N76-31147

HISTORICAL REVIEW OF C-5A LIFT DISTRIBUTION CONTROL SYSTEMS

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SUMMARY

Analytical and experimental development work on various load alleviation systems for the C-5A is reviewed to trace the development of the technical and hardware concepts to the present time. Variations in system objectives, means of implementation and effects on loads and airplane performance, stability and control are discussed.

This paper provides a logical lead in and introduction to the present system - the details of which are contained in the papers entitled "The C-5A Active Lift Distribution Control System" by W. J. Hargrove and "Some Experiences using Wind Tunnel Models in Active Control Studies" by R. V. Doggett, Jr., I. Abel, and C. L. Ruhlin.

INTRODUCTION

The work on load reduction systems for the C-5A at the Lockheed-Georgia Company began in 1967 and has progressed through several system variations to the present major effort on development of an Active Lift Distribution Control System (ALDCS). Figure 1 shows the chronological evolution of these efforts.

The Aircraft Load Alleviation and Mode Stabilization (LAMS) Program conducted by Boeing Wichita and Honeywell under contract to the Air Force Flight Dynamics Lab involved the C-5A to a small degree. The Lockheed-Georgia Company participated by providing C-5A data to demonstrate the applicability of the analysis methods and techniques to another large flexible airframe. Although the LAMS C-5A System Analysis and Synthesis was based on a single flight condition, the study results concluded that a LAMS type control system could reduce structural fatigue damage rates during flight through turbulence without significant degradation of basic aircraft stability and handling qualities.

During the conduct of the C-5A static test program in mid 1969, it became apparent that some form of wing maneuver load reduction system was highly desirable for the purpose of reducing maximum wing upbending loads - a "strength design" load reduction rather than a fatigue load reduction system. The subsequent design and development effort involved analyses and test programs on a system which used symmetrical aileron deflections as a means of altering the spanwise airload distribution as a function of load factor, hence the name - Lift Distribution Control System or LDCS. The desire to reduce maximum wing upbending loads during maneuvers with minimum effect on performance and handling qualities led to an active system having a dead band below a load factor of 1.5 such that no system activity resulted until the load factor exceeded that magnitude. An additional selling point of this system was this "dead band" characteristic which resulted in no "black box" inputs during normal operation. This latter point is mentioned because of the natural reluctance on the part of flight crews to relinquish direct control of the aircraft to automatic flight controls. This system was developed and flight tested during late 1969 and early 1970 and is referred to as the maneuver LDCS (MLDCS) system.

A simplified version of the MLDCS known as the Passive LDCS (PLDCS) - fixed aileron uprig position selectable by the flight crew - was selected for fleet incorporation because it: a. Provided the desired maximum wing upbending moment reductions, b. Provided a reduction in 1.0g wing bending moments and thus a significant improvement in analytical fatigue life, c. Was attainable with a minimum hardware change and d. Did not involve "black box" control inputs independent of flight crew commands. The major detriment of this system is an increased drag due to the fixed aileron uprig resulting in significant takeoff performance, climb, and cruise drag penalties.

The results of the C-5 wing fatigue test program during the 1970-1972 time period, indicated a need for further wing load reductions or more appropriately, wing stress reductions, both during turbulence and during low load factor maneuvering. This need resulted in the present Active Lift Distribution Control System (ALDCS) Program which was initially explored by the C-5A Independent Structural Review Team (IRT) and recommended for development and fleet incorporation by the IRT in its report to the Air Force.

Subsequent sections of this paper discuss the objectives, means of implementation, load reductions and effects on performance and handling qualities of each of these systems. A comparison of these systems is made in the concluding section.

SYMBOLS

M'_x	Bending moment (Wing Swept Axis System)
M'_y	Torsional moment (Wing Swept Axis System)
N_o	Characteristic Frequency (Cycles per Second)
V_e	Equivalent Airspeed (Knots)
g	Gravitational acceleration constant (32.2 ft/sec^2)

i_T	Stabilizer incidence angle
$N_{Z_{cg}}$	Vertical load factor at c.g.
rms	root mean square
σ_s	rms stress

LOAD ALLEVIATION AND MODE STABILIZATION - LAMS

The C-5A LAMS work was conducted by the Boeing Company and their technical partner, Honeywell, Inc., under contract with the Air Force Flight Dynamics Lab. The Lockheed-Georgia Company provided the math model and supported the analysis effort with their design background and baseline comparative data during these studies.

The purpose of the C-5A LAMS work was to demonstrate that the LAMS technology was applicable to aircraft other than the B-52 and to establish the potential benefits that such a system may offer on the C-5A. Selection of the C-5A to provide an additional aircraft on which to evaluate the LAMS technology was an excellent choice since the C-5 possesses relatively powerful-fully powered flight controls and three axis stability augmentation systems.

The major objective of this study was to develop a system having acceptable stability margins, retaining or improving existing aircraft handling qualities and providing a measurable improvement in fatigue damage rate and ride quality.

The resulting C-5A LAMS study is well documented in Reference 1. For comparative purposes, only the pitch axis portion of this system will be addressed in this paper.

The pitch axis mechanization of the C-5A LAMS Flight Control System is shown by the block diagram of Figure 2. The aileron and spoiler control loops provide a direct load reduction source through alteration of the lift distribution magnitude and shape, primarily as a function of vertical acceleration, while the inboard elevator loop provides an indirect wing load reduction by increasing the pitch damping to reduce pitch response in turbulence. In addition, it provides a pitch compensation effect to counter the pitching moment increments introduced by the ailerons and spoilers such that handling qualities remain relatively unaffected. The control column feed foward inputs provide cancelling signals to the normal acceleration and pitch rate feedback signals which would otherwise oppose a pilot command.

The aileron loop provides the required phasing for control of the first and second wing bending modes and additional gain attenuation for suppressing of undesirable higher order mode effects.

System performance as reflected by calculated stress values at selected airframe control points is summarized by Figure 3. It should be noted that these stress values represent analysis of the gust source only and that total stress changes for all load sources (gust, maneuver, landing impact, taxi, etc.) were not evaluated during this study.

System performance relative to changes in flying qualities is summarized by Figure 4. In general, the response to pitch rate commands exhibits an increase in the time to reach a desired pitch attitude change with the response being overdamped. Addition of a normal acceleration signal to the inboard elevator channel would provide faster pitch response to input commands and would result in the comparative numbers shown under Modified LAMS FCS.

MANEUVER LOAD CONTROL - MLDCS

During late 1969 and early 1970, a study was conducted of various means of reducing maximum wing upbending moments on the C-5A. Figure 5 illustrates the various load reduction techniques evaluated and provides summary type trade-off information relative to load reduction magnitudes, hardware changes, development complexity, etc. The uprigged aileron concept was selected as the most practical means of obtaining significant wing bending moment reductions with minimum hardware change/least performance penalty.

A development program was initiated to design, develop and flight test an active load reduction system. The primary objectives of the system were:

- Reduce positive maneuver maximum wing root bending moments by 10%
- Minimize effects on handling qualities
- Minimize effects on aircraft performance
- Utilize existing hardware with minimum new components
- Provide "full time - fail operative" system.

Since it was desirable to reduce the maximum upbending moments for "static strength" purposes only, the concept evolved into a system having a dead band below 1.5g with the system becoming active at higher load factors. This resulted in no drag penalty during takeoff, climb, cruise, etc., except during infrequent maneuvering to load factors above 1.5.

