N92-30113

STATUS OF THE FAA FLIGHT LOADS MONITORING PROGRAM

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ABSTRACT

In support of the Federal Aviation Administration Aging Aircraft Research Program, the Agency has established a Flight Loads Data Collection Program for Commercial Aircraft. The objectives of this Program are to:

-Review existing data collected by other sources including but not limited to U.S., Foreign, Military, etc.

-Collect current operational usage data from both large and small transport aircraft.

-Develop criteria for future generations of transports.

This paper presents the status of the various programs which are completed, underway or planned.

The FAA will be collecting, storing, and analyzing the data which characterize typical commercial transport operations. The airframe manufacturers will handle the task of calculating the loads and stresses.

BACKGROUND

Many of today's large commercial transports and smaller regional/commuter carrier aircraft are being flown beyond their original intended service lifetimes, and the only feedback the FAA and the airframe manufacturers receive from current U.S. air carrier operations is the number of flight hours and landings which define the pressurization cycles and thus the major loads on the pressure hull. The stress and load history on the rest of the aircraft, i.e., wing, tail, flaps, controls, etc., which is dependent on flight operations, is assumed, but is largely unconfirmed.

Deregulation, advances in technology, and the increased demand for air travel have significantly modified how commercial aircraft are flown. Examples of these changes include:

- Hub and spoke scheduling concepts, replacing fixed routes.
- Noise restrictions affecting airport traffic patterns.
- Elimination of most circular holding patterns at major airports.
- Higher seat utilization (higher gross weight).
- Fly-by-wire/fly-by-light (FBW/FBL) control systems.
- Flight restrictions and airport curfews.
- Improved warning of turbulence.

Because the practice of flying both large and small commercial aircraft beyond their original intended service lifetimes is expected to continue into the foreseeable future, a need exists to acquire usage information to assure that the design criteria for future generations of aircraft are based on operationally relevant data.

The FAA Flight Loads Monitoring Program includes the following elements:

- The program in which researchers will collect, review and present summaries of significant data from earlier flight loads data collection and strain survey efforts. This will include available data from National, International and Military Transport programs.

- Installation and evaluation of an experimental optical disk recorder in the NASA owned Boeing 737.

- Development of data reduction routines and ground station operation.

- Installation and operational use of a prototype recording system on a Boeing 737 in U.S. domestic routine airline service.

- A pilot program for collecting loads data on 24 revenue transports of the major U.S. air carriers.

- A commuter category flight loads monitoring program.

- An in-flight strain survey which is being conducted on the FAA owned Beech King Air, in support of the commuter category flight loads monitoring program.

PURPOSE OF FLIGHT LOADS DATA COLLECTION PROGRAMS

The objectives of the flight loads research are to instrument regular in-service aircraft with state-of-the-art data acquisition equipment to collect new loads data: (a) to determine if the loading spectra being used or developed for design and test of both small and large aircraft are representative of actual operational usage, and (b) to develop structural design criteria for future generations of small and large aircraft.

Successful completion of this research will result in the existing loads data base being updated with increased accuracy from data collected using new state-of-the-art digital recorders. The original design and test spectra for the newer in-service aircraft will be validated. More severe routes will be identified affording airlines the opportunity of restricting the continuous use of a particular airplane in a severe environment.

FLIGHT LOADS MONITORING PROGRAM STATUS

Existing Data

Major organizations and government agencies have conducted data collection programs in the past. While many of these programs have objectives that are not directly related to aging aircraft, the recording technology and applicable results will be identified and incorporated into this program. Flight Loads Data participants and research includes:

The Civil Aviation Authority Data Recording Program (CAADRP) which is primarily designed to collect data for pilot training. Data from British Airways aircraft are utilized for in-flight loads determination. Post flight analysis determines the occurrence of unusual events, some of which are used in a training program for pilot proficiency, and others are used to evaluate, for example, turbulence encounters.

The Netherlands National Research Laboratory (NRL) - Extensive studies on aircraft usage and load experience in relation to fatigue, and compilation of gust statistics were completed in 1989. Limitations in the program included the required use of the existing Aircraft Condition Monitoring System (ACMS) recorders, inability to change the aircraft operation, and cost constraints. In spite of this, extensive information was obtained for nearly 122,000 flight hours.

U.S. Navy Flight loads programs are used for the collection of maneuver statistics rather than the gust loads. Most military flight loads data collection programs are designed to determine inspection intervals in fleet aircraft. Their procedures do not support civil programs because of the different intended results and operating environment, however the equipment used to acquire the necessary information may have application in civil use.

The current FAA flight loads monitoring program includes a separate task to produce an International Flight Loads Data Bank. This task will:

- Work with the commercial airframe industry to determine the priority, needs and organization of the material.

- Identify overseas sources of flight loads data for both large transport and regional/commuter aircraft determined to be of significant value in furthering the aims of the FAA's developing program.

- Acquire and publish loads data identified above.

- Document fully the means used to acquire the data, giving the rationale for the selection of the variables recorded, sampling rates, and a description of the sensors, transducers, gauges, etc., used to develop the raw signals and their characteristics.

- Document the methods used to analyze and organize the data, filters, algorithms, statistical methods.

This task is being handled under an agreement on cooperation between the FAA and the Netherlands Civil Airworthiness Authority. Most of the work will be done in Europe.

Large Transports

Many of the parameters currently recorded as time histories on the existing large transport Digital Flight Data Recorder (DFDR) 25 hour loop tape will be routed to a special high density optical disk recorder which is capable of collecting and storing many months of flight usage information. Data from these recorders will be analyzed on the ground and periodically presented as statistical summaries in FAA Technical Reports. The complete system of onboard recorder data transfer and ground station operation is being thoroughly checked out prior to installation of the first recorder to be used during revenue operations.

An experimental optical disk recorder has been installed in the NASA owned B-737 aircraft. This system is currently collecting complete time histories of selected flights of the same data being stored in the DFDR (Crash Recorder). Analysis of these data is expected to provide the following: (a) Reliability of the optical disk recorder versus solid state recording instrumentation, (b) Comparison of data transfer rates between the optical system and a solid state system, (c) A measure of the data quality of today's advanced digital data recording systems, (d) Flight data from which data health monitoring algorithms can be derived, coded and tested, (e) Flight usage data from which flight characterization data reduction algorithms can be coded and verified, i.e., Nz exceedances, altitude, airspeed bands, etc.

The FAA is working closely with the airlines to obtain volunteers to host the recorders and provide other data as required. The anticipated onboard data acquisition configuration is described on Figure 1. The notations 429, 573, 591 and 717 refer to on-board Aeronautical Radio, Inc., (ARINC) data bus identification numbers.

Two certified Sundstrand optical disk recorders have been purchased. One will be installed on a U.S. air carrier Boeing 737 and the second used as part of the ground station. Data will be collected, transferred and analyzed by the ground station.

Twenty-four recorders will be installed in various airplane models over four years at the rate of six per year. Data will be collected while operating under the U.S. air carrier rules of Federal Aviation Regulation (FAR) Part 121 in normal passenger operations. The data flow will be as indicated on Figure 2.

Data will be off-loaded and reviewed periodically at approximately "B" level maintenance intervals. Measured normal and lateral acceleration data will be filtered to separate gust and maneuver events per Figure 3. The maneuver event summaries will be used directly by the manufacturers to develop component loads using the validated loads programs. Filtered gust data will initially be defined as high frequency accelerations measured in service. Through the use of airplane aerodynamic parameters, derived gust velocity spectra will be developed and provided in spectrum format to the manufacturer.

The manufacturer will then use both the maneuver and gust information to calculate component loads, and with the validated stress analysis program and detailed design data, develop the individual component stresses. See Figure 4. The procedure which the manufacturers use to develop reliable airplane and component loads from the relatively simple measured parameters, using their own validated loads and stress analysis programs, is described in detail in Reference 1.

