DEFINITION AND VALIDATION OF THE FLYING QUALITIES AND PERFORMANCE TEST CRITERIA FOR THE MODERN OPERATIONAL FLIGHT TRAINER

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ABSTRACT

Modern flight training devices often require performance validation against actual aircraft flight test data to help produce realistic performance and handling qualities. Prior to performing the trainer validation task, a significant analysis and manipulation effort is required to develop the flight test data into a complete and consistent set of test criteria. By performing this comprehensive data analysis early in the program development, flight modeling validation problems can be identified, minimizing the risk of cost and schedule overruns. This paper addresses the data analysis and development process performed on a modern helicopter flight trainer (AH-1W) using off-line software analysis tools, simulation modeling feedback, and extensive customer interaction. Off-line software tools are used to rapidly and efficiently perform such tasks as identifying and resolving discrepancies in the test data base, performing polynomial curve fits and data extrapolations, normalizing similar data sets, and graphically comparing data acquired from different maneuvers and from different aircraft. The paper addresses how the trainer flight simulation model can be used to adjust or establish trends in the data or to resolve conflicts between similar data sets from different sources. The necessity of extensive customer involvement in this iterative test criteria definition process is stressed. The discussion concludes with specific recommendations on the data acquisition and analysis process, based on lessons learned, including the application of trainer specification tolerances.

INTRODUCTION

To properly validate the flying qualities and performance characteristics of the modern flight trainer, an extensive set of test criteria must be defined. Most test criteria must be extracted from flight test data obtained from the design-basis aircraft. The specific tests that must be accomplished to validate the trainer are either defined in the trainer specification or established early in the trainer development cycle. In most cases, at least in the past, the test criteria have to be extracted from flight tests performed prior to the letting of the trainer contract, and the available flight test data does not always represent a sufficient set to adequately define the flight performance requirements of the trainer. This situation may require flying additional tests with another aircraft in order to fill the voids in the trainer test requirement matrix.

The collection and reduction of flight test data is subject to many sources of error, such as instrumentation tolerances, transducer misalignments, environmental factors, atmospheric irregularities, pilot techniques, etc. Data collected from different tail number aircraft of the same configuration can show differences due to these error sources as well as differences in control rigging and unique fuselage and empennage aerodynamic irregularities. Consequently, the flight test data, whether obtained from one or more aircraft, must be thoroughly analyzed and adjusted before an accurate and complete set of trainer test criteria can be established.

This paper addresses some of the tools and methods which can be used to analyze and define the test criteria. Although the use of the flight simulation model to help define trends in the data is addressed, adjusting the model to match the test criteria is beyond the scope of this paper. However, the importance of establishing a sound and consistent set of test criteria before defining the basic flight model performance is one of the intended messages of the paper.

BACKGROUND

The specific analysis examples presented herein were performed during the test criteria definition on the AH-1W Weapon System Trainer (WST) contract. The AH-1W aircraft is an armed, tactical helicopter manufactured by Bell Helicopter Textron for the U.S. Marine Corps. The AH-1W WST contracted to the CAE-Link Corporation was developed to provide both operational flight and tactical mission training for the aircraft crew members (pilot and gunner). The trainer system specification defined extensive flying qualities and performance test requirements against aircraft flight test data.

At the time the trainer contract was let, an existing set of flight test data obtained with a prototype AH-1W aircraft (Development Test, DT-IIF) was designated as the trainer test criteria. Although the DT-IIF data set was extensive, some voids in the trainer test requirements matrix existed. These voids were eventually filled from flight tests of the production version of the AH-1W during the Board of Inspection and Survey Trials (DT-III).

In summary, the prototype DT-IIF tests and the production DT-III tests produced the data set from which the AH-1W WST's flying qualities and performance test criteria were derived.

Customer Interaction

During the data analysis and definition process, it is advantageous to involve the customer as much as possible.

