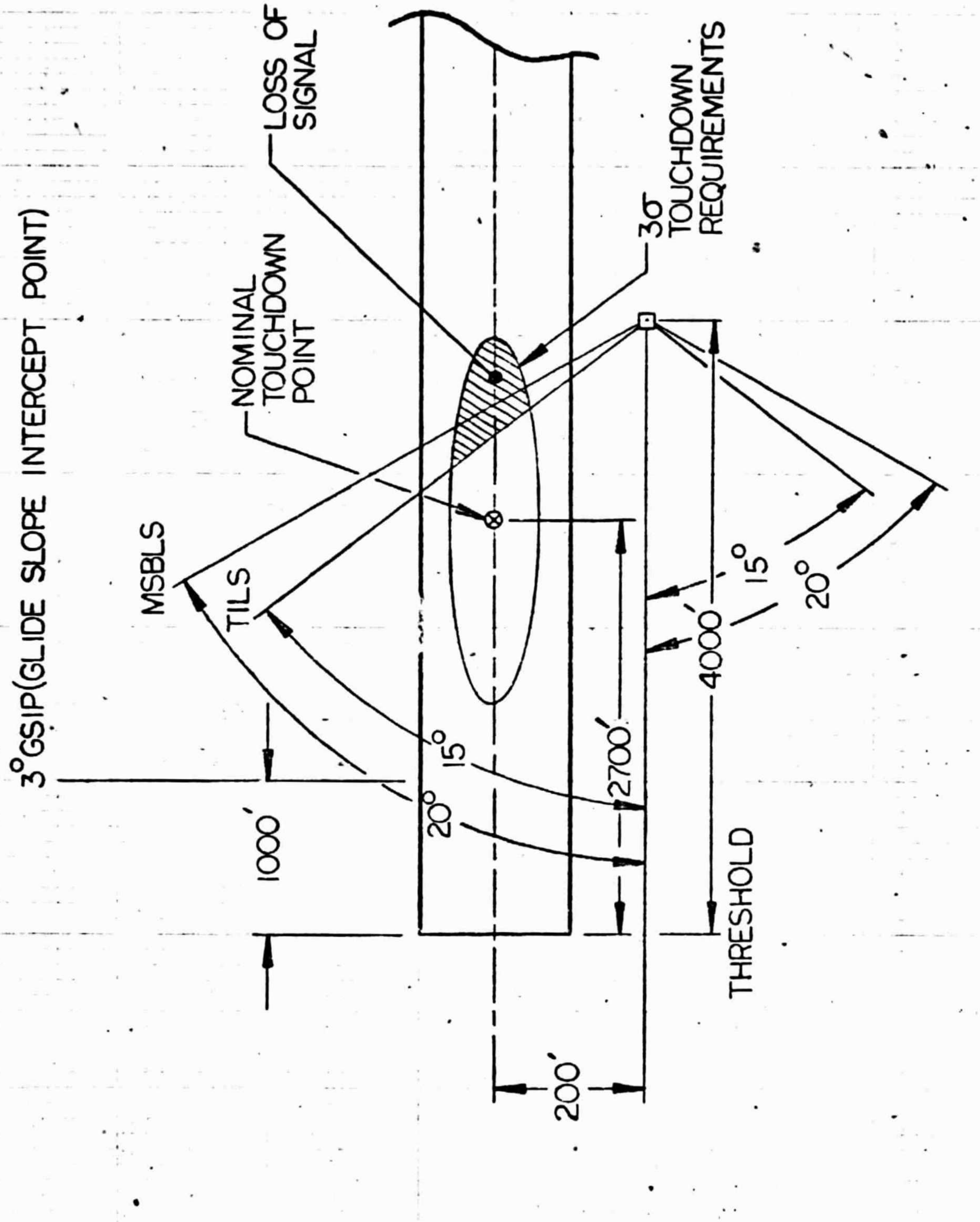
NOTES:

