USE OF FLIGHT TEST RESULTS TO IMPROVE THE FLIGHT SIMULATION FIDELITY OF THE LAMPS MK III HELICOPTER OPERATIONAL FLIGHT TRAINER

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ABSTRACT

This paper discusses the procedure used to improve the flight simulation fidelity of the LAMPS MK III Operational Flight Trainer. Early involvement of customer and airframe manufacturer personnel and their continued support throughout the simulator development program had a significant influence on the flight fidelity of the delivered training device. Automated performance evaluation and sensitivity analysis tools were developed to identify and isolate simulator flight performance problems. These tools and the techniques used to modify simulator flight performance characteristics to agree more closely with aircraft flight test results are described in this paper, along with examples of typical performance improvements.

INTRODUCTION

The Trainer

The LAMPS MK III Operational Flight Trainer (OFT) was developed by the Link Flight Simulation Division of The Singer Company under contract to IBM/Federal Systems Division for the U.S. Navy. The trainer is equipped with a six-degree-of-freedom motion system and six McDonnell Douglas Vital IV visual display systems, including a display for the pilot's chin window (see Figure 1). The simulator's Electronic Flight Control System (EFCS) consists of actual aircraft hardware which is slightly modified to be compatible with simulator run/

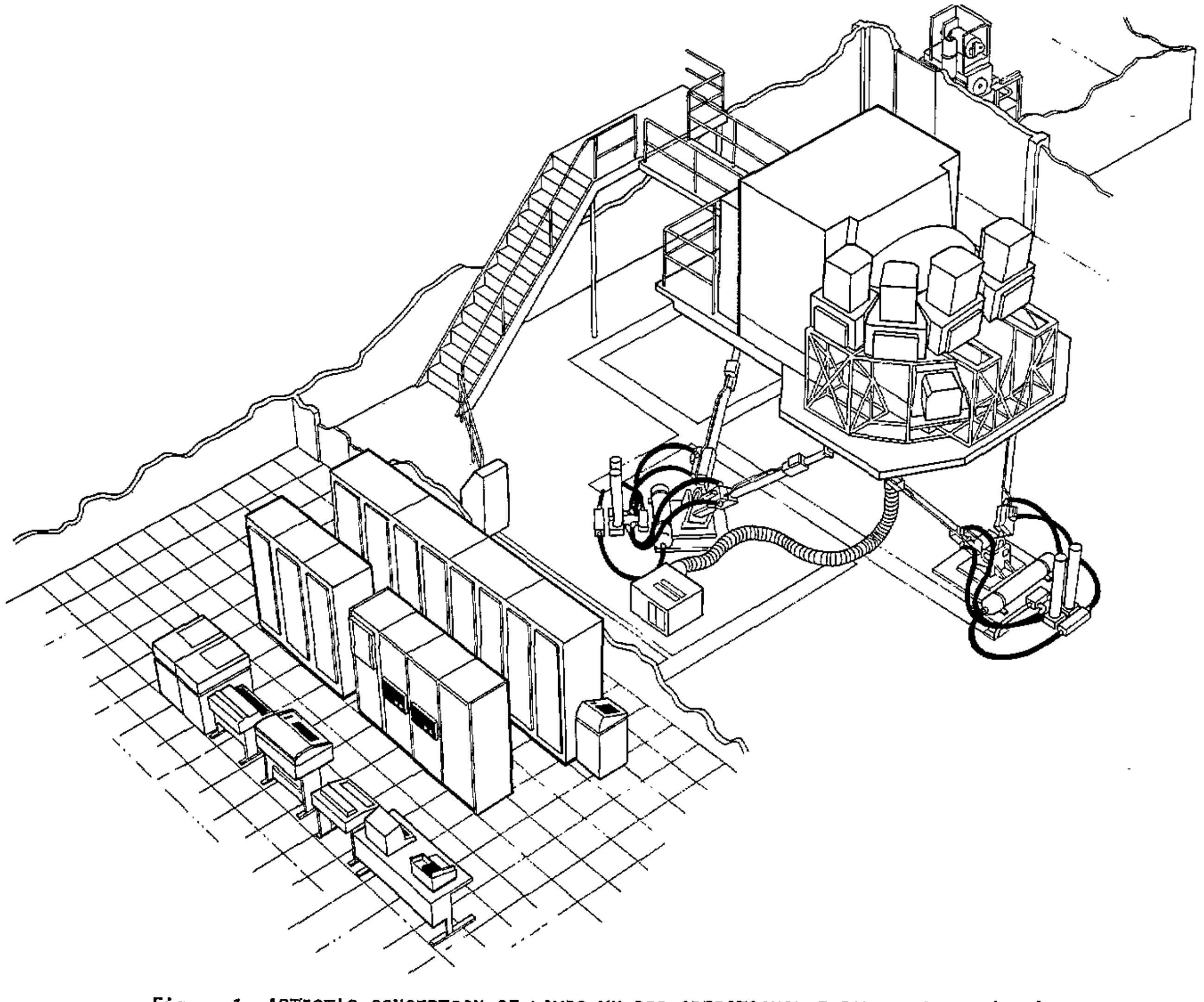

Figure 1 ARTIST'S CONCEPTION OF LAMPS MK III OPERATIONAL FLIGHT TRAINER (OFT)

freeze logic. The EFCS is "stimulated" by inputs from the simulated aircraft sensors. The primary training mission of the simulator is to train pilots in flight operations in a shipboard environment. Specific tasks include takeoff and landing in high sea state conditions on an aircraft carrier, a destroyer, and a frigate. Trainer capabilities include tethered recovery at sea using the RAST (Recovery, Assist, Secure and Traverse) system. Land-based training capabilities are also provided.

The Problem

Flight test results have been used successfully in recent years to improve the flight performance of fixed-wing aircraft simulators. The procedure includes comparison of simulator flight performance characteristics to flight test results. Where performance discrepancies exist, flight test data are used to develop refinements to the aerodynamics math model of the simulator. Progress toward applying this type of technology to helicopter simulators has been slowed by the complex interactive aerodynamics associated with rotary-wing aircraft. The lack of suitable performance evaluation tools for helicopter simulators has also slowed progress.

