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EVALUATION OF ACTIVE CONTROL TECHNOLOGY FOR SHORT-HAUL AIRCRAFT

FINAL REPORT

FEBRUARY 1975

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TO: *NATIONAL AERONAUTICS AND SPACE ADMINISTRATION*
SYSTEMS STUDIES DIVISION
AMES RESEARCH CENTER

CONTRACT NAS 2-6995

BY: *LOCKHEED AIRCRAFT CORPORATION*

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FOREWORD

This Evaluation of Active Control Technology for Short-Haul Aircraft was conducted under an extension to NASA Ames Research Center Contract NAS 2-6995. Work was initiated in August, 1974, and continued to January, 1975, as a follow-on to earlier work which was described in NASA CR 137525 and NASA CR 137526 and summarized in NASA CR 2502.

The study was under the direction of T. P. Higgins, Program Manager, and H. S. Sweet, Deputy Manager. The principal investigators were: J. H. Renshaw, J. A. Bennett, O. C. Harris, J. F. Honrath and R. W. Patterson.

The work was administered under the direction of T. L. Golloway, Technical Monitor, Systems Studies Division, NASA Ames Research Center.

This report is also identified as LG75ER0029 for Lockheed internal control purposes.

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SYMBOLS AND ABBREVIATIONS

AR	airplane aspect ratio
AW	augmenter wing
b	span
C_D	drag coefficient
C_L	lift coefficient
C_T	thrust coefficient
C_X	axial force coefficient
c	chord
c/ASSM	cents/available seat statute mile
CTOL	conventional takeoff and landing
dB	decibel
DOC	direct operating cost
DOC-1	DOC at 11.5c/gallon of fuel
DOC-2	DOC at 23c/gallon of fuel
DOC-4	DOC at 46c/gallon of fuel
DOC-10	DOC at $1.15/gallon of fuel
EPNdB	equivalent perceived noise decibel
FAR	Federal Aviation Requirements
FPR	fan pressure ratio

SYMBOLS AND ABBREVIATIONS (CONTINUED)

g	gravitational constant
IBF	internally blown flap
M	Mach number or Meter
m	meter
MF	mechanical flap
OTW	over-the-wing
OTW/IBF	over-the-wing/internally blown flap hybrid
OWE	operating weight empty
q	dynamic pressure
RGW	ramp gross weight
rms	root mean square
SFC	specific fuel consumption
SLS	sea level static
STOL	short takeoff and landing
t	wing thickness
T/O	takeoff power setting
TOFL	takeoff field length
T/W	airplane thrust/weight ratio
V	velocity
W	weight or airplane weight
α	angle of attack
Δ	increment of
η	power setting or fraction of wing span

SUMMARY

From studies conducted for NASA Ames (Ref. 1) it was determined that turboprop and turbofan powered mechanical flap airplanes were economically competitive with powered lift concepts for 914 m (3000 ft.) field length. The turbofan powered, mechanical flap airplane has higher fuel consumption than the most promising powered lift concept, but the turboprop design provides lower fuel consumption and must therefore be considered a major contender for short-haul operation. Both the turbofan and turboprop concepts would have poor ride quality because of the low wing loadings required for this short-field performance.

The primary objective of the program described in this report was to evaluate the economics of short-haul aircraft incorporating active control technology and low wing-loading. The overall approach to the program was:

- o Determine the airplane characteristics with active controls.
- o Define active controls systems for the airplanes.
- o Determine the characteristics of airplanes incorporating active control systems.

Turboprop Characteristics and Evaluation of Active Controls – The turboprop-powered concept chosen for the study utilized 2- and 4- engines. The power plant selected was a rubberized Detroit Diesel Allison T-56 engine combined with a rubberized, low tip-speed "quiet" propeller defined by Hamilton Standard for previous Lockheed work (Ref. 2).

A preliminary analysis resulted in the data shown in Figure S-1 which indicates that minimum direct operating cost at twice pre-energy crisis fuel price (identified as DOC-2) for a 278 km (150 nm) stage length is provided at -

- o Field lengths shorter than 914 m (3000 ft.) by a 4-engined configuration utilizing the deflected slipstream effect and meeting FAR Part-XX regulations (Ref. 3), and cruising at 0.5M or less.
- o Field lengths of 914 m (3000 ft.) or greater by either a 2- or 4- engine design cruising at 0.5 to 0.6 m. The 2-engine design cruising at 0.6 M and meeting FAR Part 25 (Ref. 4) was selected for further study since it provided almost miminum DOC and retained the 2-engine configuration as a variable.

100 PAX T-56 BEST ALTITUDE, SPEED AND AR FOR 278 KM (150 N.MI.)

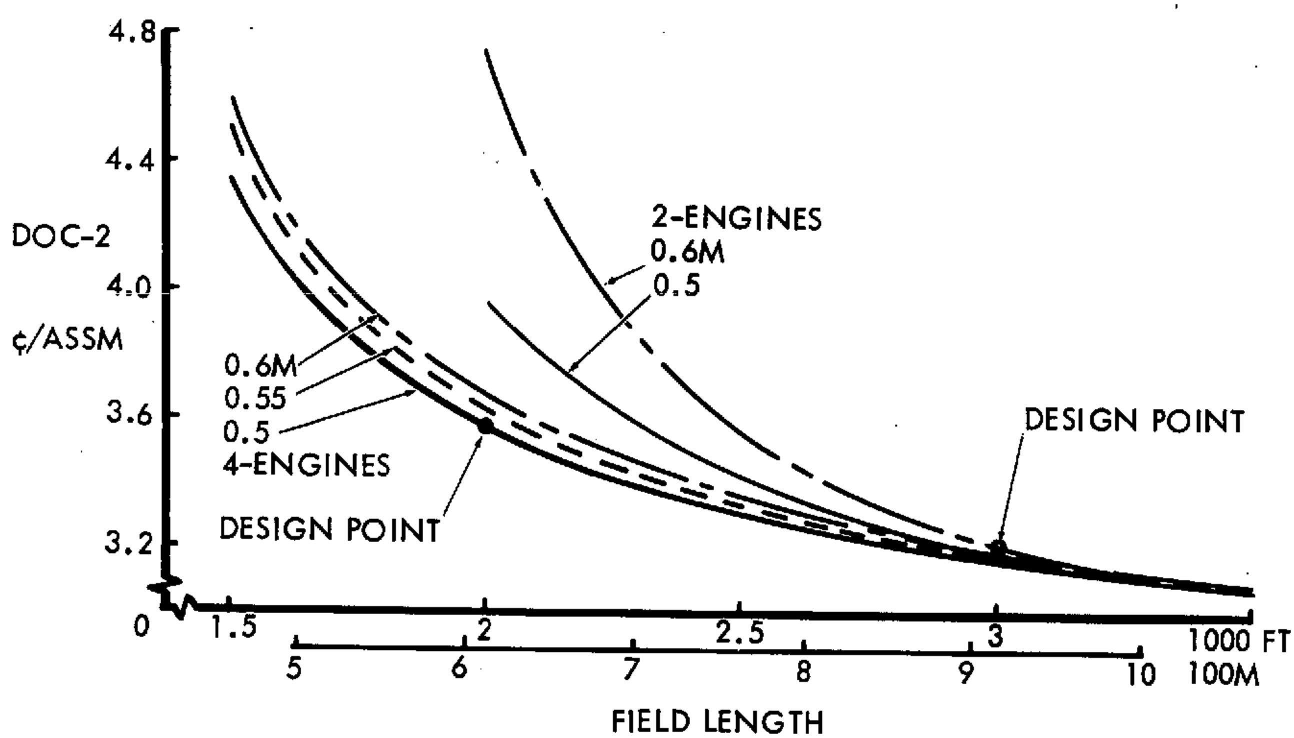


Figure S-1 DOC-2 (278 km; 150 n.mi.) vs. Field Length and Mach No. (No Active controls)

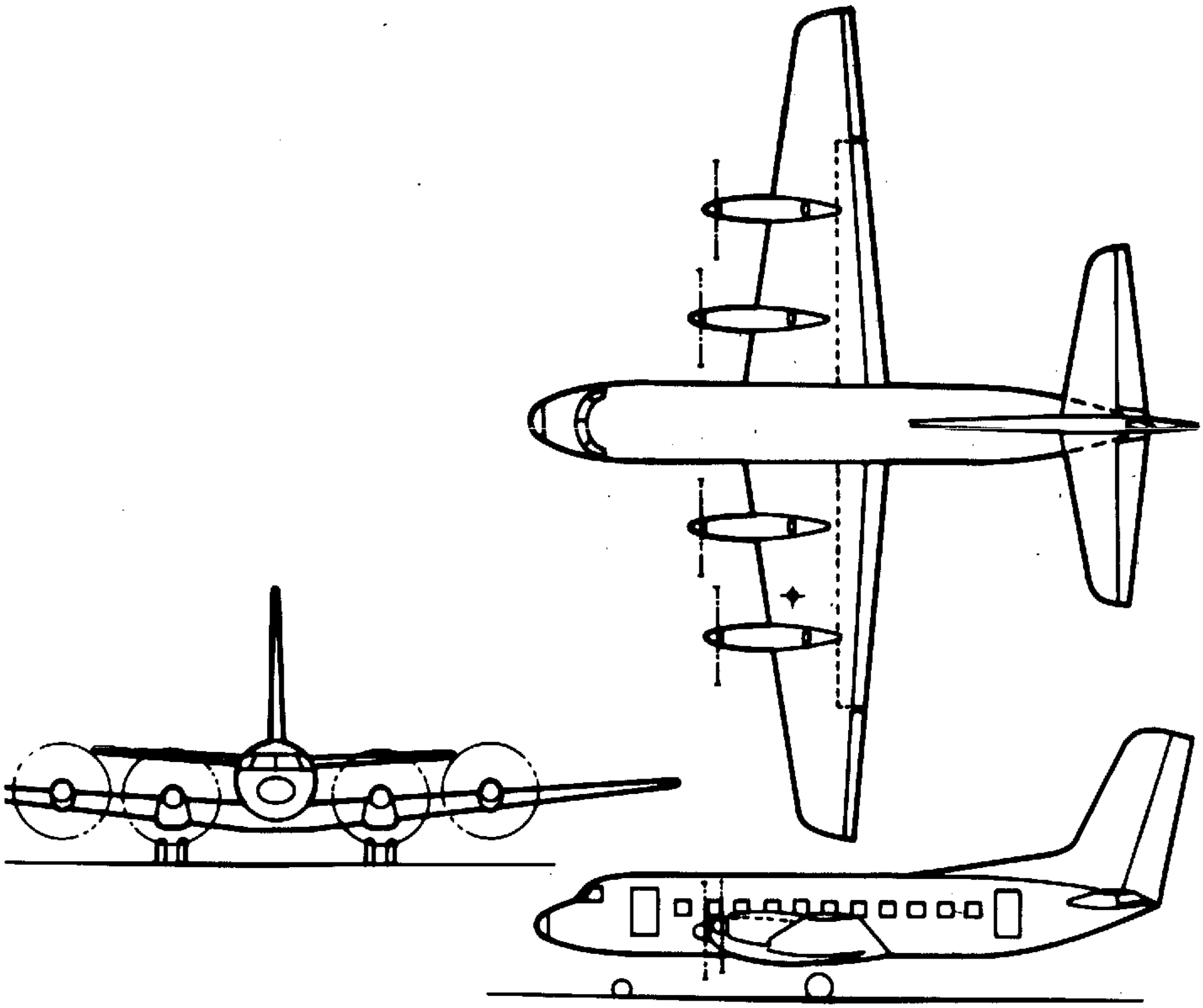
Two 44 passenger baseline configurations, one with 2-engines and one with 4-engines, were configured and are shown in Figures S-2 and S-3. Longitudinal ride quality analyses were conducted for these airplanes utilizing a 3 degree-of-freedom digital computer program. Figure S-4 indicates that these aircraft did not meet the r.m.s. vertical acceleration criteria of Ref. 5 & 6 for the descent case.

Ride quality control (RQ) systems, utilizing aileron, trailing edge flap segments and elevators were synthesized to improve the ride quality of the airplanes to equal or better that of estimated Boeing 737 data as shown in Figure S-4. Duplicated electronics were provided in these RQ systems to safeguard against run-away of the complete system but possible failure of the system was accepted, since it would only result in a less comfortable ride for the passengers.

By the addition of an extra electronics channel, larger hydraulic power supplies, dual piping and electro-hydraulic valves to each surface actuator, and modified surface sizes and electronic gains, gust load alleviation (GLA) system were synthesized for the two baseline aircraft. These systems reduced the gust load factors such that the gust cases were no more critical than the maneuver cases in designing the wing box structure. Gust load factors resulting from a 15 m/sec (50 fps) gust at cruise speed and a 20 m/sec (66 fps) gust at maximum critical gust speeds (V_B) for a series of airplanes, with gust load alleviation, were calculated. The GLA system must lower these load factors to below 2.5g. This reduction in gust effects permit the aircraft to be reoptimized with higher aspect ratio wings for which example equivalent wing box weight savings due to the GLA system are shown in Figure S-5.

The addition of a fourth channel in the pitch control electronics and additional electro-hydraulic valves provides the necessary redundancy for the system to be modified to also provide "relaxed static stability" capability which permits the size of the horizontal stabilizer to be reduced. This system is identified for briefness as the "artificial stability" (AS) system although it also provides ride quality control and gust load alleviation. Figure S-6 summarizes the capabilities of the three alternate active control systems just described.

Based on analyses of the two point designs, parametric computer methods were developed to estimate such parameters as gust load factors and speeds, wing box weight change, gust alleviation surface dimensions, and actuator, hydraulic system and electronic system weights and costs. In order to determine the effects of relaxed static stability a horizontal stabilizer sizing routine, accounting for the appropriate stability margins was developed and incorporated into the airplane sizing program.



PAYLOAD: 44 PASSENGERS

RGW: 22,251 KG (49,055 LB)

OWE: 16,005 KG (35,285 LB)

WING AREA: 103.3 SQ.M. (1,112 SQ. FT.)

