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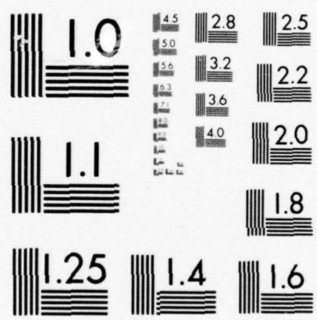

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Report No. FAA-RD-77-17

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THE ROLE OF SIMULATION METHODS IN THE AIRCRAFT CERTIFICATION PROCESS

DON M. ARCHIBALD

MARCH 1977

FINAL REPORT

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Systems Research & Development Service
Washington, D.C. 20590

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16. Abstract

Certification of an aircraft has progressed from demonstrations which were performed entirely upon the first-flight article to those in recent years which apply varying degrees of ground-based test facilities (simulators). The extent of the test facilities has been influenced by the complexity of the aircraft systems, the development philosophy and the funding for this phase of the total program.

This report assesses the extent to which the use of simulation may be increased during aircraft certification in the future by surveying recent industry experience and obtaining recommendations relative to the objectives of Advisory Circular 21-14.

In addition to the industry assessment, a review of FAR-25 requirements from the economic and technical standpoint is made.

Additional simulation in the certification process appears to be both economically attractive and technically feasible, particularly in the area of aircraft systems. The performance demonstrations, currently accomplished by flight testing, is an additional area where simulation may be applied.

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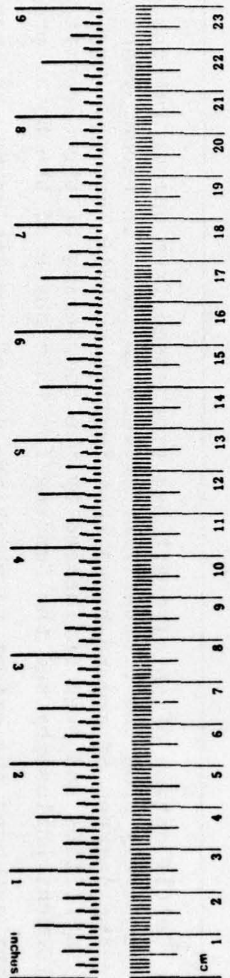
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

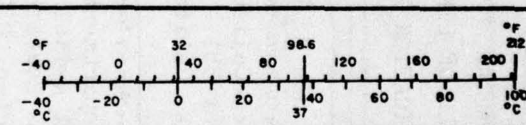
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

The subject study was conducted by the Lockheed-California Company under U.S. Department of Transportation Contract Number DOT-FA76WA-3856. The program was funded by the Federal Aviation Administrations System Research and Development Service, Washington, D.C.

The study was conducted during the period of August 1976 to January 1977.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

SECTION 1

INTRODUCTION

1.1 BACKGROUND

The certification of an aircraft has progressed from demonstrations which were performed entirely upon the first-flight article to those in recent years which apply varying degrees of ground-based test facilities (simulators). The extent of the test facilities has been governed by the complexity of the aircraft systems, the aircraft development philosophy and the funding for the test phase of the total program.

As flight test program costs increase, it is reasonable that all manufacturers consider increased utilization of development test facilities for the performance of demonstrations (certification) required by FAR Part 25, Special Conditions and related Advisory Circular (AC) documents. AC 21-14 (Appendix A-1) addresses the objective of increasing the application of simulation in the certification process. The practical procedures for accomplishing such an endeavor must be understood and accepted prior to attaining this objective. Present day aircraft have utilized simulation in varying degrees as a means of certification. Each manufacturer has established the degree of simulation to be used and has individually negotiated the technical criteria required by the FAA for acceptance of the simulator. The intent of AC 21-14 is to establish general guide lines for the use of simulation as an option in the certification of new or derivative aircraft. As a first step toward this goal, an industry study of past and present use of simulation in the certification process was conducted.

1.2 OBJECTIVES

- Conduct complete review of FAR Part 25 and associated advisory circular material to determine those requirements which possess a potential for expanded use of simulation in support of or as an alternate to flight tests for compliance demonstration. In this assessment several subgroups of requirements are to be identified:

- o Those in which simulation has already been established as an accepted alternative to flight test.
- o Those in which simulation could reduce the element of risk, associated with compliance demonstration.
- o Those which are judged to have potential for application of simulation based on certification economics.

- Assess those areas where increased simulation could have enhanced previous certification programs and where simulation may be applied to new technology systems.
- Conduct a survey of airframe manufacturers to obtain their simulation experience during aircraft certification and their recommendations for increased use of simulators in the future.

1.3 PROCEDURE

An industry survey was conducted to collect existing experience on the use of simulation relative to the problems of compliance demonstration. Based on the review of this information, FAR 25 was examined in depth and those paragraphs that had been previously demonstrated by simulation, analysis, inspection, data submittal, etc., were set aside since they would not contribute to consideration of expanded use of simulation.

Relative cost of flight and simulation compliance demonstration tests were established through review of the Lockheed L-1011 wide-bodied transport certification program. Using this cost information, FAR 25 was reviewed to isolate those paragraphs where it might prove economically attractive to use simulation for certification testing.

In addition to the economic review, consideration was given hazardous or high risk tests. If a test was determined to be in this class, it was immediately considered to have potential for simulation testing regardless of economics.

From these various analyses, recommendations were developed regarding the potential scope for the application of simulation and recommendation for follow-on steps required to implement expanded usage of simulation as an option in demonstration of compliance.

1.3.1 Industry Survey Letter

A short questionnaire was composed of questions of general nature regarding past, present and future use of simulation in the certification process. Because of the wide geographical distribution of this questionnaire, an early release was mandatory. It was anticipated that responses to this initial questionnaire would lead to a subsequent inquiry of greater depth. However, the minimal response to the questionnaire, at a much later date in the program than scheduled, precluded a second inquiry. The initial questionnaire (Appendix A-2) was sent to the following organizations:

McDonnell Douglas Corporation
Boeing Commercial Airplane Company
Rockwell International
Aerospatiale Aircraft Corporation
British Aircraft Corporation
Fokker VFW International
Lockheed-Georgia Company
De Havilland of Canada Ltd.

1.3.2 Internal Lockheed-California Questionnaire

A questionnaire was distributed to the following functional organizations within Commercial Aircraft Engineering:

Flight Test
Electrical and Avionics
Functional Systems and Passenger Accommodations
Aerodynamics
Structures and Airframe
Propulsion

The questionnaire requested that each organization review the paragraphs of FAR 25 associated with their area of responsibility, and indicate whether the requirements of the paragraph were satisfied by:

- Demonstration by flight test
- Demonstration by simulation
- Satisfied by analysis, wind tunnel data, supplier qualification, etc.
- Demonstration by a combination of flight test and simulation.

In addition, it was also requested that comments regarding simulation in lieu of flight tests, additional simulation or reduced simulation in demonstration testing be made where applicable.

1.3.3 Review of L-1011 Certification Reports

Many reports (Reference 1 through 10) and letters document L-1011 certification testing. To review systematically all these documents in detail would have required an effort far beyond the scope of this study; therefore, the results of the internal questionnaire were used as a guide for selecting the most applicable portions of the L-1011 certification documentation for detailed review. Where analysis was used to demonstrate conformity, documentation was reviewed to determine if any significant flight testing was required to support the analysis. Similarly supplier qualification testing was reviewed. Considerable time was spent reviewing the flight test certification report to identify tasks to which simulation could be applied that would eliminate or at least minimize the flight test time. Reports regarding present simulation tests for certification demonstration were reviewed for potential areas of expansion (or deletion) so as to minimize the certification costs.

1.3.4 Certification Economics

Following the review of the technical data, internal Lockheed records were reviewed to establish comparative cost figures to be used in this study. To compare meaningfully the relative costs of the certification demonstration tests it was assumed that:

- The cost of the flight test aircraft would not be considered.
- The cost of any simulator or capital equipment used would be considered as part of the aircraft development costs. (i.e., simulators developed specifically for certification are not considered.)

Items included as flight tests costs were fuel, landing fees, insurance, crew, data analysis and reduction and reports. Items considered in simulation costs were personnel to perform tests, data analysis and reduction and reports.

1.4 STUDY PLAN

Upon receiving responses from the survey questionnaire and completion of the document review, FAR 25 was reduced to a manageable set of paragraphs by identifying and eliminating those not applicable to the study.

Identifying the paragraphs for study was accomplished by first classifying them into one of the following categories:

Type I - Now demonstrated by flight test

Type II - Now demonstrated by simulation

Type III - Now demonstrated by analysis, wind tunnel data, supplier qualification, etc.

Type IV - Now demonstrated by a combination of flight test and simulation

The judgment for categorization was based on the results of the internal and industry survey.

The type II and Type III paragraphs were deleted from further consideration in this study. Those requirements in Type II already use simulation as a means of certification. Type III requirements do not require either flight test or simulation for certification; however, simulation may have specific and significant future potential for this type.

Each paragraph of Type I or Type IV was examined to determine the elements of risk or hazard involved in compliance demonstration. If the paragraph was determined to be a high risk requirement, the cost of flight test was considered irrelevant and the paragraph was retained for examination for potential demonstration by simulation.

The paragraphs not falling into the high risk type were examined for cost of flight test. Those where simulation did not appear economically attractive were discarded. To assess the economics of simulation the following procedure was used. Based on the L-1011 flight test program the cost of a flight test hour in 1976 was estimated to be $10,000 per hour.

Items included in the figure were:

- Fuel
- Landing fees
- Crew (ground and flight)
- Instrumentation
- Insurance
- Data Reduction
- Reports

As a breakpoint number for this study, it was assumed that any test resulting in less than a $50,000 flight test cost (5 hours of test time) would be dropped from further consideration as a candidate for simulation on an economic basis.