System implementation utilized existing, modified, and new hardware as shown by Figure 6. Normal accelerometers located at the wing first bending node line provided "rigid body" motion intelligence with minimum gain and phase effects for higher frequency responses. The existing pitch and yaw/lateral Stability Augmentation System (SAS) computers provided the means of introducing desired commands to the ailerons and pitch compensation inputs to the inboard elevators. The breadboard MLDCS computer was designed to accept inputs from the accelerometers, a Mach signal from the Central Air Data Computer (CADC) for gain scheduling purposes, a flap position signal to deactivate the system in flaps extended configurations and a touchdown signal to deactivate the system during landing impact and ground operations. Outputs were provided to the yaw/lateral and pitch SAS computers, through which aileron and inboard elevator deflections are commanded, and to flight crew monitoring and control hardware. Triple channel redundancies and fail safe features were incorporated in the system to fulfill the full time fail operative requirement.

A functional block diagram of the system is shown by Figure 7.

Structural load improvement attained with this system is illustrated by Figure 8. The MLDCS affects only maneuver loads at load factors above 1.5 thus there is no significant effect on fatigue loads resulting from the maneuver source. Gust loads are likewise not significantly affected due to both the rather high "g" onset level and the limited frequency response range of the system. During the development program, a compromise was made on aileron deflection magnitude due to the undesirable increase in positive wing torsion along with the desirable reduction in wing bending moment. Desirable bending moment reductions which reduced wing lower surface axial stress levels had to be limited since wing front beam web shear flow increased significantly due to the increased torsion loads as illustrated in Figure 9. The final scheduled maximum aileron deflection was set at ten degrees.

The development program included simulator testing and flight testing in addition to the analytical investigations. The flight test program evaluated handling qualities and provided substantiating data for structural load reductions. Figure 10 shows a comparison of analytical and flight test measured bending moments as function of load factor for a representative flight condition.

The effects of this system on aircraft performance and handling qualities are negligible. During flight testing it was difficult, if not impossible, to determine when this active system was operating. A more detailed discussion of this system is contained in reference 2.

PASSIVE LIFT DISTRIBUTION CONTROL SYSTEM - PLDCS

During the MLDCS development program, it became clear that some form of fatigue loads reduction was highly desirable. Moreover, it was desired to simplify the MLDCS from the standpoint of reduced new hardware in order to obtain early fleet incorporation of a load reduction system - thus the passive LDCS program was instituted.

The primary objectives of this system were:

- Reduce positive maneuver maximum wing root bending moments by 10%,
- Provide service life improvement by reduced 1.0g mean bending moments,
- Minimize effects on aircraft performance,
- Utilize existing hardware with minimum new components.

The PLDCS concept evolved into a fixed aileron uprig system with specific amounts of uprig as a function of airplane configuration and flight condition. Studies indicated that the "static" load reduction objective could be attained with a two position system having 5 degrees of uprig above 20,000 feet and 10 degrees of uprig below 20,000 feet. The objective to attain a service life improvement required that the 5 degree setting be utilized in the takeoff and landing configuration in order to provide the reduced mean load benefit throughout the flight profile.

System implementation, as shown by Figure 11, then became a rather simple matter of using the existing individual aileron trim capability as an interim measure until the equally simple production changes could be incorporated by field level kit installation. The C-5 fleet has been using the PLDCS, interim and/or production systems, since November 1971.

The structural loads improvement attained with this system is illustrated in Figure 12. Note that the mean bending moment is reduced significantly along with the maximum bending moment.

This system results in significant effects on airplane performance as summarized by Figure 13. No change in aircraft handling qualities is generated since the system involves a fixed configuration change only which is compensated for in trim by use of slightly more airplane nose down stabilizer trim setting.

ACTIVE LIFT DISTRIBUTION CONTROL SYSTEM - ALDCS

In late 1972, the C-5A Independent Structural Review Team (IRT) included the development of an active LDCS in the list of options available to the Air Force as a means of extending the service life of the C-5A primary wing structure. Air Force review of the IRT options resulted in a decision to proceed with an ALDCS development program in mid 1973. This program involved the Lockheed-Georgia Company as prime contractor with participation of The Boeing Company (Wichita Division) and Honeywell as sub-contractors. The C-5 System Project Office was the contracting authority having technical and management control of the program with the Air Force Flight Dynamics Lab providing technical assistance and program review functions.

A unique aspect of this development effort was the use of a dynamically and elastically scaled model having an onboard hydraulic system to provide power for activation of the ailerons and horizontal stabilizer. The control system was operated by a console mounted analog computer simulation of the ALDCS computer using inputs from the onboard ALDCS sensors. This model provided an experimental dynamic loads/flutter data acquisition tool with which to gain confidence in the analytical methods used in development of the ALDCS mechanization. The model wind tunnel test program was accomplished at the NASA Transonic Dynamic Variable Density Tunnel at Langley AFB and involved a test team consisting of personnel from Lockheed, Boeing, NASA, and The Air Force.

The objectives of the ALDCS being developed in this program are as follows:

- Reduce gust RMS wing root bending moments by 30%,
- Limit gust RMS wing root torsional moment increases to not more than 5%,

- Reduce maneuver incremental wing root bending moments by 30%,
- No increase in discrete gust wing loads,
- No significant changes in existing performance and handling qualities,
- Provide "full time - fail safe" system,
- Interface with existing systems and use existing hardware where possible,
- No significant degradation in flutter margins.

System mechanization was derived using the proposed IRT schematic as a baseline system. This system in itself had its beginnings in the C-5A LAMS pitch axis mechanization. System implementation includes PLDCS and involves use of existing control surfaces, actuators and servos, modified SAS and CADC computers and new hardware as shown in Figure 14. A functional diagram of the system is shown in Figure 15. This system, as was the MLDCS, is designed to interface with existing SAS and autopilot systems. It should be noted that the basic C-5A autopilot provides a significant reduction in continuous turbulence induced wing loads by means of the increased pitch damping effect attained when in the attitude hold mode.

The effects of the system on wing load improvement during maneuvering flight are represented by the plots of Figure 16. The bending-torsion plot illustrates the effect of the system on maneuvering loads for a typical strength design case. The 1.0g shift is due to the PLDCS static aileron up-rig. The significant slope change between 1.0 and 1.9g is the result of the ALDCS incremental aileron deflection. For load factors in excess of 1.9 the ALDCS incremental aileron deflection is removed such that at design limit load factor of 2.5 the system is again in the PLDCS configuration. This is necessary to prevent the generation of a wing front beam shear flow problem as discussed in the MLDCS section.

The effect of the ALDCS on the fatigue load spectra for maneuvering flight is shown by the right hand portion of Figure 16. Note that at high incremental load levels (load factors greater than 1.9) the two spectra are equal. The large number of maneuvers at load factors below 1.9 results in a significant reduction in the magnitude of the low and intermediate load levels. This is the area in which the majority of the maneuver source fatigue damage occurs; thus a significant improvement in the maneuver source damage is realized.

Loads improvement for the continuous gust source is illustrated by Figure 17. A typical wing root bending moment gust output spectrum is shown for the baseline and the ALDCS configurations. The effect of the system on the incremental gust load spectra is illustrated by the curves on the right side of Figure 17. The increase in characteristic frequency (N_O) is relatively unimportant from a fatigue damage standpoint since the load reduction effects are far more significant. As is the case with the maneuver spectra, the baseline and ALDCS curves become one at load levels corresponding with c.g. load factors greater than 1.9.