LAMPS MK III OFT Experience

Recent experience in the development of the U.S. Navy's SH-60B LAMPS MK III Helicopter Operational Flight Trainer illustrates the type and magnitude of flight fidelity improvements which can be realized through the use of flight test results.

The critical role of customer and airframe manufacturer support in defining design data integrity and interpreting flight test results was a necessary first step for a successful flight test performance matching effort. Software tools were developed to expedite performance evaluation and analysis. These tools include an automated flight trimmer capable of executing most flight maneuvers and additional supporting logic to perform sensitivity analysis to isolate specific problem origins.

The techniques used to modify simulator flight performance to agree more closely with flight test results included empirically derived rotor wake swirl effects and "split functions" which permit efficient on-line adjustments of large two- and three-dimensional aerodynamic data tables. Significant performance improvements were realized in the areas of level flight performance, climbs, autorotation, and low-speed flying qualities. Finally, inherent limitations of this type of performance adjustment activity were identified, along with areas which offer promise for further helicopter simulator fidelity improvements.

PERFORMANCE EVALUATION

Prerequisites

There are two important prerequisites to evaluating the performance of a flight simulator. The first is a firm grasp of the design data origins. The airframe manufacturer's support in identifying the best design data available and defining the extent to which these data had been compared to flight test results was essential to get an accurate picture of the design data integrity. The second prerequisite to performance evaluation is a clear understanding of the flight test results to which the simulator performance will be compared. Consultation with U.S. Navy test pilots and Patuxent River Naval Air Test Center (NATC) flight test engineers was started early in the simulator development program. The early start allowed Navy involvement in selecting the specific flight conditions and maneuvers to be used for simulator test criteria. Navy support in evaluating flight test data included interpretation of flight test data scatter, interpretation of required simulator flight performance tolerances, and the resolution of data discrepancies from one flight test vehicle to another.