The customer referred to herein is not only the trainer procuring agency but also the supplier of the aircraft flight test data. In the AH-1W case, the test data supplier was the Rotary Wing Branch of the Naval Air Test Center (NATC). Frequent meetings were held with NATC personnel to resolve problems such as:

- uncertain parameter scaling
- shifts in the data
- missing parameters
- missing or uncertain flight conditions
- identification of data trends
- misunderstood piloting technique
- application of test tolerances
- etc.

By actively involving the customer in the data analysis process, the final test criteria package (Criteria Report) became a representative and mutually agreed-to baseline for quantitative testing of the trainer.

Data Analysis and Definition

As stated in the introduction, the trainer test data is usually acquired from existing qualification flight tests of the design-basis aircraft. The normal process of data definition is to take the flight test data and remount it in a Criteria Report, which becomes the contractual test/data matching criteria for the trainer. There are many difficulties in matching data which is categorized in this way. The inherent inaccuracies in flight test data do not agree with continuous mathematical model predictions and can cause significant simulation modeling adjustments and inconsistencies, frustrating the simulation aerodynamicist. The following is the method used on the AH-1W simulation to produce the trainer test criteria. This iterative process produced a consistent set of test data and resulted in fewer design changes in the flight simulation model development.

AH-1W WST DATA DEFINITION SCOPE

The AH-1W WST test data was initially based on the DT-IIF aircraft trials conducted by NATC at Patuxent River, MD. This data set was presented to the trainer developer (CAE-Link) in the format of a standard flight test report. The report format included plots of the static and dynamic characteristics and summary plots of the aircraft control response.

The DT-IIF data was analyzed relative to the specific trainer test requirements. This analysis concluded that the DT-IIF package had data voids in several areas. Data voids as presented in this paper refer to specific flight tests not performed or parameters not recorded that are necessary to meet the trainer test specification requirements. The original AH-1W WST testing matrix requirements called for approximately 1750 test points. The DT-IIF report which was submitted to meet those data requirements contained 874 test points. After reviewing these results with NATC, the test requirements matrix was reduced to approximately 1500 test points. The remaining 600+ test point voids fell in the Static Longitudinal Stability, Dynamic Longitudinal Stability, Static Lateral Directional Stability, Low Airspeed, and Climb and Descent Performance tests.

Initially the voids were to be filled if possible from Bell Helicopter data, with the remaining voids to be qualitatively tuned in the simulator with a pilot in the loop. After a delay in the trainer schedule, it was determined that DT-III production aircraft trial data would be available to supplement the existing DT-IIF data. The additional data would provide a complete set of data as called out in the trainer criteria test matrix.

The DT-III data came in several data packages, as the tests were flown and the data were processed by the agency. Due to the overlap in trainer and aircraft contracts, additional data flights were made to complete trainer specific data requirements. The format of these data deliveries was plots of the static characteristics, with the numeric data used to generate the plots, and summary plots of the dynamics, including the time histories of each run. The analysis of the DT-III data was much easier due to the addition of numeric data for the statics (digitization done by the receiving party creates additional sources of error).

The data analysis was performed using the software tools listed in Table 1.

Table 1 Software Tools

Tool	Used For
Excel - Macintosh	Application of curve fits to the performance data. Conditioning of the numeric data for use in the Automatic Test Guide System (ATG). Data comparison for static point correlation.
Cricket Graph - Macintosh	Curve fitting numeric data. Data set visual comparison. Data presentation.
Flight Model & ATG	Trend normalization of static trend discrepancies internal to the data sets and between different data sets. Investigation of the effects of differing environmental and aircraft loading conditions on mathematical trend predictions.

The use of these tools is elaborated further in the Problem Resolution section of this paper.

The DT-III and DT-IIF data sets were compared to determine the suitability of the DT-III data. Several inconsistencies between the data sets were noted during the comparison. The customer concurred that several of the differences in the data could not be explained. The following sections discuss some of the problems encountered and their mutual resolution. Sometimes a clear solution to the problem was not evident. In these cases the solution was obtained by exercising good judgement.