The aircraft performance and handling qualities effects introduced by this system are summarized in Figure 18.

COMPARISON OF C-5A LDCS SYSTEMS

The three systems which have been/are being developed and flight tested are compared in Figure 19 relative to major objectives, means of implementation, loads improvement magnitudes and aircraft performance/handling qualities effects.

It should be emphasized that the paramount objective in each of these systems was some form of wing bending moment reduction - either strength or fatigue related - with secondary objectives of system simplicity and minimum effects on aircraft performance/handling qualities. No attempt was made to provide a "mode stabilization/control" function for purposes of flutter boundary extension or ride control improvement.

Some of the trade-offs or compromises between conflicting objectives are apparent from the comparison chart. Note specifically that the price of obtaining reduced mean bending moments, as provided by the Passive System, is an aircraft performance penalty. An offsetting benefit on this system was the ability to attain an almost immediate incorporation with a minimum hardware impact.

The next variation - to provide reductions in maneuver and gust incremental bending moments while retaining the reduced mean loads generated a significantly larger hardware design/development problem than that of the original maneuver load control MLDCS and in addition retained the performance penalties of the passive system.

A comparison of the effects of each of the three systems on wing root loads is shown by Figure 20. The flight condition selected for this illustration was chosen to depict the initial objective of reducing maximum upbending moment by approximately 10% (actually attained about 9% due to bending torsion trade-off effects). The reduction in the 1.0g bending moment is about 25% for the PLDCS and ALDCS while the incremental bending moment is reduced approximately 40% by ALDCS for this condition. Similar load reductions exist for other flight conditions.

CONCLUDING REMARKS

The work done over the past five years on the various LDCS systems has demonstrated the practicality of using existing flight control surfaces and systems to affect specific changes in structural load distributions and magnitudes and/or aerodynamic characteristics of the C-5A.

The attainment of desired primary objectives has resulted in certain compromises in one or more of the many diverse requirements of such a complex system as the C-5A.

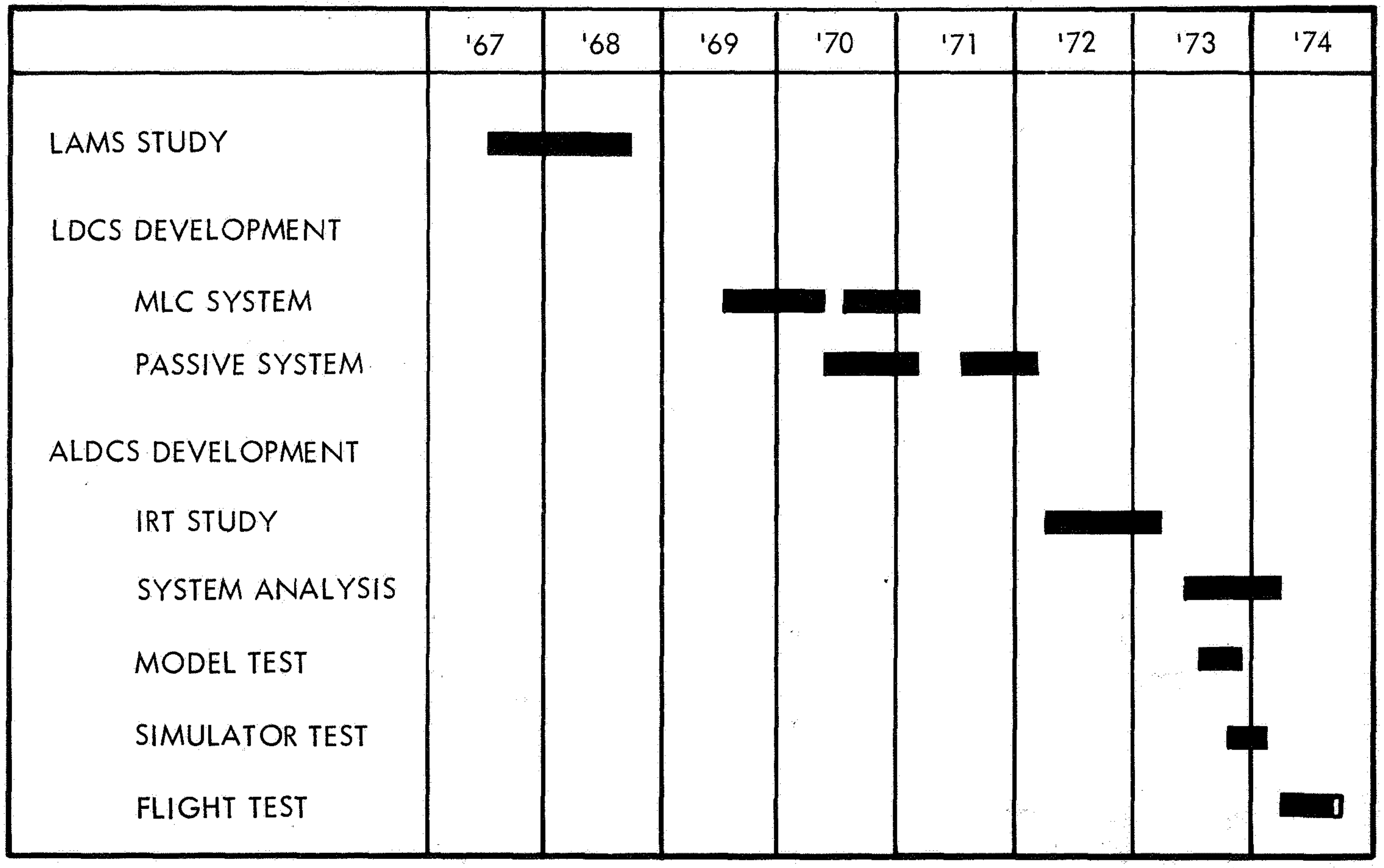
This work illustrates an application of active/passive control technology to the solution of one type of problem on an existing aircraft. Application of the same engineering principles during the design stage of a new aircraft could have significant effects on the overall "design compromise".

At this point a word of caution is deemed necessary. The success of the LDCS systems on the C-5A has been evaluated on the basis of attaining specific load reductions (primarily wing bending moments). The significance of these load reductions on the structural integrity and service life of the airframe has only been evaluated by existing state-of-the-art structural analysis and test methods. Since conventional fatigue analysis methods treat only axial stresses in a system based on constant amplitude cyclic test data, little is known about combined axial and shear stress effects on fatigue. The message here is to proceed slowly and don't commit to a design or a design fix on the basis of a partial evaluation.