The next question pertained to the fidelity of the data base required for use in simulation. If the aircraft being considered were a derivative, the cost of flight tests to verify a simulation may be economically attractive. If this were the case, these tests were evaluated for the cost of simulation.

When the cost of flight test verification approached the cost of certification by flight test, the particular paragraph was deleted from the study.

When a requirement passed the above criteria for certification by simulation, the cost of simulation was determined. For the purpose of this study an estimate of time to perform the test was made based on previous experience during the L-1011 certification program. The cost of a simulation test hour was established to be $1,000. This included the cost of:

- Test personnel
- Data acquisition/or analysis
- Reports

Each remaining paragraph at this point of the study was evaluated for total cost of simulation and compared to the total cost of flight tests. Based on Lockheed L-1011 certification experience the relationship between simulation and flight tests costs may be represented as follows:

$$C_S = 1000\ T_S \tag{1}$$

and

$$C_F = 10000\ T_F \tag{2}$$

where

C_S = Cost of Simulation (Dollars)

T_S = Time in Simulation

C_F = Cost of Flight Test (Dollars)

T_F = Time in Flight Test

The time in flight test (T_F) is generally available from past experience and is typically well defined through control of the tests to be conducted by the flight test plan and flight "card". Little deviation is made during flight from the flight card.

The time in simulation (T_S) should normally be approximately the same as time in-flight test by establishing comparable tests plans. Lockheed L-1011 certification experience has shown however, the time in simulation is longer because of test repetition and/or deviation from the test plan as requested by

FAA and/or company pilots. Typically a single FAA pilot is aboard the flight test demonstration while a great many more may be present for a simulator test. The speed at which changes in configuration may be made on a simulator obviously influences the requests for repeated or special tests by witnesses. Based on this experience the time in simulation is estimated to be four times that of flight test. Therefore:

$$T_S = 4\ T_F \tag{3}$$

Substituting equation 3 in equation 1

$$C_S = 4000\ T_F \tag{4}$$

Dividing equation 2 by equation 4

$$C_F = 2.5\ C_S \tag{5}$$

Based on equation 5, simulation is economically attractive for certification testing if the cost of simulation verification is not prohibitive and it is technically feasible to simulate the test.

Technical feasibility, again is subjective and will change as a function of "the state of the art". In this study comments regarding technical feasibility are based on L-1011 certification experience and comments made by flight test and project engineering during the internal survey.

In summary then, any paragraph that; was deemed high risk, cost to flight test exceeded $50,000, and where simulation was considered to be technically feasible, was recommended for additional consideration for certification by simulation.

Contained in Appendix A-2 is a flow chart form of the thought process used in selecting FAR 25 paragraphs for certification by simulation. This flow chart may be adjusted depending on the paragraph in question. Detailed analysis at each decision block will increase the probability of successful certification by simulation of the paragraph in question.

SECTION 2

REVIEW OF L-1011 CERTIFICATION

2.1 INTERNAL QUESTIONNAIRE

During the development phase of the L-1011, extensive use was made of system or subsystem simulators. Subsequently, many of these simulators were used to demonstrate compliance to FAR 25 requirements. To understand more fully the rationale regarding the use of the simulator for certification and to gather any comments or suggestions regarding future use of simulation, a questionnaire was formulated and distributed to engineering and flight test groups within the Lockheed-California Company. Though this questionnaire was restricted to the L-1011 certification and to FAR 25, comments and or suggestions pertaining to simulation in general were solicitated.

The questionnaire was distributed to the functional organizations listed in 1.3.2. To assure consideration of all the FAR 25 paragraphs each group received a copy of the Table of Contents of the FAR to be used as a check list (Appendix A-3). It was requested that the review consider paragraphs pertaining to the organizational technical expertise and responsibility, with an indication of the method used to certify the L-1011. Four methods were identified and the responsible organization indicated its selection by marking the margin of the FAR 25, Table of Contents.

The four methods were:

Type I - Demonstration by flight test.

Type II - Demonstration by simulator.

Type III - Satisfied by analysis, wind tunnel data, structural tests supplier qualification, visual inspection, etc.

Type IV - Demonstration by a combination of flight test and simulation.

Additional comments or suggestions for either simulation or expanded simulation were received by inter-office memo or telephone. In addition to the questionnaire, each organization and/or simulator facility was visited and many engineering or flight test personnel were interviewed.

Once all the groups responded, the data were reviewed and summarized so that any trends or duplication in effort would be recognizable.

2.2 RESULTS OF QUESTIONNAIRE

Comments and suggestions, either oral or written received from the various supporting organizations were generally helpful and encouraging; however, it was unanimously agreed that the movement of the FAA towards establishing guide lines for the use of simulation in certification must be approached cautiously. The cost of certification is the obvious concern of all involved and thus care must be taken to assure that the cost of verification of the simulation accuracy/completeness does not exceed the cost of conventional flight test methods.

Another comment often received pertained to the aircraft data base available at the time simulation is proposed for certification. In the case of new model aircraft, actual flight data may be insufficient to establish a data base to accurately define and support the parameters to be simulated. However, during developmental flying of a new aircraft, the characteristics will be increasingly better defined from instrumented data, permitting the original data base accuracy to be improved and used in the certification process. A derivative aircraft will have the benefit of even more flight data to provide a data base for excellent simulator fidelity.

2.2.1 Subpart B, Performance (25.101 through 25.253)

These requirements are for the major part certified by flight test and it is generally felt the major part of this section will continue to be certified by flight testing. However, assuming the aircraft data base is well established during the developmental flying, the flight test time may be reduced by supplementary simulation. This becomes very attractive where engine-inoperative tests are required. Simulation of critical engine failure tests would eliminate potential engine damage (compressor stalls) when fuel cuts or fast throttle reductions are made to simulate the engine failure. The static and dynamic stability demonstrations required under this subpart are other areas for simulation. The many aircraft configurations (flaps, gear, etc.,) required may be achieved in a minimum amount of time through simulation.

The stall characteristics and demonstrations are candidates for elimination from the flight test activity; however, it is generally agreed that, at this time, the state of the art is not at a point where all the detailed aerodynamic characteristics of the aircraft in stall may be defined and modeled with sufficient precision to use the simulator for actual compliance demonstrations.

2.2.2 Subpart C, Structure (25.301 through 25.581)

This subpart is, for the most part, satisfied by analysis using developmental flight test and simulation data as the basis for the analysis.

2.2.3 Subpart D, Design and Construction (25.601 through 25.875)

This subpart has been certified by supplier data submitted, analysis, simulation, and flight test. Control system failure mode demonstration has long been a candidate for simulation and it is expected to continue as systems become more sophisticated. Simulation has not only reduced flight test time for evaluation of failure modes (opens, jams, etc.) it has eliminated many of the potential hazards associated with this type of testing.

Other requirements of this subpart are certified by inspection of the system or subsystem on the aircraft. In many cases the simulator used to develop the particular system or subsystem could be used to show compliance thus eliminating some on-board inspection time.

2.2.4 Subpart E, Power Plant (25.901 through 25.1205)

Extensive use of simulators has been made to show compliance to these paragraphs. The fuel system simulator was fabricated for development and certification testing in the basic plan. The FAR 25 fuel system tests are not necessarily associated with actual flight evaluation, but the requirements do require considerable ground test time and loss of aircraft availability for other assignments.

2.2.5 Subpart F, Equipment (25.1301 through 25.1459)

Many of the requirements of this subpart may be satisfied by simulation. In reviewing the L-1011 certification documentation, though many system simulators were fabricated for development, only a few paragraphs (or associated advisory circulars) were certified by simulation. The requirements demonstrated by simulation were the failure modes of the autoland system, most of the electrical system and the hydraulic system. Some of the area navigation system requirements were also demonstrated by bench simulation methods.

The use of simulators for compliance demonstration of electronic computing systems is expected to increase considerably in derivatives and in new aircraft. The obvious safety aspects of simulation along with the reduced time to repeat tests dictate a maximum use of simulation in this area.

Typically, subsystems (autopilot, air data, EPR, weight and balance, oxygen, fire protection, etc.,) are installed on the flight test aircraft only after extensive laboratory testing. With some additional effort to make the bench testing a true simulation, all of these systems could be certified with minimum flight testing.

SECTION 3

REVIEW OF INDUSTRY QUESTIONNAIRE

3.1 DISCUSSION OF QUESTIONNAIRE

At the outset of this study program, a detailed, in depth industry questionnaire was considered as it would give the maximum information required in the study. Recognizing a questionnaire of this type would possibly require more effort than some manufacturers could allow during this particular time period, an abbreviated "quick look" survey was drafted. This survey was intended to be complete enough to allow the investigation to establish trends set by the industry without requiring significant detail. The intention was to follow-up the initial questionnaire with a more detailed request for information in areas of interest as established from the first survey. In reality, the reaction to the questionnaire was minimal and the responses were not timely to permit a second inquiry during the study. A copy of the questionnaire and cover letter, as released by the FAA is included as Appendix A-4. The responses by Boeing, McDonnell Douglas, and Lockheed-Georgia (the only ones received) are also contained as Appendices A-5, A-6 and A-7.

3.2 RESULTS OF QUESTIONNAIRE

Similar to the responses to the internal Lockheed-California Company questionnaire, the responding manufacturers emphasized that the extent of simulation used in development and certification must be determined and proposed on an individual basis by the manufacturer. It was also cautioned that the cost of flight time to validate a simulator could exceed the potential savings realized in its use for certification.

Responses to the questions regarding the individual FAR 25 subparts indicated that the responding manufacturers are using simulators for certification to varying degrees and their anticipated expanded usage plans indicate they recognize the potential cost savings.

Two manufacturers indicated their intentions to use simulators in certification of advanced technology systems including automatic control systems, active controls, navigation systems, and displays.