PROBLEMS AND SOLUTIONS

Three problem areas are exhibited, each of a different nature. Data shifts, data trend differences, and data set discontinuities will be discussed. Although each type of test requires that several parameters match the flight test data, only examples of the problem parameters are presented for simplicity.

Data Shifts

The first examination of the flight test data was for Level Flight Performance (LFP). LFP tests are a measure of the aircraft's speed/power relationship while maintaining wings level and constant altitude. For helicopter performance measurements, aircraft attitudes and control positions define the static trim requirements.

A trim correlation was done for lateral control positions for all heavy loading configurations of the DT–IIF data (Figure 1). The data shows approximately a 10% (of full scale) difference in control positions for similar configurations.

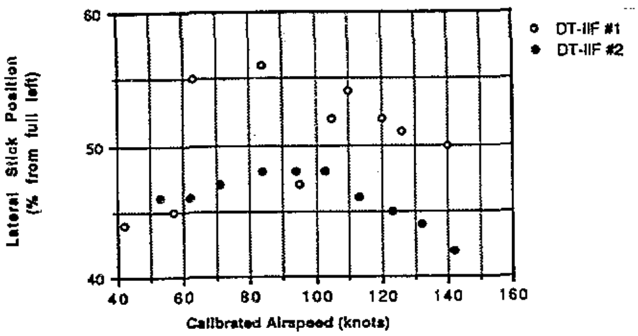

Figure 1 Lateral Stick Shift for Trim Correlation

A comparison with the flight simulation model was made to determine the effects of differences in loadings, atmospheric conditions, etc. It noted no significant change in control positions beyond +/- 1.5% for the configurations contained in the flight test data set. Therefore, configuration differences for the loading and environmental conditions of these tests could not account for this shift in data.

The difference of approximately 10% between the DT–IIF data sets could not be explained as an atmospheric condition or aircraft loading effect. DT–III data was compared to the DT–IIF data to determine which control position magnitudes were correct (the trends in all cases were consistent). The DT–III data showed magnitudes which "split the difference" between the conflicting DT–IIF data. With this in mind, the envelope of interest was increased to include low A/S tests. The data for level flight performance begins at 40 knots forward airspeed, with the Low Airspeed test defining the airspeed trim conditions from –30 to 30 knots forward. The continuity between these two tests is necessary to maintain mathematical model continuity. Comparing trends and magnitudes between these tests showed an approximate 5% shift in lateral stick positions. The magnitudes of the low A/S tests agreed with the DT–III LFP test data.

This information was presented to NATC and the DT–III was selected as the baseline for adjusting the general magnitude of lateral stick positions for the final data set. (The data trends were still taken from the DT–IIF data).

A second–order polynomial curve fit from Cricket Graph through the DT–IIF data was used to determine the slope characteristics for lateral control positions. A shift of 5% for all lateral control positions in trimmed level flight was applied to the data based on the above analysis. The final trainer test criteria, a hybrid of DT–III magnitudes and DT–IIF slopes, appears in Figure 2.

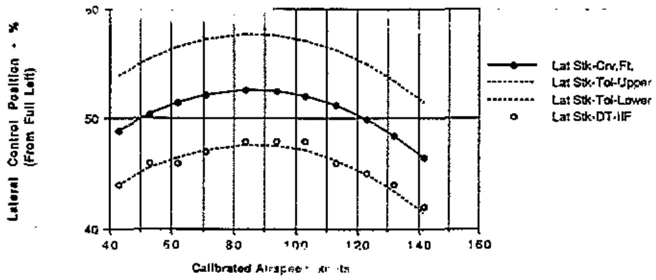

Figure 2 Lateral Stick Final Test Criteria

Data Trend Differences

Helicopter flight characteristics at and near a hover are evaluated in the Slow Flight Characteristics test. The aircraft is trimmed at test airspeeds from 30 knots forward to 30 knots aft in 5-knot increments.

