VALIDATION AND EVALUATION

Part I
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INTRODUCTION

Major topics addressed include:
- -Test Requirements & Methods
- -Flight Test Validation Data
- -Flight Test Correlation
- -Pilot Tailoring

Also enclosed:
- -Simulator Test Methods Guide: Appendix C
- -Detailed Flight Test Data Requirements
  - -Fixed Wing: Appendices D & E
  - -Rotorcraft: Appendices F & G

The successful development of a high quality manned simulator requires early planning for the evaluation process. A well disciplined effort is required to ensure the best use of capable technical personnel and to obtain the necessary validation data. Some form of management control must exist to focus and guide the simulator development and evaluation effort. Some essential tools are: a good specification to define performance requirements (intended use); effective test methods; a thorough test plan for timely identification of deficiencies; and the application of effective analysis techniques for efficient correction of deficiencies.

The following discussion describes these tools primarily as they have been applied in the acquisition of U. S. Navy flight training devices where considerable emphasis is placed on the flight test criteria data. Emphasis on the criteria data has a considerable benefit in overcoming shortcomings in both the aerodynamic design data and the model structure. Validation experience with training simulators for existing aircraft indicates that the use of simulators for development of new aircraft must be applied cautiously until the model credibility is established with appropriate flight test data.

A Validation Parable

Imagine that you are a member of a project team that has just completed the assembly of a flight simulator for the XYZ jet trainer aircraft. This simulator is supposed to help new aviators learn how to fly this particular aircraft. Your team members built a nice cockpit that closely resembles all the aircraft drawings, and there is a visual system that displays the forward out the window scene. There is a host computer system that runs an aerodynamic model based on some wind tunnel data found in reports prepared by the airframe manufacturer. Your task is to test this simulator to make sure it flies like the aircraft – in other words, you are to validate this simulator.

You invite some pilots who have flown the XYZ aircraft to come in and test the flight characteristics. Your basic approach is to let these pilots fly the simulator around and you will adjust the simulator in response to their comments. Pilot A, LT Golden Arm, comes in during week 1 of testing but leaves before pilot B arrives. Each pilot flies the simulator around for a few hours.

Pilot A offers the following comments:
- Stick pressure is too loose.
- Climb rate is too high.
- Deceleration is too fast.

- Too much pitch up with flap retraction

Pilot B offers these comments:
- Stick too sensitive, especially in roll.
- Climb rate is too low.
- Power settings not right for level flight
- No stall effects

Each of these pilots leaves with the opinion that this simulator needs to fly better before it can be used to train new pilots. Some of Pilot A's (LT Golden Arm's) comments conflict with Pilot B's. Each pilot griped items not mentioned by the other pilot. How much is 'too loose' or 'too fast'? How are you going to deal with these comments? What are you going to change in the simulator? How will you know if your changes are correct? Did you record any data to support analysis? We will return to this parable later.

Validation Defined

Validation of a simulation model refers to the process of determining how accurately the model represents the *real-world* item for the *intended uses* of the model. This is not the same as verification, which is an interim step for determining that a model properly represents the developer's conceptual description and specifications. These concepts of validation and verification are defined by the Department of Defense Modeling and Simulation Coordination Office in reference R-1. Validation is more significant than verification to the end user of a simulation because it establishes credibility with respect to real-world operating characteristics. This paper refers to the process for validating manned flight simulators. The same concepts are applicable to other types of manned vehicle operator simulators.

The validation of a flight simulation model is a process that 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 another 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.

The need to answer these two questions should make it obvious that some sort of specification must be established at the start of a simulator construction program.

PERFORMANCE REQUIREMENTS

Specifications

For simulators to be used in flight training, a detailed specification defining performance requirements is generated after the mission training requirements have been identified. This is a complex effort that requires contributions from the military user, known as Subject Matter Experts (SME), from training experts who know how to use simulators as training devices, from engineers and software experts familiar with real-time simulator hardware and software, and from people with detailed knowledge and data for the various real world subsystems to be represented in the simulator. Commercial airline training simulator specifications are developed in a similar manner between the airline user and the simulator companies to meet the users' needs.

Government airline regulatory agencies impose objective and subjective performance standards for training qualification purposes. The FAA standards for qualifying fixed-wing training devices and higher fidelity flight simulators are described in references R-2 and R-3, respectively. Similar standards for international use are contained in reference R-4. FAA qualification standards for helicopter flight training simulators are contained in reference R-5. In 2008, the FAA qualification standards were updated and incorporated in a single document referred to as Part 60 (reference R-10). It is important to note that none of the documents referenced here are intended for use as detailed design specifications. The airline training goals are less complex than military goals and so these airline standards are generally far less stringent than military performance requirements.

A typical detailed specification will declare the purpose of the simulator and then outline the training tasks to be accomplished, the simulator system components, simulator performance requirements, critical system design constraints, and acceptance testing requirements. Typical specification elements that address flight characteristics include:

- Baseline aircraft definition

- Flight envelope

- Pilot flight tasks and missions to be trained

- Tolerances for matching flight characteristics

- Simulated environment (atmosphere, other vehicle models)

- Simulator subsystems (host computer, visual, motion, control loading, cue synchronization)

- Test methods and test aids

Simulator Test Requirements

Simulator performance requirements must be written in such a way that it is clear how to test for that performance. Vague and unrealistic performance requirements have historically led to disastrous training devices. The test methods utilized for flight simulators have evolved with the technology applied to computing and image generation systems, and in many cases, there may be more than one effective test method. Flight simulator developers and customers must agree on the test methods to be utilized for acceptance testing and this is best done well before the testing actually starts. Some reference documents have been created to facilitate common understanding of simulator test methods. One such document, "Airplane Flight Simulator Evaluation Handbook", (reference R-6), was developed to support the international qualification standards for commercial aircraft simulators. The contents of this well prepared handbook address all the simulator systems typically evaluated in an FAA style qualification effort (flight, motion, aural, visual). Similar guidance was generated within NAWCTSD to foster consistent development of test procedures for flight dynamics (fixed and rotary wing), cue synchronization, control loading, motion systems, flight environment, computer systems, and visual systems. Current examples of this guidance are presented in Appendix C.

<u>Test Aids</u> - Flight fidelity testing is always an area of concern if none of the simulator development team members understands airplane flight test methods. Simulator flight tests utilize basically the same test techniques as aircraft tests. The test criteria are derived from actual flight test data as much as possible. Simulator flight testing can be facilitated considerably by implementing test aids within the simulator design - primarily in the software.

Tests performed with a test pilot in the cockpit benefit in efficiency and accuracy from aids to test set-up and data recording. An outline of desirable features or tools for manual (pilot-in-the-loop) fidelity testing is presented in the accompanying table.

MANUAL FIDELITY TEST TOOLS

-Purpose:
    -To facilitate test pilot replication of flight test data
 	
-Test Set-up:
    -Ability to control tests and plots from single location (preferably via editable IOS pages)
    -Direct access to relevant test parameters
    -Ability to modify:
        -Trim flight conditions
        -Parameter recording list and recording rate
 	
-Test Execution:
    -Automatic trim at any stable flight condition
        -Drive controls or provide position cues
        -Ready for pilot upon release from freeze
    -Manual control of data recording start/stop
 	
-Data Display & Recording:
    -Real time display of parameters
        -Test conditions
        -Test results
    -Computer based plotting (time histories, cross plots)
    -Hard copy capability
    -Ability to modify plot format and scaling
    -No interruption of testing for plotting and printing
    -Ability to save data to floppy disk for later analysis

Simulator test repeatability can be enhanced by utilizing automated fidelity test drivers. Computer controlled stick, pedal, and throttle inputs are used to exercise the flight and engine dynamics of the simulator and record the results. Inputs such as simple steps, sinusoids, or prerecorded data are useful, but what is really desired is the automatic execution of standard flight test techniques. This autopilot type of capability relieves test pilots of much of the drudgery (after validation by comparison to manually executed results) and allows them to concentrate on any special problem areas. To aid simulator engineers and maintenance/revalidation teams, it is useful to automatically record test results and then provide a pass/fail readout. An outline of desirable features for automatic fidelity testing is presented in the accompanying table. Reference V-23 describes the results of a research effort to develop a universal approach for automated simulator fidelity test systems. This research effort ultimately led to product that can be integrated into most flight training simulators.

AUTOMATIC FIDELITY TEST FEATURES

-Purpose:
- -Automatic execution of flight fidelity tests for flight controls, flight characteristics, engine characteristics, and other related subsystems and models

-Test set-up:
- -Include cockpit I/O and all practical hardware
- -Trim at pre-stored flight conditions

-Control input options:
- -Step, ramp, sinusoid commands
- -Time history of flight test recording
- -Open and closed loop execution of classical flight test maneuvers per techniques in test pilot school manuals

-Data recording:
- -Record all parameters relevant to test conditions and test results
- -Real time display of test results
- -Ability to download data files
- -Hard copy plot of test results with:
  - -Test conditions data
  - -Plain language axis labels
  - -Criteria data plus tolerance bands (plotted)
  - -Indicate pass/fail on test results
  - -Option to print only selected or failed test cases
- -No interruption of testing for plotting and printing

-Test execution features:
- -Menu driven control of tests and plots from single location
- -Ability to select individual test cases
- -Automatic calculation damping ratio, period, time constants

-AFT documentation:
- -Explain design of each automated test category:
  - -Flight test method implemented
  - -Software driver algorithm
  - -Parameters frozen (if any)
  - -Parameters recorded
  - -Criteria data utilized

Current military specifications and FAA qualification requirements for flight training simulators require this automated fidelity test capability. Significant reductions in testing time (up to factors of three) can be achieved with efficient and comprehensive test driver algorithms. The most desirable implementation is one that includes all the relevant hardware and software in the test execution, which demonstrates the total system performance. This approach includes any actual aircraft components used in the simulator such as Automatic Flight Control Systems or Flight Control Computers and most of the cockpit flight controls and instruments. Many simulator developers also utilize off-line test drivers to debug software models. These off-line drivers are useful but limited for validation purposes since the effects of important hardware components such as the control loader are not included. This is unavoidable in some simulators where the control loading system cannot be driven anyway because it consists of aircraft spring cartridges instead of servo actuators. Examples of off-line auto fidelity implementations are described in references V-1 and V-2. More sophisticated hardware in the loop implementations have been incorporated in trainers for the T-6A, TH-57C, P-3A/B, CH-53E and HH-60J aircraft.

Tolerances - Flight trainer specifications usually contain a set of tolerances as a means to quantify the extent of flight fidelity required. To be meaningful, tolerances must be applied to test parameters that can be measured directly such as control positions and forces, and aircraft rates and accelerations. Attempts to specify tolerances at the aerodynamic coefficient level are worthless because of uncertainty over exact values and the interaction of many coefficients for any given response parameter. The tolerance applied to each test parameter depends on how it relates to the pilot task in the mission being trained. Intelligent specification authors try to anticipate this, but some iterations on initially specified tolerances are usually necessary during simulator development. This has to happen as more is learned about the nature of the airplane and the quality of the criteria data. In any event, the initial tolerance requirements must be based on sound knowledge of the aircraft operational and test environment plus the simulator acceptance test environment. Modifications to these initial values by mutual agreement between buyer and seller must be expected. The important thing to keep in mind when attempting to match simulator and airplane data is to provide the pilot with appropriately representative mission tasks in the simulator. For example, a pilot can't be expected to learn navigation and communication procedures if all his attention in the simulator must be devoted to keeping the wings level (unless that situation exists in the real airplane, too).

Design tolerances for flight simulators are normally quite small and very comprehensive. This is intended to ensure that a thorough engineering match of flight characteristics is achieved for the desired simulated flight envelope. For military tactical aircraft, the fidelity requirements are quite stringent because flight tasks are complex and many of the users are low-time pilots who are still developing their flying skills. Thus, the only way to anticipate all potential applications of such a training simulator is to insist on good engineering fidelity throughout the simulated flight envelope.

Some well known flight simulator tolerance sets are found in the FAA Advisory Circulars for simulator qualification: AC 120-40B for fixed wing (reference R-3) and AC 120-63 for helicopters (reference R-5). These AC's both contain statements to the effect that these AC tolerances should not be confused with design tolerances specified for simulator manufacture, and the AC tolerances are only intended for the FAA qualification process. Thus, the FAA tolerances address only a small set of terminal operations tasks such as ground operations, takeoff, climb, approach, and landing. There are no provisions for additional tasks such as aerobatics or military tactical piloting tasks. There is another AC that was published for FAA qualification of low fidelity flight training devices – AC 120-45A (reference R-2) – but the test conditions and parameters are too coarse for validating any simulator that is intended for training refined piloting skills and so this AC will not be mentioned further. The distinction between military applications and commercial training practices with respect to simulator flight fidelity is discussed more fully in reference R-7.

A comparison of the fixed wing tolerances of AC 120-40B to typical military design specification tolerances is presented in Appendix A. This comparison reveals that many significant test categories and test parameters are not addressed by quantitative tests in the AC. Also, the AC tolerance values are too large for effective design guidance, especially the longitudinal control forces. For these reasons, AC 120-40B is not a suitable source for simulator design tolerances. A similar comparison of the helicopter tolerances in AC 120-63 to typical military design specification tolerances reveals more favorable similarities. Both tolerance sets address equivalent flight test categories and most, but not all, of the same parameters and test conditions. However, the design tolerances are more stringent and the AC has no provisions for addressing additional tasks such as tactical operations. AC 120-63 tolerances are not suitable for use as design guidance but they could provide a good starting point for developing appropriate design tolerances. Appendix A includes tables that summarize the flight fidelity test limitations encountered if AC 120-40B and AC 120-63 are applied beyond the qualification use intended by the FAA. Appendices I and J present generic sets of typical parameters and initial tolerance values for military fixed wing and rotary wing training simulators. A more refined version of generic tolerances, grouped by test type, is published on the NAWCTSD (now NAVAIR TSD) web site (reference R-8). The specification format shown in these Appendices is used as a starting point for assigning parameters and their tolerances to aircraft criteria data as it becomes available.

Simulator Test Planning

Early planning for the test and evaluation process is necessary to ensure that all participants understand both the scope of testing and the test methods. If test requirements are not planned for and enforced, then the latter stages of the simulator development time will be consumed dealing with "surprises". As a result, late identification of major deficiencies will occur during final acceptance testing which will lead to schedule slippages and improper "quick-fix" solutions. A good test program is essential for identifying critical deficiencies, assigning priorities for correction and on-going development, and for general assurance that the simulator complies with original design requirements. Some of the key elements of a thorough test program are described briefly below. More complete descriptions are available in the test planning guidance published for NAWCTSD simulator acquisition programs (reference R-9).

TTEMP - Development programs for military training simulators are now being structured to foster early test planning. The approach used at NAWCTSD is integrated into the standard milestones for a simulator acquisition program (see illustration in handout). The idea is to start discussing test issues even before contract award by including a draft test and evaluation master plan with the statement of work. This plan, called a Trainer Test & Evaluation Master Plan (TTEMP) by NAWCTSD, is updated on a regular basis by test and evaluation working group activities during the design review process. By the time trainer systems testing begins, the TTEMP should have documented test entrance/exit criteria, test resources (equipment/personnel), and test schedules. Trainer mission scenarios should also have been developed under the guidance of user representatives.

Preliminary Evaluations - Complex problems need to be uncovered early to provide sufficient time for proper resolution. An effective approach is to conduct preliminary evaluations starting in the early integration stages. For Navy flight trainers, these events are called Navy Preliminary Evaluations (NPE). During these NPEs, subject matter experts such as flight test pilots and engineers have proven invaluable for uncovering and resolving flight fidelity problems due to misunderstandings of the performance requirements and data interpretation. The results from these preliminary evaluations help realign development priorities.

Test Readiness Review - The Test Readiness Review (TRR) is the buyer's decision milestone for determining when contractor development and integration testing is complete and that the trainer is ready for customer acceptance testing. TRR entrance and exit criteria were already established in the TTEMP. The TRR consists of a review of all contractor test results, contractor certification of test readiness, and a brief mission exercise by the customer user crew.

Customer Acceptance Testing - This event, called Quality Conformance Inspection (QCI) in military contract terminology, is the formal inspection period. The QCI is complex because it addresses both functional performance tests and the documentation to be delivered. The successful execution of QCI is highly dependent on how well the testing phase was defined in the contract documents and how thorough the test planning was before hardware-software integration commenced.

DATA REQUIREMENTS

A major portion of the effort to develop a flight simulator is devoted to obtaining data. The general data problem for simulators is discussed at length in reference D-1. This reference summarizes the findings of a U.S. Air Force funded study that concluded that problems with data shortfalls and more importantly, data quality, must be resolved and prevented by a strong program management commitment. It suggests that simulator data acquisition and quality control should be formally integrated into the life cycle of the aircraft weapon system program. The findings of this study and other experience indicate that the basic limitation upon data is not a technical issue, it is a program management issue. General guidance on data requirements for airline simulators has been published by organizations such as the International Air Transport Association [reference D-2]. This is a large document that currently (2001) sells for $375.00. The test and analysis effort required to obtain the necessary data for a Beechjet Level D simulator is described in reference D-3.

The conceptual drawing shown in Figure 1 illustrates the significance of "data". Note in Figure 1 that the flight simulator validation process includes more than the model itself, but also three distinct data sets. In order to manage the development and validation of a flight simulation model, a clear understanding of the term "data" is required.

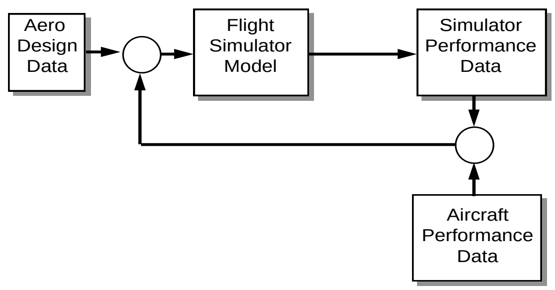


Figure 1 – Flight Simulator Validation Elements

The first data set, aerodynamic design data, is necessary to define parameters within the model. Aerodynamic math models utilize design data usually obtained from wind tunnel tests or analytical means, all of which are subject to a number of assumptions and limitations. These coefficient data have reasonable accuracy for steady state lift and drag estimates but are relatively inaccurate for dynamic characteristics due to limitations in wind tunnel measurement accuracy and assumptions based on small linear perturbations.

The next data set to consider is the aircraft performance data. This data set is absolutely essential as criteria for validating the model. Aircraft performance, or flight characteristics, data are best obtained from actual flight test results obtained with high quality test instrumentation. More will be said about flight test data later in this paper. The main point here is that a set of criteria data obtained from the real-world article being simulated must be established before the validation process can begin.

The third data set to consider is the simulator performance data. For simulated flight characteristics, this data set is best structured to use the same parameters and test conditions as the aircraft criteria data set. This matched structure greatly facilitates the comparison between aircraft and simulator behavior. Test features can be built into simulators to expedite the comparison effort, as discussed a little later.

The lines connecting the boxes in Figure 1 can be thought of as the processes required to develop and to validate a flight simulator. The aero design data is the initial input to this process and then the flight simulator model is exercised to produce performance test results. The simulator results are compared to equivalent aircraft flight test data and any differences are used as feedback to determine adjustments to the aero design data used in the model. This feedback process is followed until the specified tolerances have been met. There are usually some compromises made during this effort and case studies would be an effective way to introduce students to the process.

Flight Test Data

The flight fidelity validation of simulators is based on comparing simulator flight characteristics to aircraft test results. 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.***

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, gross weight, drag, thrust, fuel consumption, 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. 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 typical list of tests for documenting the flight characteristics of fixed wing aircraft is presented in Table 1. The 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. A similar list of tests applies to rotary wing aircraft flight characteristics with some additional test categories unique to rotary wing flight.

Table 1. Classical Flight Tests for Fixed Wing Aircraft

Test Area	**Test Category**
Flight Control System Mechanical Characteristics	1. Primary FCS mech 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 (long dir)
High Angle of Attack Characteristics	23. Stall and buffet characteristics 24. Post stall gyrations, departure 25. Spins
Landing, ground handling	26. Landing perf, 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

Flight test data sets must address two important points in order to be useful as simulator validation criteria. First, the test conditions must be thoroughly documented. A plot header may contain enough information to recreate a particular test, but a simulation modeler usually needs more details, such as trim angle of attack, all trim control and power settings, etc, to analyze any fidelity problems when trying to match these data. Such additional information is sometimes hard to get unless the flight test program is aware of this need and endeavors to capture it. The second point is that typical flight test data exhibits a fair amount of scatter. Good engineering judgment is required to interpret the scatter and decide which data points to accept and which should be ignored. This engineering judgment can only be derived from knowledge of the test techniques used and previous experience in judging what is important for matching simulator performance to the simulator design purpose.

Flight fidelity validation is always a high risk problem if the simulator project team members do not understand airplane flight test methods. A project team lacking flight test expertise is insensitive to practical flight fidelity issues and therefore dooms the project to contention and failure. Therefore, it is important for the team to know enough about flight test methods and data analysis in order to bring good technical discipline to the simulator debug and validation process.

Nature of Flight Test Programs and Engineering Development Simulations

It is desirable to obtain all these data before simulator hardware and software integration begins so that criteria are on hand to develop thorough fidelity test procedures. In many cases, useful aircraft flight test data is usually in short supply because of the nature of flight test programs. In the days before modern flight simulation techniques matured, a typical flight test program for a new airplane was structured around demonstrating mission effectiveness, safety of flight, and contract performance guarantees. Flight testing is always an expensive and time consuming process involving several prototype airplanes equipped with special test instrumentation and a large labor force to gather and analyze test results. The scope of flying qualities and performance testing will be constrained by limitations in available aircraft, instrumentation cost and installation time, and test personnel. Any expansion of testing will usually be motivated by attempts to verify correction to airplane deficiencies identified in early tests.

It is fortunate that modern aircraft development programs now include extensive flight simulation efforts to support engineering development. This means that comprehensive flight dynamics models are created before actual flight testing in order to explore design options and then these models are usually updated when flight test results indicate the necessity. However, the update process may not be as thorough as desired for potential follow-on simulation models such as pilot training simulators. Typical engineering simulation models tend to become narrowly focused on specific flight regimes and configurations where there may be a model for handling qualities studies which may be further constrained to gear down (or up) and only certain store loadings, and there may be a completely separate model that accurately represents aircraft performance. In common practice, none of these models are easily reconciled with each other. Furthermore, they are updated in an incremental process which does not ensure global validation as the changes (typically dubbed 'flight test updates') are continuously tacked on.

If simulator validation data is needed for a new aircraft where simulator and aircraft data must be obtained concurrently, two problem areas become important:

a. Significant changes to the prototype aircraft may invalidate much of the data generated previously.

b. Most of the flight tests will focus on the edges of the flight envelope. Training simulators need to be validated primarily in normal mid-envelope flight conditions with particular emphasis on control response time history data as well as validated at the edges of the flight envelope.