Technique

An automated "trimmer" was developed to expedite simulator performance evaluation. The trimmer is capable of flying simple flight test maneuvers in an accurate and repeatable manner. Careful development of the trimmer was required to ensure that specific maneuvers use algorithms which correspond to the pilot technique used during the aircraft flight test program. For example, sideslips could be flown as "constant heading or wings level" and either "fixed collective or constant altitude."

The trimmer physically drives the simulator flight controls through the aircraft trim circuits -- moving the controls to establish an equilibrium flight condition much as a pilot would in the actual aircraft. The trimmer is able to converge very quickly on a steady trim condition by taking advantage of access to the equations of motion. This is done by inhibiting selected degrees of freedom during the trim convergence, so that the time required to establish a steady trim is decreased significantly. Trim solution integrity is demonstrated by subsequent release into free flight in the trimmed condition. The steady trims are referred to as "closed-loop" maneuvers because the trimmer converges on a specified steady flight condition by driving specific error signals to zero. Specific maneuvers in this category include hover performance (including hover ladders), vertical climb performance, low-speed trims (including rearward flight, sideward flight and critical azimuth), level flight performance, maneuvering trims, and constant-heading sideslips.

The trimmer is also capable of flying "open-loop" dynamic maneuvers. For these maneuvers, a digitized control time history input is used to drive one of the pilot's flight controls. This input disturbs the simulated airframe, which is in a trimmed free-flight condition, and aircraft dynamic response is recorded on a strip chart recorder. Specific open-loop maneuvers flyable with the trimmer include collective, cyclic, and pedal steps (in hover and forward flight) for control response evaluations and longitudinal cyclic pulses for dynamic longitudinal stability evaluation.

Maneuvers flown in the aircraft with pilot control force against trim (such as static longitudinal stability and release from constant-heading sideslip) were flown manually.

Preliminary Performance Evaluation

Areas of concern were clearly identified as the simulator performance was compared to the flight test results. It is important to conduct this preliminary performance evaluation as early as possible to provide adequate lead time to resolve development problems. The circle symbols in Figure 2 show the level of performance matching for level flight trims following the first preliminary performance evaluation on the LAMPS MK III OFT.