REFERENCES

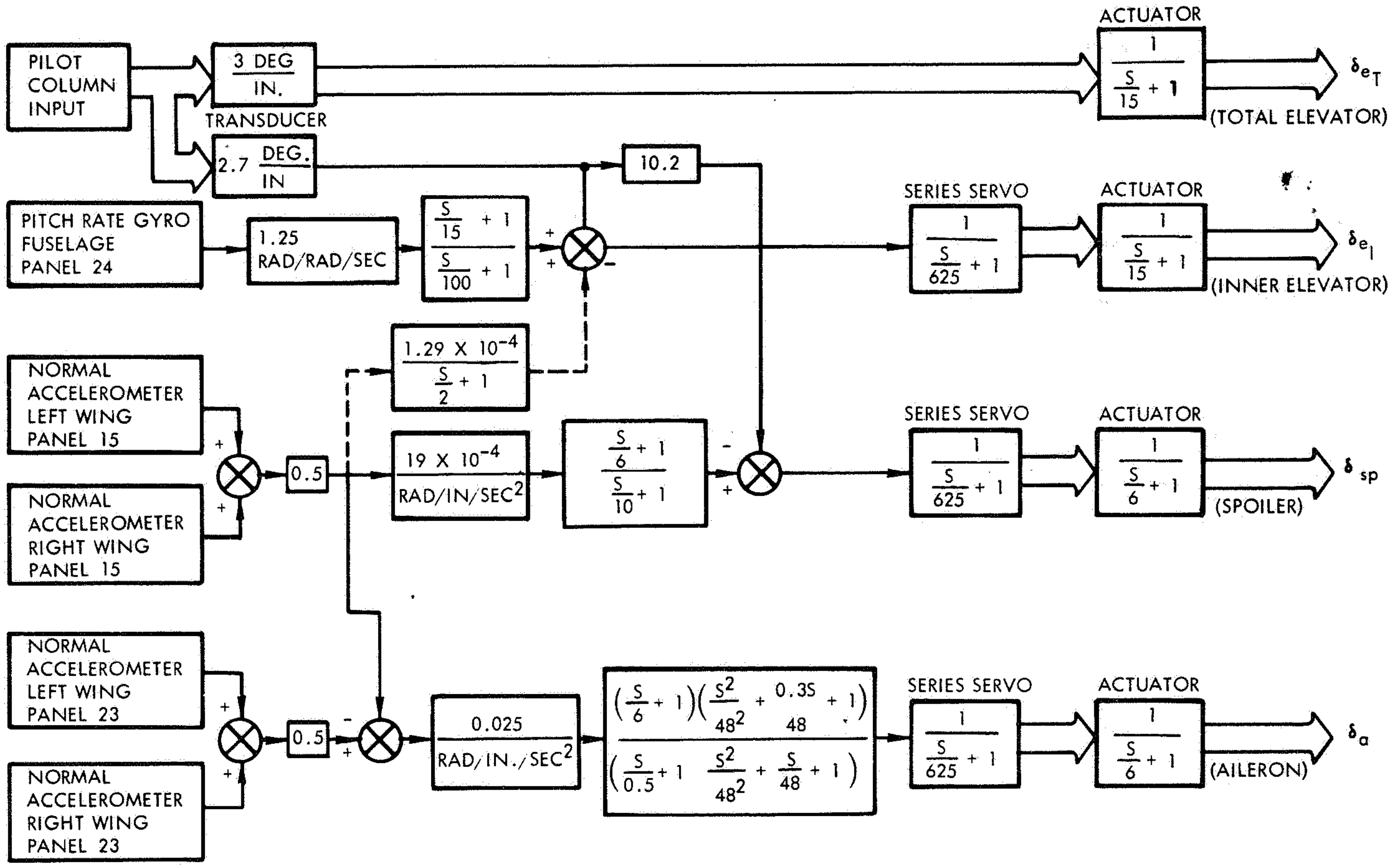
1. The Boeing Company, Wichita Division and Honeywell, Inc., Aerospace Division: Aircraft Load Alleviation and Mode Stabilization (LAMS) C-5A System Analysis and Synthesis. AFFDL D3-7901-2, September 1968

2. Silvers, C. L. and Phillips, J. W.: Documentation of C-5A MLDCS Testing on Ship 0003 during 1969-1970. Lockheed-Georgia Report LG74ER0037, April 1974



C-5A LIFT DISTRIBUTION CONTROL SYSTEM EVOLUTION

FIGURE 1



C-5A LAMS PITCH AXIS SYSTEM MECHANIZATION

FIGURE 2

ANALYTICAL STRESS ~ σ_S

STRUCTURAL LOCATION	BASELINE AIRCRAFT	LAMS
WING STATION 120	207.1	48.6
WING STATION 746	230.2	82.2
HORIZONTAL TAIL ROOT	79.1	110.7
FUSELAGE STATION 1804	42.9	70.2
FUSELAGE STATION 1106	39.9	24.0

NOTES:
1. GUST INPUT OF 1 FT/SEC RMS
2. STRESS LEVELS ARE PSI
3. STRESS LEVELS CALCULATED USING ANALYTICAL BENDING MOMENTS AND STRESS TO LOAD RATIOS

C-5A LAMS STRUCTURAL PERFORMANCE IMPROVEMENT
PITCH AXIS

FIGURE 3

PITCH ATTITUDE RESPONSE CHARACTERISTICS - ELEVATOR SQUARE WAVE INPUT

PARAMETER	BASELINE (SAS)	LAMS FCS	MODIFIED LAMS*
TIME TO 90% (SECONDS)	1.5	2.1	1.7
PERCENT OVERSHOOT	15.0	OVERDAMPED	10
ATTITUDE CHANGE	1.92	2.61	2.61

NOTE: THE USE OF UPRIGGED SPOILERS AS IN THE LAMS MECHANIZATION WOULD GENERATE A DRAG PENALTY THUS A PAY LOAD RANGE EFFECT WHICH WAS NOT EVALUATED DURING THE STUDY

C-5A LAMS FLYING QUALITIES AND PERFORMANCE EFFECTS

FIGURE 4

SYSTEM		PERCENT MAX BENDING MOMENT REDUCTION	NEW HARDWARE		MOD. EFFORT			R & D EFFORT			PERFORMANCE EFFECTS		
			SURFACE	CONTROLS	MINOR	MEDIUM	MAJOR	SMALL	MEDIUM	LARGE	NEG.	MINOR	LARGE
1 INB'D AUX. SPLIT MECHANICAL FLAP	10° 25°	2 10		●		●			●		●		
2 AILERONS	10° 25°	7 11		●	●			●				●	
3 SPOILERS	25°	7		●	●			●				●	
4 SPOILERS & AILERONS		10+		●	●			●				●	
5 LOWER SURFACE FORWARD SPOILER		10	●			●				●	●		
6 BLOWN FLAPS		10	●				●			●	●		
7 ADVERSE JETS OUTBOARD		10	●				●			●	●		
8 RESERVE FUEL/DISTRIBUTION		2						●			●		
9 CLIPPED WING TIP		5			●			●					●
10 AERODYNAMIC FENCE		1			●				●		●		

