ASSESSMENT OF MANAGEMENT STANDARDS FOR THE DEVELOPMENT OF MULTI-ENVIRONMENTAL FLIGHT SIMULATOR SYSTEMS

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As an aviation professional I have grown and learned every day of my life. At this point, I have something to contribute to those who come behind, and I am, therefore, greatly appreciative of those who have contributed to aviation, to learning, and to the safety imbedded in today's flight. Some of those who contributed to my commitment to, and knowledge of aeronautics include:

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CHAPTER I

INTRODUCTION

Background for Study

With the 1929 patent by Edwin Link, the first formal ground-based flight trainer became available (Cyrus, 1978). As early as 1934, the U.S. Army began formal use of a flight simulator to train military pilots. By the end of hostilities in World War II, more than 10,000 of Link's "Blue-boxes"were in use to train pilots in instrument flight training and radio navigation (Pausch, 1992). During the massive growth in aviation during World War II, the need for part task training was addressed in a myriad of ways. One rather creative method of part task training provided pilots and maintenance personnel with a very high fidelity P51 systems training by mounting/demounting a P51 fighter from a concrete post, where all dynamic systems could be operated (Bare, 1999). Following World War II, hundreds of these "Blue-boxes" flight simulators were used in many forms of civil aviation training, from the local fixed base flight school to air carriers' operations.

During the post-World War II period, the United States interstate transportation system began a transition from being a railroad centered system to a system incorporating interstate highway and interstate/intrastate aviation service. Following the enactment of the Federal Aviation Act of 1958, the aviation transportation system expanded to become an integral part of the United States international transportation system. To serve the aviation growth during this period, the United States aerospace industry developed and produced aircraft of increasing size, speed, conveyance, and passenger acceptance. These technical developments came with an increase in procurement cost, system complexity, and demands for safe flight operations. The indices of the continued growth include increases in the aggregate of destinations served by the numbers of airlines operating, the number of aircraft being employed, the number of technical personnel providing aviation services, and the number of revenue passenger miles (Wells, 1998). Along with growth has come a concomitant improvement in flight safety, as measured by fewer accidents and fewer fatalities per 1000 hours of flight time (Nall Report, Air Safety Foundation, AOPA, 1999). These overall improvements in aviation transportation safety, though not linear numerical improvements, occurred because of the combined contributions of many dedicated aviation professionals of all disciplines, and to the development of an integrated instructional system approach to simulation technology-based methods of training flight crews and other technical personnel. The integration of computer-based electronics in the simulation systems has facilitated the amalgamation of aircraft technologies with computer-based media to provide high fidelity flight training devices. The 1981 pioneering report of the Advisory Group for Aerospace Research and Development (AGARD) offered the first formalized "Characteristics of Flight Simulator Systems," (AGARD, 1981). This effort included defining the requirements for the system configuration and fidelity to provide spatial and temporal properties, motion and energy properties, and a visual system.

The International Civil Aviation Organization (ICAO) has long recognized the overt value of dynamic flight simulators, and has included these in guidance for the establishing and operating aviation training centers. The inclusion of flight simulators was identified as follows:

> The expansion of international civil aviation have created work for large numbers of new pilots and maintenance engineers (FAA Aviation Maintenance Technicians), and this has been particularly so in the developing countries of the world . . . up to 50 percent of specified (pilot) instrument flight training time may be in a synthetic flight trainer . . . (with) the advantages of these synthetic trainers are well known, and they include not colliding with each other, not crashing, nor the injuries and deaths. (ICAO, 1983)

The evolution of computer technologies has also led to economically mandated, computer-based, multi-environmental dynamic flight simulators that can train aircrews to perform the same tasks and in the same situations as may be encountered in the "real world of flight." The human response to the high-fidelity of the human-machine interface of these devices allows operational training and human response experiences to normal and emergency events without risking any passengers during training (AGARD, 1981).

At this time in history, all United States scheduled air carriers (FAR 121, 1998), and all military aviation operations; commercial flights operating under FAR 125; and the majority of non-scheduled/air taxi (FAR 135) operations are required to train flight crew using multi-environmental dynamic flight simulators.

Statement of the Problem

To aviation professionals, an irony exists in the development of high fidelity, potentially life saving, multi-million dollar aeronautical devices known as multi-environmental flight simulators. These complex training systems provide one of the greatest mechanisms available to improve aviation safety. These systems are, however, procured without the use or discipline provided by the FAA's aeronautical standards that are required for the design, development, and fielding of comparable aircraft. The lack of a standard for the implementation and management of the development and fielding of these flight safety devices may contribute to increased cost, lost development time, increased crew training time, increased crew training risk, lack of training transfer, increased risk of unnecessary loss of aircraft and life. This study intends to determine if a standard or standards exist, and if indicated, to develop recommendations that address these dynamic needs.

Hypothesis

With the diversity of mission requirements and available technologies, no aeronautical standards or specifications exist for managing the development and fielding of multi-environmental flight simulators that are required for contemporary aircraft and space vehicle simulator systems applications.

Purpose of the Study

This study will determine the existence of appropriate aeronautical standards for the management of development and fielding of dynamic flight simulator systems, and if needed, to develop befitting guidance for the management of these complex systems.

Objectives of the Study

1. Identify if there are aeronautical standards, systems, or documentation available for managing the development and fielding of dynamic flight simulators by developmental organization.
2. Identify and accumulate the diversity of action areas required to manage these developments, including mission requirements; educational strategies; aeronautical systems integration; simulator courseware, hardware, and software applications and integration; business and contractual management action areas; and other respondent topics.
3. Generate a comprehensive flight simulator development and fielding guide for use in the management of the procurement of these types of sophisticated aeronautical equipment.

Significance of the Study

Many management and technical challenges are inherent in developing and fielding of high fidelity, multi-disciplinary flight simulator systems. These issues may be exacerbated by the organization of the procuring agency, and by the classical challenges of cost and schedule, and also by the critical issue of the human-machine integration and performance of these types of flight vehicle. At this time either a lack of guidance or a multiplicity of guidance used by the developers-participants exists. Guidance may take the form of a Department of Defense Specification (DOD-Spec) type standards, company proprietary technical guidelines, and other ill defined sources for these developments.

The commercial aircraft flight simulators may be managed by in-house systems using proprietary standards, networks, and documentation. The development of a one-of-a-kind type simulator is usually managed by the smallest management cadre, using the least amount of standardized documentation.

The significance of this study is the development of recommendations that may be used in the management of the development, fielding, and procurement of these types of sophisticated aeronautical equipment. The use of this fielding guide may help in the reduction of the time required to develop and field a multi-environmental flight simulator. The availability of this level of information could result in the optimization of technology applications, reduced cost, and increases in availability and fidelity of the flight simulators for aircrew training. The improvement in the fidelity of flight simulators and availability could result in improvements in air safety, unquestionably making this study worthwhile.

Conceptual Assumptions

With the safe operation of current generation aircraft requiring the integration of many diverse and complex technologies, human learning and performance, and international business operations, studies in this field require that an operational baseline be established. Within this world of technological change, Borg (1987) offers the job of descriptive research is to determine "what is the status" of a population or organization. To explore the status of this portion of the aviation industry, the study endeavors to determine what (aeronautical) standards or specifications are being used to develop and field the flight simulator systems needed to train aircrew to safely fly these aircraft. In support of that determination of the "what is used" question, these design assumptions are proffered:

1. Participating organizations come from establishments that develop flight simulator, flight training devices, and flight training systems. .
2. Participating organizations come from nonprofit organizations, professional organizations, commercial corporations, plus governmental organizations.
3. Collaborating organizations have flight simulator development related business of >$4Million per year.
4. Participating organizations procure, develop, or produce multi-environmental type flight simulator systems that have the following characteristics: A high fidelity flight simulator system that simulates flight operations of in-flight, on-ground, in day or night visual conditions, with a motion and G-force simulation system, and a significant accuracy in the simulator modeled aerodynamic, performance and handling qualities, with the pilot's normal and emergency flight control and systems inputs to manage the operational mission.
5. Cooperating organizations produce these types of flight simulators to meet the diversity of mission requirements of a user organization or group.
6. Participating organizations will be integrating aeronautical, learning, technologies based systems with diverse mission mandates of the user organization.

7. Collaborating organizations have funding and other resource limitations when executing the development of such flight simulator systems.
8. No classified, commercially sensitive, or proprietary information is sought from participating organizations.

Scope and Limitations

Several limitations are present in the investigative methods and procedures reflected by this study. Some of these limitations influence the participants' responses and participants' applications of the resulting research information. The research sample size of 28 of a worldwide population of 35, presents an obvious limitation to extending the findings into recommendations for a given flight simulator development operation. These limitations have impact in the information gathering and information application aspects of the research. Information gathering limitations include:

1. The population size of the participant groups is very limited. This stratified population represents 28 (80 %) of 35 candidate international organizations procuring this type of aeronautical equipment. It is estimated that the world population of these organizations is limited to approximately 35. This limited number of international organizations involved in these complex human and technology integration may limit the validity of the statistical measurements, and the applications to other organizations, but the results will apply to that "world population" of these developmental organizations.

2. Participants' responses will likely be influenced by each participant-operator's mission being different from any other operator in the world. Each operator flies with different pay loads, across unique operational environments, using different aircraft, with different aircrews, and during unique economic conditions. Therefore, each participant may have a diverse or similar response to each questionnaire item.
3. Each participant-operator must also fit into the worldwide aviation system, as well as operate within the U.S. National Airspace System, so some responses may not be unique.
4. Each operator must operate within its resource limitations, while accommodating the advancement of aircraft and computer technology systems and integration. The size of training resources may be limited by the necessity to use resources for more expensive aircraft.
5. Each participant organization has experienced a limitation in operational budgets and corporate reorganization that may translate to limited personnel available to respond to extra-organizational inquiries such as this study.

Information Applications Limitations

The information derived in the research may have direct, profound, or no applications for any given participant-developer, depending upon that developer's need for a multi-environmental flight simulator. If an operator has a high priority need for this level of aircraft operations, crew competency, and cost control, and safety then the results of the research may provide guidance for those priorities in the following areas:

1. The applications of research developed information may be limited for a participating developing organization if the economics of a given flight simulator order is so small as to not include applications of many standards.
2. The diversity of types, configurations, and levels of training of flight simulators encompasses many recognized applications. The applications of the findings or recommendations may not be possible or desirable for some of the typical training devices and flight simulators, which include part task trainers, navigation systems trainers, team training for cockpit crews, aircraft systems training; aircraft maintenance training, and team training for maintenance crews.
3. The popularity of the PC based training devices, including those few identified in the FAA Advisory Circular 120-45A (para 6, 1992) as Personal Computer Aircraft Training Device (PCATD), may limit procurement funding for separately developed PC-BASED part task trainers.

Logical Assumptions

Elements of experience, reason, authority, intuition, and common sense are used in the definition and organization of this research, but in the research component of the study, applications of the scientific method prevail. With the hypothesis established, deductive analysis is used to determine for the relationship of the major premise, to the minor premise, and the resulting conclusion. The hypothesis can be tested by the following syllogism:

1. Major premise: No comprehensive standard exists for the development and fielding of . . . these types of flight simulators.
2. Minor premise: The commercial and governmental organizations develop and field these types of flight simulators.
3. Conclusion: Therefore, these commercial and governmental organizations do not have or use comprehensive standards for the development and fielding of these types of flight simulators.

The major issue is focused upon the premise that no comprehensive standards exist for the development and fielding of flight simulator systems. That major issue can be affirmed or rejected deductively from an analysis of the responses to the participant questionnaire items. The results of these responses may lead to the completion of the Objective of the Study, number 3, which is to generate a standard or guide for the development and fielding of these types of flight simulator systems.

Outline of Work

I. Identification of problem
   - A. Assessment of scope and impact of problem areas
   - B. Background of study

II. Hypothesis development
   - A. Preliminary search for information

B. Literature search

C. Industry communications

D. Formulation of Objectives of the study

III. Development of methodology

A. Research methodology

B. Research population/sample

C. Data collection development, and analysis

IV. Findings

A. Impacts on Objectives

B. Summary

C. Conclusions

D. Validation of hypothesis

CHAPTER II

REVIEW OF LITERATURE

The search for related literature began with the document that created the entire aviation system in the United States. The statutes that govern aviation are a result of the 85th Congress of the U.S., and are called the Federal Aviation Act of 1958 (PL 85-726). This federal legislation mandated the creation of a position for an Administrator of civil aviation, along with codifying an accompanying list of responsibilities and duties. This legislation also created the executive agency called the Federal Aviation Agency. Among the codified duties of the Administrator was the right to delegate specific responsibilities to other personnel within the Federal Aviation Agency (later the Federal Aviation Administration). Many specific functions were identified in the Act of 1958, for the Federal Aviation Agency, including the responsibilities for developing standards for aeronautical products. These standards, known as Airworthiness Standards, Technical Standard Orders (TSO), and Parts Manufacture Authority (PMA), provide technical definitions for the production of many key aeronautical products needed for aircraft, aircraft engines, propellers, as well as many other detailed components. The Federal Aviation Act of 1958, however, makes no mention of flight simulator devices, training systems, or any type of communication, navigation, or other electronic devices. In spite of more than 40 years of aviation developments and operations, and a massive growth in airline use of simulator systems, no civil aviation standard exists for the development and fielding of flight simulators.

No mention of developmental and fielding standards for flight simulators is found in the many related Federal Air Regulations, including Part 91, General Operating and Flight Rules; Part 1, Definitions and Abbreviations; Part 21, Certification of Aeronautical Products and Parts; Part 61, Certification of Pilots; or any other FAA standard, regulation, or advisory circular. The FAA focus is upon the flight simulator device passing a qualification test prior to device introduction into an FAA certified operation (AC120-45A, 1992).

With the growth in air transportation operations, aviation applications of electronic technologies, and the use of flight simulator systems as an integral part of any aircraft development, the Administrator did delegate the responsibilities for qualifying flight simulator systems to the National Simulator Program Manager (NSPM). The NSPM and staff have subsequently produced a very important document for flight simulator devices, FAA Advisory Circular, Airplane Flight Training Device Qualifications (AC120-45A, 1992). A significant value of this Advisory Circular is the definition of seven classification levels of flight training devices, based upon the functionality and fidelity of the aircraft simulation. These seven levels possess the following characteristics:

Level 1 - which is currently reserved for a future application.

Levels 2 and 3 - are generic in that they are representative of no specific airplane cockpit and do not require reference to a specific airplane. Within the generic or specific category, each higher level of flight training device is progressively more complex, with a continuum of technical definition.

Levels 4 through 7 - represent a specific cockpit for the airplane being trained for. Within the generic or specific category, each higher level of flight training device is progressively more complex, with a continuum of technical definition.

Additional simulator detail was derived from the Flight Training Device Advisory Circular (AC 120-45A) in the listing of an additional four higher levels of devices, Levels A, B, C, and D. These higher level training devices are considered flight simulators, and are defined in the Airplane Simulator Qualifications (AC 120-40B, 1993). Advisory Circular 120-40B was developed to provide the aviation industry with qualification standards to qualify flight simulators for use by United States certificated air carriers in their respective flight training programs. Within these higher levels of airplane simulators, each alphabetically higher level is progressively more complex, with a continuum of technical definition. AC 120-40B also provided a source of very useful standardized terminology, evaluation and qualification methodologies, and an extensive outline for an acceptance test guide document.

The value of contemporary flight simulator systems was recognized by the FAA's Director of Flight Standards Service, Mr. William J. White, in the "Background" statement for AC 120-40B:

> The availability of advanced technology has permitted greater use of flight simulators for training and checking of flight crews. The complexity, costs, and operating environment of modern aircraft also have encouraged broader use and advanced simulation. Simulators can provide more in-depth training than can be accomplished in airplanes and provide a very high transfer of learning and behavior from the simulator to the airplane. The use of simulators, in lieu of airplanes, results in safer flight

> training and cost reductions for the operators. It also achieves fuel conservation and reduction in adverse environmental effects. (FAA AC120-40B, 1993, p. 2)

Regardless of the recognized value of flight simulators, neither of these two Advisory Circulars provides definition of requirements nor guidance for the development and fielding of these increasingly complex human-machine integration systems.

Flight simulator experience continues to be recognized by the FAA in the training of pilots for both the Private Pilot certificate (FAR 61.4; 61.109, 1999) and for the Instrument Rating used with the Private certificate or the Commercial Pilot Certification (FAR 61.65, 1997).

On the international scene, the International Civil Aviation Organization (ICAO) has recognized the intrinsic value of dynamic flight simulators. ICAO documents provide guidance on Establishing and Operating Aviation Training Centers (ICAO 1985), and for Criteria for the Qualification of Flight Simulators (ICAO, 1995). The ICAO Criteria for the Qualification of Flight Simulators was helpful in providing some limited benchmarks for qualifying these devices after manufacture and fielding of "commercially off the shelf" systems.

A review of the aviation professional organizations and societies resulted in a very interesting finding, that dates back to 1987, wherein the American Institute of Aeronautics and Astronautics (AIAA) recognized the need for a standard for the development of flight simulators (AIAA, 2000). Since that date, the AIAA has undertaken the task to provide fifty aerospace standards under the accreditation of the American National Standards Institute (ANSI) (AIAA, 2000). As these AIAA/ANSI standards have been under development, commitments were made to produce these

AIAA/ANSI standards so as to meet the International Standards Organization (ISO) 9000 Standards. Among the 50 AIAA/ANSI/ISO standards under development, 36 are completed, of which none have been completed for flight simulator development. Since 1995, the AIAA's Technical Committee for Aerospace Modeling and Simulation (MSTC) has carried an agenda item, and staffed a development subcommittee to produce an appropriate AIAA/ISO standard for flight simulator development. To date, no documents have come from that intent. Regardless of these efforts, the FAA has no current policy that recognizes any new or existing ISO standards for aerospace program management, or technologies management, or other recommendations, guidance, or standards for aviation flight simulator qualifications (Cook, 1999).

In addition to the FAA, several other U.S. governmental agencies are involved in aviation, aircraft, and flight simulator systems. The U.S. Army, U.S. Navy, U.S. Air Force, and the National Aeronautics and Space Administration have been queried for the existence of standards for the development and fielding of flight simulator systems.

Among the 256 published simulator research projects identified by Warner (1995), one paper provided simulator development urgencies. That paper by Cyrus (1978), Advanced Simulation for New Aircraft, identified the need for diverse and risk associated management methods to integrate the dynamic technologies of fly-by-wire aircraft and the task and fidelity requirements of a multi-environmental flight simulation. One of the most revealing aspects of simulator development offered by Cyrus was his identification of the requirement to develop simulator architecture that was compatible with the changing data stream coming from the prototype development of computerized aircraft. This changing (aircraft design) data stream had contributed to events where the aircraft being introduced in operation was impacted by a flight simulator arriving late and in some cases, the flight simulator arrived out of configurations with the aircraft, resulting in diverse handling qualities and negative training effectiveness. This 1978 thesis, wherein Cyrus identified the difficulty to integrate the development of flight simulators with the aircraft design data stream, continues to be a major problem in the development of flight simulators. In an interview on that subject, the U. S. Navy's Naval Air Systems Command, Deputy Program Manager, who made a contribution to the development and fielding of the FA18 series aircraft training system, and the T45A/C aircraft training (simulator) system stated:

> Major management and procurement strategies and methods had to be developed to address the aircraft data stream issues. Substantive issues emanate from the diversity in these two aircraft design baselines. These issues extend from the acquisition strategies and contracting, through design development, developmental testing, validation testing, operational testing, and all aspects of design; configuration, performance and systems; and ultimately in the mission, logistics and fielding multi-environmental simulators. These hardline acquisition topics are themselves subject to the impacts from the aircraft performance and handling quality's definition, as well as being driven by the aircraft fly-by-wire configurations, and aircraft block number configurations, driving multiple effects upon flight simulator software, hardware, and courseware developments. (Neel, 1997, p. 2)

Since the Cyrus report in 1978, more than 250 individual research studies on flight simulator systems were conducted through the U.S. Air Force, Air Crew Training Research Division of the Human Resources Directorate, Air Force Logistics Command, Texas; and through the U.S. Navy, Naval Training Systems Center (now called the Naval Air Warfare Center), in Orlando, Florida. (Warner & Casey, 1995). Among these projects were 35 recognizable major topical categories, with some developmental related work, identified in areas that cluster in the human performance regime and simulator systems engineering exigencies. Attention was directed to four areas that are known to represent risk in developing and fielding of flight simulators. These areas of risk were identified as training effectiveness and development trends, visual systems characteristics, transport delay and related potential of asynchronous cuing induced sickness, and mission/aircraft/simulator software integration.

Reviewing the work provided by Smith (1981) in the related areas of training effectiveness, one notes a discussion of factors that will cause increased use of flight simulators, a summary of the major equipment modifications that will increase training capabilities, and a summary of simulator training-worthy research topics. Also included in a final section of that report were comments on how better to use flight simulators, a summary of planned and needed simulator-based training research, and opinions on future simulation applications.

A contributing work on visual system operations and transport delay was produced by Ricard, Cyrus, Cox, Templeton, and Thompson (1978). It identified problems and experimental solutions for image flutter that may occur during some operational conditions in a flight simulator. This work became the definitive work on the delay of the electronic produced visual scene content, which was caused by the delay of transporting the visual image at a rate that was non-perceptible to the human eye and brain. Data from this work would be included in the integration of human psychology and physiology, computer digital bus rates, and visual generator-projector systems.