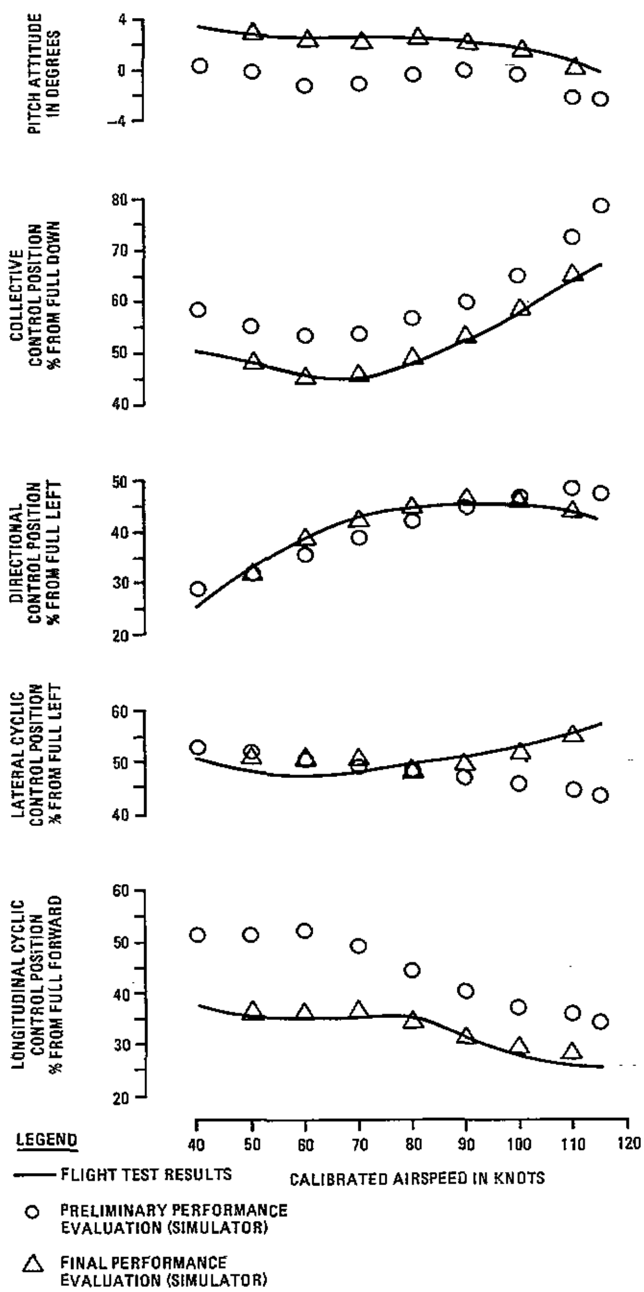

Figure 2 TRIMMED CONTROL POSITIONS IN LEVEL FLIGHT

IDENTIFYING ORIGINS OF PERFORMANCE PROBLEMS

Design and Test Criteria Review

In order to isolate the causes of the performance problems identified during the preliminary performance evaluation, the first step was a critical look at the math model implementation and flight test data integrity in light of the performance discrepancies identified. Problems such as the tendency of the trim lateral cyclic position to move to the left with increasing airspeed when flight test results indicate it should move to the right (Figure 2) brought several questions to mind. Is the simulated flight control system rigging correct? Are the rotor dynamics flapping equations correct? Do other flight test results corroborate a lateral cyclic movement to the right with increasing airspeed? Customer and airframe manufacturer support in answering questions such as these was invaluable in resolving problems related to incorrect implementation of design data or suspect flight test results.

Sensitivity Analysis

Whenever the design and test criteria review did not resolve the performance problem, the aerodynamic math model had to be refined. Isolating which portion of the math model should be modified is a difficult task because helicopter rotor dynamics tightly couple all degrees of freedom. Often problems perceived as due to one degree of freedom are actually a side effect of a problem in a different degree of freedom.

The following simplified example illustrates the "sensitivity analysis" technique used to isolate true problem origins. Figure 3 represents a three-degree-of-freedom schematic diagram of a helicopter in sideward flight (lateral, vertical, and roll degrees of freedom). The preliminary performance evaluation indicates

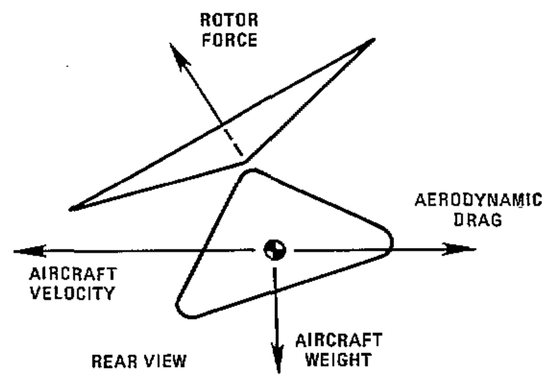

Figure 3 SIMPLIFIED DIAGRAM OF SIDEWARD FLIGHT TO THE LEFT

that (compared to flight test results) the collective control position is too low, the simulator should be rolled more to the left, and the lateral cyclic control is too far to the right. Looking only at the lateral cyclic position error, the basic question was: Is there a problem in the lateral cyclic control authority, or is the lateral cyclic "error" a side effect of the incorrect collective position and/or incorrect roll attitude? To answer this question, artificial vertical and side forces were introduced until the collective position and roll attitude exactly matched flight test results (see Figure 4). In this simplified example, if the error in lateral cyclic position goes away, then we can conclude that the problem was actually due to other degrees of freedom; if the problem does not go away, the rolling moment aerodynamics must be investigated further. Of course, with six degrees of freedom the problem is more complex, so automated logic was developed to quickly converge on flight test trim solutions, permitting straightforward evaluation of selected problems in isolated degrees of freedom.

