FLIGHT TESTS OF IFR LANDING APPROACH SYSTEMS FOR HELICOPTERS

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SUMMARY

The helicopter section of the U.S. Standard for Terminal Instrument Procedures (TERPS) was first issued in 1970, when only a few civilian helicopters were IFR certified and operations under Instrument Flight Rules (IFR) were very limited. In the subsequent decade, there has been considerable technological progress in the helicopter industry, and there has been a significant increase in civilian IFR operations. Thus, there exists a need to update the existing helicopter TERPS criteria in order that civilian operators may take maximum advantage of the helicopter's unique flight capabilities.

In response to this need for the establishment of new helicopter TERPS criteria, the Ames Research Center and the FAA Flight Standards National Field Office have conducted two joint flight-test investigations: (1) airborne radar approaches (ARA) and (2) microwave landing system (MLS) approaches. The first flight-test investigation consisted of helicopter IFR approaches to offshore oil rigs in the Gulf of Mexico, using weather/mapping radar, operational pilots, and a Bell 212 helicopter. The second flight-test investigation consisted of IFR MLS approaches at Crows Landing (near Ames Research Center), with a Bell UH-1H helicopter, using NASA, FAA, and operational industry pilots. The purposes of the flight tests were to (1) provide the FAA with statistical data for establishment of TERPS criteria and (2) provide NASA with a data base to serve as a performance measure for advanced guidance and navigation concepts.

INTRODUCTION

In the past decade, there has been increased utilization of the helicopter for transportation into remote sites as well as into high-traffic-density hub airports. Concurrent with this increased transportation utilization is a significant increase in operation under instrument flight rules (IFR). For example, the growth of the helicopter offshore transportation industry has been stimulated in recent years by the accelerated development and exploration of the Nation's offshore oil resources (ref. 1). To avoid flight cancellations or delays caused by unfavorable weather conditions, airborne weather/mapping radar has been developed by the operators as a "self-contained" navigation aid for landings on sites where there are no ground-based navigation aids. Operational implementation of the new National Microwave Landing System, which is also under way (ref. 2), will provide an expanded IFR landing approach capability particularly suited to the helicopter's unique flight characteristics. The airborne selectable glide slope and offset radial features of the microwave landing system (MLS) will permit greater approach-path flexibility, which can be utilized in noise abatement, minimum airspace, and traffic separation procedures for high-density hub airport operations.

The current edition of the U.S. Standard for Terminal Instrument Procedures (TERPS) (ref. 3) contains no criteria relative to helicopter instrument approaches that utilize either airborne radar or MLS as the primary navigation source. Operators are currently using airborne radar approach (ARA) procedures that have been approved by the FAA on a regional basis; however, these procedures have not been approved as a national standard, as would be set by TERPS. In addition, since precision MLS instrument approaches will offer many advantages to helicopter operators over the conventional instrument landing system (ILS) approach, there is a need to update existing helicopter TERPS criteria in order that civilian operators may take maximum advantage of ARA and MLS instrument approach procedures.

In response to this need, Ames Research Center and the FAA Flight Standards National Field Office have conducted two joint flight-test investigations: (1) airborne radar approaches (ARA) (refs. 4, 5, 6) and (2) microwave landing system (MLS) approaches (ref. 7). The first flight-test investigation consisted of helicopter IFR approaches to offshore oil rigs in the Gulf of Mexico, using weather/mapping radar, operational pilots, and a Bell 212 helicopter. The second flight-test investigation consisted of IFR MLS approaches at Crows Landing (near Ames Research Center), with a Bell UH-1H helicopter flown by NASA, FAA, and operational industry pilots. The purposes of the flight tests were to (1) provide the FAA with statistical data for establishment of TERPS criteria and (2) provide NASA with a data base to serve as a performance measure for development of advanced guidance and navigation concepts. The specific flight test objectives were to:

1. Develop procedures
2. Measure total system errors
3. Measure navigation equipment errors
4. Measure flight technical errors
5. Determine acceptable weather minimums

This paper presents the results of these two Joint NASA/FAA helicopter flight tests.

TEST DESCRIPTION

General Test Plan

The general plan for conducting both flight tests was to (1) include operational pilots in the tests, (2) conduct approaches "under the hood" for IFR simulation, (3) conduct both landings and missed approaches, and (4) conduct a sufficient number of approaches to allow for statistical analysis of flight envelopes.

Airborne Radar Approach (ARA) Test Description

Flight tests of helicopter airborne radar approaches were conducted using a Bell 212 helicopter (fig. 1); a cluster of seven oil platforms, located about 15 miles south of Intracoastal City, Louisiana, in the Gulf of Mexico, was used as landing sites. The tests consisted of 15 flights, 15 pilots, and 120 approaches, with both pilot and copilot hooded for simulated instrument conditions. A "chase" plane insured separation from traffic in the test area. Aircraft tracking was accomplished by triangulating range data from responders located on three separate oil rigs such that the approach area was totally covered. Cameras in the helicopter were used to photograph the cockpit radar display and a radar repeater display. The test aircraft was also equipped with a palletized data acquisition system for recording basic flight data. Pilot acceptability ratings were recorded for each approach; questionnaires, filled out by the pilots after their flights, provided more detailed comments and recommendations.

Microwave Landing System Test Description

Flight tests of MLS approaches were conducted using a NASA Bell UH-1H helicopter (fig. 2) and a simulated STOLport at Crows Landing, an Ames Research Center flight-test facility. Crows Landing is equipped with a basic narrow time reference scanning beam (TRSB) MLS ground system. The approach envelope provided by the MLS system was ±40° in azimuth and 0-15° in elevation. Fourteen pilots from various elements of the helicopter community flew 140 manual-mode (without stability augmentation) simulated instrument approaches under the "hood." Various performance parameters and radar tracking data were monitored in real time, and pilot opinion ratings were recorded during the flight tests. Digital tape recordings of these and other data were provided for postflight analysis. A comprehensive pilot questionnaire was also completed by participating pilots.

TEST RESULTS: AIRBORNE RADAR APPROACH

ARA Procedures

A typical airborne radar approach flight profile is depicted in figure 3. The instrument approach is a high workload operation that requires two pilots. The copilot operates and interprets the radar display and acts as a "GCA" controller in giving the pilot heading and altitude commands. As the aircraft approaches the target oil platform, the copilot first determines the wind direction and plans the approach so that the final approach segment will be flown directly into the wind. If the destination rig is in a cluster of platforms, the approach is planned to a platform on the downwind edge of the cluster so that the final approach segment is clear of obstructions.