In a later work on the problem areas of asynchronous cuing induced sickness, Warner, Serfoss, Barauch, and Hubbard (1992) experimentally established a valid visual systems baseline for the operational specifications and performance to avoid the dreaded "simulator sickness syndrome" experienced by pilots conducting training in some ill-designed or maintained multi-environmental flight simulator. Asynchronous cuing syndrome, known as simulator sickness, is caused by the same combination of physiological stimuli that causes "motion sickness" or "sea-sickness" in some people while riding in some automobiles, airplanes, boats, or other forms of transportation. It becomes a serious issue in flight simulators because it may incapacitate a pilot and prevent the pilot from flying an aircraft through a recovery period of 24 hours (Kaiser, 1999).

Other work conducted by the Air Force Research Laboratory (Carretta, 1998), addressed the transfer of training competencies developed in flight simulators to performance of the same tasks while flying real aircraft. During the years 1986 to 1997, 13 of 67 articles, conference papers, and reports were developed on the subject of transfer of training from flight simulators to aircraft performance. Studies by Lintern, Roscoe, Koonce, and Segal (1990) identified significantly better landing skills performances among pilot trainees. In 1991, Pfeiffer and Dwyer identified a very positive correlation measurement (r=.95, and r=.98) in transfer of training studies of pilot's in studies assessing flight simulators to real time aircraft during instrument flight, contact flight, as indicated by deviations in heading, altitude, attitude, and flight control responses. Other studies among these others 13, including some emphasizing visual scene content, and pixel quantity and quality variables, also indicating positive transfer of training between a good flight simulators and an aircraft.

One key managerial element of simulator development was reported by Thode and Walker (1983) in their paper A Model for Comparing Training Cost in a Complex Training System. That research looked at five areas for cost drivers and for consideration in development of a complex training system. Those cost variables inherent in the complexity of integrated training systems development, encompasses accurate definitions of terminal performance levels, visual systems, motion systems, mission complexity, software integration, and the formalized Instructional Systems Development (ISD) efforts. The cost risk of the ISD process emanates from the cyclic nature of that five step process. Each phase of the ISD process links to the other phases so that unsatisfactory results in any one area may result in redesign in previously completed areas.

The cost related elements and risk that are associated with the five ISD phases arise from the interrelationship of the phases. According to the FAA Academy Guidelines for the Development, Evaluation, and Delivery of Training (1998), five areas exist for development operations within these five phases of the ISD process, including those identified as:

1. Instructional Analysis
2. Instructional Design
3. Development and Production
4. Validation of Instructional Product
5. Implementation and Validation of Fielded Product

Another ISD related risk area identified by Thode and Walker (1983) arises from an accurate and disciplined definition of the required trainees' terminal performance levels. Operators typically have difficulty identifying the terminal levels of performance required of the air crews' mission, because their mission is performed as an integrated set of tasks that, if performed well, appear seamless to the operational observer. Identifying and defining these discrete tasks and the associated terminal levels of performance require a significant analysis and integration effort for operational and ISD personnel. Once established, these levels of terminal performance may constitute major fidelity issues in courseware design, software selection and design, and hardware selections. Further complications may derive from an issue similar to "mission creep," when the operator assesses changes in the terminal level of performance to be desirable, usually as part of the validation process. Any significant changes at any one of these five phase in the ISD cycle may constitute a significant cost risk to the development and fielding of the simulator because of concomitant changes in instructional strategies, courseware, software, or even additional hardware required to respond to changes in the ISD produced (simulator) training system.

An additional cost risk listed, but not detailed by Thode and Walker (1983), emanates from the ISD validation process. Operational organizations perform the functional validation when incorporating the simulator capabilities, which may then result in the organization's recognizing new and additional capabilities that can be derived from some "minor changes" of the baseline simulator design, and, ultimately, in the ISD based training system. This tendency is recognized as "mission creep," and adds cost risk to the simulator development, because the five phase ISD process may have to be recycled to accommodate the new requirements from mission creep.

Thode and Walker (1983) also identify a major cost risk from the visual system requirements, chiefly emanating from the large display area of high fidelity visual images needed to provide trainees with the appropriate levels of fidelity from the single most important training stimuli, a visual scene. These typical high fidelity flight simulation visual systems may cost 1 million dollars per channel, and a typical high fidelity flight simulator may require an expenditure of 3 to 8 million dollars for the visual system (Neel, 1997).

The motion systems required by the FAA in the publication Airplane Simulator Qualifications (AC 120-40B, 1992), represent a significant cost risk, and that requirement even specified a minimum freedom of motion of three degrees per axis, which in this year of 2000, will typically represent a cost of $500,000. These visual system costs may also be driven by mission unique priorities like flight in high velocity or high acceleration airflow models, for example, wind shears, wake-turbulence, and other dynamic conditions may yet require a six-degree freedom of motion system, at a cost of $600,000.

A smaller technology company, Environmental Tectonics Corporation's (ETC) of Southampton, Pennsylvania, has established a simulator technology and cost bench-mark for an FAA Level 2 FTD certification level of general aviation aircraft. This development of a lower cost, higher fidelity General Aviation Trainer (GAT II) flight training device (Fiorino, 1999) includes full motion (360 rotation/yaw, 12 deg. pitch, 20 deg. roll) flight simulator capabilities. The GAT II can provide basic flight instruction, instrument flight instruction, navigation instruction, and an impressive variety of pilot orientation-disorientation training dealing with serious flight illusions. Though these tasks are of limited mission use to airlines or military developments, this general aviation GAT II system is available commercially for approximately 250 thousand (year 2000) dollars, a price that is less than the cost of many comparably performing aircraft. This company did confirm their use of in-house development standards (ETC, 2000).

The level of technical and human-machine integration achievements provided in current flight simulator systems can meet the training requirements if sufficient funds exist for the courseware, software, and hardware developments. A recent example of mission achievement within cost limitations has resulted from the U.S. Navy's T45 aircraft integrated training system. The significance of these integrated systems was depicted in a recent article in Aviation Week & Space Technology by Phillips (1999), entitled "Advanced Imagery Key to Raytheon Simulation." Navy sources reported: "These (T45TS) training devices have reduced transition time to tactical jet aircraft deployed with the fleet by 15%" (Phillips, 1999, p. 82).

The T45TS was the Navy's first fully integrated training system, and has been operational since 1990. T45TS has 11 Operational Flight Trainers (OFT) and 5 Instrument Flight Trainers (IFT) installed at NAS Kingsville, Texas, and NAS Meridian, Mississippi (Engel, 2000).

The latest example of this level of technologies in training system is evidenced in the U.S. Air Force-Lockheed/Martin-Boeing-Raytheon Training Systems F-22 fighter training system. According to Proctor (1999), "The Raytheon-built F-22 full mission trainer, employs a full scale F-22 cockpit inside a partial geodesic dome, with nine realistic rear projected display facets provide realistic visual dynamics incorporating landscape, atmospheric conditions, mission threats and targets." A very significant F22 management initiative was the borrowing of aircraft operational flight (software) program for use in other (flight and maintenance) training devices (Proctor, 1999). The scale of these cost savings efforts would be considerable, because the F-22 is to include 22 Full Mission Trainers, up to 21 PC based Weapons and Tactics Trainers at the first operational base, Tyndall AFB, Florida. The inclusion of F-22 aircraft operational flight software program in the Full Mission Trainers, and the Weapons Tactics Trainer addresses a long standing dichotomy between real aircraft and flight simulator devices.

The magnitude of the F-22's inclusion of aircraft operational flight software can best be illustrated in the strident comments of US Navy Vice Admiral James Bushey, then (1984) Commander of the Naval Air Systems Command, when Bushey challenged the FA18 Flight Simulator Development Team saying:

> that you ___ ____ training systems and flight simulator development people will be doing _____ your job's (well) when your simulators are available at the operational base when the first new FA18s arrives, and the simulator is *flying exactly like the aircraft is on the first day of operation, regardless of the fact that the aircraft operational software (packages) are changing up to the delivery date of the aircraft!* (Bushey, 1984, p. 10)

The F-22 development management has attained that goal by "the inclusion of F22 aircraft operational flight software program in the Full Mission Trainers, and the Weapons Tactics Trainer . . ." (Phillips, 2000).

Perhaps the single most definitive document on the subject of military flight simulator development is the USAF Guide Specification for Flight Simulators (AFGS 87241B, 1996). This document has a very comprehensive listing of military related requirements for the human-machine interface. It also incorporates many engineering and technologies applications and specifications for these military applications. The latest, and most comprehensive version of this document AFGS 87241B, has been in a draft form since 1996, but represents a milestone document for flight simulator development for military airplanes and helicopters. As a draft document, this 87241B document also contains much of the rationale for each of the recommendations, and therefore, provides considerable insight to the specifications and values. This USAF document is not listed on any Department of Defense publications index, since the AFGS 87241B is still a draft document, but a very good one for engineering baseline values for the development of military flight simulators.

In addition to challenges from the major procurement elements of cost, schedule, and performance, other evolving segments of technology have impact the availability, usage, and acceptability of flight training devices, as well as influence the high fidelity types of flight simulator systems. The development of the consumer level IBM Personal Computer, and to a lessor extent, the Apple series personal computers has led to a fielding of increased numbers of general aviation aircraft flight training devices.

In research conducted by the FAA's Civil Aero Medical Institute (CAMI), a clone of the popular consumer product the IBM based personal computer/Intel processor (PC) has provided a beginning towards low cost fight simulation. The Personal Computer Aircraft Training Device (PCATD), that consumer PC based device, with relatively inexpensive software and courseware, was determined to be of some value for some flight training tasks. CAMI has been careful to identify that the levels of fidelity provided by these PCATDs are limited to familiarization level training, and part task training, because training is limited to the performance of such tasks as instrument flight procedures, normal and emergency response training, and for limited amounts of navigation training. The FAA allows 10 hours of PCATD experience to be credited for certification level training (FAA Order 8700.1, 98-02).

Some related work was reviewed in the newer and adjunct area of flight training devices, the personal computer air training device (PCATD). This area is discussed in the FAA's Advisory Circular (61-126, 1998) Personal Computer Aviation Training Devices, and further clarified in the FAA Order 8700.1, FSGA 98-02 (1998).

Recent federal legislation has provided the Federal Aviation Administration with research funding for General Aviation Safety Improvements. Civil Aero Medical Institute (CAMI) and NASA have continuing research, and sponsorship of research in the applications of PCATD types of devices, as well as other diverse types of safety improvement research topics using the PCATD baseline (FAA CAMI Report 95- 04).

During CAMI conducted research in 1996, a task analysis was performed on the "instrument flying mission" (FAA CAMI Report 96-8). From that research came a baseline and task-specific guidelines for part-task training events and tasks that were deemed appropriate for the PCATD. Additional relevant CAMI comparative research was conducted in 1996, with the comparison of commercially developed instrument flight trainer PCATD, and "game" type flight simulation (FAA CAMI 96-15). This research targeted the capabilities and limitations of these respective PCATDs.

CAMI also conducted research in the "transfer of training" (FAA CAMI Report 97-11) when the PCATD was used in support of instrument flight training. The results of this research indicated a positive transfer of training of 15 to 40% was experienced by some of the participants. It also identified that some participants had a decrement of training from 0 to 25%. It appears that the PCATD can have positive and negative influences, depending upon the flight training curriculum, the individual's propensities towards computers, and the task being learned. Through this, and subsequent related research topics, the PCATD was recognized to be limited to part-task training only. The PCATD was not a good candidate for mission, or aircraft performance type training, and does not provide the comprehensive training of a multi-environmental flight simulator.

In a separate program, NASA's Advanced General Aviation Transportation Experiments (AGATE), some early studies have used a combination of Flight Training Devices (FTD), Personal Computer Aviation Training Devices (PCATD) and certificated aircraft to provide integrated training for ab initio pilot trainees. In one study lead by Embry-Riddle University, the training required for the FAA private pilot certification and the instrument pilot rating were integrated. NASA's goal for these projects was the reduction of training time and training cost by 25% (Collins 2000). Among the early results of one such NASA funded study were a report that "the (Embry-Riddle) University relied heavily on PCATDs during the first (experimental) private/instrument class, and (student pilots) experienced some negative learning" (p. 5). This was apparent in some diverse areas as handling qualities, slow flight and stall performance, as well as the development of instrument scan habits.

With a significant heritage of development work in flight simulator for airplane and space applications, the National Aeronautics and Space Administration (NASA) has been actively involved in flight simulation, conducting more than 250 flight simulator/simulation studies, over a 33-year period at their NASA research centers at the Langley Research Center, Virginia, Ames Research Center, California, and at the Dryden Flight Test Center, California locations. This research produced only five reports dealing with the management of the development and fielding of these types of simulator systems. During this thirty year chronology, NASA contributed many more research reports on simulator architecture, human psychological and physiological flight vehicle interfaces, flight management and flight control systems, flight crew systems applications, and other aviation and space related topics.

NASA's Edwin Dean, of the Langley Research Center produced a paper on The Many Dimensions of Program Management (1992), that is applicable to program management for flight simulator systems. In that paper Dean identified the three dimensional aspects of NASA conducted program-project-system-subsystem development and offered the Quality Function Deployment (QFD) process of B. R. King (1989) as an effective model of that three dimensional process. Dean further observes that QFD is an effective model for the complexity of program management applications:

> . . .since it uses basic dimensionality within a program to provide a structured way of ensuring that quality is designed into a system . . . QFD addresses the dimensions of customer desire, quality characteristics, functions, parts, and failure modes. (Dean, 1992, p. 1)

Dean further diagrams the relationships of the major elements of a technical program-project development operation as "Concurrent Engineering." The association to the development complexities of a multi-environmental flight simulator system is further recognized when Dean identifies a borrowed definition of concurrent engineering. "Concurrent engineering is a systematic approach to the integrated concurrent design of projects and their related processes, including manufacture and support."(p. 4). This total systems development, whether called concurrent engineering or integrated product development, or other recognizable labels, reflects the position proffered by Winner, Pennel, Berstrand, and Slusarezuk,

> This approach is intended to cause the developers, from the onset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements. (1988, p. 7)

Perhaps the best validation of the need for this research came from a recent meeting of the standing Technical Committee for Simulation and Modeling (AIAA 2000), of the American Institute of Aeronautics and Astronautics (AIAA). In that forum, and at two previous annual conferences, discussions were held concerning the need for the AIAA to produce a standard for the development of flight simulator systems. AIAA has approximately 93 standards for aeronautical and aerospace materials, practices, and development operations(AIAA, 2000). None of AIAA's standards address the development or fielding of flight simulator systems.

Additional sources for applicable management standards were sought through Internet and telephone inquiries with five aviation industry representational organizations, including the Aircraft Owners and Pilots Association (AOPA), Air Transport Association (ATA), Aeronautical Radio, Inc. (ARINC), Flight Safety Foundation (FSF); and the General Aviation Manufacturer Association (GAMA). None of these sources identified the existence of standards for the management of simulator development and fielding.

Seven organizations that develop and field flight simulator systems were also included in the search for germane development and fielding information. The results from these inquiries varied, but they did not identify any comprehensive standards for flight simulator development and fielding. These commercial developers do have, but did not offer copies of many proprietary documents and systems in place for their product development. The responding commercial organizations included: Airbus Training

Services; Boeing-Flight Safety International; CAE, Inc.; Flight Safety International, Simulation Division; Raytheon Systems Simulation; and British Aerospace-Electronics (formally Reflectone Training, Inc.) of America.

Summary of Literature

The review of literature identified more than 600 sources for information on flight simulator systems, including over 250 from a single source, in the Warner and Casey (1995) publication called the Flight Simulator Visual System Research and Development: Bibliography of Support Provided by the Aircrew Training Research Division.

Fifteen individual publications contained germane information on simulator development relating to the technologies and to flight characteristics of flight simulators. But one publication by M.L. Cyrus (1978), entitled Advanced Simulation for New Aircraft, identified the need for:

> diverse and risk associated management methods to integrate the dynamic technologies of fly-by-wire aircraft and the task and fidelity requirements of a multi-environmental flight simulation. (p. 5)

In this publication Cyrus identified the requirement to develop simulator architecture that was compatible with the changing data stream coming from the prototype development of computerized aircraft. This changing data stream had contributed to events where the aircraft being introduced in operation was impacted by a flight simulator arriving late. In some cases, the flight simulator arrived out of configuration with the aircraft, resulting in diverse handling qualities, and negative training effectiveness. These relevant topics identified in Cyrus (1978) were recognized as requiring significant management expertise to integrate these diverse technologies, aircraft flying characteristics, and human performance.

An indicator of FAA's value of contemporary multi-environmental flight simulator systems was offered by the Director of Flight Standards Service, Mr. William J. White, in the "Background" section of the FAA's Advisory Circular, AC 120-40B, (1993):

> The availability of advanced technology has permitted greater use of flight simulators for training and checking of flight crews. The complexity, costs, and operating environment of modern aircraft also has encouraged broader use and advanced simulation. Simulators can provide more in-depth training than can be accomplished in airplanes and provide a very high transfer of learning and behavior from the simulator to the airplane. The use of simulators, in lieu of airplanes, results in safer flight training and cost reductions for the operators. It also achieves fuel conservation and reduction in adverse environmental effects. (p. 2)

This FAA statement regarding the value of the flight simulator to provide safer, less expensive, more in-depth training, clearly identifies a superior integrated technology that requires significant management of development and fielding operations.

Additional information was developed from FAA, U.S. Air Force, U.S. Navy, and NASA sources, but with limited references to the management aspects of the development of flight simulators. Citations included references to cost efficiencies, instructional systems development, and the integration of human psychology and physiology with visual generator-projector systems, and digital computer technologies.

With a history of research in aviation and space systems, National Aeronautics and Space Administration (NASA) has been actively involved in flight simulation, conducting more than 250 flight simulator/simulation studies, over a 33 year period at their NASA research centers at the Langley Research Center, Virginia, Ames Research

Center, California, and at the Dryden Flight Test Center, California locations. This research produced only five reports dealing with the management of the development and fielding of these types of simulator systems. In one of these publications, The Many Dimensions of Program Management, Dean (1992) offered a substantial source for managing technical developments. He identified the three dimensional aspects of NASA conducted program-project-system-subsystem development. He further diagrams the relationships of the major elements of a technical program-project development as possessing the characteristics of the "Concurrent Engineering" process. This approach is intended to cause the developers, from the onset to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements (Winner, Pennel, Berstrand, & Slusarezuk 1988).

Perhaps the best validation of the need for this research came from a recent meeting of the standing Technical Committee for Simulation and Modeling (Wentzell, 2000), of the American Institute of Aeronautics and Astronautics (AIAA). In that May, 2000 forum, and at two previous annual meetings, the need for the development of an AIAA standard for the development of flight simulator systems were discussed. AIAA has approximately 93 standards for aeronautical and aerospace materials, practices, and development operations. None of AIAA's standards address the development or fielding of flight simulator systems. AIAA is authorized to develop aeronautical standards by the American National Standards Institute (ANSI), and is continuing to produce both AIAA and ISO standards (French, 2000).

Additional Internet and telephone inquiries were conducted with five aviation industry representational organizations, including: The Aircraft Owners and Pilots

Association (AOPA), Air Transport Association (ATA), Aeronautical Radio Inc. (ARINC), Flight Safety Foundation (FSF), and the General Aviation Manufacturer Association (GAMA). None of these sources employed standards for the management of simulator development and fielding.

Two organizations that are involved in developing and fielding flight simulator systems, did identified technical information sources for their development operations. One, the FAA, sent a copy of an ICAO document, the Manual of criteria for the qualification of flight simulators (Doc. 9625-AN/938), which was useful in the areas of qualification testing of flight simulators upon installation at a training provider's facilities. Another study respondent sent a proprietary document used by that company in their development and manufacturers of flight simulators. That proprietary document was reviewed, and returned to that cooperating manufacturer, without extracting business sensitive information.

CHAPTER III

METHODOLOGY

Chapter Overview

This chapter provides the portion of descriptive research methodology that concentrates upon developing responses, facts, and relevant information needed to objectively illuminate and measure the objectives of the study. These foci upon the existence of appropriate aeronautical standards for the management of development and fielding of dynamic flight simulator systems. If so indicated by the results of the study, information can be produced that leads to the development of guidance, specifications, and standards for the development of these complex systems.

Research Methodology

This study utilized the methodology model of Descriptive Research. It strives to answer the question "What is the current status of a specific study area in a given population" (Borg, 1985, pg. 104). With knowledge of that status being reflected in the research findings and conclusions, the researchers may make recommendations that can provide improvements in the management of the development and fielding of these aeronautical technology system.

A stratified sample was chosen from international industry and governmental organizations involved in applications of aircraft flight simulator; simulator development and manufacturing; and in the fielding and operational elements of these systems. The classical elements of a "self-reporting" type of descriptive research are incorporated in this study (Cook, 1995, p. 178). These elements include:

1. Identifying the leading international development organizations that procure, manufacture, field, and operate these complex air vehicle simulator systems. The requisite level of fidelity to be included provides advanced technologies simulator systems for flight crews' training for all elements of normal, emergency, and mission operations.

2. Identifying the applicable population, including the reality that a limited population exists, and a stratified sample must, therefore, be used to provide the requisite organization that participate in the development of flight simulator. The pursuit of this task also incorporated elements of 1995-2000 corporate reality, became several of these development organizations are business units within major aerospace corporations, and have been candidates for parent corporation divestitures and spinoffs. Seven of the nine candidate organizations experienced corporate reorganizations, and were spun-off as new independent businesses. Only two of these candidate organizations ceased to function in the development of flight simulator, or providing simulator related services.