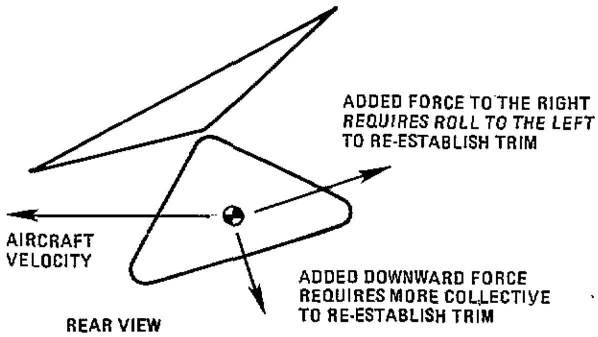

Figure 4 TYPICAL ARTIFICIAL FORCES USED FOR SENSITIVITY ANALYSIS

PROBLEM RESOLUTION

Split Functions

Following the problem isolation activity discussed earlier, specific areas of the aerodynamic math model were candidates for modification. At this point, technical consultation with the airframe manufacturer was invaluable in deciding which portions of the aerodynamic data base were good candidates for adjustment. For example, in the climb and autorotation curves of Figure 5, it was found that with the flight controls and aircraft attitudes at the proper (flight test) values, only main rotor thrust needed adjustment to get good climb and descent performance. This change was inserted into the aerodynamic data base as a "split function." The term split function is used because, in addition to the baseline data table used to describe main rotor thrust characteristics, a second, much smaller data table is developed to incorporate the adjustment to the aerodynamics. These "add on" effects can be controlled independently in real time, thus permitting pilot-in-the-loop evaluations in which proposed changes can be "turned off." Frequent simulator flight evaluations by U.S. Navy test pilots were of great help in maintaining confidence that aerodynamic corrections to improve quantitative flight performance characteristics did not adversely affect the qualitative "feel" of the simulator.