The ultra high density optical disk recorder is capable of storing up to 300 megabytes (600 using both sides) of complete time history flight data representing 600-800 flight hours of normal operation transport service.

The ground station data reduction software will have the ability to recognize the aircraft situation (take-off, climb, cruise, etc.,) and based on this situation select the appropriate data reduction and storage algorithms. The recorded data will be processed, separated, and stored on two permanent storage records: (a) typical aircraft usage characteristics, and (b) individual flight summaries.

As part of the structural life assessment process, the large transport airframe manufacturers conduct a highly detailed component by component damage tolerance analysis.

For a major structural member such as a wing, fuselage or tail, validated equations exist for computing the Bending Moment (M), Torsion (T), and Shear (V) for the wide variety of anticipated structural load conditions.

The stress at any particular location can therefore be estimated by yet another validated relationship: Stress = f(M,T,V), Figure 5, and the stress history (or anticipated stress history) for the component can be defined.

The problem in large transport commercial aviation is that the design parameters used for the fatigue and damage tolerance analyses were derived from data collected from the early 1950's and 1960's, which were obtained with sometimes questionable data acquisition and reduction processes.

Small Transports

Manufacturers and operators of small transports have indicated a strong interest in monitoring loads parameters. This has resulted in the need to conduct research in the following specific areas:

- Development of a fleet tracking system to provide fleet usage information and develop trend data.

- Development of reliable lateral load spectra for empennage service life determination.

- Possible development of a certified lightweight, low cost airframe strain or fatigue recorder.

- Development of inspection schedules which realistically reflect typical usage.

The regional/commuter effort will involve the instrumentation of aircraft with gross weights below 50,000 pounds, and will be propeller driven. Since both small and large transports will be required to be equipped with Digital Flight Data Acquisition Units (DFDAU), the flight usage data for the aircraft of 10 seats or more can be acquired in a means similar to the larger transports. Acquiring the data from the smaller airplanes having less than 10 seats operating under FAR Part 135 will involve the installation of special recorders, instruments, and sensors, and will limit the ability to transfer the equipment from one FAR Part 135 airplane to another.

The analysis and interpretation of the commuter data will include consideration of both geographic area effects and seasonal fluctuations. The latter will necessitate acquiring the aircraft usage information in yearly cycles in order to properly assess the seasonal variations. In addition, the effects of yaw damper and autopilot will be studied. A detailed literature search of both domestic and international service usage will also be conducted.

The development of a flight loads parameter recording program for regional/commuter aircraft will in many cases require additional wiring to acquire all the necessary air data signals and controls information for post flight data analysis. While the atmospheric gust environment for commuters is the same as for large transports, the small aircraft usage (i.e., length of flight, cruise altitude, etc.,) and hence the exposure is quite different. In addition, it is hypothesized that the maneuver loads environment may also be different since commuters routinely use alternate runways, and fly on different flight paths. The commuter flight loads monitoring program will be developed based on knowledge gained during the initial planning and implementation phases of the large transport flight loads monitoring program. Additional steps are considered necessary in the implementation of the small transport flight loads monitoring program.

The development of empennage lateral loading criteria, and the relationship of exposure to lateral and vertical gust velocity will form part of the research activity. Using relatively simple parameters such as lateral acceleration at the airplane c.g. and airplane weight and speed may not be sufficient for the definition of a fin and aft body lateral loading spectrum. Furthermore, some c.g. vertical acceleration and speed data have been collected on small airplanes, and it is not known if this can be used to predict a lateral loading spectrum. In order to understand these relationships, a limited flight strain survey program will be conducted on the FAA owned Beech King Air. Strain gauges, surface position transducers and accelerometers will be installed on the airplane and the relationships determined. This limited flight test program will also be used to determine the minimum number of additional sensors and their location required on the operational flight loads monitoring program.

TECHNICAL DETAILS

Airborne Flight Loads Data Recorder Hardware

The new technology Sundstrand optical disk recorders can be installed in all large transports. This recorder consists of a high performance ultra high density erasable optical disk recording system with the capability to: (a) interface with the large transport aircraft ARINC 429 data bus, flight data entry panel, CG accelerometer, and other discrete and analog inputs, (b) provide a significant amount of embedded computational capacity for data acquisition, editing, and parameter selection, (c) be reprogrammable with the capability to accommodate future DFDAU enhancements, and (d) provide sufficient non-volatile memory (minimum of 300 megabytes) for extended aircraft operation without down loading more frequently than the standard "B"

Level Maintenance check of eight to ten weeks. See Figure 6, Sundstrand Recorder.

The recorder will utilize the auxiliary output of the newer dual microprocessor DFDAUs. Microprocessor #1 is dedicated to providing the required Digital Flight Data Recorder (crash recorder) input. Microprocessor #2 is optional equipment which is fault isolated from microprocessor #1, and is beginning to attain wider use as an operator maintenance tool. See Figure 7.

This new recorder will have the ability to record complete time histories of over 40 flight, control, and configuration parameters, and record and store between 500 and 800 flight hours of the data in 12 bit words. The new system will allow for extensive data quality editing, thus assuring that the data used in the subsequent analyses will be of the highest quality.

State-of-the-art digital onboard microprocessor based recorders ("Smart Recorders") are being used extensively by the military and have eliminated nearly all the tedious ground processing required by most previous methods. These recorders can use either bubble memory or be installed with a hard drive memory for post flight data interrogation and analysis and will likely be used in the regional/commuter program. Three types of data parameters are usually obtained with this system.

- Peaking parameters. The accelerations and rates (pitch, roll, etc.), are in this category. The criteria defining these need to be specific and coded before they can be identified. Peak and valley determination is a form of data compression, such that each time a peak or valley determination of a parameter is made, the instantaneous value of numerous other parameters is also recorded. The separation of gust and maneuver normal and lateral accelerations can also be accomplished onboard.

- Time parameters such as airspeed and altitude which can be recorded whenever these parameters cross predetermined range boundaries.

- Discrete channels such as flap position, take-off and landing switches, squat switch, yaw damper, autopilot and others which trigger the recording of data whenever they change state.

These recorders can typically store 2 megabytes of compressed data, which is sufficient to store data between "B" Level Maintenance checks.

Ground Station

The new flight loads data recording ground station will be a state-of-the-art microcomputer with the capability of analyzing and making decisions on data selection and permanent storage for future flight data evaluations. In order to expedite the data transcription process (i.e., optical disk to ground based computer), the ground station will input the airborne optical disk data using an off-the-shelf hardware Standard Computer System Interface (SCSI). Data will be transcribed and stored in the ground station central memory, and software will be written to recognize the aircraft situation (climb, cruise, etc.), and based on this situation, select the appropriate data reduction and storage algorithms. When the data analysis is complete, databases consisting of individual flight summaries, and complete time histories will be compressed and stored on two sided 600 megabyte optical disks. It is estimated that downloading the optical disk to the ground station central memory will require no more than 30 minutes. The initial design of the aircraft and ground station interface is presented on Figure 8. The commuter ground station will have a similar design but will not involve the optical disk.

Data Health Monitoring

This is the FAA's initial digital flight loads data collection program, and is expected to be in existence for many years. The hardware will be transferable among most large domestic transports and operators, and a number of automated digital data processing procedures will need to be developed and incorporated into the total data reduction and analysis process. Since, at this time, no data are available from the new dual microprocessor DFDAUs, it is not possible to assess the data condition and develop and incorporate detailed data editing algorithms, however the concepts which will be used are presented and discussed. The two principal sources of data editing procedures are presented in references 2 and 3. In addition to the built-in bit tests within the optical disk recorder, the data health monitoring will consider several issues including (a) activity testing to verify that the data received from the various data channels are exhibiting at least a minimum of reasonable activity, (b) wild point editing to remove and replace data spikes and, (c) range tests to ensure that the data processed are within reasonable upper and lower limits, and represent information from a realistic physical environment.