Upon the nomination of a simulator development organization as a potential participant, a telephone contact was established at an appropriate level within the cognizance development activity. The content of the telephone discussions included the affirmation that the participating organization is, indeed, involved in the development and fielding of dynamic flight simulator systems; the participants' acknowledgment of a willingness to participate in the OSU research project; and the participants' identification of a project contact person, channels of communications, and directions for the flow of documentation.

3. The collection of data to test a hypothesis or to answer questions concerning the current status of the subject of the study was derived from the responses to the research instrument. The scope and detail of the questions used to derive data is available offered in Appendix B.

4. The self-reporting characteristic of descriptive research derives from the limited research sample of 28. The participating organizations came from four areas of the aviation and flight simulation industry, including the following:

A. Flight simulator manufacturing developers (14)

B. Government agencies & organizations (5)

C. Aviation professional organizations (5)

D. Major US airlines operating training centers (4)

Those participants were provided with a two-page "Participants Questionnaire." Upon the completion and return of these questionnaires, a review of responses was conducted.

5. The development of an appropriate research instrument was necessary. This instrument took the form of an inventory assessment questionnaire, which was pretested by the procurement group of the Flight Simulation Experiment Branch, Ames Research Center, of the National Aeronautics and Space Administration (NASA). The questionnaire was directed by project contact person to appropriate program or project

manager/leaders, or technical manager/leader for a multi-environmental simulator system. The inquiry instrument was developed to indicate the organizations' responses to the question regarding, "What standards, systems, or documentational methods of management exist, within and outside your company, for the management of the development and fielding of high fidelity flight simulators for contemporary aircraft, air vehicle, and space vehicle simulator systems applications?" The resulting pretested questionnaire is incorporated in Appendix B.

6. The "Participant's Questionnaire" contained the "yes" and "no" response blocks for specific questions. A simple item analysis was conducted from those "yes" or "no" responses from each of the respondent questionnaires. Additional objective information on developmental times of the participants' organizations were developed from responses to questions #12, #13, and #14. The participant responses should provide useful data on the existence of management standards for the development and fielding of this type flight simulator systems.

7. Prior to beginning the compilation of the questionnaire results, the returns were scrutinized for their compliance with the participant qualifications, which were indicated by the participants affirmative responses to questions #1, #2, #3, #10, and #11. These questions asked several validation type questions regarding a given organization's participation in the development and fielding of these types of flight simulator systems. Each question was used to validate a specific area of the development process, and are identified as follows:

Question #1. Identified that organization's designated representative was functioning in a program management status.

Question #2. Ascertained the organization's spectral involvement in simulator procurement, development, and use/fielding of these level of flight simulators.

Question #10. Recognized the organization's authority to contract for the procurement, development, and fielding of these technological products.

Question #11. Identified the organization's authority to influence or set the acquisition strategy for these types of training systems.

Any organization not answering affirmatively to each of these questions was scrutinized for possible exclusion from the study, as a validity check on the participating organizations.

8. The initial data retrieval started with tallying of the responses for each of the 14 questions.

9. The results of the self-reporting study were compiled and analyzed for several qualities associated with the objectives of the study.

10. Upon completion of the compilation and an analysis of the item responses, data were offered to support the three objectives of the study. The application of responses were incorporated in the "Findings section" of the study, and will form the basis for determining the number 1, and the number 2, "Objectives for the Study." These question item responses will also serve as the basis for the "Conclusions" of this study.

11. The "Findings and Conclusions" will contribute the basis for a determination of meeting the "Objectives of the Study."

12. The Findings and Conclusions may provide the foundation for generating a comprehensive management standard for development and fielding of flight simulator systems. This path will lead to fulfillment of the third "Objective of the Study."

Selection of Subjects

Jaccard (1983) defined population as the aggregate of all cases to which one wishes to generalize the results of research. Further guidance on research population and sample group sizes was obtained from Van Dalen's (1979) three factors in determining the size of an adequate sample: (1) the nature of the population, (2) the type of investigation, and (3) the degree of precision desired. From those indices, an empirical approach was begun by candidates being identified from a combination of data sources, including the empirical knowledge of corporate and governmental-sponsored flight simulator development, and from an investigation of listings in the World Aviation Directory (2000). Each potential organization was subsequently scrutinized for inclusion in the sample group if their business/organization had gross procurement revenues of $4 million per year. The establishment of a $4M dollar threshold came from the realization that a typical high fidelity flight simulator sells for a minimum of $1.0M (to $35M) per unit, with the lower priced unit requiring the sale of 4 units per year to qualify as participants. Hence, participating organizations came from internationally recognized developmental organizations, including aircraft manufacturers, training systems development companies, training organizations, government aviation agencies, and associated aviation industry associations. A world population of 35 organizations was identified for consideration. Of the 35 identified, 32 organizations were considered geographically and technologically significant in the development arena. The sample of 32 participating organizations represent four areas of the aviation and flight simulation industry, including 16 involved commercially as flight simulator development and manufacturers; 7 from government agencies, from civilian and military organizations: 5 aviation professional organizations; and 4 major US airlines that operate large training centers. Initial contact information for these organizations was pursued through the World Aviation Directory, with telephone contact used to validate the activities of the organizations' simulator development. The fidelity of the flight simulators that were developed by these organizations would qualify for FAA levels 2 through 7. In addition they would provide flight crew training in normal, emergency, and mission operations of complex air vehicles.

From those 32 organizations contacted, 28 of these organizations agreed to participate as the study sample. According to Krejcie and Morgan (1970), it would require 30 responses from a study population of 32 to attain the nominal statistical significance to the 95th percentile. This study dealt with responses from less than that number (32), which lowered the level of confidence in the data developed from the study.

The candidate organizations contacted for participant status, include:

1. Airbus (Industries) Training Services.
2. Aircraft Owners and Pilots Association.
3. Air Transport Association.
4. American Airlines Commercial Flight Training.
5. American Institute of Aeronautics and Astronautics.
6. ARINC, Inc.
7. BAE Systems
8. Canadian Aerospace & Electronics (CAE), Inc.
9. Delta Airlines.

10. EER Systems, Inc.
11. Environmental Tectonics Corporation's (ETC)
12. Federal Aviation Administration, National Simulator Program Office (NSPM).
13. FlightSafety-Boeing Training International.
14. FlightSafety International, Simulation Division.
15. FlightSafety Services, Corp.
16. Frasca Simulation International.
17. General Aviation Manufacturers Association (GAMA).
18. L3 Communications, Inc.
19. Lockheed-Martin, Flight Training Systems.
20. Lockheed-Martin Systems, Orlando, FL.
21. NASA, Ames Research Center.
22. NASA, Langley Research Center.
23. Raytheon-Canada.
24. Raytheon Systems Co., Flight Simulation.
25. Science Applications International, Simulation and Research Services Division.
26. Southwest Airlines.
27. Thomson Training & Simulation, Ltd. (UK)
28. United Airlines Flight Training Center.
29. U.S. Air Force, Air Force Systems Command (AFLC), Crew Training Research Division.

30. U.S. Air Force, Aeronautical Research Laboratory, Air Force Systems Command, (AFLC).

31. U.S. Army, STRICOM, (AMSTI-PMACTT)

32. U.S. Navy, Naval Air Warfare Center, Training System Division

Research Design

Descriptive research is recognized as providing a starting point for the current state of scientific or technological endeavors. It provides a direct source of valuable knowledge concerning human and organizational behavior (Borg, 1987), the details of the research design are organized and proffered herein:

Planning phase - The process of descriptive research includes the classic elements of problem identification; hypothesis development; population identification; investigative instrument development, with data element incorporations and analysis planning and mechanisms to develop findings, conclusions, and recommendations.

Execution phase - The execution operations were uncomplicated, with the primary source of information being the questionnaire. Initial interest, motivation, and improved completion and rates of return were facilitated by direct phone contacts with the designated person of each participating organization. Direct mailings of the questionnaires were routed to the contact persons, with instructions to complete and return within 10 days of receipt. Telephone follow-up calls were placed 15 days after the mailing of the questionnaires.

Information development phase - The returned questionnaires were reviewed for appropriate responses that met the form and format of the questionnaire. A compilation of data and information proffered in the question responses was developed as an "item analysis" table. These data and information are further summarized, and assessed for inclusion and impact upon the achievement of the Objectives of the Study.

Recommendation development phase - Using the data and information from the analysis of the questionnaire, a compendium document was developed from the research topics and other sources, and offered as a management standard for development and fielding of multi-environment flight simulator systems.

No attempt was made to standardize the research test instrument (questionnaire). Efforts were directed to towards establishing construct validity of the questionnaire, and the individual items contained on the questionnaire. That process was performed by an expert group from by NASA Ames personnel. With a very limited (35) worldwide population, the classical standardization of the research instrument was not possible without compromising the target participant populations. Therefore, no extensive statistical modeling or derivations were intended or attempted.

Research Instrument

Development of the Participants Questionnaire allowed participating organizations to respond to selected questions regarding what standards, systems, or documentation methods of management existed for the development and fielding of computer-based flight simulators for contemporary aircraft, air vehicle, and space vehicle simulator systems.

Using a method identified by Borg (1987), the Participants Questionnaire was developed and refined through the application of construct validity methods. The expert group used for to test the construct of the questionnaire items came from the flight simulator systems procurement group at the Flight Simulation Experiment Branch of the Ames Research Center, National Aeronautics and Space Administration. This expert group responded to the Research Communications Materials, which consisted of five pages of information which incorporated the Participants Questionnaire. These Research Communications Materials contained the: (1) Transmittal Letter; (2) Introduction page; (3) Participant Questionnaire; (4) the Optional Information and acknowledgment for those participating in the study, and; (5) the Oklahoma State University (OSU) Institutional Review Board (IRB) Consent to Participate in Research form (see Appendix B). The expert group addressed each of the 14 questions on the Participant Questionnaire for construct validity as defined by Carmines and Zeller (1979). This process provided the basis for, (1) the theory underlying the construct to be measured was appropriate; and, (2) that the intended measurements were adequate for the construct being evaluated (Mason & Bramble, 1989).

Following the construct validity work, and peer review, the participant questionnaire was revised and formatted into a single page document. Other pages contained in the Research Communications Materials included the transmittal letter, which provided a request to participate in the project, a commitment to provide feedback for participants, and an overview of the project. Page 2 of the document included an introduction and a "business sensitive" paragraph intended to communicate the researcher's sensitivity to the respondent's information, as well as to the time required to complete the questionnaire. This was an effort to assure participants that the project was not seeking any business sensitive or proprietary information. Page 3 requested participants to answer 14 questions, with 12 of those questions only requiring a yes or no response. These questions were focused upon the organization's use of development standards, and associated development and fielding operations. Page 3 also inquired if the researcher could review any existing management standards that were being used. Page 4 was provided for the participants to volunteer any pertinent comments that were related to the use of management standards for the development and fielding of flight simulator systems. Page 5 was the OSU-IRB Consent Form.

Data Collection Plan

Upon receipt of a completed questionnaire, the documents were to be scanned for yes or no responses to questions #1 through #12. Questions #13 and #14 were to be compiled separately to derive information about the calendar time needed to complete a multi-environmental flight simulator.

Prior to the distribution of the participant questionnaires, the data collection tools were developed. These data collection tools include the following products and processes:

1. Preparation for processing returns.
2 Develop a tally of participant responses to each question.
3. Perform validity assessment of each participating organization, using their responses to questions #1, #2, #10, and #11. These questions will identify the organizations' responses to concerns about the following validation topics:

A. To verify appropriateness of organization's contact person to participate.

B. To indicate program management cognizance for cost, technical, and fielding.

C. To assess contracting authority, for credibility and cognizance for management, cost, and schedule responsibilities.

D. To assess cognizance for reliability, availability, maintainability, and fielding of these systems.

4. Continue review of response data with the emphasis upon questions #4, #5, and #6, which are the questions that identify whether an organization uses public sector, in-house, proprietary, or no specification/standard during simulator development.

5. Identify the participants' responses to questions #7, and list any sources identified or provided.

6. Identify the responses to question #8, and a list of any sources identified or provided.

7. Identify the responses to questions #12, and develop Mean, Median, and Modal information for question #13.

8. Summarize the responses to question #14.

Analysis of Data

Reviewed and assessed questionnaire responses by item for classes, clusters, dispersions, and appropriate measurements of central tendencies, as well as the overall relevance to meet the Objectives of the Study. These analyses resulted in the following actions:

1. Identified available standards, systems, or documentation used for managing the development and fielding of dynamic flight simulators by developmental organization.
2. Identified and accumulated information regarding management of such developments, including mission requirements; educational strategies; aeronautical systems integration; simulator courseware, hardware, and software applications and integration; logistics integration, business and contractual management action areas; and other respondent topics.
3. Determined if the results of the study met each of the listed "Objectives of the Study."
4. Assessed available question item responses and other information that supported the "Hypothesis of the Study."
5. Developed a Scientific Hypothesis that reflected the research information.
6. Developed confirmation of the hypothesis through the application of a Statistical Hypothesis, as expressed H: u = <.5
7. Generated a comprehensive development and fielding guide for use in the management of the procurement of flight simulator systems.

CHAPTER IV

FINDINGS

General

With a limited worldwide population of technical organizations with the expertise to develop multi-environmental flight simulator systems, the interest of the candidate organizations was very positive. A stratified sample was chosen from international industry and governmental organizations involved in several applications of aircraft flight simulator; simulator development and manufacturing; and in the fielding and operational elements of these systems. The classical elements of a "self-reporting" type of descriptive research are incorporated in this study (Cook, 1995), where the question is asked, "what is the current status of a specific study area in a given population."

A multi-environmental flight simulator was defined to include devices where flight crew responded to normal, emergency, and mission operations training demands. The participating organizations were asked several questions about their involvement, authority, and responsibilities in the developing and fielding these multi-environmental flight simulator systems. Of the 21 responding organizations, only one, the American Institute of Aeronautics and Astronautics, was judged not to have the breadth of responsibilities in the contracting and development areas to be included in the item responses.

Among the external influences upon the study's population and sample being researched were the reorganizations and amalgamations of former defense-based flight simulator businesses. Of the 21 responding organizations, seven of the 16 simulator manufacturing organizations were exposed to corporate take-overs and/or spin-offs within the previous three years. Of these seven organizations, only two did not continue as business units, with flight simulator development product lines. With fewer new major aircraft development projects came fewer opportunities for the development of flight simulators, with the resultant amalgamation of flight simulator development organizations.

Upon selection by the researcher, all 32 of these organizations were contacted with a scripted format, and 28 of the 32 agreed to participate. In most organizations the designated contact persons completed the questionnaire themselves. In other instances, the contact person routed the questionnaire to appropriate experts on the subject. Twenty-one of the 28 questionnaires were returned.

Participant responses to each questionnaire item is depicted in the Questionnaire Item Response Compilation (Table I). There were 21 organizations participating, and the compilation indicates as many as 21 responses to most questions, and as few as 15 responses on a single question being the lowest item responses (Table II).

TABLE I

QUESTIONNAIRE ITEM RESPONSE COMPILATION

Number	Question Content	Response Yes	Response No
1.	Are you in a program manager/leader, project manager/ leader position, or technical manager/leader position for a multi-environmental flight simulator system?	20	1
2.	Does your simulator organization procure, develop, or use/field multi-environmental flight simulators?	20	1
3.	Does your simulator organization use subcontractors to manage any part of the simulator.		
	a. procurement?	5	12
	b. development?	14	7
	c. fielding?	11	7
4.	Does your simulator organization use a public sector specification or standard, or other guidance document for the management of flight simulator development and fielding?	10	10
5.	Does your simulator organization use a in-house specification or standard, or other guidance document for the management of flight simulator development and fielding?	15	5
6.	Does your simulator organization use a proprietary specification or standard, or other guidance document for the management of flight simulator development and fielding?	6	14
7.	Are any of the documents identified in questions 5, 6, or 7 available for this research Principal Investigator to review?	9	9
8.	Are you submitting those specifications, standards, or documents for use in this study?	0	18
9.	Does your simulator procurement incorporate design reliability, availability, maintainability (RAM) targets?	13	7
10.	Does your organization have contracting authority to procure, develop, and field this type simulator?	14	5
11.	Does your organization have acquisition strategy development authority?	12	6
12.	Does your organization have a typical duration for development and fielding of a multi-environmental flight simulator?	13	5
13.	If the answer to question #12 is Yes, what would be the typical duration to develop and field this type simulator?		

Number of respondents	Years	Months
1	4	0
2	3	0
4	2	0
2	-	18
1	-	15
2	1	0
1	-	9
2	-	6
Total responses to Question #13 = 15		

14. Is your primary focused for developing multi-environmental flight simulators:
Training? (12) Research? (7) Product development? (5) Other (0)

TABLE II

MEASUREMENTS OF CENTRAL TENDENCIES FOR DURATION TO DEVELOP FLIGHT SIMULATOR SYSTEMS

Mean (Mn) = 1.73 years;	Median (Md) = 2.0 years;	Mode (Mo) = 2.0

The information developed from the Participant's Questionnaire provided the following detail regarding each of the Objectives of the Study:

Objective One. Identify available standards, systems, or documentation used for managing the development and fielding of dynamic flight simulators by developmental organizations.

The findings that address objective number one are derived from the responses to questions #4, #5, and #6. Question #4 asks if the participants "use any public sector specifications, standards, or other guidance for the management of the development and fielding of these training systems." The responses were non-conclusive, because 10 (50%) of the respondents answered YES, and 10 (50%) respondents answered NO. Among the 10 affirmative responses, 4 respondents offered the titles and sources for the public sector documents that they used in some portion of their organizations' development and fielding of the multi-environmental simulators.

Question #5, which asked about the use of in-house specification or standards, or of another guidance document in the management of the development and fielding of a multi-environmental flight simulator system, resulted in responses by 20 participants; 15 (75%) affirmative responses, and 5 (25%) negative responses.

Question #6 addresses the participant's use of proprietary specifications or standards, or other guidance documents for the same type of development. Only 6 affirmative responses were reported, and 14 participants gave negative responses.

The outcome of the three questions regarding the use of standards offers clear evidence that in-house standards most often guide development of flight simulators. Neither public sector, nor proprietary sources of flight simulator development standards were used by a majority of participants. Consequently, if the majority of organizations in simulator development use their own in-house standards, and these standards are not shared by other development organizations during similar development operations, *no industry standard is use throughout the aeronautical industry.*

In a subsequent question regarding the availability for review by researchers of any in-house or proprietary documents, 9 (50%) of the respondents offered to make the document available, and 9 (50%) declined to offer these documents (Table III).

TABLE III
DISTRIBUTION OF SOURCES SELECTED FOR SPECIFICATIONS, STANDARDS, AND OTHER GUIDANCE

Source	Yes	No
Public sector standards.	50%	50%
In-house standards.	75%	25%
Proprietary standards.	30%	70 %

Objective Two: Identify and accumulate the diversity of action areas required to manage these developments.

Among the 20 respondents, 8 respondents identified 7 sources for management specific tasks in the development of specifications, standards, and guidance. These sources include:

1. FAA Advisory Circular 120-40B, Airplane simulator qualification.
2. FAA Advisory Circular 120-45A, Airplane flight training device qualification.
3. FAA Academy guidelines for the development, evaluation, and delivery of training.
4. FAA Authorization for use of personal computer-based aviation training devices under the provisions of Title 14 of the Federal Regulations (CFR 14) Parts 61 and 141. Aviation Order 8700, Flight Standards Information Bulletin 98-02.
5. USAF, Flight simulator guide specification (AFGS 87241B,draft).
6. ICAO, Manual of criteria for the qualification of flight simulators (Doc. 9625-AN/938).
7. AIAA, AIAA standards program. Engineering & Technology Management. French, 2000.

Additional source documents for specific simulator design and performance guidance are found in several technical references identified in the Literature Search section, and from the Selected Bibliography section of this dissertation.

Objective Three. Generate a comprehensive flight simulator development and fielding guide for use in the management of the procurement of these types of sophisticated aeronautical equipment.

With the information derived from the research instrument, it became apparent that there were approximately 28 (from the sum of 15 in-house, 6 proprietary, and 7 specific referenced) different source documents being used as guidance in the development of these types of flight simulators. Among that 28 source documents, only the 7 specific referenced source documents appear to be used by more than one of the participating organizations. From this data, it is clear that there is not a single, or even dominant, source document used by the participating organizations for guidance in the development of these complex aeronautical products. The abundance of guidance documents then became a useful data source from which to develop the new document reflected in Appendix E, entitled: Guidelines for Development and Fielding of Multi-environmental Flight Simulator Systems (Neel, 2000). This document is, therefore, a comprehensive guidance document as identified in the Scope paragraph, as follows:

> These guidelines represent a compendium of technical subjects and tasks to be considered by project management during the development and fielding of multi-environmental flight simulator systems. This document includes recommendations and references for developmental and fielding considerations, developmental team formation and achievement, training systems development guidance, as well as defining technical characteristics and simulator systems design parameters. These reference and guidance tasks have been organized into 18 major impact areas, and are offered for use in project planning, project management, technical and management reviews, technical references and specifications, testing, fielding, related logistics operations, and contracting operations. (p. 2)

The copyrighted document, Guidelines for Development and Fielding of Multi-environmental Flight Simulator Systems, reflected a compilation and amalgamation of data derived from a variety of sources, including the research conducted in this study; many years of developmental program management and engineering experience on five different multi-environmental simulator systems; empirical observations and airworthiness judgements made on hundreds of aeronautical products; as well as several years of concurrent responsibilities for the emergence of an integrated developmental team, and program management success among international peoples and programs.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The rewards that come from the participation of these organizations has been substantial. Though these organizations often compete for new developments, manufacturing, and support contracts, the participation and candid responses from these organizations were most professional and encouraging to the researcher.