No manufacturer is presently using simulation to demonstrate performance characteristics, however, all are using simulators in some manner to support flight test.

In the area of controllability and maneuverability, all are using simulators in varying degrees to reduce the flight test time. Flight test and simulator data both contribute to the structural load analysis. One manufacturer indicated advanced simulator work in the area of turbulance, wind shear and vortex encounter.

Demonstration of control system failures by simulation has been performed and continued activity in this area is anticipated. Also, manufacturers are using simulators to demonstrate compliance with numerous paragraphs covering engine installation, fuel, oil, cooling and induction systems. Power plant controls and fire protection are being simulated to some degree. The use of simulators for compliance demonstration of the requirements of Subpart F, Equipment, is well established, particularly in the area of failure modes and statistical reliability.

SECTION 4

REVIEW OF FAR PART 25

4.1 RATIONALE FOR PARAGRAPH DELETION

In order to reduce the FAR to a reasonable set of paragraphs to which the cost/time criteria were to be applied, many paragraphs were eliminated for the following reasons:

1. Study limited to turbojet aircraft.
2. Study limited to land based aircraft.
3. Components and materials (Subpart D) were excluded by the work statement.
4. Operating limitations and information (Subpart G) were not pertinent to study.
5. The paragraph was general in nature.
6. Paragraph was certified by data submittal, analysis or vendor qualification.
7. Paragraph was being presently certified by simulation or by minimal ground testing.

The following is a paragraph by paragraph justification for deletion. In some cases, additional comments are made concerning the paragraph. The following paragraphs were eliminated from further consideration in this study for reasons 1, 2, 3, and 4 above.

25.33 through 25.75, 25.875 (Reason 1)

25.521 through 25.537, 25.239 (Reason 2)

25.601 through 25.625 (Reason 3)

25.737 through 25.755 (Reason 2)

25.905 through 25.929 (Reason 1)

25.937, 25.1027, and 25.1101 (Reason 1)

25.1501 through 25.1587 (Reason 4)

25.1125, 25.1127, 25.1145 through 25.1159, 25.1192. (Reason 3)

NOTE: Specific paragraph title reference may be found in Appendix A-4.

The following paragraphs were eliminated from further consideration in this study for reasons of certification by data submittal, analysis or supplier qualification (Reason 6).

25.301 through 25.511	25.1143
25.561 through 25.581	25.1182
25.651 through 25.735	25.1161
25.771 through 25.871	25.1165
25.953	25.1017
25.954	25.1141
25.957	25.1163
25.994	25.1181
25.955	25.1185
25.1305	25.1201
25.1307	25.1383 through 25.1415
25.1021	25.1433 through 25.1455
25.1025	25.1333
25.1123	25.1337

It should be noted here that some simulation as well as flight testing was conducted, in conjunction with data submittal, to show conformance with the above paragraphs. It is felt that this effort was insignificant for the purpose of this study.

The following paragraphs were eliminated from further consideration in this study for reasons of certification by simulation, i.e., simulation has been demonstrated as a means of certification. (Reason 7)

25.629	25.1019
25.631	25.1023
25.951	25.1105
25.955	25.1107
25.959	25.1183
25.961 through 25.993	25.1191
25.997	25.1193
25.999	25.1199
25.1013	25.1351 through 25.1363
25.1015	25.1381

These following six paragraphs establish general guidelines for compliance to Subpart B and define weight and cg criteria to be followed in the certification process. This study was not applicable to these paragraphs, therefore, no further consideration was given to them.

25.21	Proof of Compliance
25.23	Load Distribution Limits
25.25	Weight Limits
25.27	Center of Gravity Limits
25.29	Empty weight and corresponding center of gravity
25.31	Removable Ballast

The following four paragraphs established general guidelines and procedures to be used to show compliance. No further consideration was given to these paragraphs.

25.101 General

25.1011 General

25.143 General

25.171 General

The requirements of the following paragraph were generally met by analysis of data obtained in flight tests. Here again, techniques for defining and modeling the aerodynamics characteristics are not established with sufficient precision to simulate the vibration and buffet modes of a new or derivative aircraft. No further consideration to this paragraph was given in the study.

25.251 Vibration and Buffeting

The following two paragraphs sets forth general requirements for power plant installation which were generally met by data submittal and aircraft inspection.

No further consideration was given to these paragraphs.

25.901 Installation

25.903 Engines

The requirements of the following two paragraphs were satisfied by tests performed on the aircraft. These tests require a minimum amount of that time and are not considered hazardous, therefore, no further consideration was given to this paragraph.

25.933 Reversing Systems

25.934 Turbojet engine thrust reverser system tests

The following paragraph requires investigation in-flight and under negative g conditions. Simulation of these conditions would be prohibitive from the technical and economic standpoint, therefore no further consideration was given to this paragraph.

25.939 Turbine Engine Operating Characteristics

4.2 RESULTING LIST OF PARAGRAPHS FOR ANALYSIS

The following list of paragraphs survived the first tests for potential simulation. They were next tested for level of risk or hazard. Generally, the risk or hazard was associated with economics, i.e., engine damage, etc.

25.103 through 25.125	25.1195
25.145 through 25.161	25.1197
25.173 through 25.237	25.1203
25.253	25.1303
25.1001	25.1309 through 25.1331
25.1011	25.1431
25.1041 through 25.1093	25.1457
25.1121	25.1459
25.1187	25.1419
25.1189	

4.3 DETERMINATION OF HIGH RISK TESTS

In reviewing the above list, the following paragraphs were determined to be high risk and were the first paragraphs to be tested using the technical and economics criteria.

25.103 Stalling Speeds

The entry into and more importantly the recovery from the stall has some element of risk associated with it.

25.105 Take Off

25.107 Take Off Speeds

25.109 Accelerate-Stop Distance

25.111 Take Off Path

25.113 Take Off Distance and Take Off Run

25.115 Take Off Flight Path

The risk involved in the above six requirements is associated with potential engine damage. When "critical engine" failure tests are performed by throttle chop or fuel cuts potential compressor stalls can result in engine damage.

25.149 Minimum Control Speed

The risk here is in being near stall at very low altitudes with the potential loss of a second engine and/or entering a stall with insufficient altitude for recovery.

25.201 Stall Demonstration

25.203 Stall Characteristic

25.205 Stalls, Critical Engine Inoperative

25.207 Stall Warning

Again the element of risk is the recovery from the stall. Thus, the above twelve paragraphs were tested first for technical feasibility. The remaining paragraphs listed in 4.2 were then analyzed for technical feasibility and cost of certification.

SECTION 5

PARAGRAPH ANALYSIS

5.1 NEW AIRCRAFT VS. DERIVATIVE

The first question to be answered in this study was whether the aircraft under consideration was a completely new or a derivative of a previously certified aircraft. The definition of a new aircraft is generally understood, however, a comment on what is intended by a derivative is in order. A derivative for the purpose of this study may be as simple as the change from an analog autopilot to a digital autopilot or it may mean a stretched or shortened version and/or addition or deletion of engine(s). The amount of recertification required in the derivative will be greatly affected by the extent of changes. Here the fidelity of any considered simulation will be dependent on the data base for the derivative aircraft. If the structural changes of the derivative are relatively minor, then recertification of aircraft system changes may well be simulated in their entirety. Conversely, major structural changes will undoubtedly require flight testing to establish a valid data base and/or establish credibility of any proposed simulation.

For the purpose of this study it was assumed the aircraft was not a derivative and each paragraph was examined in that light. If, however, the aircraft had been a derivative, additional simulator utilization in certification may be effective.

5.2 ECONOMIC ANALYSIS

The cost criteria as developed in Section 1.4 was applied to these remaining paragraphs. The flight test time to certify the particular paragraph was established from L-1011 records. Where tests were related to the individual paragraph, as is generally true through Paragraph 25.1203, each paragraph was analyzed on an individual basis. From 25.1301 through 25.1459 this methodology did not apply, as these paragraphs relate to many systems. In this case, the paragraph lost its identity and the study was conducted on the systems certified under these paragraphs. This approach generally follows that used in flight test certification.

Table 5-1, listing each paragraph or group of paragraphs, indicates the number of flight test hours required for certification flying. Multiplying the number of hours by $10,000 per hour results in the total flight test cost for certification.

Table 5-2 lists the systems and subsystems certified under the requirements of paragraphs 25.1301 through 25.1459. It should be noted here that, in addition to the requirements of FAR-25, additional regulatory documents must be satisfied. Some of these are:

AC 25.1329-1A	Automatic Pilot System Approval
AC 120-29	Criteria for Approving Category I and Category II Landing Minima for FAR 121 Operators
AC 120-28A	Criteria for Approval of Category IIIa Landing Weather Minima
AC 20-57A	Automatic Landing Systems
AC 90-45A	Approval of Area Navigation Systems for Use in the U.S. National Airspace System
AC 25-4	Inertial Navigation Systems

Special Conditions (as applicable)

Though, as stated earlier, the high risk tests would not be analyzed from the cost of flight test standpoint, they are included in Table 5-1 for information. All of these tests were tested for technical feasibility.