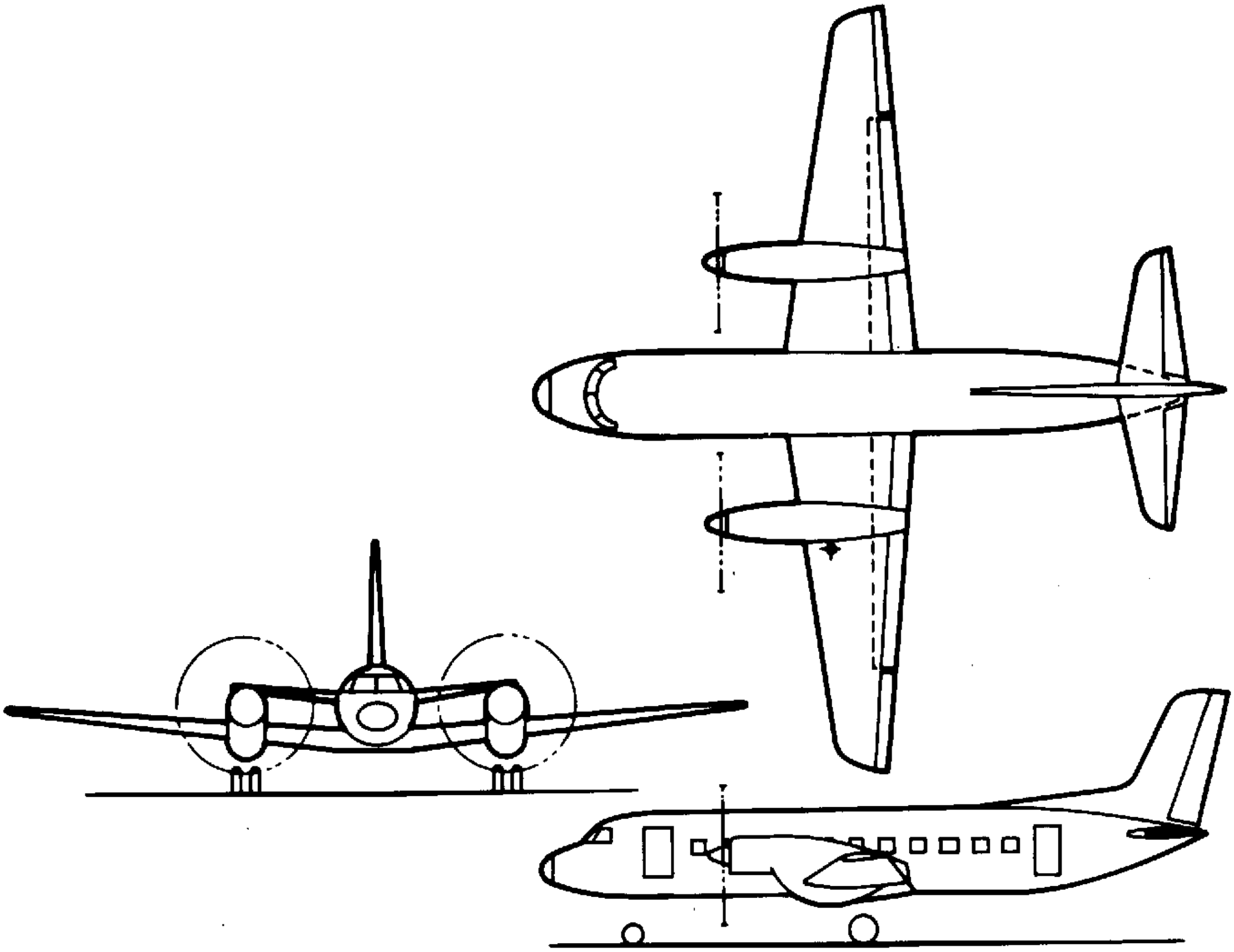
WING LOADING: 215 KG/SQ.M. (44.0 LB/SQ. FT.)

ENG/PROP S.L.S.T.: 19.12 KN (4,300 LB)

926 KM (500 N.MI.) CRUISE: 0.5M @ 7620 M (25,000 FT.)

278 KM (150 N.MI.) CRUISE: 463 KM/HR (250 KEAS) @ 4570 M (15,000 FT.)

Figure S-2 610 m (2000 ft) Field Length Design Point Aircraft



PAYLOAD: 44 PASSENGERS

RGW: 22,262 KG (49,080 LB)

OWE: 15,940 KG (35,140 LB)

WING AREA: 77.3 SQ.M. (832 SQ. FT.)

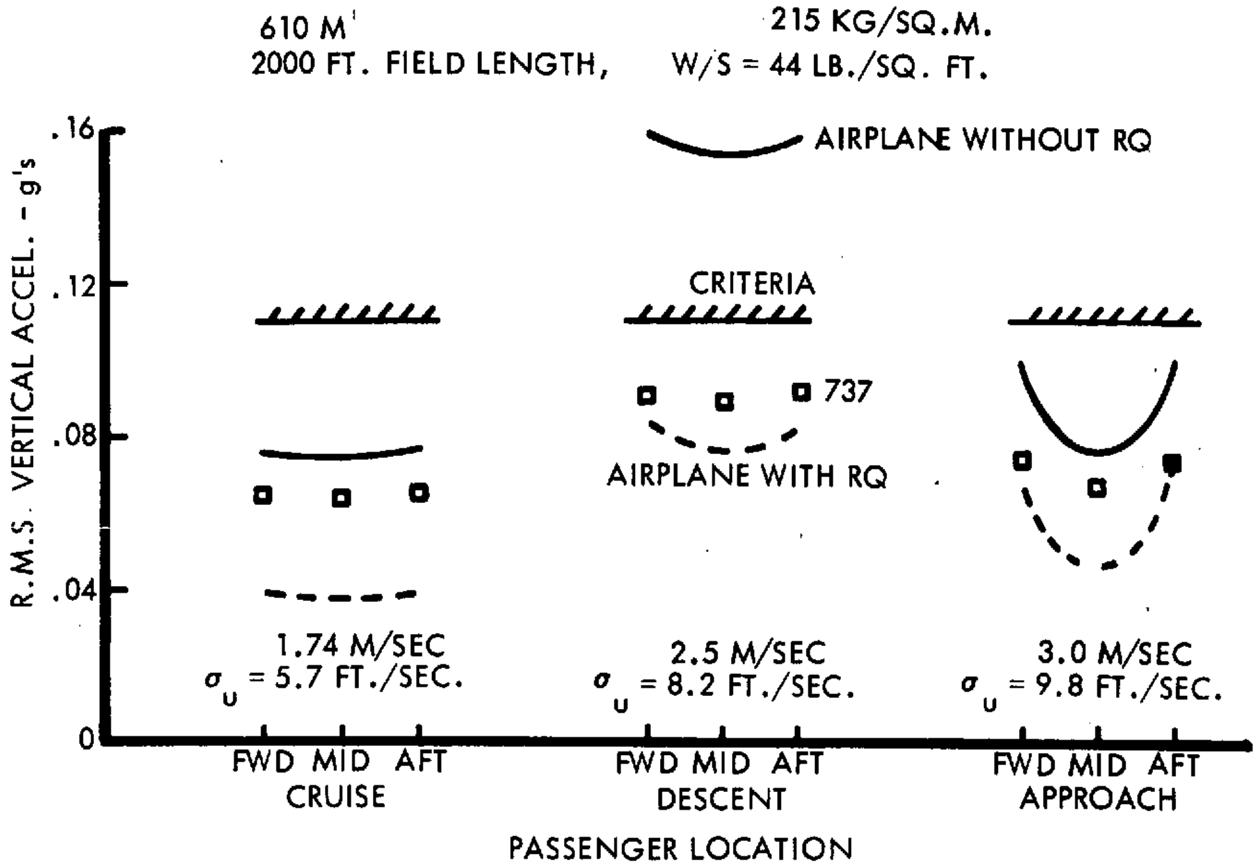
WING LOADING: 287 KG/SQ.M. (58.8 LB/SQ.FT.)

ENG/PROP S.L.S.T.: 45.64 KN (10,261 LB)

500 N.MI. CRUISE: 0.6 M @ 7620 M (25,000 FT.)

150 N.MI. CRUISE: 556 KM/HR (300 KEAS) @ 4570 M (15,000 FT.)

Figure S-3 914 m (3000 ft) Field Length Design Point Aircraft



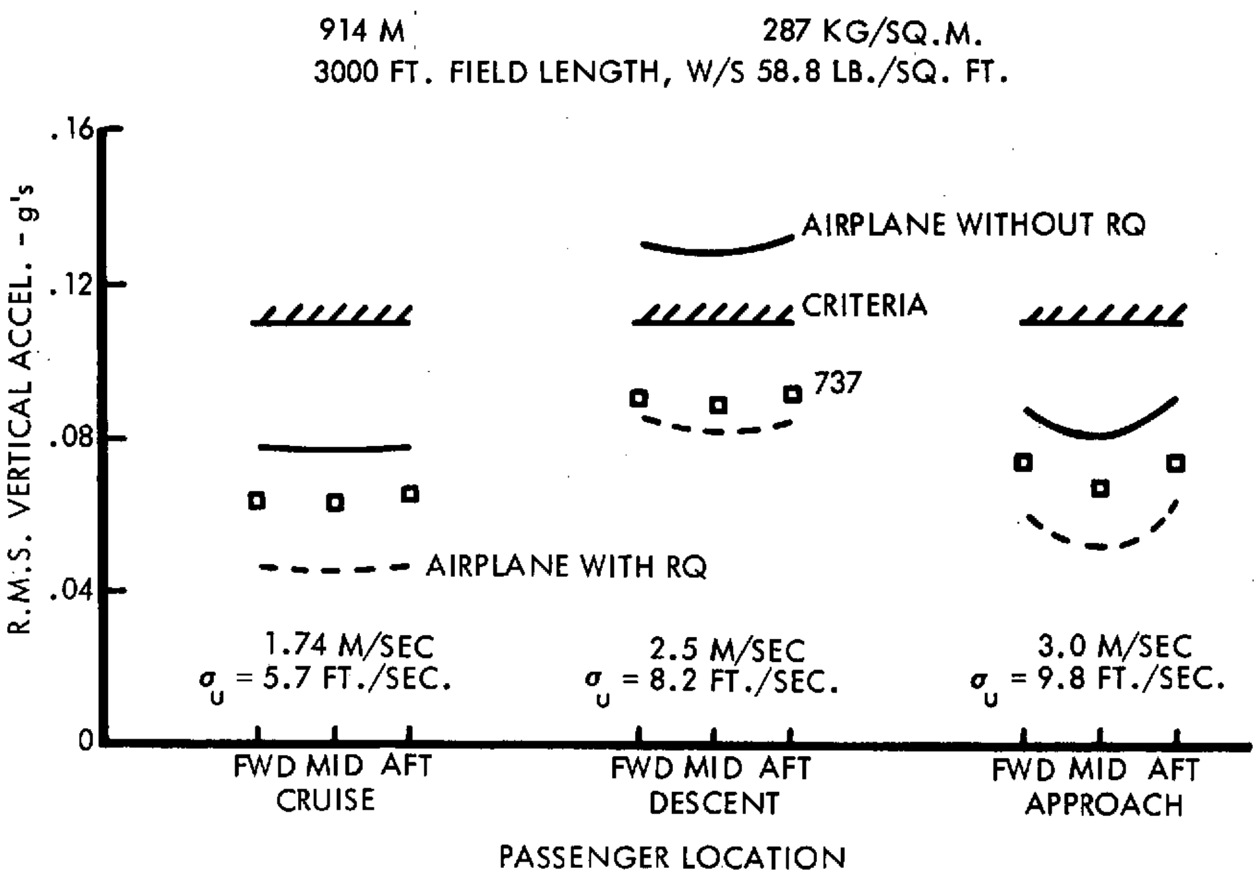


Figure S-4 Ride Quality Analysis

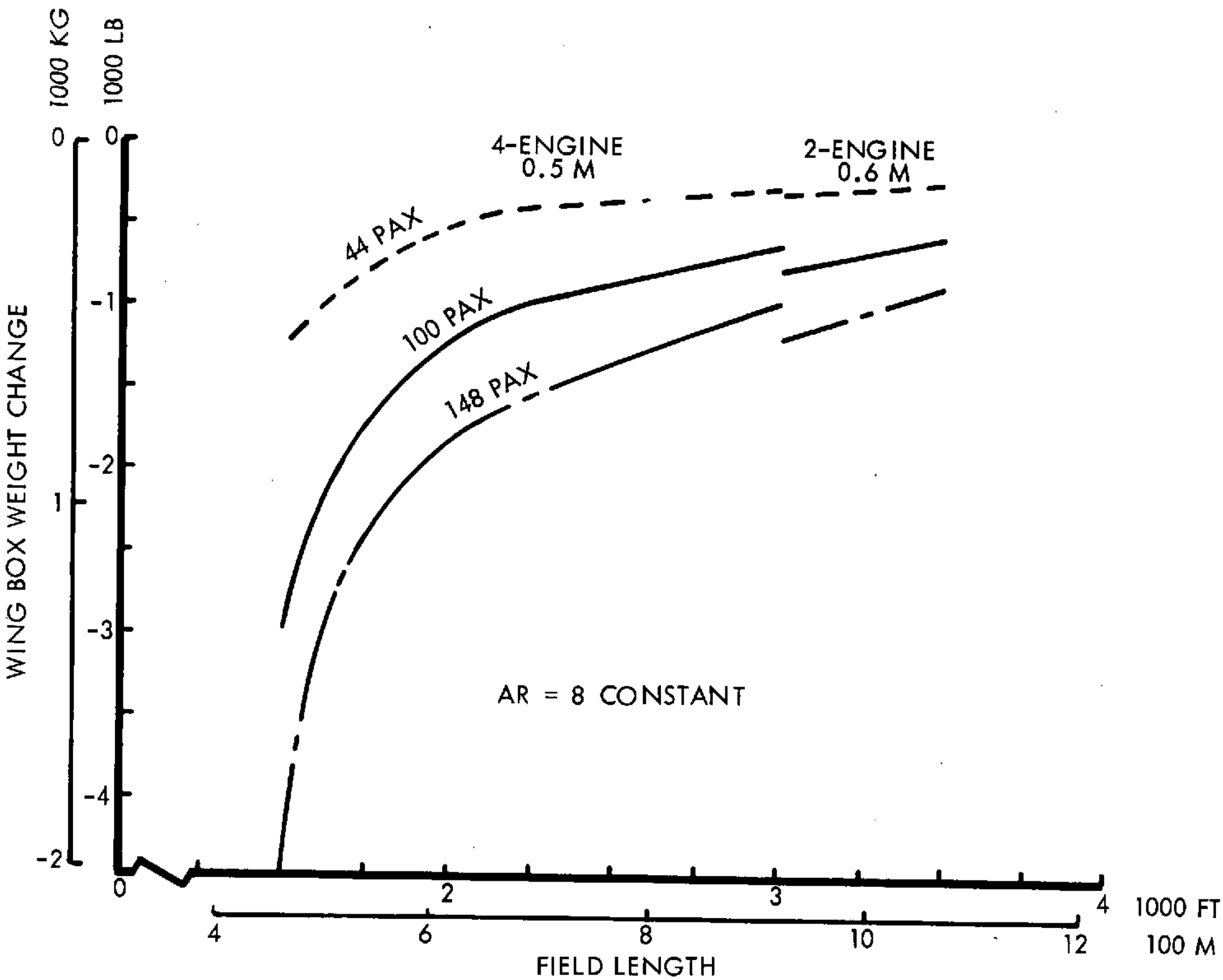


Figure S-5 Wing Box Weight Change due to GLA

Designation	Capability	Redundancy
Baseline	No Active Controls	Not Applicable
RQ (Ride Quality)	Ride Quality Control only	Multiple surfaces and hydraulic systems with individual actuators. Two electronic channels - FAIL SAFE
GLA (Gust Load Alleviation)	Ride Quality Control plus Gust Load Alleviation	As for RQ plus third electronic channel and duplicated hydraulic supplies to each surface - FAIL OPERATIVE
AS (Artificial Stability)	Ride Quality Control plus Gust Load Alleviation plus Artificial Stability	As for GLA plus fourth electronic channel and third hydraulic supply to pitch control - FAIL OPERATIVE after two identical failures.

