reduced airflow prevented early drag rise of the model (Fig. 9). 4) Blockage in the turbine exhaust is effective in changing the relationship between the primary and fan nozzle pressure ratio (Figs. 10 and 11). 5) Gas-generator surface ice was eliminated by heating the turbine-drive air. 6) Each engine needs to be calibrated for force (Fig. 17).

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JULY 1971 J. AIRCRAFT VOL. 8, NO. 7

DC-10 Test Program Effectiveness

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The DC-10 aircraft test program has been planned to provide increased over-all efficiency and effectiveness. A series of comprehensive engineering development simulations and aircraft ground tests will precede the flight test program, which will employ a sophisticated data acquisition and processing system with the capability to provide real-time data while the tests are in progress. A flight controls development test stand will be used to evaluate the prototype flight control and avionic equipment and provide the capability for pilot assessment of the Flight Guidance and Control (FG&C) System by means of an integrated simulator complex. A laser beam tracking system will be used to provide the space positioning data required in Flight Guidance and Control, noise measurement, and takeoff and landing performance tests. Training on the DC-10, which began one year prior to the scheduled first flight, will be broadened to include test runs and flight simulation to establish plans and to train all test-related personnel.

Introduction

A DEFINITION of the DC-10 test program effectiveness is presented in this paper as the efficient planning, instrumentation, execution, and analysis of engineering development simulator tests and airplane ground and flight tests to, 1) evaluate aircraft performance and flying qualities, 2) define the operational envelope, 3) evaluate systems performance, and 4) demonstrate that the aircraft and its systems comply with airworthiness standards established by applicable Federal Aviation Regulations (FAR).

As the nature and scope of aircraft testing in a general sense are well established, only aspects of testing that are innovations or otherwise uniquely related to recent aircraft design changes or test techniques and those related to changes in the Federal Aviation Administration (FAA) certification requirements are discussed in this article. Most considerations of test effectiveness presented herein are applicable to large-scale test programs on any model of commercial or military aircraft; however, because of the author's more recent experience, specific details refer to the DC-10 aircraft test program.

General

The growth of commercial aviation from its initial stages has been phenomenal as a result of public acceptance of air travel and advances in aircraft technology and design. Aircraft have increased in size, flight envelopes have grossly expanded, systems have become more sophisticated, and although costs per seat or ton mile have gone down, flight test costs have gone up. As a result of these factors, it is necessary to conclude that laboratory simulation and development and prototype ground testing must be comprehensive and effectively programed to reduce flight test requirements and in turn provide for an accelerated and efficient flight test program.

Test Planning Concepts

The initial consideration necessary to achieve an effective test program is the planning phase wherein the over-all test program must be prepared to achieve the following objectives:

Conduct an efficient and safe envelope expansion program and qualitatively and quantitatively evaluate the design flight characteristics, structural integrity, system functions, aircraft performance, and operational suitability of the aircraft and its associated equipment.

Establish configuration improvements as required during the flight test program and qualify those changes in the initial stages of test to ensure compliance with the delivery schedules.

Demonstrate the aircraft and its systems in accordance with applicable Federal Aviation Regulations and customer contractual requirements.

In the DC-10 test program, as an important part of the over-all planning effort, a comprehensive program of laboratory and ground tests was established to precede the flight test program. The technical details of this rigorous program of functional and environmental testing will contribute to minimize flight test problems. In addition, the major system integration simulators will remain active during flight test to assist in the resolution of problems discovered in flight. Laboratory and Flight Development organizations that are responsible for the ground and flight testing facilities and all test functions have been integrated to provide the means for efficient conduct of the over-all DC-10 test program. An integrated organization of this kind ensures that data are efficiently exchanged and that flight test personnel will be

Presented as Paper 70-371 at the AIAA Test Effectiveness in the 70's Conference, Palo Alto, Calif., April 1-3, 1970; submitted April 20, 1970; revision received October 2, 1970.

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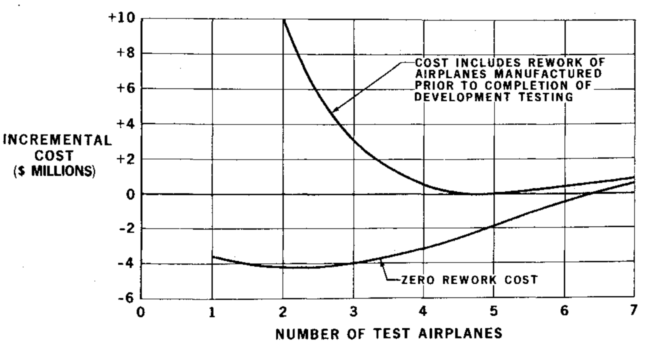

Fig. 1 Incremental cost vs number of aircraft.

familiar with system tests in advance of the development flight tests.

Modern laboratory, testing, and hanger facilities have been constructed in support of the DC-10 test program. Within this complex are a comprehensive analog and digital computer and simulation center, a sophisticated data acquisition and processing center, hangar facilities for three DC-10 test aircraft, and laboratory testing, engineering, and administration facilities.

A major DC-10 program objective is to have all systems operative on each test aircraft where they will be tested and operated on a noninterference basis with scheduled development testing, to provide baseline reliability data and accumulate operational experience.

In the initial phases of the test program, a concentrated effort will be made to expand the operating envelope to the design limits of speed, altitude, load factor, and control deflection. If problem areas are encountered, the aircraft envelope expansion will be continued by flying the aircraft around the boundary of restraint. The objective of this approach is to permit completion of parallel test programs while definition and improvement of all flight developed limitations are made.

Testing priority will be assigned to flutter, stability and control, flight guidance and control, propulsion, and avionics systems during the flight test program to uncover problem areas sufficiently early so that improvements can be incorporated prior to the FAA demonstrations without incurring schedule delays.