1. MSBLS EL COVERAGE 0.25°-30°
2 TILS EL COVERAGE 0.65°-10°



BASELINE MSBLS/TILS ELEVATION COVERAGE
STEEP GLIDE SLOPE

FIGURE 5



BASELINE–MSBLS/TILS ELEVATION PLANVIEW COVERAGE

FIGURE 6

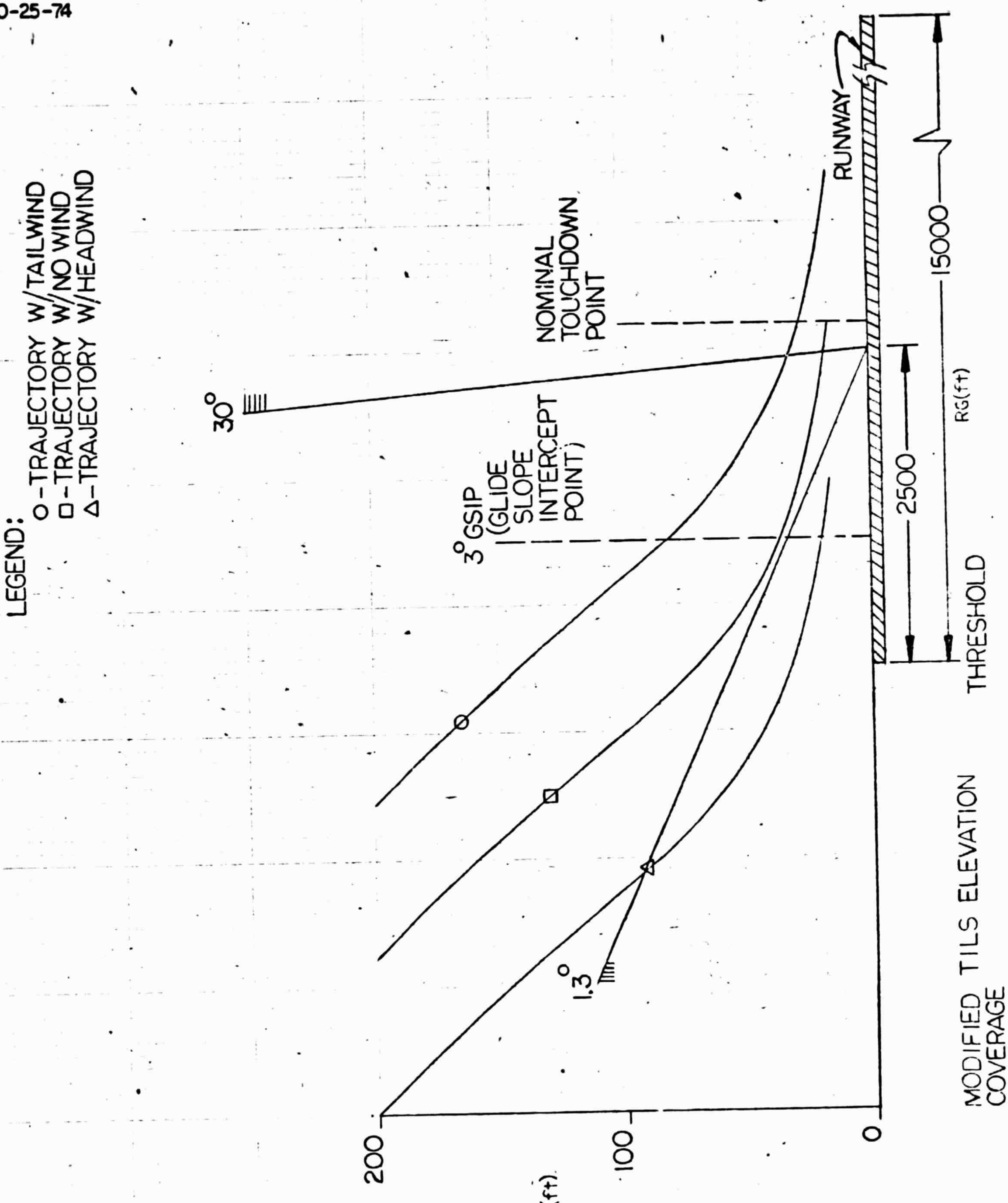

LEGEND:
○ - TRAJECTORY W/TAILWIND
□ - TRAJECTORY W/NO WIND
Δ - TRAJECTORY W/HEADWIND
30°
3° GSIP (GLIDE SLOPE INTERCEPT POINT)
NOMINAL TOUCHDOWN POINT
RUNWAY
1.3°
200
100
0
h(ft)
2500
15000
RG(ft)
THRESHOLD
MODIFIED TILS ELEVATION COVERAGE

