FLIGHT FIDELITY VALIDATION: MILITARY APPLICATIONS AND COMMERCIAL PRACTICES

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Flight simulators used for the training of flying skills must receive careful scrutiny regarding the fidelity of the flight dynamics simulation. If the goal of the training simulator is to improve pilot flying skills and eliminate bad habits, then relatively high fidelity standards must be imposed on the design and validation of the flight dynamics simulation. Lower standards may be suitable only if pilot flying skill training is not a primary goal, if only to ensure that the pilot's flying workload does not interfere with the primary training activities, such as sensor operation. Either way, training simulator requirements must express flight fidelity performance goals in explicit terms to ensure that the desired training capability will be achieved. The commonly accepted method for expressing flight fidelity performance requirements is to cite specific aircraft flight characteristics in terms of the tests and parameters obtained through established aircraft flight test practices. A trainer specification typically lists tolerance values to express how closely the simulation must match the aircraft flight test data. For USN/USMC fixed and rotary wing flight trainers, a body of knowledge and experience has built up over the last two decades on how to define and achieve high flight fidelity through the combined efforts of knowledgeable aeronautical engineers and flight test pilots and engineers from both contractor and government teams. As a result of this joint process, a set of tolerances for military flight trainers that is comprehensive and stringent (but achievable) has evolved within Naval Air Warfare Center (NAWC) to ensure that military pilot training needs are met.

The military acquisition community assesses parallel commercial practices in the quest of increased cost effectiveness, and trainer flight fidelity is no exception. Aircraft data requirements for airline transport aircraft are well documented and the Federal Aviation Administration (FAA) has established guidelines for a process to officially certify devices for commercial pilot training applications. Recent military trainer acquisition programs have applied commercial guidelines instead of the comprehensive NAWC tolerances. The result is that important military pilot training tasks, such as maneuvering flight and stall recovery, may not be trainable in the simulator. This paper will describe the differences between military flight fidelity requirements and commercial practices to show where they are equivalent and where they are not. In particular, the military pilot training tasks compromised by the use of FAA Advisory Circulars 120-40B and 120-63 will be addressed, with particular emphasis on fixed wing applications. The paper will suggest guidelines for blending the most appropriate parts of the FAA Advisory Circulars with the necessary parts of the NAWC military flight fidelity requirements.

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INTRODUCTION

Background

The terms verification and validation are commonly used in modeling and simulation work. Validation of a simulation model refers to the process of determining how accurately the integrated model represents the real-world item for the intended uses of the model. Verification is an interim step applied to model components to assure that design concepts are met. Validation is more significant than verification to the end user of a simulation because it establishes credibility with respect to real-world operating characteristics.

The validation of a flight simulation model is a process which addresses the question:

Does it fly like the aircraft?

The pilot's perception of the simulated flight characteristics is influenced by the combination of cues provided by the instrument displays, flight control forces, visual imagery, motion, vibration and aural cue systems. The fundamental driver for every one of these cue systems is the flight dynamics model. Therefore, a good validation process demonstrates that the model replicates aircraft characteristics with sufficient accuracy to support the intended use – typically, engineering studies or pilot training. The issue of "sufficient accuracy " poses the next question:

How close is close enough?

This question must be addressed before the model is developed in order to establish a basis for acceptance between the model developers, model users, and in certain applications, simulator regulatory authorities.

Flight simulator validation testing consists of both quantitative and qualitative tests. Quantitative acceptance tests are based on a mutually agreed upon set of engineering tests with tolerance values assigned to key parameters. Qualitative tests rely on expert pilot opinion to assess the suitability of the simulation for the intended tasks. Both test approaches must be applied, since neither is sufficient by itself to accomplish a credible validation. Expert pilot opinion can usually identify a flight fidelity problem on a macroscopic level, but may not necessarily isolate the specific cause. The data obtained in quantitative testing provides the hard evidence needed to demonstrate compliance or to guide the analyses of problem areas. On the other hand, quantitative test data alone does not characterize total system behavior experienced by pilots in performing closed loop, precision tasks such as weapons deployment and shipboard landings. Therefore, flight fidelity validation testing must be conducted with a properly balanced mixture of quantitative and qualitative tests performed by personnel with appropriate expertise.