The health monitoring represents a major endeavor which, in itself, does not produce new design criteria or verify existing criteria, however, the lack of a reliable and consistent data health monitoring system could compromise the results of this entire program both now and in future years.

Gust and Maneuver Acceleration Separation

Inspection of many power spectra of the center of gravity normal acceleration data indicates that the lower frequency maneuver accelerations are sufficiently far removed from the gust responses that suitable digital filters can be used to reliably separate gust events from maneuver events. Examples of such power spectra appear on Figure 9, where the peaks occurring below 0.1 Hz are due to pilot induced maneuvers, while those between 0.1 and 1.0 Hz were identified as being due to turbulence. Peaks above 1.0 Hz are thought to be due to wing first bending mode.

Accordingly, the filters used in this program, illustrated in Figure 10 and described in reference 3, were developed based on the methods of reference 4, and utilized herein to separate pilot induced accelerations from aircraft gust response.

Results of the application of these filters to a typical time history are presented in Figure 11.

Derived Gust Velocities

Derived gust velocities (U_{de}) are computed using the method described in reference 5, and use the resultant gust normal accelerations from the gust and maneuver separation process.

$$U_{de} = 2Wa_n/m\rho_oSV_eK$$

where

U_{de} = derived (effective) gust velocity (fps)

a_n = airplane non-dimensional normal acceleration in g units

m = lift-curve slope, per radian

ρ_o = air density sea level, slugs/cu ft

S = wing area, sq ft

V_e = equivalent airspeed, fps

W = airplane gross weight (lbs)

K = dimensionless "alleviation factor"

In this program, the lift-curve slope is the untrimmed flexible lift-curve slope for the entire airplane, and is a function of Mach number, altitude, and flap deflection. Since the new data recorders will be recording complete time histories of all measured parameters, the corresponding time histories of derived gust velocities will be available. These time histories will then be compacted into peak/valley exceedances using level crossing techniques, and frequency histograms of U_{de} will be plotted in pressure altitude bands (e.g., 5,000 ft, 10,000 ft, etc.)

Collection and Analysis of Data

All of the flight data from these new and improved recorders will be analyzed and then permanently stored on the double sided high density optical disks with maximum storage capacity of 600 megabytes. A flight usage database will be established and updated with the continuous supply of additional commercial aircraft recorder data. Analysis of subject data is expected to provide airframe manufacturers with information with which to assess the structural (fleet-wide) usage severity of aircraft, structural components, and control surfaces loading spectra, etc. In addition, the individual flight usage summaries will provide both operators and manufacturers with (a) trend data such as operator usage differences attributable to route structure, (b) data to assess how well the original design criteria are reflected in the current typical fleet service usage and (c) data to establish structural design criteria for future generations of aircraft.

The new flight loads data analysis will be more comprehensive than any prior commercial flight data collection endeavor, and will provide user friendly instructions which automatically separate the output into individual flight summaries and typical aircraft cumulative usage characteristics.

Flight Phase Descriptions

The analysis of the cumulative usage data will involve separating the data into the following phases of flight: taxi, take-off, departure, climb, cruise, descent, approach, and landing. (Figures 12 and 13.)

Individual Flight Summaries

Algorithms will be developed to query the time history from each flight to identify and store the salient facts about each flight, to be later printed and used in the development of statistical summaries of extreme values or typical individual flight usage characteristics. The October 1991 FAA requirements for additional flight parameters to be recorded on the crash recorder will provide additional data from which automated statistical summaries, not available from prior flight load data collection efforts, can be developed. A sample of the typical individual flight data which will be collected and stored will include take-off and landing gross and fuel weight, maximum and minimum normal and lateral acceleration by flight phase, maximum control surface deflections, and airspeed and altitude of each flap extension and retraction. Periodic reports summarizing these results will be provided which can be typified by the following:

Flight Summaries

Flight Segment	Flap Position	Altitude Range	Airspeed Range	Nz Range	Ny Range
Departure	#1				
Departure	#2				
Departure	#3				
Departure	::				
Departure	::				
Departure	#N				
Climb					
Cruise					
Descent					
Approach	#1				
Approach	#2				
Approach	#3				
Approach	#::				
Approach	#::				
Approach	#N				

Takeoff/Landing Data Summary

The new FAR Part 121 crash recorder requirements include ground velocity as a required parameter, and this could be used to calculate and present a number of new takeoff and landing parameters. A data file of these calculated takeoff and landing data records could be established.

Model/Survey-wide Statistical Flight Usage Summaries

The complete time history data collected in these surveys will be summarized by aircraft model, analyzed, and presented in periodic FAA reports. A generic summary and typical statistical summaries are presented on Figure 14.

Flight Profile Statistics

Typical flight profile statistics will include: Distributions of flight length, airspeeds, and altitudes, time on auto pilot status, altitude, airspeed, gross weight, and fuel weight when changing flight phases (cruise, climb, etc.), distributions of take-off and landing gross weight and fuel weight. See Figure 15.

In addition to Figures 14 and 15, the following are typical examples of other data which will be made available from the individual flight summaries data bank;

- Level flight airspeed and altitude distribution.
- Gross weight distribution.
- Distribution of flight duration.

Acceleration Derived Statistics

For each of the flight segments, distributions of normal and lateral acceleration will be presented. See Figure 16 for a sample for vertical acceleration from reference 6. For each of the flight phases and for each altitude band, normal (vertical) acceleration will be separated and reported as gusts, maneuvers and total normal accelerations. From the gust portion of the normal accelerations, peak and valley derived gust velocities will be calculated and sorted by altitude and flap position. See sample normal acceleration on Figure 17 and derived gust velocity on Figure 18. Lateral acceleration will be reported as totals only.

Control Surface and Configuration Data

The control surface and configuration data summaries in this new program will be the most comprehensive of any survey conducted on the civil fleet thus far. These summaries will include control position profiles for Rudder, Aileron, Elevator, Stabilizer, and Spoiler for each of the flight phases. A typical profile is presented on Figure 19.

The flaps and high lift device deflection analysis will be handled in a somewhat similar manner, as shown in the example on Figure 19. For the take-off, departure, approach, and landing phases, the altitude and airspeed for each flap extension and retraction will be stored. From these, probability plots of dynamic pressure will be created for each flap setting during both extension and retraction. The distribution of airspeed during both extension and retraction will then be plotted with airspeed limit for that model and flap position as appears on Figure 20.

SUMMARY

The various elements of the FAA Flight Loads Monitoring Program for both large and small transports are in place.

An agreement to assemble existing international transport flight loads data is in work between the FAA and NLR. Tasks are being written for the Wichita State University National Institute for Aviation Safety to support the commuter flight loads program.

A new onboard technology flight loads data recorder has been selected and delivered for evaluation on the NASA B-737, and a prototype flight loads recording system is scheduled to be installed in a B-737 aircraft during 1991.

Six additional recording systems are planned to be installed on other transport aircraft in each of the next four years. When this new data collection system for large transports is operational with 24 recorders, 75,000 flight hours of data are expected to be collected and processed yearly. The new state-of-the-art recorders, automated data reduction routines, and comprehensive data analyses will result in a highly efficient, durable, accurate, and flexible system, capable of monitoring large quantities of data for typical usage of both current in-service aircraft and new aircraft models as they enter routine fleet service.

A limited flight test strain program is being conducted on the FAA Beech King Air to determine what parameters need to be measured for the commuter flight loads program. Depending on the results of the initial phase of the flight test program, it may be necessary to record stresses directly to obtain the desired data on small transports in commuter operations.