FIGURE 7

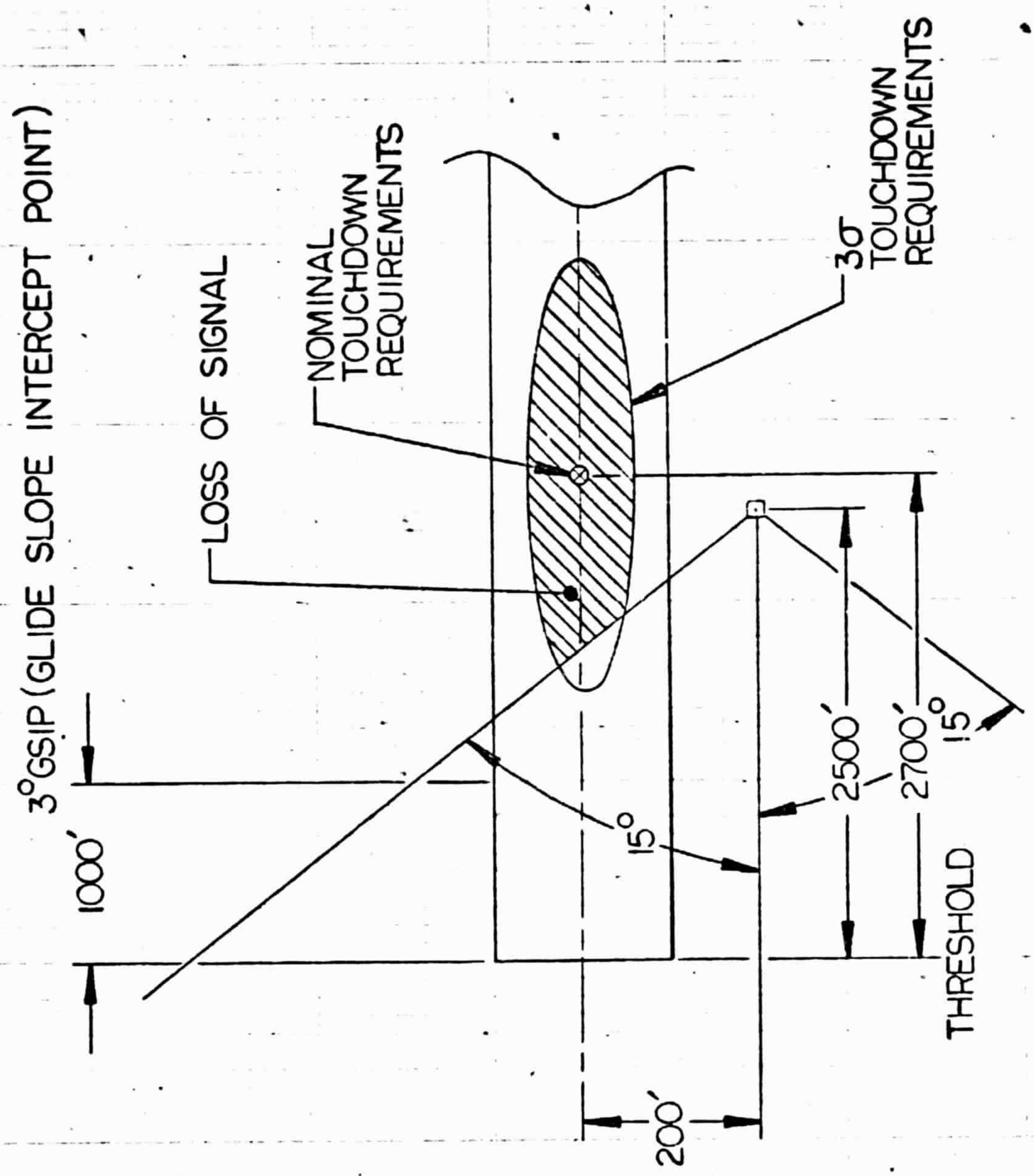


FIGURE 8
MODIFIED TILS AZIMUTH COVERAGE

FIGURE 8

	DOWN RANGE ERROR	CROSS-TRACK ERROR	ALTITUDE ERROR
BASELINE MSBLS			
At touchdown with Radar Altimeter	100.0 ft	12.1 ft	2.0 ft
At touchdown without Radar Altimeter	100.0 ft	12.1 ft	2.4 ft
MODIFIED TILS			
At touchdown with Radar Altimeter	102.5 ft	9.6 ft	2.0 ft
At touchdown without Radar Altimeter (includes 5 second inertial error)	102.5 ft	9.6 ft	4.8 ft
INERTIAL ERROR CONTRIBUTIONS DURING TOUCHDOWN AND ROLLOUT FOR TILS			
50 ft altitude to touchdown (5 seconds)	2.5 ft	2.5 ft	2.5 ft
Touchdown through rollout (30 seconds)	15.0 ft	15.0 ft	---
ACCURACY AT STOP			
Baseline MSBLS	100.0 ft	5.0 ft	---
Modified TILS	117.5 ft	24.6 ft	---

SUMMARY OF IMU, RADAR ALTIMETER, AND SCANNING BEAM ERROR CONTRIBUTIONS

FIGURE 9