TABLE 5-1. PARAGRAPH FLIGHT TEST COST

PARAGRAPH NO.	HOURS IN FLIGHT TEST	COST OF TEST ($)
25.103	20	200,000
25.105		
25.107		
25.109	50	500,000
25.111		
25.113		
25.115		
25.117		
25.119	35	350,000
25.121		
25.123		
25.125	10	100,000
25.145	3	30,000
25.147	1	10,000
25.149	6	60,000
25.161	2	20,000
25.173		
25.175	16	160,000
25.177		
25.181		
25.201		
25.203	10	100,000
25.205		
25.207		
25.231		
25.233	2	20,000
25.235		
25.237		
25.253		
25.1001	2	20,000
25.1041		
25.1043		
25.1045	3	30,000
25.1091		
25.1093		
25.1121		
25.1187	4	40,000
25.1189		
25.1195		
25.1197		
25.1203		

TABLE 5-2. SYSTEM FLIGHT TEST COST

SYSTEM AND SUBSYSTEM	HOURS IN FLIGHT TEST	COST OF TEST ($)
Aircraft Systems		
Hydraulic	3	30,000
Landing Gear	2	20,000
Aircraft Lighting	2	20,000
Airconditionnig	2	20,000
Pressurization	4	40,000
Anti-Ice	32	320,000
Misc	4	40,000
Electrical and Electronic Systems		
Navigation	14	140,000
Navigation Support	16	160,000
Communications	3	30,000
Electrical	4	40,000
Warning	6	60,000
Other	4	40,000
Avionics Flight Control Systems		
Autopilot Performance and Malfunctions	24	240,000
Yaw SAS Faults	2	20,000
Autothrottle	6	60,000
Autoland and Go Around	27	270,000
Flight Director	5	50,000
Misc	2	20,000

Applying the $50,000 breakpoint criteria to the tests listed in Table 5-1, the following paragraphs remain:

25.103 through 25.125

25.149

25.173 through 25.181

25.201 through 25.207

25.253

Again applying the same criteria to the systems listed in Table 5-2 the following systems remain:

Anti-ice

Navigation

Navigation support

Warning

Autopilot performance and malfunction

Autothrottle

Autoland and go-around

Flight director

The above paragraphs were now tested for technical feasibility.

5.3 TECHNICAL FEASIBILITY

The criteria used to determine technical feasibility was for the most part, a judgment made using the L-1011 certification program and available data base as a reference. The comments made by the various organizations have also influenced this judgment.

Those paragraphs associated with stall characteristics and speed, Paragraphs 25.103, and 25.201 through 25.207 were considered not technically feasible at this time. The discontinuities in the aerodynamic flow make an accurate simulation difficult if not impossible. With continued effort in this area, these tests may later be candidates for simulation. Those paragraphs associated with takeoff, 25.105 through 25.115, show potential for simulator usage in certification, not only in the area of critical engine failures but for normal operation as well. A certain amount of effort is being made at this time to show that simulated characteristics do indeed agree well with flight test data. If a data base of sufficient accuracy can be established during developmental flight testing, simulation for certification has potential. Paragraph 25.149, Minimum Control Speed, the last of the potentially hazardous tests, was also felt to have potential for simulation dependent on the data base available at the time of certification. If the required low altitude tests can be conducted at increased altitude and then adjusted by analysis and/or simulation to the specified conditions, the risk factor will be significantly reduced.

The remaining paragraphs in Subpart B, 25.117 through 25.181 and 25.231 through 25.253, were all considered to be candidates for simulation in varying degrees. This again is dependent on the data base available at the time of certification.

Paragraphs 25.1301 through 25.1331, 25.1381, 25.1419, 25.1457, and 25.1459 address a great number of systems or subsystems.

Simulation then, is dependent on the particular system in test. As most systems are in some manner bench tested or simulated prior to installation on the flight test aircraft, it was considered that all of the paragraphs or systems falling under the requirements of these paragraphs, may be certified by simulation to some degree.

5.3.1 Summary of Paragraphs for Simulation

The high risk requirements and economically attractive paragraphs considered to be technically feasible for certification by simulation were:

25.105 Take-off

25.107 Take-off Speeds

25.109 Accelerate Stop Distance

25.111 Take-off Path

25.113 Take-off Distance and Take-off Run

25.115 Take-off Flight Path

25.117 Climb: Gereral

25.119 Landing Climb: All Engines Operating

25.121 Climb: One Engine Inoperative

25.123 Enroute Flight Paths

25.125 Landing

25.149 Minimum Control Speed

25.173 Static Longitudinal Stability

25.175 Demonstration of Static Longitudinal Stability

25.177 Static Directional and Lateral Stability

25.181 Dynamic Longitudinal, Directional and Lateral Stability

25.253 High Speed Characteristic

25.1301 Function and Installation

25.1303 Flight and Navigation Instruments

25.1309 Equipment Systems and Installation

25.1321 Arrangement and Visibility

25.1323 Airspeed Indicating System

25.1325 Static Pressure System

25.1327 Magnetic Direction Indicator

25.1329 Automatic Pilot System

25.1331 Instruments Using a Power Supply

25.1419 Ice Protection

25.1431 Electronic Equipment

25.1457 Cockpit Voice Recorders

25.1459 Flight Recorders

SECTION 6

CONCLUSIONS

This study has indicated that FAR-25 paragraphs that have potential for the use or expanded use of simulation include:

- Those associated with the performance 25.105 through 25.125, 25.149, 25.173 through 25.181 and 25.253
- Those associated with the equipment 25.1301, 25.1303, 25.1309, 25.1321 through 25.1331, 25.1419, 25.1431, 25.1457, and 25.1459.

Those in the first group have not in the past been demonstrated by simulation yet contribute significantly to the cost of certification. Approximately 140 flight hours ($1.4 million) were required to demonstrate compliance in the L-1011 certification program. The use of simulation based on the developmental flying data base has the potential for reducing significantly the cost of certification for this group of requirements. Even further savings may be realized on a derivative aircraft whose data base is well established.

In the second group, simulation has been used in many areas to demonstrate compliance; yet, some 100 flight hours ($1 million) were still required for compliance demonstrations in the L-1011 certification program. An increase in the use of simulation for this group of requirements may reduce certification costs significantly.

These two groups of test requirements are unique from the standpoint of the method required to validate a simulator. The first group of tests are those closely associated with the aerodynamic characteristics of the aircraft. The method to verify the simulation will come from flight test data; thus the cost to verify the simulation must be closely estimated to justify the existence of the simulator.

The second group of test requirements are not as closely related to the aerodynamic characteristics of the aircraft. These tests generally address the intent of function and a simulation may well be validated by a conformity inspection.

It is obvious from the preceding sections of this report that the study was primarily based on the certification of the Lockheed L-1011 aircraft with some input from the industry questionnaire. Within the Lockheed-California Company, Flight Test has indicated that simulation can be utilized in lieu of certain tests presently accomplished by flight. Aerodynamics has indicated that, with a sound data base, the ability to describe accurately (with the exception of stalls) an aircraft analytically is possible. And finally, simulation techniques have reached a point where high fidelity simulators can be fabricated and verified for use in certification.

This brings to light the question of the guide lines for use of simulation in certification. All encountered in these studies agree that the decision on the use of simulators must be left to the individual manufacturer. What is cost effective for one may not necessarily be cost effective for another. Simulation has, in the past, been shown to be an acceptable cost effective means of certification. This study has concluded that additional simulation can potentially reduce hazards and costs involved in a certification program. What, then, are the guide lines to industry to be?

During this study it has been found that the use of a simulator for certification has been negotiated on an individual basis with the appropriate certifying FAA region. The question of what constitutes an acceptable simulator has not been addressed in present regulatory documents. The guide lines to industry may best be in the area of simulation conformity and/or validity rather than a guide to what may or may not be simulated. Here again, however, any guide lines established must be flexible enough to allow industry to select the means most effective for the individual task, yet still provide guidance as to what must be shown to establish the validity of the simulator for the purpose intended.

SECTION 7

RECOMMENDATIONS

7.1 SUMMARY

As a continuation of this study, it is recommended that a program be implemented to establish requirements, test plans, and schedule/cost trade-offs for simulator certification demonstrations. Three representative paragraphs of FAR 25 deemed to be the most promising simulation candidates are recommended for this continued study.

These candidates should jointly be selected by industry and the FAA. As a suggestion, one paragraph from each group listed in the Section 6, plus one paragraph in an area that has previously used simulation as a means of certification, could be selected.

7.1.1 Suggested Future Simulation Candidate Studies

Compliance testing in the area of performance has not previously utilized simulation. If techniques and requirements are successfully developed to show compliance by simulation of a typical performance paragraph, (e.g., 25.149 Minimum Control Speed, consideration can be given to additional performance testing by simulation.

Study of a paragraph (and/or Advisory Circular) in the area of equipment autopilot certification for instance, would again result in definition of requirements for system (or subsystem) certification by simulation.

The selection of the third paragraph could be made so as to review the economic benefits of previous use of simulation for Certification and then expansion of this simulator into increased usage in the area of new technology. An ideal possibility would be in the area of control systems. Requirements of Paragraph 25.671 and 25.672 for L-1011 certification were, for the most part, satisfied by simulation on the L-1011 Vehicle Systems Simulator. Failure modes, control jams, etc., were fully evaluated on the simulator, thus reducing flight tests and, more importantly, the hazards of such tests conducted in flight.

Paragraphs 25.671 and 25.672 were, in this case, not selected at random but rather from knowledge of the design effort now in process for the application of a Maneuver Load Control System to L-1011 derivatives. The actual performance demonstration testing would not be a part of this follow-on study but the development of the simulator requirements and test plans would be a significant step in establishing guide lines for the use and requirements for certification by simulation.

7.1.2 Simulation Candidate Study Objectives

Specifically, the follow-on program would define:

- Simulation test and configuration requirements
- Aircraft equipment and simulator facility.
- Flight test data/mathematical model correlation requirements.
- FAA data submittal requirements.
- Establish test plans, schedule and cost trade-offs for simulator demonstration.

7.1.3 Supporting Suggestion

In addition, as the certification documentation on present aircraft is generally Company proprietary and unavailable to other contractors for study, it is also recommended that a program be instituted, internal to the FAA, to review this documentation in a manner similar to this study. It is felt, through a study of this nature, FAA could establish the various means used by industry to validate the simulator as a true representation of the aircraft for the tests intended. Simulator accuracy requirements might also be established in a review of this nature.

