DOT/FAA/CT-ACD-330-90-04
COPY 1
FAA WJH Technical Center
00093284

ACD-330-90-04

[redacted]
[redacted]

APPROACH TO VALIDATION OF THE MLS MATHEMATICAL MODEL

Linda Pasquale
Jesse D. Jones



FAA Technical Center
Concepts Analysis Division
Airborne Systems Technology Branch

PURPOSE

The purpose of validation of a mathematical model is to compare the results of modeling a specific scenario with measured data obtained in the same environment. The comparison provides evidence about the capabilities and limitations of the math model. As a result of experience gained in the analysis of data from engineering flight tests performed at Midway airport in August of 1988, the microwave landing system (MLS) math modeling group has developed an approach to model validation and a philosophy of interpreting the results of a validation study. This report is a statement of this approach and philosophy.

APPROACH TO VALIDATION

In "Validation of MLS Angle Receiver Simulation Models", by Steven M. Sussman and Richard S. Orr (ATC working paper no. 44WP-5019, May 5, 1975), the authors state that "validation is accomplished by comparing the model output to data from other sources which should yield equivalent or similar results." These authors used, as their other sources, "idealized models of the transmitters and receivers and bench test experiments on hardware receivers." An advantage of this approach is that all aspects of the model can be tested, and the accuracy of model performance can be evaluated with input data representing extreme conditions that are unlikely to occur in the real world.

Another approach is to evaluate the accuracy of a model by simulating specific events and comparing the results with those obtained from comparable real world events. This is the approach used for validation of the MLS mathematical model. That is, the accuracy of the MLS math model is evaluated by comparing model output and measured data plots with respect to the location and magnitude of multipath and shadowing effects generated by a specific airport environment. This approach will only provide information about those aspects of the model that are required to simulate the specific scenario and therefore may not demonstrate all capabilities of the model. For example, the ability of the model to simulate shadowing by a humped runway was not tested in the Midway study because the Midway scenario did not require this feature. The advantage of this approach is that it allows comparison of the operation of the model to the kind of real world situation it was designed to simulate.

However, the results of such a comparison must be analyzed using careful engineering judgment since discrepancies between model output and measured data may be caused by a number of factors and are not necessarily indicative of model inaccuracy. The methods used in a validation study to create the data plots used for comparisons, and the assumptions and constraints used to analyze them, are discussed in the following sections.

BACKGROUND

The MLS Mathematical Model

The MLS Mathematical Model simulates the operation of an MLS for the purpose of predicting the effects of the airport environment on the transmitted signal and the corresponding accuracy and usefulness of the signal arriving at the receiver for providing positional information. Three categories of input data define the scenario to be modeled. One set of data describes the airport environment with emphasis on the obstacles (buildings, aircraft, terrain features) that might have reflective (multipath) or diffractive (shadowing) effects on the transmitted signal. Another set of data defines the position and signal characteristics of the MLS antenna systems, and a third set provides the coordinates of the flightpath. The model uses these data to predict (1) the characteristics of the propagated signal and (2) the receiver output angle errors caused by the scenario configuration.

Originally developed by the Lincoln Laboratory of the Massachusetts Institute of Technology, the math model has been extensively revised and baselined by personnel at the Federal Aviation Administration Technical Center. Additional validation of the model is required to determine whether the model continues to perform satisfactorily in representing the real world and to investigate model sensitivities to input parameters.

Flight Test Data

The FAA Technical Center conducts operational demonstrations of microwave landing systems at the request of the MLS Program Office and FAA Regional Offices. Preparation for a demonstration includes engineering flight tests to verify and characterize system performance and to ensure the operational feasibility of the proposed demonstration flight profiles. MLS data recorded during these flight tests provides "real world" data which can be compared with math model predictions, thereby providing an opportunity to evaluate the performance of the model in simulating the specific environment. In addition, use of a Radio Telemetering Theodolite (RTT) allows independent (non MLS) confirmation of some of the angle data. Obstacles in the airport environment (buildings, aircraft hangars, etc.), both within the airport perimeter and in the area surrounding the airport, which can have scattering or shadowing effects on the MLS signal, offer an opportunity for comparison of the measured effects with the effects of scattering and shadowing buildings as predicted by the model.

DATA COLLECTION AND REDUCTION METHODOLOGY

MLS Equipment and Siting

Azimuth and elevation stations from the MLS test bed system at the FAA Technical Center are transported via truck to the site of the demonstration. The MLS test bed is a modified Bendix FAR-171 MLS (model B-21.5-40) which meets the FAA MLS accuracy tolerances FAA-STD-022b and FAA-STD-022c. The azimuth antenna has a 2° beamwidth with ±40° proportional azimuth guidance, and the elevation antenna has a 1.5° beamwidth with proportional coverage from +0.9° to +15°. The system usually includes Precision Distance Measuring Equipment (DME/P) for ranging although a portable Motorola Mini-Ranger may

be used. Where possible, an RTT provides ground-based tracking angle data for one of the MLS transmitters (azimuth or elevation). Only single axis tracking can be performed.