Additionally, if extensive engineering models are to have further use, their fragmented nature must be overcome by deliberate integration efforts to ensure that the new application goals such as full envelope pilot training are achieved.

The generation of useful simulator validation data under the above conditions requires a deliberate commitment by the aircraft program management. If this commitment is officially sanctioned via contract or other tasking document, then model integration can be done properly and flight tests can be structured to include comprehensive data gathering at normal fleet operating conditions along with properly documented developmental tests. Also, the scope of follow-on testing can be planned if significant airplane design changes invalidate existing data.

Dedicated flight test programs for gathering simulator validation data are the most effective way to provide a comprehensive data set and this is the method utilized when development of the aircraft and simulator is not concurrent. Program planning must include the pre-test time required to properly instrument the aircraft (nominally six months) and the post-test time required to plot and analyze the data (as much as another six months). The time required to conduct the actual flight tests varies with aircraft type; a rough order of magnitude is about fifty to seventy-five flight hours. It cannot be overemphasized that continuous liaison between data generators and data users is essential. This liaison is necessary to ensure that the proper data are generated, correctly interpreted, and correctly applied in simulator tests. Discussion of simulator validation flight test data programs for helicopters and commercial airplanes was the topic of an entire session at the AIAA 1991 Flight Simulation Technologies Conference (see reference D-4).

Detailed Flight Test Requirements

The appendices D through G contain detailed outlines of the type of flight test data required to validate typical military training simulators. These outlines were derived from extensive flight test experience with military simulator validation efforts. For fixed wing aircraft, Appendix D contains the data requirements and Appendix E describes the corresponding test conditions. These requirements apply to all classes of fixed wing aircraft with respect to gross weight and maneuvering capability. Spin characteristics are not included due to uniqueness with respect to aircraft type. Helicopter (or rotorcraft) flight test data requirements are presented in Appendix F with the corresponding test conditions outlined in Appendix G. These are generic outlines that must be refined to individual simulator program needs by a team of flight test and simulator engineers. These generic outlines provide a meaningful and comprehensive starting point for early assessment of flight test support requirements. In addition, these outlines provide a guide for development of the Trainer Criteria Report throughout the simulator development process.

Flight Test Data Quality

The accuracy of flight test data is governed by the quality of test execution and by the accuracy of the aircraft test instrumentation. Examples and discussion of flight test data quality problems are discussed in references D-5, D-6 and D-7. Some frequently encountered problems are: differences between test aircraft, test technique quality, incomplete records, instrumentation errors, and naive data users.

Test instrumentation has a fundamental impact on data usefulness. Data sample rates must be appropriate for the bandwidth of the information to be extracted. Typical flight test instrumentation accuracy is presented in Appendix H. The overall quality of the flight test data should be consistent with simulator specification tolerances (or the converse, if the data already exists). Typical flight fidelity tolerances for military fixed wing and rotorcraft training simulators are presented as Appendices I and J, respectively. These tolerances must be refined for each specific aircraft application to incorporate other parameters or tolerance values as appropriate for the aircraft and the intended training mission of the simulator.

Instrumentation noise is a major problem with flight test data quality. Reference D-8 discusses filtering of data and illustrates the impact of proper and improper filtering (see Appendix H). Sometimes the instrumentation crews install undocumented prefilters in airborne recording packages to make their product look better. If the bandpass of such prefilters is too low, the dynamic character of the data is distorted and incorrect analyses will result. Users of flight test data must be aware (and **beware**) of any filtering applied to the recorded data. It may be better to provide raw unfiltered data to the user and let him filter it with one of the readily available post processing software packages.

Alternate Data Sources

When sufficient flight test data are not available, the simulator developer must utilize alternate sources. The priority for desired data sources is:

a. Directly measured aircraft flight test data.

b. Generalized flight test data (NATOPS performance charts). Available generalized flight data normally addresses only performance, and does not address stability and control.

c. Estimated data extracted by analytical methods.

d. Estimated data derived from engineering test facilities such as test stands and manned flight simulators.

Criteria data credibility decreases with each step down this list. For manned engineering simulators, it is important to remember that they are built to study specific parts of the envelope in detail, so the model structure may be significantly different from the training simulator model (applies to coefficient data more than estimated flight characteristics), and the engineering model needs to be validated with actual flight test data also. Properly validated engineering models for aircraft with highly augmented flight control systems can actually produce more useful criteria than manual test data due to the increased precision of computer generated control inputs.

Simulator Data Milestones

The ideal situation is to generate the criteria flight test data in at least two increments:

(1) A comprehensive data package delivered to the simulator developer prior to simulator design freeze.

(2) Follow-on data packages generated to augment item (1) because of data shortfalls that only become apparent after pilot testing of the simulator.

This ideal situation assumes that a dedicated flight test program can be conducted before simulator design freeze, that flight test assets will be available again later during simulator testing, and that the simulator developer is willing to accept and utilize criteria data delivered after simulator design freeze (i.e., a contractual requirement). The requirement for follow-on data generation and utilization is essential because it is a common issue in most Navy simulator development efforts. Data shortfalls become apparent when pilot testing of the simulator reveals unforeseen fidelity problems caused by undetected math modeling errors or flight test data that are inconsistent or incomplete. Additional flight hours are also necessary during the simulator test period for the evaluation pilots to maintain proficiency in actual aircraft characteristics.

Concurrent simulator and airplane development necessitates an incremental data delivery process. These data increments should represent a sensible combination or snap shot of tested conditions rather than a piecemeal collection of miscellaneous test results. Formal commitments to this process must be established with the data generator and the simulator developer. The initial criteria data package should contain as much flight test data as possible. Updates to this data package will probably be scheduled in accordance with major milestones in the aircraft program, but delivery of these updates must be timely and not restrained by a formal report approval process. It is important for the simulator interests to be fully represented during all flight test planning to ensure continued attention to simulator data needs.

Modern aircraft development programs use simulation extensively. The sophistication and success of manned flight simulators cannot be denied when the test pilots frequently comment after the very first flight of a prototype aircraft that it 'flew just like the simulator'. However, it is important to remember that modern aircraft have highly augmented flight control systems that are designed to produce desirable flying qualities that may be vastly different from the ‘bare airframe’ characteristics. Augmented flight control systems are easily implemented in simulators – it’s all software - and the control laws may be so robust that the true bare airframe characteristics need not be accurately modeled to give a favorable first impression of high fidelity at first flight. Subsequent testing of failure modes will usually bring out the need to obtain actual flight test data in order to refine and validate the bare airframe aerodynamic models.

FLIGHT TEST CORRELATION METHODS

General

The process of validating the flight fidelity of a simulator requires the ability to correlate pilot comments and flight test data comparisons with the appropriate simulator components. Simulator visual and motion cues may or may not enhance the pilot's perception of fidelity but these cues are "downstream" of the flight model. The flight model must correctly match flight data before motion and visual cues can be refined. For matching flight data, the primary components of interest are the control loader and the aerodynamic coefficients in the math model. The ability to correlate flight characteristics with specific parts of these components helps the simulator analyst identify the exact source of a given fidelity problem and make appropriate corrections. Without this ability, the analyst is very likely to create a "fix" that will inadvertently cause problems elsewhere in the simulation.

To begin the validation process, a flight simulator is flown by an experienced pilot using the same mission tasks and flying qualities and performance test techniques applied in actual airplane tests. Pilot opinion then usually establishes guidance as to where any major problem areas exist. It is important to isolate the effects of each simulator cue source (flight, motion, visual) and focus on the flight dynamics modeling first. Comparison of aircraft and simulator flight test data substantiate the pilot opinion and illustrate fidelity deficiencies in quantitative terms. An excellent example of this whole process is documented in a NASA report (reference V-3) that validates a UH-60 simulation at the Ames Vertical Motion Simulator. The UH-60 flight model is validated first by comparison with flight test data that includes frequency response. The motion cues are also analyzed using some of the same flight test frequency response data. Unfortunately, similar quantitative analysis of visual cues appears to be beyond the state of the art and more research in this area is needed.

Reuse of Legacy Models

Many new training simulators today are really refurbishments of old units or stripped down copies that are mounted in deployable containers. These ‘new’ simulator projects attempt to capitalize on existing components, especially software. This leads to the reuse of so-called legacy models and a common misconception is that if an existing flight model has been in use for several years then it must be suitable for re-use as a drop-in component. Therefore, little or no expertise will be applied to verify that the old model is really working well and more importantly, that the rehosted model will meet all the training requirements of the new simulator. This is not a safe practice because the old model may have validation deficiencies – some that were never resolved during original acceptance testing, some that crept into the model inadvertently in the course of other life cycle modifications, or some due to significant changes to the aircraft that did not make it into the simulator.

Legacy models should be subjected to the same thorough validation process that a new model requires. The first step should be a complete baseline evaluation and the test planning should consider existing documented fidelity deficiencies and should focus on the current simulator training requirements. Testing legacy models in old simulators may require special data recording features and almost always will require a custom set of test procedures. The test team should include experienced fleet pilots, a flight test pilot and engineer team, and personnel with simulator aerodynamic analysis expertise. Baseline test results should document both the recorded data and the pilot descriptions comparing the simulator to the aircraft. The resolution of legacy model deficiencies should start with analysis of the source code to correct any programming and data errors. After this step is completed, the resolution of remaining deficiencies should include review of the model structure for proper physics implementation. The corrected legacy model is suitable for reuse if it is properly validated by matching the most current flight test criteria data and by conducting disciplined pilot evaluations.

Analysis Tools

Flight simulator model analysts have a variety of software tools to aid them in refining model fidelity. These are commonly referred to as parameter identification or system identification tools, and they will be described below. However, these methods usually require flight test maneuvers beyond the usual conventional types. To a limited extent, some model analysis and fidelity correction is feasible with a fundamental understanding of the correlation between aerodynamic coefficients and the conventional flight test data.

Conventional/Manual Analysis Methods

Recall that conventional flight tests only measure the manifestation of a stability derivative or combination of derivatives and not the numerical value. However, if the flight test data comparisons are analyzed in the proper sequence, it is possible to isolate the effects of a number of the stability derivatives in the math model. Examples of project experience in applying conventional flight test techniques to improving simulator flight fidelity without sophisticated software tools are presented in reference V-4. The analysis sequence applied in the reference V-4 effort for longitudinal parameters is outlined in Appendix B, Table 1. This sequence is arranged to isolate the effect of each major simulator parameter so that it can be evaluated and adjusted as independently as possible. Also, this sequence is arranged so that flight test parameters that are manifestations of more than one derivative are not examined until all derivatives in the group except one have been adjusted. In addition, there are other flight test results that must be matched such as short period damping, phugoid frequency and damping, and runaway trim, but these are manifestations of derivative combinations that cannot be easily broken down. Therefore, these tests are better used as a check after the major parameter adjustments are made.

Lateral control effectiveness and lateral-directional stability problems are approached in the same manner as for the longitudinal axis. The analysis sequence for lateral-directional parameters is presented in Appendix B, Table 2. It is assumed that the weight and balance investigation in the longitudinal analysis included the lateral and directional axes.

The concept described here is not intended to calculate specific values of each derivative or parameter but rather to use an identical series of tests in the airplane and simulator to match the output or response of the simulator to control inputs by adjusting these parameters. This technique is iterative in that tests are repeated in the designated sequence as simulator parameters are modified until the desired match is achieved. An example of data matching achieved by this technique is shown in Figure 1, Appendix B. These data show the static longitudinal stability characteristics in the landing configuration of the TA-4J airplane and its attendant training simulator, Device 2F90. Note that the longitudinal stick force and stick position gradients for Device 2F90 before modifications are shallower than in the airplane. This deficiency caused an unrepresentative pilot workload because the simulator would inadvertently accelerate above trim airspeed whenever the pilot's attention was diverted to other tasks. In addition, the incorrect angle of attack/airspeed relationship provided unrepresentative cues during landings and practice stalls. These deficiencies were corrected using the analytical sequence of Table 1, Appendix B. After performing items 1 through 7, the elevator effectiveness term, CMDE, was adjusted until the stick position gradient was matched. The resulting stick force gradient above trim speed was steeper than in the airplane, but not objectionable to the evaluating pilots. The angle of attack/airspeed relationship was improved by adjusting CLAOA. The conditions for a satisfactory data match were determined in this case by their influence on pilot tasks. In formal acceptance testing, specification tolerance requirements must also be considered.

Parameter Identification Methods

Advanced analytical tools have been developed which can determine the numerical value of aerodynamic stability derivatives directly from flight test data. These tools typically consist of powerful digital algorithms referred to as Parameter Identification (PID) or System Identification (SID) routines. The PID/SID process allows one to work backward from the "answer" (flight test data) to help construct the "question" (model parameters). A typical algorithm employs a maximum likelihood estimation scheme to extract stability derivatives from flight test data. The algorithm is also capable of accounting for measurement noise as well as process noise.

Basically, a PID algorithm can be described as illustrated in Figure 2: An appropriately instrumented airplane is given a control input designed to excite specific dynamic modes of response. The airplane responds but the recorded data is contaminated by instrument noise and process noise. A mathematical model of the aircraft, using the equations of motion and an initial guess for the aircraft coefficients, is given the same input. The model response is compared to the contaminated aircraft response and a response error is generated. A criterion function such as error squared is formed and this criterion function is minimized by an optimization algorithm; in this case a maximum likelihood estimator. The model parameters are then modified in an iterative fashion until a best estimate of aircraft parameters is obtained. The algorithm also generates the statistics of both the measurement and process noise. PID and other methods of system identification can also be applied to other identification problems such as avionics systems, propulsion systems, and non-aviation systems such as biological or econometric models.

PID is commonly utilized by sophisticated flight test organizations such as the Naval Air Warfare Center's Flight Test Engineering Group, Air Force Flight Test Center, NASA, and Kohlman Systems Research, Inc. The military test centers and NASA use PID to validate simulators that support edge-of-the-envelope flight test programs; further descriptions can be found in references V-5 through V-8. Kohlman develops data bases specifically for training simulator applications, as described in reference V-9. The differences between wind tunnel derived and PID derived coefficients can be quite dramatic, as revealed in Figure 3 (from reference V-9).

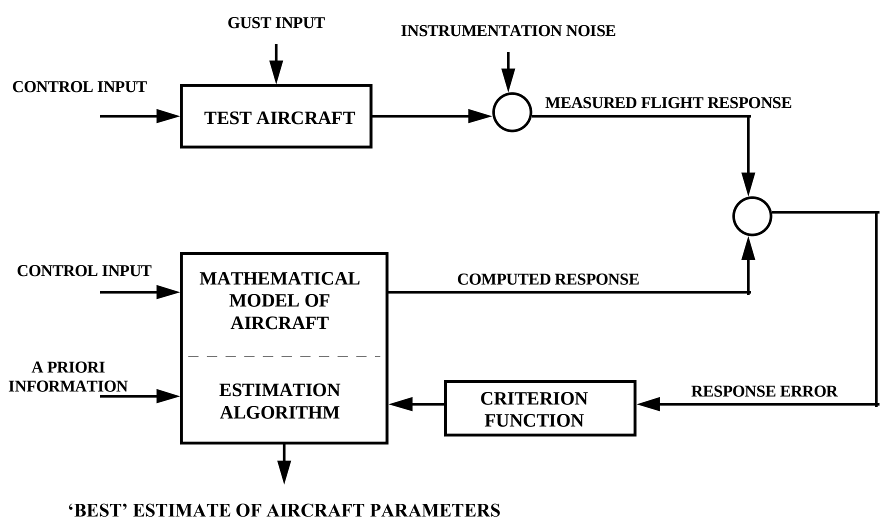


Figure 2
Parameter Estimation Procedure

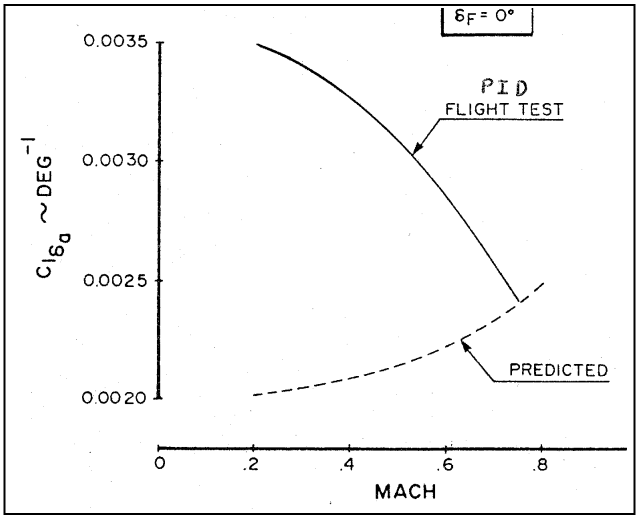


Figure 3
Comparison of PID and Predicted Values - Aileron Control Power

PID test results have the potential for greatly reducing risk in simulator validation efforts because coefficient values and supporting check cases (for dynamic response) can be produced. For fixed wing aircraft, PID techniques can generate the whole aero coefficient database if PID flight test maneuvers are flown at every flight condition and aircraft configuration of interest. The behavior of rotary wing aircraft is so complex and non-linear that successful implementation of a PID derived model that represents the whole flight regime has yet to be achieved, but very good validations have been achieved at specific flight conditions, such as hover or specified forward flight airspeeds. Discussions of state of the art capabilities can be found in references D-8, and V-10 through V-12.

A particularly promising approach, described in general terms in references V-13 and V-17, utilizes frequency sweep data from flight tests to generate a frequency response database. This approach, called **CIFER** (Comprehensive Identification from FrEquency Responses), was developed under Army sponsorship at Ames Research Center and the Army Airworthiness Qualification Test Directorate formerly located at Edwards AFB. CIFER includes software tools to process noisy, non-linear, cross-coupled test data to prepare it for analysis, and then it identifies a set of broadband frequency responses for all input/output pairs for which there is dynamic excitation. CIFER tools are then capable of generating a variety of outputs, including simplified transfer function models (useful for limited fidelity applications) and complex stability derivatives for full non-linear models. The full potential of CIFER will not be realized until the helicopter flight test community gains more experience with the frequency response flight test techniques. Reference V-20 is a Flight Test Manual for Frequency Domain Flight Testing. Application of CIFER to fixed wing aircraft characteristics is documented in reference V-18. CIFER also has possible application for analyzing and specifying simulator cue correlation as discussed in reference V-19. The concepts described in this reference are illustrated briefly in Figures 4, 5, and 6 below. The definition of appropriate tolerances need further exploration but the boundaries developed from handling qualities research shown in Figure 5 may be a useful starting point. Comparison of typical phase data is shown in Figure 6 but it should be noted that the physical interpretation of the visual cue frequency response data probably needs more study and definition.

Frequency Domain
-Validation Approach-

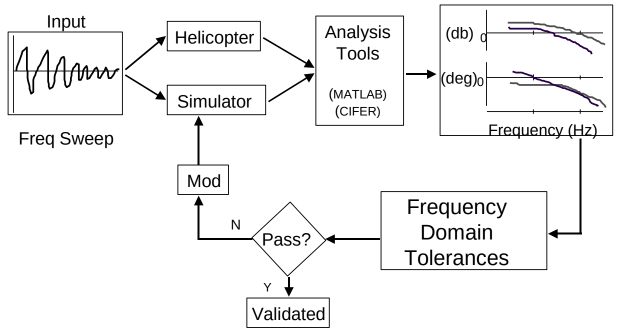
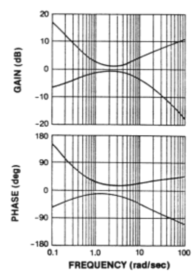


Figure 4
Basic Validation Approach using Frequency Domain Analysis Tools

Cue-Sync Compliance
Max Unnoticeable Dynamics Envelope*

- Developed For Aircraft Handling Qualities Analysis
- Tolerance Bands: Equivalent Systems Models vs Aircraft
- Consider Simulator Cue Source As Equivalent System
- Compare Aircraft And/Or Each Cue
- Do Tolerance Bands Need Refinement?



*MIL-HDBK-1797, Flying Qualities of Piloted Aircraft

Figure 5
Potential Basis for Frequency Domain Tolerances

Typical Results
Unnoticeable Dynamics - Phase Criteria

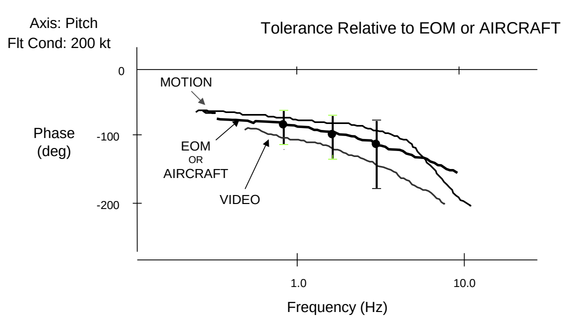


Figure 6
Potential Tolerance Application for Simulators

In summary, the application of PID techniques is a complex process that requires careful planning and skilled analysis. As an overview, the main steps of the process are:

1- *Flight test instrumentation* - the parameters of interest must be measured with high quality instrumentation systems.

2- *Flight test planning* - PID test maneuvers are designed to excite specific aircraft modes of motion utilizing steps, doublets, and sinusoidal control inputs. Test conditions must be selected for efficient and thorough coverage of the flight envelope.

3- *Data analysis and conditioning* - this involves removing wild points, reconstructing unmeasured quantities, and reconciling measurements for consistency.

4- *Model structure determination* - this step is vitally important. The model must contain an appropriate number of parameters and the physical significance of each parameter must be understood. If the model is underspecified, the identified parameters will contain gross errors. If the model is slightly over specified, the results may indicate parameters of little effect. If greatly over specified, large amounts of computer time will be consumed and the process may never converge to a useful set of parameters.

5- *Actual parameter identification* - here the actual system identification algorithm is applied. Different mathematical techniques may be employed but the choice and execution should be left to experts. The most common algorithm - the maximum likelihood technique - can estimate aerodynamic and instrumentation error parameters by employing a Kalman filter.

6- *Model validation* - the recorded pilot inputs from the flight tests are used to stimulate the identified model and the results are compared to the aircraft data. Engineering judgment and experience are necessary to determine if the model and its output are valid.

While parameter identification methods are very powerful, they are not a panacea for all simulator data problems. The sophistication level described above precludes application of these techniques in an "off-the-shelf" manner by inexperienced persons. A recurring problem with training simulators is that the trainer math model structure cannot be reconciled with the PID based model. This problem can be resolved if trainer modelers and PID analysts coordinate their efforts. Another problem is that some effects cannot be isolated sufficiently for PID analysis. Individual control surface effects in such situations as split flaps (for malfunction training) must be estimated from wind tunnel data or analytical methods. Finally, it is important to realize that PID methods only augment but do not replace the classical flight test data needed for simulator validation. PID is especially capable of identifying and validating dynamic parameters, but the static parameters must be validated with classical steady state flight test data. Therefore, classical flight test results are essential for validating simulator flight fidelity regardless of the source of the coefficient database.