Figure S-6 System Designation, Capability and Redundancy

Airplanes were initially sized without active controls and then sized with each of the 3 levels of active control for field lengths of 457 m through 1067 m (1500 through 3500 ft) and for 44,000 and 148 passenger capacities. The resulting characteristics of these aircraft are summarized as a function of design field length in Table S-I and Figure S-7. As mentioned earlier the 4-engine configurations utilize deflected slipstream effects and meet FAR Part XX requirements while the 2-engine designs meet FAR-25 which accounts for the differences in the wing loadings. The small changes in wing loading are due to the reoptimization to the higher aspect ratios with gust load alleviation. It was found that all the aircraft without gust load alleviation required aspect ratio 8, the minimum investigated, when optimized on the basis of minimum DOC-2 for 278 km (150 n.m.) stage length and 926 km (500 n.m.) range.

The weight data show the expected increase in gross weight for the 2-engined configuration relative to the 4-engine configuration, partly due to the higher cruise speed and partly due to the additional installed thrust and lower wing loading required to meet the field performance.

The provision of ride quality control incurs a weight penalty at all field lengths and for all passenger sizes, while the adoption of gust load alleviation, with or without relaxed static stability, offers weight saving benefits which are highest at the lowest wing loadings and increase with increase in passenger size. At the highest wing loading, weight penalties can actually be incurred due to the wing weight change at the higher aspect ratio and the subsystem weight exceeding the saving in fuel weight. The effects of the various systems, particularly the AS system, on horizontal stabilizer weight are shown separately in Figure S-8. These data are for identical types of stabilizer systems with and without active controls and therefore do not contain any reductions possible through the use of higher values of stabilizer lift coefficient.

As indicated in Figure S-7 large fuel savings are possible while still retaining minimum direct operating cost for short stage lengths (278 km, 150 nm) by the adoption of higher aspect ratio wings combined with a gust load alleviation system. The figure shows the savings for the longest stage length (926 km, 500 nm). Smaller, but still worth while, savings are achievable for shorter stage-lengths but only at the longer-field lengths and with the 4-engine configuration. Note the relatively poor fuel consumption of the 2-engined configurations which is caused by a combination of the following reasons. The selected 2-engine designs cruise at a higher speed than the 4-engine configurations which results in increased fuel consumption. However, even if the speeds were identical, the 2-engine design would still have poorer fuel consumption because it requires a lower wing loading (larger wing area) and higher thrust to weight ratio (larger engines) to meet the required field performance. The

FIELD LENGTH - M (FT)	457 (1500)	610 (2000)	914 (3000)	1067 (3500)
	WING LOADING - KG/SQ.M (PSF)			
4-ENGINE				
BASELINE, RQ	156 (32)	215 (44)	347 (71)	395 (81)
GLA, AS	156 (32)	215 (44)	322 (66)	381 (78)
2-ENGINE				
ALL SYSTEMS	-	-	287 (59)	347 (71)
	ASPECT RATIO			
4-ENGINE				
BASELINE, RQ	8	8	8	12
GLA, AS	8	8	12	14
2-ENGINE				
BASELINE, RQ	-	-	8	8
GLA, AS	-	-	8	10