Airborne Instrumentation and Flight Tests

The FAA aircraft used for the flight tests, a Convair-580 (N-91), includes a data collection system designed, built, installed, and tested at the Technical Center. This system records data from the MLS angle receivers, the DME/Mini-Ranger interrogator(s), and the RTT, when used. Tracked approaches from a range of appoximately 10 nautical miles from threshold at various elevation angles demonstrate MLS capabilities for standard approach flightpaths. When appropriate, flight profiles also include partial orbits through the MLS coverage volume (at various elevation angles and distances) to allow evaluation of effects on the MLS signal from buildings outside of the airport perimeter. The current RTT cannot be used for tracking during partial orbits because of angular range limitations.

Flightpath Creation

Flightpath data can be entered into the MLS math model in one of two ways. The coordinates of the flightpath segment endpoints can be included in the formatted input file, a method appropriate for theoretical flightpaths that are calculated mathematically. In the alternate method, the model reads flightpath coordinates directly from a second input file. This method allows the flightpath to be defined in greater detail and is the appropriate method to use when actual flight data is available. The second method, using the measured flightpath input file, is chosen for validation studies.

Flightpaths are created from the data collected during the engineering flight tests using the RTT angle data in place of the corresponding MLS azimuth or elevation angle data wherever possible. The angle and distance data are translated into X,Y,Z flightpath coordinates by an algorithm known as "Case 12". The Case 12 algorithm is documented in Technical Note DOT/FAA/CT-TN87/2, "Helicopter Microwave Landing System Area Navigation (MLS RNAV)" (Barry R. Billmann, James H. Remer, and Min-Ju Chang, November 1986). The software developed to reduce and analyze airborne data and create a measured flightpath is documented in Concepts Analysis Division Report ACD-330-90-02, "Data Reduction and Graphics Software for Analysis of Airborne MLS Data" (Linda Pasquale). In the absence of a completely independent (non MLS) tracking system, this method produces flightpaths that are the next best approximation to those actually flown by the aircraft. Some of the problems encountered with this method of flightpath creation are discussed in the section on the limits of this methodology.

Methods of Plot Generation

The MLS math model utilizes two stages of simulation. In the first stage, the program BMLST (and the associated plotting program BPLOTT) simulates the signal in space in the specified airport environment and produces plots which identify the multipath and shadowing effects from specific obstacles (buildings, aircraft, ground reflection surfaces). The system model programs BMLSR and

BPLOTR in the second stage simulate the operation of the receiver given the transmitted signal as output from BMLST. Plots from this processing stage show the receiver error ("raw" error) which is defined as the difference between the position of the aircraft as it is in "reality" (as defined by the input flightpath) and the position as determined by simulation of the MLS system. This raw error data is further processed with a path following error (PFE) low-pass filter algorithm and a control motion noise (CMN) high-pass filter algorithm. The PFE algorithm, a low-pass filter which removes components of the error data that will not have a measurable effect on the ability of the aircraft to follow the specified flightpath, creates plots that are particularly useful for comparison with actual airborne data because they emphasize the large-scale shape of the data curve. Large-scale comparisons are most appropriate for reasons discussed in more detail in the following section. Thus, model output for purposes of a validation study is judged primarily on the basis of the PFE error plots with support from multipath plots which identify specific sources of signal disruption.

The real world data, recorded by the airborne data collection system, are processed by data reduction and graphics software that produce plots designed to facilitate comparison with the model PFE error plots previously described. The specific nature of these plots depends on the type of flightpath and the presence or absence of RTT tracking. Approach flightpaths are described by "differential error" plots which show the angle error against the distance from the azimuth antenna at which the angle is measured. The angle error is calculated by subtracting the RTT angle from the MLS receiver angle (azimuth or elevation) and filtering the resulting value with a PFE algorithm. Similarly, the model receiver error is calculated by subtracting the angle determined from the flightpath coordinates from the angle calculated by the MLS system simulation. The resulting error is PFE filtered. Thus, the model error values and the airborne error values are both PFE filtered and plotted against distance from the MLS azimuth antenna for easy comparison and analysis. However, the meanings of the two error values are different, as is discussed in the section on limits.

Orbit flightpaths are treated differently because RTT tracking cannot be used for orbits, and therefore no "error" values can be calculated for airborne data. Consequently, model azimuth and elevation PFE error plots for orbit flightpaths are compared only to plots of the corresponding airborne (MLS receiver output) angle data (PFE filtered). Both values are plotted against the azimuth angle from the MLS azimuth antenna. This allows the plots to be compared with respect to the location and magnitude of multipath and shadowing effects.