After "overheading" the target rig, a descending turn is made to 152 m (500 ft) and to a heading within ±10° of the reciprocal of the final approach heading. The distance flown on the outbound leg is "dead reckoned" because the target rig "blip" is lost from the radarscope after passing overhead. The outbound heading is held for 3 min and a level procedure turn is made, at an altitude of 152 m (500 ft) and an airspeed of about 90 knots, to the final approach inbound heading.

The final approach begins after the aircraft crosses the downwind final approach fix (DWFAF) located 4 n. mi. from the target rig. The aircraft is slowed to an airspeed of 60 knots, and a rate of descent is initiated that will allow the aircraft to be leveled off at a minimum-descent altitude for missed-approach altitude, at about 1-2 n. mi. from the target rig. At the missed-approach point (MAP), the copilot commands the pilot to execute a missed approach if the copilot does not have the target rig in sight. If the copilot has the target rig in sight at the missed-approach point he takes command of the aircraft and performs the landing.

Two different types of MAPs were investigated: (1) a MAP located on the straight-in final approach path, and (2) a MAP laterally offset from the straight-in final approach path. The lateral offset MAP is arrived at by making a 15° aircraft heading change at 1 n. mi. from the target platform and holding the heading until the MAP range is reached. In either case the missed-approach procedure consists of a climbing turn to clear adjacent rigs in the cluster and return to the initial approach fix.

ARA Display on Typical Approach

The weather-mapping radar used in these tests had two modes of operation: beacon and primary. In the beacon mode the radar displays only those signals that are received from radio beacon transponders. In the primary mode the radar displays all radar target returns and is commonly referred to as a "skin paint" mode. The radar display presented to the copilot as the aircraft headed south from Intracoastal City across the Gulf coastline is shown in figure 4. The radar is being operated in the primary mode ("skin paint") on the 40-n. mi.-range scale which has 10-n. mi. range-mark increments. The high density of oil platforms and clusters of oil platforms in the Gulf of Mexico, which is apparent in figure 4, presents the copilot with a difficult task in correctly identifying the destination platform. In order to satisfactorily identify the target platform, the copilot must be intimately familiar with the local area or have additional position information provided by some other available navigation aid, such as VOR/DME, Loran-C or a beacon transponder located on or near the target rig. The destination cluster of seven oil platforms used in these tests is shown on the display at a range of about 18 n. mi. from the aircraft and about 5° left of the aircraft heading.

The radar display that results as the aircraft completes the procedure turn and initiates the final approach segment is shown in figure 5. The target oil platform is shown dead ahead of the aircraft at about 4-1/4 n. mi. Radar display "blips" for three oil platforms are separated; however, display "blips" for three other platforms are still merged at about 5 n. mi. as one target due to poor resolution and excessive gain control. Also showing, on the radar display, merged as one target at about 5-1/2 n. mi., are two ships that were passing through the area.

The radar display that results after the aircraft has progressed far enough on final approach for the copilot to switch to the 5-n. mi.-range scale (1-n. mi. range-mark increments) is shown in figure 6. The target oil platform is still dead ahead at about 3-1/2 n. mi., and three platforms are still merged; however, the two ships are now displayed as separate targets.

The radar display resulting after switching to the 2.5-n. mi.-range scale (0.5-n. mi. range-mark increments) is shown in figure 7. The target platform is dead ahead at about 1-1/4 n. mi., and all platforms are now displayed as separate targets. One platform has passed off the scope down and to the left. The copilot would continue to give the pilot heading commands to bring the target platform "blip" down the center cursor of the radar display until the leading edge of the target met the 1/2-n. mi. range mark, at which point a landing or missed approach would be executed.

ARA Target Mididentification

The test crews unanimously agreed in their postflight pilot questionnaires that the most difficult task in making an airborne radar approach to a cluster of oil platforms is target identification. This conclusion is strongly supported by the test results. Of the 90 approaches conducted in primary mode to the seven-rig test cluster, 5 were made to wrong target platforms, and 5 others were made to ships in the area; that is, 11% of the primary-mode radar approaches were conducted to incorrect targets. The difficulty of target identification is illustrated in the typical display shown in figure 7. Due to the wide radar antenna beam width (8°), targets are elongated in azimuth, making pattern recognition very difficult; there is further confusion if ships are in the area. If a beacon is located in the destination oil rig cluster, use of the beacon mode can aid target identification. However, there are very few beacons at offshore oil rigs, and future installations are uncertain because of the expense and possible conflict of beacons with maritime radars.

There is usually no hazard associated with incorrect target identification, if a missed approach is not required; the pilot can simply locate himself upon arrival at the wrong platform and fly to the correct platform in the cluster. A serious problem can be created, however, in the event a missed approach is executed from the wrong target because the aircraft may not have sufficient obstruction clearance.

In contrast with an approach to an oil rig cluster, an approach to single rig does not present such a serious target-identification problem. In the case of a single-rig approach, transient shipping presents the only target identification difficulty.

ARA Final Approach Lateral Flight Envelope

The minimum descent altitude in these tests was not based on vertical obstacle clearance, as is the case in conventional instrument approaches. Rather the aircraft was flown at minimum descent altitudes on final approach that placed it below the tops of some surrounding oil rigs. This was made possible by relying on the airborne radar to provide sufficient lateral clearance from obstacles in the area and using the radar altimeter to provide necessary vertical clearance from the water surface. Thus, to help establish criteria that will provide satisfactory lateral obstacle clearance, it is important to analyze statistically the actual ground track relative to the intended ground track of the final approach (ground track that passes through the downwind final approach fix). An ensemble plot of individual final approaches is shown in figure 8. The individual final approach ground tracks indicate that the aircraft crews accepted initial cross-track deviation at the DWFAF and simply flew homing-type approaches by keeping the target platform centered on the radar display. The mean and 2-sigma cross-track deviations of final approach ground track relative to intended final approach ground track are shown in figure 9. The 2-sigma "envelope" can be closely approximated by a ±30° sector about the intended final approach track. Thus, if the final approach area is clear of known oil platforms within ±30° of the selected final approach ground track, there is a 95% probability (2-sigma) of incurring only shipping or other transient obstacles.