Summary of Correlation Methods

The best approach for correlating an aerodynamic math model to flight test data and pilot opinion is to use a combination of all the methods available. The conventional methods must be understood in order to guide the overall effort. Parameter identification methods are powerful tools for augmenting the database with both stability derivative and dynamic test criteria data. Automated test drivers, both off-line and on-line, should be applied to achieve repeatable results. The specified tolerance requirements should be reevaluated in terms of mission requirements if data matching conflicts cannot be resolved by checking for model errors or criteria data inaccuracies. Overviews of typical correlation efforts for military aircraft can be found in references V-1, V-4, D-5 and D-7. A similar overview for commercial aircraft is presented in reference V-14.

PILOT TAILORING

In a typical simulator development effort, the final phases are devoted to pilot evaluations. Pilots from the using organization exercise the simulator in all the intended mission tasks in order to identify any deficiencies prior to final acceptance. If this pilot evaluation process is not properly managed, chaos will result and the simulator will be haunted by "band-aid" fixes and limited growth potential for the rest of its service life.

Experienced pilots are usually able to identify differences but not the source of differences between aircraft and simulator behavior. Engineering test pilots have the training to discern some of these differences, but test data and analysis by simulator engineers is required to solve most fidelity problems. For simple phenomenon such as a navigation system display change due to a switch action, there is very little difficulty in identifying a simulation error. For complex phenomenon such as flight characteristics, more careful analysis is necessary to identify the true source of a pilot complaint. For example, if a pilot claims that simulator response to lateral stick inputs is too sensitive, he has only flagged a problem whose solution is not immediately obvious. The simulation engineer must analyze all of the simulator components involved in the pilot's process of controlling bank angle. Two components, the lateral control loader and the aerodynamic math model, can be analyzed by the correlation methods presented earlier. If automated test drivers are available, the simulator engineer can exercise the simulator in the same manner as a test pilot and obtain repeatable results for analysis and validation.

Other simulator components which must be considered include phase lags introduced by integration algorithms and iteration rates in the equations of motion and transport delays introduced in the output to pilot displays (cockpit instruments and visual scenes) and motion cueing devices. The only way to sort these problems out is with an organized engineering test program that commences as early as possible in the simulator integration process. References V-15 and V-16 document an investigation of perceived fidelity problems in the NASA Ames Vertical Motion Simulator for the helicopter Nap of the Earth (NOE) task. The flight dynamics model produced an excellent match of the UH-60A flight test data but pilots still did not consider the simulation to be representative for this task. Engineering measures of the motion system dynamics and the visual system characteristics (delays, field of view, and scene content) indicated that the motion and visual cue environment, not the aerodynamic model fidelity, were the primary problem sources. The same approach was utilized more recently when the model was updated, and the validation results are thoroughly documented in reference V-3.

Another factor in pilot evaluations is short pilot "memory." Subjective pilot evaluations are always necessary to assess mission tasks with integrated cues or to evaluate problems where data are lacking. Some success will be achieved if the pilot has flown the actual aircraft recently. After about 30 minutes, however, a pilot adapts to the simulator and his ability to distinguish flying qualities differences from the airplane is significantly reduced. After this point, only quantitative testing using proper flight test techniques will be worthwhile. To accommodate short pilot memory, an effective evaluation approach commences with a subjective evaluation of the overall flight characteristics to identify significant problem areas, followed by quantitative engineering tests. The evaluation pilot should return to the actual aircraft often to refresh his "memory."

When the simulator engineer must consider changes to satisfy pilot opinion, he must be careful not to undo the engineering data match previously achieved. An evaluation of all flight characteristics should be made before any simulator changes are made. If the aerodynamic math model is sufficiently robust, the simulator flight dynamics should never vary significantly from the flight test data. Failure to satisfy major pilot complaints when all available data are matched is an indication that the flight model testing is really still incomplete or that other important cues are not simulated adequately. Enlightened program management and sound engineering judgment are required to resolve these situations.

CONCLUSION

Parable Conclusion

Our opening parable would have a happier ending if you applied the principles discussed in this article. If you compared the simulator flight characteristics to a good set of flight test data for the XYZ airplane before bringing in LT Golden Arm and his associates, the pilot evaluation would have been much more effective. Also, the pilots should have participated as a team with LT Golden Arm designated as the lead pilot spokesman. As it happened, you could not easily interpret or reconcile the pilots' comments since they did not provide enough specific information about flight conditions (weight, altitude, airspeed, power setting, etc.) and pilot technique. If you did not record any of their maneuvers, then you have no data to guide your analysis and debug process. Incredible as it may seem, this is a major blunder that some simulator manufacturers still commit. On the other hand, if you structure the pilots' evaluations around aircraft test data or flight manual data, then you would be in a better position to sort out their comments. Also, if you work closely with the pilots during the actual testing, you can ask questions to clarify their comments and to repeat tests as necessary to narrow the focus of a complaint. Flight simulator validation is a team effort that requires close coordination – along with the right data.

Summary

Flight simulator validation and evaluation is a complex and lengthy process, which requires advanced planning and considerable coordination in order to succeed. The desired performance must be clearly specified and enforced with comprehensive test requirements. Considerable effort must be devoted to obtaining adequate criteria data from an aircraft flight test program. The simulator validation process can be expedited by the utilization of automated tools such as built-in auto fidelity testing and parameter identification techniques. Pilot evaluations must be reconciled with engineering data matches by using sound engineering judgment in analyzing and acting upon pilot comments. A well organized engineering validation program with adequate flight test criteria data should be able to confine subjective pilot tweaking efforts to small refinements related to closed loop characteristics in mission tasks. The milestones pertinent to flight dynamics for a Navy training simulator are outlined in Appendix K. The principles behind these milestones, especially the early quest for criteria data and early preliminary evaluations, are effective for any complex training simulator. A recent example of a simulator program that was successful because these processes were diligently applied is the aircrew training device development for JPATS (T-6A), as documented in reference V-21.

This article has focused on the validation portion of the full verification, validation, and accreditation process (VV&A). For some perspective, examples of the full VV&A process applied to flight simulators can be found in the literature in papers such as reference V-22. This paper describes the VV&A process for the simulation of UH-60A helicopter operations with an LHA type ship. The Accreditation aspect of this program revealed the need for tradeoffs in validation criteria due to the complexity of the elements involved. The lack of some validation criteria data may be overlooked, if the sum total of the evidence collected shows that a simulator can be accredited for its intended purpose. Accreditation is difficult to achieve because evidence is required to demonstrate that the simulator actually accomplished its purpose, i.e., pilot training did transfer to the airplane, or engineering simulation results proved to be equivalent to actual flight test results. Gathering such evidence is an expensive process.

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APPENDICES

Validation and Evaluation Lecture Notes

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Appendix A

AC 120-40B Test Limitations

Test Area	Flight Test Category	AC120-40B 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	-

Appendix A

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	-

Appendix A

Detailed Comparison of AC 120-40B to Typical NAWCTSD Tolerances

Major Flight Area	Test Category	Test Subcategory	FAA Advisory Circular (AC No: 120-40B)	FAA Comments	NAWCTSD Specifications	NAWCTSD Comments
General						
	All tests		Paragraph 8.d. - Tolerances listed for parameters in appendix 2, should not be confused with design tolerances specified for simulator manufacture.		OFT/WST performance shall meet the trainer design criteria within the tolerances specified.	All tolerances are applied as +/-.
	Flight Conditions		Test conditions primarily for Takeoff, Approach, Landing. Limited testing at Cruise and Climb conditions.			Detailed test categories and test conditions are established during OFT/WST development to address the full flight envelope and document flight characteristics relevant to all pilot mission tasks.
	All Flight Characteristics (not covered by specific tolerances)		Not addressed		10%	Essential to ensure proper handling of unforeseen critical parameters.
	Curve Slope		Not addressed		Same sign as aircraft data 10% (or suitable EU)	Essential to ensure correct matching of trends.
Aircraft Mass Characteristics						
	Weight & Balance		Not addressed		1% Weight 0.1 unit Center of Gravity	
	Moments of Inertia		Not addressed		1%	
Performance						
	Taxi					
		Min. Radius Turn	± 3 Feet or 20 % of Airplane Turn Radius			
		Rate of Turn vs. Nosewheel Steering Angle	± 10 % or ± 2 °/sec. Turn Rate		10% Heading vs Time	
	Takeoff					
		Ground Acceleration Time And Distance	± 5 % Time and Distance or ± 5 % Time and + 200 ft Distance	Unfactored aircraft certification data may be used. Acceleration Time and Distance should be recorded for a minimum of 80 % of total segment (Brake release to V_r).	10% Distance 1 sec Time	
		Minimum Control Speed (Vmcg) Aerodynamic Controls	Maximum Airplane Lateral Deviation ± 25 % or ± 5 Feet	Engine failure speed must be within ± 1 knot of airplane engine failure speed.	5 kt Vmcg 5 kt Vcontrol eff.	
		Minimum Unstick Speed or equivalent as provided by the airplane manufacturer	± 3 Kts Airspeed ± 1.5 ° Pitch	V_{mu} is defined as that speed at which the last main landing gear leaves the ground. Main landing Gear Strut Compression or equivalent air/ground signal	2 kt Vnwlo 2kt Vto	

Major Flight Area	Test Category	Test Subcategory	FAA Advisory Circular (AC No: 120-40B)	FAA Comments	NAWCTSD Specifications	NAWCTSD Comments
				should be recorded. Record as a minimum from 10 Kts before start of Rotation.		
		Normal Takeoff	± 3 Kts Airspeed ± 1.5 ° Pitch, ± 1.5 ° Angle of Attack ± 20 Feet Altitude ± 5.0 lb or ± 10 % Column Force*	Record Takeoff profile from brake release to at least 200 ft. Above Ground Level (AGL). *Applies only to reversible control systems.	Same as above.	
		Critical Engine Failure on Takeoff	± 3 Kts Airspeed ± 1.5 ° Pitch, ± 1.5 ° Angle of Attack ± 20 Feet Altitude ± 2 ° Bank and Sideslip Angle ± 5.0 lb or ± 10 % Column Force* ± 5.0 lb or ± 10 % Rudder Pedal Force* ± 3.0 lb or ± 10 % Aileron Wheel Force*	Record Takeoff profile at maximum takeoff weight to at least 200 ft. (61 m) AGL. Engine failure speed must be within + 3 Kts of airplane data. *Applies only to reversible control systems.	5 kt V mcg 15% Dynamic response	Dynamic response to sudden engine failure (time response and magnitude of angular rate).
		Crosswind Takeoff	Same as above.	Record Takeoff profile to at least 200 ft. (61 m) AGL with same relative wind profile as aiplane test. *Applies only to reversible control systems.	Same as normal takeoff.	
		Rejected Takeoff	Overall Distance TBD Braking effort TBD	Auto brakes will be used where applicable. Maximum braking effort, Auto or Manual.		
	Stopping					
		Deceleration Time and Distance, Wheel Brakes Using Manual Braking, Dry Runway (No Reverse Thrust)	± 5 % of Time. For Distance up to 4000 Feet ± 200 Feet or ± 10 % whichever is smaller. For distance greater than 4000 Feet ± 5 % of distance)	Time and Distance should be recorded for at least 80% of the total segment (TD to Full Stop). Brake system pressure should be available.	1 sec Time 10% Distance	
		Deceleration Time and Distance, Reverse Thrust, Dry Runway (No Wheel Braking)	± 5 % Time and the Smaller of ± 10 % or 200 Feet	Time and Distance should be recorded for at least 80% of the total demonstrated reverse thrust segment.	Same as above.	
		Stopping Time and Distance, Wheel Brakes, Wet Runway (No Reverse Thrust)	Representative Stopping Time and Distance	FAA approved Airplane Flight Manual (AFM) data is acceptable.	Same as above.	
		Stopping Time and Distance, Wheel Brakes, Icy Runway (No Reverse Thrust)	Representative Stopping Time and Distance	FAA approved Airplane Flight Manual (AFM) data is acceptable.	Same as above.	
	Climb					
		Normal Climb All Engines Operation	± 3 Kts Airspeed ± 5 % or ± 100 FPM Climb Rate	May be a Snapshot Test. Manufacturer's gross climb gradient may be used for flight test data.	Climb Rate: 5% or 50 FPM	May have to reconcile NATOPS performance data with most current flight test results.
		One Engine Inoperative	± 3 Kts Airspeed ± 5 % or ± 100	May be a Snapshot Test.	Same as above.	Tested with all practical

Major Flight Area	Test Category	Test Subcategory	FAA Advisory Circular (AC No: 120-40B)	FAA Comments	NAWCTSD Specifications	NAWCTSD Comments
		Climb	FPM Climb Rate, but not less than the FAA Approved Flight Manual Rate of Climb.	Manufacturer's gross climb gradient may be used for flight test data. Test at weight altitude, temperature limited conditions.		combinations of engine out conditiions .
		One Engine Inoperative Approach Climb for Airplanes With Icing Accountability per Approved AFM	Same as above.	May be a Snapshot Test. Manufacturer's gross climb gradient may be used for flight test data. Use near maximum landing weight.	Icing not addressed in this manner.	Icing effects on performance evaluated qualitatively.
	Level Flight Performance					
		Level Accel/Decel	Not addressed.		Airspeed: 5%	Decels with speedbrake IN & OUT
		Level Turn Performance	Not addressed.		Normal Acceleration: 5%	Sustained and instantaneous turn performance.
		Speed / Power	Not addressed.		See engine steady state below.	
		Maximum Airspeed	Not addressed.		Airspeed: 3 kt/ 1%	
	Engines					
		Acceleration	$T_i \pm 10$ % $T_t \pm 10$ %	T_i = Total time from initial throttle movement until a 10% response of a critical engine parameter. T_t = Total time from T_i to 90% go-around power. Critical engine parameter should be a measurement of power (N1, N2, EPR, Torque, etc.) Plot from flight idle to go-around power for a rapid (slam) throttle movement.	5 to 10% Applied to time history of relevant parameters (RPM, Torque, EGT, etc.)	Engine dynamic response measured for any task relevant flight condition. (Starts, shutdowns, throttle inputs, power loading, air starts, etc.)
		Deceleration	$T_i \pm 10$ % $T_t \pm 10$ %	Test from max takeoff power to 10% of max takeoff power (90% decay in power). Time history should be provided.	Same as above.	Same as above.
		Steady State	Not addressed except for RPM vs PLA (see below)		Fuel Flow: 5% RPM : 1 unit (%RPM) RPM vs PLA: 1 to 5% (Varies with RPM range) Windmilling RPM: 1% RPM EGT /JPT: 1 to 3% (Varies with RPM range) Thrust: 3% or 0.3% max	
Handling Qualities						
	Static Control System Checks					
	(Flight Control System Mechanical Characteristics)	Pitch (Column) Position vs Force and Surface Position Calibration	$\pm$ 2 lbs Breakout $\pm$ 5 lbs or $\pm$ 10 % Force $\pm 2^o$ Elevator	Uninterrupted control sweep, stop to stop.	Breakout+Friction: 0.5 lbf/ 5% Force: 1.0lbf/ 10% Surface Gearing: 1 deg Freeplay: 0.1 in/ 10% Control envelope: 0.5 in/ 5%	Tests include control sweeps and specific tests for freeplay, B/O+F. Control envelope is cockpit control range of motion.
		Lateral (Wheel) Position vs	$\pm$ 2 lbs Breakout	Uninterrupted control sweep, stop	Same as above.	Same as above.

Major Flight Area	Test Category	Test Subcategory	FAA Advisory Circular (AC No: 120-40B)	FAA Comments	NAWCTSD Specifications	NAWCTSD Comments
		Force and Surface Position Calibration	± 3 lbs or ± 10 % Force ± 1° Aileron ± 3° Spoiler	to stop.		
		Pedal Position vs Force and Surface Position Calibration	± 5 lbs Breakout ± 5 lbs or ± 10 % Force ± 2° Rudder	Uninterrupted control sweep, stop to stop.	Breakout+Friction: 0.5 lbf/ 5% Force: 2.0 lbf/ 10% Surface Gearing: 1 deg/ 5% Freeplay: 0.1 in/ 10% Control envelope: 0.5 in/ 5%	Same as above.
		Nosewheel Steering Force & Position	±2 lbs Breakout ± 3 lbs or ± 10 % Force ± 2° Nosewheel Angle	Uninterrupted control sweep, stop to stop.	Not commonly tested but tolerances similar to FAA values considered appropriate.	
		Rudder Pedal Steering Calibration	± 2° Nosewheel Angle		Same as above.	
		Pitch Trim Calibration Indicator vs Computed	± 5° of Computer Trim Angle +10% Trim	Measure trim rate for go-around. Trim rate input and surface rate time history is appropriate	See all axes tests below.	
		Trim system - all control axes	Not addressed.		Surface gearing: 1 deg/ 5% Control envelope: 0.5 in/ 5% Trim Rate: Per aircraft maintenance manual.	
		Alignment of Power Lever Angle vs Selected Engine Parameter (EPR, N1, Torque, etc)	± 5° of Power Lever Angle	Simultaneous recording for all engines. A 5 deg tolerance applies against airplane data and between engines	RPM: 1 unit at idle and above 90%. 2 units elsewhere. (unit=%RPM)	Test conducted on deck. Power lever is the independent variable.
		Brake Pedal Position vs Force	± 5 lb or 10% Force ±10% or 150 psi brake hydraulic pressure	Simulator computer output results may be used to show compliance. Relate hydraulic system pressure to pedal position in a ground static test.		
	Dynamic Control SystemChecks					
		Pitch Control	± 10% of time for first zero crossing, and ± 10 (n+1)% of period therafter. + 10% amplitude of first overshoot. ± 20% of amplitude of 2nd and susequent overshoots greater than 5% of initial displacement. ± 1 overshoot.	Data should be normal control displacement in both directions. Approximately 25% to 50% of full throw. n is the sequential period of a full cycle of oscillation.	Number of Overshoots: Same as aircraft. Time to first Peak: 0.1 sec	
		Roll Control	Same as above.	Same as above.	Same as above.	
		Yaw Control	Same as above.	Same as above.	Same as above.	
	Longitudinal					
		Power Change Dynamics	± 3 Kts Airspeed ± 100 ft Altitude ± 20% or ± 1.5° Pitch	Wing flaps should remain in the approach postion. Time history of uncontrolled free response for time increment from 5 seconds before the initiation of the configuration change to 15	General: Control position: 0.5 deg Control force change: 1 lb/ 10% Pitch attitude change: 1 deg Angle of attack change: 1 deg Altitude change: Lesser of 10 ft/	Test technique may be open loop or closed loop. Open loop tests apply tolerances to time history, Closed loop tests typically document the change in stick

Major Flight Area	Test Category	Test Subcategory	FAA Advisory Circular (AC No: 120-40B)	FAA Comments	NAWCTSD Specifications	NAWCTSD Comments
				seconds after completion of the configuration change.	10% Airspeed change: Lesser of 5 kt or 10%	force after the configuration change(power, gear, flaps, speedbrake, etc.) while the pilot maintains constant altitude, attitude, or airspeed.
		Flap/Slat Change Dynamics	± 3 Kts Airspeed ± 100 ft Altitude ± 20% or ± 1.5° Pitch	Time history of uncontrolled free response for time increment from 5 seconds before the initiation of the configuration change to 15 seconds after completion of the configuration change.	See above.	See above.
		Spoiler/Speedbrake Change Dynamics	Same as above.	Same as above.	See above.	See above.
		Gear Change Dynamics	Same as above.	Same as above.	See above.	See above.
		Gear and Flap/Slat Operating Times	± 1 second or 10% of Time	Normal and alternate flaps, extension and retraction. Normal gear, extension and retration. Alternate gear, extension only.	Per aircraft maintenance manuals.	
		Longitudinal Trim	± 1° Pitch Control (Stab and Elev) ± 1° Pitch Angle ± 5% Net Thrust or Equivalent	May be Snapshot Tests.	Angle of attack: 0.5 unit Control position: 1 deg/ 10% Indicated trim: 1 deg/ 10% On-speed airspeed: 1 KIAS Attitude: 1 deg	Trim data obtained with specific tests and from initial conditions for other flying qualities tests. Engine parameters obtained as listed for engine steady state tests.
		Longitudinal Maneuvering Stability (Stick Force/g)	± 5 lbs or ± 10% Column Force Control position: not addressed Surface position: not addressed Angle of attack: not addressed	May be Snapshot Tests. Force or surface deflection must be in correct direction. Approximately 20°, 30°, and 45° bank angle should be presented.	Stick Force/g: 1 lb/ 10% Control postiton: 10% Surface position: 10% Angle of attack: 10%	Test methods include steady turns, wind-up turns, sudden pull-ups and push-overs. Test conditions must address mission tactical maneuvering requirements.
		Longitudinal Static Stability	± 5 lbs or ± 10% Column Force Control position: not addressed Surface position: not addressed Angle of attack: not addressed	Data for at least 2 speeds above and 2 speeds below trim speed. May be a series of Snapshot Tests.	Stick Force: 1 lb/ 10% Control position: 0.5 deg/ 10% Surface position: 0.5 deg/ 10% Angle of attack: 0.5 unit	Test methods include steady points about trim and slow accel-decel.
		Stick Shaker, Airframe Buffet, Stall Speeds	+ 3 Kts Airspeed + 2 deg Bank for speeds higher than stick shaker or initial buffet	Stall Warning Signal should be recorded and must occur in the proper relation to stall.	Buffet Onset airspeed: 2 kt Buffet Onset AOA: 0.5 unit Stall airspeed: 2 kt Stall AOA: 0.5 unit	
		Stall characteristics	Not addressed.		Match general trends in time history data.	
		Spins, post-stall gyrations	Not addressed.		Match general trends in time history data. Departure Boundary: 1 unit AOA	General response to control input combinations for entry and recovery must be correct.
		Phugoid Dynamics	+ 10% of Period + 10% of Time to 1/2 or Double Amplitude or + 0.02 of Damping Ratio.	Test should include 3 full cycles (6 overshoots after input completed) or that sufficient to determine time to 1/2 amplitude whichever is less.	Undamped Natural Freq.: 15% Damping Ratio: 25% or 0.05 Amplitude Response: 10%	
		Short Period Dynamics	± 1.5° Pitch or ± 2°/sec. Pitch Rate ± 0.10g Normal Acceleration		Undamped Natural Freq.: 15% Damping Ratio: 25% or 0.05	Stability augmentation ON & OFF.

