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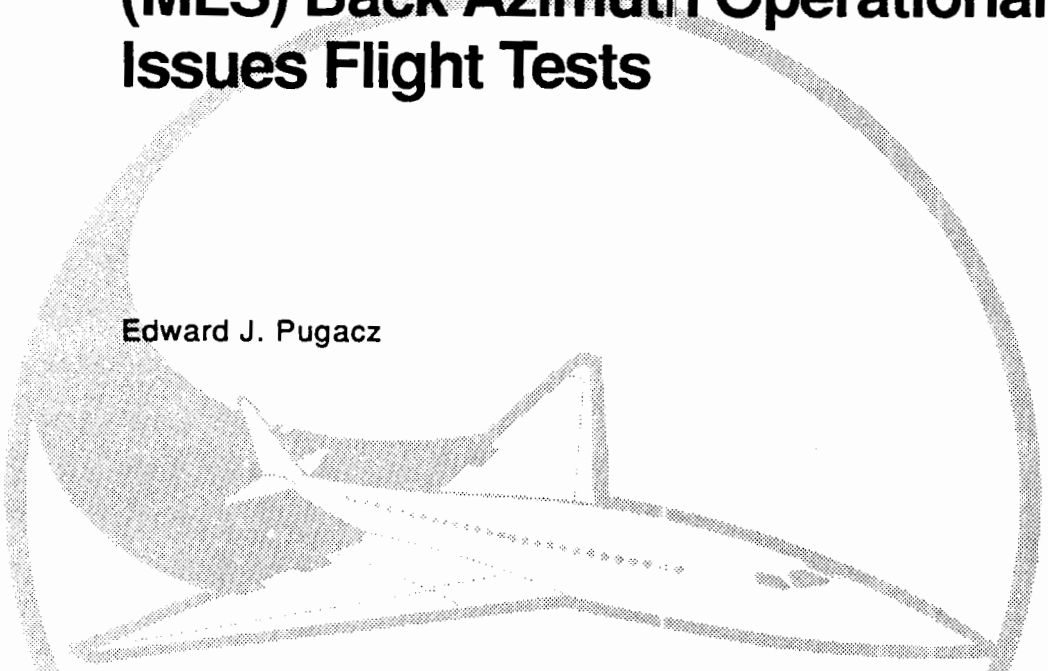
Microwave Landing System (MLS) Back Azimuth Operational Issues Flight Tests

Edward J. Pugacz



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16. Abstract

This test plan is presented to describe a series of flight tests using Microwave Landing System (MLS) back azimuth guidance for missed approach and departure procedures. Issues to be addressed during these flight tests are: (1) The proper point in a missed approach to switch from approach azimuth to back azimuth guidance; (2) the largest MLS back azimuth offset angle usable for departures and missed approaches; and (3) the correct back azimuth full scale sensitivity. Approximately 10 industry pilots will participate as test subjects. The flights will be tracked by a radar tracker throughout each procedure. Individual and composite plots of each approach will be produced, and answers to in-flight and post-flight questionnaires will be compiled. The processed data will be made available to the international aviation community to aid in the formulation of back azimuth usage guidelines.

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EXECUTIVE SUMMARY

Microwave Landing System (MLS) back azimuth guidance has much potential for providing positive course guidance during missed approach and departure procedures. While many theoretical uses for this capability have been discussed, only recently have the operational issues been addressed by flight testing in simulators and actual aircraft. This test plan presents the outline of flight tests designed to verify the results of MLS back azimuth simulator tests conducted jointly by the Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA). The issues these flight tests should resolve are:

1. The proper point in a missed approach to switch from approach azimuth to back azimuth guidance.

2. The largest MLS back azimuth offset angle usable for departures and missed approaches.

3. The correct back azimuth full scale sensitivity.

Approximately 10 industry pilots will participate as test subjects. The flights will be tracked by a radar tracker throughout each procedure. Individual and composite plots of each approach will be produced, and answers to in-flight and post-flight questionnaires will be compiled. The data will be made available to the international aviation community to aid in the formulation of back azimuth usage guidelines.

INTRODUCTION

OBJECTIVES.

This test plan describes flight tests and data processing to be performed to determine various issues related to the use of Microwave Landing System (MLS) back azimuth guidance during missed approach and departure procedures. The specific objectives of these flight tests are:

1. Determination of the proper point in a missed approach to switch from approach azimuth to back azimuth guidance.

2. Determination of the largest MLS offset angle usable for departures and missed approaches.

3. Determination of the correct back azimuth full scale sensitivity.

BACKGROUND.