The quantity and quality of participants were sufficient to provide viable sources of objective information and data. Sufficient information and data were provided to formulate the Conclusions and Recommendations.

The hypothesis of the study was confirmed, with the results of the research instrument (participant questionnaire) providing the source of measurable data. This hypothesis was attained because the hypothesis offered, ". . . that no standards or specifications exist for managing the development and fielding of multi-environmental flight simulators that are required for contemporary aircraft and space vehicle simulator systems applications."

The Findings report that many in-house sources exist for management guidance in the development of flight simulators. No single public source document exists to meet these management requirements, but several public domain documents contain qualifications or testing criteria that would be applied after the device is built and is about to be qualified and accepted by the user organization.

Conclusions

The responses, data, and objective offerings indicated that no single standard or specification is used in the aerospace industry to develop and field flight simulator systems. What was learned is that partial sources for standards, specifications, and guidance are used by these organizations, primarily in-house standards that are available only to the respondent organization. The lack of a single comprehensive standard causes many partial source documents to be used during the development of these dynamic flight simulator systems. Some of these sources address testing and qualifications of the system, some offer guidance for software development, courseware development, or were "requirements definition" documents. The compendium of these sources would leave large gaps in the management of these very complex integrated systems. A comprehensive development document would reduce exposure to risk in several management areas involving cost, schedule, and performance. A logical conclusion may follow that the absence of a comprehensive development document may translate into the loss of simulator mission performance. This impact resulted from the most simulator development efforts come as a fixed price contract which has been negotiated between the buyer (user organization) and the developer organizations. The Schedule aspect of a fixed price contract is defined in the terms and conditions of a negotiated contract, and any change would add cost. No changes are likely to generate contract and legal issues, which the development technical and management personnel do not control. Thus, performance risk is most likely impacted by a lack of development documentation standards. The inevitable flow from a lack of system performance is an impact to the "user and sponsor organization" in mission readiness. Any significant loss in the performance of a simulator is most likely to be viewed as a "lack of due diligence," or technical competency of the development management during the development and fielding.

The need for formative work in flight simulator development standards has been identified in the Literature Search, as illustrated by the actions of the prestigious American Institute of Aeronautics and Astronautics (AIAA). The AIAA's Modeling and Simulation Technical Committee has been endeavoring for a period of four years, to develop an aeronautical (and ISO 9000) standard for the development and fielding of flight simulator systems. This study's evolutionary work was significantly further advanced than the AIAA's standards development efforts.

Recommendations

1. That a comprehensive simulator development document should be developed for use by the aerospace industry.
2. That the American Institute of Aeronautics and Astronautics (AIAA) Technical Committee on Modeling and Simulation should be the organization designated to continue movement of that document.
3. That the new standards for flight simulator development be produced in compliance with AIAA, ANSI, and ISO standards.

4. That a complementary copyrighted version of Appendix E of this study, Guidelines for Development and Fielding of Multi-environmental Flight Simulator Systems, be provided to each of the participating organizations.

5. That any participant requesting a copy of the associated dissertation shall be provided a "no cost" copyrighted version of the Guidelines for Development and Fielding of Multi-environmental Flight Simulator Systems.

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APPENDIXES

APPENDIX A

DEFINITION OF SIMULATOR TERMS

Acquisition Strategy Authority. Constitutes an appropriate level of organizational authority necessary to procure multi-million dollar, high-fidelity flight simulator device.

Activity. Significant actions or operations that occur during a simulator event which may be of importance for training or developmental purposes, and may, therefore be captured at key intervals.

Advisory Circular (AC). A non-regulatory document issued by the FAA to provide information, guidance, and in some cases airworthiness communication for aircraft. AC's are numbered for the Federal Air Regulation that is closest to the subject of the Advisory Circular, but the AC does not have the status of a regulation.

Air Carrier. An airline, either scheduled or non-scheduled, which operates under the provisions of Part 121 of the Federal Aviation Regulations (CFR 14).

Aircraft Flight Simulator. A generic assemblage of aeronautical, computer equipment and software programs intended to represent an aircraft in ground and flight conditions. The level of fidelity is limited to the extent of the systems installed in that flight simulator.

Airplane Flight Training Device (FTD). A full size replica of an airplane cockpit area with appropriate geometry, containing instruments, equipment, panels, and controls in an open flight deck area or an enclosed airplane cockpit, including the assemblage of equipment and computer software programs necessary to represent the airplane in ground and flight conditions to the extent of the systems installed in the device. It does not require a force (motion) cuing or visual system; is found to meet the criteria outlined in AC 120-45A for a specified level of flight training device; and may be used to accomplish flight training or flight checking event identified in para. 6 of the AC120-45A (1992).

Airplane Simulator: A full size cockpit replica of a specific type or make, model, and series airplane, including the assemblage of equipment and computer software programs necessary to represent the airplane in ground or flight operations, a visual system providing an out of the cockpit view, a force (motion) cuing system which provides cues at least equivalent to that of a three degree of freedom motion system; and is in compliance with the minimum standards for a Level A simulator specified in AC 120-40, as amended. (AC120-45A, para.6, 1992)

Aliasing. The degradation of a visual image that appears to have two superimposed visual images moving slightly with elevated levels of brightness. Aliasing is known to contribute to asynchronous cuing syndrome.

American Institute of Aeronautics and Astronautics (AIAA). AIAA is the principal professional society and voice serving the aerospace field of endeavor. AIAA's primary purpose is to advance the arts, sciences, and technology of aeronautics and astronautics, and to foster and promote the professionalism of those engaged in these pursuits. AIAA is U.S. based, and has nearly 30,000 individual members. (AIAA 2000).

Area of Interest Displays. An area of interest display provides additional visual details and dynamics to a mission critical area of the visual scene to allow the pilot the opportunity to concentrate upon the mission critical visual elements, while minimizing the details or information of other visual scene elements. An example of an area of interest display could be the visual picture seen through a HUD device,, which is provides a simulated IFR approach toward a foggy runway.

Asynchronous cuing sickness. The human reaction to multi-environmental stimuli that are outside the normal parameters and rates of change experienced by an individual in the normal earth environment. In flight, many environmental conditions are at the extreme, especially rapid aircraft (vehicle) motions, accelerations, G-forces, visual, vestibular, and other stimuli. When these combination of stimuli exceed normal rates, or one or more of these stimuli are outside the normal parameters of change, these difference may induce a variety of physiological symptoms, including fatigue, loss of equilibrium, vomiting, and other symptoms. A well recognized type of asynchronous cuing sickness is the "car sickness" or other motion sickness syndrome. In flight training these problems are expanded with the environment, and referred to as "simulator sickness" syndrome.

Automatic testing. Flight simulator testing wherein all system and device stimuli and response are under computer control. (ICAO, 1995)

Availability. Starting with the mission requirements, the preliminary and detailed design process will accommodate the mission required number of hours of daily simulator utilization. Simulators with low system reliability, or complex maintenance requirements will have difficulty in meeting many availability requirements. Mil Std. provides standards for design (inherent) availability(Ai), and for operational availability (Ao)

Blind cockpit checkout. Perhaps the first form of flight simulation was offered to "blind-folded" pilot trainees when they were required to sit in the cockpit of an aircraft, accurately touch and /or describe the operation of every control, switch, lever, and other devices that would be required to operate the aircraft being trained for. The blind-folded pilot could develop a cognitive, tactile, psychomotor, and spatial knowledge of cockpit geometry, as well as the sequential relationship of the required flight actions.

Block numbers (Aircraft Set): During the multi-year production of aircraft changes in the original design are often necessary and desirable. When significant changes are implemented, a configuration control accounting method is used to identify a group of production numbers as a block number or aircraft set. Block number changes are very significant to the development of flight simulators because the changes contained within each block-number have the potential to drive many design aspects of the flight simulator devices.

Blue-box. The "nickname" given to the Link instrument and navigation trainer of World War II fame, produced in the thousands, which provided a limited three axes motion base system to enhance the reality of flight for the pilot trainee.

Closed loop testing. A test method for which input stimuli are generated by controllers which drive the simulator to follow a defined target response. (ICAO, 1995)

Collimated (visual) Display. The essential features of the collimated display is that light rays coming from a given point in a picture, are reflected from a collimating mirror, back to the observers eye in appear lines. When a collimated display is viewed, the light is interpreted as having come from distant objects, and the angular position of the objects will appear to be independent of the viewing position. Hence collimated displays are viewed from several eye-points, and can be used effectively in crew served aircraft cockpits without major concern with eye-point positioning. Collimated displays can provide flight deck visual cues for side-by-side crew stations, as well as for a field of view of 220 degrees horizontal coverage, and 60 degrees vertical coverage. (Fernie, 2000)

Condition set. A set of computer instructions required to form a single lesson or training event may be identified as a condition set. The condition set can provide a rapid initiation of computer instructions for a given lesson.

Control sweep. Movement of appropriate pilot's controls from neutral to an extreme limit in one direction (forward, aft, left, or right), as a continuous movement back through neutral to the opposite extreme position and then return to the neutral. (ICAO, 1995)

Convertible Flight Training Device: A convertible flight training device has the capabilities of being used to train for more than one type aircraft, or for more than one mission. The convertible flight training device has an inherent limitation of the lack of fidelity or mission level definition when being converted between types of aircraft or mission requirements.

Control Breakout Forces: The force (lbs/kg) required to begin movement of a dynamically loaded flight control surface in an aircraft, or flight simulator is referred to as control breakout force. The control breakout force in a flight simulator has the additional level of simulation burden of providing some measurable dynamic response of another type, such as motion system, G-force sensing, or visual system.

Control Hysteresis: The energy loss, or time delays encountered in any hydro-electro-mechanical device upon reversal of direction, may create a lag in response by that device. Control hysteresis is present in flight simulators by the nature of pilot input devices (stick or throttle), but this may be increased by the electronic and computer induced hysteresis simulator operating system.

Crash (aircraft). A crash event of the simulated aircraft may be programed to occur upon reaching specified ballistics parameters, flight environment parameters, geographical locations, and other interrelated activities. The crash event does not require any external operator inputs.

Crash Override (aircraft). An instructor-operator selected function that will impede the "crashed" aircraft parameters from freezing or otherwise indicating to the aircrew that a crashed condition has occurred. This simulator feature provides a training environment not available in the operational aircraft.

Crash (simulator/computer). A crash of the simulator system is an undesirable shut-down of the simulator system caused be a malfunction of some major operational system, subsystem, or component. Any crash is an undesirable event which will causes a loss of training continuity, cause negative learning, and the loss of training efficiencies .

Deadband. The amount of movement of the input for a system for which there is no reaction in the output or state of system observed. (ICAO, 1995)

Department of Defense (Military) Standards, (DoDStd). Official guidance for the design and development of a substantial military system, such as an aircraft, vehicle, weapon, training system, or other complex system. A DOD/MilStd provides substantial guidance and defines much of the standardization needed to design, produce, and support these systems.

Department of Defense (Military) Specifications, (DoDSpec). Official guidance for the design and development of an individual component, or device, such as a bolt, fastener, or even a software item. These items are not of a complex nature, but rather provides a minimum standard for an off-the-shelf component. A DOD/MilSpec provides substantial detailed information needed to produce such a standard component.

Damping. (ICAO, 1995)

1. Critical damping. That minimum damping of a second order system such that no overshoot occurs in reaching a steady state value after being displaced from a position of equilibrium and released. This corresponds to a relative damping ratio of 1.0.
2. Overdamped. That damping of a second order system such that it has more damping than is required for critical damping. This corresponds to a relative damping ratio of >1.0.

3. Underdamped. That damping of a second order system such that a displacement from the equilibrium position and a free release results in one or more overshoots or oscillations before reaching a steady state value. This corresponds to a relative damping ration of <1.0.

Dome (visual) display. The situation in a dome display is very different from that of a collimated display, since the visual image appears to be located on the (inner) surface of the dome enclosure. Although the source of the visual object is, in fact, only a few meters from the eye-point, the angle from the scene image will be very small, resulting in only one good eye-point location. With the single eye-point configuration, dome visual systems do not have the parallel images of the collimated display, and cannot serve multi-crew station aircraft simulation well. With dome configuration visual projection equipment limited to approximately 30 degrees of quality visual content per channel, it is necessary to have several projectors to provide the required angular coverage, resolution, and details. It is typical to configure dome visual systems to serve approximately 260 degrees x 90 degrees of visual coverage (Fernie, 2000).

Events (training). An operational term that occurs when a specific training occurrence is preplanned, coordinated for resources, briefed, and conducted for training purposes.

Federal Air Regulation (FAR). Regulations promulgated under the authority of the Code of Federal Regulations 14, which proffers the regulation as having the status of law. FARs provide the regulatory requirements for many aviation matters, operations, designs, certifications, and standards.

Federal Aviation Administration (FAA): The U.S. Executive branch of government that was created by the Federal Aviation Act of 1958, and recodified in 1994, with responsibilities to foster the development of aviation; develop a safe aviation navigation system; develop and enforce regulations, aeronautical standards for products, certification of operators, and personnel.

Fielding. To place into service, to maintain and support a technical system (including flight simulator systems) at the designated location. Fielding flight simulator systems may incorporate all elements of support, including personnel training, test equipment and tooling, spare parts, installation of the equipment, a variety of support publications and diagrams, and the specifications and/or operations of the physical plant, building, and device.

Flicker. The degradation of a stationary visual image that appears to have motion as a result of a dim to bright cycling of image light lumens. Flicker is often perceived at a rate associated with data bus rates. Flicker is known to contribute to asynchronous cuing syndrome.

Flight simulator (see airplane simulator)

Flight simulator approval. The extent to which a flight simulator of a specified qualification level, may be used by an operator or training organization as agreed by the competent authority. It takes account of some differences between aircraft and simulators an the operating and training ability of the organization (ICAO1995).

Flight simulator data. The various types of data used by the simulator manufacturer to design, manufacture, or test the flight simulator.

Flight test data. Actual aircraft data obtained from the aircraft manufacturer during an aircraft flight test program.

Freeze. A Freeze event shall occur when commanded by the operator, and shall cause the flight simulator to "stop where it is" with reference to all position updates, attitude, airspeeds, and all other dynamic activities. All displays and derivatives shall be computed but will not be integrated. A design choice may be integrated so that all specified flight controls and vehicle interactions is allowed. An opposite design choice may allow no responses in the simulator during the Freeze event. Upon command, all integration of time and systems shall resume.

Functional test. A quantitative assessment of the operation and performance of a flight simulator by a suitability qualified evaluator. The test may include verification of correct operation of controls, instruments, and systems of the simulated aircraft under normal and non-normal conditions (ICAO, 1995).

Functional performance. An operation or performance that can be verified by objective data or other suitable reference material that may not necessarily be flight test data.

G- forces. The perceived effect of a mass (including the mass of a human being) on earth is acted upon with an acceleration (or attraction) of gravity, at 32.2 feet/second/second. In a static condition, a human (mass) would be acted upon with a force measured as 1G, or one gravity. At 1G, a 200 lb person would exert a force of 200 lbs when seated or where standing, and all body sensations and operations would be normal. The dynamics of flight will induce G's in excess of one, where typical flight maneuvers may induce a range of G forces from 2.0's to 9.0G's. The effect upon a human would vary from a mild level of downward load from the 400 lb load exerted at 2.0G's, or an incapacitating or unconscious condition may result from such high G loads as 9.0G's, that would produce an 1800 lbs load upon the human body and internal systems.

G-instantaneous. The abrupt G forces that can be applied to the human body over a short period of time that could not be sustained without the loss of body movement, awareness, or consciousness.

G-load. The apparent force of gravity. A G load of 2 would mean a force equal to twice the force of gravity. The G load that a pilot feels is a very important cue in a simulation environment.

G-onset. The instant G forces are beginning to be perceived by the pilot of an aircraft or simulator is referred to as G-onset.

G-seat. A piece of simulation equipment that physically reacts to G induced increases or decreases in a pilot being forced into and away from the aircraft seat, may be referred to as a G-seat. The G-seat gives pilots the effect of sinking in their seat, which the brain will interpret as the body being pushed into the seat from the forces of gravity.

G-sustained. The prolongation of high G forces on the pilot's body are most significant in causing the loss of pilot capacity to perform necessary job tasks. Simulator training must provide the pilot with knowledge and counter training of the detection and sustained magnitude of G forces upon the individual's body. A well-modeled simulator G-seat and system can provide these levels of cues for training.

G-suit. An aircrew personnel equipment/device used in the aircraft as well as in multi-environmental simulator, to apply air bladder pressure to the outside of key body areas to squeeze G-pooled blood supplies back toward the upper torso, vital organs, and brain areas to prevent G-induced loss of consciousness from a lack of cranial blood flow.

Halt. A halt is an operator command, that when used, the event shall suspend all changes to the simulator state, and may be used to allow safe exit/ingress from the crew station. Upon command, the simulator shall be restored to it's state at the initiation of the original halt command. If the system is operating in an interactive training mode, the Halt command shall remove the simulator from the interactive training mode.

1. Uncommanded Halt. An undesirable halt of the simulator system that was not solicited or commanded by the instructor/operator. An uncommanded halt will suspend all changes to the simulator state, and is an indication of a computer or system malfunction. Uncommanded halts must be logged and monitored for fault isolation purposes.

Job Task Analysis. An analytical process that identifies the many and diverse functions, skills, knowledge, and attitudinal operations required to perform a specific job in an organization.

Instructional Systems Development (ISD). A systematic approach to planning, developing, implementing, and maintaining training. ISD is typically organized into five phases of the development, including the analysis, design, development, implementation or delivery, and evaluation or validation phases. The disciplined execution of the ISD process may be greatly influenced by subsequent changes known as in "mission creep," where the user of these training systems change their needs or requirements. .

Integrated testing. Testing of the flight simulator such that all aircraft systems models are active and contribute appropriately to the results. None of the aircraft systems models should be substituted with models or other algorithms intended for testing purpose only. This may be accomplished by using controlled displacements as inputs. These controllers must represent the displacement of the pilot's control and must be calibrated (ICAO, 1995).

Irreversible control systems. A control system in which movement of the control surface will not back drive the pilot's control on the flight deck.

Latency. The additional response time of the flight simulator or flight training device beyond that of the basic aircraft perceivable response time. This includes the update rate of the computer system combined with the time delays of the instruments, and of the visual system and motion systems if installed.

Maintainability. Starting with the mission requirements, the preliminary and detailed design process will accommodate the mission required number of hours of daily simulator utilization. To provide a practical likeliness that design availability targets are met, the system must also incorporate practical methods of performing scheduled and unscheduled maintenance operations. These maintenance events are measured as mean time (hours) between specified maintenance events, including design targets such as; mean time to repair (mttr); mean time between (scheduled/unscheduled) maintenance actions; mean time between overhaul (mtbo); mean time between replacement (mtbr). Mil Std. provides standards for design (inherent) maintainability, and for operational maintainability.

Manual testing. Flight simulator testing wherein the pilot conducts the test without computer inputs except for the initial set-up. All modules of the simulation must be active.

Mission Trainer (MT). A training device that provides the crew with sufficient fidelity and variety of learning modes to meet the mission requirements of the air vehicle, including the operation of systems, mission tasks, physical stimulation, and psychological affectations.

Modes. A training mode offers a mission defined requirement to perform a certain function, such as allowing an single aircraft air crew to practice and perform flight in IMC conditions. This example would be identified as a "single station mode." Other examples of training modes include; demonstration mode; play-back mode; part task training mode; multi-station mode; interactive mode; and device maintenance mode

Multi-environmental simulator. A high fidelity flight simulator system that simulates flight operations of in-flight, on-ground, in day or night visual conditions, with a motion and/or G-force simulation system, and a significant accuracy in the simulator modeled aerodynamic performance and handling qualities, as well as the pilot's normal and emergency flight control and systems inputs to manage the operational mission.

Objective test. A quantitative assessment based on comparison to data.

Operational Flight Trainer (OFT). A training device that provides learning through a series of experiences of operational tasks, environments, and the integration of specific functional tasks. The OFT may provide excellent instrument flight training, but does not include all aspects of the flight environment or mission level operations.

Part Task Trainer (PTT). A training device that provides learning of specific function or tasks. The PTT trains on a limited number of mission tasks, such as programming a global positioning system (GPS) flight route, but does not include flying the flight route in a dynamic flight simulator, nor the many other aircraft flying tasks.

Personal Computer Aircraft Training Device (PCATD). A personal computer based training device specifically identified and approved by the FAA under the terms of FAR 61.126. The PCATD has a limited application, and is not considered a Flight Training Device (FTD), but does provide part task training, primarily associated with the instrument flight environment.

Pilot induced oscillations (PIO). In the real world of air vehicle responses, the inputs to flight control systems from a pilot may require some measurable amount of time to produce an appropriate flight vehicle response. If this measurable amount of time is too long a period, the pilot may sense that additional inputs are required, resulting in too much, or opposing inputs, that may result in the aircraft over reaction. In these circumstances, the input-over response cycle may result in the aircraft becoming astable and potentially uncontrollable, and are referred to as pilot induced oscillations. A more insidious product from these asynchronous cues may cause the pilot to experience a type of motion sickness, so called "simulator sickness," properly identified as asynchronous cuing syndrome. Pilot induced oscillation is likely to exist when there is a delay in the input-response cycle of more than 60 milliseconds (ms).

Pixel. A pixel is the smallest unit of light that can be projected or perceived by the human eye. Higher numbers of pixels per square inch/cm will produce a vivid image when viewed by a human subject. In flight simulator systems pixels are associated with visual system quality to produce "real looking visual scenes." The unit of measurement of pixels is pixels per square cm/inch, or pixels per line of (rastor/caligraphic) scan lines. Either method of pixel measurement is referred to as the pixel count.