SECTION 8

REFERENCES

1. LR 25089 Vol. 1 through Vol. 10 FAA Type Certification Report.
2. LR 24731, Test Results of the PFCS-FAA Demonstrations on the Vehicle Systems Simulators.
3. LR 24745, Test Results for Vehicle Systems Simulator FAA Demonstration Tests of Hydraulics, Landing Gear and Secondary Controls
4. LR 24317, Thrust Modulation Systems Installation.
5. LR 24318, Engine Installation Support Systems.
6. LR 24319, Engine Installation Protection Systems.
7. LR 24320, Accessory Power Extraction Systems.
8. LR 24331, Engine Systems.
9. LR 25174, Fuel System Simulator Tests Demonstrating Compliance with Federal Aviation Requirements.
10. LR 25044, Test Results of FAA Autoland Failure Demonstration on the Vehicle Systems Simulator.
11. Anon: Federal Aviation Regulations, Part 25 - Airworthiness Standards: Transport Category Airplanes. Federal Aviation Administration, February 1, 1965.

APPENDIX A-1

AC 21-14 - THE ROLE OF SIMULATION IN THE AIRCRAFT CERTIFICATION PROCESS

AC NO: 21-14

DATE: June 12, 1975

ADVISORY CIRCULAR

DEPARTMENT OF TRANSPORTATION

FEDERAL AVIATION ADMINISTRATION

SUBJECT: THE ROLE OF SIMULATION IN THE AIRCRAFT CERTIFICATION PROCESS

1. PURPOSE.

a. This Advisory Circular is issued to inform the industry that the Federal Aviation Administration intends to conduct an exploratory program to determine the degree to which simulation can support the aircraft certification process. It is FAA's opinion that greater use of simulation could be cost effective and could improve the quality of certification for both industry and government. This is true, particularly where introduction of new technology is involved, and therefore should be exploited to the fullest extent practicable.

b. Examination of compliance demonstrations through simulation will include, but is not limited to, structures, systems, performance, handling qualities, and operations. Particular attention will be directed at defining the technical criteria which simulators must meet to enable demonstration of compliance for any given design feature.

2. DISCUSSION.

a. The use of simulation to demonstrate compliance has been used in cases where flight tests are considered to be hazardous or impossible; examples of this can be found in aircraft structures and systems compliance demonstrations. From these experiences it is concluded that demonstrations of compliance through simulation could be a useful alternative to some or perhaps most of the flight demonstrations in other cases. Further, early simulation studies could reduce the possibility of requiring design changes late in a development program. It is FAA's opinion that this alternative, if proven successful, should be available to industry.

FAA Form 1320-7 (2-71) SUPERSEDES PREVIOUS EDITION — Initiated by: AFS-107

b. Only limited guidelines exist for using simulation in the certification process. If the full range of possible alternatives is to be made available, expanded guidelines and formal recognition of simulation must be established. No explicit effort has been made to establish the most effective uses of simulation to assist the design development and certification processes. Limited experience indicates that the potential uses could be much more extensive than in current practice. It is possible that firm agreement on special conditions could be established before development was undertaken; that systems and structural compliance could be demonstrated during development prior to flight to a greater extent than at present; that preflight training and planning could reduce significantly the flight time required to complete certification. The combined effect of these actions could provide significant savings to industry and to government and therefore supports the need for a careful determination of how simulation could be used effectively in certification.

c. It is recognized that the requirements for achieving valid simulations for any specific purpose and for verifying the validity of the simulations are not established at this time. A primary objective of the exploratory program is to provide the information necessary to define procedures to meet both of these requirements.

3. PLANNED ACTION. To identify the roles that may be found possible and desirable for simulation in the certification process, two concurrent activities will be initiated:

a. A collection and technical review of those cases where simulation has been used already in the certification process with the view toward standardizing the procedures.

b. Hopefully, an exploratory program with industry to investigate other potential uses of simulation in the certification process and to identify where it would be cost effective to overcome limitations presently preventing such uses.

In both of these activities, close industry participation is solicited; since it is FAA's view that industry as well as government will gain if the objectives are realized.

4. OBJECTIVES. The following objectives are expected to be realized from these activities:

a. Identification of current simulation activities adaptable to use in the certification process.

(1) For these cases specify the technical criteria required for application of the technique for certification purposes.

(2) Develop the procedural modifications necessary to formalize inclusion in the current certification process, considering technical, regulatory, and legal aspects.

b. Identification of those uses for which simulation, with further development, could enhance the certification process.

(1) Conduct an exploratory program to substantiate and document the potential usefulness of these new applications.

(2) Define clearly the nature of any technical development required in simulation techniques to make new applications possible.

J. A. Ferrarese

J. A. FERRARESE
Acting Director
Flight Standards Service

APPENDIX A-2

CONSIDERATION OF CERTIFICATION BY SIMULATION

APPENDIX A-2

CONSIDERATION OF CERTIFICATION BY SIMULATION

To reduce FAR 25 to a manageable set of paragraphs in this study certain assumptions were necessary that, in actual practice, may require adjustments to realize fully the benefits offered by simulation. The accompanying flow chart might be used to determine the economics involved in the anticipated use of simulation for certification.

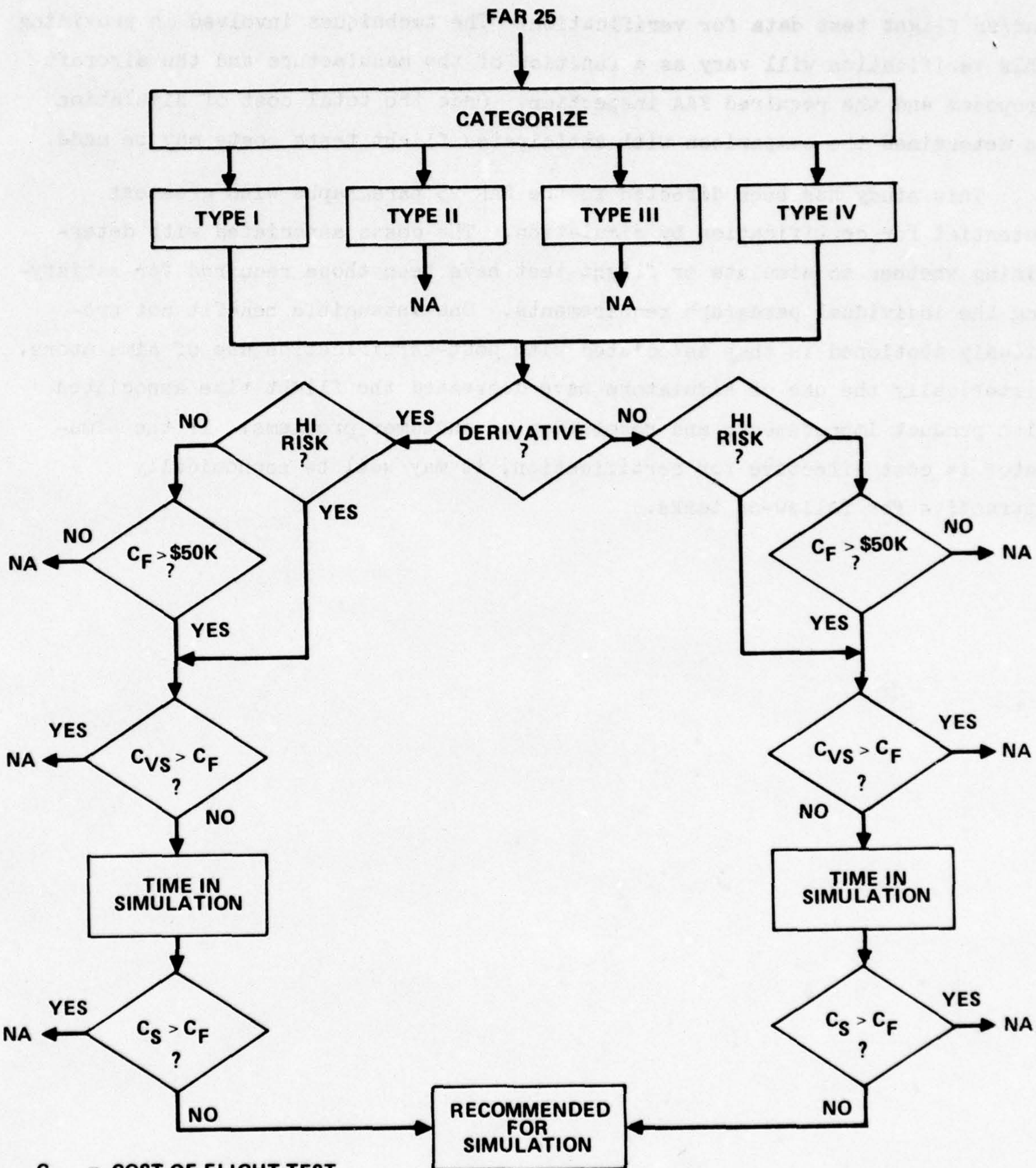
The first decision block addresses the question of the data base available. Typically, the data base for a derivative aircraft will be extensive enough for increased use of simulation with little or no flight time required for simulation verfication. For a new aircraft, the data base will be dependent on the amount and fidelity of the data taken during the developmental flight testing. If maximum utilization of simulation is a goal established at the outset of a new program, the data base may be continuously updated through the developmental flight test period such that at the time of certification, the simulator in question will be well established.

The high risk tests will vary to a certain degree from one design to another; however, they should be examined for potential simulation without regard to cost of flight test.

The $50,000 breakpoint for cost of flight test used in this study may be adjusted to any value applicable to the aircraft in question.

The costs to verify the simulation of a particular requirement may well be the most difficult task in determining whether to flight test or perform simulation. The utilization of a particular simulator for certification must also be capable of passing conformity inspection. In addition, the simulators associated with the aerodynamics of the aircraft typically require wind tunnel and/or flight test data for verification. The techniques involved in providing this verification will vary as a function of the manufacture and the aircraft proposed and the required FAA inspection. Once the total cost of simulation is determined the comparison with anticipated flight tests costs may be made.