ARA Missed Approach Lateral Flight Envelope

The acceptability of weather minimums for instrument approaches is largely determined by resulting obstacle clearance provided in the missed-approach procedure. Lateral obstacle clearance from the target platform of missed approaches conducted in these tests, using the laterally offset MAP, is shown in figure 10. The mean missed-approach ground track had a minimum lateral clearance from the target platform of 625 m (2,050 ft) with a 2-sigma deviation of ±427 m (±1,400 ft). Based on these statistics, the probability of overflying the target platform into the cluster area is 0.2%, if the distribution is assumed to be normal.

ARA Weather Minimums

Weather minimums recommended by the subject test pilots are shown in table 1. It is significant that although 25% of the approaches were conducted to 1/4-n. mi. minimums for test purposes, none of the 15 pilots recommended that 1/4-n. mi. minimums be operationally approved for either primary- or beacon-mode approaches. Most of the pilots recommended that 61 m (200 ft), 1/2-n. mi. weather minimums be approved, but a considerable number felt that 91 m (300 ft), 1/2-n. mi. minimums would be appropriate; a few thought that the approved minimums should even be higher in both altitude and visibility.

TEST RESULTS: MICROWAVE LANDING SYSTEM

MLS Approach Procedures

In order to determine "worst case" airspace requirements, MLS approaches were flown using raw data guidance (glide slope and localizer only) without the aid of stability augmentation, flight director, or DME. The flight profiles flown by the 14 evaluation pilots included 3°, 6°, and 9° glide-slope, centerline approaches to decision heights of 15, 30, and 46 m (50, 100, and 150 ft), respectively. A 20°, lateral-offset approach was also flown on a 3° glide slope to a decision height of 61 m (200 ft).

Approach plates for each of the flight-test profiles were provided to the evaluation pilots for use during the approaches. A typical approach plate is shown in figure 11 depicting the appropriate headings, fixes, decision heights, and missed-approach procedures. The final approach was conducted at constant airspeed, and deceleration for landing was performed under visual conditions after the decision height was reached.

Decision heights for the runway centerline approaches were established to provide an approximate constant range of 305 m (1,000 ft) from the DH to glidepath intercept point (GPIP). A 15-m (50-ft) DH for 3° glide slope, 20° offset radial approach was not possible at this facility because MLS glide-slope guidance signal was lost on the 20° azimuth radial at an altitude just under 61 m (200 ft) (because of antenna coverage geometry of the "split-site" facility - azimuth antenna 1341 m (4,400 ft) past the elevation antenna). Thus, a 61-m (200-ft) DH was used for the 20° offset radial approaches.

MLS Final Approach Lateral Flight Envelope

A composite plot of the lateral tracking for 6° glide-slope approaches on runway centerline is shown in figure 12(a). The 2-sigma lateral flight envelope for the approaches in the composite plot is shown in figure 12(b). Shown on both approach plots is a plan view of the STOLport to which the approaches were conducted. The short dashes on either side extend from runway threshold to the end of the STOLport (610 m (2,000 ft)) and represent the lateral course window (±107 m (±350 ft)) at the 30 m (100-ft) decision height. The reference flightpath is depicted by the dashed line; the dotted lines indicate the full-scale limits of the course deviation indicator (CDI) instrument. Therefore, the lateral flightpath plots show graphically the relative position of the CDI needle displacement, throughout the approach, as seen by the pilot.

In figure 12(b), the mean ground track and small 2-sigma flight envelope for the approaches indicate good lateral tracking performance. The slight bias to right of centerline is probably related to the prevailing left-to-right cross winds which occurred during most of the flight tests. The 2-sigma lateral flight envelope boundary corresponds to about a 1/2 dot deflection on the pilot's CDI instrument. The lateral dispersion at the 30-m (100-ft) decision height window is shown in figure 13. Also shown in figure 13 for comparison are the "2-dot" CDI window and the conventional ILS CAT II window. The mean lateral flightpath at the 30 m (100-ft) decision height window was 5 m (17-ft) to right of centerline; the 2-sigma lateral flight envelope at the 30 m (100-ft) decision height window was ±37 m (±120 ft) about the mean. The lateral tracking performance for the 3^{o} and 9^{o} glide-slope approaches was essentially equivalent to that of the 6^{o} glide-slope approaches. It should be noted that missed approaches were conducted outside the MLS coverage area under dead reckoning. Thus, the wide missed-approach path variations evident on the composite approach plot (fig. 12(a)) resulted from lack of navigation guidance during this procedure. The MLS system can provide back-azimuth guidance for missed approaches when optional equipment is provided.

MLS Final Approach Vertical Flight Envelope

A composite plot of the vertical tracking for 6° glide-slope approaches on runway centerline is shown in figure 14(a). The 2-sigma flight envelope for the approaches in the composite plot is shown in figure 14(b). The zero point roughly corresponds to the glide-path intercept point (GPIP), or the extension of the glide slope to its intersection with the runway. The reference flightpath is depicted by the dashed line, and the vertical wedge defined by the dotted lines represents the full-scale limits (±2 dots) of the pilot's vertical deviation indicator (VDI). Thus, the vertical flightpath plots provide a graphic indication of the relative position of the glide-slope indicator through the complete approach.

The mean glidepath and small 2-sigma deviations shown in figure 14(b) indicate good glide-slope tracking performance. The 2-sigma vertical flight envelope boundary corresponds to generally about 3/4 of a dot deflection on the pilot's VDI instrument. However, there was a tendency for the aircraft to arrive at the 30 m (100-ft) decision height window slightly high on glide slope, as illustrated in figure 13. The mean flightpath at the 30 m (100-ft) decision height window was 6 m (21 ft) high, corresponding to about 1-1/2 dots deflection on the pilot's VDI instrument. The 2-sigma vertical flight envelope at the 30 m (100-ft) decision height window ranged from a lower boundary of 22 m (71 ft) to an upper boundary of 53 m (173 ft). The vertical flightpath dispersions for the 3^{o}, 6^{o}, and 9^{o} glide slopes were essentially equivalent, as seen on the pilot's VDI. However, full-scale VDI deflection sensitivity was varied with glide slope (full-scale deflection = $GS^{o}/3$). Therefore, for equivalent VDI deflection, the actual flight envelope of the 3^{o} glide slope was about 50% less than that of the 6^{o} glide slope, and the 9^{o} glide-slope vertical flight envelope was about 50% greater than that of the 6^{o} glide slope.