Predictive data. Data derived from sources other than flight test of an air vehicle (ICAO, 1995).

Pulse input. A step input to a control followed by an immediate return to the initial position(ICAO, 1995).

Reliability. Starting with the mission requirements, the preliminary and detailed design process will accommodate the mission required number of hours of daily simulator utilization. For a system to operate many hours per day, the simulators must be reliable, so that required training availability is not impacted by system crashes or stoppages in training events. Reliability is measured in mean times between (unscheduled) maintenance actions (mtbma), or mean times between failures (mtbf). Low system reliability, as indicated in operational mtbma's, will cause great difficulty in meeting many availability, and training throughput requirements.

Scene Content. The accuracy, dynamics, fidelity, color, definition, lack of spurious displays, and other aspects of human visual perception are replicated as scene content in flight simulator visual systems. Scene content represents a major variable in adequately replicating aircraft training environments.

Simulator Data. The software developed to operate the PCATD, FTD, OFT, IFT, WST, and other types of flight training and simulator devices.

Simulator sickness (asynchronous cuing sickness)

Simulator States. The normal operation of a flight simulator may require actions that, "far exceed turning on a key" and beginning to operate. Simulator states include:

1. Initialization state occurs in the proper sequence, when simulator systems, sub-systems, and components are brought to an operational condition prior to entering the Normal training state.
2. Normal training state occurs when performing all fully dynamic training are in use, including simulated aircraft systems and operational environment in the single station training mode.
3. Normal soft freeze state
4. Replay state
5. Stabilization state
6. Maintenance state
7. Other selected software configurations that drive the training functionality of a simulator system.

Step input. An abrupt input held at a constant value. (ICAO, 1995).

Synthetic trainer. (see airplane simulator)

Task Trainer (TT). (see part task trainer)

Time history. The presentation of the change of a variable with respect to time.

Training Devices. An apparatus or object that provides an appropriate method or path for learning a task or skill. A training device may be simple or complex. The aircraft flight simulator is a very complex type of training device.

Training Media Allocation. Following the identification of the variety of candidate media, a realistic evaluation of appropriate media is performed to provide the correct media for the training tasks and mission.

Training Media Identification. Upon completion of the analysis phase of the ISD process, the design of the instructional product leads to identifying the appropriate types of media that could represent viable vehicle to convey training. These media may vary in complexity and cost from a sample printed chart or other print media, to a complete operational aircraft in flight. If this function is performed professionally, a great variety of media will be considered, and identified.

Training Media Selection. Following the media allocation process, recommendations are made for the best application of media. The elements of that process are the cost of media, and effectiveness of the media to provide the required training. The outcome of this process is the training media selection for that aircraft.

Training Requirements Identification. As a critical part of the ISD analysis phase, the user of this training is engaged to identify the desired outcomes, or requirements for training. These requirements may begin with definitions of the organizational mission, functional tasking, and these lead to a hierarchy of outcomes and objectives in the ISD design phase.

Transfer of Training. In this study, transfer of training is achieved when a flight simulators is used to perform selected flight training tasks to a level of performance that facilitates the performance of those tasks in the aircraft (Carretta, 1998).

Transport Delay. One very demanding area for technical development in high fidelity multi-environmental flight simulator systems exists within the area of transport delay. When the rate of change in the real flight environment is great, such as when flight controls are displaced as a current generation aircraft as it approaches the touchdown point on a runway, the pilot's reactions and responses must be quick and precise. If the flight control systems also are well engineered, the resulting aerodynamic responses will be appropriate. In flight simulators, those input and output processes become the beginning for other reactions and responses through several computer simulations and operational programs, so all aspects of the simulator respond at the proper time and with the correct visual, motion, and force stimuli. Any delay over approximately 100 msec. may contribute to asynchronous cuing. The integration of these transport delay methodologies have a great impact upon flight simulator fidelity and the ability to meet the mission requirements. Transport delays of less than 50 msec. are generally acceptable for normal aircraft flight simulator responses.

Validation testing. Testing performed to prove that the flight simulator performance corresponds to that of the air vehicle.

Verification methodology. To verify compliance and functionality of hundreds developmental, specification, and contract details, several methods are used to verify the system acceptance. In ascending order, the methods and details of verification include:

1. Analysis is performed by calculation, assessment, evaluation of data, or other forms of objective review of the work.
2. Inspection is to determine compliance by observing the operation or material condition of the work being reviewed.
3. Testing uses a comparative judgement with finite measurements to determine compliance.
4. Operation uses the performance of normal system or component.
5. Functional is completed by conducting a non-instrumented, operational, observational determination from the perspective of the system user.

Visual Display. During normal human learning events, most often, the most powerful stimulus for learning comes from the visual inputs. Video projections are the mechanisms
most often used to provide the visual image in flight simulators. These video projections may be accomplished by several methods, including the cathode ray-tube (CRT) direction viewing, three color tube projection, light valve projection, laser (LZ) projection, liquid crystal displays, as well as combinations of these.

Visual system response time. The interval (msec) from an abrupt control input to the completion of the visual display scan of the first video field containing the resulting different information.

APPENDIX B

RESEARCH COMMUNICATIONS MATERIALS

May 3, 2000

Dear

Thank you for your willingness to participate in this study. I know there are many demands upon your time, and I can assure you that your information is important. We will provide feedback on the findings and conclusions developed during this study.

You will notice that the questionnaire we are using for this study is very short, and we estimate you can complete it in approximately 12 minutes. When you have completed the questionnaire, please mail it back in the franked, self-addressed envelope that is provided.

Thank you for your assistance, and thanks to (organization's name) for the willingness to collaborate on this study.

Respectfully,

H.C. McClure

Professor of Aviation & Space Education

College of Education

Oklahoma State University

David L. Neel,

Principal Investigator/ Department Chair, Aviation

San Jose State University

dn7095@aol.com

INTRODUCTION

Please expect this questionnaire to require approximately 12 minutes to complete. An additional 10 minutes may be required to locate any related documents and prepare the return mail envelope. I hope that your investment in time will be worthwhile, because this study will identify and assess the existence of the common management elements for development and fielding of multi-environmental flight simulator. For this study, we define these devices as being used for ground-flight, day-night, VFR-IFR, and dynamic conditions. The results of this study will be shared with all the participants.

BUSINESS SENSITIVE INFORMATION

No business sensitive information is being sought. The questions submitted, and associated documentation requested are not seeking business sensitive, proprietary, or classified information. If any information we ask about is sensitive, please do not include that information in your response.

When completed, please return this completed document to:

D.L. Neel
711 Old Canyon Road #3
Fremont, CA 94536
Hm. Ph. (510) 739 3833 (Fremont, CA); Hm.Email:dn7095@aol.com

Flight Simulator Development & Fielding Questionnaire: Please circle correct response.

1. Are you in a program manager/leader, project manager/ leader position, or technical manager/leader position for a multi-environmental flight simulator system? .... Yes No
2. Does your simulator organization procure, develop, or use/field multi-environmental flight simulators? .... Yes No
3. Does your simulator organization use subcontractors to manage any part of the simulator.
   a. procurement? .... Yes No
   b. development? .... Yes No
   c. fielding? .... Yes No
4. Does your simulator organization use a public sector specification or standard, or other guidance document for the management of flight simulator development and fielding?.. Yes No
5. Does your simulator organization use a in-house specification or standard, or other guidance document for the management of flight simulator development and fielding?.. Yes No
6. Does your simulator organization use a proprietary specification or standard, or other guidance document for the management of flight simulator development and fielding?.. Yes No
7. Are any of the documents identified in questions 5, 6, or 7 available for this research Principal Investigator to review? .... Yes No
8. Are you submitting those specifications, standards, or documents for use in this study? .... Yes No
9. Does your simulator procurement incorporate design reliability,

availability, maintainability (RAM) targets? ....Yes No

10. Does your organization have contracting authority to procure, develop, and field this type simulator? ....Yes No

11. Does your organization have acquisition strategy development authority? ....Yes No

12. Does your organization have a typical duration for development and fielding of a multi-environmental flight simulator? ....Yes No

13. If the answer to question #12 is Yes, what would be the typical duration to develop and field this type simulator? .....Years_____ Months_____

14. Is your primary focused for developing multi-environmental flight simulators Training?........... Research?.......... Product development?........... Other............?

Optional Information:

If you care to provide any additional information, comments, clarifications or details, please add anything you may choose to offer on the subject. It may prove useful to our study.

____
____
____
____

Please list any documents that you or your organization are sending to enhance communication about the development and fielding of multi-environmental flight simulator systems.

____
____
____
____

Please sign this form as your consent to participate in this study. The results of this research may be used in a doctoral dissertation, and AIAA standards development project. We look forward to providing you with the collective information that is derived from this project.

______________________	______________	________
name	job title	date

Thank you again for your response and information.

H.C. McClure
Professor of Aviation & Space
College of Education
Oklahoma State University

David L. Neel,
Principal Investigator/Aviation Department Chair
San Jose State University
dn7095@aol.com

APPENDIX C

TELEPHONE SCRIPT FOR INITIAL CONTACT

1. Hello/Hi/Good morning Mr./Ms._________, my name is Dave Neel, I am the Aviation Department Chairman at San Jose State University and I am conducting a research project at Oklahoma State University on the development and fielding of flight simulator systems.
   Callee response: ______________________

2. We know of your organization's involvement of developing flight simulators, and we would like to have your inputs in our project.
   Callee response: ______________________

3. We appreciate your interest.
   Callee response: ______________________

4. The primary area of focus of this research project is in the applications of standards and specifications to the development and fielding of flight simulator systems. Generically, we would like for you to tell us how your organization is dealing with standards and specifications.
   Callee response: ______________________

5. We will send you an objective questionnaire as the information gathering media. I can assure you that the questionnaire can be completed in 15 minutes or less, and it can be returned in a pre-addressed envelope.
   Callee response: ______________________

6. If you have a more appropriate person in your organization you would prefer to designate for communications with on this project, please offer that name and phone number, and we will contact them directly.
   Callee response: ______________________

7. Thank you for your assistance, and your interest. We will commit to providing your company with the outcome of this project.

8. Good day, Mr/Ms ________________..

APPENDIX D

CANDIDATE ORGANIZATIONS AND DESIGNATED REPRESENTATIVES

1) *Mr. Jeanluc Gresse
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5) *Karl Wentzell
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All of the organizations listed above were invited to participate in the study, and those marked by the (*) agreed to participate in the study.

APPENDIX E

GUIDELINES FOR DEVELOPMENT AND FIELDING OF MULTI-ENVIRONMENTAL FLIGHT SIMULATORS

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DEVELOPMENT SPECIFIC TERMS AND DEFINITIONS

Activities. Significant actions or operations that occur during a simulator event which may be of importance for training or developmental purposes, and may be captured at key intervals.

Availability. The successful completion of required flight training events is impacted by the availability of the training devices and flight simulators. Availability is expressed in hours per day that these devices are designed to be operational. Availability is impacted by any unscheduled or scheduled maintenance periods, or from facilities downtime. Availability is predicted as a value of Ai, called Inherent Availability; and represented as Ao for Operational Availability.

Event (simulation). An event that is designed to be signaled into or out of a training event is referred to as a simulator event. The system may incorporate a freeze event, or a halt event, in each case where the normal simulator dynamic action is stopped, and the values and time derivatives are held constant.

Event (training). An operational term that depicts a specific training occurrence that has been preplanned, coordinated for resources, briefed/debriefed, and conducted for training purposes.

Maintainability. Maintainability is designed into a flight simulator (or aircraft) to provide maximum allowable thresholds of time to perform specific maintenance actions. Some maintainability targets are for scheduled maintenance actions, and others are for unscheduled maintenance actions. Maintainability actions are identified as Mean time between maintenance actions (mtbma); mean time between failures (mtbf); mean time to repair (mttr); and other subsets of time required to perform anticipated and unanticipated inspections, maintenance, and repairs. Maintainability may very well drive the Availability of any aeronautical product.

Simulation State. A subset of state space which represents a useful description of simulator conditions, and is normally identified with a functional precursor name such as “freeze” state, “replay” state, “normal mission” state, etc..

States (control theory based). A State in simulation represents the information that must be captured to compute the future behavior of the system. A state is the set of quantities X(t) which if they are known at t=t(0) by specifying the inputs to the system for t=>t(0) (Kirk, 1971).

State space. A term borrowed from control theory, is a set of all possible states of simulators.

Reliability. If an aeronautical product operates faithfully, and without complications to provide service whenever demanded, it is recognized as being reliable. Reliability is measured by the number of times the product is not operational when scheduled. The challenge is to identify those critical path components that can cause the loss of system reliability, and engineer for redundancies those failures. Reliability is an integral portion of systems level designs, and may be of more significance in other types of aeronautical products such as aircraft and spacecraft, where operational reliability may be measured in lives lost.

APPLICATION

Persons involved in the operation of air vehicles, aircraft, spacecraft, airplanes, helicopters, and other aeronautical conveyances can benefit from these guidelines for the development and fielding of the complex technologies systems referred to as multi-environmental flight simulator systems. Operational managers, program management, engineering and technical, as well as financial, contract performance, and legal management can all benefit from the information contained in this publication. Development organizations are well advised to not disregard their own experience, history, or organizational uniqueness, and jump into the use of any document as a developmental check-list. This guidance document should be used as a vehicle to achieve the "custom tailoring" needed to produce and integrated a multi-environmental flight simulator system into an operational flying organization.

SCOPE

These guidelines represent a compendium of technical subjects and tasks to be considered by project management during the development and fielding of multi-environmental flight simulator systems. This document includes recommendations and references for developmental and fielding considerations, developmental team formation and achievement, training systems development guidance, as well as defining technical characteristics and simulator systems design parameters. These reference and guidance tasks have been organized into 18 major impact areas, and are offered for use in project planning, project management, technical and management reviews, technical references and specifications, testing, fielding, related logistics operations, and contracting operations.

RATIONALE

Theses guidelines can be used for any simulator or flight training device used to train aircrew, or to support rehearsal of a flight operations mission. It is the intent to provide topical coverage for the spectrum of training devices from the Level 2 Flight Training Devices through the Level D Flight Simulators. These technical subjects, technologies, and methodologies can also be used in the development of other aerospace simulators, or for other modes of transportation simulation systems.

These guidelines can lead to a training capability with a high level of fidelity that provides options for mission level, full-task, or part task training requirements. The types of simulators included in these guidelines may embody the following characteristics:

1. Those simulators that operate in a totally stand-alone mode, providing training to a pilot and other aircraft crew member(s). There would be one position for each crew member. The entire crew station environment shall be replicated, and the aggregate external world environment will be simulated.
2. The simulators that consist of multiple representations of the same crew position(s) with central processing and instructional processes. These guidelines recognize the reality that any multi-station simulators may experience degraded operations, whether the loss is of one or more crew positions.
3. The interactive operations of above listed #1 or #2 types. Here the guideline only addresses the simulator that would interface to a communication network, not interface with a dedicated network.
4. The applications of these guidelines must be tailored to meet the specific requirements of the organizational mission and requirements. This tailoring process shall incorporate the "requirements guidance," as well as "verification guidance" for each major specification item. Additional "process guidance" should discuss items that deserve consideration in the development of a "Statement of Work," in development of other non-specifications documents, or in design reviews criteria.

The availability of requirements guidance, verification guidance, and/or process guidance should be considered by developers of Systems Specifications, Prime Item

Development Specifications (PIDS), or for a Systems Requirements Document (SRD). Requirements information should also be incorporated into the development and production contracts.

ACQUISITION STRATEGIES

With the level of financial, material, and human resources required to develop a multi-environmental flight simulator system it is imperative that the acquisition of these technologies be integrated with the acquisition of the aircraft or air vehicle selection for the mission. The nature of the air vehicle integration can vary, but program management's traditional concerns for cost, schedule, or performance may well be served by the acquisition of a multi-environmental flight simulator predating the building of the first air vehicle. There are many good examples of successful high technology aircraft acquisitions that utilized high fidelity flight training simulators, as well similarly configured engineering test stations/tools in direct support of the development of aircraft systems and performance developments. The compatibility and mutual support advantages are obvious when these high fidelity devices are used for training for early engineering flight crews, through the same calendar period where work is also being conducted in the flight simulator on aircraft systems design work. These concurrent uses include aircraft systems operational testing; human factors assessments; ISD analysis and learning theory applications; diversified data measurements, recording, and analysis of predictive aircraft handling qualities and performance; systems operations, as well as prototyping aerodynamics design software. The levels of financial expenditures, resources dedication, technologies applications, and technical competitors competencies all mitigate for an early, and integrated selection for a high fidelity multi-environmental flight simulator system.

Acquisition decisions are often driven more by geo-political events, international business decisions or strategies, or other organizational mission commitments. Given the scale of the financial commitment required for the acquisition of any object as complex as a high tech aircraft, it is likely that budgeting, business, financial, and contracting issues will greatly influence the acquisition by setting the rate of implementation, schedules, contracting/subcontracting, development and testing, production and fielding of the product. Flight simulator development acquisition strategies may even be influenced by the intended city & state of the installation, especially when government funding may represent positive impacts upon local economic generation or recession. When a flight simulator development has international ramifications, an international customer nation may receive discrete benefits from currency exchange rates, or from financial off-sets for other trade or technical work performed in that country as part of the development process.

With so many non-technical variables inherent in a procurement, the most important strategy for success is to have both the procurement authorization official(s) and the program manager aware of the importance of the multi-environmental flight simulator to the success of the air vehicle production. The "Program Bosses" must believe in the critical value to the aircraft of these training/engineering development systems.

OTHER CRITICAL RESOURCE

There are no more critical resources in the development of complex human-machine systems than the commitments of the sponsoring organization. This organizational commitment must exist from all aspects of the institution/organization/air-lines, but it must be evidenced by the conduct of top levels. The system being developed also have direct and vocal support and team representation by the user community, project development management, training, engineering, budget and finance, logistics, and contract personnel, with executive level personnel ready to lead supporting discussions. The greatest single aid to a successful system development is the organization's commitment to provide dedicated and responsible team members. Team members must have a mature commitments and a continuity of assignment, so that there are defined areas of responsibility, actions, consequences, and achievements can be tracked, maintained, and rewarded.

Concomitant with the organization's commitment of development team member resources, are organization's responsibilities to provide the necessary operational resources. These resources include office equipment and facilities; laboratory and testing facilities; developmental and management computer resources; development team member professional development in systems specific and professional areas; as well as resources for travel, conferences, project review meetings, team member training and development, and other developmental team resources.

DESIGN DOCTRINE, DISCIPLINE, AND DOCUMENTATION

The existence of organizational doctrine will have great influence upon any multi-million dollar developments. This is especially true with the multitude of representative groups and individuals within a flight simulator development team, and reality dictates that these representative groups are likely to generate strategic and practical issues, as well as strategic and practical solutions to many problems areas. *Wise executive level management* will structure an atmosphere that reflects a "fundamental organizational commitment" to the success of the project, incorporating issues identification and issues solutions in the representative group (Mish, 1994). This executive level leadership must emphasize that the system under development shall:

1) Be the subject of organizational priorities and doctrine.
2) Be important to the mission, and its success have relevance to the organization.
3) Include the importance of applications of professional standards and discipline among the operational and developmental team members.
4) Incorporate the need for an appropriate level of documentation to meet operational and life-cycle support requirements.
5) Facilitate communications through electronic mail, printed documents, working focus area groups and larger team level discussions, intra-team process and product information, contract required documents, and a commitment to team success during the concurrent engineering challenge of a multi-environmental flight simulator system.

6) Be rewarded for their professional, technical, and overall team contributions by their peers and cognizant development team management.

Developmental team management will expand upon these executive level direction by organizing and conducting developmental team development sessions, where the following major issues areas are clarified:

1) Organizational doctrine, priorities, and disciplines are emphasized in the conspicuous sub parts of the systems development, including; acknowledgment of the operational requirements of the system; implementation strategies; contract status, and subpart organization; contract resources organization, cost control & cost-benefits; research sources and models, including trade studies and product historical configurations; financial resource planning, near and out year budgetary supports; events, schedules, and time lines; and generic and specific team organization and areas of responsibilities.

2) Discipline of operational and developmental professional standards, and the inherent risk of "constructive changes" to developmental contracts. Also communicated are areas of project responsibilities and "chain of command," technical expertise, opportunities, as well as the dynamic benefits of co-generation of ideas and methods, and of the holistic benefits among the team members. The imperative of discipline is imparted among team members for all official communication with system and component level contractors expected to come from the project manager, contract officer, and contracting officer's technical

representatives, so as to minimize the potentialities of contract constructive changes.

3) Documentation needed to support the operational life-cycle of the system, which is the natural derivative of the mission requirements for the system. Among the greatest drivers of life-cycle cost are the logistics elements, which must operate as an integral part of the systems development team. The inclusive logistic elements include:

A. Field support preparation.
B. Support parts access & inventory system.
C. Field level tooling and test equipment.
D. Technical media, publications, and documentation.
E. Personnel training for operator and maintenance personnel.

3) Developmental team commitment to the three levels of the design process, with team members contributing to achievement of each of the sequential levels. Team design contributions and discipline will be required to meet each of the corresponding levels and characteristics of design:

A. Concept exploration.
  1) open and non-threatening concepts exploration.
  2) Out of the box topic discussions.
  3) Reality of requirements.
  4) Results are not final.

B. Preliminary design.
  1) "Paper" Prototype Design
  2) Mission Application Prototyping
  3) Objectives Validation

C. Final/Detailed & fielded design.
  1) Evolutionary Design
  2) Definitization
  3) Configuration is frozen
  4) Configuration is operationally confirmed through:
    a. Validation.
    b. Verification.

c. Contract testing.