C-5A WING LOAD REDUCTION TECHNIQUES EVALUATION

FIGURE 5

NEW HARDWARE

- LDCS COMPUTER
- WING MOUNTED ACCELEROMETERS
- CONTROL PANEL
- ANNUNCIATOR LIGHTS

MODIFIED EXISTING HARDWARE

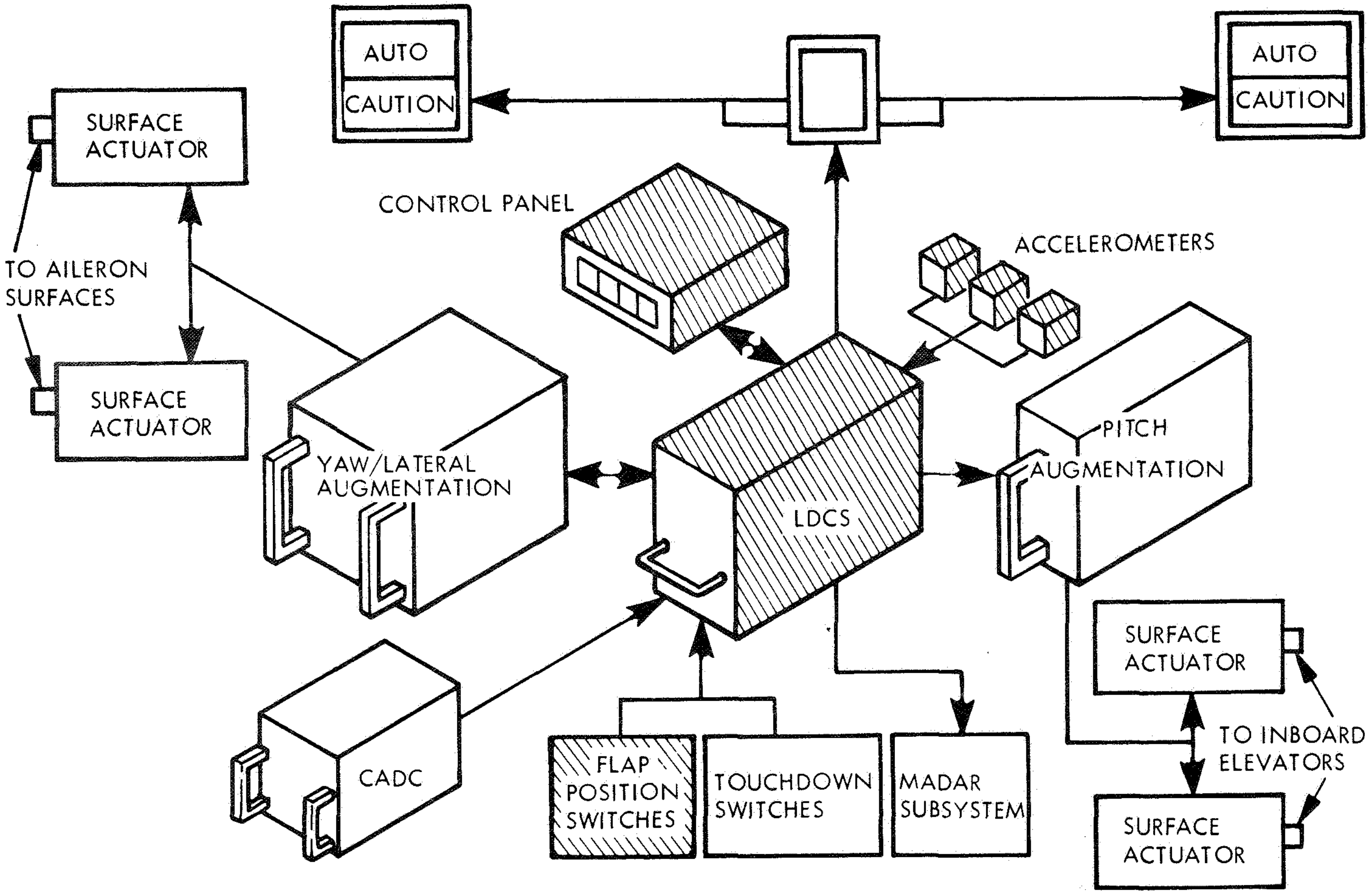
- YAW/LATERAL STABILITY AUGMENTATION COMPUTER
- PITCH STABILITY AUGMENTATION COMPUTER

EXISTING HARDWARE

- CENTRAL AIR DATA COMPUTERS
- FLAP POSITION SWITCHES
- TOUCHDOWN SWITCHES
- MADAR SUBSYSTEM

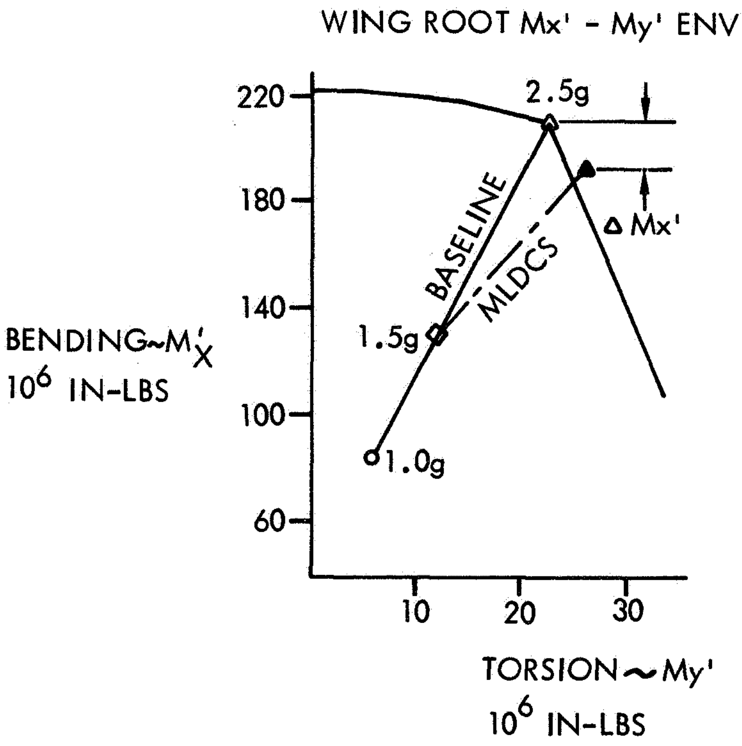
C-5A MLDCS SYSTEM IMPLEMENTATION

FIGURE 6



C-5 MLDCS FUNCTIONAL BLOCK DIAGRAM

FIGURE 7

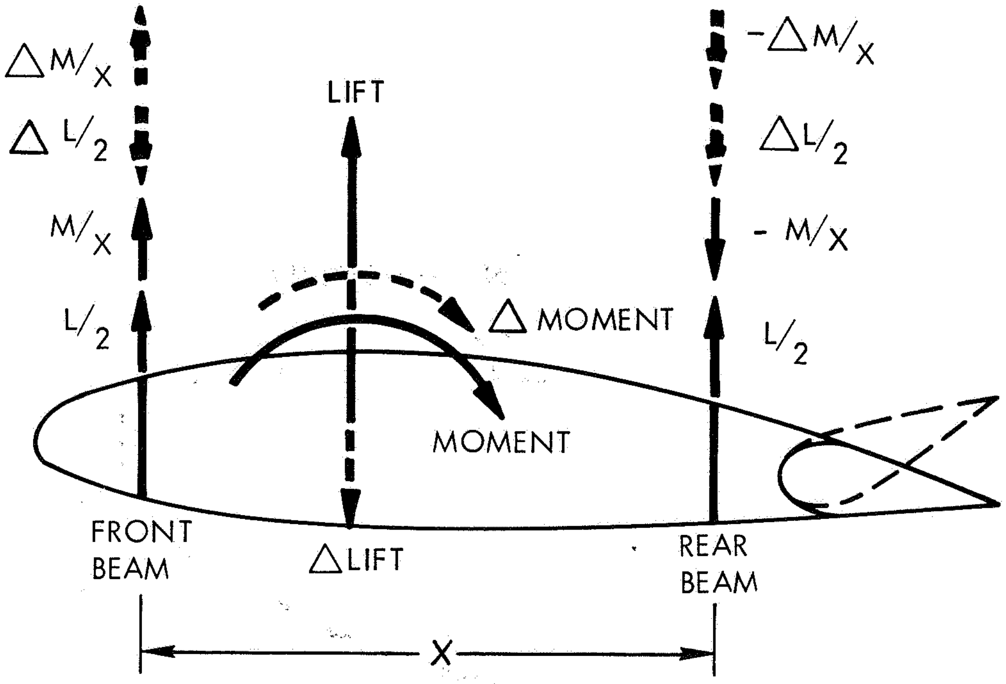


- "STATIC" BENDING MOMENT REDUCTION @ HIGH LOAD FACTORS

- NO SIGNIFICANT EFFECTS ON FATIGUE LOADS - MEAN LOADS UNAFFECTED - VARIABLE LOADS UNCHANGED OVER NORMAL RANGE OF LOAD FACTORS