Further expansion of the program, into monitoring foreign aircraft operating under U.S. Registry, or U.S. manufactured aircraft operating abroad, will be considered following an initial evaluation of data collected during the pilot transport and commuter monitoring programs.

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3. Systems Development Corporation Integrated Services, Inc., Company Document PDD-79-01, Program Description Document for Automated Edit Program for Digital VGH Data Analysis, August 1977.

4. NASA TRR 179, Determination and Analysis of Numerical Smoothing Weights, Graham, R. J., 1963.

5. NACA Report 1206, A Revised Gust-Load Formula and Re-Evaluation of V-G Data Taken on Civil Transport Airplanes From 1933 to 1950, Pratt, Kermit, and Walter Walker, 1954.

6. FAA-RD-71-69, Airline Operational Data from Unusual Events Recording Systems in 707, 727, and 737 Aircraft, August 1971.

Figure 1

U.S. AIR CARRIER ON-BOARD LOADS DATA ACQUISITION

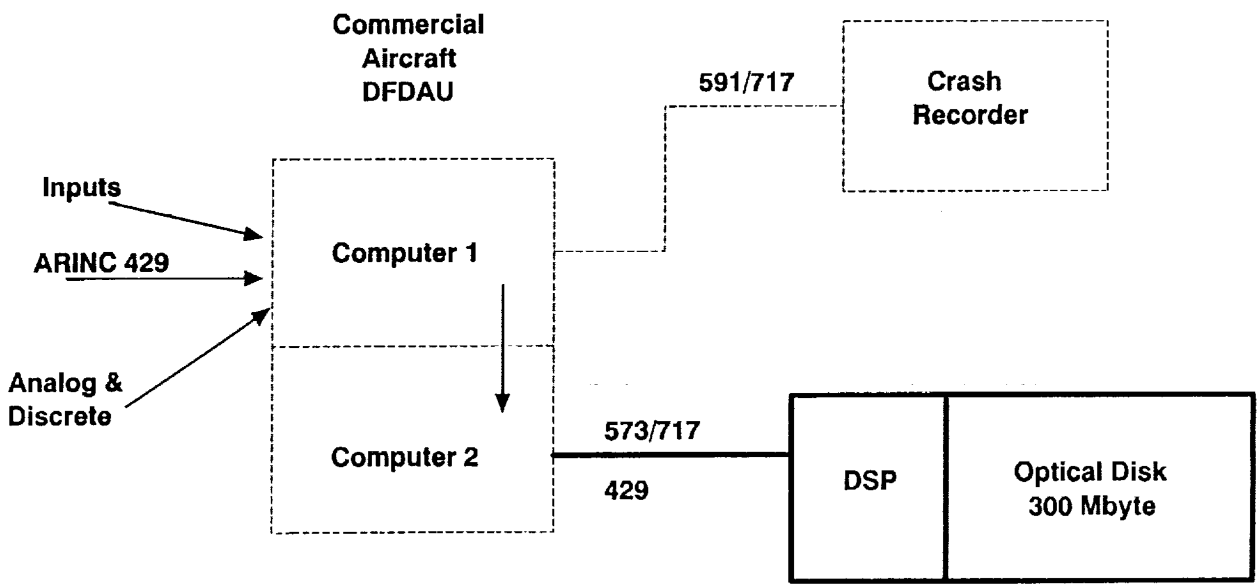


Figure 2

COLLECTION DATA FLOW - STEP 1

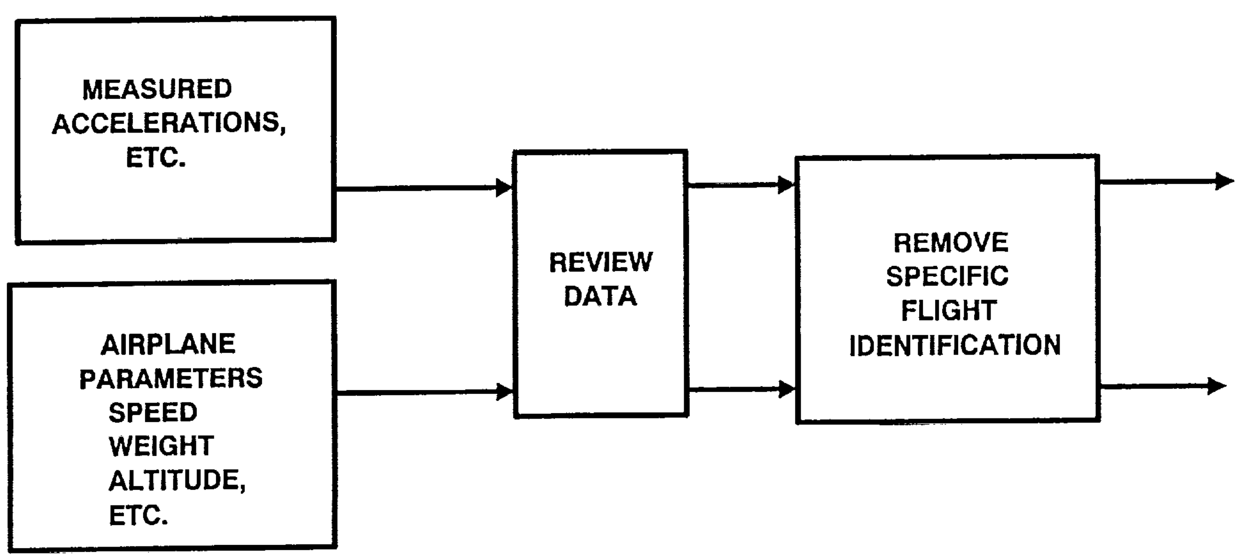


Figure 3

COLLECTION DATA FLOW - STEP 2

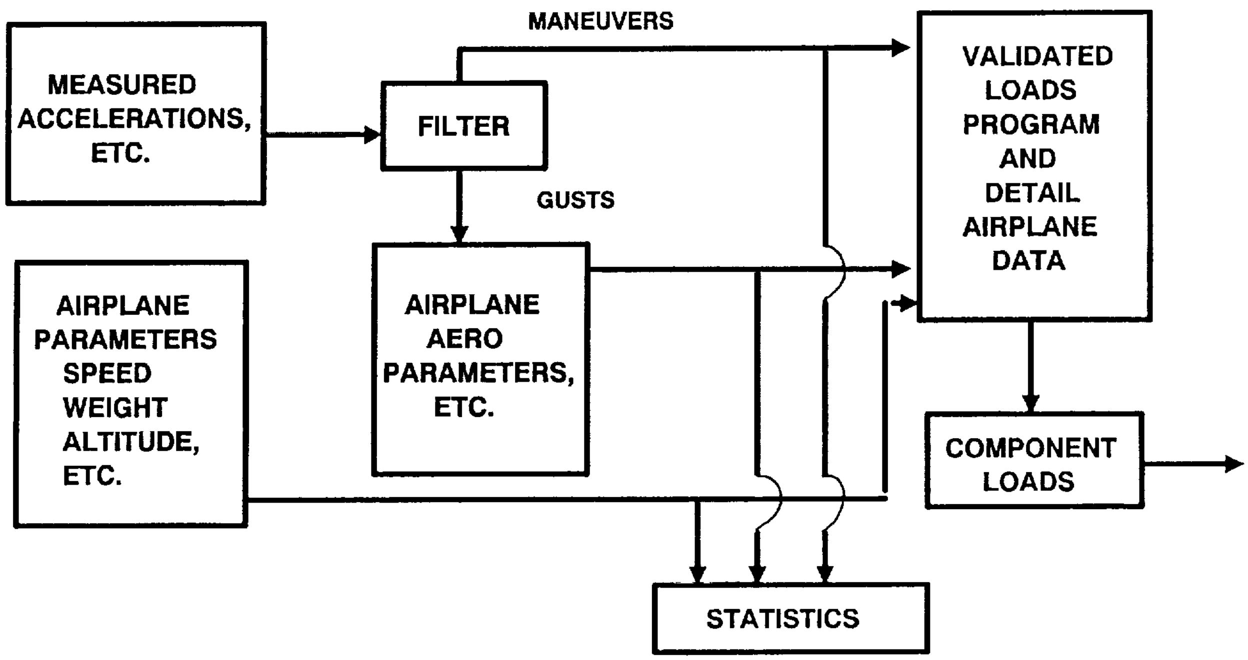
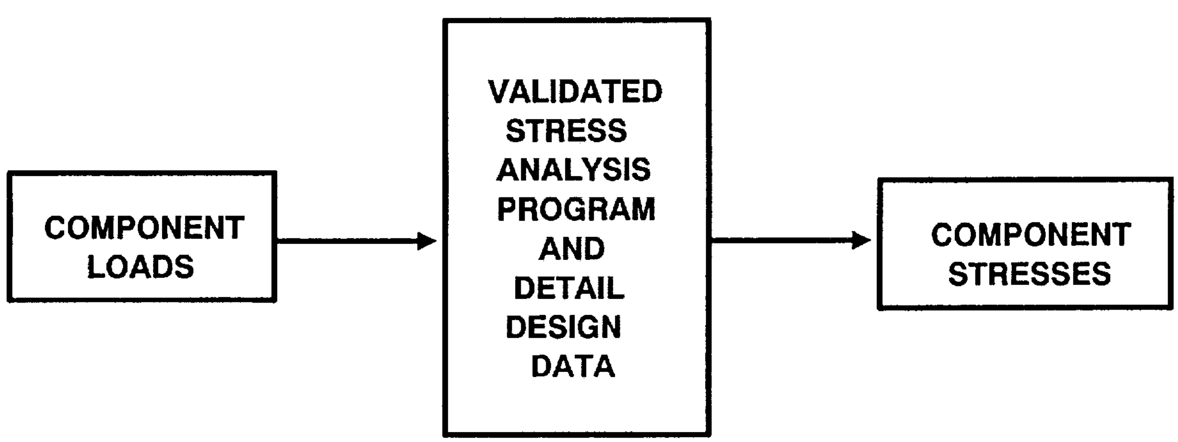


Figure 4

COLLECTION DATA FLOW - STEP 3



MANUFACTURER

Figure 5

FLIGHT LOADS - FATIGUE RELATIONSHIPS

FOR EACH AIRFRAME STRUCTURAL COMPONENT, THE FOLLOWING EXISTS:

BENDING MOMENT (M)	= F (DESIGN PARAMETERS)	VALIDATED
TORSION (T)	= F (DESIGN PARAMETERS)	VALIDATED
SHEAR (V)	= F (DESIGN PARAMETERS)	VALIDATED
STRESS	= F (M, T, V)	VALIDATED
FATIGUE	= F (STRESS)	

PROBLEM:

DESIGN PARAMETERS = F (1950's, 1960's USAGE)