Table S-I Effect of Active Controls on Wing Loading and Aspect Ratio

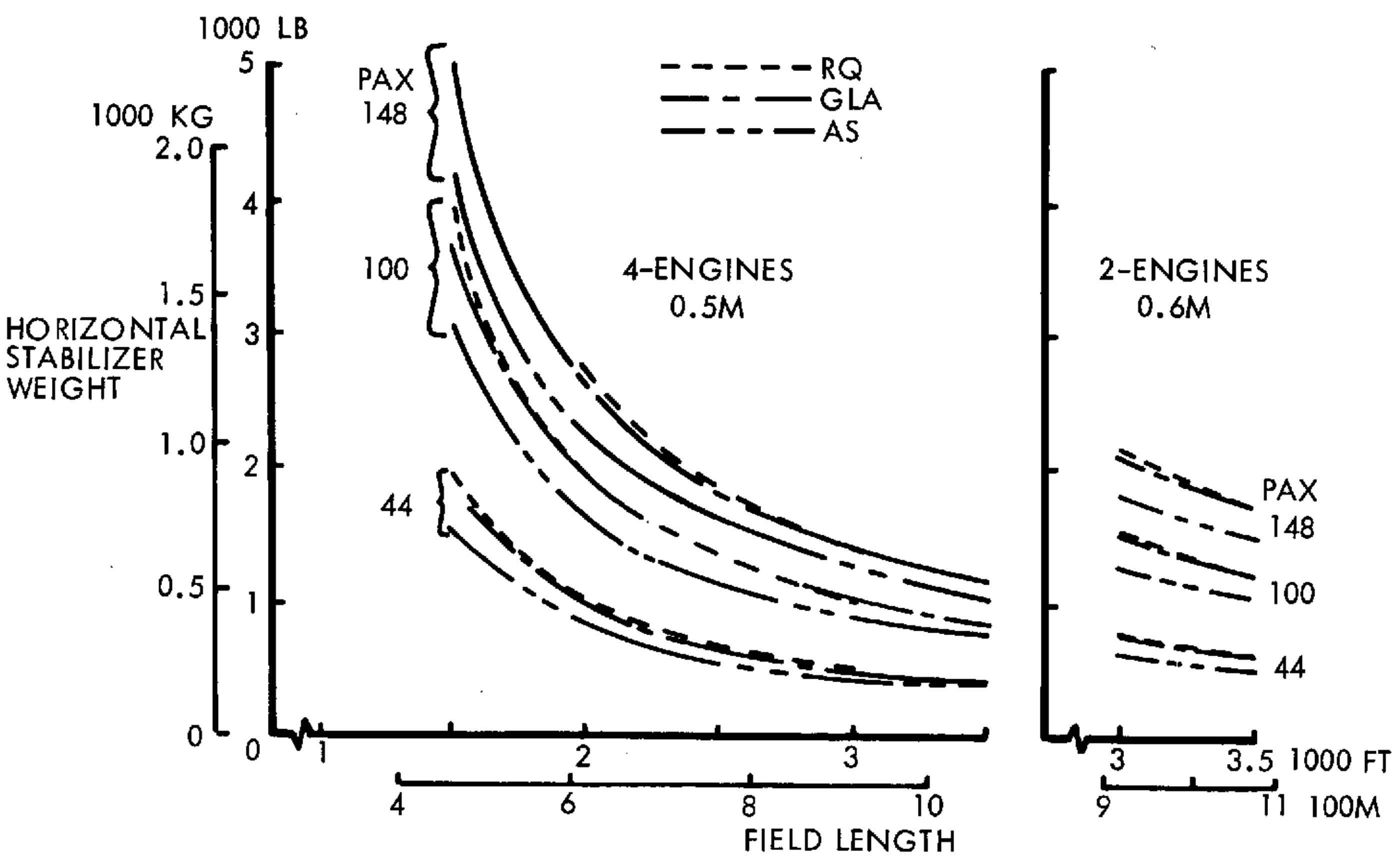


Figure S-8 Effect of Active Controls on Horizontal Stabilizer Weight

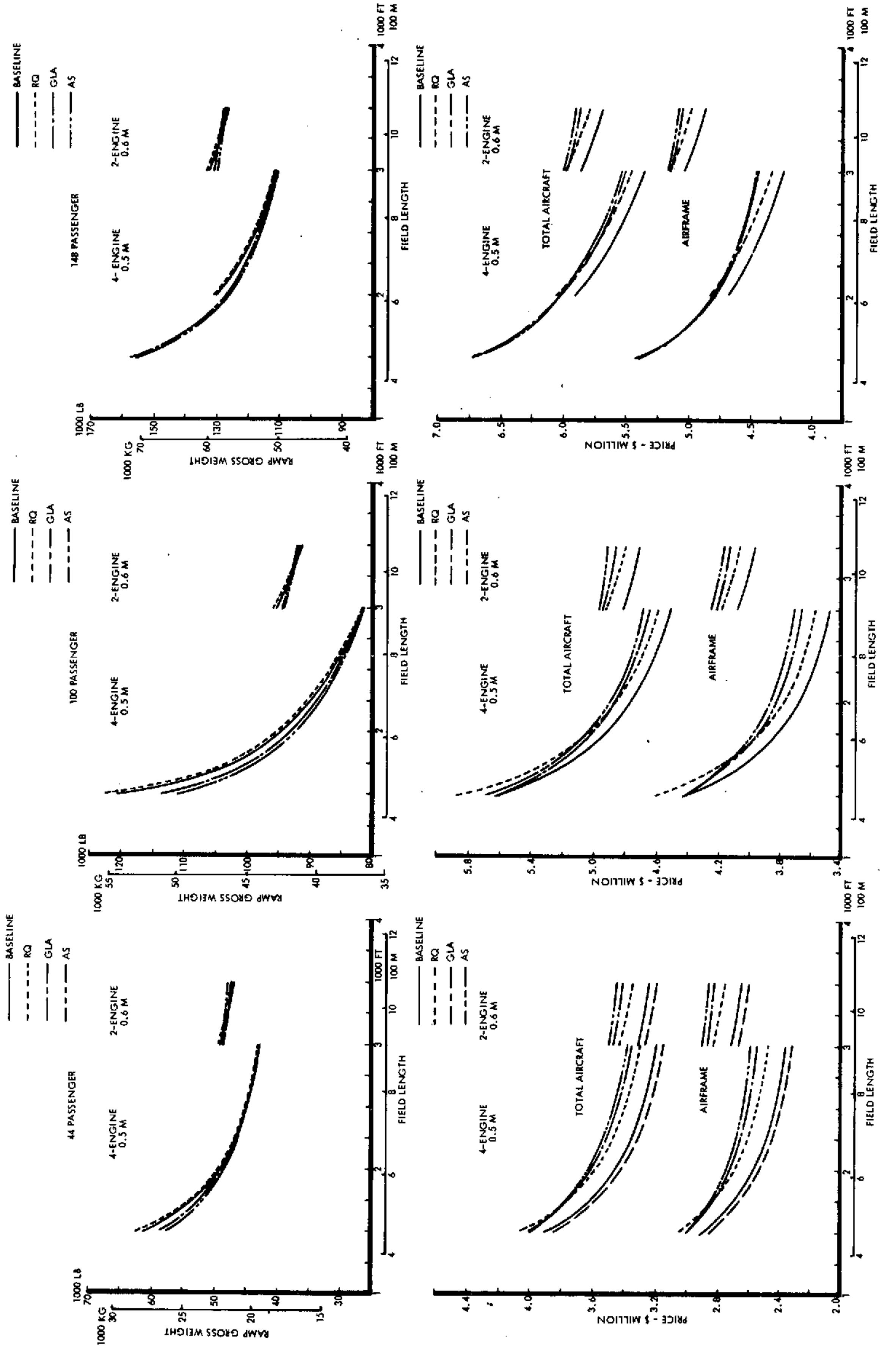


Figure S-7 (Sheet 1 of 3) Comparisons of Aircraft Characteristics

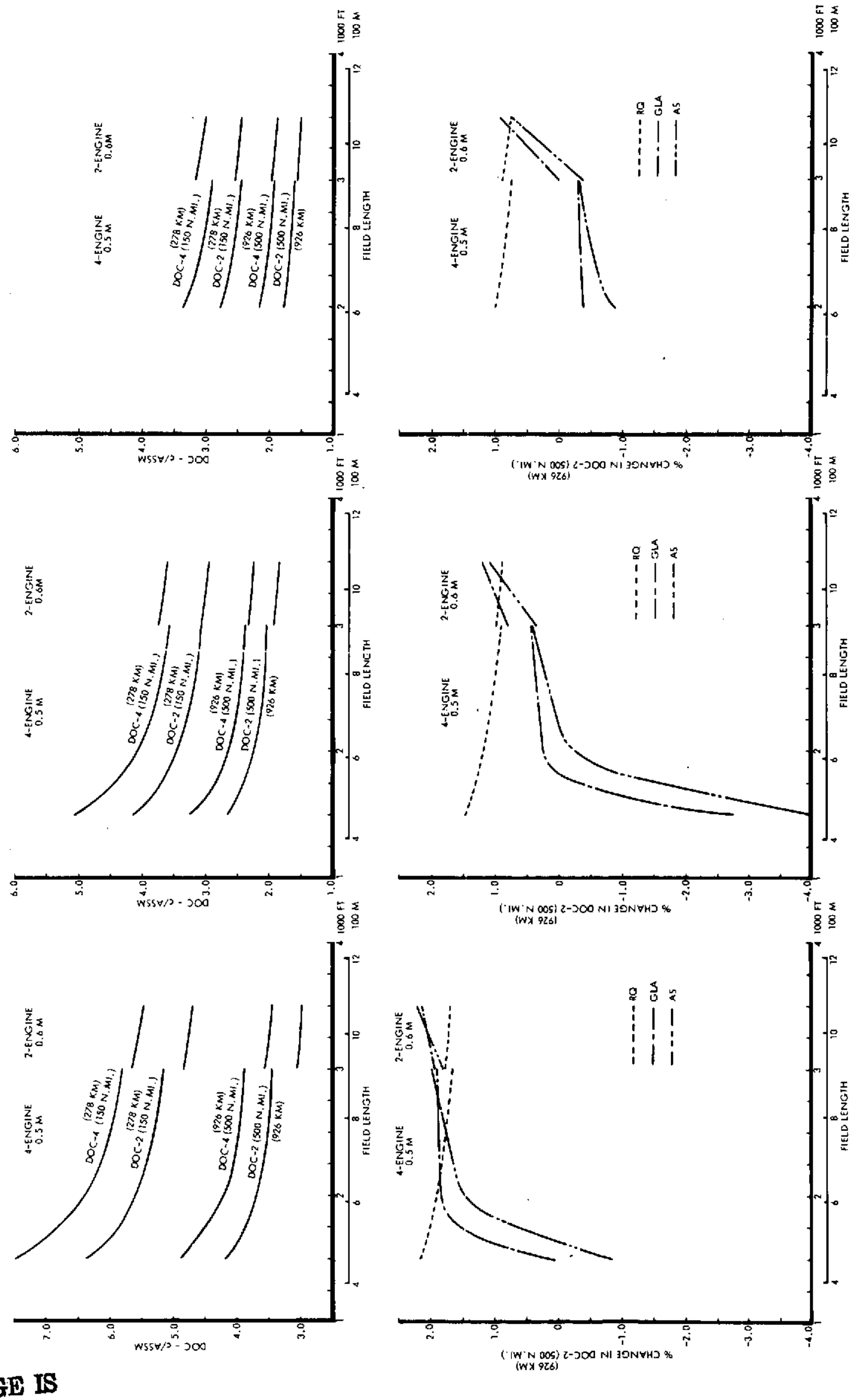


Figure S-7 (Sheet 2 of 3) Comparisons of Aircraft Characteristics

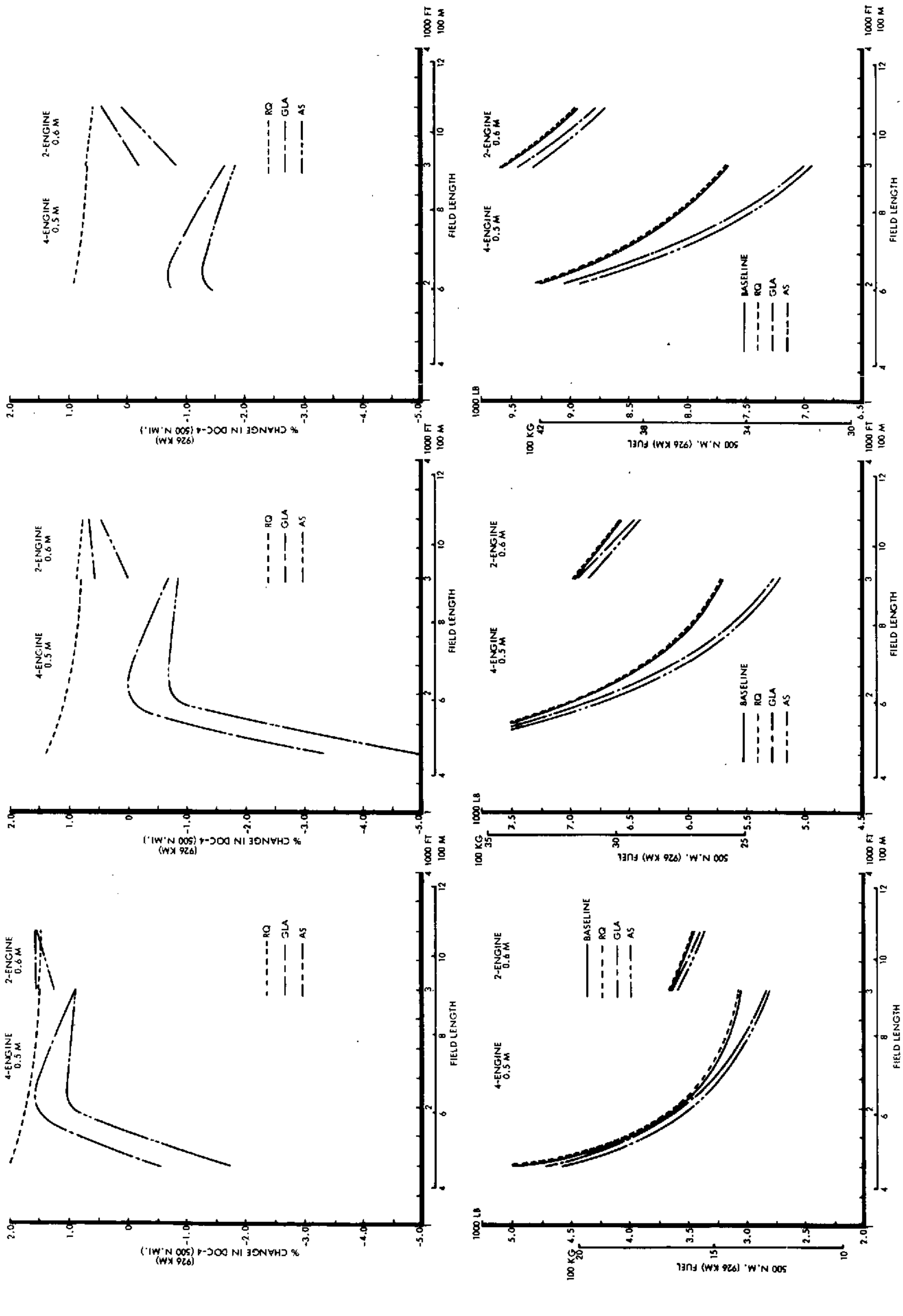


Figure S-7 (Sheet 3 of 3) Comparisons of Aircraft Characteristics

larger wing requires more thrust and hence more fuel, while the larger engines actually result in the airplane cruising at a lower percent power setting than the 4-engined designs, despite the difference in speed. The lower percent power setting makes the specific fuel consumption poorer which of course increases the fuel consumption even further. Figure S-9 presents, as a measure of fuel efficiency, seat statute miles per gallon for the aircraft optimized with the RQ and AS systems, as a function of field length. Note again the poor performance of the 2-engine design and the drastic effects of reducing field length to 457 m (1500 ft). As expected the largest 4-engined aircraft incorporating the AS system has the best fuel efficiency while also providing excellent ride quality.

The aircraft price estimates shown in Figure S-7 show a price increase due to the introduction of active controls for all but the larger aircraft at the shorter field lengths. In these cases, the reoptimization with GLA and AS retains the same aspect ratio as the basic airplane and results in weight and cost savings sufficient to offset the weight and cost introduced by the active control system. The introduction of the RQ system incurs a cost increase for all field lengths and all passenger sizes.

The direct operating cost at 2 and 4 times 1972 fuel prices (DOC-2 and DOC-4) are shown in Figure S-7 for the baseline airplanes for stage lengths of 278 and 926 km (150 and 500 n.m). Note the expected large reductions due to increase in passenger size and the rapid increase as the shortest field length is approached.

It is interesting to compare the 2- and 4-engine configurations at 914 m (3000 ft) field length. The 2-engine designs are heavier, cost more and use more fuel, but in some cases the higher speed results in a lower DOC than for the 4-engine designs. For 44 passengers, 2-engines provides minimum DOC for both fuel prices and both stage lengths. For the 100 passenger case, 2-engines are better at 926 km (500 n.m); the two configurations are equal at DOC-2 and 278 km (150 n.m), while the 4-engine design is better for DOC-4 and 278 km (150 n.m). For 148 passengers the 4-engine design is best except for 926 km (500 n.m). and DOC-2.

The effects of the active control systems on DOC are presented in Figure S-7 as percent change for the DOC-2 and DOC-4, 926 km (500 n.m) cases. The RQ system results in a 0.75 to 2.2 percent increase in DOC dependent on field length and passenger size. The GLA and AS systems can provide reductions in DOC at the shortest field lengths while providing excellent ride comfort. Between 610 and 914 m (2000 and 3000 ft) field length, these two systems will provide the improved ride quality for the 100 and 148 passenger sizes while holding DOC-2 within 0.5 percent of the basic airplane value; DOC-4 can be as much as 1.7 percent below the baseline airplane. For the 44 passenger size the increased weight and cost of the GLA and AS systems offset any savings and result in a further increase in DOC above the RQ system.

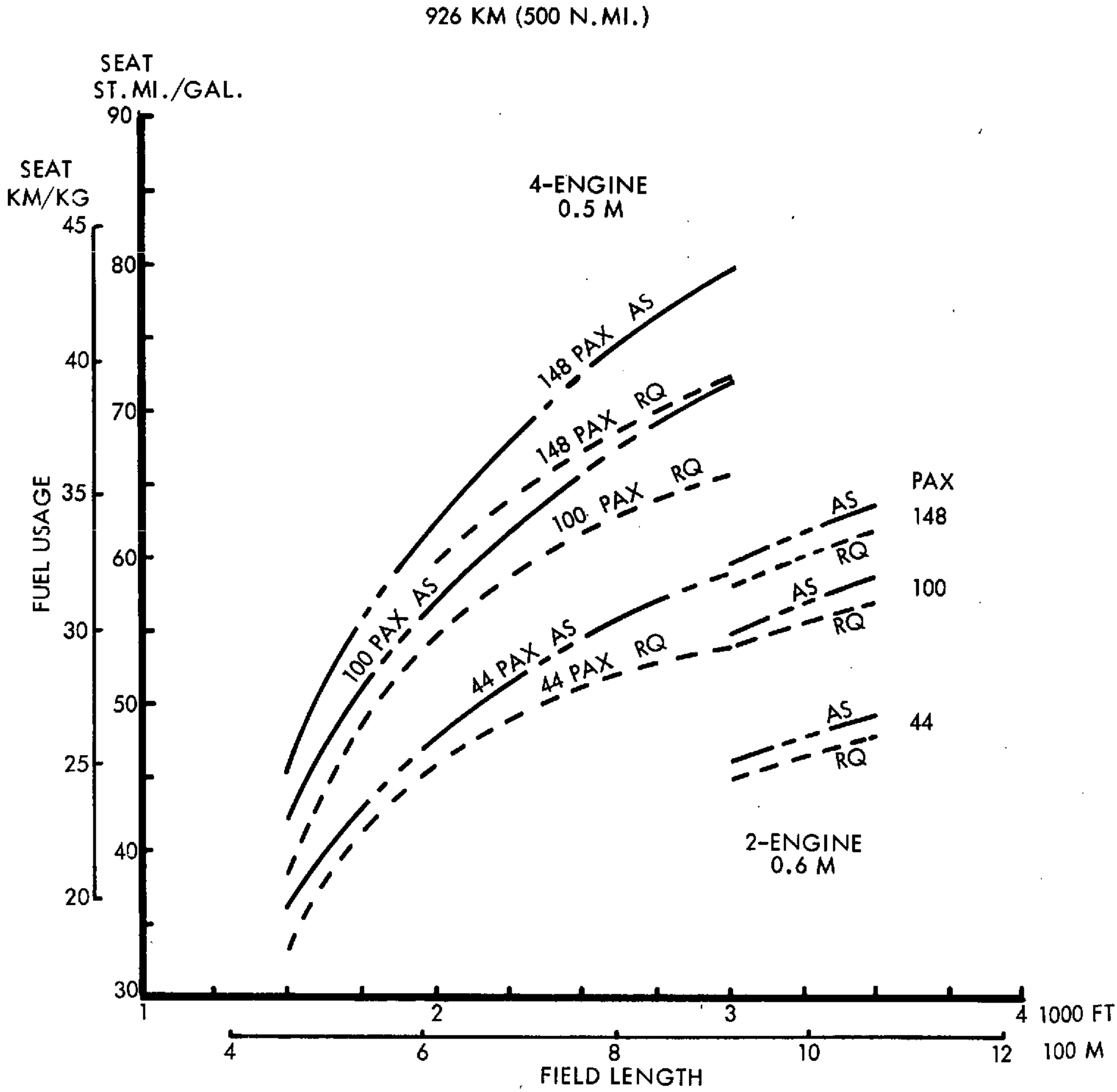


Figure S-9 Effect of Active Controls on Fuel Usage Per Passenger

Turbofan Powered MF Characteristics and Comparison of Concepts

In an earlier phase of the study (Ref. 1) it was determined that the mechanical flap (MF) concept which is illustrated in Figure S-10 and which is powered by two 1.35 FPR engines, provided optimum DOC-2 for 926 km (500 n.m.) at 0.70 M. This compares to the OTW/IBF concept which is illustrated in Figure S-11 and which optimized with four engines at 0.75 M. The results of the present study cannot be directly compared to the data from the previous phase for these airplanes because of different economic assumptions, updating of the computer program and some differences in equipment standards. Table S-II presents the characteristics of OTW/IBF, turbofan MF and turboprop aircraft which are all sized on a consistent basis and can be directly compared.

The wing loading of the OTW/IBF is high enough to obviate the need for a RQ system but both the MF and turboprop concepts are shown with and without active control systems. The turboprop configuration is shown to have the lowest fuel consumption, DOC-2 and DOC-4 of the three concepts. It should be noted however that the turboprop engine performance and cost are based on a rubberized Detroit Diesel Allison T-56. It is obviously not possible to achieve these costs except at the actual T-56 size which would result in a 200 passenger aircraft rather than 148. Alternate sizes are possible for other speeds, field lengths and configurations. For example, a 2-engined, 48 passenger vehicle can be sized for 1067 m (3500 ft) field length and 0.6 M. Further alternates can be sized using other available engines while approximating the rubberized T-56 data. If a new advanced turboprop engine is used the DOC-2 and DOC-4 are increased by 11 and 6.5 percent respectively and the turboprop is then only competitive with the other concepts at and above DOC-4 fuel price. It is concluded that any new turboprop aircraft must be sized to use an existing engine in order to keep the engine price down, and the aircraft economically competitive.

The MF with a ride quality system and the OTW/IBF are almost identical based on DOC-2 but the OTW/IBF has the advantage of a lower fuel consumption and a lower DOC-4. In order to be competitive at DOC-4 the MF must use the AS system.