Because aircraft downtime is critical in a flight test program, a rapid response system for configuration changes will necessarily be established as a top priority function with preplanned engineering, test, and fabrication capabilities. To increase aircraft utilization and provide backup support, each prime test aircraft will have a secondary test assignment. The flight endurance of the DC-10 coupled to the comprehensive onboard instrumentation system will permit joint development of several technical areas on a given aircraft.

Test Aircraft Selection

The number of test aircraft required in the DC-10 flight test program was determined after development of a flight test plan which was initiated during the aircraft design phase by consideration of the following:

Design and configuration review of the aircraft and systems; detailed systems and FAA and customer specification test requirements, and the scope of the estimated development program; and Test procedures established to satisfy the requirements for systems development, test, and demonstration.

The initial flight test plan was also used to define the requirements for test equipment, instrumentation, test facilities, and FAA participation, and to establish necessary organizational procedures.

The number of planned flight test hours was established on the basis of the flight test plan which contained an estimate of the hours required for evaluation and demonstration of each technical area. However, experience gained from previous programs necessitated consideration of additional hours for normal development and the occurrence of unexpected problems. A total number of 1500 hr was determined to be required, after accounting for savings gained by parallel testing. The ability to combine or perform parallel tests was made possible by the comprehensive instrumentation system onboard each test aircraft, which allows combining tests requiring unique instrumentation. The total number of flight test hours required will be reduced by the takeoff, climbout, descent, and landing times that otherwise would be required if the capability for parallel testing was not developed. For a nominal flight duration of 3 hr, this will represent a saving of approximately 16% of the total flight time.

The flight test schedule and number of test aircraft were determined by considering manufacturing capabilities with respect to detailed test program requirements, including projected flight rate, test planning, and scheduling factors. The DC-8 flight test program was initiated in 1958 and averaged 27.5 flight hours per month per test aircraft. The projected test flight rate of the DC-10 was established as 33 hr/month/aircraft on the basis of the automated data handling system which was not available during the DC-8 program, and other improvements in operating methods and ability to produce configuration changes.

Five aircraft were selected as an optimum number of test aircraft for the DC-10 flight test program as a result of the factors previously discussed. This in turn will enable the major part of development testing to be accomplished prior to the start of FAA certification testing to avoid costly modification of production aircraft. Cost analyses indicated the lowest number of aircraft, with their corresponding extended schedules, that will produce the lowest direct test costs; however, this economic advantage was eliminated when modification costs of the aircraft which are manufactured before completion of flight testing were considered. Figure 1, which shows estimated incremental cost curves versus the number of test aircraft, also includes consideration of instrumentation costs, modification of test aircraft to the final configuration, and cost of maintaining staffs and laboratories for varying time periods. Aircraft flight rates and required test time were considered as fixed, and curves are shown for no modification costs per aircraft and for a phased modification cost schedule. This latter curve optimizes at five aircraft, and is relatively flat for additional aircraft. It should be recognized that the depicted curve considered schedules only with regard to rate of production deliveries, which in turn affected the number of aircraft requiring modification.

A six aircraft test program would add instrumentation and operation costs without commensurate gains in calendar time because the aircraft could not be flown for sufficiently long periods of time prior to certification. With seven or eight test aircraft, all gain from additional aircraft would disappear.

Upon determination of the optimum number of test aircraft, the test schedules for individual aircraft were established as shown in Fig. 2 on the basis of the following considerations: 1) Test aircraft availability, 2) test aircraft flight rate, 3) individual test flight hour requirements, 4) individual test instrumentation requirements, 5) compatibility for parallel testing, 6) anticipation of development problems, 7) time-phased development improvements into production aircraft, 8) FAA Type Certification date, 9) customer training requirements, and 10) production delivery schedules.

The DC-10 flight test program commenced on August 29, 1970 with Aircraft No. 1 designated as the primary stability and control aircraft. Aircraft No. 3 will be the performance aircraft and will fly 2 months later. The No. 2 test aircraft will be used exclusively for flight guidance and control tests

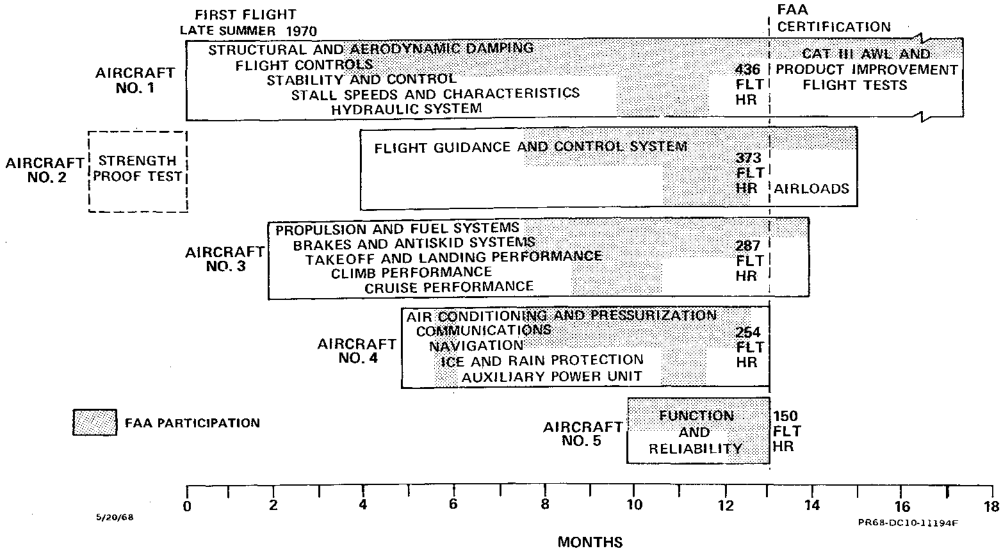

Fig. 2 DC-10 flight test schedule.

and demonstrations. It will fly 4 months after first flight date. Aircraft No. 4 will be the systems test aircraft and No. 5 will be used for function and reliability tests. Each test aircraft will be uniquely configured and instrumented to fulfill the special requirements in each test area.