MLS back azimuth guidance has much potential for providing positive course guidance during missed approach and departure procedures. While many theoretical uses for this capability have been discussed, only recently have the operational issues been addressed by flight testing in simulators and actual aircraft. This test plan presents the outline of flight tests designed to verify the results of MLS back azimuth simulator tests conducted jointly by the Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA). The results of the two FAA/NASA back azimuth simulation studies conducted at NASA Ames Research Center were presented in International Civilian Aviation Organization (ICAO) paper AWOP-WG/B-IP121. These studies used a Boeing-727 phase II simulator and addressed three back azimuth issues:

1. Determining the operationally acceptable limits on the use of offset back azimuth radials for missed approach and takeoff guidance, and the airspace used in capturing the specified radial.

2. Determining pilot acceptability of various approach to back azimuth switching techniques.

3. Determining the optimum back azimuth display sensitivity required for straight out and offset radial departures.

For item 1, the simulation studies found that offsets of up to 30° from the inbound course could be easily intercepted and tracked. For item 2, the simulation studies examined six switching logics either analytically or in simulator flight tests: loss of approach azimuth signal, equal deviation of approach and back azimuth signals, predetermined distance measuring equipment (DME) value, loss of elevation signal, and a combination of the DME, equal deviation, and loss of approach azimuth logics. The recommendation based on the simulator flight tests is that an automatic switch is preferred, with the loss of approach azimuth logic recommended as the switching point. In addition, manual switching must be available for departures and pilot control.

For item 3, the study found that a $\pm 6^{\circ}$ full scale back azimuth sensitivity was preferable to one of $\pm 3^{\circ}$.

The results of preliminary flight tests conducted at the FAA Technical Center in a Boeing-727 aircraft agree with the recommendations for items 1 and 3. However, these flight tests indicate that the recommendation for an approach azimuth to back azimuth switching logic using the loss of approach azimuth as the switching point is in error. The preliminary flight tests found the loss of approach azimuth switching logic to be seriously flawed. The reason for this conflict is the MLS model resident in the simulator. The model is not an entirely accurate representation of the true MLS signal in space. The MLS coverage used in the simulator model represents that of the minimum guaranteed coverage prescribed by the MLS ground station specification. This specification calls for a vertical approach azimuth coverage of 27° to 2000 feet, 20° to 20,000 feet, and back azimuth coverage the same as approach azimuth except only to 5,000 feet. While this specification outlines the minimums of commissioned coverage, in reality, the azimuth antennas (both approach and back) radiate a receivable signal almost 90° from perpendicular to the face of the antenna. The result of this disparity is that in the simulator, the approach azimuth signal is lost while it is still navigable, and the aircraft is approximately one-half to two-thirds the way down the runway. During actual flight tests, however, the loss of approach azimuth by the MLS receiver does not occur until the aircraft has nearly overflown the approach azimuth antenna. By this time the approach azimuth signal has become so sensitive, it is unnavigable, with the horizontal situation indicator (HSI) needle swinging violently left and right. The pilot, at this point, must fly a heading until the switch is made, and then resumes navigating, now on back azimuth guidance.

These flight tests will evaluate three methods of switching from approach to back azimuth guidance during the execution of a missed approach. The tests will also gather flight test data in a "real" aircraft to verify the recommendations of the FAA/NASA simulation studies regarding back azimuth full scale sensitivity and maximum usable MLS offset radials.

RELATED DOCUMENTATION

1. Scott, Barry and Tsuyoshi, Goka, Simulator Evaluation of "Basic" Mode Back Azimuth Issues in Departure and Missed Approach Usage, ICAO AWOP-WG/B-IP121. Describes the results of two studies examining back azimuth issues for missed approaches and departures performed at NASA Ames Research Center in a Boeing-727 simulator.

2. Pugacz, Edward, Initial Flight Tests of Microwave Landing System Back Azimuth Guidance for Missed Approaches and Departures, ICAO AWOP-WG/B IP-146. Presents the results of preliminary flight tests in a Boeing-727 examining the results of the FAA/NASA back azimuth simulation studies.

TESTING AND DATA COLLECTION

PROCEDURE EVALUATION FLIGHTS.