Flight simulators developed for military pilot training are acquired via a contracting process, which includes a declaration of the training objectives and a specification defining the performance requirements. Specifications for flight fidelity have been generated jointly by Naval Air Warfare Center (NAWC) Training Systems Division and Aircraft Division aeronautical/flight test engineers. The NAWC specifications address both fixed wing and rotary wing flight training simulators and include a comprehensive set of quantitative flight characteristics tests and tolerances. Compliance with these tests and tolerances, in conjunction with test pilot and fleet pilot opinions, are a successful means of validating the simulator for training purposes. The comprehensive flight tests are particularly useful for identifying fidelity deficiencies and then arbitrating fixes.

The military acquisition community applies commercial practices where it appears that increased cost effectiveness or simplified processes could be achieved. Commercial aircraft operators train their pilots on flight simulators that have demonstrated compliance with flight fidelity standards mandated by the Federal Aviation Administration (FAA). Recent military trainer acquisition programs have applied the FAA standards, in the name of commercial practices, instead of the comprehensive NAWC tests and tolerances. The use of FAA standards in a military trainer contract makes it difficult to validate the flight model developed in these programs for important military flight regimes such as maneuvering flight, stall recovery, and others, since the FAA standards do not address these characteristics in sufficient depth.

Purpose

The purpose of this paper is to describe the differences between military flight fidelity requirements and certain commercial practices to show where they are equivalent and where they are not. In particular, the flight model areas and consequent military pilot training tasks compromised by the use of FAA Advisory Circulars 120-40B and 120-63 will be addressed. Guidelines for analyzing flight fidelity requirements for military training simulators will also be discussed.

VALIDATION METHODS

General

The flight fidelity validation of simulators is based on comparing simulator flight characteristics to aircraft test results. References (1) and (2) describe typical flight test efforts for fixed wing and rotary wing validation data. Special expertise is necessary to ensure that high quality data are obtained and applied properly (3). Aircraft flight test results are generated by commonly recognized and accepted test methods that have evolved in the aircraft industry. Flight test evaluations are based on a combination of careful quantitative measures and expert test pilot opinion. The pilot's opinion and the test data must always be reconciled in a proper analysis of flight test results.

Flight Test Categories

Aircraft flight testing falls into two broad categories: performance testing and flying (or handling) qualities testing. Performance testing is concerned with characteristics resulting from the airframe and powerplant combination such as lift, drag, thrust, fuel consumption, climb rates, etc. Flying qualities testing is concerned with those stability and control characteristics that influence the pilot workload during steady and maneuvering flight while executing mission tasks. Flight test techniques for performance and flying qualities testing are described in reference manuals such as those prepared by the USAF and USN Test Pilot Schools (4,5,6,7,8,9). Variations in these documented test techniques are developed when necessary to test unique aircraft features (e.g., vectored thrust, highly augmented flight controls) or to enhance safety of flight.

A comprehensive list of tests for documenting the flight characteristics of fixed wing aircraft is presented in Table 1. The items shown in the table are organized in logical groups to indicate the general purpose of each of the specific test categories listed. The 33 test categories listed in Table 1 are considered the classical set of tests and therefore, the foundation for any test plan for investigating and documenting fixed wing aircraft flight characteristics.