Major Flight Area	Test Category	Test Subcategory	FAA Advisory Circular (AC No: 120-40B)	FAA Comments	NAWCTSD Specifications	NAWCTSD Comments
					Amplitude Response: 10%	Stick fixed & free.
	Lateral Directional					
		Minimum Control Speed, Air (V_{mca}), per Applicable Airworthiness Standard or Low Speed Engine Inoperative Handling Characteristics in Air	± 3 Kts Airspeed Dynamic response: not addressed	V_{mca} may be defined by a performance or control limit which prevents demonstration of V_{mca} in the conventional manner.	Vmc: 3 kt Dynamic Response: 15%	Dynamic response to sudden engine failure: time response and magnitude of angular rates.
		Roll Response (Rate)	± 10% or ± 2°/sec. Roll Rate Not Addressed: -Roll angle -Roll mode time constant -Sideslip angle -Adverse/Proverse yaw	Test with normal wheel deflection (about 30%).	Roll Rate: 10% Roll angle: 10% (at specific time) Roll mode time constant: 25% Sideslip angle: 10% Adverse/Proverse yaw: 10%	Full and partial lateral control inputs. Full 360 deg rolls for highly maneuverable aircraft. Control augmentation ON & OFF
		Roll Response to Roll Controller Step Input	Correct Trend, ± 2° Bank or ± 10% in 20 Seconds.	Roll rate response.	Same tests as above.	
		Spiral Stability	Correct Trend, ±2 deg Bank or ±10% in 20 sec	Airplane data averaged from multiple tests may be used. Test for both directions.	Roll angle: 20% and convergent, neutral, divergent per aircraft.	
		Engine Inoperative Trim	+/-1 deg Rudder or +/-1 deg Tab or Equivalent Pedal +/-2 deg Sideslip	May be Snapshot Tests.	Trim positions: 1 deg/ 10%	
		Rudder Response	+/-2 deg/sec or 10% Yaw rate	Test with stability augmentation ON and OFF. Rudder step input of approximately 25% rudder pedal throw. (Approach & Landing Conditions)	Included within Stall, Spin tests.	
		Dutch Roll	+/-0.5 sec or 10% Period +/-10% Time to .5 or 2 Amp +/-.02 Damping Ratio +/-20% or 1 sec of Time Difference between peaks of Bank and Sideslip.	Test for at least 6 cycles with stability augmentation OFF.	Period: 10% Damping Ratio: .05 Roll/Sideslip Ratio: 10% Sideslip: 10%/ 1 deg of peak amplitude	Test with stability augmentation ON & OFF
		Steady State Sideslip	For given rudder position: +/-2 deg Bank +/-1 deg Sideslip +/-10%/2 deg Aileron +/-10%/5 deg Spoiler or Equivalent Wheel Position	May be series of Snapshot Tests.	For given Sideslip angle: Lateral control position: 10% Lateral control force: 10% Lateral surface position: 10% Roll angle: 10% Pedal position: 10% Rudder position: 10% Pedal force: 10%	Test methods include stabilized points and slow rudder sweeps.
	Landings					
		Normal Landing	±3 kts Airspeed ±1.5 deg Pitch ±1.5 AOA ±10%/10 ft Altitude	Test from a minimum of 200 ft AGL to Nosewheel Touchdown. Derotation may be shown as a separate segment from the time of main gear touchdown.	Distance: 10% Stopping time: 1 sec	
		Crosswind Landing	Same as above plus ±2 deg Bank Angle	Test from a minimum of 200 ft AGL to Nosewheel Touchdown		Primarily evaluated qualitatively.

Major Flight Area	Test Category	Test Subcategory	FAA Advisory Circular (AC No: 120-40B)	FAA Comments	NAWCTSD Specifications	NAWCTSD Comments
			±2 deg Sideslip or Yaw	and rollout to 60 kt. Use near max landing weight with same Relative Wind Profile as aircraft test.		
		One Engine Inoperative Landing	Same as above.	Test from a minimum of 200 ft AGL to Nosewheel Touchdown.		Primarily evaluated qualitatively.
		Directional Control (Rudder Effectiveness)) With Reverse Thrust, Symmetric and Asymmetric	±5 kt Airspeed	(See AC 120-40B)	Not applicable.	Few USN/USMC aircraft have reverse thrust capability. OFTs tested qualitatively only.
	Ground Effect					
		Test to Demonstrate Longitudinal Ground Effect	±1 deg Elevator/Stab Angle ±5% Net Thrust or Equivalent ±1 deg AOA ±10% /5 ft Height ±3 kt Airspeed ±1 deg Pitch	(See AC 120-40B)	Customized set developed when applicable.	Not significant for carrier landings.

APPENDIX B

TABLE 1
ANALYSIS SEQUENCE FOR LONGITUDINAL PARAMETERS

TEST	TEST PARAMETER	SIMULATOR PARAMETER
1. Longitudinal Control System Mechanical Characteristics	a. Breakout Forces b. Friction c. Centering d. Stops e. Gearing f. Force Gradients	Control system model in control loading hardware. Software routines where appropriate
2. Weight and Balance	a. Gross Weight b. Moments of Inertia c. CG variation w/fuel,store loading, configuration	Software routines
3. Steady State Trim (Gear and Flaps Up)	Airspeed, Gross Weight, AOA	CL vs AOA
	Longitudinal Trim	CMTRIM (Lower AOA Range)
	Engine RPM, Fuel Flow, EGT, Throttle Position	Steady state engine characteristics, Thrust-Drag Balance
4. Level Accelerations & Decelerations	Time from Vmin - Vmax a. Cruise configuration b. “a.” w/speed brakes open c. Landing configuration	 a. Basic airframe drag b. Speedbrake drag c. Landing gear & flap drag
5. Longitudinal Trim changes (Open Loop)	Pitch change due to: a. Flap operation b. Landing gear operation c. Power changes d. Speedbrake operation	Pitching moment contribution of each device
6. Steady State Trim (Landing Configuration)	Airspeed, Gross Weight, AOA, Power Settings Longitudinal Trim	Delta CL due to flaps Delta CD due to flaps,landing gear CMTRIM (higher AOA range)
7. Short Period Excitation (Doublet, Step, Sinusoidal Pumping)	Short period frequency	CMAOA
8. Static Longitudinal Stability	Stick position gradient	CMAOA, CMDE
	Stick force gradient	Stick position gradient
	AOA gradient	CLAOA
9. Maneuvering longitudinal Stability	Stick position gradient	CMAOA, CMDE, CMO
	Stick force gradient	Stick position gradient, Bobweight
	AOA gradient	CLAOA
10. Stalls	Minimum airspeed	CLmax
	Rate of decent	Thrust-Drag Balance
	Oscillations, Buffet	Characteristics at high AOA

APPENDIX B

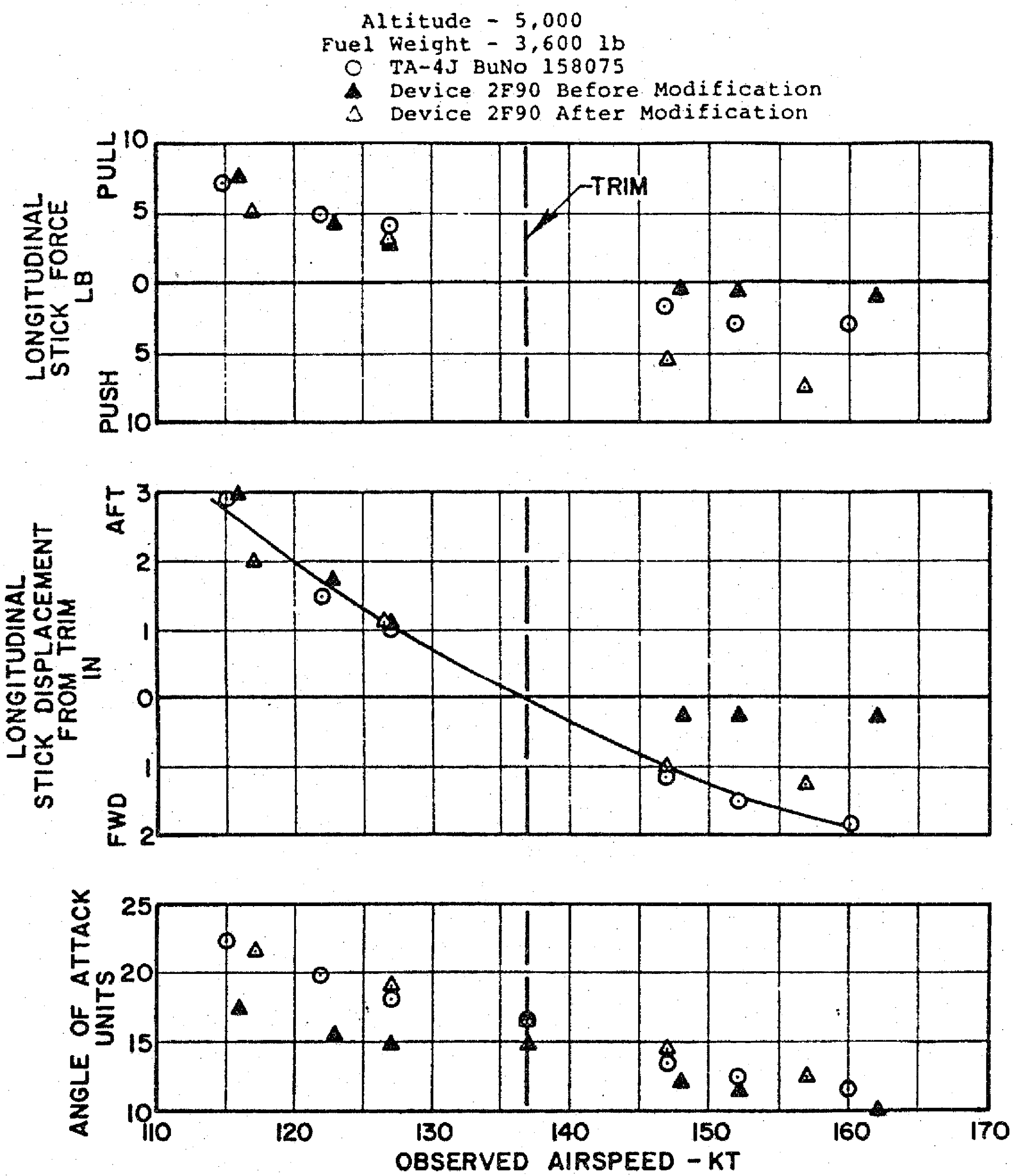
Table 2
ANALYSIS SEQUENCE FOR LATERAL-DIRECTIONAL PARAMETERS

TEST	TEST PARAMETER	SIMULATOR PARAMETER
1. Lateral & Directional Control System	Same as Longitudinal	Same as Longitudinal
2. Lateral Control Effectiveness	a. Initial roll response to partial deflection inputs	a. CLDA and CLP (1)
	b. Full deflection rolls	b. CNDA and CNP (2)
3. Dutch Roll	a. Frequency	a. CNBETA
	b. Damping	b. CNR
4. Steady Heading Sideslip	a. BETA/RUDDER slope	a. CNBETA, CNDR
	b. BANK/BETA slope	b. CYBETA
	c. AILERON/BANK slope	c. CLDA, CLBETA

NOTE: (1) CLDA and CLP must be considered simultaneously to adjust initial response although CLP can be adjusted somewhat independently matching bank angle overshoot after a step aileron return to neutral.

(2) CNDA and CNP must be considered simultaneously to adjust adverse yaw characteristics.

APPENDIX B
Figure 1



STATIC LONGITUDINAL STABILITY CHARACTERISTICS
Configuration PA
5,000 Feet

APPENDIX C

TEST METHODS GUIDE FOR FLIGHT TRAINERS

TABLE OF CONTENTS

INTRODUCTION

The purpose of this document is to provide a common basis for test methods utilized for acceptance testing of flight simulators. The intent is to foster a clear understanding between contractor and acquisition agency technical team members of the methods employed to demonstrate contract compliance. This document should serve as a starting point for developing the specific test methods to be used in each trainer acquisition program. Appropriate subject matter experts from the contractor and acquisition agency should discuss these test methods in the early stages of the trainer development program to minimize conflicts when the detailed TTPRR is generated. Early resolution of test methodology will reduce the schedule and technical risks that typically appear when testing begins.

This document was produced by engineering personnel who are experienced in the areas presented. Therefore, only certain portions of flight trainer technology are addressed in this version. It is envisioned that engineering personnel experienced in other technical areas such as acoustics and radar would contribute additional sections to this document. All sections will be subject to continuous updating by the cognizant experts as technology changes and as lessons are learned in trainer test methodology.

I. Flight Dynamics.

PURPOSE : The purpose of these tests is to verify that the operation of the flight dynamics programs for the simulated aircraft satisfy the specification requirements for flight fidelity.

METHOD: Tests will be conducted both manually and automatically. Automatic test methods are the preferred method but only after validation by comparison to manual test results.

Manual Tests: Test methods used shall conform to those defined in the U.S. Navy Test Pilot School Flight Test Manuals for both fixed wing and rotary wing aircraft. Personnel with knowledge and experience in flight test methods are required to conduct manual tests. Detailed analysis of the results requires a skilled aerodynamicist/flight test analyst.

Automatic Tests: Test methods employed by automatic flight fidelity test drivers shall also conform to those defined in USNTPS flight test manuals. Automatic test drivers will be validated by comparison to manually executed tests. Detailed analysis of the automatic test results requires a skilled aerodynamicist/flight test analyst. Simple pass/fail analysis capability shall be provided by displaying tolerance boundaries with the test results.

TEST EQUIPMENT: A means of recording data from the trainer is required (i.e., plotter, stripchart recorders, etc.) Test control and data recording control features should be implemented as part of the IOS.

TEST CONDITIONS: The trainer should be powered up and initialized to a state that reflects the specific flight test conditions for that test. The IOS should include pages and parameter controls to facilitate initialization to any specific flight test condition.

RESULTS FORMAT:

-A flight test page displaying aircraft parameters will be available at the IOS.
-Rapid hard copy capability should be provided.
-Both the IOS console and the trainee station will have the capability to activate data save.
-Output will be plotted as time histories and cross plots in an identical format to the criteria data contained in the TCR.
-Comparison of actual results and criteria data shall be automatic.
-All output will identify specific test conditions associated with that data, i.e., all information

TESTS:

1.0 Fixed Wing Aircraft (typical set).

a. Mechanical Characteristics (See Control Loader Test Methods)

b. Weight & Balance

c. Flying Qualities (SAS, AFCS ON/Off)
- Steady State Trim
- Longitudinal Trim Changes
- Static Longitudinal Stability
- Dynamic Longitudinal Stability
- Maneuvering Stability
- Static Lat/Dir Stability
- Dynamic Lat/Dir Stability
- Lateral Control Effectiveness
- Asymmetric Flying Qualities (thrust & stores)
  - Static & Dynamic Characteristics

d. Performance
- Cruise Performance
- Accel & Decel
- Climb & Descent
- Turn Performance
- Stall Characteristics (1-g & maneuvering)
- Buffet Characteristics (maneuvering & mach)

e. AFCS Characteristics

f. Ground Handling

g. Takeoff & Landing

h. Departure, Spin, & Spin Recovery

I. Power Plant
- Engine Dynamics
- Engine Steady-State
- Ground Starts
- Air Starts

j. Qualitative
- NATOPS Functional Check Flight
- Mission Tasks
- Aerial Refueling
- Formation Flight
- Formation Flight
- Carrier Operations
- Low Level
- Emergencies
- Weapons Delivery
- Approaches (TACAN, GCA, ILS, Etc)
- ACM

2.0 Rotary Wing Aircraft (typical set).

a. Mechanical Characteristics (See Control Loader Test Methods)

b. Weight & Balance

c. Flying Qualities (SAS, AFCS ON/OFF)
- Level Flight Trim Control Positions
- Static Longitudinal Stability
- Dynamic Longitudinal Stability
- Maneuvering Stability
- Static Lat/Dir Stability
- Dynamic Lat/Dir Stability
- Control Response
- Time Histories of Mission Maneuvers
- Frequency Sweeps

d. Performance
- Level Flight
- Climb and Descent
- Hover
- Blade Stall
- Autorotation

e. AFCS Characteristics

f. Ground Handling

g. Takeoff & Landing

h. Power Plant
- Engine Dynamics
- Engine Steady-State
- Ground Starts

i. Qualitative

- Autorotation
- NATOPS Functional Check Flight
- Mission Tasks
- Aerial Refueling
- Formation Flight
- Ship Board Operations
- Low Level
- Emergencies
- Weapons Delivery
- Approaches (TACAN, GCA, ILS, Etc)

II. Cue Synchronization and Transport Delay.

PURPOSE: To verify that total system end-to-end simulator response of the motion cue, visual display and instrument displays to cockpit control inputs meet the specification requirements.

METHOD: Tests will consist of introducing step and sinusoidal input commands and measuring the resulting cues. While it is desirable to drive the control stick physically, providing a true end to end test, this is usually not practical. Therefore, a signal generator connected at a point equivalent to the control stick deflection input should be used. End to end response measurements will be obtained for:

Motion - stick input to platform (or g-seat cell) response

Visual - stick input to visual display response

Instruments - stick input to instrument response

Tests will be structured so that aircraft lags will be eliminated. Typically this is accomplished by using special software that bypasses the effects of aerodynamic forces and moments but retains the associated computation time. During sinusoidal input testing the effects of any phase compensation schemes must not be bypassed.

TEST EQUIPMENT:

- High speed, high bandwidth stripchart recorder
- Accelerometer
- Signal Generator

TEST CONDITIONS:

Trainer should be powered up and initialized to an appropriate state.
Activation of special software associated with this test shall utilize normal trainer displays, controls, and software.

RESULTS FORMAT:

The outputs will be plotted on a time history strip chart recorder simultaneously with the stick input so the time responses can be directly compared. The source of the outputs for each type of system will be as follows:

Motion - For G-seat motion cues, the output will be the feedback pressure from one of the cells.

The motion platform response will be sensed by accelerometers mounted on the platform.

Visual - The visual response will be recorded using one of the RGB video drive signals for a raster display. For a calligraphic display, the response will be recorded using one of the deflection amplifier signals. Typically, special data base provisions are required to support this test.

Instruments - The instrument response will be recorded directly from the instrument drive signal. For HUD displays, direct measurement may not be possible and the signal will have to come from the INS command data via a signal bus analyzer to the strip chart recorder.

The test procedures will contain complete diagrams and drawings of equipment connection schematics for each system.

III. Control Loading.

PURPOSE: The purpose of these tests is two-fold: (1) to validate the simulation of the mechanical characteristics of the (aircraft name)flight control system; and (2) determine that the control loading system performance is in accordance with the specification requirements.

METHOD: These tests will be performed in sequence using the procedures outlined for each specific tests. The areas that will be checked include the characteristics of the control loader (friction, linearity of force/position transducers), and the characteristics of the simulated flight control system (control envelopes, trim, AFCS effects, etc.).

Two procedures should be provided for each of the tests. The first (high-fidelity) procedure utilizes the same equipment used to obtain the aircraft data. The second procedure utilizes common force and deflection measurement tools to emphasize speed, ease of setup, and repeatability and does not require the use of sophisticated test equipment.

The use of an Automatic Fidelity Test is acceptable after manual validation, but must always have tests for sensor calibration and mechanical characteristics not demonstrated by the auto test (i.e., linkage friction & freeplay).

TEST EQUIPMENT:

- Data recording device
- Force gauges
- Deflection measurement device
- Stop watch
- Control Force Measurement set or comparable equipment (if used to obtain aircraft criteria data)

TEST CONDITIONS: Trainer should be powered up and linked to a data recording device. Simulated aircraft systems are in the operating mode appropriate for the particular test being conducted. Control loading system performance tests may require special conditions to demonstrate bandwidth and other characteristics.

RESULTS FORMAT: Each test page should contain columns for actions required, expected results, and a blank column for recording actual results. Drawings indicating placement of test equipment (i.e., orientation with respect to the cockpit flight controls) should also be included. Results should be in both tabular and plotted form (as appropriate), showing criteria data and associated tolerances.

TESTS:

1.0 Control Loader Tests.

- Force Calibration (Linearity/scaling of force transducers)
- Position Calibration (linearity/scaling of position transducers)
- Friction & Stiffness
- Control Positioning Characteristics (freeze, reset, autotest)
- Dynamic Response (gain/phase shift)

2.0 Aircraft Flight Control System Simulation Tests.

- Control Rigging, Envelopes, Mixing
- Force vs Displacement Curves
- Trim System (freeplay, envelopes, rates)
- Centering, Jump, Dynamics
- Force Coupling
- Total System Freeplay
- AFCS Effects

IV. Motion Systems.

PURPOSE: The purpose of these tests is to verify that the simulation of motion cues felt by the trainee(s) is in accordance with the specification requirements.

METHOD: Both qualitative and quantitative tests will be conducted for the motion cuing system(s). The motion cuing system may consist of a motion base or platform, a seat-shaker, or a g-seat. The quantitative tests consist of measuring static and dynamic performance of the systems to ensure that the cuing systems have the capability to provide the required accelerations, velocities, positions, frequencies, and amplitudes, that may be required when coupled with the equations of motion and cuing software. Qualitative tests consist of pilot evaluations of cues provided during various flight maneuvers related to specification requirements. Also system safety features need to be verified as much as possible.

TEST EQUIPMENT:

- Accelerometers
- Power supply (if necessary)
- Signal generator
- Eight-channel strip-chart recorder
- Frequency analyzer (e.g. Bafco)
- Necessary cabling

TEST CONDITIONS: Depending upon system design, the trainer may require the motion cuing systems to be in a maintenance mode to drive system hardware with signals from the signal generator or potentiometers. During qualitative tests, the trainer must be in an integrated real-time mode with equations of motion and cuing algorithms in the loop. Visual cues should also be available for total cuing assessment.

RESULTS FORMAT: Strip-charts, tables of directly measured values, and subjective comments regarding quality of the cues.

TESTS:

1.0 Platform.

- Degree of Simulation
- Step Response
- Excursion Envelop
- Platform Velocities
- Accelerations and Onset Rates
- Leg Space Frequency Response -- All Legs Driven
- Leg Space Frequency Response -- Single Leg Driven
- DOF Space Frequency Response
- Damping
- Smoothness
- Stability
- Static Accuracy
- Crosstalk
- Drift
- Worst Case Test Maneuver
- Real-time Self-test
- Off-line Self-test

2.0 G-Seat. To be supplied

3.0 Seat Shaker. To be supplied

V. Flight Environment.

PURPOSE: The purpose of these tests is to verify that the simulation of both the meteorological and tactical environments are in accordance with the specification requirements.

METHOD: **Meteorological -** Several missions are entered to place the ownship in necessary locations to observe various atmospheric media and visual effects. System performance will be verified by monitoring cockpit instruments and IOS displays.

Tactical - Subsystem and mission test scenarios are entered to place the ownship in various tactical situations in order to assess the performance of the simulation.

TEST EQUIPMENT A means of recording data from the trainer is required (i.e., plotter, strip-chart recorder, printer, etc.).

TEST CONDITIONS: The trainer should be powered up and initialized to the specific condition appropriate for each test.

RESULTS FORMAT: **Meteorological -** For those tests (such as instrument response to ambient temperature and pressure) which are not purely qualitative, results should be reported in tabular format along with expected results and tolerances. Qualitative tests (ship burble, turbulence levels) should be graded as either satisfactory or unsatisfactory with supporting comments as needed.

Tactical - Results should be presented in tabular or graphical format as appropriate, in addition to a qualitative evaluation.