Pitch attitude data from DT–IIF and DT–III slow flight tests are plotted in Figure 3. Examination of the data shows a significant trend difference in the pitch attitude from hover to –30 knots. The NATC test pilots could not make a determination as to the correctness of either the DT–IIF data or the DT–III data in the aircraft due to the difficulty in maintaining this type of trim for extended periods of time. The simulation was run for these cases to determine what the model slope showed for this speed region.

The simulation model showed a similar trend to the DT–IIF data as shown in Figure 3 by the dashed line. After reviewing these results with NATC, the DT–IIF data was selected as the simulation test criteria. The rationale for the selection was the correlation of the DT–IIF data with the simulation model and the minimal changes to the model that would be necessary to match the test criteria. The DT–IIF data were curve–fit with a second–order polynomial using Cricket Graph for smoothing out the data scatter. The final resulting criteria data appears in Figure 4.

Data Set Discontinuities

Static Lateral Directional Stability tests are a measure of an aircraft's sideslip characteristics, effective dihedral, side

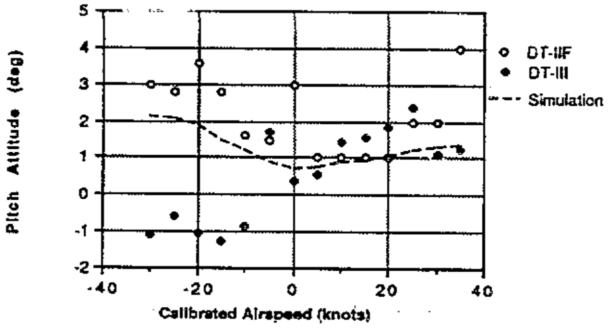

Figure 3 Pitch Attitude Trend Disparity

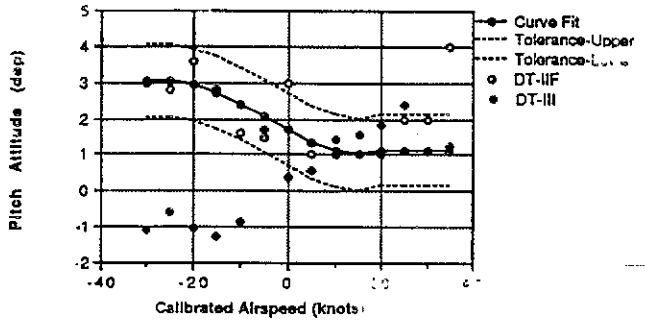

Figure 4 Pitch Attitude Final Test Criteria Definition

force, tail rotor control power, etc. The tests are flown with constant airspeed and altitude for a range of sideslips. The initial aircraft trim data (from the LFP tests) shows a trim (roll attitude of 0 degrees) of 2 degrees of sideslip at 125 kts (Figure 5). The trim data provided for lateral directional stability shows a trim solution of −1 degree sideslip for 125 kts at zero roll attitude (Figure 6). This created a 3-degree relative shift or discontinuity which the model could not compensate for. This discrepancy was determined to be an error in the lateral directional stability data, and the roll attitude was shifted to match the LFP trim beta conditions (Figure 7).