Table 1. Classical Flight Tests for Fixed Wing Aircraft

Test Area	Test Category
Flight Control System Mechanical Characteristics	1. Primary FCS mechanical characteristics 2. PFCS gearing 3. PFCS trim system 4. Secondary FCS rates, limits
Aircraft Mass Characteristics	5. Weight and Balance
Performance	6. Takeoff performance 7. Climb/Descent performance 8. Cruise performance 9. Level Accel/Decel performance 10. Level Turn performance 11. Stall speeds
Flying Qualities	12. Steady state trim 13. Longitudinal trim changes 14. Longitudinal short period dynamics 15. Longitudinal phugoid dynamics 16. Static longitudinal stability 17. Maneuvering longitudinal stability 18. Static lateral-directional stability 19. Dutch Roll dynamics 20. Spiral stability 21. Lateral control effectiveness 22. Step inputs (longitudinal, directional)
High Angle of Attack Characteristics	23. Stall and buffet characteristics 24. Post stall gyrations, departure 25. Spins
Landing, ground handling	26. Landing performance, ground effects 27. Ground handling (taxi, braking)
Engine characteristics	28. Steady state performance 29. Start-up transients (ground and air) 30. Throttle transients
Asymmetric Power (multi-engine aircraft)	31. Engine-out performance 32. Engine-out flying qualities (static & dynamic)
Automatic Flight Control System (AFCS)	33. AFCS characteristics

A similar list of comprehensive tests for rotary wing aircraft flight characteristics is presented in Table 2. The list is organized in a manner similar to the fixed wing table. Some of the test categories are similar to fixed wing tests but there are several that are unique to rotary wing flight. The 27 test categories listed in Table 2 could be considered a classical set of tests that would be the foundation of any test plan for investigating and documenting rotary wing aircraft characteristics.

Table 2. Classical Flight Tests for Rotary Wing Aircraft

Test Area	
Flight Control System Mechanical Characteristics	1 Force vs. deflection (all modes) 2 Cyclic control envelope. 3 Stick release dynamics. 4 Trim system characteristics.
Weight and Balance	5 Gross weight vs. cg position
Performance	6 Hover performance. 7 Level flight performance. 8 Vertical climb performance. 9 Forward flight climb/descent performance. 10 Low airspeed performance (fwd, aft, left, right).
Flying Qualities	11 Trimmed flight control positions. 12 Longitudinal static stability. 13 Critical azimuth. 14 Lateral-directional static stability. 15 Maneuvering stability. 16 Longitudinal dynamic stability (short period). 17 Longitudinal dynamic stability (phugoid). 18 Lateral-directional dynamic stability. 19 Control response (all axes, stabilization equipment ON & OFF). 20 Vortex ring state.
Autorotation	21 Autorotational entry, steady state performance, and flare characteristics.
Ground handling	22 Ground handling (taxi, braking).
Engine characteristics	23 Engine start/shutdown performance. 24 Steady state performance. 25 Rotor Droop Characteristics
Automatic Flight Control System (AFCS)	26 AFCS characteristics.

The flight test data generated with these classical flight test methods is the most reliable criteria for validating simulator flight dynamics models. It should be pointed out again that expert test pilot opinion is also necessary for validation purposes and it must be reconciled against the quantitative flight test data.

NAWC Military Flight Fidelity Validation Methods

The planned use of comprehensive flight test data and test services for USN/USMC flight training simulators commenced in the mid 1970s when Navy trainer acquisition officials requested assistance with data problems on current programs. At that time, trainer manufacturers created aerodynamics models from airframe manufacturers' wind tunnel or estimated coefficient data, but there was very little actual flight test data available to refine and validate the model. The Naval Air Test Center at Patuxent River, MD, provided the expertise to define and generate the needed flight test data plus the follow-on analytical support to interpret simulator fidelity deficiencies (10). Initial work with fixed wing simulators expanded shortly thereafter into helicopter training simulators (11).

The scope of the data collected was based on the tables of classical flight test categories listed previously. The set of test conditions always covered the full operating envelope of the military aircraft involved. Such full envelope coverage was necessary from a flight test engineering perspective because military mission tasks are so extensive and involve overlapping flight regimes. This is in contrast to the commercial aircraft validation test scope discussed later, which tends to focus on a limited set of flight regimes.