TESTS:

1.0 Meteorological factors affecting aircraft systems and flying qualities.

- Earth Atmosphere (temperature, pressure, density)
- Magnetic Variation
- Winds (steady, gusts)
- Turbulence
- Wind Shear
- Icing Conditions
- Weather
- Other Aircraft Airwake
- Landing Platform Motion/burble
- Pinnacle Burble

2.0 Tactical factors affecting tactical mission.

- Moving Model Dynamics
- Weapon Performance, Scoring
- Emissions
- Tactical Player Logic and Decision Making

VI. Computer System.

1.0 Software Testing.

Software testing as defined in current literature is the execution of a program to find its faults. In itself, software testing can never provide for a system that is totally reliable. This is because testing can show the presence of bugs, however, you can never test enough to show the absence of bugs. Therefore, in order to have a reasonable chance to develop reliable software, we must really address the software process rather than look at one aspect of the process that is testing.

Here at NAWCTSD, the software process that a contractor will use is extremely important, since we do not test software. We write TTPRR's which test overall functionality at the system level. The information provided on the pages to follow will aid the Project Engineer with some guidelines during the various testing phases of the software development process. Currently, no CDRL's support software testing during the development of a trainer.

Unfortunately, even the software process is not as firmly defined aas we might hope it to be. Both government and industry are making attempts to bound the software development process, however, there are no quick fixes. The Software Engineering Institutes evaluation process is one such attempt between government and industry to better define the software process to ensure more reliable software.

Four types of testing are of major importance during the software development process:

a. Unit Testing
b. Software Integration Testing
c. Function Testing
d. System Testing

Unit and integration testing are performed by the contractor as dictated by Mil-Std-2167A. Here at the Center, we perform a combination of functional and system test. This type of testing occurs during acceptance testing with a TTPRR. The function test is somewhat of an ad hoc test (we no longer purchase computer program test procedures (cptp's)) where by we exercise the software through the use of the TTPRR and determine if the functionality meets the system requirements. The system test through the use of the TTPRR tells us if the overall system performs and acts like the real thing.

1.1 Unit Testing. Unit testing as defined by DOD-STD-2167A requires the folllowing as a minimum:

a. Reestablishment of the test cases. (These will reside in the SDF's)
b. The test cases shall be in terms of inputs, expected results, and evaluation criteria.
c. Stressing the software at the limits of its specified requirements.

The contractor is required to record all this information in the software development files (SDF's)

In addition to this the Software Engineering Institute (SEI) in its book, "Managing the Software Process" provides a unit test checklist which can be helpful while reviewing the unit tests in the contractors SDF's. They are as follows:

a. Is the design clear? Does it do what is intended?
b. Is the coding clear? Did you have trouble understanding it?
c. Are the comments helpful in understanding the routine?
d. Would you have trouble modifying it?
e. Would you be proud of this work it it were yours?
f. Does the code meet the established coding standards?
g. Does input data vary, including maximum, minimum, and nominal values? (All alike data, especially all zeros, is usually a poor choice.)
h. Is erroneous input data used? (All error conditions should be checked.) Can you think of erroneous data conditions that were not used?
i. Do the tests show that the routine has functional capabilities allocated to it?
j. Do the tests demonstrate that the code completely satisfies each requirement allocated to it?
k. Does the actual output match the expected output?

Tools also have become an essential part of the software development and testing process. Many tools are provided as part of the Ada Programming Support Environment (APSE). Several tools have been identified as essential to the testing process which includes coverage/frequency analyzers (i.e. McCabes) and logic analyzers. Coverage/frequency analysis tools assess test adequacy measures associated with the invocation of program structural elements. Coverage analysis is useful when attempting to execute each statement, branch, path, or program. It is recommended that the contractor use these tools as well as other tools provided for as part of the APSE.

1.2 Integration Testing. Integration testing involves putting two or more units together and testing the software interfaces between these units. Once these units have been successfully integrated into a CSC, the CSC integration testing may take place. The proper approach to integration depends on both the kind of system being built and the nature of the development project. On very large systems it is often wise to do integration testing in several steps. Such systems generally have several relatively large components that can be built and integrated separately before combination into a full system. Since integration is a process of incrementally building a building a system, there is often a need to have special groups do this work. In building large software systems, build experts often integrate the components in system builds, maintain configuration management control, and distribute the builds back to development for unit test. These experts work with development to establish an integration plan and then build the drivers and integrate the system.

The key considerations in a system build are detailed planning and tight control. The plan specifies the number of builds and their schedules. At one extreme you take all the units put them together with only one build. This is the big bang integration. The recommended approach is the opposite in which there is continuous integration. This has turned out to be the most successful approach for large systems.

1.2.1 Software Development Files. It is helpful and mandated by DOD-STD-2167A to establish a development file system to retain information during the design process and for the test plan in general as well as for each test and test case. This file should contain the following:

a. Specifications
b. Design
c. Documentation
d. Review History
e. Test History
f. Schedule and Status Information
g. Test Requirements and Responsibilities
h. Test Cases
i. Test Procedures
j. Anticipated Results
k. and success criteria for each test case.

It is highly recommended that the SDF's be retained in electronic format under a centralized control preferably configuration management. In this way SDF's can be tracked with a check out and check in library system.

1.3 Function Testing. Functional tests are designed to exercise the program to its external specifications. The testers are typically not biased by knowledge of the program's design and thus will likely provide tests that resemble the user's environment. The two most typical problems with functional testing are the need for explicitly stated requirements and the ability of such tests to cover only a small portion of the possible test conditions.

In almost all cases exhaustive functional testing is impossible, these tests should be viewed as a statistical sampling; when errors are found, a closer examiniation is required.
Functional testing starts by examining the functions the program is to perform and devising a sequence of inputs to test them. Test cases can be developed for all valid input conditions and options at nominal values, at their limits, and beyond these limits.

1.4 System Test.

The purpose of the system test is to find those cases in chich the system does not work as intended, regardless of the specifications. If the system fails these tests, the debate about whether or not it meets specifications is really an argument over who is at fault and who should pay for repair. Concern about these issues often causes contractor management to insist that system testing be limited to the requirements and specifications. While this defers such problems, it makes them more damaging and expensive when later found by users. Regardless of what the contract says, if the system does not meet the users' real needs everyone loses.

2.0 Conclusion.

While rigorous unit and integration testing will add confidence that a system has few errors, the contractor has the responsibility to perform adequate analysis (through the use of software tools) and testing throughout the software development cycle, especially in areas which he considers to be at risk. In today's climate of streamlining and performance based requirements, it is more appropriate for the contractor to apply his specialized knowledge of the details of the system to determine the amount and depth of testing of the systems components parts including software units.

VII. Visual System.

PURPOSE: The purpose of these tests is to verify that the visual simulation system complies with specification requirements. The following material is intended to facilitate planning and management of visual system testing by providing an overview; however, it is not a stand alone guide to visual system testing.

METHOD: Qualitative and quantitative tests of the visual system will be conducted. Most characteristics will be verified by end to end tests using test images produced from environment data vases in the same way that training scenes are produced. Many artifacts such as raster noise are verified by simply observing that the effects are not manifested during the testing process, including the examination of scenes in which they are likely to occur. Special effects such as weather and weapon effects are evaluated by a comparison of the achieved performance to specification requirements and approved design decisions. Environment data base testing is very individualized, depending on the kind of data base, the extent of quality assurance in the design process, and other factors. A combination of direct observation during task performance, checklist verification of the presence of required features, statistical sampling and the like are typically used.

Testing methods and the extent of testing vary considerably from one system to the next because of the difference in complexity, cost, and criticality of different aspects of the visual simulation. For example, freedom from geometric distortions may be absolutely essential in some applications and a relatively minor consideration in others where resolution or some other parameter is the critical issue. Consequently, a competent visual specialist must oversee development of test plans and procedures.

TEST EQUIPMENT: Primary measuring instruments are photometers for luminance and theodolites for angles. Specialized variations of these instruments and other specialized instruments will be used to facilitate the test process. For example, a slit photometer is usually used if mtf (modulation transfer function) measurements are required. Special fixtures for mounting theodolites and other instruments are usually required to obtain precise results. Laser spots are often projected through the theodolite optics to permit direct viewing of the aim point on the screen. Operational Night Vision Goggles are used to evaluate the night scene when such is specified. A key problem to be overcome is locating the test instrument at the design eyepoint. Ejection seats and other structures obstruct the needed test setup. Furthermore, it is usually difficult to accurately locate the design eyepoint, and be sure that it corresponds to the same point in the weapon system.

TEST CONDITIONS: Many of the tests can be conducted independently of the host simulation, but some depend on inputs from the host and cannot be conducted independently. Almost all tests must be performed with the simulator crew station in its normal operating condition except for removal of seats and other adaptations which may be required to accommodate instruments. Projection drive levels are especially important considerations. Most performance requirements must be met for all image positions (on screen) and all viewing positions within the specified eye envelope.

RESULTS FORMAT: Tabulated measurement data with spaces for calculated results and intermediate values should be used whenever multiple entry of similar data is required. The tabulated data shall be logically correlated with test conditions and requirements information in the tables. Both verification check columns and comment space should be provided for the results of qualitative tests. Space for entry of comments and notes should be provided.

TESTS: The following tests are typical of the required tests.

1.0 General training scene requirements.

Airfield scenes
Formation flight Scenes
Ocean scenes
Shipboard landing scenes
Anti-submarine warfare scenes
Anti-ship tactical scenes
Sea search and rescue
Strike search and rescue
Terrain flight scenes
Confined area landing (CAL) scene
Vertical replenishment
In-flight refueling

2.0 Special real-time processing.

a. Atmospheric and meteorological effects.

Cloud simulation
Ambient visibility (haze)
Fog simulation
Rain simulation
Lightning
Sky and horizon
Storm cells
Illumination
Time of day
Artificial illumination
Landing lights and search lights
Floodlights
Illumination glare
Flares
Special lights
Fresnel Lens Optical Landing System
Stabilized Glideslope Indicator (SGSI)
Glide Angle Indicator Light (GAIL)
Visual Approach Slope Indicator (VASI)
Approach Strobe Lights
Runway End Identification Light System
Beacons (Fixed)
Beacons (Rotating)
Directional Lighs
Other aircraft lights
Light Point Intensity Control

b. Visual simulation of motion

Ownship dynamics
Moving models
Animation and special effects
Rotor disc
Rotor wash

Landing signal, Enlisted (LSE)
Helicopter support team
Weapon effects
Marine markers

c. Special geometric computations.

Simulated position
Collision and surface contact
Radar altitude

d. Image quality.

Field of view
Visual image sharpness
Surface resolution
Impulse response
Light point resolution
Critical item resolution
Luminance
Luminance variation
Contrast
Display region performance
Color
Color processing
Color registration
Image perspective and geometric accuracy
Total geometric distortion
Relative geometric errors
Vernier resolution
Adjacent channel matching
Image stability
Video rates
Update rate
Transport delay
Smear
Flicker
Stepping
Occulting (hidden surface elimination)

e. Image quantity (system capacity).

Continuous image density
Terrain density and accuracy
Other feature density and distribution
Light point considerations
Scene content management
Scene management dynamics
Overload prevention

f. Night vision goggle (NVG) simulation.

Simplified NVG shadow simulation
Modeled NVG terrain
NVG scene contrast
Lunar and stellar image and illumination
Artificial illumination

Flares
Moving Models
Object detail

g. Design requirements.

Visual environment design
Compensation for image system limitations
Environment Continuity and blending
Programmable parameters

3.0 Major component characteristics.

a. Image generator subsystem.

Image generation system throughput
Displayed Image Artifacts
Anti-aliasing
Texture and Photographic Imagery
Mapping
Anti-aliasing and blending
Image data quantity
Dynamic texture
Transparency
Shading

b. Displays.

Viewing volume
Image distance
Optics

4.0 Image data base development system.

a. Image data base.

General data base design requirements
Deliverable training environments
West Coast Training Environment
Cross country navigation area
Primary airfields
Secondary airfields
Alternate airfields
Terrain flight region
Confined area landing (CAL) sites
Jacksonville Training Environment
Cross country navigation areas
Primary airfields
Secondary airfields
Alternate airfields
Terrain flight regions
Confined area landing (CAL) sites
Norfolk Training Environment
Cross country navigation areas
Primary airfields

Secondary airfields
Alternate airfields
Terrain flight regions
Confined area landing (CAL) sites
General use terrain flight regions
Deliverable general use models
Requirements for specific areas and models
Cross country navigation areas
Real-world feature models
Real-world feature capture criteria
Airfield area requirements
Primary airfields
Secondary airfields
Surrounding area
Generic airfields
Terrain flight regions
Confined area landing sites
Generic terrain
Generic ocean
High detail dynamic ocean
General use models
Parent ships
Formation aircraft
Other models
General data base requirements
Generic fill-in and scene enrichment
Level of detail
Data base compatibility
DMA data selection

b. Operation and maintenance facilities.

Operating and maintenance software
Remote control unit
Maintenance console

APPENDIX D

FIXED WING DATA REQUIREMENTS

10. GENERAL

10.1 Scope. This appendix provides a guide of flight test data requirements for use as simulator criteria and simulator validation data.

20. APPLICABLE DOCUMENTS. Not applicable to this appendix.

30. DEFINITIONS. Not applicable to this appendix.

40. GENERAL REQUIREMENTS.

40.1 Data requirements. Data requirements listed in this appendix are comprised of:

a. Minimum data required from the subject test.

b. Supporting data to verify the quality of the test maneuver.

40.2 Data format. Data format depends on the characteristic being described. Suggested data format is one of or a combination of the following:

Tabulation
Crossplot
Time history

40.3 Documentation. Documentation of test conditions is imperative for data to be usable. See notes at the end of this appendix for documentation requirements applicable to all tests unless modified under a particular test. Any additional documentation necessary to further define conditions of a specific test is cited under the subject test. Annotation requirements on time histories are specified where required to define pertinent test maneuver events.

50. DATA LIST

50.1 Weight and balance/inertia characteristics.

Test	Data	Remarks
50.1.1 Aircraft/Store weight and balance.		
Weight and balance	a. Aircraft operating gross weight range without stores	See NOTE 1 at end of appendix
	b. Aircraft fuel moment (long, lat, vert) vs fuel weight for each fuel tank	
	c. Effect on aircraft CG (long, lat, vert) of each aircraft configuration change (flaps, landing gear, deployable devices, etc)	
	d. Effect on CG of representative store weights (long, lat, vert in convention of aircraft CG dimensions)	
	Tabulation Documentation:	
	Source of data (reference, actual weight and balance, etc)	
50.1.2 Inertia characteristics.		
	Crossplot:	
	a. Moments and products of inertia vs gross weight	For fuel consumption store loadings, variable geometry (wing sweep, landing gear).

Test	Data	Remarks
50.2	Flight control systems characteristics.	

50.2.1 Primary flight control system mechanical characteristics (See Note 2).

Test	Data	Remarks
Static Characteristics	Tabulation: a. Cockpit controls (1) Max positions (2) Freeplay (3) Centering range (4) Breakout force (5) Friction at two deflections each side of neutral	Normal status, degraded status (e.g., Boost OFF, backup flight control system, etc) (as applicable) include effects of flaps, Mach, etc.
	b. Control Surface Characteristics: (1) Max deflections (2) Max rate of operation	
	Crossplots: a. Control force vs cockpit control position. b. Control force vs control surface position c. Cockpit control position vs control surface position. d. (If applicable) Control system coupling (e.g., aileron-rudder interconnect)	Irreversible control systems: Trim setting zero, and each extreme
	Crossplot documentation: 1. Ground tests: (a) NOTE (4) (b) Average winds In-flight tests: NOTE (4) 2. Flight control trim setting 3. Convention of measurement (a) Cockpit control (whether MIM, Other)	MIM: Maintenance Instruction Manual

Test	Data	Remarks
	(b) Control Surface (whether MIM, w.r.t. fixed surface, other)	
Dynamic charac- teristics	Time history: a. Control force b. Cockpit control position c. Control surface position	Reversible control systems: (1) Control releases
	d. Computer-driven flight control schedules (limiters scheduled surface deflections, etc)	Irreversible control systems: (1) Control releases
	Additional items for in-flight frequency sweeps e. Calibrated airspeed f. Indicated press altitude	(2) Constant amplitude
	g. AOA (true and production) (cockpit indicated) h. Angle of sideslip i. Attitudes (including heading) j. Angular rates k. Longitudinal, lateral, normal acceleration (pilot's seat and CG)	Frequency sweeps (min to max frequency)
	Time history documentation: 1. Ground tests: (a) NOTE (4) (b) Hydraulic power source (external, or engine (list no. of on-line hydraulic pumps)) In-flight tests: NOTE (4)	

Test	Data	Remarks
50.2.2 Secondary tabulation.		
Control system mechanical characteristics (Trim systems, flaps, landing gear, speedbrake	a. Cockpit control characteristics: (1) Detent/max deflections (2) Freeplay (3) Breakout force (include friction) b. Surface/control characteristics:	
Engine control, nosewheel steering, direct lift control, etc) (See NOTE (2))	(1) Max deflections (2) Computer-driven flight control schedules (e.g., limit-scheduled surface)	
	Tabulation documentation: 1. Ground and in-flight tests See NOTE (4)	
Flight control system response to command and sensor inputs		Ground test
Static gain tests	Cross plots: a. Control surface position vs each control law input showing hysteresis effects	Flight control component gains and frequency responses checked on bench prior to test
Step response	Time history: a. Control surface positions b. Control law inputs and outputs	Commands and sensors calibrated prior to test. If feasible, conduct static gain tests with sensors removed from aircraft and mounted on calibration equipment. Otherwise, use signal substitu-
Frequency response	Cross plots and tabulations frequency vs. phase and gain: a. Control surface position	

Test	Data	Remarks
	b. Control law inputs positions Time history: a. Control surface positions b. Control law inputs and outputs Documentation: a. NOTE (4) b. Flight control com- ponent serial numbers c. Flight control schedule input values d. Hydraulic power source	tion method

50.3 <u>Engine operation characteristics.</u>

50.3.1 <u>Engine start/shutdown (ground and in-flight).</u>

Test	Data	Remarks
	Time history: a. Cockpit engine con- trol position b. Engine thrust c. Engine RPM d. Turbine (gas) tempera- ture e. Fuel flow Additional items for in-flight: f. Calibrated airspeed g. Calibrated press, altitude h. Angle of attack (true) i. Angle of sideslip Time history annotation: 1. Commencement of start/ shutdown sequence 2. Attainment of intermediate start/shutdown criteria 3. End of start/shutdown cycle 4. Other cockpit engine control (a) Initial and change in setting (e.g., condition lever) 5. Oil pressure changes	Normal and emergency shutdown procedures.

Test	Data	Remarks
	Time history documentation: 1. Ground tests: (a) NOTE 4 (b) Wind speed and relative direction In-flight tests: NOTE (4) 2. Copy of handbook start/ shutdown procedures	

50.3.2 <u>Engine static operation.</u>

Test	Data	Remarks
Ground	Crossplots: Cockpit engine control position vs: a. Engine thrust b. Turbine (gas) temp c. Fuel flow d. Engine RPM Crossplot documentation: 1. NOTE (4) 2. Wind speed and relative direction 3. Bleed status	Engine bleeds ON and OFF
In-flight	Crossplots: a. Referred values appropriate to the installed power plant b. Variable geometry positions as function of driving variable(s) (s) (inlet geometry, exhaust nozzle position, etc.) Crossplot documentation: 1. NOTE (4) including range of calibrated airspeed, calibrated press altitude 2. Bleed status 3. Electrical load status	Engine bleeds ON and OFF. Electrical load ON and OFF.

Test	Data	Remarks
	Tabulation: (a) Limits (RPM, fuel flow, etc) and datum shifts as function of flight condition	Effect of power extraction and bleed demands

50.3.3 Engine dynamic operation.

Test	Data	Remarks
Ground	Time history: a. Cockpit engine control position b. Engine thrust c. Engine RPM d. Turbine (gas) temperature e. Fuel flow Time history documentation: 1. NOTE (4) 2. Wind speed and relative direction 3. Bleed status	Small and large step thrust changes. Effect of power extraction and bleed demands.
In-Flight	(included in Test 50.9.11, Trim changes)	Effect of power extraction and bleed demands.

50.4 Ground handling characteristics.

50.4.1 Ground taxi.

Test	Data	Remarks
	Tabulation: a. Engine thrust commence ground roll b. Engine thrust to maintain taxi speed (straight, turning track) c. Distance to stop from representative taxi speed	Two gross weights. Symmetric and asymmetric engine operation(if applicable). High and low engine RPM.

Test	Data	Remarks
	Tabulation documentation: 1. NOTE (4) 2. Engine(s) operating (identify by engine number) 3. Wind speed and relative direction	
	Crossplot: (a) Turn radius vs nosewheel steering angle	Two representative taxi speeds (no brake application).
	Crossplot documentation: 1. NOTE (4) 2. Average ground speed 3. Wind speed and relative direction	

50.5 <u>Takeoff characteristics.</u>

50.5.1 <u>Catapult launch.</u>

Test	Data	Remarks
	Time history: a. Control forces b. Cockpit control positions c. Control surface positions d. Flight control trim settings e. Attitudes f. Angular rates g. Heading h. Engine thrust i. Cockpit engine control position j. Angle of attack (production) k. Angle of sideslip l. Calibrated airspeed m. Indicated pressure altitude n. Longitudinal acceleration (CG) o. Normal acceleration p. Radar altitude (optional)	All engines operating. One engine inoperative.

Test	Data	Remarks
	Time history documentation: 1. NOTE (4) 2. Flight control trim settings 3. Carrier data (a) Wind-over-deck and relative direction (b) Carrier track (straight, or turning & direction) (c) Catapult no. and whether waist or bow (d) Name of carrier	
50.5.2 <u>Field takeoff.</u>		
	Time history: a. Calibrated airspeed b. Indicted press altitude c. Horizontal distance traveled d. Attitudes e. Heading f. Engine thrust g. Nosewheel steering angle h. Control forces i. Control surface positions j. Radar altitude (optional) k. Angle of attack (production) l. Longitudinal acceleration (CG) m. Normal acceleration (CG) n. Ground speed o. Flap position Additional items for crosswind takeoffs p. Lateral acceleration (pilot's seat and CG) q. Lateral displacement from runway centerline r. Yaw rate	All engines operating. One engine failure during take-off roll. Also high crosswind.

Test	Data	Remarks
	Time history annotation: 1. Brake release 2. Initiate rotation 3. Landing gear commence UP Time history documentation: 1. NOTE (4) 2. Flight control trim settings 3. Wind speed and relative direction	

50.6 Landing characteristics.

50.6.1 Arrestments.

	Time history: a. Control forces b. Cockpit control positions c. Control surface positions d. Flight control trim settings e. Attitudes f. Angular rates g. Heading h. Engine thrust i. Cockpit engine control j. Angle of attack (production k. Angle of sideslip l. Calibrated airspeed m. Calibrated press. altitude n. Longitudinal acceleration (CG) o. Normal acceleration (Pilot's seat and CG) p. Radar altitude (optional) Time history annotation: 1. Distance to touchdown (1/4 mi increments) 2. Passage over rounddown Time history documentation: 1. NOTE (4) 2. Engine(s) operating	Commence one-mile from touchdown. All engines operating. One engine inoperative. Include off-center arrestments.