C-5 MLDCS STRUCTURAL LOAD IMPROVEMENT

FIGURE 8

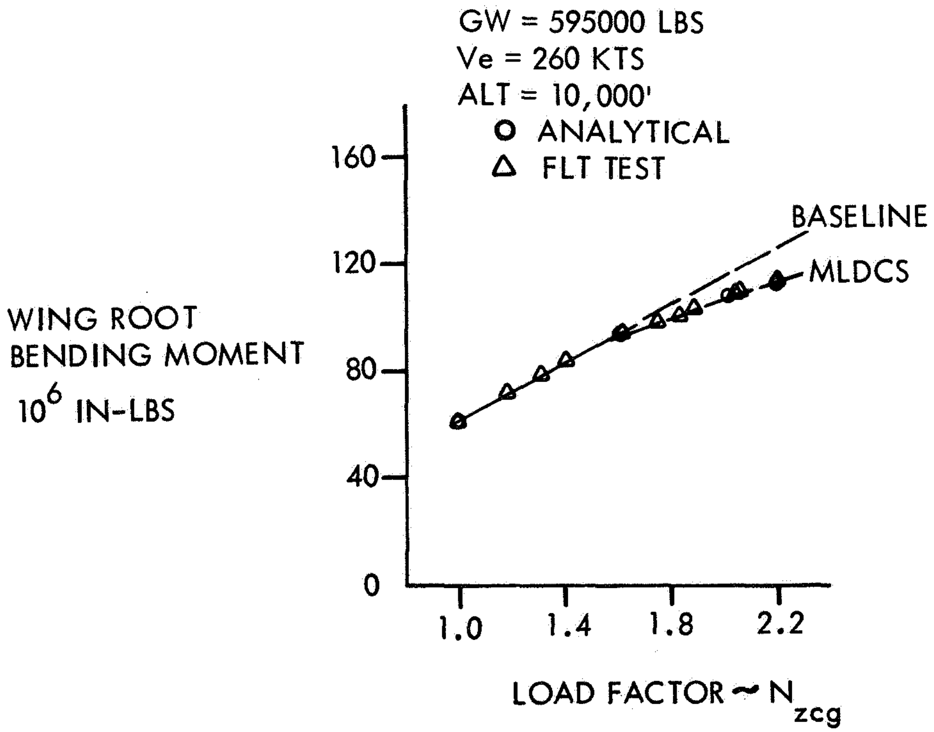


$\Delta M/X$ IS LARGE IN COMPARISON WITH $\Delta L/2$

∴ FRONT BEAM SHEAR INCREASES WITH UPRIGGED AILERONS

EFFECT OF UPRIGGED AILERON ON FRONT BEAM SHEAR

FIGURE 9



C-5 MLDCS COMPARISON OF ANALYTICAL AND FLIGHT TEST LOADS

FIGURE 10

INTERIM SYSTEM

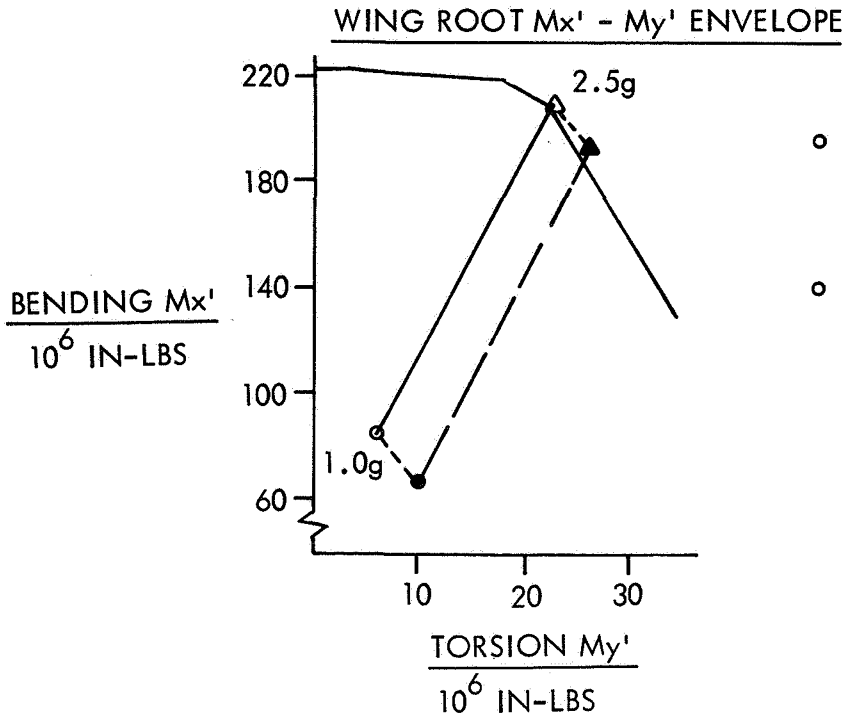
- USE EXISTING INDIVIDUAL AILERON TRIM CAPABILITY
- ADD INSTRUCTIONS TO FLIGHT HANDBOOK

PRODUCTION SYSTEM

- INCREASE POSITIVE PITCH TRIM ACTUATOR STOP FROM 1.5 TO 2.7 DEGREES
- INSTALL SHORTENED AILERON FEED BACK ROD - 6 DEGREES UPRIG NEUTRAL
- ADD LDCS ARM SWITCH AND MOMENTARY ON UPRIG AND DOWNRIG SWITCH
- ADD INDEX MARKS ON AILERON TRIM INDICATOR

C-5A PLDCS SYSTEM IMPLEMENTATION

FIGURE 11



- o "STATIC" BENDING MOMENT REDUCTION @ ALL LOAD FACTORS
- o REDUCED MEAN LOADS - IMPROVED FATIGUE LIFE - NO CHANGE IN VARIABLE LOADS

C-5A PLDCS STRUCTURAL LOAD IMPROVEMENT

FIGURE 12

EFFECTS ON AIRCRAFT PERFORMANCE

- o INCREASED T. O. FIELD LENGTH OR REDUCED T. O. G. W. OR INCREASED ROTATION SPEED
- o REDUCED CLIMB PERFORMANCE (GRADIENT REDUCED .23%)
- o PAYLOAD RANGE REDUCTION (150 - 300 NM)