This study has been directed to the FAR 25 paragraphs with greatest potential for certification by simulation. The costs associated with determining whether to simulate or flight test have been those required for satisfying the individual paragraph requirements. One intangible benefit not previously mentioned is that associated with post-certification use of simulators. Historically the use of simulators have decreased the flight time associated with product improvements and resolution of customer problems. If the simulator is cost effective for certification, it may well be economically attractive for follow-on tasks.



C_F = COST OF FLIGHT TEST
C_{VS} = COST TO VERIFY SIMULATOR
C_S = COST OF SIMULATION
NA = NOT APPLICABLE

Consideration of Certification by Simulation

APPENDIX A-3

FAR PART 25 INDEX

Part 25—Airworthiness Standards: Transport Category Airplanes

Contents

Section | *Page*

FLOATS AND HULLS

PERSONNEL AND CARGO ACCOMMODATIONS

EMERGENCY PROVISIONS

VENTILATION AND HEATING

PRESSURIZATION

FIRE PROTECTION

MISCELLANEOUS

Subpart E—Powerplant

GENERAL

APPENDIX A-4

TYPICAL INDUSTRY SURVEY QUESTIONNAIRE

SEP 30 1976

Mr. W. H. McKee
Engineering Coordinator
Lockheed Aircraft Corporation
86 S. Cobb Drive
Department 72-01, Zone 12
Marietta, Georgia 30063

Dear Mr. McKee:

For many years, aircraft development programs have included mockups, or "Iron Birds," to test systems for function and endurance. As redundancy, complexity, and the need for greater reliability in systems have increased, the use of more sophisticated simulators has become attractive to support the certification phase. Assuring a more efficient flight test program and development of confidence via "ground based" demonstration of the fault and failure modes can result in saving dollars in the testing phase, as well as permitting safe testing of hazardous conditions.

Federal Aviation Administration (FAA) Advisory Circular 21-14 (copy enclosed) was issued to inform industry of the intent of the FAA to conduct an exploratory program to determine the degree to which simulation can support the certification process. In pursuing the objectives of the circular, the Lockheed-California Company, under contract to the FAA, is studying the past, present and future plans for the use of simulators in the certification phase. To aid in gathering the industry history and the consideration being given to future simulator utilization, the enclosed questionnaire, based on FAR Part 25, is being distributed throughout the aircraft industry. We would welcome your input.

If direct communication is desired with the Lockheed personnel engaged in the subject study, please contact:

Loren H. Harms
(213)847-6121, Ext. 131-525

or: Don M. Archibald
(213)847-6121, Ext. 131-521

Upon completion of the questionnaire, please return to:

Federal Aviation Administration
Attention: Jack E. Cayot
P. O. Box 25
Moffett Field, CA 94035

For timely incorporation of all industry data, we would appreciate your response by October 15, 1976. The objective of improved cost effectiveness and quality in the certification process will benefit the industry as well as the FAA. We thank you in advance for your thoughtful assistance and advice.

Sincerely,

ORIGINAL SIGNED BY:
R. P. SKULLY
DIRECTOR
FLIGHT STANDARDS SERVICE

2 Enclosures

IDENTICAL LETTER SENT TO:

1. Mr. William Starlof
   Manager, Regulatory Affairs
   and FAA Liaison
   McDonnell Douglas Corporation
   Douglas Aircraft Company
   3855 Lakewood Blvd.
   Long Beach, California 90846

2. Mr. H. J. Badger
   Chief, Airworthiness and Safety
   The Boeing Commercial Airplane Company
   P.O. Box 3707
   Seattle, Washington 98124

3. Mr. Frank P. Fleming
   President, Aerospatiale Aircraft
   Corporation
   Suite 508, Hayes Building
   2361 S. Jefferson Davis Highway
   Arlington, Virginia 22202

4. Mr. A.H.C. Greenwood
   Chairman of the Board
   British Aircraft Corporation
   399 Jefferson Davis Highway
   Arlington, Virginia 22202

5. Mr. Robert B. Bieck
   Washington Representative
   The de Havilland Aircraft of Canada Ltd.
   Suite 704-N
   Skyline Towers, N.
   5601 Seminary Road
   Falls Church, Virginia 22041

6. Mr. Stuart Matthews
   Vice President
   Fokker-VFW International
   Hayes Building
   2361 S. Jefferson Davis Highway
   Arlington, Virginia 22202

7. Mr. Kenneth Hamilton
   FAA Administration
   Saberliner Division
   Rockwell International
   827 Lapham Street
   El Segundo, CA 90245

In answering the following questions the word "simulation" may be interpreted as a system or subsystem simulator in either an analytical or hardware sense.

1) Has simulation been used in the certification process in past designs?

Yes____

No ____

2) Will simulation be used or expanded for certification tasks in future designs?

Yes____

No ____

3) Are reports concerned with certification by simulation published and available for use in this program?

Yes____

No ____

If available, please indicate report reference numbers. ____________________

4) Are areas of new technology (active control, fuel management, etc.) being studied with certification by simulation in mind?

Yes____

No ____

What areas are being considered and to what degree is simulation to be utilized? ____________________

5) a) Has simulation been used to establish and/or demonstrate:

1. Weight and CG limits? (FAR 25, Par. 25.21 through 25.33)

Yes____

No ____

2. Performance? (FAR 25, Par. 25.45 through 25.125)

Yes____

No ____

b) What areas are now supported by simulation? ____________________

c) What areas do you expect expanded use of simulators in the next ten yrs.?

Question 5) - continued

d) What new areas of simulation are being considered? ______________________

____

____

6) a) Has simulation been used to demonstrate controllability, maneuverability, trim, stability, stalls, ground handling, vibration, buffeting or high speed characteristics (FAR 25, Par. 25.143 through 25.253)?

Yes ____

No ____

b) What areas are now supported by simulation? ______________________

____

____

c) What areas do you expect expanded use of simulators in the next ten yrs.?

____

____

d) What new areas of simulation are being considered? ______________________

____

____

7) a) Has simulation been used to determine and demonstrate structural limit loads?

Yes ____

No ____

b) What areas are now supported by simulation? ______________________

____

____

c) What areas do you expect expanded use of simulators in the next ten yrs.?

____

____

d) What new areas of simulation are being considered? ______________________

____

____

8) a) Under Sub-part D "Design and Construction" of FAR 25, has simulation been used to demonstrate compliance of:

1) Materials and Methods? Yes ___ No ___

2) Safe flight after failure of control system? Yes ___ No ___

3) Integrity and safe operation after failure in landing gear? Yes ___ No ___

4) Personnel and cargo accommodations, emergency provision, ventilation and heating, pressurization and fire protection? Yes ___ No ___

b) What areas are now supported by simulation? ___

c) What areas do you expect expanded use of simulators in the next ten yrs.? ___

d) What new areas of simulation are being considered? ___

9) a) Under sub-part E, "Power plant" of FAR 25, has simulation been used to demonstrate compliance of:

1) Engine installation and operation? Yes ___ No ___

2) Fuel, Fuel systems and oil system? Yes ___ No ___

3) Cooling, induction and exhause systems? Yes ___ No ___

4) Power plant controls and fire protection? Yes ___ No ___

b) What areas are now supported by simulation? ___

9) continued

c) What areas do you expect expanded use of simulators in the next ten yrs.?

____

____

d) What new areas of simulation are being considered? ____________

____

____

10) a) Under Sub-part F, "Equipment" of FAR 25, has simulation been used to demonstrate compliance of:

1) Installation and application of electrical equipment and instruments?

Yes ____

No ____

2) Lighting, safety equipment, miscellaneous equipment and systems?

Yes ____

No ____

b) What areas are now supported by simulation? ____________

____

____

c) What areas do you expect expanded use of simulators in the next ten yrs.?

____

____

d) What new areas of simulation are being considered? ____________

____

____

11) Is there an individual that may be used as a technical contact for this study?

Name ____________

Title ____________

Phone ____________

APPENDIX A-5

BOEING RESPONSE TO QUESTIONNAIRE

BOEING COMMERCIAL AIRPLANE COMPANY

P.O. Box 3707
Seattle, Washington 98124

A Division of The Boeing Company

October 25, 1976
B-7671-G-260

Federal Aviation Administration
P.O. Box 25
Moffett Field, California 94035

Attention: Mr. Jack E. Cayot

Subject: Simulation in the Certification Process

Reference: R. P. Skully letter to H. J. Badger dated September 30, 1976

Gentlemen:

In response to the request contained in the reference the completed attached questionaire is forwarded. We regret being late in this submittal, but it was unavoidable because of the complexity of collating the responses from the various segments of the company.

Additionally, attached are copies of previous correspondence on this subject which may be useful background material.

Very truly yours,

H. J. Badger
Chief, Safety and Airworthiness
Boeing Commercial Airplane Company

Attachment

BOEING

In answering the following questions the word "simulation" may be interpreted as a system or subsystem simulator in either an analytical or hardware sense.

1) Has simulation been used in the certification process in past designs?

Yes X

No ___

2) Will simulation be used or expanded for certification tasks in future designs?

Yes X

No ___

3) Are reports concerned with certification by simulation published and available for use in this program? Certification documentation is available to the FAA. Most of this documentation is Boeing proprietary information. Examples are listed below.

Yes X

No ___

If available, please indicate report reference numbers.

(1) D6-34242, 747 Fail Operational Autoland & Rollout System Performance Analysis, 5-27-76.

(2) D6-33835, 747 SP AFCS Performance Analysis, 4-30-75

4) Are areas of new technology (active control, fuel management, etc.) being studied with certification by simulation in mind?