MLS Minimum Missed Approach Altitude

The minimum altitude to which an aircraft descends after initiation of the missed approach is an important parameter, for it affects the establishment of an acceptable decision height for a particular flightpath geometry.

Flight-test data for the 3°, 6°, and 9° runway centerline approaches were analyzed to determine the statistical means and 2-sigma deviations of the minimum altitude to which the aircraft descended after initiation of the missed approach procedure. These data are shown in table 2.

As one would expect, the means and 2-sigma deviations of the minimum missed-approach altitude increase with increasing sink rate (steeper glide slopes). The mean minimum missed-approach altitudes were 13, 23, and 36 m (43, 77, and 118 ft) for decision heights of 15, 30, and 46 m (50, 100, and 150 ft), respectively. The 2-sigma (95% probability) missed-approach vertical envelopes for the same decision heights were bounded by minimum altitudes of 8, 18, and 27 m (26, 58, and 87 ft), respectively.

MLS Decision Height Pilot Ratings

The pilot acceptability ratings of the decision heights for the 3°, 6°, and 9° runway centerline approaches are shown in table 3. Eleven pilots rated the 15 m (50-ft) decision height for the 3^{o} glide slope acceptable. High airspeeds, tracking errors, unacceptable obstacle clearance, wind gusts, and turbulence were stated as reasons by three pilots who felt the 15 m (50-ft) decision height was "too close to the ground for manual flight." All 14 pilots rated the 30 m (100-ft) decision height "acceptable" for the 6^{o} glide-slope approaches. Twelve pilots considered the 46-m (150-ft) decision height acceptable for the 9^{o} approaches, and two rated it unacceptable. Excessive sink rate and pilot workload were stated as the reasons for the unacceptable ratings.

CONCLUDING REMARKS

Joint NASA/FAA helicopter flight tests have been conducted to investigate airborne radar approaches (ARA) and microwave landing system (MLS) approaches. Flight-test results have been utilized to provide (1) NASA with a data base to be used as a performance measure for advanced guidance and navigation concepts and (2) FAA with data for establishment of TERPS criteria. NASA is using the ARA test data to develop flight director concepts which will be superimposed on the radar display for improved tracking and reduced pilot workload. The FAA has used the ARA test data to draft an Advisory Circular for use of Airborne Radar for instrument approaches to offshore oil rigs, which will serve as a forerunner to actual TERPS publication. NASA is using the MLS test data to develop advanced concepts for high-traffic density operations such as 3D/4D, helical, decelerating approaches. The FAA is using the MLS test data as a basis for suggested helicopter landing criteria in their System Test and Evaluation Program (STEP), a program designed to accomplish operational implementation of the new National Microwave Landing System.

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TABLE 1.- ARA WEATHER MINIMUMS RECOMMENDED BY SUBJECT TEST PILOTS

Weather minimum	Recommended number of pilots	
	Primary mode	Beacon mode
200 ft, 1/4 n. mi.	0	0
200 ft, 1/2 n. mi.	7	10
300 ft, 1/2 n. mi.	4	3
Higher	4	2
Total	15	15

TABLE 2.- MLS MINIMUM MISSED-APPROACH ALTITUDE STATISTICS

	3° glide slope 50-ft decision height	6° glide slope 100-ft decision height	9° glide slope 150-ft decision height
Mean minimum missed-approach altitude, ft AGL	43.5	57.5	118.0
2-sigma deviation, ft	17.0	20.0	31.0
2-sigma (95% probability) minimum altitude, ft AGL	26.5	57.5	87.0

TABLE 3.- MLS DECISION HEIGHT RATINGS (14 PILOTS)

Decision height, ft	Glide slope, deg	Rating, number of pilots	
		Acceptable	Unacceptable
150	9	12	2
100	6	14	0
50	3	11	3

1 FOOT = 0.3048 METERS

Figure 1.- Bell 212 helicopter landing on oil rig in the Gulf of Mexico.

Figure 2.- NASA UH-1H helicopter on MLS approach (selected approach angle = 9^{o}).

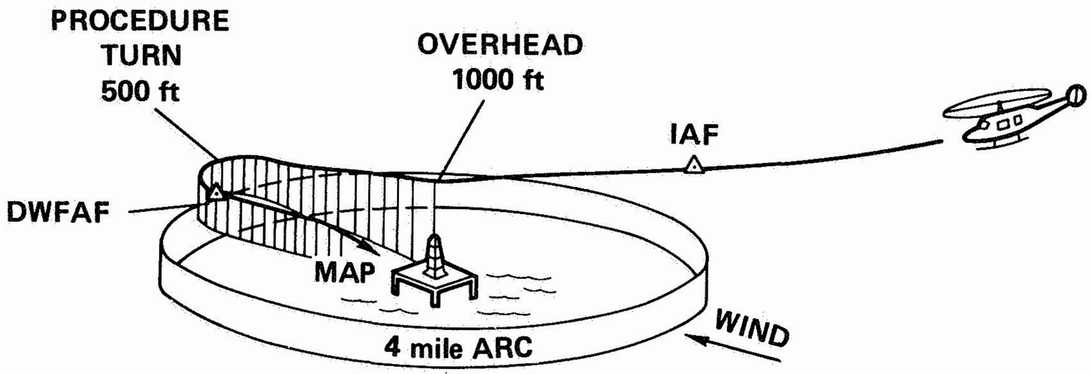


Figure 3.- Airborne radar approach to offshore oil rig. 1 ft = 0.3048 m.