As experience was gained on several fixed wing and helicopter simulator programs, reasonable tolerance values for matching the test parameters evolved by a mutual consensus process involving aero modeling experts from Navy and trainer manufacturing organizations. This experience demonstrated, by fleet pilot acceptance, that when these tolerance values were met, the training simulator could support a broad range of military pilot training tasks without imparting negative training in piloting skills. These evolved tolerance values (19) became useful as generic initial values that were tailored when applied to specifications for new trainer acquisitions. This tailoring process was very useful for new trainer acquisition programs because there was no Military Specification that could effectively serve this purpose

The specification tolerance tailoring process first considered the flight regimes associated with the aircraft mission tasks to be trained. The generic set of tests and parameters usually had the normal military flight regimes covered, but sometimes unique characteristics needed consideration, such as high angle of attack flight, VSTOL flying qualities and performance, and control system failure modes. Also, the practical issues of data availability and accuracy had to be considered. The collective knowledge gained from this experience by Navy aero/flight test engineers and test pilots was documented in a set of guidelines for data requirements for Navy flight training simulators (12,13). These references describe the flight test data, test conditions, and simulator fidelity tolerances that are necessary for a comprehensive validation of military fixed wing and rotary wing flight training simulators. The reference material has been utilized to plan and execute aircraft flight test programs for the specific purpose of supplying simulator validation data.

FAA / Commercial Simulator Qualification Methods

The FAA has long acknowledged the value of simulators for recurrent training of air carrier pilots. In 1980, the Advanced Simulation Plan was published to define goals for simulator capabilities that would support total training and certification of air carrier pilots in simulators (14). The simulators used for pilot certification have to demonstrate compliance with FAA-defined qualification requirements which are currently documented in Advisory Circulars 120-40B for fixed wing aircraft simulators, and 120-63 for helicopter simulators (15 and 16, respectively). Another document, Advisory Circular 120-45A (17), contains qualification requirements for certain types of lower fidelity fixed wing simulators, referred to as Flight Training Devices (vice Simulators).

These Advisory Circulars (AC) define a very well organized evaluation process with three major components: (1) objective tests, (2) subjective measures, and (3) a defined test process for initial and recurring simulator qualification. The recurring qualification process is a vital part of the program for maintaining high quality fidelity in these simulators. It is important to keep in mind that these AC's were intended to spot-check simulator performance; they are not as comprehensive as a simulator design specification. This limitation is declared in all three AC's where the section on evaluation policy states that *tolerances [listed in the AC] should not be confused with design tolerances specified for simulator manufacture.* This paper focuses on the objective tests listed in the AC's because these tests have been inappropriately cited in military trainer acquisition specifications as a misguided application of commercial practices.

The objective tests for fixed wing air carrier simulator qualification are outlined in Appendix 2 of AC 120-40B. The types of tests defined in table form in the Appendix include aircraft flying (handling) qualities and performance (FQ&P), motion system, visual system, and simulator systems such as sound, transport delay, and diagnostic testing. The FQ&P tests are the subject of this paper and so the other types of tests will not be mentioned further. The scope of the FQ&P tests is based on typical air carrier operating regimes: ground operations, takeoff, climb segments, cruise, approach, and landing. Tests are required for about two thirds of the complete set of classical flight test categories listed in Table 1. Parameters and associated tolerances are defined for each test along with some comments on test methods or data analysis. The scope of FQ&P testing outlined in AC 120-40B is primarily focused on spot checking the simulation fidelity related to terminal piloting tasks for transport aircraft operations.

The objective tests for helicopter air carrier simulator qualification are outlined in Appendix 2 of AC 120-63. The helicopter test requirements are structured with the same format and content as the fixed wing tests described above except that helicopter unique FQ&P test categories are inserted. The scope of testing is again based on typical air carrier operating regimes. Tests are required for about 80% of the complete list of classical flight test categories listed in Table 2. The helicopter FQ&P test parameters and tolerances are considerably more comprehensive than the fixed wing set.

AC 120-45A contains a short list of objective tests which is about 30% of the complete set of classical flight tests listed in Table 1. The type of flight training device addressed by AC 120-45A is of much lower fidelity than the performance expected in typical military operational flight trainers for training piloting skills in a specific aircraft type, therefore this AC will not be discussed further.