Procedure evaluation flights were flown during August of 1989. During these flights, the results of the FAA/NASA back azimuth simulation studies were used as a baseline for designing the tests to be flown in an actual aircraft. As a result of these flight tests, a matrix of runs, appendix A, was designed to examine three basic back azimuth issues:

1. The maximum acceptable offset MLS back azimuth radial for missed approach and departure guidance.

2. The optimum back azimuth full scale display sensitivity.

3. The optimum switchpoint from approach to back azimuth guidance during missed approach procedures.

DATA COLLECTION FLIGHTS.

Using the matrix specified in appendix A, approximately 10 subject pilots will be flown. All runs will be tracked by a ground based radar system. The subjects for these flight tests will primarily be line pilots from commercial airlines. All will be type rated and current in a Boeing-727 aircraft.

The data collected during these flights will come from four sources:

1. An airborne data collection system.

2. A ground-based position tracking system.

3. Observer logs.

4. Pilot questionnaires.

The test conductor will fill in an observer's log during each flight, appendix B. In addition, he will operate the MLS receiver control head and approach to back azimuth switch, and will simulate each type of "automatic" switch from approach to back azimuth. Each subject pilot will complete a questionnaire after each run, appendix C, and will be given a post-flight questionnaire, appendix D, to complete at the conclusion of the test. Parts of the in-flight questionnaires will be answered using the modified Cooper-Harper rating scale, appendix E. The answers given on the in-flight and post-flight questionnaires will be tabulated and presented as percentages of the whole sample.

FACILITIES AND INSTRUMENTATION

TEST AIRCRAFT.

The test aircraft will be an FAA owned Boeing-727-100QC, registration N-40. This is a large, three engine turbojet aircraft, with a maximum gross weight

of 160,000 pounds, a cruising speed of 350 knots, and approach speeds in the range of 130 to 140 knots. A Bendix MLS-201A MLS receiver will be interfaced with the aircraft's navigation instruments for these tests.

GROUND TRACKING.

Aircraft position in space will be recorded by a radar tracker. The Technical Center's Nike tracking radar is a modified military Nike Hercules missile tracking radar. Operating in X-band, Nike records aircraft position in azimuth, elevation, and slant range. Nike has the capability of accurately tracking an aircraft at ranges up to 200 nautical miles (nmi). The data recording rate will be 10 samples per second. Nike radar accuracies are listed in table 1.

TABLE 1. NIKE RADAR TRACKING ACCURACIES

Azimuth And Elevation:	20 arc seconds
Range:	3 meters

AIRBORNE DATA COLLECTION SYSTEM.

Aircraft parameters will be recorded by an onboard data collection system. This system was designed and built by FAA ACD-330 personnel. It is based on a Motorola 68020 microprocessor, and records pertinent ship's state data on magnetic tape. All data are collected at the full rate output for that parameter. For the MLS ground equipment being used for these tests, full rate angular data is 39 hertz (Hz) for elevation, 13 Hz for approach azimuth, and 6.5 Hz for back azimuth. The parameters being recorded are listed in table 2.

TABLE 2. AIRBORNE DATA COLLECTION PARAMETERS

1. Time: hours, minutes, seconds, milliseconds
2. MLS azimuth and elevation deviation: ±150 millivolts
3. MLS azimuth and elevation angles: full data rate
4. DME: 0.1 nmi
5. MLS and distance measuring equipment (DME) flags
6. MLS auxiliary data

MLS AND DME/P GROUND EQUIPMENT.

The MLS ground equipment for these tests will be a Bendix FAR-171 non-federal system. It consists of separate approach azimuth, elevation, and back azimuth subsystems. Beamwidths for each subsystem are 1.0° for the approach azimuth, 1.5° for the elevation subsystem, and 2.0° for the back azimuth. The system is configured in a typical split-sight arrangement.

The precision distance measuring equipment (DME/P) ground station will be an E-Systems production unit. It is fully capable of supporting DME/P airborne interrogators. For these tests however, the standard distance measuring equipment narrow band (DME/N) interrogators installed in the B-727 will be used.

SCHEDULE

Installation of the data collection system in the aircraft was completed in December 1989. Preliminary data collection flights using FAA pilots were accomplished in December 1989. Industry subject pilots will be flown in January-February 1990. Data processing will be completed December 1990.

APPENDIX A

FLIGHT TEST MATRIX

APPENDIX A
FLIGHT TEST MATRIX

Session One

Run 1 Departure on C/L (309°) Radial, 3° Sens.