Test	Data	Remarks
	(identify by engine number) 3. Carrier data (a) Wind-over-deck and relative direction (b) Carrier track (straight, or turning & direction) (c) Carrier speed (d) FLOLS settings (e) Name of carrier	
50.6.2 Field landing.		
	Time history from a. Calibrated airspeed b. Calibrated press altitude c. Horizontal distance traveled d. Attitudes e. Heading f. Engine thrust g. Nosewheel steering h. Control forces i. Radar altitude (optional) j. Angle of attack (production) k. Glide path	All engines operating with two methods of braking. One or more engines inoperative (simulated and actual failed). Also with/ without aerodynamic braking. Also with and without reverse thrust. Also with high crosswind.
	Time history annotation: 1. Initiation of change in landing gear/flap position 2. Touchdown 3. Initiation of deceleration device deployment 4. Antiskid cutout 5. Initiation/degree of braking (moderate, heavy, etc)	
	Time history documentation: 1. NOTE (4) 2. Initial drag device position 3. Antiskid ON or OFF 4. Wind speed and relative direction	

Test	Data	Remarks
	Crossplot: Gross weight vs: (a) Calibrated airspeed (b) Flight control trim settings (all axes) (c) Engine thrust setting	

50.7 In-flight performance characteristics.

50.7.1 Climb performance.

Test	Data	Remarks
Normal climb	Crossplot: Calibrated press. altitude vs: a. Time b. Fuel used c. Horizontal distance traveled d. Rate of climb e. Cockpit engine control position f. Engine thrust g. Pitch attitude h. Flight control trim settings i. Calibrated airspeed j. Ambient temperature	Continuous climb: sea level to service ceiling.
Degraded climb	Crossplot: Calibrated airspeed vs: a. Rate of climb b. Pitch attitude	Sawtooth climbs. All engines operating. One or more engines inoperative. Also with landing gear extended. Also with flaps extended.

50.7.2 <u>Level flight performance.</u>

Test	Data	Remarks
	Crossplot: Calibrated airspeed vs: a. Cockpit engine control position b. Engine thrust c. Turbine (gas)	All engines operating. One or more engines inoperative. Also with drag devices deployed. Also with mission devices

Test	Data	Remarks
	temperature d. Fuel flow e. Engine RPM f. Pitch attitude g. Angle of attack (true and production) h. Control surface positions i. Flight control trim settings	deployed (if significant drag change). All effects of sideslip in landing configuration. See also item 50.3.2.
50.7.3 Level flight accel/decl.		
	Time history: a. Calibrated airspeed b. Calibrated press altitude c. Pitch attitude d. Angle of attack (true and production) e. Cockpit engine control position f. Engine thrust g. Fuel used h. Longitudinal acceleration i. Normal acceleration j. Control surface positions	Also with drag devices deployed. Also in landing configuration.
50.7.4 Sustained turning performance.		
	Crossplot: Calibrated airspeed vs: a. Normal acceleration b. Radius of turn c. Rate of turn	Maximum thrust
50.7.5 Instantaneous turning performance.		
	Crossplot: 1. Normal acceleration vs Mach no., showing lines of (a) Onset buffet (b) Tracking buffet (c) Limit buffet (d) Aerodynamic limit	

Test	Data	Remarks
50.7.6 Descent performance.	Crossplot: Calibrated press altitude vs: a. Time b. Fuel used c. Horizontal distance traveled d. Rate of descent e. Cockpit engine control f. Engine thrust g. Pitch attitude h. Flight control trim settings i. Calibrated airspeed j. Ambient temperature	
50.8 Pitot-static system position error characteristics.		
50.8.1 Position error correction (production pitot-static system).	Crossplot: a. Airspeed correction vs indicated airspeed b. Altitude correction vs indicated pressure altitude	In flight: All configurations. In-ground effect: takeoff and land configurations. Alternate static source (if applicable).
50.9 Stability and control characteristics.		
50.9.1 Static longitudinal stability.	Crossplot: Calibrated airspeed vs: a. Longitudinal control force b. Longitudinal control position c. Elevator position d. Rate of climb e. Angle of attack (production)	Cockpit engine control position. Unchanged from trim condition. Stability enhancing systems ON and OFF.

Test	Data	Remarks
	Added documentation: 1. Flight control trim settings	

50.9.2 <u>Dynamic longitudinal stability.</u>

Test	Data	Remarks
Short and long period modes	Tabulation: a. Frequency b. Damping ratio	Stick-fixed and stick-free. Stability enhancing systems ON and OFF.
	Time history: a. Longitudinal control force b. Elevator position c. Angle of attack (production and true) d. Normal acceleration (pilot's seat and CG) e. Pitch rate f. Pitch attitude g. Engine thrust	At least three complete cycles following excitation maneuver.
	Added measurements for long period: h. Calibrated airspeed i. Indicated press. altitude j. Engine thrust	

50.9.3 <u>Longitudinal maneuvering stability.</u>

Test	Data	Remarks
	Crossplot: CG Normal acceleration vs: a. Longitudinal control force b. Longitudinal cockpit control position c. Elevator position d. Angle of attack (true and production) e. Calibrated airspeed f. Indicated press altitude Added documentation: 1. Type of maneuver - Windup/	

Test	Data	Remarks
	steady turn (include direction of turn), steady pull-up, etc.	

50.9.4 Longitudinal control effectiveness (ground).

Test	Data	Remarks
	Time history: a. Calibrated airspeed b. Longitudinal control force c. Longitudinal cockpit control position d. Elevator position e. Pitch attitude f. Pitch rate g. Engine thrust Time history annotation: 1. Nosewheel lift-off point Added documentation: 1. Wind speed and relative direction	Nosewheel lift-off.

50.9.5 Lateral and directional control effectiveness (ground).

Test	Data	Remarks
	Tabulation: a. Minimum indicated airspeed for aileron effectiveness b. Minimum indicated airspeed for rudder effectiveness c. Engine thrust Added documentation: 1. Type of maneuver and criteria	

Test	Data	Remarks
50.9.6 Longitudinal and directional control effectiveness (in-flight).		
	Time history a. Control force b. Cockpit control position c. Control surface position d. Pitch attitude e. Roll attitude f. Heading g. Pitch rate h. Roll rates i. Yaw rate j. Angle of attack (true and production) k. Angle of sideslip l. Calibrated airspeed m. Indicated press. altitude n. Lateral acceleration (pilot's seat and CG) o. Normal acceleration (pilot's seat and CG)	Step control input on a single axis commencing from constant-altitude wings-level flight 5, 10, 20, 50%, 100%. Deflections not to exceed aircraft structural, attitude or aerodynamic limits.
50.9.7 Lateral control effectiveness (in-flight).		
	Crossplot: Calibrated airspeed vs a. Time for control input b. Peak rate of roll c. Bank angle change in first second d. Roll mode time constant Sample time histories: a. Cockpit forces b. Cockpit control positions c. Control surface positions d. Pitch attitude e. Bank angle f. Heading g. Pitch rate h. Roll rate	5, 10, 20, 50, 100% step control inputs (commence from constant-altitude wing-level flight whenever possible). Selected points with and without lat-dir stability enhancing systems operating

Test	Data	Remarks
	j. Angle of attack (true and production) k. Angle of sideslip l. Calibrated airspeed m. Indicated press altitude n. Lateral acceleration (pilot's seat and CG) o. Normal acceleration (pilot's seat and CG)	

50.9.8 Static lateral-directional stability.

Test	Data	Remarks
	Crossplot: Angle of sideslip vs a. Lateral control force b. Lateral cockpit control position c. Ailerson position d. Rudder control force e. Rudder pedal position f. Rudder position g. Bank angle h. Turn-and-slip ball position i. Production airspeed system correction-to-be-added j. Production angle of attack system correction-to-be-added k. Longitudinal control force	

50.9.9 Dynamic lateral-directional stability.

Test	Data	Remarks
Dutch roll mode	Tabulation: a. Frequency b. Damping ratio c. Roll-to-yaw ratio Time history: a. Control forces b. Cockpit control positions c. Control surface positions d. Bank angle	Stability enhancing systems ON and OFF controls-fixed and controls-free.

Test	Data	Remarks
	e. Heading f. Roll rate g. Yaw rate h. Angle of sideslip i. Lateral acceleration (CG)	
Spiral mode	Time history: a. Rudder pedal force b. Rudder position c. Lateral control force d. Aileron position e. Bank angle f. Calibrated airspeed g. Indicated press altitude h. Pitch attitude Time history annotation: 1. Control release	Release at bank angle. Ensure rudder surface and aileron surface positions are at exactly trim value.

50.9.10 <u>Coordinated turn (constant altitude).</u>

Test	Data	Remarks
	Time history: a. Control forces b. Cockpit control positions c. Control surface positions d. Pitch attitude e. Bank angle f. Heading g. Angle of attack (true and production) h. Angle of sideslip i. Normal acceleration (pilot's seat and CG) j. Lateral acceleration (pilot's seat and CG)	LT and RT turn. Include entire sequence of level flight, roll-in 360 degree turn, roll out to level flight.

Test	Data	Remarks
50.9.11 Trim changes.		
Configuration changes, thrust changes, and run-away trim	Time history for configuration: a. Calibrated airspeed b. Calibrated press. altitude c. Control forces d. Cockpit control e. Control surface positions f. Pitch attitude g. Bank angle h. Heading i. Pitch rate j. Roll rate k. Yaw rate l. Angle of attack (production) m. Angle of sideslip n. Normal acceleration (pilot's seat and CG) o. Longitudinal acceleration (CG) p. Configuration change position to pin-point initiation of system change, define rate of operation and max deflections (e.g., flaps, landing gear, spoilers, etc.)	Open and closed loop, with emphasis on open loop. Closed loop tests per table XV of MIL-F-8785C. Small and large step thrust changes w/ bleeds ON and OFF.
	Additional data for thrust changes: q. Cockpit engine control position r. Engine thrust s. Engine RPM t. Turbine (gas) temperature u. Fuel flow	Small and large step thrust changes w/ bleeds ON and OFF. Include bleed and power extraction activation and deactivation.

Test	Data	Remarks
	Additional data for runaway trim: q. Flight control trim settings (all axes) Time history annotation: (applies if change item is not instrumented) 1. Initiation of pilot action 2. Completion of pilot action 3. Completion of configuration change	
50.9.12 Stall.		
Normal and accelerated	Time history: a. Control forces b. Cockpit control positions c. Control surface positions d. Pitch attitude e. Bank angle f. Heading (optional) g. Pitch rate h. Roll rate i. Yaw rate j. Angle of attack (true and production) k. Angle of sideslip l. Normal acceleration m. Lateral acceleration n. Indicated airspeed o. Indicated press. altitude p. Cockpit engine control position q. Engine thrust Time history annotation: 1. Onset of buffet 2. Marked change in control effectiveness	Accelerated stall: Decel at constant G Two G's.

Test	Data	Remarks
	3. Stall 4. Initiation of artificial recovery devices	
50.9.13 Asymmetric Power.		
In-flight static	Crossplot: Calibrated airspeed vs: a. Control forces b. Cockpit control positions c. Control surface positions d. Angle of bank e. Angle of sideslip f. Angle of attack (true and production) Added documentation: 1. Failed engine status (actual or simulated) 2. Minimum trim airspeed	0 and 5 degree angle angle of bank. Several airspeeds combinations of engine(s)-out. Separate left and right engine(s)-out if there is a critical engine.
In-flight dynamics	Time history: a. Control forces b. Cockpit control positions c. Surface positions d. Pitch attitude e. Bank angle f. Heading (optional) g. Pitch rate h. Roll rate i. Yaw rate j. Angle of attack (true and production) k. Angle of sideslip l. Normal acceleration (pilot's seat and CG) m. Lateral acceleration (pilot's seat and CG) n. Calibrated airspeed o. Indicated press. altitude p. Cockpit engine control	

Test	Data	Remarks
	position q. Engine thrust Added documentation: 1. Minimum control airspeed	
Ground dynamics	Tabulation: 1. Minimum control airspeed Time history: a-q (same as in-flight dynamics) r. Lateral displacement from runway centerline	Range of thrust asymmetry

50.9.14 Transonic/supersonic characteristics.

Static longitudinal stability	Same as Section 50.9.1 except use Mach instead of calibrated airspeed	Constant altitude accel and decel.
Dynamic longitudinal stability short period	Same as Section 50.9.2 except use Mach instead of calibrated airspeed	
Longitudinal maneuvering	Same as Section 59.9.3 except use Mach instead of calibrated airspeed Perform wind-down turns	
Lateral control effectiveness	Same as Section 50.9.7 except use Mach instead of calibrated airspeed	
Static Lateral-directional stability	Same as Section 50.9.8	
Dynamic lateral-directional stability - Dutch roll	Same as Section 50.9.9 except use Mach instead of calibrated airspeed	

Test	Data	Remarks
Speedbrake effectiveness	Same as Section 50.9.11 except use Mach instead of calibrated airspeed Speedbrake position Time history annotation: 1. Transonic buffet onset and subsidence	

50.9.15 Ground effect.

Test	Data	Remarks
	Crossplot: Height AGL vs: a. Elevator position b. Engine thrust c. Indicated airspeed Crossplot documentation: 1. Wind speed and relative direction (if specific ground track heading maintained) Time history: a. Control forces b. Control surface positions c. Indicated airspeed d. Indicated press. altitude e. Radar altitude (optional) f. Angle of attack (true and production) g. Pitch attitude h. Cockpit engine control position i. Engine thrust	Constant-altitude passes, include out-of-ground effect point.

50.10 Automatic flight control system characteristics.

NOTE: Only functions common to most aircraft are included here.

Test	Data	Remarks
50.10.1	Altitude or airspeed hold function.	
Static	Tabulation: a. Min. and max. indicated pressure altitude/airspeed in 3 min period Added documentation: 1. Degree of turbulence (very light, moderate, etc)	Level flight (function engaged).
Dynamic	Time history: a. Indicated press altitude b. Calibrated airspeed c. Pitch attitude d. Pitch rate e. Longitudinal control force f. Elevator position Time history annotation: 1. Engagement of function	Engage function in climb/descent or during accel/decel Engage/disengage in level flight for transients.
50.10.2	Attitude hold.	
Static	Tabulation: Min. and max. attitude in 3 min period Document degree of turbulence	Level flight (function engaged).
Dynamic	Time history: a. Indicated press. altitude b. Calibrated airspeed c. Pitch or bank angle d. Pitch or roll rate e. Control forces f. Control surface positions	Engage function in changing attitude. Flight engage/disengage in level flight for transients.

Test	Data	Remarks
	Time history annotation: Engagement of function	
50.10.3 Fly-to point.		
	Time history: a. Indicated press. altitude b. Calibrated airspeed c. Attitudes d. Heading e. Horizontal distance to point f. Angular rates g. Control forces h. Control surface positions	Engage function at: orientation to point of 0, 45, 90, 135, 180, 270 degree close-in and distant from point.
50.10.4 Automatic carrier landing system (ACLS).		
Open loop step response	Time history: a. Control surface positions b. Control law inputs and outputs c. Aircraft state parameters d. Engine parameters e. Pitch (or vertical rate) and bank step command f. AFCS and ACLS discretes	See NOTE (7).
Open loop frequency response	Cross plots and tabulations Frequency vs phase and gain: a. Control surface positions b. Control law inputs and outputs c. Aircraft state parameters d. Engine parameters e. Pitch (or vertical rate) and bank sine wave commands	

Test	Data	Remarks
	Time history: a. Control surface positions b. Control law inputs and outputs c. Aircraft state parameters d. Engine parameters e. Pitch (or vertical rate and bank sine wave commands f. AFCS and ACLS discretes	
Closed loop step response	Time history: a. Control surface positions b. Control law inputs and outputs c. Aircraft state parameters d. Engine parameters e. Pitch (or vertical rate) and bank commands f. AFCS and ACLS discretes g. ACLS tracking data h. Vertical or lateral step command	Closed Loop tests are normally conducted on glide slope during the final 2 miles prior to touchdown.
Closed loop frequency response	Cross plots and tabulations Frequency vs phase and gain: a. Control surface positions b. Control law inputs and outputs c. Aircraft state parameters d. Engine parameters e. Pitch (or vertical rate and bank sine wave commands f. ACLS tracking data g. Vertical and lateral sine wave commands Time history: a. Control surface positions	

Test	Data	Remarks
	b. Control law inputs and outputs c. Aircraft state parameters d. Engine parameters e. Pitch (or vertical rate) and bank sine wave commands f. AFCS and ACLS discretes g. ACLS tracking data h. Vertical and lateral sine wave command	
Mode 1 approaches	Time history: a. Control surface positions b. Control law inputs and outputs c. Aircraft state parameters d. Engine parameters e. Pitch (or vertical rate) and bank sine wave commands f. AFCS and ACLS discretes g. ACLS tracking data	ACLS mode 1 approaches are conducted both shore based and shipboard

50.10.5 Approach power compensator system (APCS).

Test	Data	Remarks
Specification maneuvers: Airspeed control Turn performance Throttle control Throttle damping Transients	Time history: a. Control surface positions b. Control law inputs and outputs c. Aircraft state parameters d. Engine parameters	Specification maneuvers are conducted shore based.
Approach and landing Turn performance Glideslope control Turbulence	Time history: a. Control surface positions b. Control law inputs and outputs c. Aircraft state parameters d. Engine parameters	APCS approaches are conducted both shore and shipboard.

Test	Data	Remarks
50.11 Identified aircraft deficiencies.		
50.11.1 Performance and handling qualities deficiencies.		
	Crossplot and/or time history as appropriate to ensure that both good and bad flight characteristics of the aircraft are modeled properly in the simulator.	
50.12 Cockpit aural cues.		
50.12.1 Cockpit noises.		
	Tape recordings of dominant aural cues during mission relevant tasks.	Annotate start/end of specific events on tape

NOTES:
(1) Operating gross weight as defined in Weight and Balance Clearance Form F under Item 5, Operating Weight.

(2) Flight control system data should be measured on actual aircraft. Prior to obtaining the control system data specified: primary and secondary flight control systems rigging should be checked and documented by maintenance personnel to be in accordance with established rigging criteria.

(3) Primary flight control system characteristics tabulation is a synopsis of data from crossplots listed under Section 50.2.1.

(4) Documentation of test data:

a. Test maneuvers

Ground tests - as cited in the table under each test.
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APPENDIX D

In-flight tests (including tabulation, crossplots, time histories) -

1. Airplane BuNo
2. External store loading (store and store station)
3. Flap setting
4. Landing gear position
5. Gross weight
6. Center of gravity (fuselage station (percent MAC and inches), butt station, waterline station
7. Trim calibrated airspeed
8. Trim calibrated pressure altitude
9. Ambient temperature (optional: deviation from standard)
10. Engine thrust
11. AFCS/stability augmentation modes engaged
12. (As applicable) degraded condition
13. Turbulence rating. Use ratings of light or moderate as described in DOD flight information publications. No data should be collected at turbulence ratings of severe and extreme. The ratings to be used are:

    No turbulence/chop

    Light turbulence - momentarily causes slight, erratic changes in altitude and/or attitude.

    Light chop - causes slight, rapid and somewhat rhythmic bumpiness without appreciable changes in altitude or attitude.

    Moderate turbulence - causes changes in altitude and/or attitude but with the aircraft remaining in positive control at all times. It usually causes variations in indicated airspeed.

    Moderate chop - causes rapid bumps or jolts without appreciable changes in aircraft altitude or attitude.

b. Instrumentation

1. Sensor location in terms of fuselage station, butt station, waterline station. The location of sensors on the flight control system (e.g., control force, cockpit control position, surface position, etc.) may alternatively be described in terms of control system component. There should be adequate information to indicate the relative location of the sensor in the control system stream.

2. Accuracy of the sensor. Preferably based on actual calibration of the sensor used; alternatively, based on the sensor manufacturer.

(5) Engine measurements cited in the table are generic. The measurements are to be tailored to the power plant involved (e.g., for a turbofan engine, engine RPM should include both core RPM and fan RPM; engine thrust may be thrust or horsepower (including propeller blade angle for turboprop installations))

(6) Pressure altitude has been listed as either "calibrated altitude" or "indicated press(ure) altitude." Calibrated altitude indicates that pressure altitude has been corrected for static-source position error, whereas indicated pressure altitude indicates no static-source position error correction. Calibrated altitude may be substituted for indicated pressure altitude; however, indicated pressure altitude may not be substituted for calibrated altitude.

(7) Aircraft state parameters include:
Calibrated airspeed
Calibrated pressure altitude
Pitch and roll attitudes
Heading
Pitch, roll, and yaw rates
Longitudinal, lateral, and normal body accelerations
True angle of attack
Angle of sideslip

APPENDIX E

FIXED WING TEST CONDITIONS

10. GENERAL

10.1 Scope. This appendix contains a list of suggested test conditions for obtaining flight test data for simulator criteria, and simulator validation data.