Comparison of NAWC and FAA Methods

The test processes for establishing fixed wing simulator flight fidelity evolved at NAWC and the FAA on parallel but separate paths. Both organizations now have similar approaches based upon objective and subjective testing to characterize flight fidelity. However, the scope of testing is quite different because the FAA and NAWC goals are different. The referenced FAA Advisory Circulars are intended as a means to regulate the quality of simulators used to train commercial air carrier pilots. The NAWC goal is to determine compliance with simulator design performance requirements for military pilot training tasks. The NAWC scope of testing is more comprehensive because: (1) the military tasks involve more flight regimes than commercial operations; and (2) it is necessary to determine if design requirements are met. As a result, more test conditions, test parameters, and tighter tolerances are applied by NAWC than the FAA.

In the mid 1980's the USAF discovered the value of a well organized validation process in acquisition programs for C-5 and C-141 transport aircraft simulators (14). At that time, the Military Airlift Command (MAC) determined that the commercial FAA standards would provide MAC devices with higher flight fidelity than the military acquisition approach used previously which depended upon existing military specifications. As mentioned earlier, there was no military specification that effectively addressed simulator flight fidelity. Application of the FAA commercial standards brought order and success to the USAF trainer acquisition process. This success encouraged the USAF to cite FAA AC 120-40B for flight fidelity requirements in contracts for subsequent trainer acquisition programs for aircraft such as the C-130H2, C-17, AC-130U, and T-6A.

Impact of Differences

The separate flight fidelity validation methodologies used in NAWC and USAF trainer acquisition programs in the 1990s contain some significant differences. The need for some sort of reconciliation effort became apparent when NAWC engineers became involved in joint acquisition efforts with the USAF for T-6A and AC-130U trainers. This reconciliation effort is necessary because when the FAA AC is cited as the performance specification for flight fidelity in a military trainer contract, the simulator manufacturer cannot be held responsible for performance beyond the AC content. As a result, the trainer acceptance testing is limited in scope to spot checks that do not fully validate the simulation of flight characteristics. As it turns out, the shortcomings of a military contract based on FAA AC 120-40B requirements became self-evident to USAF and contractor personnel in the development of a C-130H2 trainer, and the flight fidelity validation acceptance test criteria was augmented to fill some of the gaps in the AC objective test requirements.

Fixed Wing Aircraft The specific differences in fixed wing validation testing between full envelope military test requirements and AC 120-40B test requirements are summarized in Table 3. For each of the required flight test categories, Table 3 shows what cannot be validated when a military trainer contract is based only on the objective tests listed in the AC in terms of missing test categories, test conditions, test parameters, and loose tolerances. For example, tests for longitudinal, lateral, and pedal control forces as

Table 3. AC 120-40B Test Limitations

Test Area	Flight Test Category	AC 120-40B Levels C, D Explicit Tests	Missing Test Cond.	Missing Test Param.	Loose Tolerance
Flight Control System Mechanical Characteristics	1. Primary FCS force vs deflection	Limited	X	-	X (Force)
	2. PFCS gearing	OK	-	X	-
	3. PFCS trim system	Limited	X	X	-
	4. Secondary FCS rates, limits	OK	-	-	-
Weight and Balance	5. Gross weight vs cg position	None	X	X	-
Performance	6. Takeoff performance	OK	-	-	-
	7. Climb/Descent performance	OK	-	-	-
	8. Cruise performance	None	X	X	-
	9. Level Accel/Decel performance	None	X	X	-
	10. Level Turn performance	None	X	X	-
	11. Stall speeds	OK	-	-	-
Flying Qualities	12. Steady state trim	Limited	-	X	-
	13. Longitudinal trim changes	OK	-	-	-
	14. Longitudinal short period dynamics	Limited	X	-	-
	15. Longitudinal phugoid dynamics	OK	-	-	-
	16. Static longitudinal stability	Limited	X	X	X (Force)
	17. Maneuvering longitudinal stability	Limited	X	X	X (Force)
	18. Static lateral-directional stability	Limited	X	X	-
	19. Dutch Roll dynamics	Limited	X	-	-
	20. Spiral stability	OK	-	-	-
	21. Lateral control effectiveness	Limited	X	X	-
	22. Step inputs (pitch, roll, yaw)	OK	-	-	-
High Angle of Attack Characteristics	23. Stall and buffet characteristics	OK	-	-	-
	24. Post stall gyrations, departure	None	X	X	-
	25. Spins	None	X	X	-
Landing, Ground Handling	26. Landing performance, ground effects	OK	-	-	-
	27. Ground handling (taxi, braking)	OK	-	-	-
Engine Characteristics	28. Steady state performance	Limited	X	X	X
	29. Start-up transients	None	X	X	-
	30. Throttle transients	OK	-	-	-
	31. Airstarts	None	X	X	-
Asymmetric Power (multi-engine aircraft)	32. Engine-out performance	OK	-	-	-
	33. Engine-out flying qualities (static & dynamic)	OK	-	-	-
Automatic Flight Control System (AFCS)	34. AFCS characteristics	None	X	X	-