Data Acquisition, Processing, and Test Instrumentation System

An important factor in the consideration of test effectiveness for any multiaircraft flight test program is the data acquisition, processing, and instrumentation system which in terms of costs represents a significant part of the total millions of dollars involved.

The amount of data required to evaluate and rigorously define the aircraft stability and control and performance characteristics is directly related to the size and complexity of the aircraft and systems. Historically, on each successive aircraft development program the data accumulation and processing requirements for flight test have increased.

Data acquisition systems typical of those used in the past decade would seriously inhibit large-scale test programs of the current and future generations of commercial transport aircraft. The most critical limitation of these systems occurred as a result of man's primary role in the data acquisition and evaluation process. Each step in the data processing sequence required large amounts of manual data processing. This was time consuming and costly. In addition, reduced system flexibility resulted in increased cost and time delays when instrumentation changes were required. Schedule commitments coupled with accelerated data requirements have required that the flight rates of test aircraft also increase with new programs. To maintain pace with this growth rate and assure economic feasibility, the data reduction process, which in the past has required from 1 day to several weeks, must in the future be accomplished within several hours after the flight, and in some instances, be presented in real-time engineering units while the test is in progress.

Table 1 Airborne system capabilities

CHANNEL TYPE	SELECTED (DIGITAL SYSTEM) DATA SAMPLES PER SECOND PER CHANNEL					
PRIME (90 CHANNEL)	400	200	100	50	20	10
SUBCOM (290 CHANNEL)	40	20	10	5	2	1
FREQUENCY (20 CHANNEL)	20	10	5	2½	1	½
COMBINED CHANNEL (INCLUDING DATA AND ALIGNMENT) 404 CHANNEL	50K	25K	12.5K	6.25K	2.5K	1.25K
SYSTEM RECORD TIME ONE ROLL TAPE-MINUTES	32	64	128	256	512	1024
TAPE SPEED IN/SEC	60	30	15	7½	3¾	1⅞

The obvious solution to these demanding requirements is an automated data acquisition and processing system. The use of automated techniques will permit a drastic reduction in turn-around time to final data and make possible a real-time telemetry system not limited to the channel capacity as in the past.

To ensure a complete, accurate, and timely flight test program for the DC-10, an advanced digital data system is being used. The system consists of the following three basic elements.

Airborne System

The airborne system is primarily digital with secondary AM-FM recording capability. The system contains 400 data channels, with 90 channels recorded at prime sampling rates, 290 channels recorded at a 10:1 subcommutation rate, and 20 channels recorded at a 20:1 subcommutation rate. The system can record data at a variety of sampling rates as shown in Table 1. The basic elements of the airborne system are as follows: 1) Signal conditioning subsystem—Accepts analog data signals, provides calibration, gain, balance and filtering on each channel; 2) Digital subsystem—Converts analog signals into digital words, accepts digital data signals, and provides for cumulative counting of frequency inputs; 3) Onboard data display—Each airborne system is equipped with three 10-channel bar chart display systems and six digit-count readouts; 4) Tape recorder—Using 1-in. tape with 14 tracks, the recorder has the capability of using 1 track for 400 channels of data in serial format, 1 track for time, and 12 tracks for analog recording of high frequency data; and 5) Telemetry—Two telemetry transmitters operating on individual frequencies in the L-band transmit the same data simultaneously. The ground station continually monitors the prime channel and in the event of signal loss or interference will automatically switch to the secondary channel to minimize data dropout.

Telemetry and Microwave System

The telemetry link has the capability of transmitting 400 data channels simultaneously. To accommodate TM transmission over a 250-mile range, a microwave relay station is located on an 8400-ft elevation mountain top. The TM signals are received by means of an automatic tracking 10-ft parabolic antenna and transmitted by way of the microwave

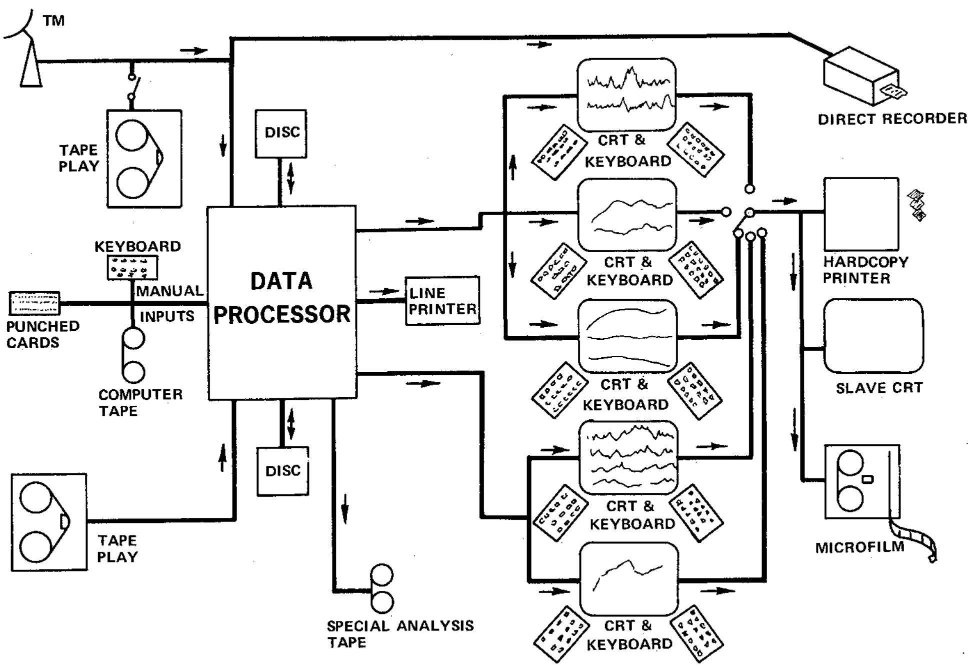

Fig. 3 Data processing system.

link to the flight control and data center. The system includes channels of UHF and VHF audio and 14 fault and alarm channels to monitor equipment performance and the data stream.