Operational requirements testing

Acceptance testing

d. Operational demonstration & performance.

Much emphasis will be placed upon being prepared for major design review activities at these three levels of design. It is typical that achieving acceptable designs at each of these three development point will consummate major billing milestones for contractors, sub-contractors, and suppliers.

4. Overall emphasis upon the mission critical contribution of mission specialists, requirements representatives, as fully integrated team members, and; the importance of overall team commitment, communications, initiatives and discipline, and the completion of challenging, and routine production work, while producing a system that meets the mission requirements.

TYPICAL MISSION REQUIREMENTS

An important, often soul searching, first step towards producing a high fidelity, yet cost effective multi-environmental flight simulator system is to define the mission of the air vehicle which the simulator is attempting to replicate. Regardless of the intended use of the aircraft, one must first ask the question, "What do we want this aircraft to do?" Do we really know what this aircraft is to be used for? What are the aircraft capabilities? The definition of mission elements comes from the answers to these types of questions. A typical set of mission elements definitions are:

1. Provide high fidelity dynamic training for normal systems operation for the aircraft.

throughout all ground and flight regimes.

2. Provide high fidelity dynamic training for abnormal and emergency systems operations for the aircraft, throughout all ground and flight regimes.

3. Provide high fidelity dynamic flight experience in VMC conditions, throughout all ground and flight regimes.

4. Provide high fidelity dynamic flight experience in IMC conditions, throughout all ground and flight regimes.

5. Provide high fidelity dynamic flight experience performing aircraft normal operations on the ground, taxi, takeoff, climb, cruise, decent, holding patterns, approaches, and landings.

6. Provide high fidelity dynamic flight experience performing aircraft abnormal and emergency maneuvers during ground operations, taxi, takeoff, climb, cruise, decent, holding patterns, approaches, and landings.

7. Additional list of other aircraft mission requirements.

REQUIREMENTS DEFINITION

The user of these flight training systems is encouraged to produce a major listing of operational requirements, with identified acceptable levels of performance for operational tasks. This major listing of requirements will become an expanded subpart of the Mission Elements, and it will include a comprehensive list of tasks for which to be trained. This major requirements listing can be developed from the results of an Instructional Systems Development (ISD) process, using needs identification or job task analysis (JTA) methodologies. The quality of the outcome of either a JTA or generic needs assessment efforts will be greatly influenced by the technical knowledge and professionalism of the user team members who may have participated in the requirements definition efforts. One product of the Instructional Design Phase of the ISD process, may be a typical Mission Element Matrix (Figure A), which when produced, will accommodate the expanding inclusion of the training requirements with the appropriate media selected to meet the performance of these tasks.

INSTRUCTIONAL SYSTEMS DEVELOPMENT

To produce an effective, integrated simulator training system, within cost constraints, and with the minimum "mission creep," the disciplined methodology of the Instructional Development Process (ISD) is appropriate. The FAA Academy Guidelines for the Development, Evaluation, and Delivery of Training identifies five phases of the ISD process. These phases are intended to function sequentially, with some iteration of product in the latter phases. These five phases are:

I. *Instructional Analysis Phase* - which is used to perform the up-front analysis of the training needs, and, therefore, would have great benefit from the existence of the Mission Elements and the Training Requirements documentation. If these documents were not developed, the instructional analysis phase would generate similar types of information and data bases prior to commencement of the next phase. Within the instructional analysis phase many strategic level decisions will be considered, if not decided. These may include dealing with the realities, assumptions, and the defined needs

Figure A. Typical Mission Element Training Matrix Candidate Training Media

A._____Classroom discussion/presentation, with static or dynamic visuals
B._____Hard copy descriptions & charts.
C._____Computer based (general subject) training.
D._____Computer based interactive training.
E._____FAA PC Aircraft Training Device (PCATD)
F._____Flight Training Device (Levels 2 - 4)
G._____Multi-environmental flight simulator.
H.____ Aircraft type

Typical mission elements:

1.	Dynamic training for normal systems operation.			C	D		F		H
2.	Dynamic training for abnormal and emergency systems operation.				D		F	G	
3.	Dynamic flight experience in VMC conditions.	A	B		D			G	H
4.	Dynamic flight experience in IMC conditions.	A	B		D	E		G	
5.	Dynamic flight experience performing operations on ground, taxi, takeoff, climb, en route navigation, cruise, decent, holding patterns, approaches, and landings.		B	C				G	H
6.	Dynamic flight experience performing aircraft abnormal and emergency maneuvers & practices during ground operations, taxi, takeoff, climb, en route navigation, cruise, decent approaches, and landing.		B				F	G	
7.	Other required mission requirements.								
8.	(As required for user missions)								

that will be critical to the success of the next ISD phase of Instructional Design. According to the FAA academy guidelines for the development, evaluation, and delivery of training (1998), "the primary purpose of the analysis phase is to determine if a training need exists. This is accomplished by conducting a needs assessment." Obviously, this is a gross understatement when it comes to the development of a flight simulator system, but by taking such a basic position, one may be motivated to review other training approaches, options, and media.

A Training Proposal is likely to come from the Instructional Analysis Phase activities with the following characteristics (FAA Academy, 1998):

1. Contact and participant information.
2. Description of training needs.
3. Training requested.
4. Cause for training.
5. Requirements and benefits of resulting training.
6. Numbers of persons requiring this training.
7. Demographics and learning characteristics of the trainee population.
8. Requisites, prerequisites, for the prescribed training.
9. Other organizational and individual factors.
10. Training development completion schedule.

II. *Instructional Design Phase* - The purpose of the design phase is to prepare for training based upon the information compiled in the analysis phase. This phase guides the development of all training materials; strategies; terminal and enabling objectives; outcomes; job tasks; instructional media, which may include flight simulators; and appropriate assessments of learning and performance (FAA Academy, 1998). These products must be developed within the inherent challenges of cost, schedule, technical performance, validity, reliability, transportability, availability, and maintainability of the training system. The typical output of the design phase includes:

1. Analyzing the training outcomes.
2. Developing the course, terminal, and enabling objectives.
3. Outlining the technical content that meets the training requirements.
4. Identifying an appropriate variety of instructional methods, media, including training aids and documents.
5. Identifying instructional and testing methods.
6. Systematically planning and structuring the training being developed.
7. The Course Design Guide (FAA Academy, 1998) provides documentation of the design and training documentation, including descriptions of courseware, software, and hardware.

The implementation of appropriate training objectives is a critical component in the development of an effective training system. One traditional taxonomy of training objectives identifies the following terminologies and applications, which refer to human learning as evidenced by the premise that the successful completion of a specific training objective occurs when the trainee will: ______.

KNOW (cognitive domain), respond to, recognize, identify, state, communicate, etc., to the specified level of performance.

DO (psychomotor domain) perform a physical task(s), through the integration of multiple stimuli, to a specified level of performance.

BE (Affective domain), demonstrate attitudinal responses, resulting from the integration of multiple stimuli, to a specified level of performance.

The objective measurement of these types of learning are determined by comparing the demonstrated or observed performance of the trainee, with a previously established performance standard.

In the case of training for flight, many of these objectives are previously known from organizational studies, FAA certification standards, and other ISD products. Those objectives that are peculiar to the user of the system may be more challenging to identify, but these are the very objectives that include the user unique tasks. Those unique objectives may lead to significantly improved training effectiveness, as well as to the acceptance of the training system by the user community.

Learning Technology Integration - With the potential of designing, developing, building, and fielding a very complex and expensive training system technologies, it is imperative that the discipline of a media assessment process be conducted. As expressed by Mish, (1994), "media is the mechanism that conveys information and knowledge," and media can be effectively and efficiently employed through the use of a large variety of information vehicles. A limited number of media can also be effectively employed, depending upon the complexity of the training task. The ISD process provides the basis for the conduct of a media application study, which includes subparts for media identification, media selection, and, finally, for media allocation to specific training objectives and tasks. The results of a typical media application study, including several varieties of media, from the simple printed page to the complexity of a real aircraft, are depicted on the *Candidate Training Media* portion of the Mission Element Training

Matrix (Figure A). Media allocation may be the single most effective, or single most expensive aspect of the ISD process, since it recommends the use of specific training media for specified training objectives and tasks. This portion of the media applications process could recommend the extremes of using "hand launched paper airplanes" for pilot mission preparation; or "the procurement of more $200 million aircraft, for pilots to take turns learning to fly."

Mission Element Matrix - During the early years of aviation, most flight training experiences were conducted in the aircraft. The choice of the aircraft to perform all the training tasks did expose the trainee to artificially created emergencies that were unsafe, as well as added risk of the loss of human and aircraft resources. Using aircraft to conduct training also generated higher costs of acquisition, as well as operational and support elements. Consequently, it is vital to strategically select which type of training resources are to be used to do what training task. These training tasks can be performed in many types of training media, not the least of which are aircraft, a multi-environmental flight simulator, flight training device, PC based computer aided instructions. hard copy checklist and cockpit mockup, other types of training materials, or through the human communication of a flight or ground instructors. The typical mix of candidate training media may be displayed effectively in the format offered in Figure A. Mission Elements Training Matrix.

III. *Instructional Development and Production Phase* - The purpose of the developmental phase is to correctly interpret and implement the direction and content derived from the Design Phase, and to produce and convey these materials and instructional methodologies to the *Delivery Phase* of the ISD process. The development process is conducted in the following steps (FAA Academy, !998):

1. Analyze existing instructional materials, and communicate the details through the use of lesson specifications.
2. Develop lesson plans.
3. Develop instructional materials, including instructor guides, student guides, course manuals, static visuals, dynamic visuals, lesson performance assessment, and terminal performance assessment methodology.
4. Validate materials through the use of a validation (population) class.
5. Revise materials with validation provided changes.
6. Produce and provide revised methodologies and materials to the *Delivery Phase.*

IV *Instructional Delivery Phase* - The delivery phase involves the presentation of the course materials to real students. In addition to the true conduct of instruction, additional aspects of the *Delivery Phase* includes:

1. Organization of presentation materials.
2 Management of student reference and learning materials.
3. Operation of training and audio-visual devices.

4. Development and execution of the training flow and sequencing operations.
5. Administration of performance assessment.
6. Distribution and collection of course critiques.

V. *Instructional Product Evaluation Phase* - The evaluation phase is used to measure the effectiveness of the instructional process. It assesses the achievement of the learning objectives by the trainee, through measurements of job task performance. The evaluation phase is the final phase of the ISD process, and is conducted as an interactive process throughout the initial and subsequent course/training offerings. The *Evaluation Phase* can also provide benefits such as (FAA Academy, 1998):

1 Identifying and reducing problems within, or among training methodologies.
2. Identifying and reducing problems associated with and among training media.
3. Identify deficiencies in technical content.
4. Establish and track cost effectiveness baseline.
5. Measure transfer of learning to personnel operational performance.
6. Provide correlational information for transfer of learning.

A crucial aspect of the completion of the *Evaluations of the Instructional Product Phase* will come from the implementation of the two distinct methods of evaluating instruction (FAA Academy, 1998):

1. Formative (internal) evaluations are the process used to measure how well

training is being conducted in the designated training location, as indicated by measurements of the student's ability to meet the instructional objectives. Course exercises, progress assessment exams, end of course exams, as well as integrative performance in flight simulators or in aircraft can be used for these evaluations.

2. Summative (external) evaluations are the process used to determine how well course completers are performing on the job. This information may come from post-course evaluations, or from an objective assessment of on-the-job performance.

SIMULATOR REQUIREMENTS

When meeting mission level requirements, the flight simulator is recognized as a part of an overall training system. It provides training system definition and implementation through various modes and condition sets, which establishes the intrinsic training capabilities of a synthetically replicated air vehicle. Many of these training modes and condition sets provide features, benefits, and liabilities that are not available when flying an aircraft. These modes and condition sets also provide learning without placing air crew at risk during training events. Subsequent to the definitions of states, modes, and condition sets, system integration shall embody the following major characteristics (USAF, AFGS-87241B, 1996):

1. The synthetic environment, which *corresponds closely to world outside the air vehicle.* The entities modeled in the environment must include properties

applicable to all systems(e.g., earth geo-gravitational equations; traditional Earth applications of laws of physics (motion, mass, energy & operational characteristics), visual, radar, communications and navigation, geo-landmass features, etc.)

2. The simulated air vehicle should *correspond as directly as possible to the air vehicle being simulated.* The term "as closely as possible" can best be attained by corresponding simulation to the performance of the air vehicle operating in an accurately modeled environment.

3. Cue generators organized as subsystems for visual image generators, motion systems, G-cuing, human-machine flight control feed-back, ambient, discrete, operational, and instructional audio systems.

SIMULATOR CHARACTERISTICS

The high fidelity of simulation required in a multi-environmental flight simulator must be sufficiently defined and integrated so that it provides a system with the following characteristics:

1. Properties applicable to all in and out of cockpit stimuli, including visual, collision avoidance, radar, air ocean weather environment, weather generated visual and motion cues, emitter signatures, and communication & navigation methods.

2. The flight simulator must incorporate computational modeling for the atmospheric properties and dynamics, and; flight dynamics, handling qualities, and performance parameters of the aircraft type.

3. The flight simulator must employ various technologies to provide the proper human machine responses from physiological que generators, including visual image modeling and generation, motion response modeling and generation, g-force modeling, flight control force modeling and generation, and other physiological forces that contribute to the real-world of flying.
4. The integration of the learning objectives hierarchy to be employed by an instructor who uses the system controls and displays, ISD provided menus, lessons, demonstrations, replays, performance demonstrations, remediation, and other instructionally strategic method.
5. These requirements include the support capabilities to load initial and revised data bases, generate data based from the simulators, and to produce a reliable, available, and maintainable simulator system that will operate within the projected support cost of the integrated simulator system.

SYSTEM TECHNICAL REQUIREMENTS

Exploration and Integration, vs. Reality - With many technologies available during the systems level design definition time-line, there must be a substantial level of discipline in place to shape these complex decisions. There is a right for developmental engineering and technology team members to explore and study new and improved applications for design integration in the simulator. However, with the previous design serving as the technology baseline, system design team members often show a propensity for finding a better, faster, newer, cheaper way to perform a given system level operation. These decisions often become known as “the enemy of good enough,” when many design, integration, and testing tasks could have been reduced, or even avoided, by accepting a baseline design, “that was already proven to be good enough.” Appropriate design decisions regarding the selection and integration of appropriate levels of technology implementation can be favorably influenced by consideration of the following:

1. Compatibility of simulator systems and components with aircraft technologies, including hardware & software.
2. Integration of existing technologies with applications of industry trade studies.
3. Emphasis upon the use of commercial off the shelf systems and components (COFS). Even though this approach has been used for many years.
4. Product maturity, longevity, and availability.
5. Product manufacturer’s financial, business, and historical perspective, and previous evidence of commitment to their support of the technology being considered.
6. Development team experience with the product, component, and/or software being considered.
7. Developmental team *courage of their convictions* to identify areas *where a basic design does not currently meet the requirements*, and flag that area(s) as being of continuing technical risk at time in the development program.
8. Developmental engineering and technology team members’ *obligation to withhold support for some element of the design that does not meet the requirements* of the system.

<u>Configuration Definition</u> - Technology alone can not dictate, or even predominate the definition of a simulator configuration. The requirements documentation that comes from the user community, the purchasing airline, the aircraft manufacturer, etc., must be the primary motive source for a simulator configuration, because the simulator configuration must be predisposed to incorporate:

6. Training system operational intent, operational environment, and training doctrine, strategies, and surge capabilities for periods of atypical operational requirements.
7. Replication of the "fielded aircraft's"(not original specification aircraft) normal systems operations.
8. Replication of the "fielded aircraft's"(not original specification aircraft) malfunctioning systems operations.
9. Human factors hierarchy, including the definition or lack of definition of human population that the aircraft is to serve, and the definition of the human population who is to fly or operate the aircraft and/or the simulator. Those human air crew, and simulator operator/instructors have many characteristics that, for fidelity purposes must be replicated in the flight simulator; and, must be incorporated in the simulator design to allow safe and efficient use of the simulator as a training and learning media. Among the more important human machine variables identified for simulator uses are:
    A. Target Population Morphology = 95th percentile human.
    B. Human learners will have the full range of motion of their musculo-skeletal system.

C. Human learners will possess a Class 2, FAA Medical Certificate.

D. Human learners may exhibit several forms of learning disabilities, but will be most likely be in the "normal range" in experiential, visual, and tactile stimuli areas.

E. Aircraft specific model information and data is required to provide accurate simulation of the aircraft-human interface, including:

Physiological Cuing

> Visual image, fidelity, and dynamics
> Audio frequency aural replication
> Motion system requirements that include cockpit motion, G sensing and cuing, and control loading.
> Tactile cuing for control yoke, stick, rudder, and throttle sources.

F. The human machine interface is also of concern when the aircraft, learning technologies, and other engineering processes create a flight simulator. Among the human factors present in these technologies is the human physical condition identified as Ataxia, and often referred to as Asynchronous Cuing Syndrome. This condition can be avoided by avoidance of known conditions, including:

> Sources of cue asynchrony
> Levels of asynchrony
> Resulting physiology
> Design methodologies for avoidance of conditions.

> Operational methodologies for avoidance of conditions.

Training events - As part of an ISD developed curriculum, specific training events will be identified for incorporation in each training session. The *term training* event is an operational term that occurs when a specific training occurrence is preplanned, coordinated for resources, briefed, and conducted for training purposes. Each training event will contain a set of enabling objectives, and terminal learning objectives.

Training modes and states - A training mode represents the fundamental processes of using and operating the simulator from the viewpoint of an aircrew member or a simulator operator. Simulator training modes may include:

10. Normal operating mode
11. Part task training mode
12. Self-training mode
13. Other major system functional levels

Embedded in any of these training modes will be other functionalities, called "training states". These states are software configured features which provide improved aspects for the training modes. The typical training mode will likely incorporate several typical states, or combinations of states, such as; record states; replay states; hard freeze or freeze fly-out state; halt state; crash state; brief-debrief state; and other prepackaged functional features (states) within a given mode of training.

Simulator operational environmental resources - Of direct impact to flight safety are the capabilities of the flight simulator to provide dynamic navigation and maneuvering experience. By use of the flight simulators to provide high fidelity training during the enroute, transition, approach to landing, and low level navigation phases of flight, a significant improvement in crew performance and safety can result. A very significant portion of the quality of navigation and approach to landing training comes from the attributes of the geo-landmass and airways data. Among the sources of this type data are:

1. U.S. National Oceanic and Atmospheric Administration (NOS) data.
2. Jeppesen-Worldwide data.
3. US Geological Survey data
4. Defense Mapping Agency data
5. NASA near satellite imagery
6. Contract training configuration packages.

Air Vehicle Configuration - Another significant aspect of simulator provided improvements in flight safety comes from high fidelity configuration, modeling, and simulation of the operational aspects of the aircraft. These configurations and simulations must include accurate human factors and operational details of the aircraft systems, comprising:

1. Electrical power generation and distribution system(s).
2. Hydraulics/pneumatics
3. Landing gear systems
4. Flight controls
5. Instrumentation
6. Environmental systems
7. Propulsion

8. Position & warning systems
9. Avionics
10. Integrated avionics
11. Flight management system.

When combined with proper system design architecture, computational system and configuration, and software programs, the fidelity provided in these aircraft simulation models can be of great value beyond the training requirements. It is fairly routine to use a training simulator to reproduce a real world flight situation that may have lead to an incident or accident, in an effort to understand the situation and explore potential causes. Well designed flight training simulators have also been used to validate many engineering concepts and tasks.

Simulator Technologies - That part of a multi-environmental flight simulator that provides the greatest impact upon human learning and experience comes from the visual system. It is acknowledged that the visual system can have a substantially positive or profoundly negative impact upon learning by the participating air crew member. A good visual system, which include the capabilities to process visual scenes and objects at high speed, with near real-world scene details, appropriate colors and shades, object definition, geometry, human interface, and rapid access to visual data base objects. With these features of the visual system, the integration with aircraft systems can be obtained to provide safer, effective and efficient flight training. Conversely, a visual system done badly can produce serious negative training, or contribute to asynchronous cuing syndrome, which may even produce asynchronous cuing syndrome resulting in "incapacitating" aircrew for a period of time after a "bad simulator" events. Many other aspects of the simulator design will influence the effectiveness and efficiency of a simulator system.

Visual system - In the defining and selecting of a high quality performing visual system the traditional engineering development process. The visual system represents a continuous matrix of technical demands and compromises among and between many other variables, including; operational requirements of the mission; the availability and capability of the technology; the budgetary support; and the contract amount for the training system. Experts and users alike offer the opinion that the quality of the visual system may have the greatest impact upon the success of a fielded flight simulator (Engel. 1999). Successfully integrating a visual system is greatly influenced by other technical variables, including the following:

1. *Cockpit visual environment.* The challenge comes when the human subject requires that this level of learning from a quality visual system product be obtained at an airline training facility; or at an average crew hotel room; or in a shipboard personnel compartment; or in the back of a HumVee military vehicle, that can be moved each day. The environmental aspect of these applications have major impacts upon crew learning, physiological performance, visual perception, and other aspects of learning that can come from the operational realities of; uncontrollable ambient lighting; spurious motion; high humidity; high & low temperatures; contaminants from environmental gasses, dirt/dust; and from electrochemical, electromagnetic, and electrical power variations. The

reality of impacts upon equipment reliability, maintainability, and availability will also shape the learning environment where a visual system must provide mission level fidelity.