specified in the AC do not address airborne test conditions which are essential for reversible flight control systems as implemented in the T-6A and C-130 aircraft. Also, the AC tolerances do not address cockpit control position and the force tolerances are too loose for the force levels typically encountered in military aircraft. A control force tolerance of 5 lb is not meaningful when the maximum full deflection force is on the order of 10 lb; the same is true with a breakout force tolerance of 2 lb when actual aircraft values are less than 1 lb. The AC does not address the characteristics of the lateral or directional trim systems.

Aircraft performance characteristics are a very significant omission in AC 120-40B in that there are no tests for cruise performance, level accelerations and decelerations, and level turn performance. These characteristics must be validated in military trainers so that aviators are fully aware of aircraft performance limitations in tasks requiring aggressive maneuvering and weapons delivery, especially with heavy store loadings. Flying qualities validation tests are limited in several respects. Trim tests do not include angle of attack as a parameter. Short period and dutch roll test conditions are insufficient. Longitudinal static and maneuvering longitudinal stability test requirements are particularly troublesome because the AC only addresses control forces and applies a very loose tolerance of 5 lb. While control force is of primary interest in these tests, the control position gradient is also very significant to the pilot. The validation of control position is essential because it impacts the computation of control force. The loose control force tolerance can result in very unrepresentative simulations, especially for aircraft with shallow static stability gradients. Test results from the C-130H2 simulator contain a case where the force gradient is reversed from the actual aircraft data and yet the test meets the loose tolerance criteria. Lateral control effectiveness tests are limited with respect to test conditions and test parameters, especially since important cross coupling effects are not addressed nor are full and partial lateral control inputs or various combinations with rudder pedal inputs, including rudder only rolls. The lack of sufficient test conditions and test parameters for lateral control effectiveness is a severe limitation when validating a simulator for military tasks involving aggressive maneuvering (air combat maneuvering) and precision alignment (carrier landing, target tracking, formation flight). Automatic flight control system (AFCS) characteristics are not addressed in a specific manner in AC 120-40B but this can be a significant aspect for military aircraft with highly augmented flight control systems. The effects of normal and emergency AFCS operation have a severe impact on military mission accomplishment and simulator training is considered essential. In addition, some military training simulators, such as the F-14 and S-3, are used to train pilots on post maintenance check flight procedures where the AFCS is a major part of these procedures.

Another significant flight regime not addressed in AC 120-40B is high angle of attack flight beyond initial stall airspeeds. Military mission tasks in fighter, attack, and training aircraft that involve aggressive maneuvering require pilot training in post stall gyrations, departure from controlled flight, and spin recognition and recovery. Successful simulator training capabilities have been implemented in AV-8B and F-14 trainers by applying custom validation requirements based on NAWC generic requirements tailored to the dominant characteristics of these highly dynamic maneuvers.

Engine characteristics validation tests are not fully addressed in AC 120-40B. Most of the parameters necessary to assess steady state characteristics are not included and test conditions are not comprehensive. The USAF C-130H2 simulator validation tests augmented the AC 120-40B requirements considerably in this area to ensure that performance characteristics were correct for military mission applications. Typical test matrices applied by NAWC address engine steady state characteristics efficiently by combining these tests with the cruise performance and steady state trim tests mentioned earlier. Other engine characteristics not addressed in AC 120-40B include start transients on the ground and in the air.