Flight Control and Data Center

The data processing system, shown functionally in Fig. 3, serves both as a data reduction center and a flight control monitor station for flight test aircraft. The system has the capability of handling data from the airborne tape or in real-time through the telemetry link to accomplish the primary function of displaying engineering unit time histories or tabulations with complete annotations. The data processing and real-time monitoring can be accomplished simultaneously with a strip chart backup redundancy independent of the computer.

The use of the Cathode Ray Tube (CRT) graphic display units for complete data reduction is a primary feature of this system. The use of the CRT display allows real-time and on-line monitoring, editing, and processing of flight test data. thus eliminating many preliminary steps normally involved in digital systems.

The primary control and operation of the data processing system is accomplished by means of alphanumeric and control

Fig. 4 CRT display.

function keyboards designed specifically for flight test data reduction. The control function keyboard will provide the engineer with a rapid means of displaying engineering unit tabulations and time histories as well as all information required for data reduction such as calibrations and parameter lists. The parameter selection, scales, annotation, or parameter placement on the graphical presentations need not be predetermined but can be selected or changed through two keyboards. Hard copy and/or microfilm equipment will provide a means of retaining information created on the CRT. A typical example of a CRT display is shown in Fig. 4.

Technical Areas

Flight Guidance and Control

The greatest advances in the operational capability of the DC-10 aircraft over earlier aircraft are embodied in the flight guidance and control system. The DC-10 FG&C system will have the capability to automatically control the aircraft during go-around, climb, cruise, altitude level off, descent, approach, runway align, flare, and rollout after touchdown. A control wheel steering function with manual attitude hold control of the autopilot will be provided. Design objectives which provide the DC-10 aircraft with capability of certification initially to Category IIIa approach minimums and eventually to Category IIIc, have imposed innovative fail-operational constraints on the design of the aircraft and its systems. FAA definition of approach conditions by category are as follows: Category I; 2600 ft RVR, 200 ft decision height; Category II; 1200 ft RVR, 100 ft decision height; Category IIIa; 700 ft RVR, 100 ft decision height; Category IIIb; 150 ft RVR, no decision height; and Category IIIc; Zero RVR.

FAA rules governing the autoland system are contained in Advisory Circular 20-57 and the requirements for Category IIIa operations are tentatively contained in Advisory Circular 120-28 which state that for approaches conducted during all Category III conditions the total autopilot/aircraft system must be fail-operational. Fail operational is defined by the FAA as follows: "An airborne system which provides redundant operational capability down to alert heights. The redundant operational system must not have common failure modes. If one of the two required operational systems fails below the alert height, the flare and touchdown may be accomplished using the remaining operational system."

Upon sustaining a single failure, a fail-operational system must become fail-passive, which is defined as: "An automatic flight control system which upon occurrence of any failure not shown to be extremely improbable is protected against hard-overs, leaves the aircraft in trim, causes warning signal and does not interfere with the pilot's normal control of the aircraft."

The DC-10 FG&C system has been designed to comply with these requirements by the inclusion of two automatic pilots, flight directors, automatic throttles, and unique configurations of the electrical, flight control, hydraulic, air data computer, flight instrument, attitude reference, compass, and virtually all other associated aircraft systems. The basic FG&C system consists of two completely independent autopilot/flight director computers which in turn consist of two separate computation channels, each channel consisting of pitch, roll, and yaw axis computers. Any one channel is capable of operating the autopilot/flight director system. This design feature provides the DC-10 with a quad channel autopilot where, during an autoland approach, each one of the four channels is controlling an individual flight control surface segment (see Table 2). A high level of safety is provided in this system through the design and use of redundant and backup systems. The DC-10 electrical system is so configured that during an approach the electrical busses are isolated to prevent a fault on one from carrying over to the other. The remaining generator and the aircraft auxiliary power unit, however, are on standby to take over a bus load if a generator failure occurs.

Direct lift control which was installed on a DC-8 and flight tested by Douglas in 1968 is used during the approach and flare maneuver, because of the size and inertia characteristics of the DC-10, to provide the aircraft response required for accurate beam following. A comprehensive FG&C self-test and monitoring system together with automatic mode reversion and annunciation is integrated into the design.

During flight test, the automatic landing system must demonstrate touchdown dispersions as defined by Advisory Circular 20-57 based upon the use of Category II ILS approach facilities which on a two-sigma basis meet a localizer course alignment accuracy of ± 10 ft (to touchdown) and a glideslope receiver centering error of $\pm 5\mu a$. The aircraft touchdown limits are laterally, 27 ft off the centerline of the runway on a two-sigma basis, and longitudinally, the dispersion of the main gear touchdown point should not exceed 1500 ft total after a nominal point, on a two-sigma basis (see Fig. 5).

Environmental conditions should encompass headwinds up to 25 knots, tailwinds up to 10 knots, crosswinds up to 15 knots, moderate turbulence, and wind shear of 8 knots per 100 ft from 200 ft to touchdown. Conformation of these dispersion limits may be demonstrated on the basis of analysis

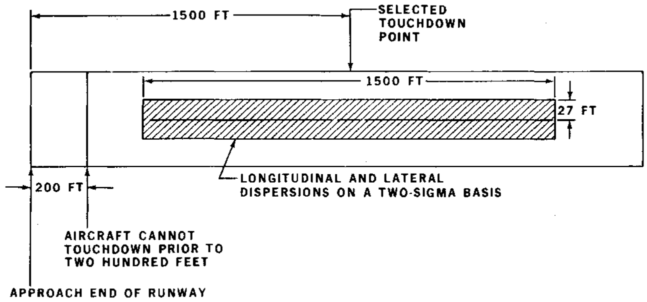

Fig. 5 Autoland touchdown dispersion requirements.

conducted in support and cognizance of the flight test results and evaluation.