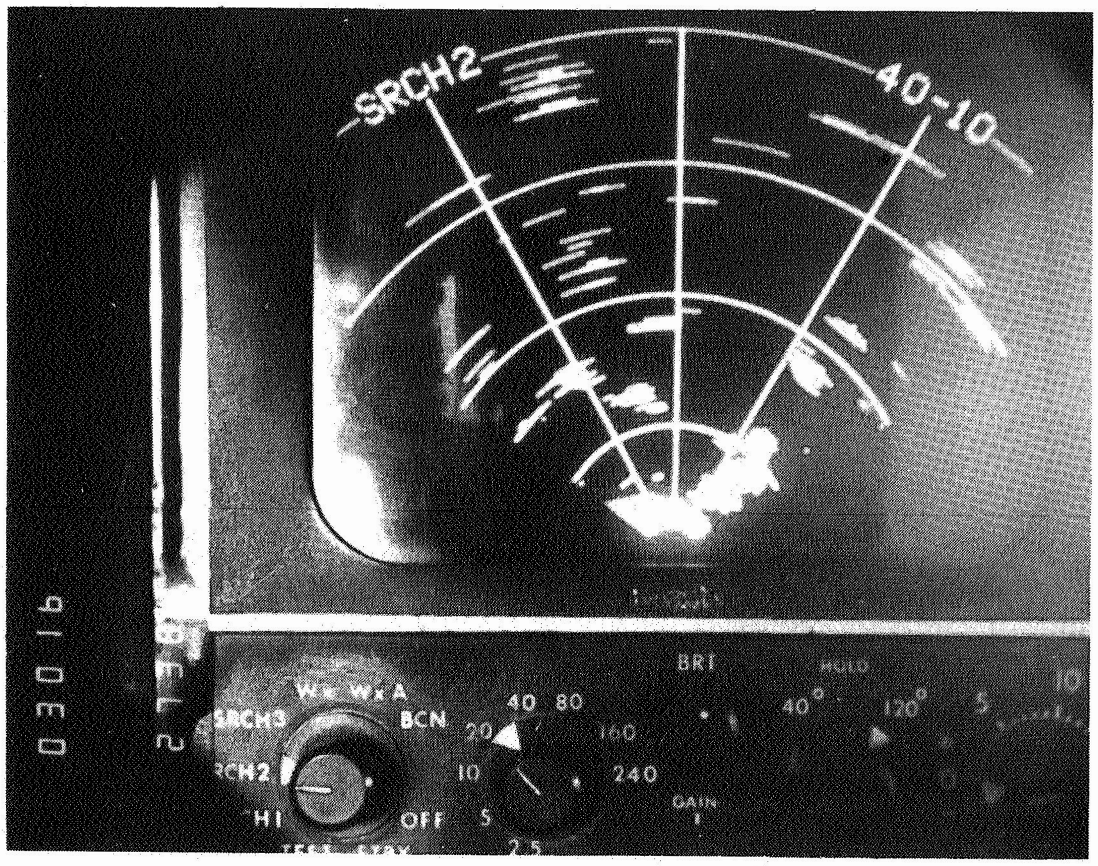


Figure 4.- Primary radar return display looking south over Gulf coastline south of Intracoastal City, Louisiana (40-n. mi.-range scale).

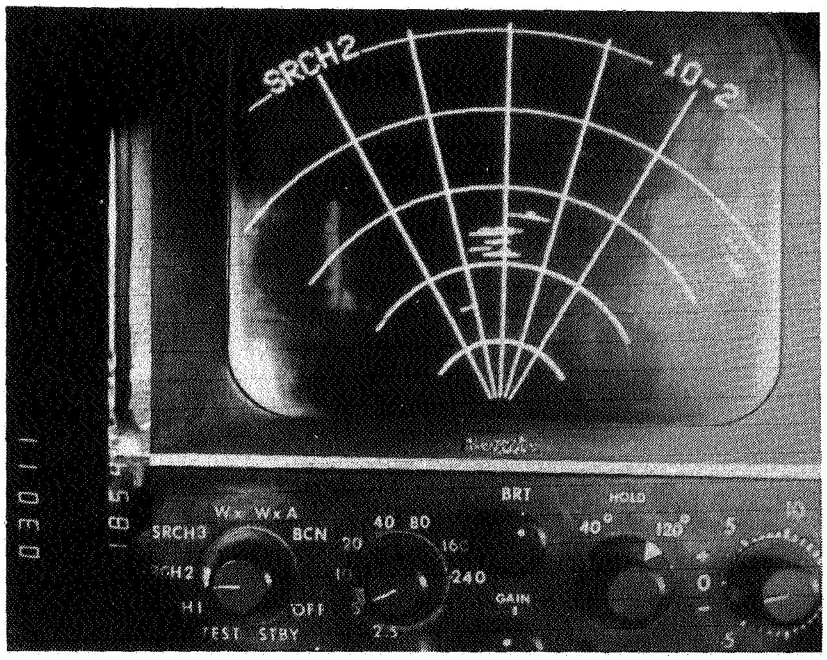


Figure 5.- Primary radar return display on final approach (10-n. mi.-range scale).

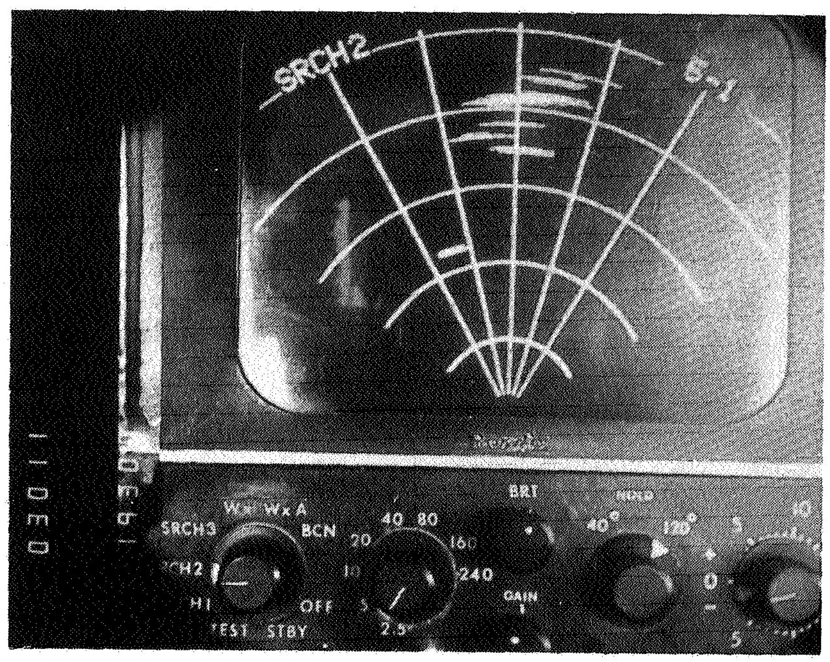


Figure 6.- Primary radar return display on final approach (5-n. mi.-range scale).