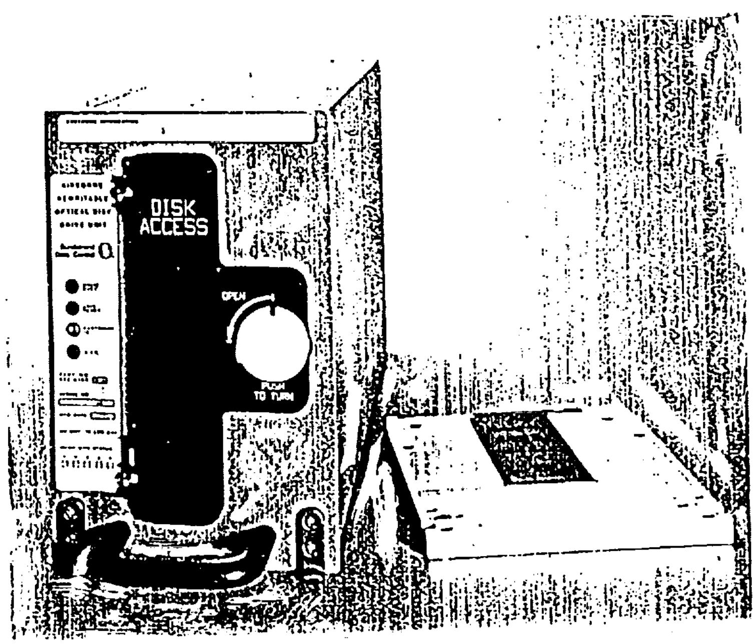


Figure 6

SUNDSTRAND RECORDER

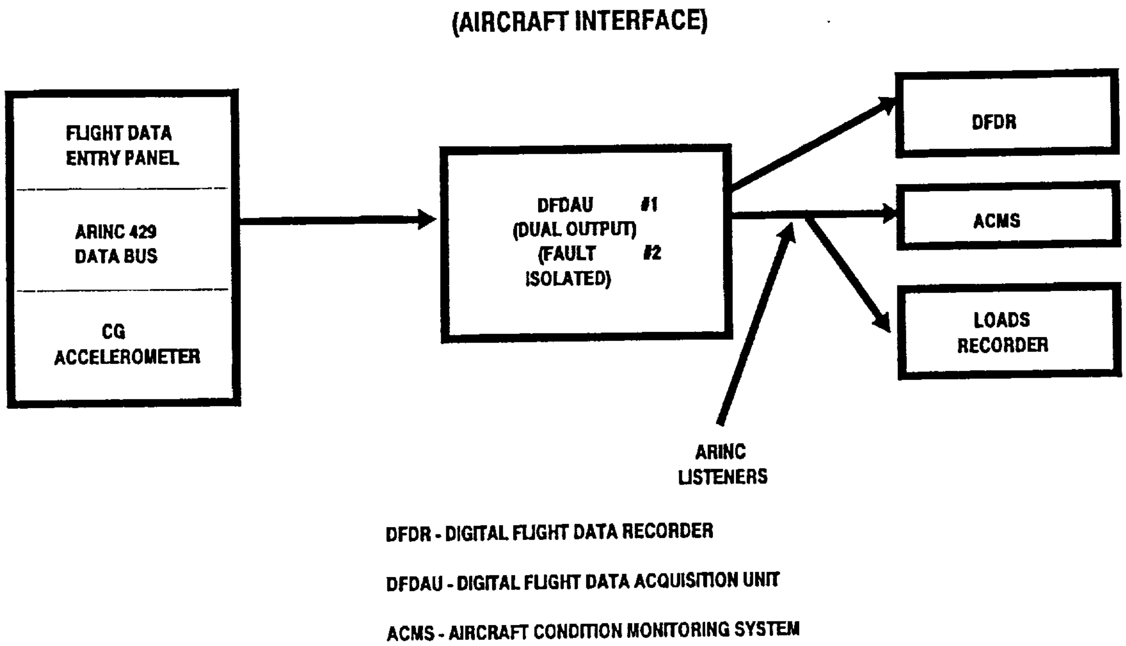


Figure 7

FAA Flight Loads Data Collection Program

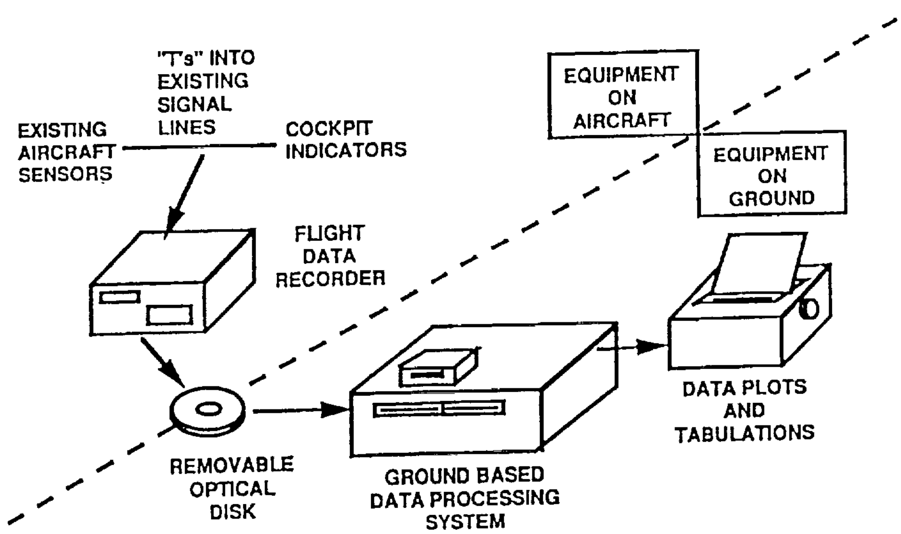


Figure 8

NEW RECORDER SYSTEM CONCEPT

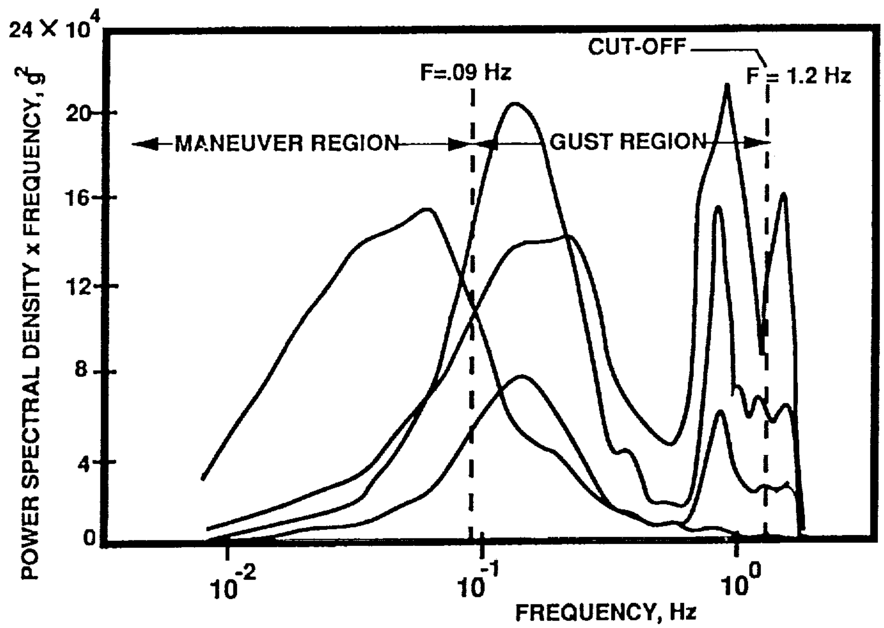


Figure 9

SAMPLE L1011 NORMAL ACCELERATION POWER SPECTRA

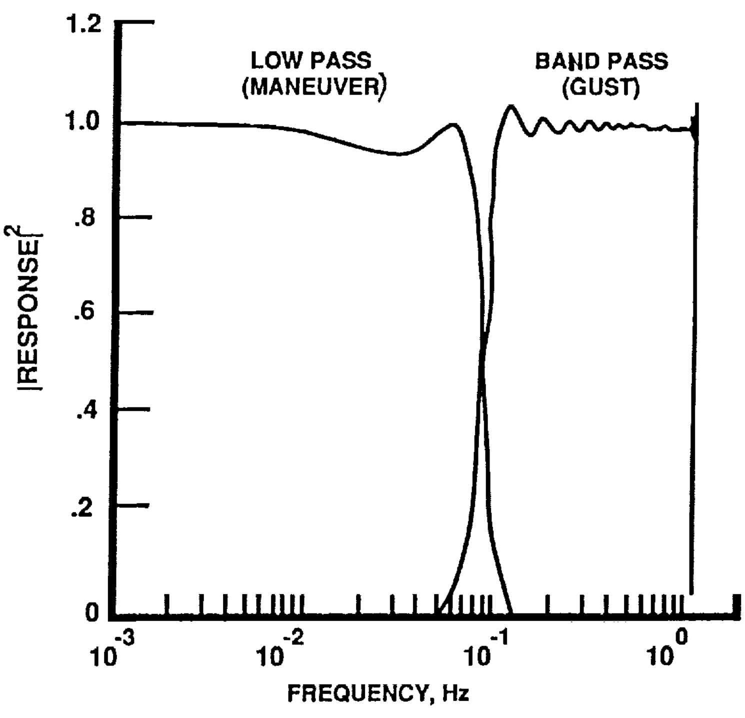


Figure 10

FREQUENCY RESPONSE OF NUMERICAL FILTERS USED TO SEPARATE GUST AND MANEUVER ACCELERATIONS, AND TO ELIMINATE ELASTIC RESPONSES ABOVE 1.2Hz