As a prerequisite to flight test and to specifically permit the test and integration of flight hardware, Douglas has built a full-scale controls development test stand (CDTS) that will thoroughly test and evaluate the prototype flight control system and related parts of the hydraulic and the FG&C systems. Results of preliminary analytical and simulator studies on control system gains, responses, and forces will be mechanized into the CDTS and varied as required on the basis of tests and pilot evaluation. Typical tests would initially involve, on an individual basis: the pitch axis (elevators), and lateral axis (aileron and spoilers), direct lift control, directional (rudder), trim (horizontal, aileron, and rudder), throttles, and flaps. Upon completion of these single axis tests, total system integrated tests would be performed.

As an integral part of the controls development fixture, an extremely sophisticated and comprehensive simulator complex will be developed to insert the pilot in the flight guidance and control loop.

A high-fidelity DC-10 cockpit and a Sigma 5 digital and C_i 5000 analog computer complex configured in a hybrid configuration will be tied to the actual flight controls and avionics hardware to provide a high-performance avionics and control system simulation. In addition, an advanced special purpose visual simulator will be integrated into the simulator to enable the evaluation of Category III approach maneuvers to actual touchdown and rollout.

The total systems test and evaluation described herein is extremely important and yields dividends during the flight test program with regard to safety, cost, and schedules and will, in addition, provide the "pilot in the loop" assessment which is so critical and essential toward development of the autoland Category III maneuver. In summary, the following factors will be thoroughly assessed by the control development fixture/simulator facility:

1) workload, 2) pilot monitoring capabilities, 3) monitoring requirements, 4) flight instrument verification or requirements, 5) warning and caution constraints, 6) automatic mode reversion requirements, 7) mode annunciation require-

Table 2 Fail operational autopilot

SENSING	COCKPIT DISPLAY	AUTOPILOT SYSTEM NO. 1	
	COMPUTATION CHANNEL "A"	ACTUATION	CONTROL SURFACE
	COMPUTATION CHANNEL "B"	ACTUATION	CONTROL SURFACE

SENSING	COMPUTATION CHANNEL "A"	ACTUATION	CONTROL SURFACE
	COMPUTATION CHANNEL "B"	ACTUATION	CONTROL SURFACE
	COCKPIT DISPLAY	AUTOPILOT SYSTEM NO. 2	

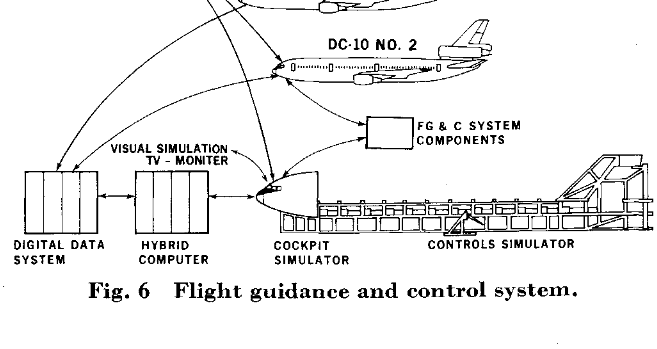

Fig. 6 Flight guidance and control system.

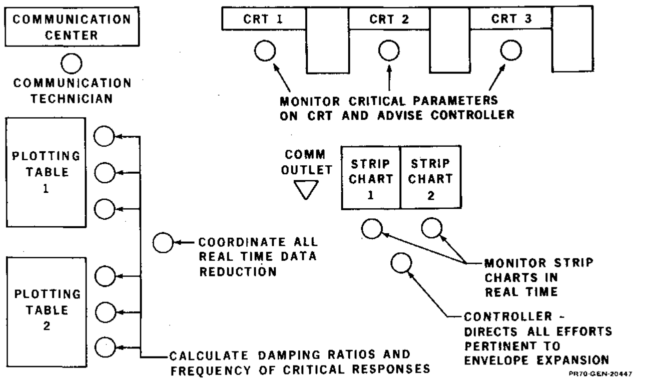

Fig. 7 Data center configuration during flutter flights.

ments, 8) control system gains, responses, 9) aircraft response to control inputs, and 10) direct lift control.

As the flight test program progresses, flight data will be used to determine aircraft stability and control derivatives which, in turn, will be used to update the CDTS simulator. This update will be accomplished on a continuing basis so that the controls development fixture and simulator will match the stability and control characteristics of the test aircraft. With this degree of fidelity, inflight control system or FG&C system performance and equipment problems will be thoroughly evaluated and assessed on the ground on an expeditious basis in support of subsequent flights (see Fig. 6).

A category II-quality ILS beam will be installed by Douglas at the Marine Corps Air Station, Yuma, Ariz., for the purpose of the DC-10 FG&C system flight test program. The beam characteristics will be programmable with regard to noise, gains, and convergence. A mobile laser tracking system in conjunction with an optical system will be employed to provide accurate aircraft space positioning data which will be used to perform three-dimensional ILS beam mapping and wind profiles. Onboard the test aircraft a simulated ILS beam will be implemented with the capability of providing upsets to be used for air work.

The data acquisition and processing system will make it possible to handle the large quantities of flight guidance and control system data, perform the test data evaluations, and the integration of the test data with the CDTS simulator on an efficient and necessarily time-critical basis.

The DC-10 has an all-hydraulic flight control system that is supported by three independent hydraulic systems. Each hydraulic system has two primary engine-driven hydraulic pumps, and hydromechanical pumps are used to interconnect and transfer energy from one system to another without the transfer of hydraulic fluid. The hydraulic systems redundantly supply fluid to the flight control surface actuators. The control surfaces consist of four elevator segments, horizontal stabilizer, upper and lower rudder segments, inboard and outboard aileron segments, spoilers, and direct lift control. This system has the backup and redundancy which covers every possible contingency. Flight test requirements will be dictated by special conditions imposed by the FAA for control systems without manual backup wherein redundancies and the simulation of two failures must be demonstrated.