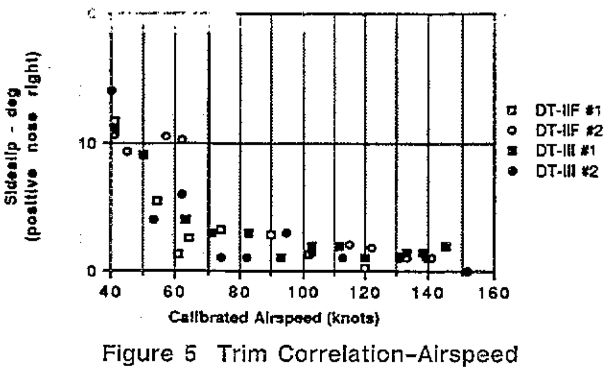

Figure 5 Trim Correlation–Airspeed vs. Sideslip

APPLICATION OF TOLERANCES

As shown in the examples, definition of the test criteria for each parameter concludes after a curve fit is applied to the adjusted data. The testing performance requirements are then established by applying the test tolerances stated in the trainer specification. This is usually depicted by a dashed line

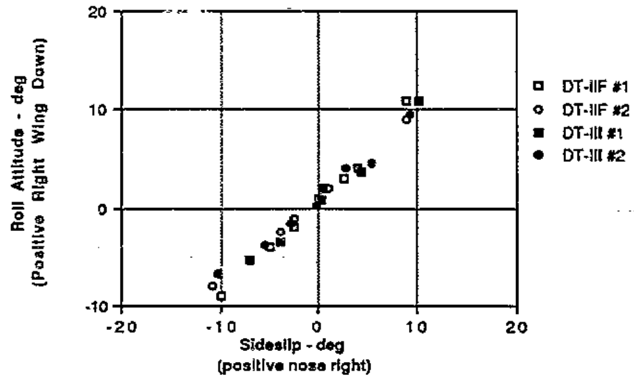

Figure 6 Roll Attitude vs. Sideslip, 125 Knots

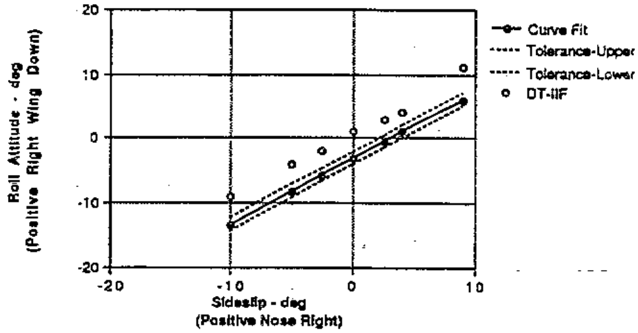

Figure 7 Roll Attitude vs. Sideslip Final Criteria Data

band about the curve fit with a width of some fixed value or some percentage of the parameter value. For most parameters which have well behaved data and a reasonable tolerance, the application of the tolerance is straightforward, as depicted in Figure 8. On the other hand, if the data shows a significant amount of scatter, application of a tight tolerance

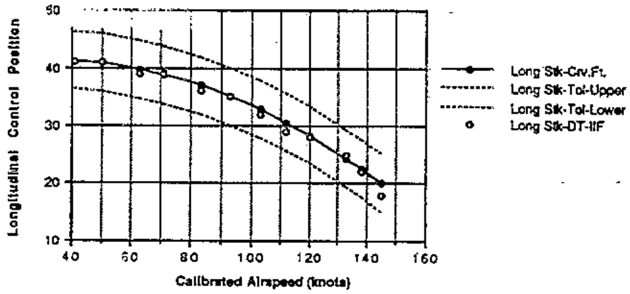

Figure 8 LFP Longitudinal Stick vs. Airspeed – Easy Application of Tolerances

could result in a test performance requirement that is unreasonable to attain. An example of this situation is Figure 9, which shows pitch attitude plotted versus rotor torque. As shown, the data scatter far exceeds the application of the specification tolerance band (tolerance band is +/− 1 degree). For test conditions such as this or where significant data shifts have been made, adjustments to the tolerance bands which consider scatter or shifts would be legitimate.

This approach has been used on other trainers without degrading the resulting performance. In the case of the AH-1W, the customer believed that scatter adjustments to the tolerances could not be interpreted from the trainer specification and therefore these adjustments were not applied. However, the performance matching emphasis was placed on matching parameter trends as opposed to strict compliance to constraining tolerance bands. The shortcoming of this approach is that the parameter matching requirement becomes a subjective determination as to when the simulation is "good enough."