EFFECTS ON HANDLING QUALITIES

- o NO SIGNIFICANT CHANGE

C-5A PLDCS EFFECTS ON PERFORMANCE AND
HANDLING QUALITIES

FIGURE 13

NEW HARDWARE

- o ALDCS COMPUTER
- o WING MOUNTED ACCELEROMETERS
- o CONTROL PANEL
- o ANNUNCIATOR LIGHTS

MODIFIED EXISTING HARDWARE

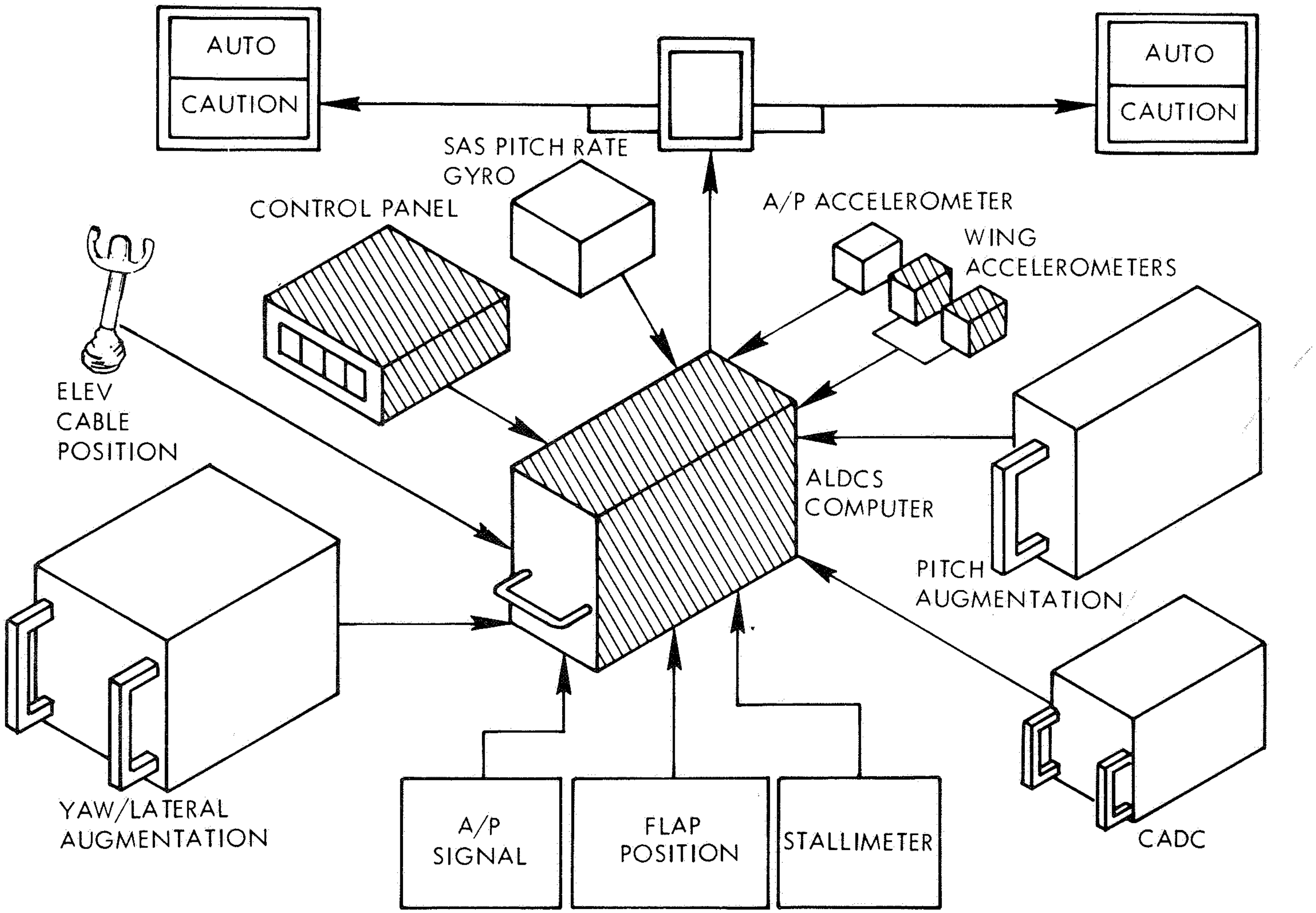
- o YAW/LATERAL STABILITY AUGMENTATION COMPUTER
- o PITCH STABILITY AUGMENTATION COMPUTER

EXISTING HARDWARE

- o CENTRAL AIR DATA COMPUTERS
- o AUTOPILOT NORMAL ACCELEROMETER
- o SAS PITCH RATE GYRO
- o CONTROL COLUMN POSITION SENSOR
- o FLAP POSITION SWITCHES