2. *Crew station visual system fidelity.* With the changes in crew tasking which may be very diverse and time sensitive, visual system fidelity can be very important for the safe completion of the mission. A typical cockpit visual scenario can, over a short time, have the pilot viewing (at very close range) a navigation "fix" on a navigation chart; moving to an out of the cockpit view of a possible conflicting (co-altitude) high speed visual target at ranges of hundreds of feet to infinity; and back to the instrument panel for attitude, airspeed, and altitude information; now back to the view of the runway environment with effectively no visual cues (because of fog or cloud obscurations); to a runway environment for the proper sink rate cues from scene content, alignment and descent angles, and the visual motion, needed for landing. These are all circumstances where the integrated quality of the visual system is critical to safe crew performance of the mission.

3. *Cockpit window/canopy reflections, polarities, and mechanical attachments*. The aeronautical characteristics, physical configuration, as well as operation requirements of real world aircraft are sufficiently challenging that visual perception and visual based learning become critical safety of flight issues. In some aircraft like the Concorde supersonic jet transport, crew vision of the external area around the aircraft

is quite limited by the geometry of the fuselage; crew station locations; high glare shield positioning over necessary instruments; reflections from multiple glass planes; from inner and high speed positioning sections of the drooped-nose; and from mounts and mechanisms needed for the droop-nose of the forward fuselage. Each of these required mechanisms create areas that block crew view, called masking of the external aircraft area, while requiring good fidelity from the visual scene during all aspects of flight. Imagine the potential impact on crew performance and safety from cluttering the visual system with panels, braces, reflections, and obstructions while routinely performing during the operational scenario listed in paragraph C above:

> A typical cockpit visual scenario can, over a short time, have the pilot viewing (at very close range) a navigation "fix" on a navigation chart; moving to an out of the cockpit view of a possible high speed (co-altitude) conflicting visual target at range of hundreds of feet to infinity; and back to the instrument panel for attitude, airspeed, and altitude information; and now back to the view of the runway environment with effectively no visual cues (because of fog or cloud obscurations); and back to a runway environment for the proper sink rate cues from scene content, alignment and descent angles, and the visual motion, needed for landing. These are all circumstances where the integrated quality of the visual system is critical to safe crew performance of the mission (Neel, p. 25 , 1997).

All of these dynamic conditions may be occurring, but the visual system must continue to provide a good quality visual scene with high pixel counts, appropriate polygon use, acceptable resolution, object aspect, and correct angles and rates of change.

4. *Visual scene fidelity* (empirical vs. specification). As a valued resource, where flight simulators are used for many hours per day, the continued

visual system fidelity is a serious concern. So too, is the continued operation of the flight simulator with a good quality visual system fidelity.

Scheduled Maintenance Intervals. The operator of these systems may choose to schedule regular maintenance intervals for the simulators for scheduled checks or maintenance on the simulator systems, in a manner similar to those tasks for aircraft.

Automatic Testing of Critical Components. Another option available to simulator operators is to prioritize the systems where mission effectiveness training is compromised if a system like the visual system is not operating properly. These critical systems may be tested at prescribed intervals, automatically through an imbedded software program that reports any unacceptable conditions to the operator.

Empirical observations and performance. Through experience and observation, flight simulator developers/engineers/operators determine quick reference scenarios that tax the total simulator system, with high processing rates, high fidelity of visual systems, a lack of visual system flicker or dropping out of visusl scene objects, with many aircraft operating systems commands, and a high rates of aerodynamics computations. If under these compounding conditions the visual scene content and detail remains of high quality, and the aircraft responds correctly to flight control responses, these conditions may be substituted for a more formal and time consuming set of tests to determine a reasonable level of visual system performance. Many experienced simulator engineers, maintainers, and FAA inspectors use these abbreviated techniques to operationally load and check system fidelity and visual quality.

5. *Instructor/operator/debriefer environment.* Having a flight instructor physically close to a pilot has long been a tradition in training for air crew. With the concept of the instructor in the other seat, or in the back seat, many flight simulator were developed with an instructor in the simulator cockpit area or in a nearby instructor position. There is value in having the instructor close enough to observe the entire cockpit evolution, including the flying activities, cockpit organization, compliance with procedures, crew resource utilization, switchology, etc.. This proximity may also cause some problems for the individual serving as the "on-board" instructor. This configuration creates a compromised position for viewing the visual scene by the "on-board" instructor because the viewing position would be from outside the "eye box"area, which may contribute to instructor asynchronous cuing conflicts. This configuration does lead to instructor/ operator exposure to some physical risk from the motion created at aircraft rates (high or low) from a typical long stroke actuating cylinder induced motion platform system. The other disadvantage of the "on-board" instructor comes from the placement of the operator terminal, and the associated ambient light from the instructor station. The value of placing the instructor/operator/debriefer "onboard" the simulator is often positive, but it is derived with several design compromises.

6. *Contemporary visual system technologies.* With a variety of visual systems available for simulator applications the most logical choice is the system system that fits the aircraft and mission requirements, and, better yet, at the lowest cost. This selection of a visual system must begin with the documented mission requirements, leading to the mission element matrix (or equivalent) list of candidate media. The rationale for this progression is to discipline the selection of the a high cost (visual) system with the requirements for any visual system, which is to provide the cockpit with a good view of the operational scene. The candidate visual systems may include a 100 foot diameter optical dome, with 12 to 14 channels of video, and calligraphic enhanced areas of interest for quality imaging in a very dynamic operational environment; or be met from the other end of the technology spectrum, and consist of a single 25" CRT video monitor matched to each cockpit windscreen or window of a relatively slow flying, and non-tactical navigation and approach to landing environment. Obviously there are many design approaches for both of these examples, but procurement cost and logistics cost would be much greater from these two examples. So the mission requirements will be assessed and dissected for elements that can be met by various visual system technologies, in several configurations. Trade studies will be of great assistance in matching the mission to the technology, to the configuration, to the timelines, and with the available budget. One might focus upon many factors for selection of the visual system technology, but

any one area of any myopic view will not serve the selection well, since there is no one answer for which visual system technology to employ, since each aircraft, each mission, and each application is different.

Candidate visual system technologies:

Direct CRT Video

Front view image projection

Back view image projection

Three tube projected CRT Video

Collimated projected video

Rastor scanned enhanced video

Caligraphic projections

Light valve projections

Light emitting matrix

Laser Image Projection

G. *Visual system design and performance recommendations.*

Number of visual channels - The number and configuration of visual images will dictate the number of visual channels. This requirement to provide adequate visual scene coverage is a function of the *field of view from the pilot position(s)*. This can be determined empirically by the conical view from the "eye-point box" through the viewable area of the cockpit canopy, windscreen, and/or windows to the scene being viewed, and is identified as the "out the window" (OTW) position. Whereas cockpit windscreen/

canopy areas are often irregular in size and shape, it is not unusual to need more visual channels than the specified visual channel coverage is listed for. A typical area of a visual channel may vary from 30 to 60 degrees horizontal x 60 degrees vertical. It is also typical to lose visual coverage when matching the edges of adjacent channels.

In the final selection the number of visual systems and numbers of visual image sources (channels), the distribution of the viewing areas must be dictated by the mission requirements. An example of a visual system configuration can be identified in the application of several channels arrayed to depict the view required for aerobatic flight training. In-flight refueling training provides another example of a non-symmetrical configuration needed because of an overhead view.

Field of View Values - Field of view is an important quality component for a flight simulator system. The emphasis is to provide a visual system that provides a *continuous and unobstructed view from the eye point box, that is equal to the dimension derived from the aircraft eye point position.*

A typical air carrier visual system field of view is 150 degrees horizontal x 60 degrees vertical, centered on the aircraft X axis, with equal portions seen from both pilot positions.

Visual image quality indicators -

Polygon count and configuration - All certifiable flight simulators require a considerable number of visual objects (light) to provide realism in the visual scene by supplying images of surface texture, grass areas, dirt, trees, buildings, runways, urban background, and many other significant shapes and objects. These objects require visual system capabilities called polygons. Approximately 2000 polygons of full color images are required for a quality Daytime visual system operation. It is not unusual to need to trade some background-earth-sky polygon count for use as detailed image pixel count. This is possible, because the visual image generator system is generating, prioritizing, selecting and directing all of the visual image signals, and is capable of managing the pixel and polygon images.

Pixel count and configuration - A pixel is the smallest unit of light that can be projected and perceived by the human eye, also referred to as "light points." Higher numbers of pixels per square inch/cm will produce a vivid image when viewed by a human subject. In flight simulator systems pixels are associated with visual system quality to produce "realistic looking visual scenes." The unit of measurement of pixels is pixels per square cm/inch, or pixels per line of (rastor/caligraphic) scan lines. Either method of pixel measurement is referred to as the pixel count or light points per line or frame.

Recommended Pixel/Light points values per frame -

	Day	Night/dusk
High performance aircraft	750	2500
Helicopter	750	4000
Spacecraft	2500	4000

*Light point size (max)** = 6 arc minutes
*(USAF GS 87241B/draft, pg. 163, 1996).

Visual scene content and detail requirements - The amount and details provided in the visual scene are always a function of the mission requirements. Flight simulators normally use combinations of sky-earth, object detail, mission dictated areas of interest, texture, background objects, all viewed from the OTW position.

Resolution - "The resolution of the display image determines to a great extent the how much detail is visible and how sharp the picture appears (FAA AC120-40B, 1993). Resolution may influence the quality perception of the visual in many areas, including:

> Field of view per display channel

> Numbers of pixels per display channel

> Characteristic of the image generator anti-aliasing filter

> Resolution of the display system at specified brightness

> Bandwidth of the display system's video amplifier stream.

- Display /optics selection.

Measurement of Resolution - The smallest visible object in a display scene is ½ of the smallest resolvable optical line pair is called a resolution element or Rexel.

- *Horizontal resolution* - acceptable standard is 6 arc-minutes per optical line pairs (OLP).
- *Vertical resolution* - acceptable standard is 6 arc minutes per optical line pairs (OLP).
- It is *not a requirement that resolution standards have the same value for horizontal and vertical resolution.*
- Resolution values may be determined empirically by noting a fixed reference point observable in a specified visual scene, that may be a specific antenna installed at a given position; or a canopy mount line on a given aircraft. Then observing the physical dimensions of the selected equipment and subtending the angle in arc-minutes per OLP, and accepting that figure as the empirical resolution standard.

Brightness - Projected day light brightness must produce sufficient ambient light to allowed the pilot to read a NOS formatted approach chart while seated in the appropriate cockpit crew seat, while measuring a minimum of 6 foot-lamberts at the pilot's eye point.

> *Brightness uniformity* - Although brightness is a quality that is both measurable and empirically determined, uniformity of bright and dim areas are also a concern.

> *Contrast ratio* - Contrast ratio is expressed as CR=W/B, or the ratio of the brightest projected image, usually a White image, divided by the value for the least bright projected area, likely a Black. A good quality visual image will result when a the higher the contrast ratio is present with a high resolution figure. The FAA's requires a minimum CR value of 5:1 for night scene class D simulators. The FAA also requires a minimum CR of 25:1 for day/dusk scenes for the air carrier (class D) flight simulator. ICAO (1995, pg.26) recommends the same CR values (25:1) for day scenes. It is possible to attain CR values of 30:1. There are no recommended CR values for simulators below the class D level. The USAF uses a slightly different calculation for CR. All of these values must be the results of measured by photometric instrument.

Image detail quality requirements

> *Image continuity* - The visual image shall be continuous across display channel boundaries. A maximum discontinuity along boundary edges is (.3 to .5 deg.)

> *Geometric distortion* - There is a tendency for taller images

to not retain parallel lines as the image gets taller. The image will typically get wider near the top of the image, depending on aspect ration of the image. There is no FAA value for geometric distortion, but the maximum value for geometric distortion is (.5%) of total picture height.

> *Collimation Quality* - In a visual system employing a collimated projection system it is desirable to have all light rays reach the pilot's eye point in a parallel path that starts at infinity, and ends at infinity, which is the naturally occurring way. However, with the light sources in a simulator visual system not coming truly from infinity, it is possible to have light rays diverging or converging as a result of optical misalignment. This is undesirable from the pilot's perspective, and poor collimation can result in pilot fatigue, headaches, or nausea, all conditions similar to asynchronous cuing syndrome.

The *maximum collimation convergence shall be (.02 diopters)*; and the *maximum divergence shall be (0.1 diopters)*. FAA offers no absolute values for these measurements.

I. *Visual scene degradation* - It is not unusual to perceive as well as measure a degradation/time of visual system performance. This degradation can come from several diverse sources, including the following:

1. *System load management* - Because the visual system is an integrated system that responds to dynamic changes in training scene demands for polygons, pixels, geometry, and even geographic positioning, it is not unusual in high demand periods to begin to see a degrading of the visual system quality. This degrading often indicates an overload of the processing and prioritizing parts of the visual system, and is evidenced by scene flickering, aliasing, flashing, tearing, popping, swim-ming or dimming of the proper visual scene. *No flashing, flickering, popping, or other variations in visual scene content is acceptable.* This is especially of concern because these visual stimuli are *likely to contribute to asynchronous cuing syndrome.*

2. *System reliability and maintenance* - Depending upon the type of visual system projection technology(s) being employed in a given simulator, some form of electro-optical device is employed to convert software instructions to a human perceptible visual signal. These electro-optical devices, usually some form of projector, have many dynamic adjustments of voltage levels, brightness levels, motor and optics alignments, motor-gear trains maintenance, optical tube and lens cleanings, and other on-going maintenance requirements. There are also planned maintenance actions required. Failure to faithfully perform these planned events or to respond to other sources of visual system hardware degradation will also

cause a loss of visual system performance, resulting in losses of training event.

Levels of Occulting - In flight simulation it is possible for one visual object to be hidden behind another object, where the real world geometry and size would not allow this to occur. No occulting is acceptable in the a flight simulator visual system.

Motion Systems - *The motion system is the part of a simulator that changes a video game experience to a real dynamic aircraft in 50 msec!* If the visual system makes a pilot believe that what he is seeing is the real world, then the motion system makes the seat of their pants think they are off the ground and in flight. Motion systems provide a very valuable additional stimuli, and is most effective when coupled with the visual system. Motion begins to provide a three-dimensional aspect to the simulated flight, since both motion and G perception can be provided by the motion system. The combination of a good quality visual system with multi-sensing motions systems will produce for the pilot, the perception of an environment of flight within a very short time. As was the case in the selection of a visual system, the selection of a types of motion systems must be a result of the mission requirements of the aircraft. Transport type aircraft are limited in their design to less than 2 G's, and would only require a motion system that had a 60 degree bank angle. A general aviation aircraft that may operate in the Normal or Utility categories may encounter higher G loads, and greater gust dynamics, so a more dynamic motion system may be required. A fighter type aircraft will have to train pilots in the most dynamic circumstances, including very high pitch & bank angles and rates, and high (7 to

9) G's, that would be impossible to perform using an airline type platform motion system. Types of motion systems include the following discrete types, and types that are often used in combination with other motion systems for improved reality.

A. *Platform motion* - Many commercial airline flight simulators obtain motion cues for pilots by building the entire aircraft flight deck and forward fuselage on a moveable platform, and then moving that platform as accelerations, turns, banks, and G forces occur. Despite the training value of these dynamic motion cues, these systems are limited in motion to approximately 8 degrees of motion on the X, Y, and Z axis. These roll, pitch, yaw motions are not equal to the normal dynamic values of X, and Y travel in the real aircraft, but do provide good training with onset and continuous cues for some conditions. The obvious limitation is that a platform motion system can never provide sufficient physiological cues for highly maneuverable, and rapid roll, pitch, yaw, and high G aircraft.

B. *Crew restraint systems* - In aircraft where a platform motion system does not provide adequate cuing, one system that can assist cuing is the crews' restraint system. These systems use hydro/pneu-mechanical devices to tighten, loosen, and inflate strategic parts of the lap & shoulder harnesses, seat cushion, parachute shoulder harness, or by exerting loads on the pilot's helmets, as individual subsystems or in combinations. These crew restraint systems are operated with response times, and force magnitudes that replicates both motion and G forces. The fidelity of these motion cues exceeds a motion platform system, because the crew restraint system can retain forces and movement over a longer duration.

C. *Flight control loading & tactile feedback* - A very significant motion and speed cue available back to the pilot which represents tactile feedback normally provided by the real aircraft, comes from the aerodynamic, acceleration, and gyroscopic force feedback into the flight control (stick, yoke, pedals, throttles, etc.). This control feedback is also important for the pilot to feel how great an effort must be put into the flight control to derive a desired response from the aircraft. Therefore, a type of motion simulation that provides these types of feed through from the pilot to the (simulator) aircraft, while the pilot also receives a form of motion feedback from the control loading (motion) system. The control loading system may provide these motion cues into the stick/yoke, rudder, and throttle controls. There are several technologies used to provide these valuable training cues. All control loading systems use electronic signals from the simulator's motion system (flight computer section) partitioned section. This computer section also receives inputs from the simulator computer section that models the aircraft systems, the aerodynamics, performance, and handling qualities models of the aircraft. Control loading systems are identified for their dominant operational modes of hydro-pneumatic, mechanical, and electronic operations. Among these systems are options for position sensing, or force sensing of control input and appropriate feedback.

<u>Crew Station</u> *(flight deck/cockpit)* - The primary location for the human machine interface is the flight deck or crew station. To produce a high fidelity flight simulator, it is imperative that the simulator cockpit have the same dimension, configuration, geometry; accurate visual replication; correctly placed controls, switches and instrument location so that all human machine interface, and system hardware developments begin from an accurate datum. Additionally, all aircraft systems that the crew touches, controls, positions, or responds to as stimuli must be accurately placed in the three dimensional world of the crew station. Simulator design discipline must focus upon:

A. *Crew station visual system fidelity* is also a very important datum point for simulator development. Details of the visual system have been offered in Section 1 of this document.

B. *Flight control positioning, travel, motion and response* - Flight controls must be properly placed, operationally positioned, and dynamically operational within the flight deck/crew station. To replicate the real aircraft, each control must be properly placed, tactically correct, with proper throw, positioning, and response-feedback provided. These critical control components include the following:

1. Side stick controller
2. Stick/Yoke
3. Hands on throttle & stick (Hotas).
4. Rudder
5. Control loading system(s)
6. Landing gear, with correct position, operation and aural cues
7. Arresting equipment
   A. Controls
   B. Indicators
   C. Aural cues
8. Cockpit Aural Cues

A. Ambient noise
B. Conversation
C. Transmitted & received audio
D. Other dynamic systems aural signals
    - Ground power cart
    - Onboard APU
    - Equipment cooling fans
    - Standby electrical hydraulic pump
    - Gasper Fan
    - Air conditioning pack
    - Auto speed brake deployment
    - Nose gear extension
    - Nose gear retraction
    - Nose tire spin down
    - Nose tire landing touch down
    - Runway rumble (high speed)
    - Runway expansion joint thump (low speed & taxi)

E. Engine responses to increased and decreases in commanded power.
F. Flight control deployment
G. Landing gear deployment
H. Rain on windshield
I. Lightning strike
J. Explosive decompression
K. Other audible clunks, thumps, squeaks, hissings, etc, from normal or abnormal systems operation.

<u>Aircraft Performance and Handling Qualities</u> - It may be a matter of life or death to those onboard an aircraft for the pilot to have control of a hugh amount of information and data. With the focus and control of the aircraft being in a single geographical location, the cockpit, and a single human being operating that very large or high speed air vehicle, the performance of that pilot is quite dependent upon the aircraft design data that has been incorporated, or derived from testing. Therefore, the accuracy, and fidelity of that data is critical to flight, and to the performance of the flight simulator. The types and levels of data and flight information that is needed include:

J. Performance data that was obtained through flight testing and operational experience.

K. Handling qualities documentation/software obtained from flight testing and operational experience.

L. Aerodynamics documentation/software obtained by flight testing. This data must be scrutinized for it's origin, since successful integration in a flight simulator requires a the level of confidence about the data, and that may start from knowing whether given data package is obtained from actual, analytical, or predictive sources. Other data source issues include the media and formats (contemporary disc packs or warehouses of paper) of the delivered data, the origin/history and levels of confidence in data, and the level of corporate sensitivity for the business and technology baseline being communicated in the data.

<u>Simulator Technology and Performance Integration</u> - Flight simulator developments are seldom begun as an accidents of history. The development of these training devices represents a significant investment of resources and organizational commitment. These developments also represent a significant level of imbedded technology with high levels of technical risk to both the user community and the developing organization. One mitigating influence on technical risk is the organization's or individual's history of success using these technologies, to perform similar tasks. Technical risk can be reduced when the simulator development organization has previously demonstrated successful commercial products. The advantage of beginning

from a design or product baseline, with a successful organization contributing to the development is a very major advantage over a "clean sheet of paper" development effort. Consequently, it is most appropriate to determine what is the status, and experience level within the developmental organization with these levels of technology, before beginning the development and design process. Significant reference points include identifying:

1. Sources of appropriate training technology products, including the competition's products, and applications philosophy.
2. Operational baseline systems previously or currently in development, in production, and in the field. This operational baseline information just includes available performance data, such as the instructional loading, Ao, MTTR, spares usage rates and breadth, and user acceptance of previous systems.
3. Product configuration baseline information is also an integral part of determining the organizational baseline, which includes the major elements, systems, subsystems, and components being operated (not marketed) in existing products. These major elements would include defining:
    A. Hardware systems including the computational system, and any sub-parts in distributive PC configurations, distributed or partitioned central processors, a linked central processor with smart of dumb terminals, or other configurations of the computational system.