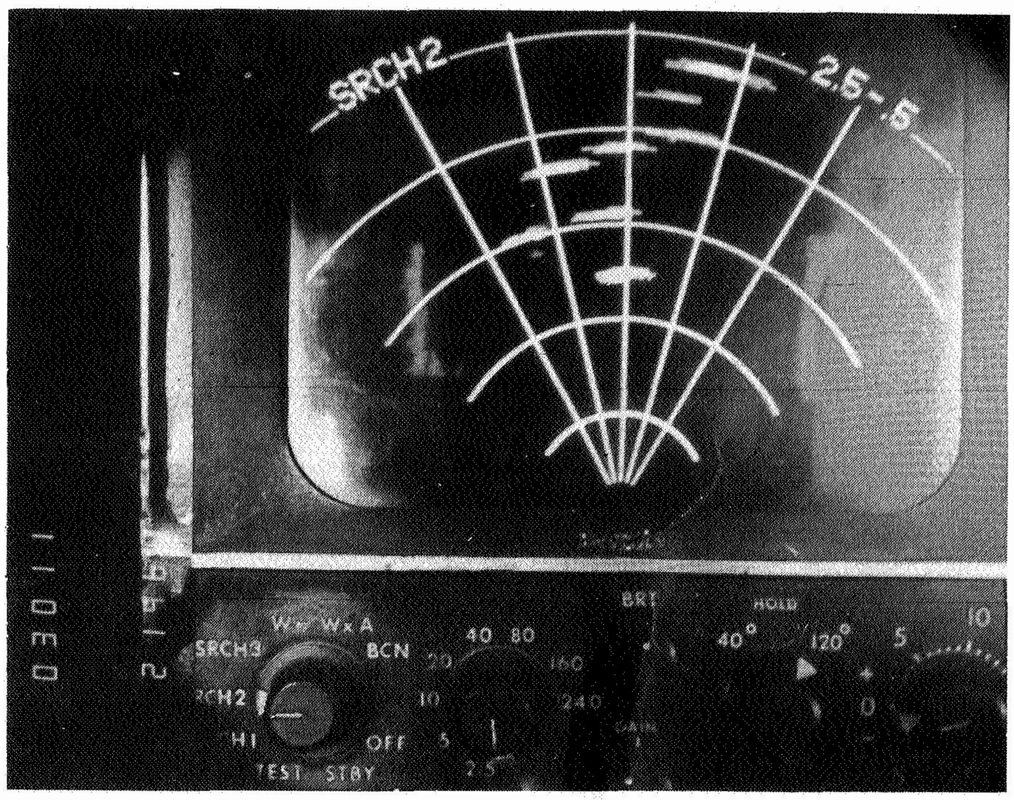


Figure 7.- Primary radar return display on final approach (2.5-n. mi.-range scale).

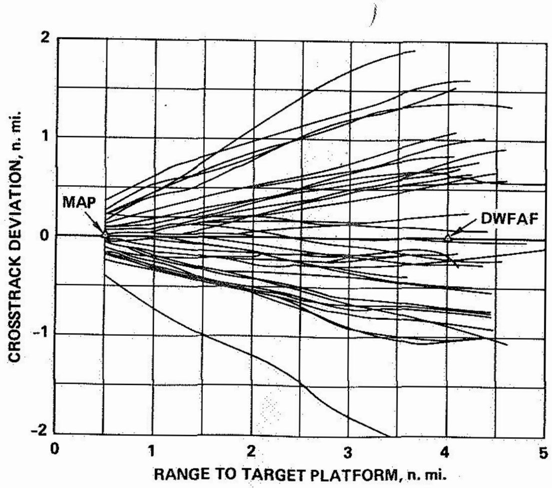


Figure 8.- ARA individual final approach ensemble plot.

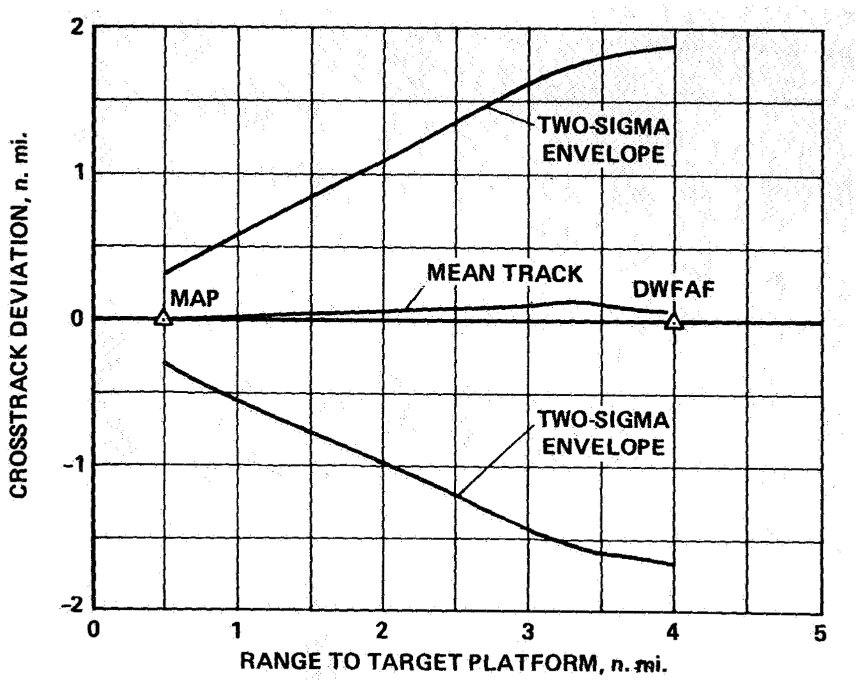


Figure 9.- ARA final approach envelope.

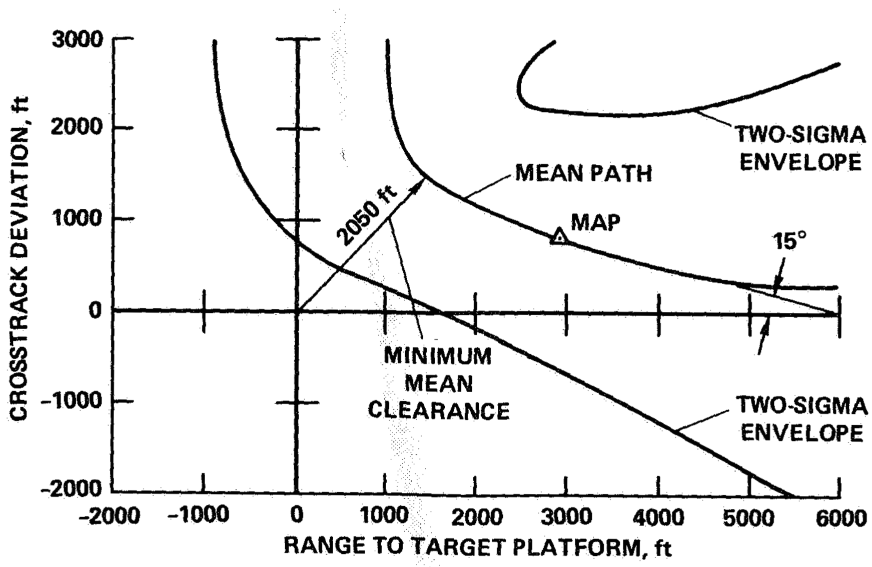


Figure 10.- ARA missed-approach envelope (laterally offset MAP).
1 ft = 0.3048 m.