Rotor Wake Swirl Effects

In some areas a straightforward aerodynamic

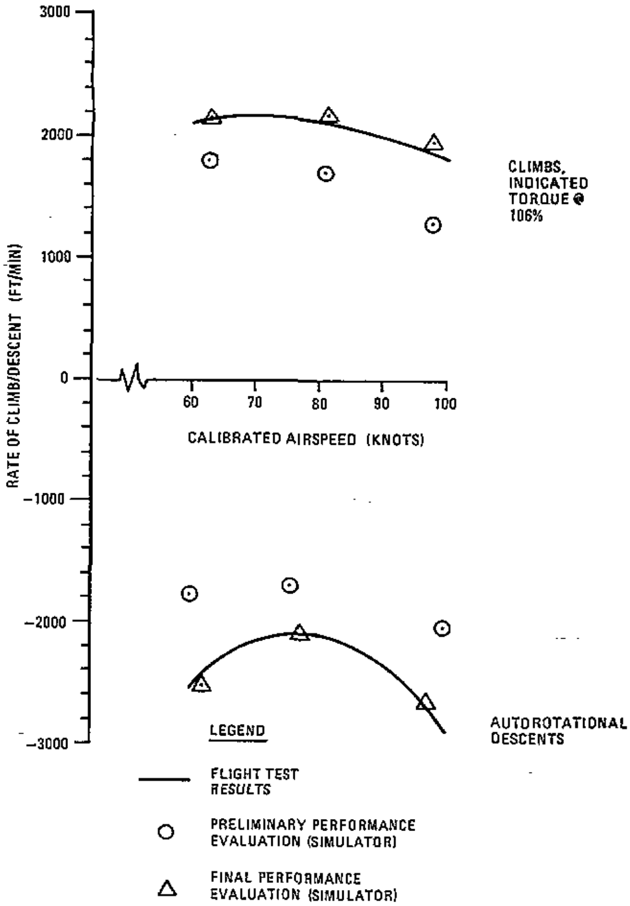

Figure 5 CLIMB AND DESCENT PERFORMANCE

data base correction was not practical. For example, incorrect pedal position may be a consequence of the aerodynamics in the area of the tail rotor, where significant interference with the vertical tail and the main rotor wake exists. There are too many unknowns to uniquely identify problem origins in an area such as this. To resolve this type of problem, empirical corrections were developed and labeled "rotor wake swirl effects." These effects were derived from flight test results using the sensitivity analysis logic described earlier. The rotor wake swirl effects are simply implemented as additional forces and moments exerted on the airframe as a function of airspeed.

For example, at a calibrated airspeed of 60 knots the flight test aircraft longitudinal cyclic control position was well forward of neutral (see Figure 2). The corresponding simulator trim solution resulted in a centered longitudinal cyclic position. An empirically derived "nose up" rotor wake swirl pitching moment at this airspeed resulted in a more forward cyclic stick position for trim, like the flight test aircraft. The triangle symbols in Figure 2 illustrate the improvements in simulator control positions (compared to flight test results) realized through the use of rotor wake swirl effects.

Limitations

Rotor wake swirl effects are a legitimate aerodynamic characteristic of rotary-wing aircraft, due primarily to the impingement of the main rotor wake on the fuselage. The empirical technique described above, however, is powerful and must be used with caution. Frequent re-evaluation of simulator static stability, dynamic stability, and control response characteristics is required to verify that the rotor wake swirl effects do not adversely impact related areas of flight performance.

Piloted qualitative evaluations played a key role in identifying subtle problems related to overall trainer flying qualities. For example, the sensitivity of the EFCS autopilot "black box" to these empirically derived rotor wake swirl effects was greater than anticipated. During an autopilot departure from hover, the actual aircraft will smoothly accelerate to 100 knots from a hover condition with the pilot flying "hands off." During this maneuver on the simulator, pilots observed an unrealistic tendency of the aircraft to roll to the left with increasing airspeed. A more gradual variation of rotor wake swirl rolling moment with airspeed was implemented which yielded simulator automatic departure characteristics like those in the actual aircraft. The resulting impact on trim control positions was minimal.

CONCLUSIONS AND RECOMMENDATIONS

1. Customer and airframe manufacturer involvement in the LAMPS MK III Operational Flight Trainer development resulted in a significantly higher level of flight fidelity than would otherwise have been possible.

2. The use of an automated trimmer expedited simulator performance evaluation and problem resolution, greatly reducing development time.

3. Caution must be exercised when adjusting helicopter simulator flight characteristics. Flight test results must be analyzed to support proposed changes, and frequent piloted qualitative simulator evaluations are necessary to identify any subtle adverse impact of aerodynamics modifications on the simulator flying qualities.

4. Areas of interest for future work include analysis of those areas where aerodynamics corrections were implemented, in order to determine what type of design data might alleviate these problems on future helicopter simulators.

5. Government action to encourage airframe manufacturers to reconcile aerodynamic coefficients with flight test data to satisfy the requirements for a high-fidelity helicopter training simulator would be valuable. That is, plan a flight test program that will satisfy the data needs of the trainer as well as the aircraft. Increased involvement of airframe manufacturers would lead to an improved end product and streamlined simulator development schedules.

ABOUT THE AUTHOR

Michael R. Hazen is a Senior Staff Systems Engineer for The Singer Company/Link Flight Simulation Division, Houston, Texas. His experience includes 10 years in the area of training simulator flight dynamics. Mr. Hazen holds a BS degree in Aerospace Engineering from the University of Missouri-Rolla and an MS degree in engineering from Princeton University.