20. APPLICABLE DOCUMENTS. This section is not applicable to this appendix.

30. DEFINITIONS. See Definitions, paragraph 3. of this standard.

40. GENERAL REQUIREMENTS.

40.1. Flight control system characteristics.

40.1.1 Primary flight control system mechanical characteristics.

Test	Configuration (See NOTE (1))	Altitude	Airspeed	Weight	CG
Irreversible control system (See note (2))		On deck	Static		Any
		Low to medium	Three subsonic airspeeds.	Any	Any
Reversible control system (include boosted)	One	Low to medium	Two, (optional: plus static)	Any	Any

40.1.2 Secondary control system mechanical characteristics.

Test	Configuration (See NOTE (1))	Altitude	Airspeed	Weight	CG
	One	On deck, except for flight only operable device	Static , one airspeed for flight only operable devices	Any	Any

40.1.3 Flight control system response to command and sensor inputs.

Test	Configuration (See NOTE (1))	Altitude	Airspeed	Weight	CG
Static gain tests		On deck	Static	Any	Any
Step response		On deck	Static	Any	Any
Frequency response		On deck	Static	Any	Any

Test	Configuration (See NOTE (1))	Altitude	Airspeed	Weight	CG
40.2	Engine operation characteristics.				
40.2.1 Engine start/shutdown.					
Ground	Normal start	On deck	Static	--	--
In-flight	One	Max and min start envelope	Max and min at each altitude	Any	Any
40.2.2 Engine static operation.					
Ground	Any	On deck	Static	--	--
In-flight	(Obtain under Test 40.6.2, Level flight performance)				
40.2.3 Engine dynamic operation.					
Ground	Any	On deck	Static	--	--
In-flight	(Obtain under test 40.8.11, Trim changes)				
40.3	Ground taxi characteristics.				
Ground taxi		On deck	0-25 kt	Low and high	Any
40.4	Takeoff characteristics.				
40.4.1 Catapult launch.					
	Normal catapult alternate (if applicable)	CV deck to 500 ft	0 to fly away speed	Low and high	Fwd and aft
40.4.2 Field takeoff.					
	Normal takeoff (ext store)	Deck to 500 ft	Brake rel to clean up	Low and high	Fwd and aft
40.5	Landing characteristics.				
40.5.1 Arrestments (normal and emergency).					
	Land	500 ft to CV deck	On-speed to 0 kt	Low and high	Any

Test	Configuration (See NOTE (1))	Altitude	Airspeed	Weight	CG
40.5.2 Field landing (normal and emergency)					
	Land	500 ft to on deck runway	On-speed to full stop	Low and high	Any
40.6 In-flight performance characteristics.					
40.6.1 Climb performance.					
Normal climb	Clean (ext store)	Sea level to cruise ceiling	NATOPS schedule	Low and high	NOTE (3)
Degraded climb	Flaps down, and gear down, flaps/ gear down (ext store)	4000 ft	Max rate of climb +/-30 kt	Low and high	--
40.6.2 Level flight performance.					
	Clean (ext store)	Mid	Min to max	One	--
	Mission (ext store)	Mission dependent	Min to max	One	--
	Takeoff/land (ext store)	4000 ft	Min to max	One	--
40.6.3 Level flight accel/decel.					
	Clean (ext store)	Low, mid, high	Min to max	One	--
	Mission	Mission	Min to max	One	--
	Takeoff/land (ext store)	4000 ft	Min to max	One	--
40.6.4 Turning performance.					
	Clean (ext store)	Mission dependent	Five speeds	One	--

Test	Configuration (See NOTE (1))	Altitude	Airspeed	Weight	CG
40.6.5 Descent performance.					
	All NATOPS include max range, enroute , penetration, emergency	Cruise ceiling to sea level	NATOPS schedule	One	--
40.7 Pitot-static system position error.					
Position error correction	Clean	Sea level and one other altitude	Min to max	Any	Any
	Mission	Sea level and one other altitude	Min to max	Any	Any
	Takeoff	Sea level	Min to max	Any	Any
	Land (normal and emergency)	Seal level	Min to max	Any	Any
40.8 Stability and control characteristics.					
40.8.1 Static longitudinal stability.					
	Clean (ext store)	Low and high	Max range and max speed	One	Fwd and aft
	Mission (ext store)	Mission dependent	Mission	One	Fwd and aft
	Land (normal and emergency) (ext store)	4000 ft	Normal	One	Fwd and aft
40.8.2 Dynamic longitudinal stability.					
	(same configurations and conditions as Test 40.8.1, static longitudinal stability, plus below).				
	Takeoff	4000 ft	Climbout	One	Fwd and aft

Test	Configuration (See NOTE (1))	Altitude	Airspeed	Weight	CG
40.8.3 Longitudinal maneuvering stability.					
	(same as Test 40.8.1 Static longitudinal stability)				
40.8.4 Longitudinal control effectiveness (ground).					
	Takeoff	On deck	0 to nose-wheel lift-off speed	One	Fwd and aft
40.8.5 Lateral and directional control effectiveness ground.					
	Takeoff	On deck	--	One	Any
40.8.6 Longitudinal and directional control effectiveness (in-flight).					
	(Same as Test 40.8.1, Static longitudinal stability)				Any
40.8.7 Lateral control effectiveness (in-flight).					
	(Same as Test 40.8.1, Static longitudinal stability)				Any
40.8.8 Static lateral-directional stability.					
	(Same as Test 40.8.1, Static longitudinal stability.)				Any
40.8.9 Dynamic lateral-directional stability.					
	(Same as Test 40.8.1, Static longitudinal stability.)				Any
40.8.10 Coordinated turn (constant altitude).					
	(Same as Test 40.8.1, Static longitudinal stability.)				Any
40.8.11 Trim changes.					
Configuration change	Appropriate for configuration	Appropriate for configuration	Appropriate for configuration	One	Fwd and aft
	Change (ext store)	Change	Change		
Engine power Change	Clean	Low and high	Low and high	Any	Fwd and aft
	Land	4000 ft	Normal	Any	Fwd/ aft

Test	Configuration (See NOTE (1))	Altitude	Airspeed	Weight	CG
40.8.12 Stall.					
Normal and accelerated	Cruise	Low and high	--	One	One
	Mission	Minimum	--	One	One
	Land (normal and emergency)	Minimum	--	Low	One
	Takeoff	Minimum	--	High	One
40.8.13 Asymmetric power.					
In-flight static and dynamic	Cruise (ext store)	Mid	Five speeds from min control to max speed	Min	Any
	Takeoff (normal and emergency)	4000 ft	Five speeds from min control to max speed	Min	Any
	Land (normal and emergency)	4000 ft	Five speeds from min control to max speed	Min	Any
	Wave-off	4000 ft	Five speeds from min control to max speed	Min	Any
Ground static and dynamic	Takeoff	On deck	Min control	One	Any
40.8.14 Transonic/supersonic characteristics.					
Static longitudinal stability	Cruise (ext store)	Mid & high	0.85 Mach to max	Any	Fwd and aft
Dynamic longitudinal stability - short period	Cruise (ext store)	Same	Same		Same

Test	Configuration (See NOTE (1))	Altitude	Airspeed	Weight	CG
Longitudinal maneuvering stability	Cruise (ext store)	Same	Same		Same
Lateral control effectiveness	Cruise (ext store)	Same	Same		Any
Static lateral-directional stability	Cruise (ext store)	Same	Same		Any
Dynamic lateral-directional stability - Dutch roll	Cruise (ext store)	Same	Same		Any
Speedbrake effectiveness	Cruise (ext store)	Same	Same		Any
40.8.15 <u>Ground effect.</u>					
	Takeoff	Four alti tudes: 10 ft AGL to one wing-span AGL; and one altitude: two wingspans AGL (Note (4))	Rotate speed	One	Any
	Land (normal and emergency	Same as above	Approach	One	--

40.9 <u>Automatic flight control system characteristics.</u>

40.9.1 <u>Automatic flight control system.</u>

	Clean	Mid	Max range	Any	Any
	Mission	Mission	Mission	Any	Any

40.9.2 <u>Automatic carrier landing system (ACLS).</u>

Open loop step response	Land	5000 ft	On speed AOA	Low & high	Fwd and aft
Open loop frequency response	Land	5000 ft	On speed AOA	Low & high	Fwd and aft

Test	Configuration (See NOTE (1))	Altitude	Airspeed	Weight	CG
Closed loop step response	Land	On glide-slope	On speed AOA	Low & high	Fwd and aft
Closed loop frequency response	Land	On glide-slope	On speed AOA	Low & high	Fwd and aft
Mode 1 approaches	Land	On glide-slope	On speed AOA	Low & high	Fwd and aft

40.9.3 Approach power compensator system (APCS).

Test	Configuration	Altitude	Airspeed	Weight	CG
Specification maneuvers	Land	5000 ft	On speed AOA (off speed en-gagement)	Low & high	Fwd and aft
Approach and landing	Land	On glide-slope	On speed AOA (off speed en-gagements)	Low & high	Fwd and

40.10 Identified deficiencies. (Test conditions as required.)

NOTES:

(1) The flap, landing gear, and power setting are implicit for the configuration listed. Those tests likely to be affected by external store loading (denoted by the term "(ext store)") should be tested with the store combination that gives the highest aerodynamic drag or highest additional weight. Store asymmetry should also be considered.

(2) Irreversible primary flight control system mechanical characteristics should be obtained on a sample of at least two aircraft.

(3) Performance tests should be conducted at a mission- representative center of gravity (CG).

(4) The intent of ground effect testing is to obtain data for at least four altitudes in ground effect, and an altitude out of ground effect
.

APPENDIX F

ROTORCRAFT DATA REQUIREMENTS

10. GENERAL

10.1 Scope. This appendix provides a guide for flight test data requirements for use as simulator criteria and simulator validation data.

20. APPLICABLE DOCUMENTS. This section is not applicable to this appendix.

30. DEFINITIONS. Not applicable.

40. GENERAL REQUIREMENTS

40.1 Data requirements. Data requirements listed in this appendix are comprised of:

a. Minimum data required from the subject test.

b. Supporting data to verify the quality of the test maneuver.

40.2 Data format. Data format depends on the characteristics being described. Suggested data format is one or a combination of the following: tabulation, crossplot, time history.

40.3 Documentation. Complete documentation of test conditions is essential to reproduce the aircraft test maneuver in simulator validation tests in accordance with Note (1). Additional data requirements shall be formulated to document specific flight deficiencies identified in previous related simulator validation tests.

50. DATA LIST

50.1 Weight and balance/inertia characteristics.

Test	Data	Remarks
50.1.1 Aircraft weight and balance.		
	Aircraft operating, gross weight, empty weight,	Production and instrumented test aircraft

Test	Data	Remarks
	Longitudinal,lateral and vertical CG	Configuration control is critical during testing.
	Inertia properties	
	CG variation with fuel burnoff, stores expenditure, external load, gear extension/retraction, etc. static aircraft attitude.	

50.2 Flight control system characteristics.

50.2.1 Mechanical characteristics.

Test	Data	Remarks
	Total control travel	All tests on actual aircraft. Rigging checked by maintenance personnel prior to testing.
	Control free play (total system and trim system dead band)	
	Breakout plus friction forces	
	Control force gradients and hysteresis	
	Control centering	
	Control system dynamics Damping (all axes) Stick jump	

50.2.2 Rigging and sub-system tests.

Test	Data	Remarks
	Blade/control surface positions with control deflections (total system freeplay)	
	Trim system lags and trim rates	

Test	Data	Remarks
	Trim authority, Trim control displacement band	
	Stabilator programming	
	Control limits as affected by other control positions	
	Control system coupling (Control system nomogram)	

50.3 Engine operating characteristics.

50.3.1 Start/shutdown.

Engine start/stop, rotor engagement shutdown	Time history of throttle position, engine torque, rotor torque, rotor speed, turbine inlet temperature, gas generator speed and fuel flow	Rotor brake used, not used.

50.3.2 Engine performance.

Test cell data	Power available vs altitude, airspeed	
Power checks	Corrected engine shaft horsepower, corrected gas generator speed, corrected fuel flow, corrected specific fuel consumption vs corrected turbine inlet temperature	

50.3.3 Engine dynamics.

Selected throttle, engine control lever (ECL), and collective movements covering	Time history of throttle position, engine torque rotor speed, fuel flow, gas generator speed, power turbine speed, and turbine	

Test	Data	Remarks
full range of control accels and decels with rotor coupled/uncoupled	inlet temperature	
Static droop	Stabilized torque, rotor speed, airspeed for inc/dec collective	
Transient droop	Time histories of torque, rotor speed, collective position for inc/dec collective	
Response to trim system actuation		
Response to automatic load sharing system operation		
Engine/rotor system governing characteristics	Collective inputs vs rotor speed engine contribution during autorotations	

50.4 Pitot-static system characteristics.

50.4.1 Airspeed/altimeter calibration.

	Airspeed position error for level flight, climbs and descents, sideslips	Pilot and co-pilot Power ON/OFF descents.
	Altimeter position error (same as above)	

50.4.2 System lag tests.

	Vacuum testing Time histories of cockpit instruments responses to pressure changes	

Test	Data	Remarks
50.5 Ground handling characteristics.		
50.5.1 Ground taxi.		
	Control positions and pitch attitude during ground taxi for specific ground speed, wind speed and direction, and surface elevation.	
	Power increase and control deflections to start taxiing and to conduct taxi turns.	
	Power required for steady taxi	
	Power, torque, pedal position required to break from deck (skid helos)	
50.5.2 Braking.		
	Brake force vs. ground speed acceleration (for wheeled helos) as fuction of brake temperature, runway condition rating (RCR)	
50.6 Slow speed performance and flying qualities.		
50.6.1 Sideward flight.		
	Control positions, aircraft attitudes, rotor speed, engine torque, control surfaces vs. paced ground speed. Radar altitude, vibration and handling qualities rating (HQR)	

Test	Data	Remarks
50.6.2 Rearward/forward flight.		
	Same as above parameters	
50.6.3 Critical azimuth.		
	Above parameters vs relative wind azimuth	
50.7 In-flight performance.		
50.7.1 Hover performance.		
	Rotor, engine, tail rotor power vs gross weight, rotor speed, temperature, hover height AGL.	Include as much engine data as possible for performance tests (fuel flow, temp. and RPM parameters etc.)
	Tail rotor power as function of Military rated (MR power or thrust) referred data.	
	Collective control position vs. gross weights	
	Radar altitude vs engine torque in ground effects (IGE/ out of ground effects (OGE) (hover ladder).	
	Rotor speed vs engine power.	
	Time history of control positions, attitudes, and rates for pilot workload analysis	
50.7.2 Vertical climb performance.		
	Rate of climb vs. engine torque	

Test	Data	Remarks
	Collective position vs engine torque	
	Various weights and rotor speeds. Try to generalize performance data.	
50.7.3 <u>Level flight performance and trimmed control positions.</u>		
	Referred rotor power vs referred true airspeed for a full range of referred gross weights (can also use nondimensional presentation.	
	Individual tail and main rotor power vs calibrated airspeed. Ratio of main rotor power to engine power vs calibrated airspeed	
	Control positions, aircraft attitudes, and engine torque vs calibrated airspeed, sideslip.	
50.7.4 <u>Climb and descent performance and trimmed control positions.</u>		
	Rate of climb and descent, engine torque vs calibrated airspeed.	Also, rate of descent vs bank angle.
	Control positions and aircraft attitudes vs calibrated airspeed.	
50.7.5 <u>Power effects.</u>	Control positions, attitudes and cockpit vertical velocity vs engine torque	

Test	Data	Remarks
50.8 Stability and control characteristics.		
50.8.1 Control response.		
	Time history of control positions, angular accelerations, rates, and attitudes. Also, present load factor and airspeed (except hover) for longitudinal inputs and load factor for collective inputs. Minimum data to include hover, normal cruise, fast cruise, and endurance airspeeds for multiple sized inputs of longitudinal, lateral, directional, collective controls.	Step control inputs in all axes. Frequency sweeps in all axes.
50.8.2 Static longitudinal stability.		
	Control positions, longitudinal cyclic force, aircraft attitudes, rate of climb/descent, sideslip.	
50.8.3 Dynamic longitudinal stability.		
Short term	Control doublet response at observed natural frequency of aircraft: Time history of control positions, attitudes, rates, angular accelerations, load factor, airspeed.	

Test	Data	Remarks
Long term	Time history of control positions, attitudes, airspeed response to air-speed increase/decrease by longitudinal control.	

50.8.4 Maneuvering stability.

Test	Data	Remarks
	Control positions, aircraft attitudes, rate of climb/descent, load factor, engine parameters, longitudinal cyclic force	Steady turns, constant collective, pull ups, push-ups, push-overs.

50.8.5 Static lateral-directional stability.

Test	Data	Remarks
	Control positions, aircraft attitudes, ball position, rate of climb/descent, and indicated airspeed vs sideslip.	Steady heading sideslips.

50.8.6 Pedal only turns and cyclic only turns.

Test	Data	Remarks
	Control positions, air craft attitudes, ball position, rate of climb/ descent, and indicated airspeed vs sideslip. Time histories of aircraft attitudes, angular rates, sideslip.	

50.8.7 Dynamic lateral directional stability.

Test	Data	Remarks
Lateral and pedal control doublets and pulse inputs	Time history of control positions, angular accelerations, rates and attitudes.	

Test	Data	Remarks
Spiral stability	Time history of bank angle.	
Release from steady heading sideslips	Time history of control positions, sideslip, heading, yaw rate, roll attitude, roll rate, and airspeed.	

50.9 Rotor characteristics.

50.9.1 Autorotation assessment.

Auto entry	Time history of control positions, throttle position, engine torque, rotor speed, aircraft attitudes, and rates.	
Auto descents	Vary rotor speed and airspeed to determine effect on descent rate.	
Flare effectiveness and full autos (if allowed)	Time histories of control positions, throttle positions, engine torque, rotor speed, attitudes, rates, accelerations, sideslip, airspeed, ground speed (Doppler), pressure altitude, descent rate, load factor. For flare effectiveness perform aft cyclic inputs up to 2 in. (1/2 or 1/4 in increments) during steady state descent.	
Power recovery	Same as above.	
In-flight engine shutdown	Same as above	

Test	Data	Remarks
50.9.2 Blade stall.		
	Stall boundary as a functions of airspeed, rotor speed, density altitude, and loading condition.	
50.9.3 Power settling characteristics.		
	Time history of control positions, attitudes, rotor speed, engine torque, rate of descent.	
50.9.4 Vibration.		
	Vibration amplitude vs. frequency for given condition (airspeed and loading). Subjective vibration assessment. Time history of vibrations in 3-axes at pilot and CG positions.	
50.9.5 Gust response.		
	Time history of control positions, attitudes, rates, accelerations, airspeed, load factor	Longitudinal and vertical
50.10 Automatic flight control system characteristics.		
50.10.1 Mode evaluations.		
	Document pilot work load required for identical tasks under each mode of AFCS operation, i.e.: Heading hold ON/OFF Bar alt ON/OFF Rad alt ON/OFF	

Test	Data	Remarks
	Hardovers Degraded modes	
50.10.2 Mode switching transients, status checks.		
	Document system transients, document pilot diagnostic procedures.	
50.11 Mission tasks.		
50.11.1 Perform mission tasks.		
	Time history of control positions, aircraft attitudes, rates, accelerations, engine/rotor parameters. Qualitative pilot evaluations to include subjective vibration assessment	

NOTES:

1. Documentation of test data:

a. Test maneuvers

(1) Rotorcraft BuNo
(2) External store loading (store type and station)
(3) Landing gear position (if applicable)
(4) Gross weight
(5) Center of gravity (fuselage station, butt station, waterline station)
(6) Trim calibrated airspeed
(7) Trim pressure altitude
(8) Outside air temperature (optional: deviation from standard)
(9) Engine torque and RPM
(10) AFCS/stability augmentation modes engaged

(11) Turbulence rating. Use ratings of light or moderate as described in DOD flight information publications. No data should be collected at turbulence ratings of severe and extreme. The ratings to be used are:

No turbulence/chop

Light turbulence - momentarily causes slight, erratic changes in altitude and/or attitude.

Light chop - causes slight, rapid and somewhat rhythmic bumpiness without appreciable changes in altitude or attitude.

Moderate turbulence - causes changes in altitude and/or attitude but with the aircraft remaining in positive control at all times. It usually causes variations in indicated airspeed.

Moderate chop - causes rapid bumps or jolts without appreciable changes in aircraft altitude or attitude.

b. Instrumentation

(1) Sensor location in terms of fuselage station, butt station, waterline station. The location of sensors on the flight control system (e.g., control force, cockpit control position, surface position, etc.) may alternatively be described in terms of control system component. There should be adequate information to indicate the relative location of the sensor in the control system stream.

(2) Accuracy of the sensor. Preferably based on actual calibration of the sensor used; alternatively, based on the published accuracy from the sensor manufacturer.

APPENDIX G

ROTORCRAFT TEST CONDITIONS

10. GENERAL.

10.1 Scope. This appendix contains a list of suggested test conditions for obtaining flight test data for simulator criteria and simulator validation data.

20. APPLICABLE DOCUMENTS. This section is not applicable to this appendix.

30. DEFINITIONS. Not applicable.

40. GENERAL REQUIREMENTS.

40.1 Weight and balance characteristics.

40.1.1 Weight and balance.

Test	Conditions	Remarks
	Test loadings representative of mission loadings	

40.2 Flight control system characteristics.

40.2.1 Mechanical characteristics.

Test	Conditions	Remarks
	On ground Artificial excitation of any feel system devices driven by airspeed, g, etc.	Obtain critical cockpit measurements from at least two aircraft. Include qualitative in-flight evaluation

40.3 Engine operating characteristics.

40.3.1 Start/shutdown.

Test	Conditions	Remarks
	On ground	Time history and video tape recordings of cockpit gauges

Test	Conditions	Remarks
	Cold, warm, hot engine Various wind azimuths	Aural recording to document rotor and equipment sounds during normal procedures. Note wind direction/magnitude
40.3.2 <u>Engine performance.</u>		
	Installed engine	
40.3.3 <u>Engine dynamics.</u>		
	Installed engine ECU lockout/override engine protection.	
40.4 <u>Pitot-static system characteristics.</u>		
40.4.1 <u>Airspeed/altimeter calibration.</u>		
	1 GW, mid CG 0 to V_{ne}. To sideslip limits. Various climb/descent rates.	Mission representative conditions
40.4.2 <u>System lag tests.</u>		
	On deck	Test set required.
40.5 <u>Ground handling characteristics.</u>		
40.5.1 <u>Ground taxi.</u>		
	Several gross weights	
40.5.2 <u>Braking.</u>		

Test	Conditions	Remarks
40.6 Slow speed performance and flying qualities.		
40.6.1 Sideward flight.		
	To limits of basic aircraft in 5 kt increments. Heavy and light GW. Wind speed: 0-3 kt no gusts	Also, CG effects. Lateral asymmetries (mission typical extremes of lateral CG)
40.6.2 Rearward/forward flight.		
	40 kt forward to limits of basic aircraft (LBA)	Longitudinal asymmetrics (mission typical extreme of long CG).
40.6.3 Critical azimuth.		
	Airspeed: 10 kt increments until control authority or structural limits approached. Wind: 15 degree azimuth increments.	
40.7 In-flight performance.		
40.7.1 Hover performance.		
	2 IGE and 1 OGE tethered hover.	Need IGE and OGE power.
	Free hover	Rotor efficiency tests.
40.7.2 Vertical climb performance.		
	0 - 1,500 ft AGL 2 GW 3 rotor speeds	Also, variations from standard day.

Test	Conditions	Remarks
40.7.3 Level flight performance and trimmed control positions.		
	5 referred GW's	Wings level, ball centered.
	Mid CG	
	Airspeeds:	Airspeed increments no greater than 10 kts in the bucket, 20 kt elsewhere.
	40 KCAS - V_{max}	
		CG effects. External loading effects. Investigate ball out flight for tandem rotor aircraft.
40.7.4 Climb and descent performance, trimmed control positions, and power effects.		
	3 GW 3 Airspeeds 1 Altitude band Engine torque increments: 5% up to +/-30% from trim	Constant rotor speed
40.8 Stability and control characteristics.		
40.8.1 Control response.		
	1 Altitude	Any step response data for cue synch purposes must include: Known sample rate Computer generated input High quality accel data Cockpit instrument drive.
	2 GW	
	Hover, 3 airspeeds, AFCS ON/OFF	
	Control Inputs: Steps, up to +/-2 in. in 1/4 inch increments	
	Swept sinusoid frequency range: 0.05 - 5.0 Hz	Frequency response with swept sinusoid input.