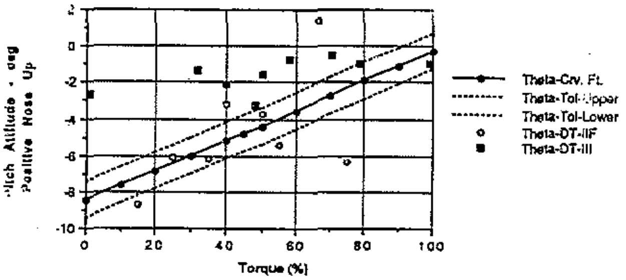

Figure 9 Climb and Descent – Pitch Attitude vs. Torque – Application of Tight Tolerance for Data with Large Amounts of Scatter

There is no clear-cut solution to the consideration of scatter in the application of tolerances. On the LAMPS MK III OFT program, expanding the tolerance band proportionately to the scatter worked well. Another possible approach would be to eliminate quantitative matching of parameters that displayed significant scatter in the flight test data. These parameters could then be used as trend reference data for modeling improvement. Whichever approach is used, the ultimate goal should be to eliminate unreasonable constraints on the modeler and to minimize subjective determination of performance acceptability.

RECOMMENDATIONS

The following recommendations are based on lessons learned from several flight trainer contracts, including the AH-1W WST. The recommendations are divided into two phases or periods. The first phase is the data acquisition phase, or the period when the flight test data is being collected. If the trainer developer is fortunate enough to be under contract during this period, he can work with the flight test team to help define the specific test and data requirements needed for the Operational Flight Trainer or Weapon Station Trainer. The second phase is the data analysis period, when the data is processed into a set of test criteria as previously discussed. The recommendations for the data acquisition phase are addressed because of their obvious ramifications on the level of complexity of the data analysis task.

Data Acquisition Phase

To minimize problems such as missing data or parameters, poor data resolution, etc., the trainer developer should work with test data supplier to define or clarify issues such as:

- Test maneuvers and conditions
- Test instrumentation and recorded parameters
- Test data media and format
- Test data scaling and presentation format

Where voids exist in a data set that will be filled by tests from another aircraft, assure where possible that the test aircraft are compatible in terms of:

- Type and extent of instrumentation
- External configuration
- Empty weight and changes in weight and center of gravity with fuselage
- Rigging of control surface position versus pilot flight control position
- Operation or revision level of SCAS/SAS or autopilot functions

Where time or budget will allow, repeat test maneuvers which may produce results that are subject to piloting technique and the test conditions (example: helicopter slow speed sideward and rearward flight). This should help in defining the true trim control positions and the correct parameter trends.

Data Analysis Phase

Use state-of-the-art graphics and data base tools to rapidly analyze data sets, perform polynomial curve fits, and produce report-quality cross-plots and time histories. This increases the number of iterations possible for development, resulting in a more representative model.

Develop the basic flight simulation model and auto test driver early enough to help establish trends in poorly defined data and to normalize data sets obtained from different flight conditions or different aircraft.

Work closely with the customer to mutually:

- resolve problems with the data
- define the specific test criteria
- prudently apply the test tolerances considering scatter and shifts in the data

CONCLUSIONS

Producing high-fidelity flying qualities and performance characteristics in a modern flight trainer, especially a helicopter trainer, is a monumental task. To minimize the amount of adjusting and readjusting of the flight model to match the design-basis aircraft, a thorough analysis of the test criteria data must first be accomplished. The flight model and many PC-based tools can be used to efficiently expedite this important task. A close working relationship between the trainer developer and the customer is essential to the development of a consistent set of test criteria which fulfills the trainer test requirements matrix and ensures that the fidelity of the flight simulation will meet the intent of the simulation specification.

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