Rotary Wing Aircraft The specific differences in rotary wing validation testing between full envelope military test requirements and AC 120-63 test requirements are summarized in Table 4. For each of the required flight test categories, Table 4 shows what limitations would be encountered with a military trainer contract based only on the objective tests listed in the AC. In general, AC 120-63 is very representative of the scope of testing applied to military helicopter trainers by NAWC. There are a few areas where more comprehensive testing is needed. Tests for control envelope are missing which are necessary to validate cyclic control system gearing and interconnect features. Other missing tests include weight and balance, vortex ring state, and AFCS characteristics. Tolerances for control positions and aircraft attitudes in the AC are generally too large, especially for static longitudinal stability, maneuvering longitudinal stability, and static lateral-directional characteristics, where 10% position tolerances may allow gradient reversal and an incorrect pilot perception of actual aircraft stability. Critical azimuth validation tests for military helicopters are conducted at several windspeeds at 12 directions over 360 degrees but the

AC only addresses one windspeed at 3 azimuth directions. Control response tests cited in the AC are more limited than is typically applied in military testing which incorporate tests with multiple input step sizes, tests for vertical response in forward flight, and assessment of off-axis trends with stabilization both ON and OFF. Validation tests for steady state engine performance in military helicopter simulators typically include airborne test conditions in addition to the ground conditions stated in AC 120-63.

Helicopter flight characteristics are very difficult to simulate because of the highly dynamic and interacting physical phenomena associated with rotary wing aerodynamics. High validation standards are necessary to promote solid physics based modeling and to minimize the use of special ‘tuning’ functions in the aero model. In military helicopter trainers, experience has shown that adherence to tight tolerances in the static and low dynamic flight test categories (i.e. control response, longitudinal dynamics, lateral-directional dynamics, etc.) helps to meet the challenge of correctly simulating highly dynamic piloting tasks such as autorotation recovery and tail rotor failures. Specifically, achieving a closer match to criteria data in terms of damping, time constant, and coupling characteristics during the dynamic portion of flying qualities testing is particularly important in yielding representative results for the high gain, higher dynamic flight regimes and degraded modes.

Difference Resolution

The desire to apply commercial practices to military acquisition programs is motivated by the goal of achieving better cost effectiveness. Careful analysis of the perceived commercial practice is prudent before implementing it in a military acquisition contract. For military training simulators, the flight fidelity validation performance requirements are not identical to the commercial requirements that have been applied to date. The FAA Advisory Circulars discussed here are guidelines for spot checking performance in a regulatory process; they are not design performance specifications. A more appropriate indication of the level of detail required for commercial aircraft data and

Table 4. AC 120-63 Test Limitations

Test Area	Flight Test Category	AC 120-63 Levels C, D Explicit Tests	Missing Test Conditions	Missing Test Param.	Loose Tolerance
Flight Control System Mechanical Characteristics	1. Force vs. deflection (all modes)	OK	-	-	-
	2. Cyclic control envelope.	None	X	X	-
	3. Stick release dynamics.	OK	-	-	-
	4. Trim system characteristics.	OK	-	-	-
Weight and Balance	5. Gross weight vs. cg position	None	X	X	-
Performance	6. Hover performance.	OK	-	-	-
	7. Level flight performance.	OK	-	-	-
	8. Vertical climb.	OK	-	-	-
	9. Forward flight climb/descent.	OK	-	-	-
	10. Low airspeed performance (fwd, aft, left, right).	OK	-	-	-
Flying Qualities	11. Trimmed flight control positions.	OK	-	-	-
	12. Longitudinal static stability.	Limited	-	-	X
	13. Critical azimuth.	Limited	X	-	-
	14. Lateral-directional static stability.	Limited	-	-	X
	15. Maneuvering stability.	Limited	-	-	X
	16. Longitudinal short period dynamics.	OK	-	-	-
	17. Longitudinal phugoid dynamics.	OK	-	-	-
	18. Lateral-directional dynamic stability.	OK	-	-	-
	19. Spiral stability	OK	-	-	-
	20. Control response (all axes, stabilization equipment ON & OFF).	Limited	X	-	-
	21. Vortex ring state.	None	X	X	-
Autorotation	22. Autorotational entry, steady state performance, and flare characteristics.	Limited	-	-	X
Ground handling	23. Ground handling (taxi, braking)	OK	-	-	-
Engine characteristics	24. Engine start/shutdown performance.	OK	-	-	-
	25. Steady state performance.	Limited	X	-	-
	26. Rotor Droop Characteristics	OK	-	-	-
Automatic Flight Control System (AFCS)	27. AFCS characteristics.	None	X	X	-