Conclusions and Recommendations

The ride quality of short-haul airplanes with low wing loading can be improved to the standard of contemporary high wing loading airplanes by the use of active control systems. The direct operating cost penalty for improved ride quality is 2 percent or less for all cases; incorporation of gust load alleviation and augmented stability overcomes this penalty and gives better DOC than aircraft without active controls in all the very low wing loading

148 PASSENGERS

0.70 MACH

OPTIMIZED FOR DOC-2

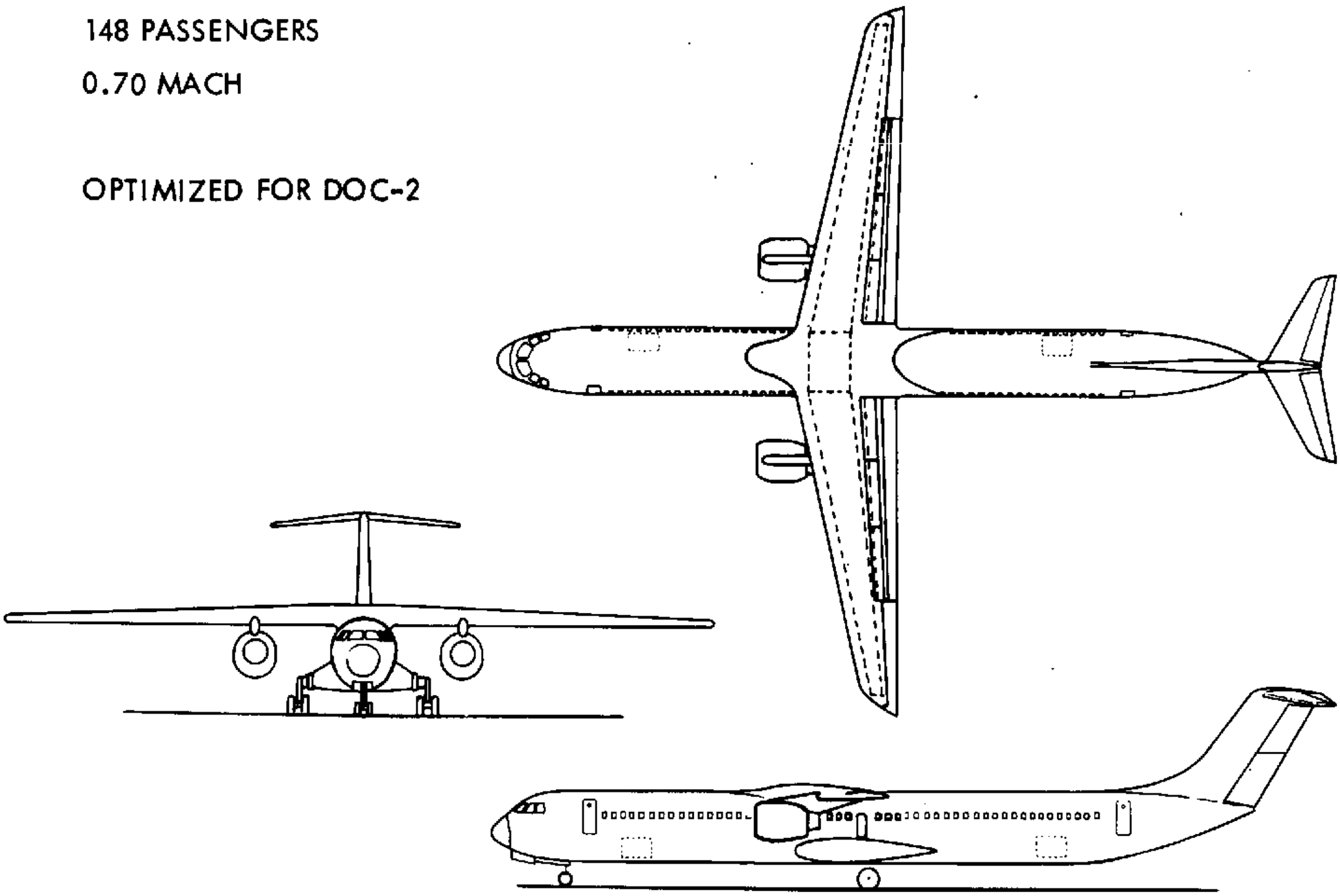


Figure S-10 MF Vehicle

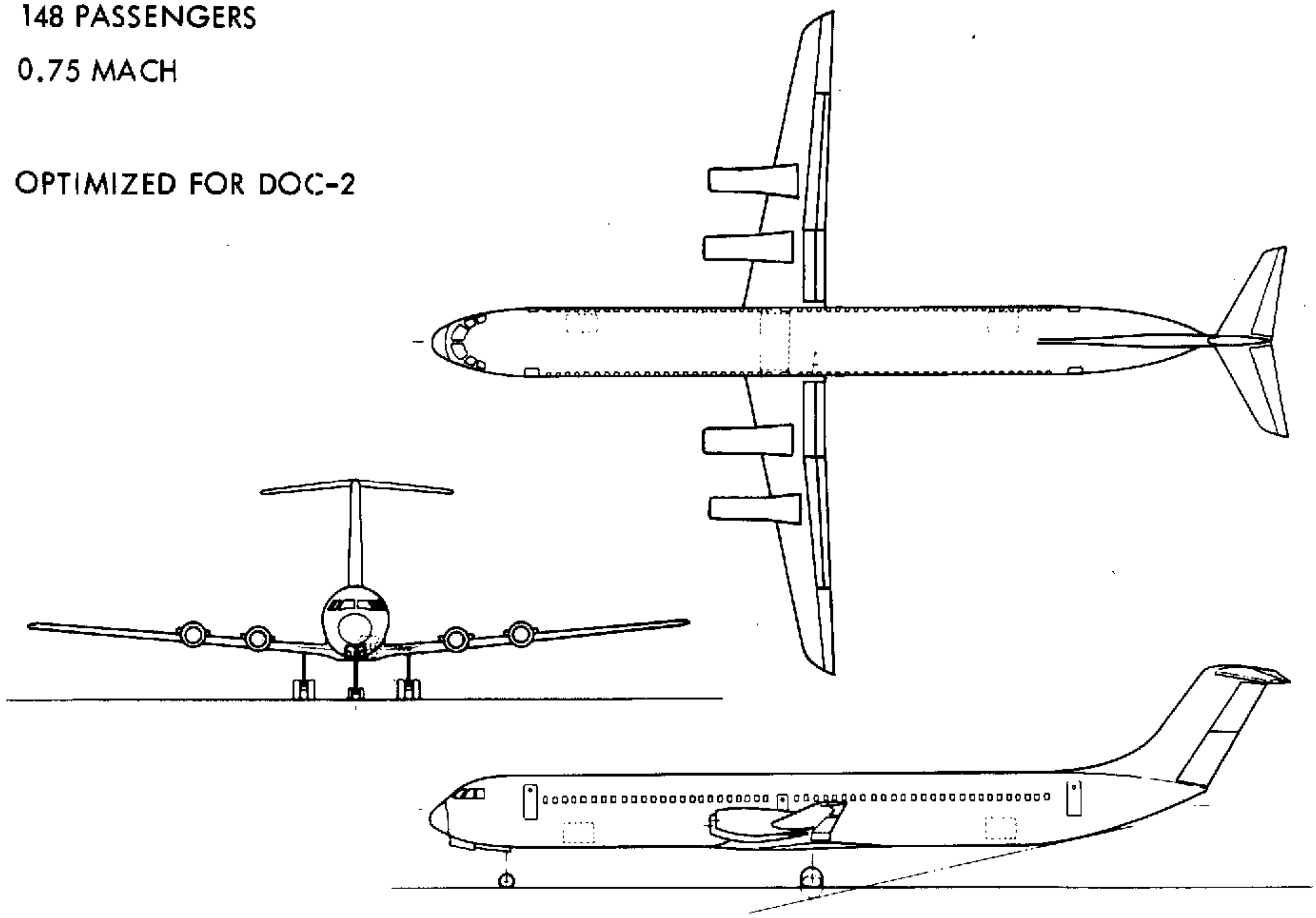


Figure S-11 OTW/IBF Vehicle

A/C OPTIMIZED FOR DOC-2, 914M (3000 FT.) F.L., 926 KM (500 N.MI.)

CONCEPT	OTW/IBF 1.35 FPR	MF 1.35 FPR				TURBOPROP D.S.			
ACTIVE CONTROL	NONE	NONE	RQ	GLA	AS	NONE	RQ	GLA	AS
NO. OF ENG.	4	2	2	2	2	4	4	4	4
MACH NO.	0.75	0.70	0.70	0.70	0.70	0.5	0.5	0.5	0.5
OWE - KG	36,510	39,687	39,850	39,189	38,970	34,179	34,303	35,135	34,981
(LB)	80,490	87,494	87,853	86,396	85,913	75,351	75,623	77,458	77,119
RGW - KG	56,446	59,848	60,026	59,387	59,110	52,694	52,828	53,278	53,084
(LB)	124,440	131,940	132,332	130,924	130,314	116,168	116,464	117,457	117,028
RATED THRUST - KN	55.33	119.6	119.9	112.8	107.8	41.5	41.59	37.19	37.05
(LB)	12,440	26,890	26,948	25,365	24,231	9,330	9,350	8,355	8,332
MISSION FUEL - KG	4,400	4,790	4,802	4,749	4,708	3,601	3,609	3,335	3,304
(LB)	9,700	10,560	10,586	10,470	10,380	7,938	7,956	7,352	7,285
$W/S_{T.O}$ - KG/SQ.M	554	287	287	287	287	347	347	322	322
(LB/SQ.FT)	113.5	58.8	58.8	58.8	58.8	71.0	71.0	66.0	66.0
AR	12	8	8	10	10	8	8	12	12
DOC-2 ¢/ASSM	1.911	1.897	1.909	1.884	1.876	1.7866	1.799	1.793	1.788
DOC-4 ¢/ASSM	2.326	2.333	2.347	2.336	2.304	2.117	2.129	2.097	2.090
A/C PRICE $M	9.103	8.2736	8.3984	8.4015	8.3778	5.5163	5.6248	5.7253	5.7143

Table S-II Comparison of Concepts

airplanes (457 m, 1500 ft field length) and in the 100 and 148 passenger airplanes at 610 m (2000 ft.) and 914 m (3000 ft.) field length. For small aircraft (44 passengers) a GLA or AS system is recommended for very short field lengths but for field lengths of 610 m (2000 ft.) and longer the simpler RQ system results in a smaller DOC penalty. For larger airplanes (100-148 passengers) the GLA and AS systems generally provide smaller DOC penalties than the RQ system for field lengths of less than 914 m (3000 ft.). Above this field length the RQ system appears to minimize DOC effects except at the longer ranges and higher fuel prices where the increased aspect ratio of the GLA and AS systems results in improved fuel consumption and an advantage in DOC. Fuel savings of 11% were obtained by use of active controls in a 148 passenger airplane at 914 m (3000 ft.) field length and 347 kg/sq.m (71 lb/sq. ft.) wing loading.

Weight savings were obtained with the GLA and AS system at the lower wing loadings where reoptimization did not increase wing aspect ratio. At longer field lengths and higher wing loadings the best economics of aircraft with active controls were obtained at increased aspect ratios. Fuel consumption was improved but small weight and cost penalties were incurred compared to baseline aircraft. Generally, the active control systems increased the initial cost of the airplane; the only exception being the largest aircraft at the shorter field lengths.

Due to the favorable fuel consumption and competitive direct operating costs, the turboprop-powered configuration with active controls must be considered a major contender for the short-haul low/medium density market, particularly for the shorter route segments where the time increase due to low speed is negligible. It must be stressed however that these turboprop aircraft, to be competitive, must be designed to match existing turboprop engines. The increased cost of a new turboprop engine will nullify most of the advantage of this configuration.

It may be that the low s.f.c. of a diesel engine might make consideration of this engine cycle worthwhile. Similarly since the development of a new turboprop engine is questionable it may be that a new, very high bypass ratio fan would be advantageous at these speeds and field lengths. The incorporation of active controls in the turbofan MF airplane results in it being equal to the OTW/IBF hybrid in terms of DOC and ride quality. However, the OTW/IBF, because of its higher wing loading, retains its advantage of lower fuel consumption.

This study has been limited to short-haul; it is likely that larger fuel savings are available by the use of active control systems on long haul aircraft which stand to gain so much more from higher aspect ratio wings, providing the wing weight increases can be minimized. Active control systems combining features such as ride quality improvement, gust load alleviation, flutter control and relaxed static stability could result in very efficient high aspect ratio wings. It is recommended that such a program be considered with the final step being the flight demonstration of the wing design.

1.0 INTRODUCTION

Background – Under Contract NAS2-6995, Lockheed addressed the medium to high density short haul areas with 926 km (500 n.m.) as a key design range; airplanes were sized for 148 passengers and the studies were concentrated on low-noise fan-powered aircraft (Ref. 1, 5). It was shown that the "simple" mechanical flap (MF) configuration has better direct operating costs than both the externally blown flap (EBF) and the augmentor wing (AW) concepts at all field lengths longer than 914 m (3000 ft.) and is competitive with the less-well-developed hybrid over-the-wing/internally blown flap (OTW/IBF) concept at field lengths longer than 1067 m (3500 ft.)

Additionally, it was shown that turboprop powered aircraft operating at cruise speeds of .6 M and below, and field lengths of 914 m (3000 ft) and less, have the best fuel consumption and direct operating costs of all the concepts studies. This indicated superiority of the slower turboprop airplane is expected to be accentuated as shorter stage lengths are considered. At design ranges longer than 926 km (500 n.m.), the economic value of higher speed becomes overriding (as well as passenger preference).

Thus, it can be seen that turboprop powered deflected-slipstream airplanes must be considered as major contenders for the short-haul market operating at field lengths of 914 m (3000 ft) or less.

The turboprop must overcome the problem of passenger appeal, and since these concepts have low wing loadings, they must overcome problems such as poor passenger ride comfort and perhaps gust criticality of the structure.

With the recent development of active control technology, systems can be designed to improve ride quality, alleviate gust loading and provide artificial stability in addition to other possible applications. A system providing ride quality improvement only will not be required to achieve "failoperative" operation and would accept poor ride quality if failure of the system occurs. While such a system would provide some gust load alleviation, the structure cannot be designed to the reduced loading since failure of the system could result in failure of the structure. However, the structural relief provided by the system will provide an improved fatigue life or can be used to provide a weight saving due to the reduced fatigue loading. The degree to which these benefits offset the system weight and cost has not been established previously.