Limits of this Methodology

Interpretation of the plots produced by the methods described above is only meaningful within the limitations of this methodology. Some of these limitations are:

1. The error as determined by the math model is the difference between the position of the aircraft as it is in "reality" (ie: its

position along the flightpath defined in the input file) and the position as determined by the MLS system simulation in the scenario. The position of the aircraft in "reality" is precisely defined by the flightpath coordinates and is assumed by the model to be accurate. Flight data errors (for approaches), on the other hand, reflect the difference between an angle measured by an MLS system and the same angle measured by an RTT system. The interpretation of this value as an MLS "error" is based on the assumption that the RTT provides the actual angle of the aircraft relative to the MLS antenna boresite. However, this measurement of aircraft position is not accurate in the same absolute sense as the position of the aircraft defined by model coordinates. Therefore, the meaning of the two error measurements is quite different. This difference is inherent in any attempt to model the real world since a model is always an ideal representation. Comparison of model and airborne data error plots must be made with this difference in mind.

The problem of comparison becomes extreme in the case of orbit flightpaths where the model error values are compared to measured angle data. The meaning of such a comparison must be analyzed with engineering knowledge and judgment since the two values are different in nature.

2. The above picture is further complicated by the fact that the ideal flightpath used by the model to predict MLS errors is created from real world data collected from the very MLS system whose behavior is being simulated. This means that the "ideal" flightpath input into the model already includes some inherent MLS errors.

Ideally, evaluation of an MLS system, and a mathematical simulation thereof, requires independent (non MLS) determination of the position of the aircraft in space. This would provide a space position measurement against which MLS data could be compared and the MLS error calculated. It would also be input into the math model as the "real" position of the aircraft, and the model would then simulate the MLS system in the given environment and predict the resulting MLS error. The two error values would be directly comparable, and the performance of the model would be judged accordingly. Unfortunately, no such independent tracking system has been available for the flight tests used in validation studies to date. Therefore, airborne data differential errors can be calculated for only one MLS system, when the RTT is tracking for that system, and no errors can be calculated when RTT data is not available. The flightpath used by the model as "reality" is determined (in whole or in part) by the very MLS system for which the model is predicting errors.

3. Similar conflicts between the ideal and the real arise in the description of the airport environment entered into the model. It is not feasible to include all possible sources of multipath or shadowing when modeling an airport, nor would the model be capable of accommodating all such sources due to limitations on the number of objects permitted by the model software. Those obstacles which are modeled are defined within the limits of accuracy provided by the airport maps and the digitizing hardware and software used to determine input coordinates. Any obstacle in the environment that

is not modeled will not show any effect on the signal. Real world data, in contrast, will reflect all obstacles in their actual locations. As a result, some differences between airborne data and model output might be caused by the limits of the accuracy with which model input can be defined and may not be a significant factor in evaluating model performance. Real data will show noise which is not going to be present in an idealized simulation.

4. Because of the above considerations, real world and model plots should be compared only in their large scale aspects. Comparison of small details is inappropriate and may lead to erroneous conclusions. For this reason, low-pass filters (such as the PFE filter) are particularly useful in helping to eliminate some of these small details and allow the over-all shape of the data to emerge more clearly.

Interpreting a simulation of the real world in this way is entirely appropriate since it is the confusing noisiness of real world behavior that motivates the creation of artificial simulations. Simulations facilitate the presentation of the salient features of real world behavior. However, as a result, care must be taken when comparing the output of a simulation with real data since they can never be identical.

PHILOSOPHY OF INTERPRETATION

With the above limitations in mind, real world and model plots are compared, and the validity of the model is evaluated, using the following assumptions.

1. If the model and real world data are in agreement, it can be concluded that the output of the model is valid.
2. If the model and real world data are not in agreement, it is assumed that there are two possible reasons for the discrepancy, both of which must be investigated. They are that:
    a. the model is inaccurate in its representation of the real world. (This conclusion is reached only if the following reason has been rejected.)
    b. the model is accurately representing the input scenario, but the input scenario does not accurately represent the real world.
3. Determining that the model is inaccurate (ie: it has received an accurate input scenario yet has produced results that differ from real world data) does not justify the conclusion that the results are invalid. Model output must always be interpreted within the limits of the model's ability to reflect the real world. If these limits explain the inaccuracy of model output, the model can be said to be valid within those limits. Therefore, any inaccuracy must be investigated. The following conclusions are possible:
    a. The model fails to show an effect or event which should be present based on the input scenario. In this case, the model is considered to be invalid with respect to this category of effect or event.
    b. The model shows an effect or event which should not be present based on the input scenario. In this case, the model is considered to be invalid since the results are unpredictable.

FAA WJH Technical Center
00093284

c. The model shows an effect or event which should be present based on the input scenario but the location or magnitude of the event is inaccurate. In this case, the model can be said to be valid for this effect or event within certain limits of accuracy, which should be carefully defined.

SUMMARY

This report presents the approach, philosophy, and methodology that will be used for mathematical model validation studies. As additional data is collected and analyzed, the approach may be modified. Any changes will be documented in subsequent reports.