validation testing is contained in a flight simulator data requirements document published by the International Air Transport Association (IATA)(18). However, the IATA document is not suitable for military applications because it only addresses typical commercial air transport mission operating conditions.

A complete validation of flight fidelity for a military training simulator involves more extensive testing than what is listed in the objective test sections of AC 120-40B and AC 120-63. This is especially true for fixed wing validation since many key flight characteristics are not addressed, as explained above. Training simulator performance requirements must be expressed in a way that ensures that the flight dynamics modeling will support the training tasks. For military training simulators, a simple citing of these AC's in the specification is not sufficient. For programs where this was done, experience has shown that validation test requirements must be augmented, as was done for the C-130H2, AC-130U, and T-6A simulators. A complete validation effort mandates a full set of aircraft flight test data. Therefore, it is not reasonable to claim a cost savings with the FAA scope of testing if the military training objectives are not addressed. A competent flight test organization can obtain the necessary data with reasonable cost.

The differences between AC tests and full military relevant tests are best resolved by detailed analysis of the aircraft mission and the simulator training goals. The flight fidelity validation guidelines developed by NAWC use this approach so that the trainer performance specification contains a tailored list of flight tests and tolerances. Further, the NAWC process includes a criteria report, which assembles all of the available flight test data necessary to conduct the simulator validation effort. The commercial process has a similar document called a proof of match report but it is typically applied to interim partial model verification testing rather than validation testing of a totally integrated complete simulator.

The commercial aircraft simulator data and testing guidelines do contain some potentially useful elements that could be exploited in military trainer programs. One element is the increased emphasis on data and tests for aircraft ground handling. Military flight test programs typically do not devote much effort to this regime, but if it becomes relevant to a military simulator program, these commercial guidelines may be useful. Another element is the recurring qualification process established by the FAA and the equivalent regulatory agencies in other countries. This well defined process ensures that flight simulator performance remains at an acceptable level throughout the life cycle of the device. The USAF has initiated some adaptation of this process but it is not easy to implement with the myriad of mission training requirements that must be addressed.

CONCLUSIONS AND RECOMMENDATIONS

The validation of a simulator flight dynamics model requires testing and flight test data for the full mission envelope intended for the simulator. For military training simulators, this requires a custom analysis of the aircraft and the desired training goals, followed by a comprehensive set of performance goals to be included in the simulator contract requirements. Any effort to ignore this analysis and replace this approach with unmodified documents and practices applied to commercial aircraft simulators will result in incomplete validation and potentially unsatisfactory flight fidelity.
An effective validation process for military training simulators has evolved over the past 25 years in NAWC acquisition practices. The NAWC process has been conducted by a relatively small group of government and contractor specialists and so the process is not as well publicized as the commercial processes documented in the FAA Advisory Circulars. The USAF MAC found the FAA commercial simulator qualification processes to be effective because they were highly relevant to military transport aircraft characteristics and they provided process guidelines where none previously existed. However, the FAA commercial process does not address flight areas significant to military pilot training such as tactical maneuvering and high angle of attack flight. The extension of commercial simulator qualification practices, such as the FAA Advisory Circulars, to the acquisition of all military training simulators is not appropriate unless they are modified to address military modeling requirements.

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