B. Hardware history for visual computers, visual projection, motion systems, control loading systems, and the successful integration of these and other similar systems.

C. Software applications and integration come from knowledge and experience for which there is no substitute. This success may come from commercial off the shelf (COFS) PC office products; large system main frame applications running on UNIX, ADA, PASCAL, Fortran, etc.; or from current applications of C, C++, ADA, Basic or similar products; from imbedded S/W in operational components. Despite the type of software, a benchmark of the development organization history is important.

D. Simulation Media - The integration of the media technologies for computer image generators, projectors, CRT display units, matrix display devices, optics and combinations of these technologies.

E. Dynamic Response - Throughput latency and cue synchronization of the physical motion, visual, cockpit instrumentation cue responses to a control input at the pilot station shall be used to determine simulator dynamic response. This time lag will include all computational and operating bus rates, but with aerodynamic forces and moments attenuated (USAF GS 87241B/draft, 1996).

Simulator dynamic response is a form of bench-marking of the ability to perform the training tasks to a level of fidelity that the transfer of that training is very likely. Response times must also replicate the operating rates of the aircraft systems, so there is no perceived time lag, time lead, or discernable differences in human performance between the simulator and the aircraft. The lack of dynamic response, often called throughput delay or lag time, can result from several individual, as well as integrated sources, including:

1. Host computer operating system bus rates.
2. Simulator system & component delays associated with the:
   - Motion system bus rate.
   - Control loading system bus rate.
   - Visual system bus rate and throughput times
   - Cockpit displays bus rates
   - Aircraft installed equipment
   - Computer bus rate
3. Data bus operating rate
4. Aircraft system & component delays
5. Any software originated delays

6. *Levels of acceptability for transport lag time* * = <60msec.

   * The FAA allows up to 150 msec for level D flight aircraft simulators (AC120-40B, pg.20), but this is judged as too slow for most high performance aircraft handling qualities' simulations.

<u>Computational Systems Resources.</u> Though most of the techno-freaks would look to the early Apple, or Commodore PC's or to the computer imagery generated in the Star War movie of the late 1970's, as the genesis for flight simulator development; the operational personnel in the airline, nuclear powerplant, air traffic control, and military know that the multi-environmental flight simulators were fielded in the late 1950's. Let there be no doubts that flow down developments from Big-Blue, DEC, and SEL that produced the

digital 32 bit main frame computer, provided a huge tool used to develop contemporary flight simulators.

The complexity of the system, and the life-cycle support risk dictate that all flight simulator software shall be written in ADA, C++, or other Higher Order Language. Exceptions are reasonable for commercial off the shelf (COTS) software typically used in work stations, and a computer vendor developed software. Software developed for a specific simulator will be developed as an object oriented design, but using the DOD STD 2167 structural modeling.

A. *Computational System Characteristics* - The software architecture shall have three levels:

1. Executive level, which shall manage the subsystem modules.
2. Subsystem level shall model each of the aircraft systems, and be devoted to managing a group/team of (previously modeled) system level components. (Such as a fuel pump, engine fuel control with the associated performance). A subsystem shall have no direct knowledge of other subsystems. All information shall be transferred from the dedicated memory location where the subsystem places data.
3. Component level, that shall only be responsible for computations.
4. Operational check out for the simulator shall be performed by a software with numbers of instructions, and other rates and values characteristics to the normal mission.

5. Diagnostic software shall be provided to perform fault isolation on equipment.

6. COTS software shall not be modified.

B. *Operating Systems Qualities* - It is necessary for the operating system to be *compatible* with commercial grade products, including COTS, PC work station hardware & software. The host computer must also be compatible and flexible to accommodate aircraft installed software, and with aircraft common hardware, while providing *portability.* The system must also be *flexible* in managing the operations all the systems, non standard software system protocol, and components at a rapid rate. The computer operating system shall also have *expansion capabilities* that will likely be needed as the simulator and aircraft mature.

C. *Computer Expansion Space* - A range of required expansion space will vary from 20 to 50 per cent of installed memory, depending upon the maturity of the simulator design, and the complexity of the technologies being modeled. When sizing the computer memory, and making judgements as to the requisite spare capacity, remember that it takes resident memory and processing time to conduct runtime checking. For life cycle purposes, memory shall be expandable to 400% of the specified installed value.

D. *Processing Speed & /timing* - Each processor shall, with full operational functionality, and with the Maximum Software Transport Delay (MSTD), retain a minimum of 40% of the processing time allocated for spare time.

E. *Computer Hardware Configuration* - The selection and configuration of hardware must be a result of the design process, where decisions are made regarding the system architecture, executive, operating, and component levels designs are known and sized. Beginning the development process with a computer hardware configuration already identified is a very risky "beginning point" for the product. Compatibility, configuration, speed, and memory size are more important than a given model of a computer, using an on-hand model of compiler, and other known components.

<u>Systems Interfaces</u> - The simulator application of the term interface means to transfer or conduct a signal between two or more independent operating units. There are thousands of these connecting signals within a flight simulator system. Most of these interfaces have standards for the levels and conditions required for the interface to pass the signal. The following list is offered for a reference point for the many types of interfaces:

A. Major System Interfaces
- > Visual system (contractor furnished equipment)
- > Visual system; Interface Specification for PQR Visual Systems, 202020 (separately provided equipment).
- > Distributed Interface Simulation Network, IEEE Std. 1278-1993
- > Interface with other simulators acquired under IEEE Std. 1293-1993.
- > Interface with up to three other appropriately specified simulators in the same facilities.

B. Other types of Interfaces
- > Facilities interfaces
- > Facility electrical power and environmental systems
- > Facility hydro-pneumatic power
- > Interface with the Training Management System

(TMS) for real time student tracking, records, performance & progress.

> Interface with the Training System Support Center (TSSC) for real time diagnostic purposes.

> Interface with the Training System Support Center (TSSC) for real time environmental database loads.

C. Interface Verification

Systems Engineering Applications - To develop, manufacture, install, and operate a system as complex as a multi-environmental flight simulator system it is desirable to involve professionals in many non-aeronautical fields, like software development, computer systems applications, ISD, and many others. To develop, manufacture, install, and operate these systems one must have the professional involvement of many types of engineers and technologist's. Especially since these systems are large enough to fill one or more buildings.

1. Mechanical Engineering - Because an aircraft is a mechanical vehicle, the contributions of the mechanical engineers are massive, and the integration of an aircraft structures and systems involve these professionals from the beginning of the project. Among the specialty areas that the mechanical engineers have responsibilities for in the development are the following:

Systems Safety - An area where special skills and intuition are needed to design and implement simulator unique safety systems, procedures, and devices. These designs may take the form of limiting devices to prevent motion system ram travel during any spurious signaled event; or designing and building operational interlocks so that a cockpit door or other related mechanisms cannot be opened during a maneuvering event on a platform motion system; or developing a guard rail that prevents an instructor from falling from an instructional platform during low light conditions inside a domed visual system device.

Operational systems - Any aircraft system controlled from the cockpit must be replicated and active in the simulator cockpit. Every one of these controls, indicators, and moveable devices like flight controls, ejection seats, etc., are the responsibilities of the development mechanical engineer.

Structural requirements - Some full motion flight simulators weigh >4000 kg., and can move across 10 meter diameter hemispheres at rates of 5 meters per second. In These conditions there are serious loads that require substantial structural design and load path definitions.

Facilities' configurations - There is also a civil engineering component where these very large aircraft and simulator equipment transfer loads and forces into building structures and building foundations. The concerns for the continuity of the simulator structural loads transferring into a building may fall with the project mechanical engineer.

Equipment configurations - All physical configurations of the flight simulator are the responsibility of the mechanical engineer. The functionality of a flight simulator comes from the ability to replicate the environment and dynamics of flight without leaving the ground. But that is very challenging to build a device that fools a pilot into believing they are flying.

2. Electrical Engineering - The contributions of the electrical engineer to a flight simulator development are too vast to describe or list, because under the shell of an aircraft, a flight simulator is all electrical! Literally, every system, subsystem, and operational component has a wire, electrical interface, or signal associated with it. There are infinite numbers of electrical circuits, devices, components, for which the electrical engineering group is responsible. Among the systems are a few areas of electrical engineering that are not simulator unique, but are essential to simulator operation. This includes the electrical engineering associated with the supply and distribution of electrical power, which can be the cause of subtle or serious simulator malfunctions if not properly engineered. Power supply considerations include:

A. Grades of electrical power available for simulator use, including:

1. Commercial
2. Residential
3. Computer conditioned power
   > Filtered & surged protected
   > Uninteruptable power supply (UPS), including the capacity and response times required by the simulator.

B. Quantity or amount of power available vs. amount of power required to operate the flight simulator system.

C. Power factor should be <85%

D. Earth grounding requirements.

1. Building power and grounding bundles, harnesses, and circuitry.
2. Simulator system, subsystem, and component grounding and bonding.

3. Digital equipment ground loop protection
4. Static charge dissipation network
5. Computer system grounding grid design
6. Lightning strike protection
7. Earth-ground surface materials chemistry

E. Electrical power distribution to the simulator, and throughout the simulator major systems and assemblies.

3. Design and Construction - With a systems development of the size and complexity of a multi-environmental flight simulator there are multitudes technical issues that do not fit into a classic engineering task list. Among those issues are the very important subject of:

Safety system & engineering
Material's standards
Simulator ingress and egress
Building ingress and egress
    Normal operations
    Equipment installation & maintenance
    Physically challenged
Electromagnetic Radiation
Communications Security
System Security

4. Facilities and System Installation

A. Architectural and construction.

1. *Constructing a building* that can house a device as large and complex as a flight simulator system is a very significant fete. Such a facility must accommodate all the simulator support systems including electrical power, lighting, heat-air conditioning, plumbing and sanitation, hydraulic systems, load-bearing floor, optical device load-bearing floor area, the simulator installation,

test and maintenance areas, material's storage, brief-debrief stations, class rooms, break and lunch areas, administrative, and management areas. Above all, the facilities must provide a location where simulator training supports the mission of the flying organization.

2. *Reality checks* - Among any large developmental project are likely to be several requirements, tasks, or features that would be done differently if the opportunity arose. Special consideration may be appropriate in several areas, including:

   a. Providing adequate building access for equipment and support systems:
      > "UPS not fitting through the door."
      > "UPS system falling through the floor."
      > Building floor strength too low in simulator cockpit area.
      > Chain fall track not sufficiently long to traveling across work area.
      > Ceilings not high enough to allow for erection equipment to be installed when needed.

   b. Grounding devices materials not compatible with the soil chemistry.

   c. Reasonable building access and egress for major assemblies.

3. *"Form follows function"*- From a facilities view, it may be prudent to have sufficient populations using the flight simulator system and facilities for some period before the ready for training day. This may assist in making last minute arrangements and adjustments regarding human traffic and use patterns, signage, notice boards, and other human factor influences. Politically, don't hesitate to

have time available for VIP's to have their personal demonstration /functional check flight in the new system. These are usually close to the person who provides the financial resources to pay for these system, or who may also sign your paycheck.

<u>Systems Verification, Testing, Validation & Certification</u> - Perhaps coming from the testing and evaluation requirements of the aerospace industry, there is an operable hierarchy of actions that are inherent in the developmental process. These actions endeavor to determine that the system is performing to a level that meet the requirements, specifications, and contracts. Often, the *system is performing as it was designed to*, but it is *not performing to the required level.* Among these performance assessment activities a hierarchy of commitment and precedence exists, including:

1. *Testing Doctrine and Documentation* - Being committed to the mutual benefits of a well-defined testing and evaluation program is important for all developmental team members. Testing and other forms of progress checks, or performance measurements must only be performed when the design is completed, and testing should not need to be repeated. There should be no "progressive testing" of a single design, but progressive testing may be used during product/component development.

   Testing and evaluation program/plan must be contained in a published document that contains well-defined specific application terms, conditions, and operations; as are activities, events; types of testing to be performed, with dates, durations, materials, equipment & facilities required; plus identifying the participating cognizant/contributing/ representative/test results approval personnel, with organizational charts and the program and testing "chain of command" diagramed. With a well-developed test and evaluation plan all development team members can know what is planned for any and all aspects of the simulator development. The test document must also provide descriptions of the protocols, standards, organization and scope of the types of tests being performed, and include the following test documents:

- Protocols
- Test Record Document
- Test Results
- Demonstration Plan
- Certification Testing Plan

There are many categories of testing and evaluation and for this document, the following typical list and hierarchical relationship is offered:

Verification - Design and contract compliance assessment can be attained through the verification process, which can be achieved by using one or more of these methodologies, depending upon the level of complexity, or criticality of the design:

- Analysis (least complex method)
- Inspection
- Testing
- Demonstration (most comprehensive method). Will be organized and formatted to include operational assessments under normal training operations, with real trainees', at the user's location.

The selection and scheduling of the desired types of verifications are chosen by the customer's technical staff, and approved by the test director or program engineer.

Design audits - Involves the operation and assessment of the entire system, starting with the specifications and design documents, leading through the entire menu of operational and training functionalities. .

Validation - The assessment to determine if the system exists, in hardware and software, as the design document prescribes.

2. *System Functionality* - Regardless of the results of any development, design, testing, and evaluation sequence, the system must operate as the aircraft operates.

3. *Specification Compliance* - Because a specification is normally the part of the contract that tells what is being contracted for, compliance with the specification is imperative. Whether this document is a system specification, or product specification, or a performance specification it is the document that describes what is being bought. If the applicable specification does not describe what is being bought accurately, the specification must be revised to do that.

4. *Mission Element Confirmation Demonstration* (MECD) - A good flight simulator product can be displayed by executing a Mission Element Confirmation Demonstration. This demonstration is usually performed at the operational site after all other developmental operations are completed. If organized effectively, gaining insight into the RAM elements of the

development as part of the MECD is also possible. This demonstration is normally conducted just before the final acceptance and payment for the flight simulator system.

5. *System Certification Testing* - (see latest revision of FAA Advisory Circular 120-40B, Airplane Simulator Qualification)

6. *System Acceptance Testing* - Depending upon the acquisition strategy established for the simulator development, the acceptance testing will be tailored to meet the criteria identified in the contract. So depending upon the details, terms, and conditions in the contract it is possible to use any one of several processes, as is identified in the development and production contract.

- Contracted Methodology
- Specification/Technical Compliance
- Mission Compliance
- Fielded System Performance

Design Guidance and Standards Availability - The search for design standards, specification, or meaningful guidance for the development of multi-environmental flight simulator system has been a long one. During the related literature search on the subject, no definitive single document was identified. Many related documents were identified, but there was little information on the development process. This accompanying list identifies many sources and types of the related documents.

A. Aerospace/Aircraft Systems Specification - none

B. Aerospace/Aircraft Performance Specification - none

C. Government Specifications -

US Air Force Guide Specification (AFS87241A/Bdraft)

D. Government Standards

1. Federal Aviation Regulations (FAR's)
   a. Airworthiness Standards (aircraft only)
   b. Flight Simulator Standards (none)
   c. FAA (technical) Advisory Circular
      AC 120-40C Airplane Simulator Qualifications.
      AC 120-45A Airplane Flight Training Device Quali- fications.
      AC 120-63A Helicopter Simulator Qualifications.
2. DOD/Military Standards
   a. DOD STD 2167, Software Development Standard.
   b. FED-STD 376, Preferred Metric Units for General Use by the Federal Government.
   b. MIL-STD 454, Standards General Requirements for Electronic Equipment.
   c. MIL-STD 882, Systems Safety Program Requirements.
   Government Handbooks

3. Military Publications
   a. MIL-HANDBOOK-248, Acquisition Streamlining.
   b. AFP 36-2211, Guide for Management of Air Force Training
      Systems.
   c. ESD-TR-86-278, ESD Guidelines for Designing User Interface Software (NTIS # ADA 177198).

E. Existing International Standards

1. AIAA/ANSI R-004-1992, Recommended Practice for Atmospheric and Space Flight Vehicle Coordinate Systems.
2. AIAA/ANSI/ISO9000, Recommended Practices for Multi-environmental Flight Simulator Development (in development).
3. Royal Aeronautical Society, International Standards for the Qualification of Flight Simulators.

F. Existing Related Industry Standards

1. ASTM 268, Standard for Metric Practice.
2. IEEE 1278, Standard for Information Technology-Protocols for Distributed Interface Simulation Applications.

3. Thompson Simulation, Ltd, Airplane Flight Simulator Evaluation Handbook.

Equipment and Materials - It is typical for a flight simulator to contain equipment that was procured from outside sources, by some organization that is not manufacturing the simulator. There are many combinations of conditions, events, and equipment that prescribe management of these materials. A separate management effort is dedicated to minimize the technical, performance, and schedule risk associated with the following types of provided equipment:

1. Purchasers provided equipment
2. Contractors provided equipment
3. Required performance vs. good faith effort.
4. Loaned property

Personnel & Training - The human part of a development program deserves rewards, consideration, motivation, and hard work. A team will evolve during development, and it is the duty of the development management to collaborate with their supervisory and technical staff to develop the team as a cohesive working group(s). These working groups are task oriented, but also provide encouragement and facilities from which growth and professional contributions are recognized.

Professional Development Plan - Each team member must have an approved professional development plan, and be actively progressing on the target development areas. This plan will be part of the individuals, and team's performance evaluations, and a source of recognition for their achievements. An integral part of any technical development of the magnitude of a multi-environmental flight simulator system is the development of the team personnel.

Orders of Precedence - During any commercial contract operation there are hierarchies of documentation and of execution that will provide guidance and direction for the contracted goods and services being provided. During the development and production operations questions will arise regarding which document or publication should be followed. That order of precedence within the developmental effort's focus goes to the *Executed Contract*. Any document, publication, or developmental information not identified in the Executed Contract is not a requirement of that contract.

Other levels of precedence that can greatly influence technical and programmatic decisions include:

- Government Specifications
- Government Standards
- Government Technical Order
- Government Handbook
- Government Regulation
- Government Advisory Circular
- State environmental law
- State environmental regulations
- State contract law statutes
    - Uniform commercial code
- Federal statutory law
- Federal international trade and technology statutes

APPENDIX F

INSTITUTIONAL REVIEW BOARD

APPROVAL FORM

Oklahoma State University
Institutional Review Board

Protocol Expires: 11/28/2001

Date : Wednesday, November 29, 2000 IRB Application No ED0160

Proposal Title. MANAGEMENT STANDARDS FOR THE DEVELOPMENT AND FIELDING OF MULTI-ENVIRONMENT FLIGHT SIMULATOR SYSTEMS

Principal
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Reviewed and
Processed as. Exempt

Approval Status Recommended by Reviewer(s) : Approved

Signature :

Carol Olson, Director of University Research Compliance

Wednesday, November 29, 2000
Date

Approvals are valid for one calendar year, after which time a request for continuation must be submitted. Any modifications to the research project approved by the IRB must be submitted for approval with the advisor's signature. The IRB office MUST be notified in writing when a project is complete. Approved projects are subject to monitoring by the IRB. Expedited and exempt projects may be reviewed by the full Institutional Review Board.

VITA

David L. Neel

Candidate for the Degree of

Doctor of Education

Thesis: ASSESSMENT OF MANAGEMENT STANDARDS FOR THE DEVELOPMENT OF MULTI-ENVIRONMENTAL FLIGHT SIMULATOR SYSTEMS

Major Field: Applied Educational Studies

Biographical:

Personal Data: Born in San Diego, California, the second of two sons of Elmo L. and Iva L. (Chambers) Neel.

Education: Graduated from San Diego High School, San Diego, California; received a Bachelor of Arts with a major in Industrial Education-Electronics degree from California State University at Long Beach, California in August 1969. Obtained a Masters of Science degree from Utah State University with a major in Industrial Technology - Aeronautics, in May 1973. Graduated from the U.S. Defense Systems Management College as a Program Manager, in December 1982. Completed the requirements for the Doctor of Education degree with a major in Applied Educational Studies at Oklahoma State University, Stillwater, Oklahoma in December 2000.

Experience: Served in operational and training management positions for general aviation, air carrier, and military flying and technical procurement organizations. Managed program and technical elements in aircraft and training systems development for international applications of airline and military aircraft. Served in aviation maintenance and engineering positions on a variety of aircraft, and engines procurements for airline and military programs. Functioned as an Aeronautical Engineering Duty Officer (AEDO), in positions of the U.S. Navy's Assistant Program Manager for flight simulator development for the F/A18 and T45 aircraft programs.

Also served NAVAIR as the Project Leader for the T45 Alternate Engine Technology Qualification. Possesses a variety of FAA certifications, as a Commercial pilot, and has flown 18 types of civil and military aircraft. Is an FAA certificated Aviation Maintenance Technician with airframe and powerplant ratings, Inspection Authorization, and designated by the FAA as a Technical Personnel Examiner (DME). Has served in leadership positions as Department Chair & Professorial positions at four Colleges and Universities, including San Jose State University, the University of the District of Columbia, the San Diego Community Colleges, and Metro Tech Aviation Career Center, Oklahoma City, Oklahoma.

Professional Memberships: American Institute of Aeronautics and Astronautics (AIAA), University Aviation Association (UAA), Aviation Technician Education Council (ATEC), Professional Aviation Maintenance Association (PAMA), and Aircraft Owners & Pilots Association (AOPA),

Professional Leadership Positions: AIAA, member of Simulation & Modeling Technical Committee (Flight Simulator Standards Development sub-committee). UAA, member of Flight Simulator Standards subcommittee. UAA, member of the Technical Education Committee.

National Service: Served the nation during the Cold War, Vietnam, Desert Storm, and peace time periods. As a team player, and leader, contributed to unit successes, while sharing twelve commendations, meritorious awards, and campaign ribbons.