Yes X

No ___

What areas are being considered and to what degree is simulation to be utilized? Automatic control systems, active controls, electrical power systems, displays, and navigation systems. Simulation will be used during development & evaluation phases, and in development of certification criteria for advanced aircraft.

5) a) Has simulation been used to establish and/or demonstrate:

1. Weight and CG limits?
(FAR 25, Par. 25.21 through 25.33)

Yes ___

(Not for certification purposes) No X

2. Performance?
(FAR 25, Par. 25.45 through 25.125)

Yes ___

(Not for certification purposes) No X

b) What areas are now supported by simulation? None

c) What areas do you expect expanded use of simulators in the next ten yrs.? Limited - The Flight Test Program to obtain data to validate a performance simulator is probably greater than current flight certification demonstration.

Question 5) - continued

d) What new areas of simulation are being considered? Development of certification criteria for advanced aircraft.

6) a) Has simulation been used to demonstrate controllability, maneuverability, trim, stability, stalls, ground handling, vibration, buffeting or high speed characteristics (FAR 25, Par. 25.143 through 25.253)?

Yes X

No ___

b) What areas are now supported by simulation? Stall warning, autoland, brakes, and anti-skid systems are examples. Selection of critical demonstrations to minimize flight test conditions.

c) What areas do you expect expanded use of simulators in the next ten yrs.? Simulators are expected to play an increased role in evaluating and modifying existing FAR's and developing new regulations for advanced technology aircraft.

d) What new areas of simulation are being considered? Use of simulation during early phases of design as an aid to develop the configuration.

7) a) Has simulation been used to determine and demonstrate structural limit loads

Yes X

No ___

b) What areas are now supported by simulation? Determination of dynamic loads during maneuvering and system failure conditions.

c) What areas do you expect expanded use of simulators in the next ten yrs.? None at present.

d) What new areas of simulation are being considered? None at present.

8) a) Under Sub-part D "Design and Construction" of FAR 25, has simulation been used to demonstrate compliance of:

1) Materials and Methods? Yes ___ No X

2) Safe flight after failure of control system? Yes X No ___

3) Integrity and safe operation after failure in landing gear? Yes X No ___

4) Personnel and cargo accommodations, emergency provision, ventilation and heating, pressurization and fire protection? Yes X No ___

b) What areas are now supported by simulation? Primary, secondary and automatic flight control systems; landing gear, steering, and braking.

c) What areas do you expect expanded use of simulators in the next ten yrs.? Evaluation of handling qualities over the full flight envelope for advanced aircraft.

d) What new areas of simulation are being considered? Improved simulator fidelity in systems area.

9) a) Under sub-part E, "Power plant" of FAR 25, has simulation been used to demonstrate compliance of:

1) Engine installation and operation? Yes X No ___

2) Fuel, Fuel systems and oil system? Yes X No ___

3) Cooling, induction and exhause systems? Yes X No ___

4) Power plant controls and fire protection? Yes X No ___

b) What areas are now supported by simulation? Nacelle component cooling, engine oil cooling, fuel heating, generator cooling, fuel feed, fuel venting, fuel jettison and re/defeuling.

9) continued

c) What areas do you expect expanded use of simulators in the next ten yrs.?
Fuel vent system analysis, surge pressure analysis, nacelle cooling, inlet distortion analysis, transient engine performance.

d) What new-areas of simulation are being considered? Improved fuel gaging systems, c.g. control, low and high fuel temperature operation, engine structural math model, propulsion control systems.

10) a) Under Sub-part F, "Equipment" of FAR 25, has simulation been used to demonstrate compliance of:

1) Installation and application of electrical equipment and instruments?

Yes X

No

2) Lighting, safety equipment, miscellaneous equipment and systems?

Yes X

No

b) What areas are now supported by simulation? Proper function of electrical equipment, failure modes, electric power system capacity and quality, protective devices, lighting compliance, electrical system status indication and monitoring.

c) What areas do you expect expanded use of simulators in the next ten yrs.? Increased sophistication of simulation in areas where partial simulation is now used.

d) What new areas of simulation are being considered? Window heat and anti-icing system evaluation.

11) Is there an individual that may be used as a technical contact for this study?

Name Richard L. Schoenman

Title Chief Engineer- Flight Controls Technology

Phone 206-237-1700

BOEING COMMERCIAL AIRPLANE COMPANY
P.O. Box 3707
Seattle, Washington 98124

A Division of The Boeing Company

May 16, 1975
B-8240-205

Mr. James F. Rudolph
Acting Associate Administrator
for Aviation Safety
Federal Aviation Administration
Department of Transportation
Washington, D. C. 20591

Dear Jim,

Thank you for your letter regarding the advisory circular addressing the role of simulation in the certification process. We had also received a request from Jack Cayot to review this circular, and have attached a copy of our response to him.

As you know, we are proceeding with a short study to investigate what we think could be done in this area, and will send you a copy of our report to Mr. Cayot.

We would, of course, be pleased to discuss with you our feelings on this matter at any time.

Sincerely,

B-L

H. W. Withington
Vice President - Engineering

Enclosure

BOEING

BOEING COMMERCIAL AIRPLANE COMPANY P.O. Box 3707
Seattle, Washington 98124

A Division of The Boeing Company

May 15, 1975
B-8240-204

Mr. J. E. Cayot
Resident Director for FAA
Ames Research Center
Box 25
Moffett Field, California 94035

Subject: Proposed Advisory Circular, "The Role of Simulation in the Certification Process"

Dear Jack,

The Boeing Commercial Airplane Company endorses the planned action of the subject advisory circular, and is in general agreement with the objectives stated therein. These objectives, particularly paragraph 4.b., the further development of simulation, have greater applicability to future advanced aircraft than to conventional subsonic transports.

Several important points to be recognized in any consideration of the role of piloted simulation are:

1. We believe strongly that simulations used in the development and certification process must be under the control of the manufacturer to provide an adequate control of the technical, schedule, and cost aspects of an airplane development program.

2. We believe that the proper role for FAA and NASA is to use its facilities (e.g., FSAA) for research in the development of certification requirements and flight test techniques for compliance demonstrations that would be applicable to advanced aircraft with features which are presently unconventional for civil transport aircraft. Examples are powered lift aircraft and aircraft with CCV/ACT features.

3. Such research in developing the certification requirements for advanced aircraft should also provide additional insight on the most effective use of simulation in the certification process, i.e., in demonstrating that a specific aircraft meets these requirements.

BOEING

Mr. J. E. Cayot
B-8240-204
Page 2

4. With the present state of the art as applied to conventional transport airplanes, more flight time and manpower costs may be expended in validating a simulation of a new aircraft than would be saved in reduced certification flight testing.

5. Because of computer memory size and other limitations, a full flight envelope simulation of a given airplane may be inadequate to perform detailed investigations of a specified problem area. Specific problems are best handled by partial simulations specifically oriented to the problem under consideration, e.g., investigation of autopilot malfunctions in Category III landings requires detailed modelling of the autopilot and flight control system, but Mach No. and most aeroelastic effects can be neglected.

Presently, extensive use of "simulation" in its broadest sense, including real time piloted flight simulation, is used extensively in the engineering development of new and derivative airplanes. We would welcome a formalization of the guidelines on the acceptable useage of simulation to demonstrate compliance with certification requirements. However, considering particularly points 1. and 5. above, the details of simulator useage in the certification of a particular airplane should continue to be determined by agreements reached between the manufacturer and the responsible FAA region using the general guidelines as proposed in the referenced advisory circular.

Very truly yours,

BOEING COMMERCIAL AIRPLANE COMPANY

R. L. Schoenman
Chief Engineer
Flight Controls Technology

BOEING

APPENDIX A-6

DOUGLAS AIRCRAFT RESPONSE TO QUESTIONNAIRE

DOUGLAS AIRCRAFT COMPANY

3855 Lakewood Boulevard Long Beach, California 90846

GEN

C1-29-5906
December 14, 1976

To: Federal Aviation Administration
P. O. Box 25
Moffett Field, CAlifornia 94035

Attention: Jack E. Cayot

Subject: Use of Simulators

Reference: FAA Letter dated September 30, 1976

1. In response to the referenced letter from Mr. Skully, we are enclosing answers to questions regarding use of simulators.

2. Any simulation activity must be under the direct control of the cognizant design and development personnel of the manufacturer. Also, the use of simulation should be to reduce the amount of certification flight testing that would be done otherwise and not simply to do additional work for certification.

William C. Starlof, Manager
Regulatory Affairs & FAA Liaison

LWF/jo
Enclosure

MCDONNELL DOUGLAS
CORPORATION

Enclosure to letter C1-29-5906
12/14/76

In answering the following questions the word "simulation" may be interpreted as a system or subsystem simulator in either an analytical or hardware sense.

1) Has simulation been used in the certification process in past designs?

Yes X
No ___

2) Will simulation be used or expanded for certification tasks in future designs?

Yes X
No ___

3) Are reports concerned with certification by simulation published and available for use in this program?

Yes ___
No X

If available, please indicate report reference numbers.

Note-These reports are proprietary.

4) Are areas of new technology (active control, fuel management, etc.) being studied with certification by simulation in mind?

Yes ___
No X

What areas are being considered and to what degree is simulation to be utilized?

5) a) Has simulation been used to establish and/or demonstrate:

1. Weight and CG limits?
(FAR 25, Par. 25.21 through 25.33)
Directed primarily towards automatic landings and required flight test verification.

Yes X
No ___

2. Performance?
(FAR 25, Par. 25.45 through 25.125)

Yes ___
No X

b) What areas are now supported by simulation? Flight Guidance and Navigation (i.e. R-NAV)

c) What areas do you expect expanded use of simulators in the next ten yrs.? Flight Guidance and Navigation

Question 5) - continued

d) What new areas of simulation are being considered?
See 10 d)

6) a) Has simulation been used to demonstrate controllability, maneuverability, trim, stability, stalls, ground handling, vibration, buffeting or high speed characteristics (FAR 25, Par. 25.143 through 25.253)?