To provide gust load alleviation, which permits the structure to be designed to reduced loads, requires a similar system but with redundancies incorporated to ensure continued system operation after a failure. Such a system will provide ride quality control, structural design load reduction and reduced fatigue loading. It must be established whether these benefits will save sufficient structure weight to offset the system weight and cost.

Low wing-loading means a large (relatively) wing area and generally a large horizontal stabilizer area. Active control technology can be used to reduce the size of the horizontal stabilizer by providing artificial stability. Since failure of such a system would mean an unstable airplane, sufficient redundancy must be provided to ensure continued operation after one or more failures. Again the economic tradeoff of the benefits versus the system weight and cost must be evaluated for short-haul aircraft.

Objectives — The primary objective is to evaluate the economics of short-haul aircraft designed with active controls technology and low wing-loading to achieve short field performance with good ride quality. To fulfill this objective the following secondary objectives are necessary:

- Determine the unaugmented ride qualities of two typical short-haul aircraft with low wing-loadings, suitable for 610 m (2000 ft) and 914 m (3000 ft) field length performance.
- Determine the gust criticality of these aircraft.
- Define active control systems for these aircraft to provide:
    - Ride quality equivalent to present short-haul aircraft such as the B737 and DC9.
    - The above plus gust load alleviation and reduced structure weight.
    - The above plus artificial stability and reduced horizontal stabilizer area.
- Determine the weight and cost of these systems.
- Determine the effect of these systems on the weight, first cost and operating costs of short-haul aircraft covering a range of field lengths and passenger sizes.

Approach — The general approach to the program was to divide it into three primary tasks, namely:

- o The determination of airplane characteristics without active controls.
- o The definition of active control systems for these airplanes.
- o The determination of airplane characteristics with active controls.

To achieve the primary objective of this study, the choice of airplane concept is not critical. Data are required to compare the turbofan MF concept with the powered lift concepts at 914 m (3000 ft) field length but the major portion of the study has been conducted with the turboprop concept since:

- o It provides lowest operating cost.
- o It provides lowest fuel consumption.
- o It is expected to rate even better at shorter ranges.
- o It is already operating from short runways at major hubs.
- o Quiet turboprop engine/propeller combinations exist.

The first task required the parametric sizing of turboprop aircraft for short-haul operation. Two- and four-engined configurations have been sized for Mach numbers of 0.5 to 0.6 and field lengths of 457 m through 1070 m (1500 - 3500 ft) which results in wing loading ranging from 161 kg/sq m through 415 kg/sq m (33-85 lb/sq ft.). From this family of aircraft two baselines were selected and their ride qualities determined and compared to those of a present-day turbofan short-haul aircraft known to provide a satisfactory ride. This work is described in Sections 2 and 3.

Active control systems were then defined for the baseline airplanes to provide:

- o Ride quality improvement.
- o Gust load alleviation and ride quality improvement.
- o Artificial stability, gust load alleviation and ride quality improvement.

The weight and cost of these systems were determined and then used to develop parametric weight and cost relationships for different wing loadings and aircraft sizes. These data are described in Section 4.

The third task involved the incorporation of these active control system data into the sizing program and the resizing and reoptimization of the baseline and parametric family of aircraft to determine the characteristics of the aircraft including active control systems as described in Section 5.

Section 6 then compares the characteristics of the aircraft before and after the introduction of active controls and determines the benefits and penalties associated with each system as a function of field length (wing loading) and passenger size. Finally the aircraft with active controls are compared to equivalent data for the powered lift aircraft developed under the earlier NASA contracts (Ref. 1, 5) and recommendations for further research and development listed.

2.0 DESIGN REQUIREMENTS AND EVALUATION CRITERIA

2.1 Design Requirements

The general performance requirements for 926 km (500 n.mi.) range are as stated in Ref. 1. The requirements and evaluation criteria used in the present study are summarized in Table I.

Power Plant – The primary concept used throughout the study is the turboprop with both 2 and 4 engines. The primary power plant considered is a combination of the Detroit Diesel Allison T-56 engine and the Hamilton Standard 4.9 m (16 ft) diameter quiet propeller, both rubberized to provide the required thrust. The pricing for the engine and propeller is based on the current price of the T-56 and a study price for the propeller. The airplane cost data generated using this engine are therefore accurate only at the design points using the actual engine size. This is considered the most desirable approach since a new turboprop engine is unlikely to be initiated and therefore any new turboprop aircraft is most likely to use existing or modified engines. The relative trends provided by rubberizing these engine data are of course unaffected.

Passenger Capacity – The initial study to determine optimum parameters such as aspect ratio, cruise Mach number and altitude used a 100 passenger capacity. Later studies, to illustrate the effect of passenger capacity, used values of 44, 100 and 148. The baseline airplanes used for the structural and ride quality studies accommodate 44 passengers since this size is considered reasonable for introducing a new short-haul system operating from short runways (914 m; 3000 ft) at major hubs, and is representative of the aircraft suitable for short stage lengths in the low density market.

Range – As in the previous studies a range of 926 km (500 n.mi.) is required. Extended range up to 2778 km (1500 n.mi.) is not included since the turboprop concept is not considered suitable for such ranges.

Field Length – To provide an adequate range of wing loadings for the evaluation, field lengths of 457,610, 914 and 1067 m (1500, 2000, 3000 and 3500 ft) were included.

Cruise Speed – Based on the turboprop data generated in Ref. 1, 926 km (500 n.mi.) cruise Mach numbers of 0.5, 0.55 and 0.6 were considered and the optimums determined. Comparison to results of previous studies involves comparison of aircraft with design speeds up to M 0.8.

REQUIREMENTS

- o POWER PLANT: RUBBERIZED T-56 AND "QUIET" PROPELLER
- o NUMBER OF ENGINES: 2 AND 4
- o PASSENGER CAPACITY: 44, 100, AND 148
- o RANGE: 500 N.MI.(926 KM)
- o FIELD LENGTH: 1500, 2000, 3000 AND 3500 FT.
  (457, 610, 914 AND 1067 M)
- o SPEED: 0.5 - 0.6M AND 250 KEAS (463 KM/HR) MINIMUM
- o ALTITUDE: UP TO 25,000 FT (7620 M)
- o ASPECT RATIO: 8, 10 AND 12
- o FAR 25 FOR TURBOFAN AND 2-ENGINED TURBOPROP DESIGNS
- o FAR XX FOR 4-ENGINED TURBOPROP (DS) DESIGNS

SELECTION CRITERIA (PRIMARY)

- o MINIMUM DOC AT FUEL PRICE OF 23¢/GALLON OF FUEL (DOC-2)
  FOR 150 N.M. (278 KM) STAGE LENGTH AT BEST ALTITUDE AND SPEED

Table I Design Requirements and Selection Criteria

For a stage length of 278 km (150 n.mi.) alternate speeds were considered as described in Section 2.2.

Cruise Altitude – The aircraft were sized for 916 km (500 n.mi.) cruise at 7620 m (25,000 ft) altitude. For shorter stage lengths the altitude was optimized as described in Section 2.2

Aspect Ratio – Aspect ratios of 8, 10 and 12 were considered and the optimum selected for each case.

Federal Aviation Requirements – The requirements of FAR Part 25 (Ref. 4) were applied to the turbofan mechanical flap and 2-engined turboprop designs while the requirements of FAR Part XX (Ref. 3) were applied to the 4-engined turboprop deflected slipstream and the hybrid powered lift designs.

Costing Methods – Airframe and engine costing were on the same basis as used in Ref. 1 except for inflation of 12% (6%/year) from 1972 to 1974.

The 1967 DOC estimating methodology was used except for the following changes, by agreement with NASA.

1. Block time minus flight = 10 min.

2. Block fuel as determined from the flight profile, using 6 minutes ground time and 4 minutes air maneuver time.

3. Reserve fuel for 370 km (200 n.mi.) at cruise altitude plus 15 minutes at 3050 m (10,000 ft) altitude, maximum endurance speed.

4. Crew cost = $2 \times (0.05 \times \frac{WG}{1000} + 63)$

5. Hull insurance: 1% rather than ATA 2%.

6. Utilization: 2500 hr. per year.

7. Labor rate: \$7.45/hour.

8. Maintenance cost: 75% of 1967 ATA value.

9. Maintenance burden: Retain ATA factor of 1.8

10. Depreciation: 15 years, 15% residual, 25% engine spares.

11. Fuel costs: 11.5c/gallon

DOC applicable to 11.5c/gallon is identified as DOC-1.

Note also the following:

DOC-2 - 23c/gallon

DOC-4 - 46c/gallon

DOC-10 - $1.15/gallon

2.2 Selection Criteria

Although the aircraft were sized for 926 km (500 n.mi.) range cruising at 7620 m (25,000 ft) altitude, the optimum aspect ratio and design cruise Mach number were selected on the basis of Direct Operating Cost at 23c/gallon fuel cost (identified as DOC-2) for a stage length of 278 km (150 n.mi.) which is considered more realistic for short-haul. At this shorter stage length it is unlikely that the cruise altitude will reach 7620 m (25,000 ft); the aircraft have therefore been flown by the computer at altitudes of 3050, 4572 and 6100 m (10,000, 15,000 and 20,000 ft). Similarly the optimum cruise speed for this shorter stage length may be different then the design cruise Mach number for 926 km (500 n.mi.) range. Accordingly 3 cruise speeds have been flown at each altitude and the value determined for minimum DOC-2. If DOC-2 did not provide a definite choice, DOC-4 and fuel consumption were considered.

3.0 AIRPLANE CHARACTERISTICS WITHOUT ACTIVE CONTROLS

In order to determine the effects of incorporating active controls into low wing loading aircraft, it is first necessary to size low wing loading aircraft without active controls and determine the characteristics of the parameters which may be affected by the incorporation of active control systems. To identify the magnitude of the effects at various wing loadings a family of aircraft with field performance varying from 457 m through 1070 m (1500 - 3500 ft) were sized. To identify the effects of size, passenger capacities of 44, 100 and 148 have been configured.

Before sizing this complete matrix of airplanes a parametric study of the 100 passenger capacity aircraft was conducted to identify the optimum number of engines (2 or 4), and the optimum aspect ratio, cruise altitude and speed to provide minimum DOC-2 for a 278 km (150 n.mi.) stage length, and for field lengths of 457, 610, 914 and 1066 m (1500, 2000, 3000 and 3500 ft). This work is described in Section 3.1.

The optimum parameters obtained from this study were then used to size and configure the two baseline airplanes defined in Section 3.2. The ride qualities of these aircraft were then determined and compared to a contemporary short/medium haul aircraft known to have satisfactory ride qualities. These analyses are described in Section 3.3 and were used to design the ride quality control systems described in Section 4.0.

The two baseline aircraft were also used to conduct a wing structural analysis with the object of confirming or updating the sizing program weight routine. These analyses identified the degree of gust criticality of the baseline wings for use in designing the gust load alleviation systems of Section 4.0, and are described in Section 3.4.

Finally in Section 3.5 the matrix of airplanes without active controls are defined, reflecting the optimization of the configuration parameters and the updating of the weight routines.

3.1 Initial Parametric Sizing

As explained in Section 1.0 the turboprop was chosen as the primary concept for this study. Both 2- and 4-engined configurations have been sized. The 2-engined designs were treated as conventional propeller driven airplanes with lift margins meeting the requirements of FAR Part 25, while the 4-engined designs make use of the slipstream-generated lift which qualifies as a powered lift concept under FAR Part XX performance ground rules. The aircraft could be either low-wing or high-wing arrangements, each having some advantages and disadvantages. The choice between them is too detailed to be determined in this study and will have little, if any effect on the conclusions. It was therefore assumed that all the airplanes would have a conventional low-wing configuration similar to the Convair 580 and Lockheed Electra.

3.1.1 **Basic Aerodynamic Data.** The aerodynamic performance for the deflected slipstream concept is based on detailed C-130 cruise and terminal operating data from which slipstream effects have been derived. In determining thrust and wing area requirements for takeoff and landing the power-on stall speeds, including one-engine inoperative, were used as permitted by FAR Part XX. C_L, C_X, C_T data for the all-engines operating and one-engine failed cases are provided in Tables II and III for ranges of angle of attack and flap angle.

The 2-engine configurations do not consider the effects of deflected slipstream for the engine-failed case and are therefore made compatible with the power-off stall speeds dictated by FAR Part 25. The data of Table II and III were used in sizing these airplanes but for the engine-out cases only the $C_T = 0$ data of Table III were used.

3.1.2 **Basic Propulsion Data.** The T-56-A-15 engine, manufactured by the Detroit Diesel Allison Division of GMC, was selected as the baseline turboprop engine for this study. While this engine is not representative of the latest technology, data were immediately available from the previous program (Ref. 1). Additionally, Ref. 1 showed that a new advanced turboprop of identical shaft horse power to the T-56 would result in an increase in DOC due to the higher price of the new engine compared to the T-56. It is considered that any new aircraft powered by turboprops will use existing or modified engines and the T-56 data are therefore typical.

The propulsion data used for the turboprop concepts are based on the existing T-56-A-15 engine combined with a quiet propeller, for which data had been generated by Hamilton Standard for a previous Lockheed study (Ref. 2). This propeller is designed for 95 EPNdB at 152 m (500 ft) sideline which was achieved by increasing the propeller diameter to 4.9 m (16 ft), lowering the tip speed and lowering the disk loading. The propeller design takes advantage of advanced technology spar and shell composite construction and results in only a small weight penalty, which includes the penalty associated with a T-56 gearbox change to provide the lower shaft speeds required. Cost increases for this propeller, including the distributed development costs of the propeller and the gearbox changes were found in a previous study (Ref. 2) to be more than offset by an increase in thrust at takeoff and the cost/thrust ratio at cruise only increased slightly.

The T-56 engine and propeller data generated for this program are essentially identical to those described in Ref. 1; slight alterations have been incorporated to improve the accuracy at the lower cruise altitudes. A discussion of the installation effects, bleed airflow corrections and bookkeeping procedures used in the performance estimation is also included in Section 7.5.3 of Ref. 1.