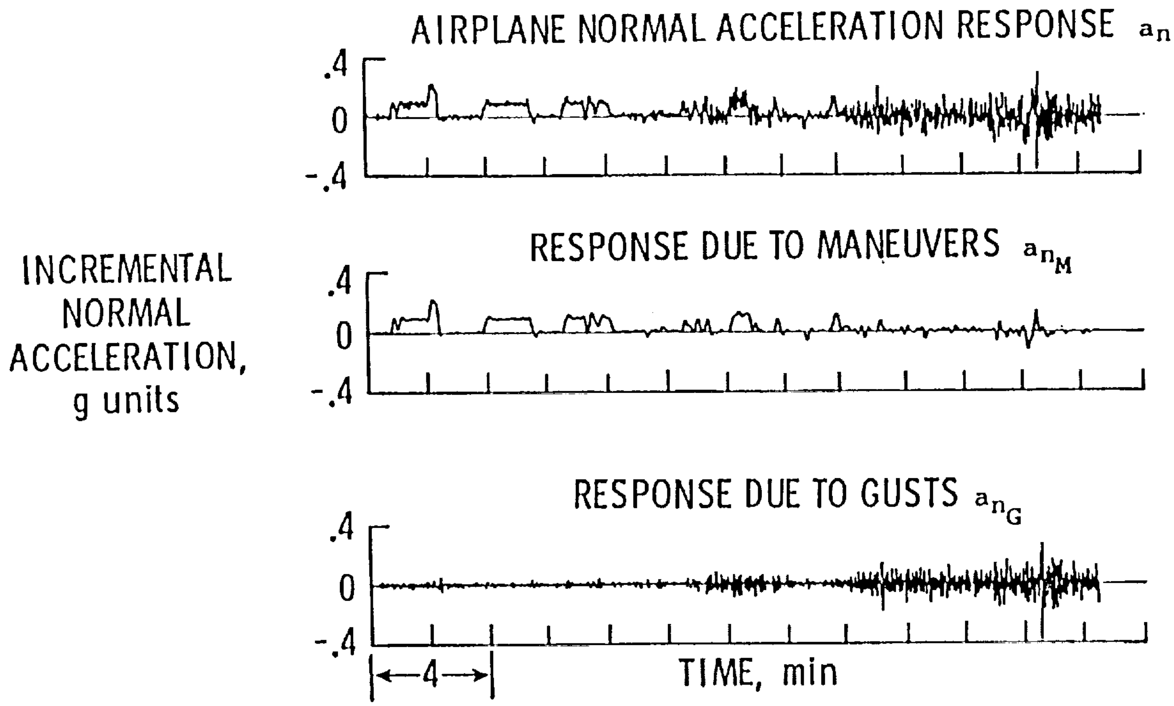


Figure 11

FILTER SEPARATION OF NORMAL ACCELERATION TIME HISTORY

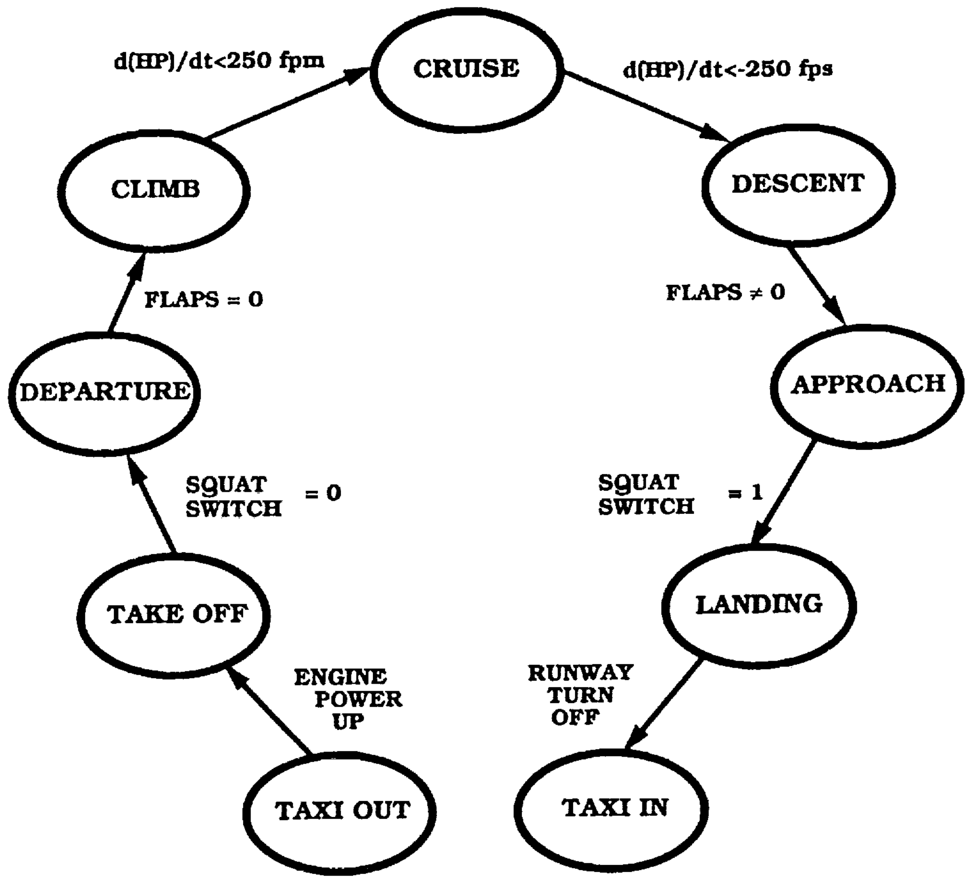


Figure 12

FLIGHT PROFILE DETERMINATION

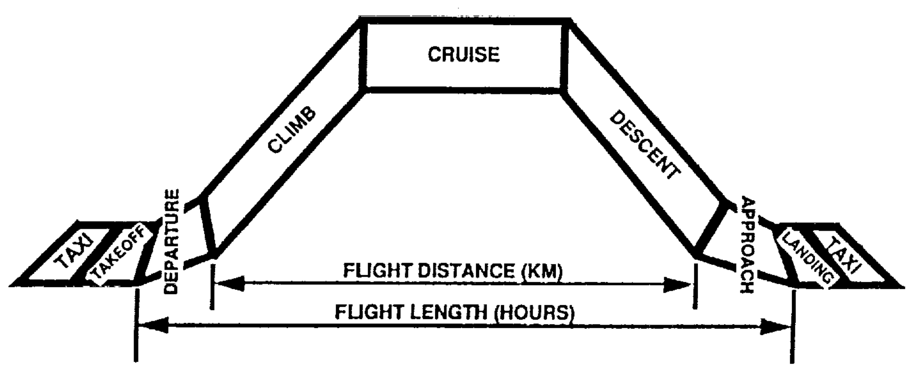


Figure 13

FLIGHT PROFILE SEGMENTS

Figure 14

OUTLINE OF PROPOSED ANALYSES

PHASE OF FLIGHT	*ANALYSIS CATEGORY*												
	FLIGHT PROFILE STATISTICS	ACCELERATION DEFINES QUANTITIES		CONTROL PARAMETERS					OTHER PARAMETERS				
	ALTITUDE, AIRSPEEDS, WEIGHTS, AND DURATIONS	NORMAL ACCEL	LATERAL ACCEL	RUDDER	AILERON	ELEVATOR	SPOILER	STABILIZER	FLAPS	POWER	PITCH	ROLL	YAW
PER FLIGHT SUMMARY													
TAXI OUT													
TAKE OFF													
DEPARTURE													
CLIMB													
CRUISE													
DESCENT													
APPROACH													
LANDING													
TAXI IN													