Yes X
No

Equivalent FAR 25 work on the YC-15 pre-first flight handling qualities demo.

b) What areas are now supported by simulation? Controllability for approach and landing with all engines inoperative on DC-10 was certificated based in part on computer simulation results.

c) What areas do you expect expanded use of simulators in the next ten yrs.?
Possibly some of the less critical stability, trim, and controllability cases.

d) What new areas of simulation are being considered?
Integrated cockpit display systems, calagraphic and raster scan.

7) a) Has simulation been used to determine and demonstrate structural limit loads?
We assume this question applies to Subpart D

Yes X
No

b) What areas are now supported by simulation? All full scale structural qualification is performed with a 3 degree of freedom simulation of all critical flight conditions.

c) What areas do you expect expanded use of simulators in the next ten yrs.?
Greater refinement of the flight spectrum simulation related to full scale structural life demonstration.

d) What new areas of simulation are being considered? Direct digital links from computers to servo system controlling the physical flight simulation.

8) a) Under Sub-part D "Design and Construction" of FAR 25, has simulation been used to demonstrate compliance of:

1) Materials and Methods? Yes X No ___

2) Safe flight after failure of control system? Yes X No ___

3) Integrity and safe operation after failure in landing gear? Yes ___ No X

4) Personnel and cargo accommodations, emergency provision, ventilation and heating, pressurization and fire protection? Yes X No ___

b) What areas are now supported by simulation?
Fire resistance, air conditioning system.

c) What areas do you expect expanded use of simulators in the next ten yrs.?
Greater emphasis on subsystem design evaluation through simulation

d) What new areas of simulation are being considered?
Preliminary design evaluation and verification. CRT graphics development for cockpit displays.

9) a) Under sub-part E, "Power plant" of FAR 25, has simulation been used to demonstrate compliance of:

1) Engine installation and operation? Yes X No ___

2) Fuel, Fuel systems and oil system? Yes X No ___

3) Cooling, induction and exhause systems? Yes X No ___

4) Power plant controls and fire protection? Yes ___ No X

b) What areas are now supported by simulation? Extensive engine modeling is presently being accomplished through simulation

Enclosure to letter C1-29-5906
12/14/76

continued

c) What areas do you expect expanded use of simulators in the next ten yrs.? Advanced engine control systems and refined computer modeling.

d) What new areas of simulation are being considered?

10) a) Under Sub-part F, "Equipment" of FAR 25, has simulation been used to demonstrate compliance of:

1) Installation and application of electrical equipment and instruments?

Yes X
No

2) Lighting, safety equipment, miscellaneous equipment and systems?

Yes X
No

b) What areas are now supported by simulation? Generator controls, load monitoring, variety of basic flight instruments, hydraulic system. DC-10 autoland statistical reliability certification was done in part on the iron bird simulator. The major design areas of Aero, Avionics, Structures & Controls are supported by simulation.

c) What areas do you expect expanded use of simulators in the next ten yrs.? Simulation of advanced cockpit displays.. Avionic systems, digital simulation of automatic flight control systems, higher fidelity related to increasing simulation applications in crew training.

d) What new areas of simulation are being considered? Integrated cockpit display systems, calagraphic and raster scan.

11) Is there an individual that may be used as a technical contact for this study?

Name No specific person - depends on subject.
Title
Phone

APPENDIX A-7

LOCKHEED-GEORGIA RESPONSE TO QUESTIONNAIRE

LOCKHEED-GEORGIA COMPANY

A DIVISION OF LOCKHEED AIRCRAFT CORPORATION

MARIETTA, GEORGIA 30063

14 October 1976

LGD/732051

Federal Aviation Administration
Attention: Jack E. Cayot
P. O. Box 25
Moffett Field, California 94035

Subject: Industry Survey on the Role of Simulation In the Aircraft Certification Process

Reference: (A) FAA ltr to Lockheed-Georgia Company, dtd 30 Sept. 76, same subject, (LGD/731940)

Enclosure: (a) One copy of Industry Survey Questionaire

Dear Mr. Cayot:

In response to your reference (A) request for a copy of the Industry Survey on the Role of Simulation in the Aircraft Certification Process, we are pleased to forward the enclosure (a) copy of our response to your questionaire.

Very truly yours,
LOCKHEED-GEORGIA COMPANY

W. H. McKee
Engineering FAA Coordinator

WHM/BNF/ec

Enclosure (a) to LGD/732051

INDUSTRY SURVEY

In answering the following questions the word "simulation" is interpreted as a system or subsystem simulator in either an analytical or hardware sense.

1) Simulation has been used in the certification process in past designs.

2) Yes simulation will be used or expanded for certification tasks in future designs.

3) Reports concerned with certification by simulation are published and available for use in this program.

Available reports with reference numbers are listed below:

ER 4362	Model 1329 Test Program of the JetStar Air Conditioning System Functional Mockup - Structural Qual.
ER 4361	Model 1329 Test Program of the JetStar Fuel System Functional Mockup to Demonstrate Compliance with Civil Airworthiness Requirements
ER 4522	Negative "G" Simulation Test on JetStar Fuel System Mockup
ER 4770	Fire Test of Components Located Within the JetStar Engine Support
ER 4729	Performance Evaluation of the JetStar Fuel System with JP-4 Fuel Utilizing Full-Scale Functional Mockup
ER 4701	Performance Evaluation of the JetStar Fuel System with Aviation Kerosene Utilizing Full-Scale Functional Mockup
ER 5013	C-141A: Test Procedures for Performance Evaluation of Fire Protection System
ER 6325	C-141 - Reliability Test of Heated Windshield System
ER 5009	C-141 Environmental Control/Ice Protection Systems Laboratory Test Results
ER 5008	C-141A Fuel System Laboratory Test Results
ER 7844	C-141A Windshield Rain Repellent System Development
ER 9048	C-141A Engine Cross Feed - Single Pump in Main Tank Configuration
ER 9760	C-141A Engine Driven Pump Suction Feed Endurance Test Results
ER-5011	Power Plant Extinguisher System Performance Evaluation

NOTE: Some of the above data are proprietary and may not ordinarily be released except under license or contract.

4) Yes areas of new technology (active control, fuel management, etc.) are being studied with certification by simulation in mind.

Utilization of full scale simulation is being considered in the following areas:

Fly by wire, active control, fuel management, digital control of flight, environmental, hydraulic and pneumatic systems.

5) a) 1. Simulation has been used to establish but not demonstrate weight and CG limits (FAR 25 Par 25.21 through 25.33).

2. Simulation has been used to establish but not demonstrate performance (FAR 25.45 through 25.125).

b) The areas now supported by simulation include the following:

Full Scale System Simulators

- Automatic flight controls
- Manual flight controls
- Landing gear
- Cargo openings
- Hydraulics
- Fuels
- Air conditioning
- Pneumatics
- Fire protection
- Oxygen
- Secondary power
- Electrical
- Avionics
- Antennas
- Static loads
- Fatigue loads

c) The areas of expanded use of simulators in the next 10 years are all of the items listed in 5 b).

d) One new area of simulation being considered is a method of satisfying the icing requirements.

6) a) Simulation has reduced, demonstration requirements of controllability, maneuverability, trim, stability, stalls, ground handling, vibration, buffeting or high speed characteristics (FAR 25, Par. 25.143 through 25.253).

b) The areas now supported by simulation are all of the items listed in 6 a) above.

6) continued

c) Expanded use of simulators in the next ten years will be in all areas listed in 6 a) above plus active flight control and digital flight control.

d) One new area of simulation now being considered is terminal navigation using MLS.

7) a) Yes simulation has been used to determine and demonstrate structural limit loads.

b) The areas now supported by simulation are static, ultimate, limit and fatigue loads, crack growth, NDT techniques, acoustic emission measurements and fail safe analysis.

c) Expanded use of simulators in the next ten years will be in all areas listed in 7 b) above plus computer simulation of design loads for fatigue testing.

d) New areas of simulation being considered are turbulence, wind shear and vortex encounter by using a flight simulator.

8) a) Under Sub-part D "Design and Construction" of FAR 25, simulation has been used to demonstrate compliance of:

1) Materials and Methods

2) Safe flight after failure of control system

3) Integrity and safe operation after failure in landing gear

4) Personnel and cargo accommodations, emergency provision, ventilation and heating, pressurization and fire protection

b) Areas now supported by simulation are all items in 8 a) above.

c) Expanded use of simulators in the next ten years will be in all areas listed in 8 a) above plus windshield qualification.

d) New areas of simulation being considered are tire and brake qualification.

9) a) Under sub-part E, "Power plant" of FAR 25, simulation has been used to demonstrate compliance of:

1) Engine installation and operation
2) Fuel, fuel systems and oil system
3) Cooling, induction and exhaust systems
4) Power plant controls and fire protection

b) Areas now supported by simulation are all of item 9 a) above plus propeller vibration and thrust reverser qualification.

c) Expanded use of simulators in the next ten years will be in all areas listed in 9 b) above.

d) One new area of simulation being considered is satisfying icing requirements by simulation (AEDC engine test facility).

10) a) Under Sub-part F, "Equipment" of FAR 25, simulation has been used to demonstrate compliance of:

1) Installation and application of electrical equipment and instruments
2) Lighting, safety equipment, miscellaneous equipment and systems

b) Areas now supported by simulation are all of item 10 a) above.

c) Expanded use of simulators in the next ten years will be in all areas listed in 10 a) above.

d) One new area of simulation being considered is satisfying icing requirements by simulation.

11) The individual that may be used as a technical contact for this study is:

Name: C. W. James

Title: Research and Development Manager, Engineering Test Division

Phone: (404) 424-3599