AR = 10

δ_f	0.						
C_T	0.	.3264	.653	1.224			
α	-4.	0.	4.	8.	12.	16.	20.
C_L	-.20	.24	.67	1.095	1.53	1.62	1.56
	-.18	.37	.89	1.4	1.93	2.21	2.25
	-.16	.48	1.09	1.69	2.29	2.62	2.75
	-.08	.6	1.28	1.94	2.60	3.04	3.30
C_X	-.06	-.045	-.055	-.087	-.135	-.186	-.24
	.262	.277	.25	.198	.115	.027	-.065
	.586	.596	.56	.479	.362	.235	0.1
	1.145	1.155	1.103	1.0	.848	.65	.41
	7.5						
	0.	.3264	.653	1.224			
	-4.	0.	4.	8.	12.	16.	20.
	-.02	.40	.84	1.26	1.68	1.83	1.81
	.03	.535	1.08	1.63	2.135	2.43	2.49
	.1	.71	1.32	1.92	2.50	2.81	2.98
	.19	.8	1.55	2.19	2.81	3.28	3.58
	-.06	-.05	-.067	-.105	-.162	-.25	-.395
	.255	.261	.225	.164	.072	-.04	-.16
	.575	.575	.527	.460	.307	.168	.01
	1.14	1.135	1.073	.968	.802	.592	.345
	15.						
	0.	.3264	.653	1.224			
	-4.	0.	4.	8.	12.	16.	20.
	.16	.585	1.02	1.45	1.87	2.05	2.08
	.27	.75	1.30	1.87	2.35	2.65	2.73
	.38	.96	1.57	2.17	2.69	3.04	3.25
	.50	1.19	1.87	2.50	3.08	3.56	3.86
	-.078	-.072	-.092	-.128	-.201	-.324	-.52
	.245	.237	.193	.124	.013	-.125	-.293
	.562	.545	.485	.392	.241	.080	-.11
	1.12	1.095	1.025	.91	.72	.5	.245
	25.						
	0.	.3264	.653	1.224			
	-4.	0.	4.	8.	12.	16.	20.
	.44	.875	1.31	1.74	2.16	2.35	2.42
	.62	1.13	1.70	2.25	2.70	2.98	3.05
	.78	1.36	1.99	2.59	3.11	3.44	3.59
	1.0	1.68	2.39	3.02	3.62	4.1	4.24
	-0.1	-.106	-.135	-.184	-.288	-.45	-.695
	.21	.185	.130	.045	-.097	-.293	-.53
	.518	.481	.401	.289	.123	-.075	-.372
	1.06	1.063	0.9	0.748	.517	.270	.055
	30.						
	0.	.3264	.653	1.224			
	-4.	0.	4.	8.	12.	16.	20.
	.80	1.31	1.78	2.27	2.63	2.74	2.78
	1.16	1.74	2.29	2.85	3.23	3.35	3.38
	1.4	2.04	2.67	3.32	3.80	3.91	3.93
	1.68	2.41	3.13	3.83	4.43	4.59	4.63
	-.159	-.177	-.22	-.312	-.475	-.632	-.83
	.10	.047	-.03	-.170	-.382	-.570	-.783
	.362	.292	.186	.015	-.240	-.490	-.738
	.854	.742	.595	.395	.03	-.3	-.675

Table II (Sheet 1 of 2) Defelcted Slipstream Aero Data, -4 Engines (Takeoff)

AR = 10

δ_f	36.						
C_T	0.	.3264	.653	1.224			
α	-4.	0.	4.	8.	12.	16.	20.
C_L	.80	1.31	1.78	2.27	2.63	2.74	2.78
	1.16	1.74	2.29	2.85	3.23	3.35	3.38
	1.4	2.04	2.67	3.32	3.80	3.91	3.93
	1.68	2.41	3.13	3.83	4.43	4.59	4.63
C_X	-.155	-.177	-.222	-.312	-.475	-.632	-.83
	.10	.047	-.03	-.170	-.382	-.570	-.783
	.362	.292	.186	.015	-.240	-.490	-.738
	.854	.742	.595	.395	.03	-.33	-.675
	51.						
	0.	.3264	.653	1.224			
	-4.	0.	4.	8.	12.	16.	20.
	1.04	1.52	1.99	2.50	2.94	3.09	3.11
	1.47	2.08	2.74	3.29	3.60	3.70	3.71
	1.79	2.51	3.25	3.86	4.22	4.27	4.27
	2.24	3.04	3.88	4.45	4.90	4.96	4.96
	-.249	-.279	-.33	-.42	-.537	-.692	-.865
	-.046	-.125	-.236	-.355	-.488	-.645	-.823
	.15	.025	-.124	-.270	-.427	-.600	-.790
	.51	.324	.093	-.075	-.30	-.532	-.75
	60.						
	0.	.3264	.653	1.224			
	-4.	0.	4.	8.	12.	16.	20.
	1.08	1.58	2.04	2.55	3.02	3.23	3.24
	1.59	2.22	2.85	3.39	3.70	3.82	3.855
	1.985	2.67	3.40	3.98	4.33	4.40	4.41
	2.50	3.30	4.13	4.66	5.03	5.10	5.10
	-.272	-.319	-.382	-.465	-.559	-.699	-.86
	-.082	-.185	-.306	-.417	-.540	-.676	-.825
	.068	-.072	-.215	-.355	-.497	-.65	-.80
	.368	.162	-.06	-.236	-.395	-.588	-.778
	66.						
	0.	.3264	.653	1.224			
	-4.	0.	4.	8.	12.	16.	20.
	1.10	1.57	2.05	2.59	3.05	3.30	3.30
	1.65	2.29	2.90	3.45	3.75	3.86	3.91
	2.09	2.79	3.48	4.03	4.35	4.44	4.46
	2.65	3.44	4.25	4.78	5.15	5.15	5.15
	-.280	-.328	-.393	-.484	-.573	-.705	-.86
	-.116	-.216	-.33	-.447	-.552	-.69	-.825
	.02	-.12	-.273	-.406	-.535	-.670	-.805
	.31	.106	-.13	-.298	-.52	-.641	-.77
	81.						
	0.	.3264	.653	1.224			
	-4.	0.	4.	8.	12.	16.	20.
	1.13	1.60	2.06	2.60	3.06	3.26	3.30
	1.81	2.39	2.99	3.53	3.90	3.92	3.90
	2.30	2.96	3.62	4.13	4.43	4.49	4.50
	2.93	3.71	4.46	4.98	5.14	5.18	5.18
	-.238	-.295	-.377	-.485	-.60	-.717	-.835
	-.123	-.229	-.363	-.495	-.625	-.725	-.825
	.002	-.144	-.308	-.448	-.580	-.700	-.82
	.27	.045	-.2	-.375	-.515	-.64	-.76

Table II (Sheet 2 of 2) Deflected Slipstream Aero Data-4 Engines (Landing)

δ_f	.00000						
C_T	.00000	.24480	.48975	.91800			
α	-4.00000	.00000	4.00000	8.00000	12.00000	16.00000	20.00000
C_L	-.20000	.24000	.67000	1.09500	1.53000	1.62000	1.56000
	-.18500	.33875	.83626	1.32470	1.83251	2.07376	2.08939
	-.17000	.42502	.99003	1.54505	2.11006	2.41508	2.50009
	-.12126	.53365	1.17300	1.79721	2.42351	2.80922	2.99804
C_X	-.06000	-.04500	-.05500	-.08700	-.13500	-.18600	-.24000
	.18139	.19670	.17345	.12701	.05270	-.02593	-.10812
	.42405	.43655	.40505	.33854	.23854	.13103	.01753
	.84511	.85[illegible]6	.81191	.72198	.58958	.42959	.24692
	7.50000						
	.00000	.24480	.48975	.91800			
	-4.00000	.00000	4.00000	8.00000	12.00000	16.00000	20.00000
	-.02000	.40000	.84000	1.26000	1.68000	1.83000	1.81000
	.01563	.49876	1.02001	1.54251	2.02689	2.29376	2.33189
	.07001	.62252	1.20004	1.77505	2.31756	2.62007	2.73509
	.14[illegible]16	.78292	1.41994	2.03900	2.63457	3.02720	3.25407
	-.06000	-.05500	-.06700	-.10500	-.16200	-.25000	-.39500
	.17482	.18214	.15139	.09632	.01345	-.09237	-.21993
	.41505	.41805	.37605	.30204	.18954	.06403	-.07797
	.83745	.83535	.78077	.68649	.53973	.36700	.16791
	15.00000						
	.00000	.24480	.48975	.91800			
	-4.00000	.00000	4.00000	8.00000	12.00000	16.00000	20.00000
	.16000	.58500	1.02000	1.45000	1.87000	2.05000	2.08000
	.24250	.70595	1.23064	1.77251	2.23876	2.51314	2.57564
	.32502	.85003	1.43504	2.02006	2.52006	2.84508	2.99009
	.43[illegible]10	1.06059	1.70335	2.31947	2.86751	3.28130	3.52594
	-.07800	-.07200	-.09200	-.12800	-.20100	-.32400	-.52500
	.16464	.15982	.12132	.06001	-.04137	-.17512	-.34793
	.40355	.39105	.33904	.25804	.12703	-.02247	-.20147
	.82127	.80070	.73648	.63574	.46581	.27697	.05736
	25.00000						
	.00000	.24480	.48975	.91800			
	-4.00000	.00000	4.00000	8.00000	12.00000	16.00000	20.00000
	.40000	.87500	1.31000	1.74000	2.16000	2.35000	2.42000
	.57626	1.06782	1.60876	2.13313	2.57314	2.83314	2.89814
	.70003	1.24504	1.84505	2.42006	2.90507	3.21008	3.32009
	.83051	1.50625	2.17455	2.78833	3.34284	3.74580	3.86359
	-.10000	-.10600	-.13500	-.18400	-.28800	-.45000	-.69500
	.13264	.11[illegible]95	.06339	-.01318	-.14655	-.33605	-.57081
	.36405	.3[illegible]04	.26554	.16704	.01303	-.18397	-.45098
	.76973	.72329	.63[illegible]	.50278	.30540	.08214	-.1932[illegible]
	[illegible].00000						
	.00000	.24480	.48975	.91800			
	-4.00000	.00000	4.00000	8.00000	12.00000	16.00000	20.00000
	.80000	1.31000	1.78000	2.27000	2.63000	2.74000	2.78000
	1.07[illegible]51	1.64063	2.17064	2.71189	3.08190	3.20065	3.23[illegible]14
	1.28005	1.89006	2.48007	3.08508	3.51509	3.63009	3.65009
	1.52824	2.20975	2.87973	3.54853	4.08006	4.21623	4.24686
	-.15000	-.17700	-.2[illegible]00	-.31200	-.47500	-.63200	-.83000
	.03582	-.01630	-.07949	-.20816	-.40831	-.58652	-.79462
	.23104	.16954	.07803	-.07747	-.31098	-.52900	-.76049
	.59137	.50105	.37629	.19221	-.1[illegible]526	-.41551	-.70927

Table III (Sheet 1 of 2) Deflected Slipstream Aero Data -3 Engines (Takeoff)

AR = 10

δ_f	36.00000						
C_T	.00000	.24480	.48975	.91800			
α	-4.00000	.00000	4.00000	8.00000	12.00000	16.00000	20.00000
C_L	.80000	1.31000	1.78000	2.27000	2.63000	2.74000	2.78000
	1.07751	1.64063	2.17064	2.71189	3.08190	3.20065	3.23314
	1.28005	1.89006	2.48007	3.08508	3.51509	3.63009	3.65509
	1.52824	2.20975	2.87973	3.54853	4.08006	4.21623	4.24686
C_X	-.15500	-.17700	-.22200	-.31200	-.47500	-.63200	-.83000
	.03582	-.01030	-.07949	-.20818	-.40831	-.58662	-.79462
	.23104	.16954	.07803	-.07747	-.31098	-.52999	-.76049
	.59137	.50105	.37629	.19221	-.11526	-.41551	-.70927
	51.00000						
	.00000	.24480	.48975	.91800			
	-4.00000	.00000	4.00000	8.00000	12.00000	16.00000	20.00000
	1.04000	1.52000	1.99000	2.50000	2.94000	3.09000	3.11000
	1.36939	1.94814	2.56751	3.10627	3.43752	3.55002	3.56252
	1.63006	2.29508	2.99510	3.57510	3.91010	3.98509	3.99009
	1.99794	2.75159	3.53959	4.12527	4.52219	4.58033	4.58096
	-.24900	-.27900	-.33000	-.42000	-.53700	-.69200	-.86500
	-.09631	-.16324	-.26062	-.37250	-.50100	-.65662	-.83294
	.05203	-.04998	-.17998	-.31249	-.45749	-.62249	-.80649
	.31789	.16520	-.02302	-.17838	-.36766	-.56877	-.77182
	60.00000						
	.00000	.24480	.48975	.91800			
	-4.00000	.00000	4.00000	8.00000	12.00000	16.00000	20.00000
	1.08000	1.58000	2.04000	2.55000	3.02000	3.23000	3.24000
	1.46970	2.07189	2.66377	3.19564	3.53315	3.67315	3.79878
	1.78757	2.44508	3.12510	3.68511	4.01510	4.11009	4.13255
	2.22087	2.96198	3.73763	4.28984	4.64184	4.71388	4.70809
	-.27200	-.31900	-.38200	-.46500	-.55900	-.69900	-.86000
	-.12700	-.21718	-.32593	-.42987	-.54625	-.68194	-.83312
	-.00697	-.12848	-.26049	-.38599	-.51850	-.66300	-.81250
	.20969	.03849	-.14362	-.29978	-.44936	-.62071	-.79029
	66.00000						
	.00000	.24480	.48975	.91800			
	-4.00000	.00000	4.00000	8.00000	12.00000	16.00000	20.00000
	1.10000	1.57000	2.05000	2.59000	3.05000	3.30000	3.30000
	1.51939	2.12376	2.70439	3.25252	3.58127	3.71877	3.76127
	1.87008	2.54009	3.19011	3.74011	4.05010	4.15009	4.18509
	2.34541	3.08967	3.83602	4.37630	4.71510	4.75805	4.77213
	-.28000	-.32800	-.39300	-.48400	-.57300	-.70500	-.86000
	-.15525	-.24300	-.34537	-.45650	-.55700	-.69406	-.83281
	-.04798	-.16798	-.30149	-.42649	-.54350	-.68000	-.81500
	.15723	-.01258	-.20491	-.35468	-.52846	-.65689	-.78834
	81.00000						
	.00000	.24480	.48975	.91800			
	-4.00000	.00000	4.00000	8.00000	12.00000	16.00000	20.00000
	1.13000	1.60000	2.06000	2.60000	3.06000	3.26000	3.30000
	1.65189	2.20627	2.77627	3.31814	3.70939	3.76064	3.75002
	2.05509	2.67510	3.30512	3.83012	4.16510	4.20509	4.20009
	2.58947	3.30528	4.00871	4.52641	4.76026	4.80170	4.80235
	-.23800	-.29500	-.37700	-.48500	-.60000	-.71700	-.83500
	-.15237	-.24668	-.36906	-.49606	-.62312	-.72506	-.82719
	-.06048	-.18649	-.33549	-.47150	-.60250	-.71250	-.82250
	.12788	-.05536	-.25858	-.41602	-.55225	-.67248	-.79018

Table III (Sheet 2 of 2) Deflected Slipstream Aero Data -3 Engines (Landing)

Data for the T-56-A-15 baseline engine with the quiet propeller are shown in Table IV. All appropriate scaling of the propulsion system is carried out in the airplane performance computer programs. The installed engines are scaled to match the airplane thrust requirements with the scaling of engine weight and cost based on the factors shown in Figure 1.