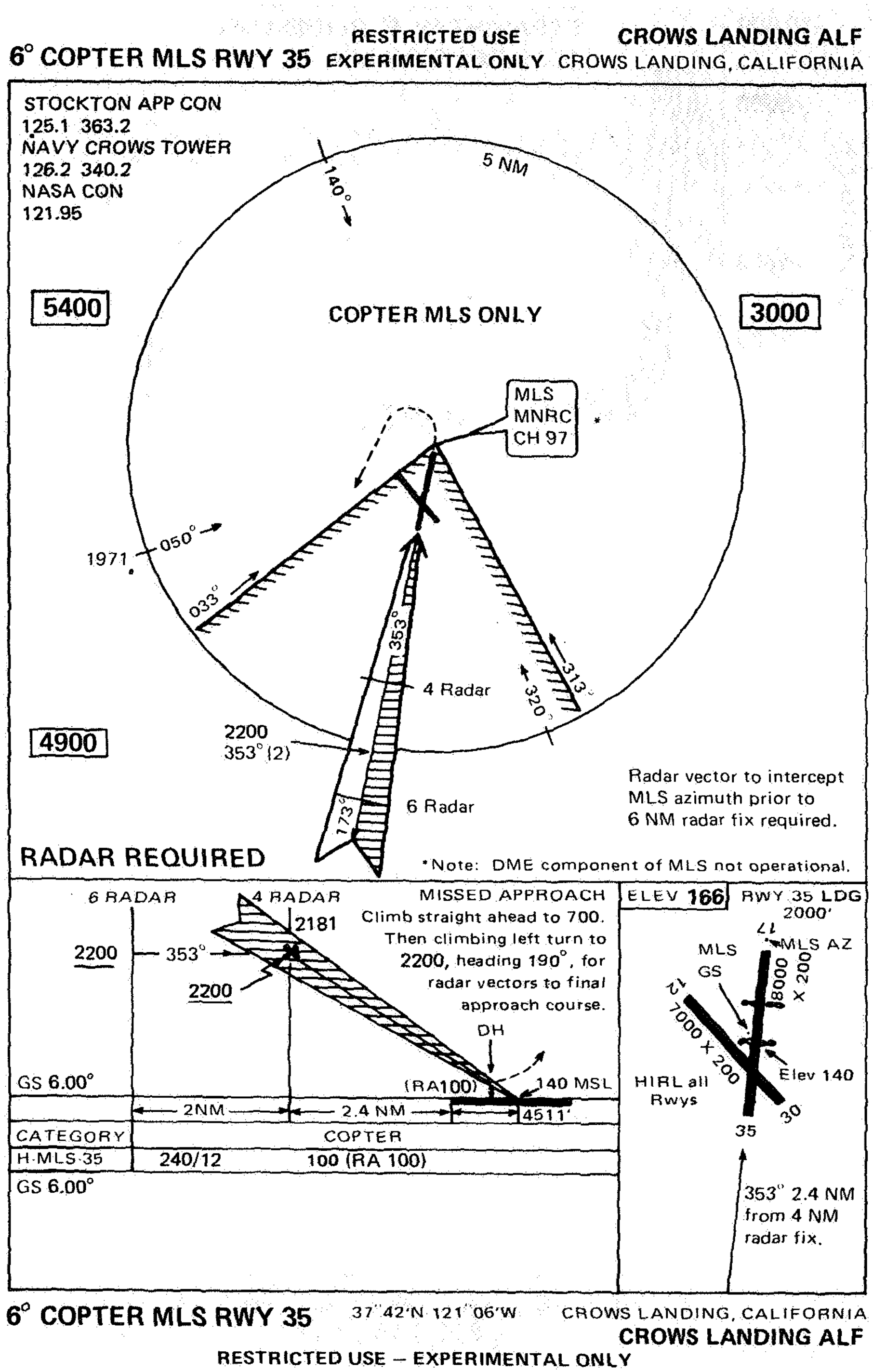
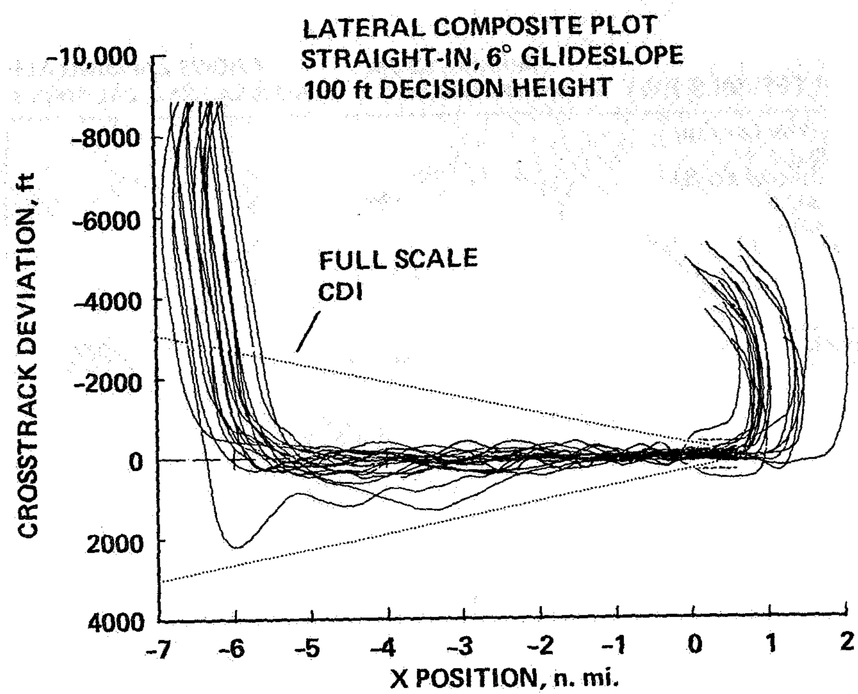
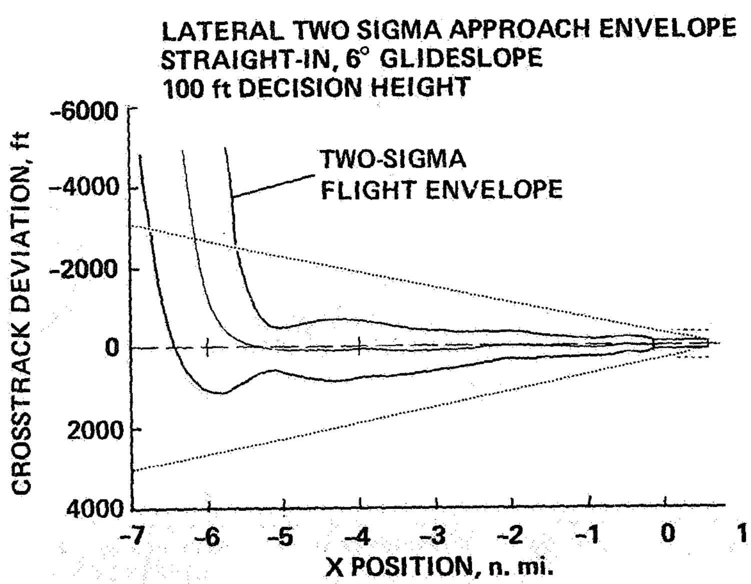