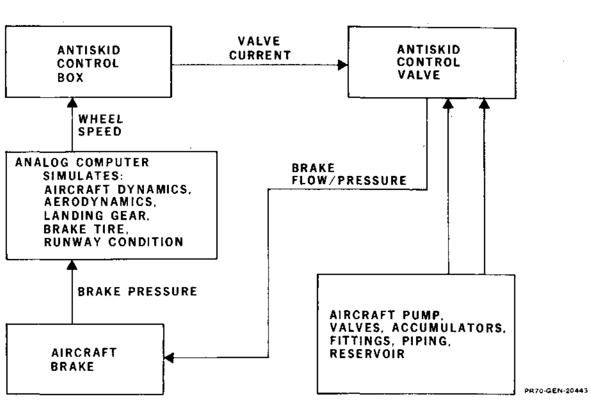

Fig. 8 Antiskid braking system simulator.

Flutter Testing

Flutter testing will be conducted in the early phase of the flight test program to expand the aircraft flight envelope to design altitudes and airspeeds, and thereby allow uninterrupted progress of stability and control tests. The flight tests will be performed with the airplane in the critical combinations of airplane loading, fuel distribution, altitude, Mach number, and dynamic pressure.

The general flight procedure which will be used on the DC-10 involves the excitation of various oscillatory modes by means of manual control surface pulses and controllable aerodynamic vanes installed on the wings and the horizontal and vertical surfaces. The vanes can be operated separately or in combinations at preselected displacements, discrete frequencies, and sweep frequency rates. Combination of these excitation techniques provides the means for early identification of critical modes and an in-depth analysis of the damping characteristics at and near these modes.

While the flutter test methods to be employed on the DC-10 are similar to those previously used, the increased airplane size and control system complexity have established requirements for more extensive instrumentation and an expansion of the real-time data monitoring capability. The primary instrumentation will consist of accelerometers, strain gages, and control surface position indicators. This instrumentation will be used in conjunction with the high-speed computation capability of the digital data system to determine the damping ratios and frequency response as a means to verify the absence of divergence and control surface buzz. The data will be transmitted in real-time to the ground station by means of the telemetry link, and the onboard tape will be subsequently processed at the ground station to provide frequency analysis, damping coefficients, modal analysis, transfer functions, and trend studies.

Although complete failure analysis will be performed, the flight test will include unique fail-safe test configurations such as failed control surface actuators, control and damping actuators with free play links, and balance weights in critical areas of the control surfaces.

During the inflight tests, the ground station, shown in Fig. 7, will be manned by a flight controller, data monitors, data analyzers, data plotters, and communication technicians. A real-time analysis of critical test parameters, with regard to flight safety, will support the flight test aircraft at the ground station.

Landing Gear and Antiskid System

The optimization of airplane stopping distance requires an antiskid system that is compatible with landing gear and brake system dynamics. To derive the most meaningful data on these systems during the aircraft landing tests, extensive preliminary ground tests and simulations are being performed. These include the following.

Dynamometer test

Dynamometer tests are being conducted by the Goodyear Company using the complete landing gear, brakes, wheels, tires, and antiskid system in an integrated assembly. These tests will provide data for normal landing life cycle, rejected takeoff energy absorption characteristics, wheel fuse plug integrity, and antiskid operation. In this manner, the dynamic relationship between each of the subsystems can be evaluated simultaneously to provide optimum performance.

Antiskid braking system

A full-scale analog engineering development simulator using actual antiskid and brake components will be used to provide a more accurate prediction of the system performance. The simulator, shown schematically in Fig. 8, utilizes wheel speed, brake pressure, coefficient of friction slip-ratio curves, coefficient of friction airplane velocity curves, landing gear dynamic parameters, airplane drag loads, normal loads, and airplane vertical bounce and pitching characteristics to achieve a realistic evaluation of systems performance.

In addition to an accurate prediction of system performance, the simulator will be used to evaluate the following factors: 1) the effect of radio frequency interference, 2) the effect of electrical surge resulting from power transients at nose wheel touchdown, 3) the effect of spoiler operation on system performance, 4) the effect of pilot response, 5) optimization of braking techniques, and 6) functional checkout of flight test instrumentation.

It is of interest to note that these latter factors, while on the surface appearing to be of secondary importance, have historically accounted for a significant portion of many braking test programs.

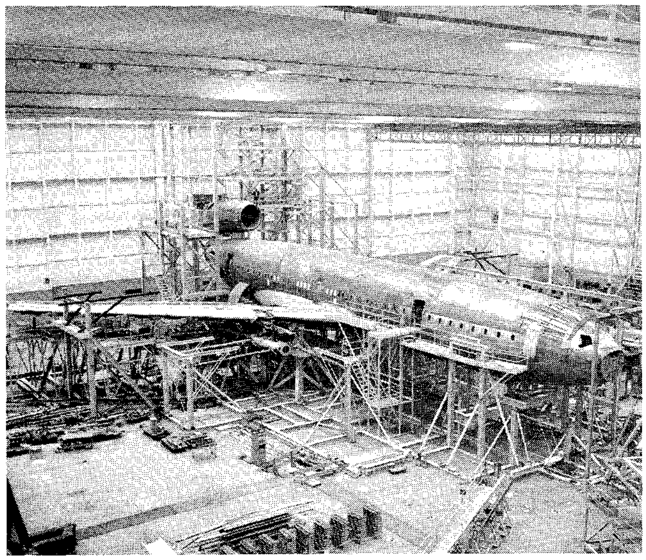

Fig. 9 Proof test arrangement.

Takeoff and Landing Performance

The evaluation of both takeoff and landing performance has been historically measured by means of a manually operated photographic tracking system that measured aircraft ground speed, height, and distance along the runway as a function of time. Although this system provided relatively accurate results for airplane velocity and space positioning, the data processing was dependent on an excessive number of manual operations which were both costly and time consuming.