Run 2 100′ DH C/L Missed Approach, 3° Sens., Loss of AZ

Run 3 100′ DH C/L Missed Approach, 6° Sens., Loss of AZ

Run 4 100′ DH C/L Missed Approach, 3° Sens., Loss of EL

Run 5 Land, Departure on 324° Radial, 3° Sens., Turn @ 400′

Run 6 100′ DH C/L Missed Approach, 6° Sens., Loss of EL

Run 7 600′ DH C/L Missed Approach, 6° Sens., Loss of EL

Run 8 100′ DH C/L Missed Approach, 3° Sens., 1.0 DME/P

Session Two

Run 9 Departure on 324° Radial, 6° Sens., Turn @ 400′

Run 10 100′ DH C/L Missed Approach, 6° Sens., 1.0 DME/P

Run 11 600′ DH C/L Missed Approach, 6° Sens., 1.0 DME/P

Run 12 100′ DH 339° Missed Approach, 3° Sens., Loss of AZ

Run 13 Land, Departure on 339° Radial, 3° Sens., Turn @ 400′

Run 14 100′ DH 339° Missed Approach, 6° Sens., Loss of AZ

Run 15 600′ DH 339° Missed Approach, 3° Sens., Loss of AZ

Run 16 600′ DH 339° Missed Approach, 6° Sens., Loss of AZ

Session Three

Run 17 Departure on 339° Radial, 6° Sens., Turn @ 400'

Run 18 100' DH 339° Missed Approach, 3° Sens., Loss of EL

Run 19 100' DH 339° Missed Approach, 6° Sens., Loss of EL

Run 20 600' DH 339° Missed Approach, 3° Sens., Loss of EL

Run 21 Land, Departure on 339° Radial, 3° Sens., Turn @ 1000'

Run 22 600' DH 339° Missed Approach, 6° Sens., Loss of EL

Run 23 100' DH 339° Missed Approach, 3° Sens., 1.0 DME/P

Run 24 100' DH 339° Missed Approach, 6° Sens., 1.0 DME/P

Session Four

Run 25 Departure on 339° Radial, 6° Sens., Turn @ 1000'

Run 26 600' DH 339° Missed Approach, 3° Sens., 1.0 DME/P

Run 27 600' DH 339° Missed Approach, 6° Sens., 1.0 DME/P

Run 28 100' DH C/L Missed Approach, Pilot's Choice of Sens. and Switch

Run 29 Land, Departure on 339° Radial, Pilot's Choice of Sens. and Turn Altitude

Run 30 600' DH C/L Missed Approach, Pilot's Choice of Sens. and Switch

Run 31 100' DH 339° Missed Approach, Pilot's Choice of Sens. and Switch

Run 32 600' DH 339° Missed Approach, Pilot's Choice of Sens. and Switch

APPENDIX B

OBSERVER'S LOG SHEET

MLS BACK AZIMUTH DETERMINATIONS OBSERVER LOG

DATE:_____ SUBJECT:_____ SAFETY PILOT:_____

DATA COLLECTION CREW:_____

RUN #	START RUN	EVENT 1 DH/TURN	EVENT 2 SWITCH	EVENT 3 ESTABLISHED	EVENT 3 DME/P	END OF RUN	COMMENTS

APPENDIX C

SUBJECT PILOT IN-FLIGHT QUESTIONNAIRES

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SUBJECT PILOT IN-FLIGHT QUESTIONNAIRES

Pilot: Run#: Offset Angle: Sensitivity:

Missed Approach Questionnaire

Please answer each question using the modified Cooper-Harper rating scale:

1. How do you rate the sensitivity of the azimuth (localizer) needle on the HSI while navigating on back azimuth guidance?

1 2 3 4 5 6 7 8 9 10

2. How do you rate the appropriateness of the switchover point from approach azimuth to back azimuth guidance?

1 2 3 4 5 6 7 8 9 10

3. At what altitude did you consider yourself established on the outbound back azimuth radial?

_____feet

4. How would you rate the acceptability of the back azimuth offset angle? (If flown)

1 2 3 4 5 6 7 8 9 10

5. Do you feel this procedure is acceptable for revenue service with passengers?

YES NO NOT SURE

Pilot: Run#: Offset Angle: Sensitivity:

Departure Questionnaire

Please answer each question using the modified Cooper-Harper rating scale:

1. How do you rate the sensitivity of the azimuth (localizer) needle on the HSI while navigating on back azimuth guidance?