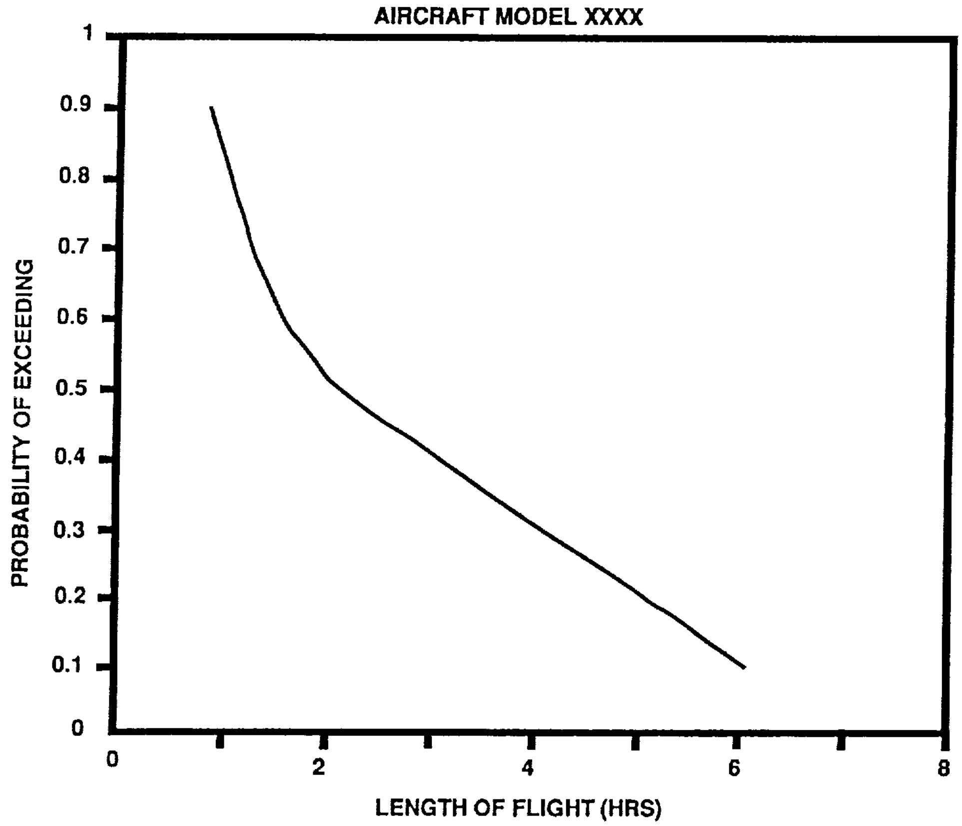


Figure 15

DISTRIBUTION OF FLIGHT LENGTH

Figure 16

CUMULATIVE FREQUENCY

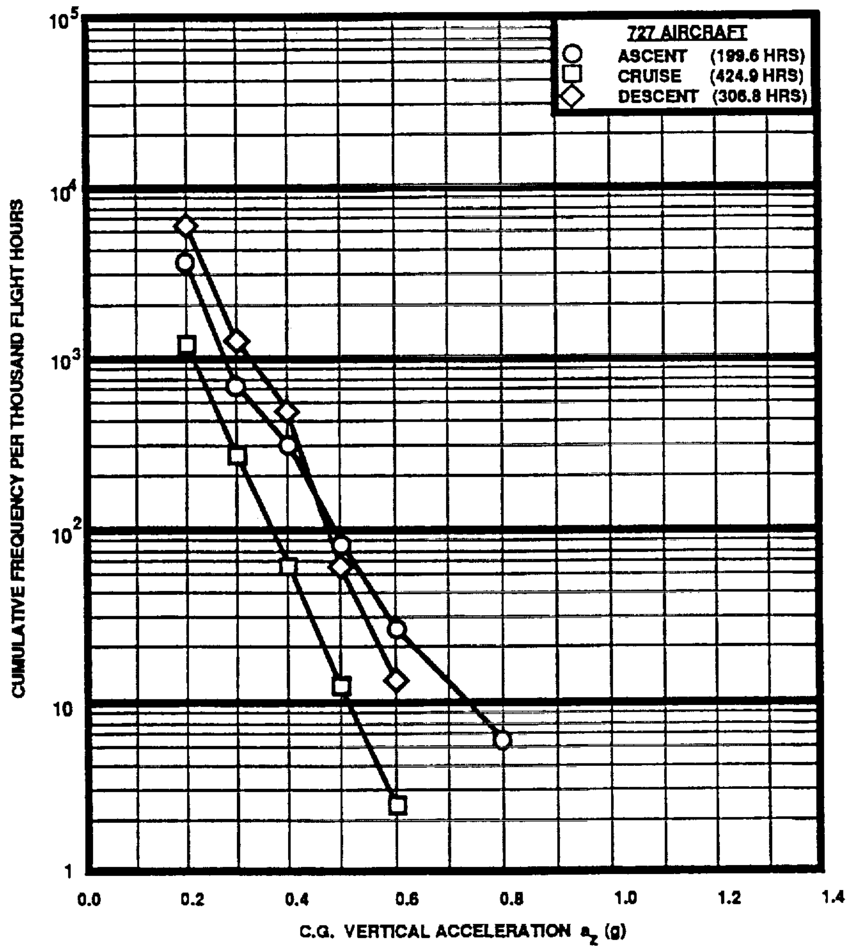


Figure 17

FLIGHT PHASE #: NORMAL ACCELERATION: PEAK-VALLEY COUNTS/HOUR

PEAK NORMAL ACCELERATION (g UNITS)

FOLLOWING VALLEY NORMAL ACCELERATION (g UNITS)

	>2.0	1.8 to 2.0	1.6 TO 1.8	1.4 TO 1.6	1.2 TO 1.4	1.0 TO 1.2	.8 TO 1.0	.6TO .8	.5 TO .6	.4 TO .5	.3 TO .4	-.3 TO -.4	-.4 TO -.5	-.5 TO -.6	-.6 TO -.8	-.8 TO -1.0	-1.0 TO -1.2	-1.2 TO -1.4	-1.4 TO -1.6	1.6 TO 1.8	-1.8 to -2.0	<-2.0
>2.0																						
1.8 to 2.0																						
1.6 TO 1.8																						
1.4 TO 1.6																						
1.2 TO 1.4																						
1.0 TO 1.2																						
.8 TO 1.0																						
.6TO .8																						
.5 TO .6																						
.4 TO .5																						
.3 TO .4																						
-.3 TO -.4																						
-.4 TO -.5																						
-.5 TO -.6																						
-.6 TO -.8																						
-.8 TO -1.0																						
-1.0 TO -1.2																						
-1.2 TO -1.4																						
-1.4 TO -1.6																						
1.6 TO 1.8																						
-1.8 to -2.0																						
<-2.0																						

FOR ALTITUDE <4500 FEET

TOTAL FLIGHTS ______
TOTAL HOURS ______
TOTAL MILES ______
CALENDAR START/STOP ______

Figure 18

DEPARTURE: NORMAL GUST VELOCITY EXCEEDANCES: PEAK-VALLEY COUNTS/HOUR

PEAK U_{de}, FEET PER SECOND

FOLLOWING VALLEY U_{de}, FEET PER SECOND	< -110	-90 to -110	-70 to -90	-60 to -70	-50 to -60	-40 to -50	-30 to -40	-25 to -30	-20 to -25	-15 to -20	-10 to -15	10 to 15	15 to 20	20 to 25	25 to 30	30 to 35	35 to 40	40 to 50	50 to 60	60 to 70	70 to 90	90 to 110	> 110
> 110																							
90 to 110																							
70 to 90																							
60 to 70																							
50 to 60																							
40 to 50																							
30 to 40																							
25 to 30																							
20 to 25																							
15 to 20																							
10 to 15																							
-10 to -15																							
-15 to -20																							
-20 to -25																							
-25 to -30																							
-30 to -35																							
-35 to -40																							
-40 to -50																							
-50 to -60																							
-60 to -70																							
-70 to -90																							
-90 to -110																							
< -110																							

U_{de} FOR ALTITUDE <4500 FEET

TOTAL FLIGHTS ________
TOTAL HOURS ________
TOTAL MILES ________
CALENDAR START/STOP ________

AILERON SUMMATION

	DYNAMIC PRESSURE PSF														
BELOW	19	34	53	77	101	139	176	219	267	321	380	445	516	593	
	AIR SPEED														
BELOW	75	100	125	150	175	200	223	250	275	300	325	350	375	400	TOTAL
DELTA AILERON LESS															
-60															
-50		2													2
-40		10	17	6	1	3									38
-30		34	107	56	17	30	28	14	4	5		1	1		297
-20		135	324	215	110	110	199	132	87	67	61	33	39	19	1521
-10		35	81	81	27	34	64	87	80	83	100	57	86	16	831
0		15	50	28	13	24	50	42	57	86	80	70	100	16	633
10		113	319	190	97	123	247	175	78	55	39	23	17	1	1477
20		61	169	95	37	75	69	39	3	1		1			550
30		9	25	5	2	1		1							43
40		3	3	1											7
50															
60															

Figure 19A - 727 DATA

RUDDER SUMMATION

	DYNAMIC PRESSURE PSF														
BELOW	19	34	53	77	101	139	176	219	267	321	380	445	516	593	
	AIR SPEED KTS														
BELOW	75	100	125	150	175	200	223	250	275	300	325	350	375	400	TOTAL
RUDDER POSITION															
-60															
-50															
-40			3	1											4
-30		1	9	8											18
-20		7	100	77	4		1	1			1	1			192
-10		159	563	177	78	121	197	104	102	154	127	89	146	22	2039
0		351	729	275	116	244	443	262	208	272	317	309	318	58	3904
10		9	91	46	2										144
20			10	2											12
30			1												1
40		1													1
50															
60															

Figure 19B - 727 DATA

STABILIZER SUMMATION

	DYNAMIC PRESSURE PSF														
BELOW	19	34	53	77	101	139	176	219	267	321	380	445	516	593	
	AIR SPEED KTS														
BELOW	75	100	125	150	175	200	223	250	275	300	325	350	375	400	TOTAL
STABILIZER POSITION															
0															
10							1	1	2	23	109	235	413	117	901
20					2	60	180	165	270	417	374	292	203	46	2012
30				3	58	343	379	113	18	9	1				924
40		14	69	150	160	96	28	2							519
50		393	440	396	18	7									2254
60		43	135	3											181
70															
80															
90															

Figure 19C - 727 DATA

Figure 20

PROBABILITY OF EXCEEDING DURING EXTENSION AND RETRACTION