To eliminate the disadvantages of this method, the DC-10 test program will use a laser tracking system with an optical system as backup as a means of measuring both takeoff and landing performance. The laser tracking system will use automatic tracking to eliminate manual tracking error and will record instantaneous airplane velocity and space positioning data on a magnetic tape format which is compatible with the digital data system. As the data tapes are processed, the preprogramed computers will make the necessary corrections for airplane gross weight, runway slope, pressure altitude, and runway wind conditions. In this manner, standardized results of the airplane performance will be available within hours after the completion of the tests, thereby providing the data necessary for subsequent tests without delay.

Structural Proof Tests

Structural proof tests were conducted on the DC-10 to demonstrate airframe structural integrity for critical static loading conditions. This program follows the normal structures design and development phase and consists of a comprehensive series of loading conditions established to develop limit stresses in primary structural members.

The proof test setup, Fig. 9, is a relatively fixed arrangement of electrohydraulic, servo-controlled actuators and tension/compression load whiffling with load application controlled by a computerized load control and data acquisition system.

Noise Measurement

Concern introduced by social groups over noise pollution by all industrial causes has also directed attention to aircraft operations. Part 36 of the FAR, as amended November 18, 1969, provides for a more rigorous control of aircraft noise certification and is particularly explicit with regard to test conditions and requirements. Effective perceived noise level (EPNL) is used as the primary unit to evaluate aircraft flyover noise.

The importance of noise certification must be considered because of the necessity to establish a compatibility between noise levels and airworthiness standards. Noise level standards can be complied with but, if this occurs as a result of reduced takeoff gross weight, then an undesirable performance compromise and, in turn, economic constraint to the operators is offered. Tests to show compliance with the FAR consist of a series of takeoffs and landings on a prescribed course and flight path during which noise measurements must be taken at designated points. A minimum of six samplings, which have a 90% confidence limit not exceeding ± 1.5 EPN_{dB}, must be made at each measuring point. For takeoff, approach, and sideline, a noise level of 108 EPN_{dB} for maximum weights of 600,000 lb or more must not be exceeded at the measuring points. A correction factor adjusts this noise level for gross weight down to 102 EPN_{dB} for maximum weights of 75,000 lb and under.

The selected test site requires a relatively level topography and the surroundings, either man-made or natural, must not provide any sound attenuation. Temperature, relative humidity, winds, and other weather conditions must meet established nominal conditions. During the test, the aircraft position relative to the noise measurement stations will be accurately determined by means of laser tracking.

The takeoff maneuver, as shown in Fig. 10, starts at the beginning of the takeoff roll and continues until the aircraft is at 6 naut miles from that point. During this time, the aircraft must remain in the takeoff configuration except for landing gear up and the flight path must be constrained to pass directly over the noise measurement stations.

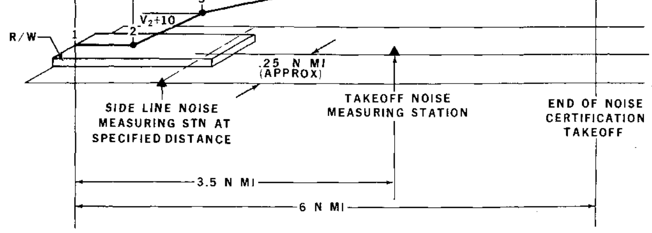

Fig. 10 Noise measurement takeoff maneuver.

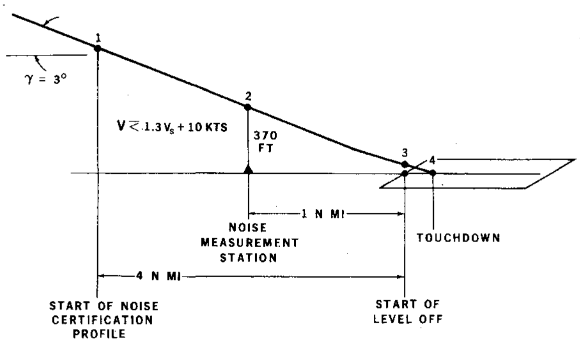

Fig. 11 Noise measurement—approach maneuver.

After liftoff, the aircraft accelerates and is flown at $V_2 + 10$ and must continue with takeoff thrust to at least 1000 ft where thrust reduction may be started. This power reduction may not go lower than the power or thrust that will provide level flight with one engine inoperative, or below that power or thrust that will maintain a climb gradient of at least 4%, whichever power or thrust is greater.

The approach maneuver, shown in Fig. 11, starts four miles from the end of the runway on a glidepath of 3° with the aircraft in its most critical configuration at a speed of not less than $1.3\ V_s + 10$. All engines must be at the same thrust level. The noise measuring station is located 1 nautical mile from the end of the runway. In addition to the takeoff and approach, sideline measurements are also taken.

As the requirements for quantity and quality of noise data increase and the time requirements decrease, flyover noise data processing techniques must become more sophisticated and automated. As a result, Douglas has developed an automatic data handling and analysis system called the parallel analog filter system which enables the real-time analyses of flight test data.

In an initial aircraft test program, the tests may progress in stages from basic sampling to determine the order of magnitude of noise levels and the development of pilot procedures and data system operations, to the tests themselves and finally, FAA demonstrations.

Area Navigation

Area navigation has become the subject of intense interest by the FAA and the airline industry as a result of the dependency present navigation methods have upon established routes linked together by the VOR/DME/TACAN ground facilities which limit the number of routes available. When consideration is given to arrival and departure routes, these factors represent a more serious limitation. As a means of establishing a more comprehensive, flexible, and functional navigation system, the concept of area navigation has been introduced. Area navigation (RNAV) as defined by the FAA is a method of navigation that permits aircraft operation on any desired course within the coverage of station-referenced navigation signals or within the limits of self-contained system capability. The basic components of the ARINC Mark II area navigation system usually assume inertial sensor system and VOR/DME's as basic navigation inputs and a maximum degree of navigation automation with design capable of expansion to accommodate future requirements. Flight data storage units and a moving map display are usually assumed as part of the system (see Fig. 12).