Test	Conditions	Remarks
40.8.2 <u>Static longitudinal stability.</u>		
	3 GW, 3 CG 3 trim airspeeds +/-2, 5, 10, 15 kt increments about trim. 2 altitudes AFCS ON/OFF as appropriate.	Collective fixed
40.8.3 <u>Dynamic longitudinal stability.</u>		
	3 GW, 3CG 2 Airspeeds 1 Altitude AFCS ON/OFF	
40.8.4 <u>Maneuvering stability.</u>		
	2 GW, 3 CG 2 Altitudes 2 Airspeeds AFCS ON/OFF	
40.8.5 <u>Static lateral-directional stability.</u>		
	3GW, 3CG 2 Altitudes 3 Airspeeds AFCS ON/OFF	Steady heading side-slips: 0 deg sideslip point required Increments: Trim plus +/-2, 5, 10, 15 degree, or to limits of basic aircraft.
40.8.6 <u>Pedal only turns and cyclic only turns.</u>		
	Same as 40.8.5 above Both directions	

Test	Conditions	Remarks
40.8.7 Dynamic lateral-directional stability.		
	3 GW, 3 CG 2 Altitudes 2 Airspeeds at each GW	
	AFCS ON/OFF	
40.9 Rotor characteristics.		
40.9.1 Autorotation assessment.		
Auto entry	2 GW, 2 CG 3 Airspeeds 3,000 ft AGL	
Auto descents	2 GW 3 Rotor speeds 5 Airspeeds	
Flare effectiveness and full autos (if allowed)	2 GW 2 Airspeeds	Min rate of descent airspeed. Max glide airspeed.
Power recovery		
In-flight engine shutdown	1 GW, level flight 3,000 ft AGL	
40.9.2 Blade stall.		
40.9.3 Power setting characteristics.		
	1 GW, 5,000 ft AGL	
40.9.4 Vibration.		
	Obtain during tests for: Hover Level flight Low airspeed translation/transition	Use standardized assessment ratings.

Test	Conditions	Remarks
	Turns Climbs/descents Autorotations Mission tasks	

40.9.5 Gust response.

	Level flight, 3,000 ft AGL	Perform in actual gust conditions

40.10 Automatic flight control system characteristics.

40.10.1 Mode evaluations.

	2,000 to 4,000 ft AGL	Perform mission tasks
	Airspeed range: 0 to V_{ne}	Normal and degraded modes
	3 GW	

40.10.2 Mode transients, status checks.

40.11 Mission tasks.

40.11.1 Perform mission tasks.

	As appropriate	

APPENDIX H

TYPICAL FLIGHT TEST INSTRUMENTATION

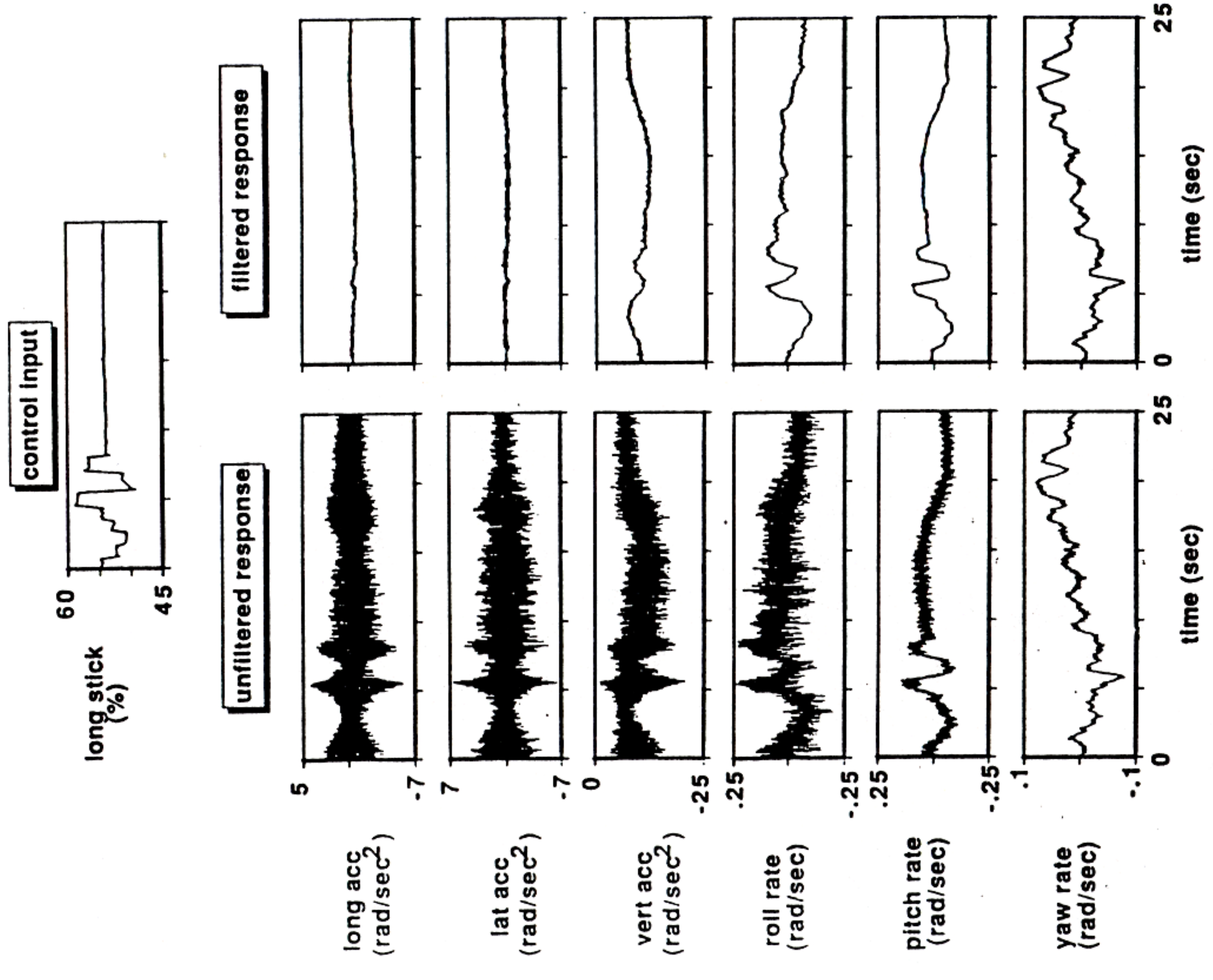
This appendix contains a list of typical flight test instrumentation along with suggested range, accuracy, and resolution. The following list will require tailoring for an actual application.

SENSOR	RANGE	ACCURACY	RESOLUTION
Pitch Attitude	+/-90 degree	+/-0.5 degree	0.1 degree
Roll Attitude	+/-90 degree	+/-0.5 degree	0.1 degree
Heading	0 to 360 deg	+/-0.5 degree	0.2 degree
Pitch Rate	+/-100 deg/sec	+/-0.5deg/sec	0.1 deg/sec
Roll Rate	+/-300 deg/sec	+/-1.0deg/sec	0.2 deg/sec
Yaw Rate	+/-100 deg/sec	+/-0.5deg/sec	0.1 deg/sec
Normal Acceleration	-5 to 10 g	+/-0.02 g	0.01 g
Axial Acceleration	+/-5 g	+/-0.02 g	0.01 g
Lateral Acceleration	+/-5 g	+/-0.02 g	0.01 g
Angle of Attack	-45 to 70 deg	+/-0.3 deg	0.1 degree
Angle of Sideslip	+/-45 degree	+/-0.3 deg	0.1 degree
Static Pressure	0 to 15 psi	+/-0.005 psi	0.005 psi
Total Pressure	0 to 100 psi	+/-0.005 psi	0.005 psi
Static Temperature	350 - 600deg R	+/-1 degree R	1.0 deg R
Total Temperature	350 - 1000degR	+/-1 degree R	1.0 deg R
Pressure Altitude	0 - 60000 ft	+/150 ft	20 ft
Radar Altitude	0 - 1000 ft		
True Airspeed	0 - 1500 kt	+/-2 kt	1 kt
Mach Number	0 - 2.4	+/-0.005	0.005
Elevator Position	Limits of Travel	+/-0.2 deg	0.2 deg
Aileron Position	Limits of Travel	+/-0.1 deg	0.1 deg
Rudder Position	Limits of Travel	+/-0.2 deg	0.2 deg
Flap Position	Limits of Travel	+/-0.2 deg	0.2 deg
Power Lever Angle	0 - 150 deg	+/-0.5%	0.1%
Engine Speed (RPM)	Idle to Military	+/-0.5%	0.1%
Exhaust Gas Temp	Range of Engine	+/-1.0 deg R	1.0 deg R
Stick Forces	Aircraft Dependent	+/-1.0%	1.0%
Stick Position	Limits of Travel	+/-0.1%	0.1%
Fuel Weight	0 - 100%	+/-2% of Full	1% of Full
Fuel Flow	0 - Max lb/min	+/-1.0%	1.0%

APPENDIX H

BENEFITS OF DATA FILTERING
Ref: AGARD Lecture Series No.178

Helicopter flight test data before and after filtering.

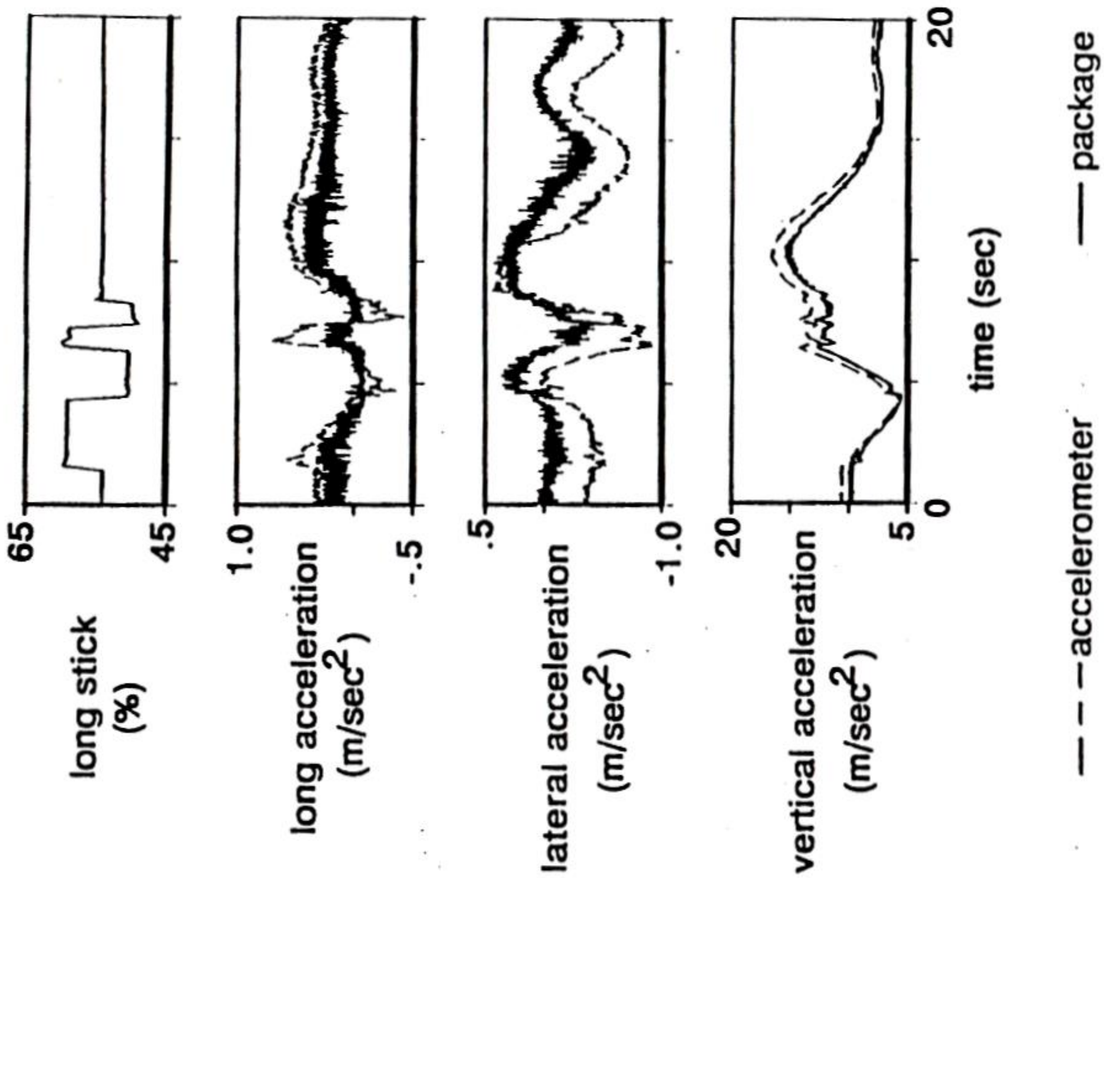


APPENDIX H

IMPACT OF IMPROPER DATA FILTERING
Ref: AGARD Lecture Series No. 178

Accelerometer: truth data

Package: data polluted by improper filtering in the instrumentation



APPENDIX I

TYPICAL FIXED WING SIMULATOR TOLERANCES

10. GENERAL

10.1 Scope. This appendix contains a list of typical tolerances for fixed wing simulator applications.

20. APPLICABLE DOCUMENTS. This section is not applicable to this appendix.

30. DEFINITIONS. This section is not applicable to this appendix.

40. GENERAL REQUIREMENTS

40.1 Tolerances. The OFT/WST performance shall meet the trainer design criteria within the tolerances specified. When the tolerance specifications for the operational equipment being represented are smaller than the tolerances specified herein, the smaller tolerance shall apply throughout the entire range of operation of the design basis aircraft regardless of whether the range can be considered normal or abnormal. Unless otherwise specified, the tolerances herein shall be construed to mean plus or minus values. The tolerances shall be applicable at any place the values may be read; i.e., at the computer, instructor station, trainee station, etc. In cases where the accuracy of the operational aircraft instrument or indicator is less than the tolerance specified below, the operational aircraft instrument accuracy shall be the tolerance for that instrument but not for the related parameter.

40.2 General. Performance characteristics of the design basis aircraft not covered by specific tolerances listed herein shall be within 10 percent of the design criteria data. The slope of a trainer performance curve shall have the same sign as and shall be within 10 percent of the slope of the corresponding trainer criteria curve.

40.3 Aircraft Mass Characteristics.

a. Total Mass	1 Percent
b. Moments of Inertia	1 Percent
c. Center of Gravity	0.1 Unit (units: % MAC)

40.4 Flight Controls Mechanical Characteristics.

Axis	Freeplay	Force	Breakout plus Friction	Control Envelope
Longitudinal and Lateral	.1 inch or 10%	1.0 lbf or 10%	.5 lbf or 5%	.5 inch or 5%
Pedal	.1 inch or 10%	2 lbf or 10%	.5 lbf or 5%	.25 inch or 5%

Gearing: (Control surface vs cockpit control): 0.5 deg or 5%

Dynamics: Number of overshoots: Same as aircraft.
Time to first peak: 0.1 sec (All controls).

Trim Rates: Per aircraft maintenance manual.

Frequency response (Bandwidth): +50%,-10% of aircraft value

40.5 Aerodynamic tolerances.

40.5.1 Steady state flight conditions. The following tolerances apply to trimmed level flight, climbs, descents, static longitudinal stability, static lateral-directional stability, steady turns, asymmetric power, etc.

a. Indicated airspeed — 2 kt for specific reference values such as optimum approach speed, minimum control speed, or stall speed; otherwise, 5%

b. Indicated altitude — 1% of aircraft value for performance parameters such as service ceiling; otherwise 5%

c. Attitude about any axis — 1 degree

d. Normal acceleration — 0.1g or 5%, whichever is greater

e. Angle of attack — 0.5 degree and 0.5 units (if so displayed)

f. Sideslip angle	0.5 degree
g. Vertical velocity	10% or 100 ft/min, whichever is greater
h. Lateral and longitudinal velocity	2 kt
i. Cockpit control position	5%
j. Control surface position	0.5 degree
k. Control force	1 lbf or 10%, whichever is greater

40.5.2 Dynamic response. The following tolerances apply to dynamic response parameters for short and long-term modes as represented by time history data or modal parameters such as undamped natural frequency and damping ratio for oscillatory responses. Dynamic response is typically generated by inputs such as pulse, step, doublet, sinusoid, configuration changes, etc.

a. Transient characteristics (initial response).

(1) Peak amplitude	15%
(2) Time to first peak	15%
(3) Undamped natural frequency	15%
(4) Damping ratio	25% or .05, whichever is greater
(5) Time constant	25%
(6) Time delay for initial	Per aircraft acceleration response data plus simulator delay as specified for system dynamic response

b. Post transient dynamics.

(1) Angular displacement	1 deg or 10%, whichever is greater

(2) Angular rate	1 deg/sec or 10%, whichever is greater
(3) Translational velocity (including takeoff and landing ground speed)	2 kt or 5%, whichever is greater
(4) Normal acceleration	0.1g or 5%, whichever is greater

40.6 Propulsion system tolerances.

a. Power lever position and detent locations	Per operational aircraft tolerances
b. RPM vs power lever position	1 unit at idle and greater than 90% RPM; 2 units elsewhere (RPM units: %)
c. RPM	1 unit (RPM units: %)
d. Fuel flow	5%
e. Turbine and exhaust gas temperature	20 deg C below 90% RPM, 10 deg C above 90% RPM
f. Engine oil pressure	5%
g. Light off time	10%
h. Thrust	3%, or 0.3% of max value, whichever is greater
i. Rate of change for all significant propulsion system parameters	15%

APPENDIX J

TYPICAL ROTORCRAFT SIMULATOR TOLERANCES

10. GENERAL

10.1 Scope. This appendix contains a list of typical tolerances for fixed wing simulator applications.

20. APPLICABLE DOCUMENTS. This section is not applicable to this appendix.

30. DEFINITIONS. This section is not applicable to this appendix.

40. GENERAL REQUIREMENTS

40.1 Tolerances. The OFT/WST performance shall meet the trainer design criteria within the tolerances specified. When the tolerance specifications for the operational equipment being represented are smaller than the tolerances specified herein, the smaller tolerance shall apply throughout the entire range of operation of the design basis aircraft regardless of whether the range can be considered normal or abnormal. Unless otherwise specified, the tolerances herein shall be construed to mean plus or minus values. The tolerances shall be applicable at any place the values may be read; i.e., at the computer, instructor station, trainee station, etc. In cases where the accuracy of the operational aircraft instrument or indicator is less than the tolerance specified below, the operational aircraft instrument accuracy shall be the tolerance for that instrument but not for the related parameter.

40.2 General. Performance characteristics of the design basis aircraft not covered by specific tolerances listed herein shall be within 10 percent of the design criteria data. The slope of a trainer performance curve shall have the same sign as and shall be within 10 percent of the slope of the corresponding trainer criteria curve.

40.3 Aircraft mass characteristics.

a. Total Mass	1 Percent
b. Moments of Inertia	1 Percent
c. Center of Gravity	0.2 inch of actual

40.4 Flight controls mechanical characteristics.

Axis	Freeplay	Force	Breakout plus Friction	Control Envelope
Longitudinal and Lateral and Collective	.1 inch or 10%	1.0 lbf or 10%	.5 lbf or 5%	.5 inch or 5%
Pedal	.1 inch or 10%	2 lbf or 10%	.5 lbf or 5%	.25 inch or 5%

Gearing (Control surface vs cockpit control): 0.5 deg or 5%

Dynamics: Number of overshoots: Same as aircraft.
Time to first peak: 0.1 sec (All controls).
Trim release stick jump: Pilot Evaluation.

Trim Rates: Per aircraft maintenance manual.

Frequency response (Bandwidth): +50%,-10% of aircraft value

40.5 Aerodynamic tolerances.

40.5.1 Steady state flight conditions. The following tolerances apply to trimmed level flight, climbs, descents, static longitudinal stability, static lateral-directional stability, steady turns, hover, slow flight, etc.

a. Indicated airspeed	1 kt for specific reference values; otherwise, 5%
b. Indicated altitude	1% of aircraft value for performance parameters such as service ceiling; otherwise 5%
c. Attitude about any axis	1 degree
d. Normal acceleration	0.1g or 5%, whichever is greater
e. Angle of attack	0.5 degree
f. Sideslip angle	2.0 degree

g. Vertical velocity	10% or 100 ft/min, whichever is greater
h. Lateral and longitudinal velocity	2 kt
i. Cockpit control position	2%
j. Control surface position	1 degree

40.5.2 Dynamic response. The following tolerances apply to dynamic response parameters for short and long-term modes as represented by time history data or modal parameters such as undamped natural frequency and damping ratio for oscillatory responses. Dynamic response is typically generated by inputs such as pulse, step, doublet, sinusoid, configuration changes, etc.

a. Transient characteristics (initial response).

(1) Peak amplitude	15%
(2) Time to first peak	15%
(3) Undamped natural frequency	15%
(4) Damping ratio	25% or .05, whichever is greater
(5) Time constant	25%
(6) Time delay for initial response	Per aircraft acceleration data plus simulator delay as specified for system dynamic response

b. Post transient dynamics.

(1) Angular displacement	1 deg or 10%, whichever is greater
(2) Angular rate	1 deg/sec or 10%, whichever is greater
(3) Translational velocity	2 kt or 5%, whichever is greater

(4) Normal acceleration	0.1g or 5%, whichever is greater

40.6 Propulsion system tolerances.

a. Power lever position and detent locations	Per operational aircraft and tolerances
b. Torque	3 units (torque units are %)
c. Rotor RPM (Nr)	1 unit (Nr units: %)
d. Gas generator RPM (Ng)	1 unit (Ng units: %)
e. Turbine gas temperature	20 deg C below 75% torque, 10 deg C above 75% torque
f. Engine oil temperature	15 deg C
g. Engine oil pressure	5 psi
h. Transmission oil temperature	15 deg C
i. Transmission oil pressure	5 psi
j. Fuel flow	5%
k. Light off time	10%
l. Rate of change for all significant propulsion system parameters	15%

APPENDIX K

FLIGHT DYNAMICS VALIDATION PROCESS

MILESTONE	PRODUCT/ACTIVITY
Contract Award	-Begin data collection -Begin detailed design

Preliminary Design Review	-Identify significant problem areas
	  -Criteria data shortfalls & remedies
	  -System design options

Critical Design Review	-Criteria data report complete (?) -System design complete -Math model design complete and documented in MMR & SDD
Hardware/Software Integration	
Early	-First NPE (evaluation of flight characteristics) -Auto Fidelity Test (AFT) should be available

Mid & Subsequent	-Follow on NPE's
	  -Re-evaluate gross problem areas
	  -Evaluate additional systems:
	    -Motion
	    -Visual
	    -Major tactical systems
	-Update criteria data as required
	-Refine AFT
	-Develop Acceptance Test Procedures

In-plant Testing	-Execute Acceptance Test Procedures
	  -Control loading
	  -Flight dynamics
	  -Cue synchronization
	  -Effects of integrated cues
	-Engineering tests & mission tasks

On-site Final Acceptance	-Repeat Acceptance Test Procedures -AFT very beneficial