Figure 11.- MLS 6° glide-slope approach plate. 1 ft = 0.3048 m.



(a) Lateral composite.



(b) Lateral 2-sigma approach envelope.

Figure 12.- MLS composite individual approach and 2-sigma envelope plots of lateral tracking: centerline, 6^{o} glide slope. 1 ft = 0.3048 m.

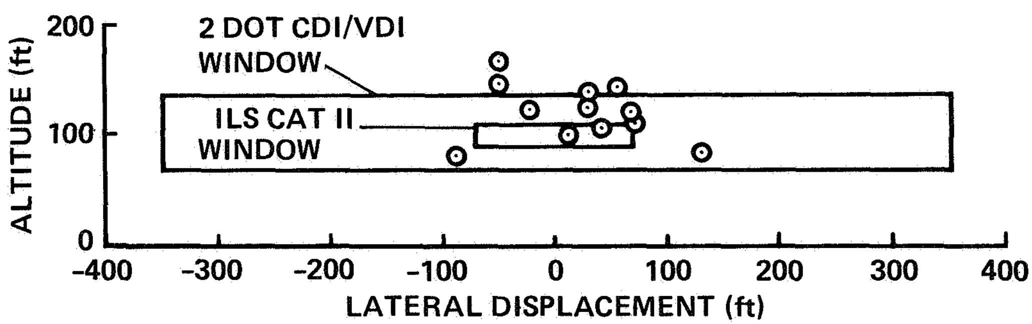
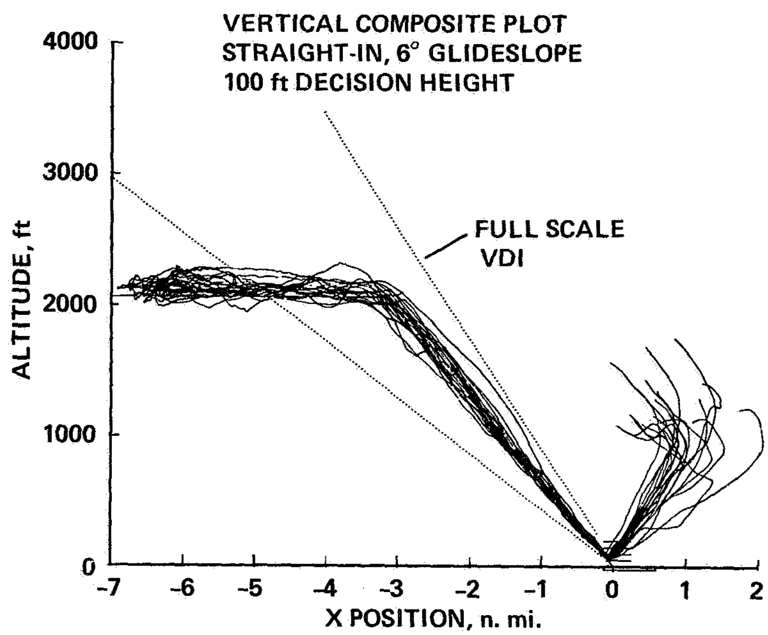
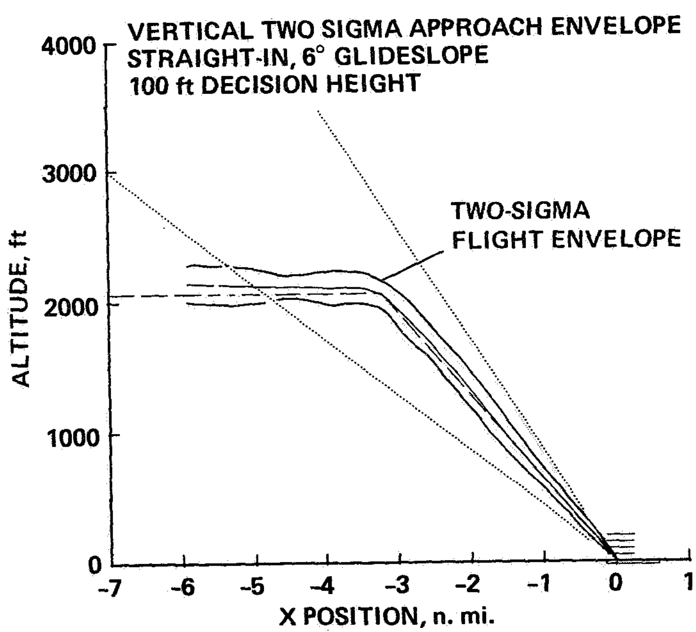


Figure 13.- MLS flightpath dispersions at 100-ft decision height window for 6° glide-slope approaches. 1 ft = 0.3048 m.



(a) Vertical composite.



(b) Vertical 2-sigma approach envelope.

Figure 14.- MLS composite individual approach and 2-sigma envelope plots of vertical and lateral tracking: centerline, 6° glide slope. 1 ft = 0.3048 m.