1 2 3 4 5 6 7 8 9 10

2. For an offset angle back azimuth departure, is having the HSI azimuth (localizer) needle at full scale deflection during takeoff and before reaching the turn altitude a distraction?

YES NO DOESN'T MATTER UNSURE

3. Would having a runway centerline indication during climbout until reaching turn altitude be preferable?

YES NO NO DIFFERENCE UNSURE

4. At what altitude did you consider yourself established on the outbound back azimuth radial?

_____feet

4. How would you rate the acceptability of the back azimuth offset angle? (If flown)

1 2 3 4 5 6 7 8 9 10

5. How would you rate the turn altitude for this procedure?

1 2 3 4 5 6 7 8 9 10

6. Do you feel this procedure is acceptable for revenue service with passengers?

YES NO

APPENDIX D

SUBJECT PILOT POST-FLIGHT QUESTIONNAIRE

APPENDIX D
SUBJECT PILOT POST-FLIGHT QUESTIONNAIRE

Pilot: Date:

Post-Flight Questionnaire

1. Do you feel the annunciation of MLS approach and back azimuth availability and use was adequate?

Yes No Unsure

If answer is no or unsure, please elaborate.

2. What would you recommend as the maximum offset angle (0°-30°) for departures? ___ Missed approaches? ___

3. What is the lowest turn altitude you feel is acceptable for an offset departure? _____AGL.

Why?

4. Which automatic approach azimuth to back azimuth switching method do you feel is preferable?

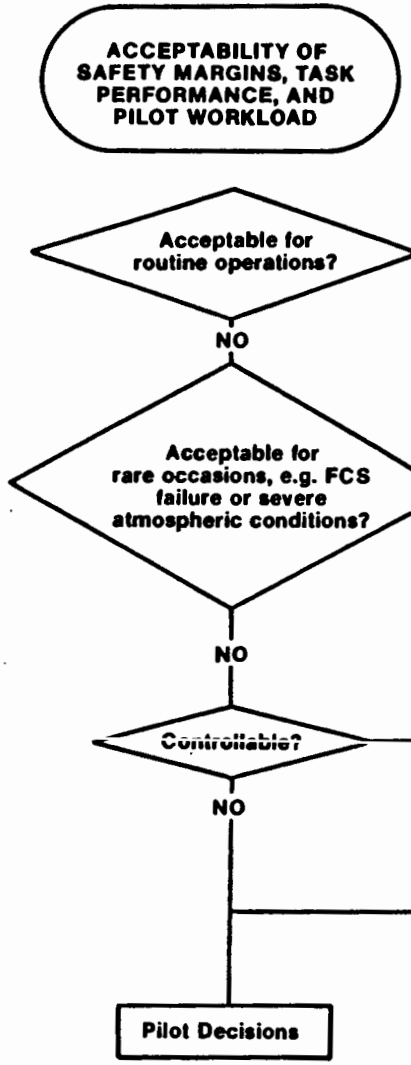
Loss of Approach Azimuth Loss of Elevation 1.0 DME

Why?

5. Are there any situations where you would prefer to switch from approach to back azimuth guidance manually?

APPENDIX E

MODIFIED COOPER-HARPER RATING SCALE



GENERAL CHARACTERISTICS	SAFETY MARGINS	DEMANDS ON THE PILOT	PILOT RATING
Excellent highly Desirable	Clearly adequate	Pilot compensation not a factor for desired performance	1
Good Negligible Deficiencies	Clearly adequate	Pilot compensation not a factor for desired performance	2
Fair - Some mildly Unpleasant Deficiencies	Clearly adequate	Minimal pilot compensation required for desired performance	3
Minor but annoying deficiencies	Clearly adequate	Desired performance requires moderate pilot compensation	4
Moderately objectionable deficiencies	Adequate	Adequate performance requires considerabole pilot compension	5
Very objectionable but tolerant deficiencies	Marginal	Adequate performance requires extensive pilot compension	6
Major deficiencies	Inadequate	Adequate performance not attainable with maximum tolerable pilot compensation - Controllability not in question	7
Major deficiencies	Inadequate	Considerable pilot compensation is required for control	8
Major deficiencies	Inadequate	Intense pilot compensation is required to retain control	9
Major deficiencies	None	Control will be lost during some portion of required operation	10