According to FAA AC 90-45, acceptable means of compliance (for use under IFR) may be demonstrated by a combination of bench tests of the individual components, and ground and flight tests of the installed area navigation system. Flight tests for accuracy for the enroute and terminal cases are only necessary if not adequately determined by ground test or if it is suspected that the pilot display is such that pilotage errors of ±1.0 naut mile may be exceeded. There will be flight test, however, for the approach maneuver because of the importance of the pilot display during an approach. In addition, the area navigation system will be checked out in flight to determine whether the design and installation criteria are satisfied.

Flight Test Personnel Training

The scope and comprehensiveness of aircraft and systems training for the flight test pilots, flight engineers, flight test engineers, and all other test-related personnel impacts directly on test effectiveness. Training on the DC-10 began one year prior to the scheduled first flight and will be broadened to include test runs and flight simulation to establish plans, and to train data acquisition and processing center personnel in procedures and operations techniques. In addition, flight test crews participate in DC-10 design and development, and in engineering simulations that are used to design, develop, and establish system operational characteristics.

Aircraft Flight Training Simulator Data

One of important economic problems confronting airlines today is related to the technical aspects of flight crew training. The loss of an aircraft from line operations and associated hourly operating costs make the exclusive use of aircraft for

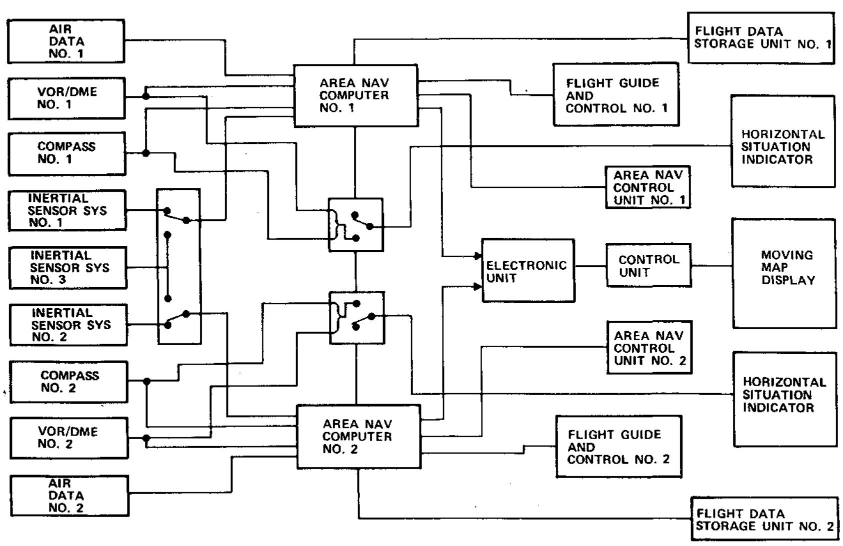

Fig. 12 Mark II area navigation system.

flight training economically prohibitive and establish the requirement for a high fidelity, ground-based simulator. Unless the simulator flies like the real airplane, flight crew training is degraded, simulator effectiveness is reduced, and the number of aircraft hours required for crew training and certification increases. The fidelity of the simulator is based on design, hardware, and software factors, and the scope and type of flight test data supplied for simulator update. Flight test data required for simulator update fall into three categories: 1) Specific types or range of flight test data not normally provided by the airplane contractor; 2) Specific data, not of flight test nature, requiring an instrumented or otherwise specially equipped aircraft; and 3) Specific (or coefficient) form of flight test data normally provided by the airplane manufacturer.

The concept of providing data of this type to simulator manufacturers, although not unique, has not generally been practiced heretofore.

Impact of Government Regulations

The government regulations that deal with the Type Certification of commercial aircraft are continually changing to be compatible with the increasing size and complexity of the present and future generations of aircraft. A typical example of such change was the replacement of Civil Air Regulation Part 4b with FAR Part 25. While these documents are not drastically different in scope, the latter presented a more specific delineation of the regulation requirements in many areas which involve aircraft flight testing.

The design of any commercial aircraft is, by nature, bound to contain unique features and the basic regulations intended for this type of aircraft may not include specific test requirements which are applicable. To ensure a level of safety equivalent to those provided by the basic regulation, a series of Special Conditions is imposed to cover the flight test demonstration requirements of these unique aircraft design features.

In addition, the interpretation of certain regulations or the method of demonstrating compliance will at times present questionable areas when applied to a specific airplane model. To more clearly define these areas, the FAA periodically publishes Advisory Circulars which are intended to either clarify the intent of a specific regulation or offer alternate test methods to demonstrate compliance. The interrelationship between all of the regulatory documents is not, however, as precise as it would appear on the surface. Each new airplane model has its own unique characteristics and no preconceived regulation or combination of regulations could anticipate the standards to be applied to future aircraft developments.

One of the key requirements in the conduct of an effective flight test program is the thorough understanding of all regulations which are applicable to the certification of that particular aircraft. Such knowledge applied in the planning stages will effectively contribute not only to a more systematic test program but will preclude the possibility of costly and time consuming test repetitions.

Conclusions

The increased size and system complexity of commercial jet transports has dictated the need for more extensive testing to define the airplane and system performance and to assure a sufficient margin of operational safety. Because of the high operating cost of test airplanes, it becomes necessary to not only minimize the inflight tests but to perform these tests in timely, effective manner without compromising the quality of the results. To achieve these goals the following methods are currently being employed on the DC-10 test program:

1) A more extensive test planning effort to provide for increased use of parallel testing and optimization of the number of test airplanes and quantity of instrumentation.

2) Implementation of an advanced digital data acquisition and processing system which was designed specifically for flight test applications.

3) An increase in scope and utilization of simulators and ground testing to minimize the inflight development time and provide more accurate prediction of inflight test results.

4) The use of more sophisticated test equipment to provide for more efficient use of flight time.

5) A design engineering team oriented toward rapid response to design changes to decrease time delays during the development phase of the test program.