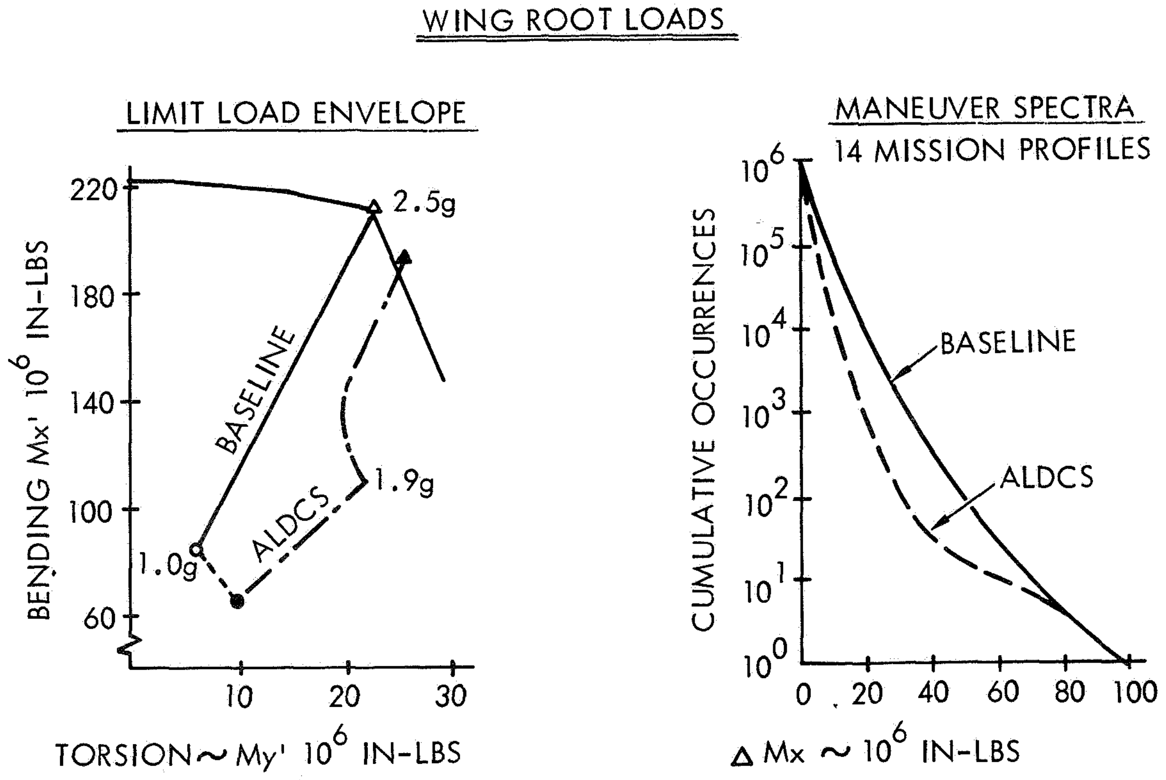
C-5A ALDCS SYSTEM IMPLEMENTATION

FIGURE 14



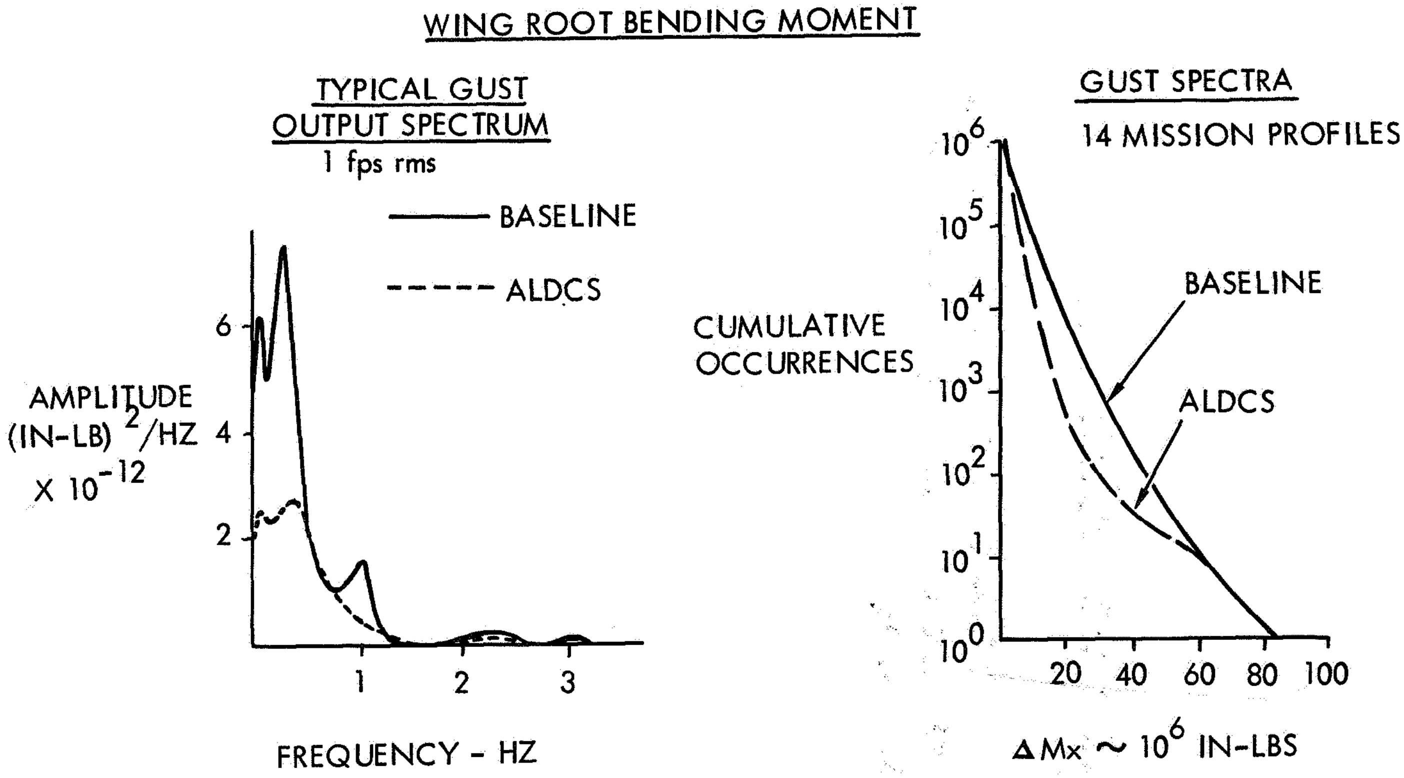
C-5A ALDCS FUNCTIONAL BLOCK DIAGRAM

FIGURE 15



C-5A ALDCS MANEUVER LOADS IMPROVEMENT

FIGURE 16



C-5A ALDCS GUST LOADS IMPROVEMENT

FIGURE 17

EFFECTS ON AIRCRAFT PERFORMANCE

- o INCREASED T. O. FIELD LENGTH - (SAME AS PLDCS)
- o REDUCED CLIMB PERFORMANCE - (SAME AS PLDCS)
- o PAYLOAD RANGE REDUCTION - (SAME AS PLDCS)

EFFECTS ON HANDLING QUALITIES

- o NO SIGNIFICANT CHANGES

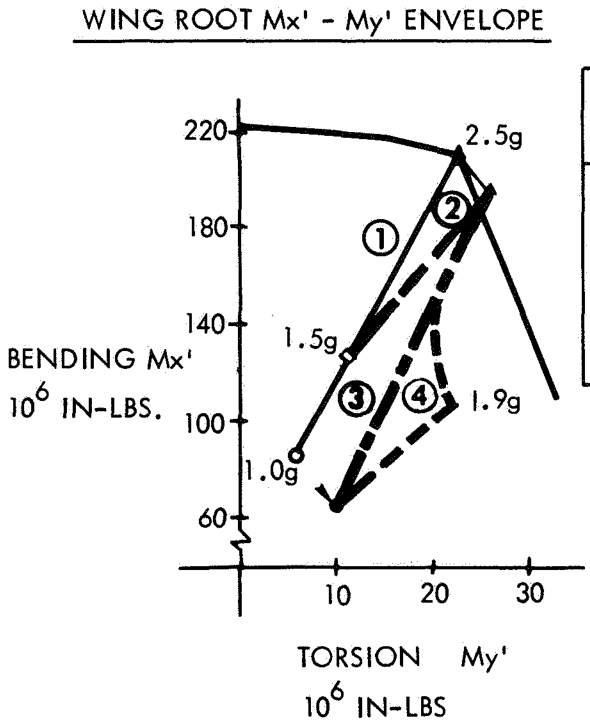
EFFECTS OF ALDCS ON PERFORMANCE AND HANDLING QUALITIES

FIGURE 18

SYSTEM	MAJOR OBJECTIVES	MEANS OF IMPLEMENTATION	LOADS IMPROVEMENT			PERF. & HAND. QUAL. EFFECTS
			MAX STATIC Mx'	FATIGUE Mx		
				MEAN	INC.	
MLDCS 1969 - 70	REDUCE MAX UPBENDING (Mx') @ DESIGN LOAD FACTOR	EXISTING SAS & CONTROL SYS. PLUS NEW COMPUTER & ACCEL'S	$\approx$-9%	-	-	NONE
PLDCS 1970 - 72	SAME AS MLDCS PLUS REDUCED FATIGUE MEAN Mx'	EXISTING TRIM SYSTEM - INTERIM NEW CONTROL BOX & FOLLOW UP LINK AILERONS OPEN UP $+i_T$ STOP	$\approx$-9%	-10 TO -30%	–	T.O. CLIMB & CRUISE DRAG PENALTY NO F.Q. EFFECTS
ALDCS 1973 - 74	SAME AS PLDCS PLUS REDUCED FATIGUE INCREMENTAL	EXISTING SAS A/P & CONTROLS NEW COMPUTER & ACCEL'S	$\approx$-9%	-10% TO -30%	-30 TO -50%	SAME AS PLDCS

COMPARISON OF C-5 LDCS SYSTEMS

FIGURE 19



LINE	SYSTEM	MAX. Mx' 10^6 IN-LBS	MEAN Mx' 10^6 IN-LBS	VARIABLE Mx'/nz 10^6 IN-LBS
①	BASELINE	212	85.2	84.4
②	MLDCS	194	85.2	84.4/67.8
③	PLDCS	194	64.2	84.4
④	ALDCS	194	64.2	50.9

FLIGHT CONDITION

CLEAN CONFIG.
265 KNOTS @ S.L.
728000 LBS. GW.

COMPARISON OF STRUCTURAL LOAD EFFECTS FOR LDCS SYSTEMS

FIGURE 20