3.1.3 Basic Weights Data – The weight estimation logic within the sizing program is essentially the same as that used for earlier Short-Haul Aircraft Studies (Ref. 1). Modifications were made to the wing, electrical, instruments, air conditioning, furnishings, and operating equipment weight items to obtain a more general set of weight estimating relationships.

In the wing weight logic, the wing box weight is determined by subtracting base weights for the control surfaces and secondary structure from a base weight for the total wing as determined from a statistically correlated wing weight equation; this procedure was described in Ref. 1. In this earlier procedure, the base aileron weight was assessed at 6.58 psf for an aileron area equal to 5.3% of the wing area. This assessment was suitable for the previous studies which involved relatively high wing loadings; for the present study, however, this assessment resulted in high base aileron weights because of the low wing loadings under consideration. Therefore, the base aileron weight assessment was changed to use the following logic:

- o (E AIL) B = Aileron chord per unit wing chord = 0.27
- o $(\Delta\,\eta$ AIL)B = Aileron span per unit wing span = 0.3
- o $(\bar{\eta}$ AIL)B = Aileron spanwise centroid per unit wing span = 0.85
- o (SAIL/SW)B = 2 (1- (1-TR) ($\bar{\eta}$ AIL) B)(E AIL) B ($\Delta\,\eta$ AIL)B) $\div$ (1 + TR)
- o (W/S AIL = 0.1445 (WG) $\div$ (SW $(T/C)_A^{.29}$ ($\bar{\eta}$ AIL) $^{.54}$)
- o $(WAIL)_B = (W/S)_{AIL}\ (SAIL/SW)_B\ (SW)$

Where,

TR = Wing taper ratio

SW = Wing area (sq. ft.)

$(T/C)_A$ = Wing thickness-to-chord ratio at the aileron centroid (%)

WG = Airplane gross weight

	Uninstalled		Installed	
Overall Pressure Ratio	9.5			
Airflow (power Section - Kg/Sec. (Lb./Sec.)	14.67	(32.35)		
ESHP	4910			
Thrust (Total, Prop. + Power Section) KN (Lb.)	52.48	(11,798)	48.55	(10,915)
Weight (Power Section - Kg (lb.)	871	(1,920)		
(Propeller) - Kg (lb.)	502	(1,107)		
Diameter (Max., Power Section + Gearbox - m (In.)	0.99	(39)		
(Propeller) - m (Ft.)	4.88	(16.0)		
Length (Power Section) - m (In.)	3.71	(146)		
Stages - Compressor	14			
Turbine	4			
TIT 1F	1970			
T/W - T/O	3.89		2.58	
Price/Lb. Thrust - T/O*	20.70		31.90	
Speed Lapse (M - 0.2) **			0.788	
At 9140 m (30,000 Ft., M - 0.6				
Thrust (KN) Lb.			9.1	(2046)
Lapse			.1736	
SFCP			.5744	

* Uninstalled T/O Thrust/Engine + Prop. and Controls Weights

** Engine + Prop. and Controls Price T/O Thrust Including Estimated Prop. Development Cost.

Table IV T-56 Engine/Quiet Propeller Characteristics

BASED ON T-56 AND QUIET PROPELLER

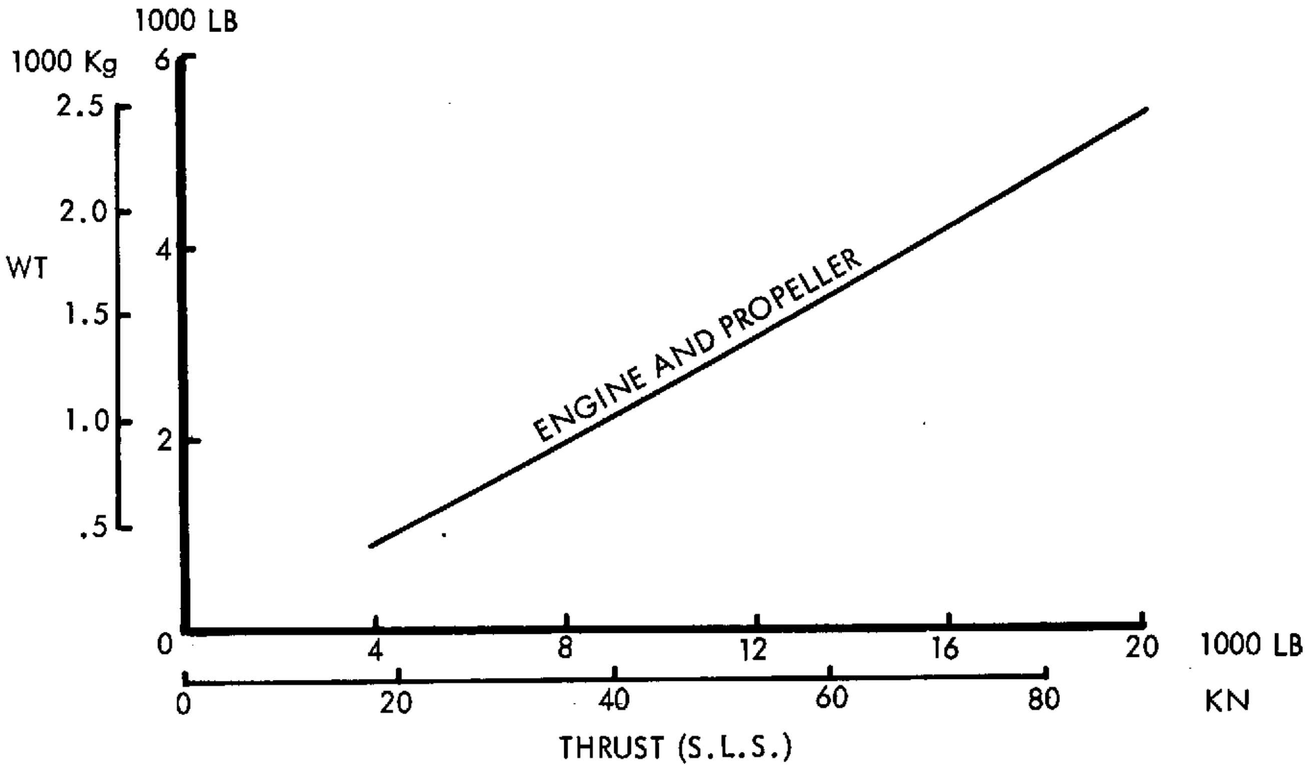


Figure 1 Engine and Propeller Weight and Cost

The correlation of the total wing weight estimating relationship was presented in Figure 127 of Ref. 1, page 203, for a broad range of contemporary transport aircraft. In the initial phase of the present study, further correlation of this estimating relationship was derived for aircraft with low-to-medium wing loading and medium-to-high aspect ratio. This correlation is presented by Figure 2 which illustrates that this relationship also adequately predicts the wing weight for these aircraft. It should be recognized that the high aspect ratio wings on these contemporary aircraft are relatively straight wings (i.e., little or no sweep) and that this correlation does not imply that high aspect ratio swept wings would be accurately predicted by this technique. For the present study, however, this proof is sufficient since the low-speed configurations being studied have essentially straight wings.

The effects of aspect ratio and gust loads on wing weight was also a primary concern in the present study. To correlate the statistical weight relationship used in the sizing program, a weight study was conducted using Lockheed-Georgia Company's analytical "Wing Weight Analysis Program". The two initial baseline aircraft were analyzed using this analytical method and the wing statistical weight estimating relationship. The aspect ratios were then varied over the range of 7 to 10 (the baseline aspect ratio was 8) to view the effects of aspect ratio and the comparative weight quantities from the two methods. To isolate these effects, only the baseline configurations are sized to perform the design mission with the remaining configurations defined by changing the Aspect Ratio to 7, 9, and 10 from the baseline of 8. The results of this analysis is shown by Table V which indicate close correlation between the two methods. The analytical method uses estimated maneuver, gust, and ground load conditions in conjunction with stiffness, strength, and geometric constraints. For the above described study, all of the wing configurations were gust critical indicating that the statistical method does produce satisfactory results for a slightly swept wing, low wing loadings, medium to high aspect ratios which is the spectrum of interest for this study.

The electrical, instruments, air conditioning, furnishings, and operating equipment weight estimating relationships were modified to reflect the wide range of fuselage sizes caused by passenger capacity variations from 44 to 148. These relationships were developed from statistical correlation of passenger transport weight and design data. These relationships are as follows:

(1) Electrical

$$W\ ELEC = 8.6\ (NPASS) + 114\ (WG/1000)^{0.5}$$

where, NPASS = Number of Passengers

WG = Gross Weight (lbs)

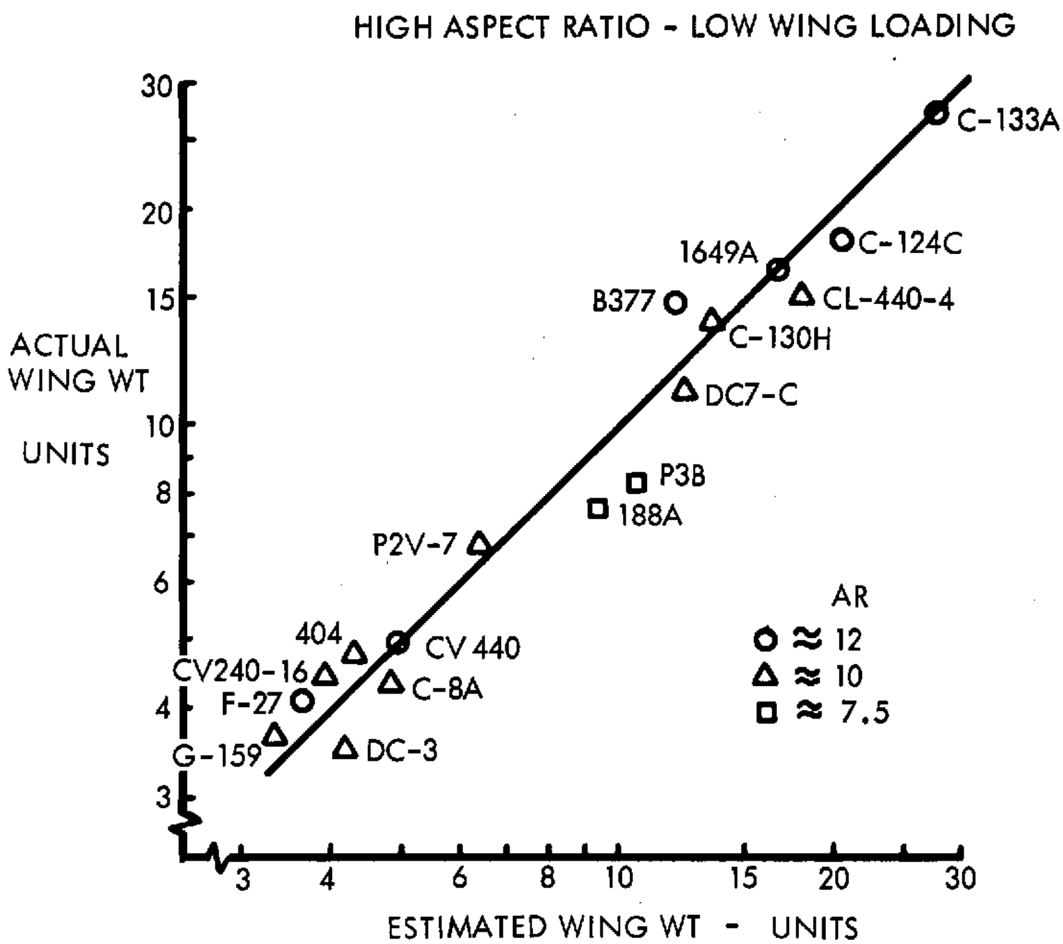


Figure 2 Wing Weight Correlation

Table V Comparison of Analytical and Statistical Wing Weights

44 PAX GUST CRITICAL

AIRCRAFT	AR	WING WEIGHT - KG (LB) STATISTICAL*	WING WEIGHT - KG (LB) ANALYTICAL**	% DIFF. WEIGHT
o 4 ENGINES				
M = 0.5	7	2874 (6335)	2817 (6210)	+ 2.01
W/S = 215 KG/SQ.M. (44 PSF)	8	3038 (6698)	2983 (6577)	+ 1.84
WG = 23,130 KG (51,000 LB)	9	3192 (7037)	3136 (6914)	+ 1.78
SW = 107.3 SQ. M. (1155 SQ. FT.)	10	3337 (7357)	3314 (7306)	+ 0.70
o 2 ENGINES				
M = 0.6	7	2313 (5099)	2272 (5008)	+ 1.82
W/S = 287 KG/SQ. M. (58.8 PSF)	8	2449 (5398)	2430 (5357)	+ 0.77
WG = 23,100 KG (50,900 LB)	9	2576 (5678)	2593 (5716)	- 0.31
SW = 80 SQ. M. (862 SQ. FT.)	10	2695 (5942)	2761 (6087)	- 2.38

* DETERMINED BY EQUATIONS IN AIRPLANE SIZING PROGRAM

** DETERMINED BY ANALYSIS OF LOADS, STIFFNESS, STRENGTH AND MATERIAL DISTRIBUTION.

(2) Instruments

$$W\ INSTR = 9.21\ (NCREW)^{.451} \times (CIN)(NENG)\ (FL + BW)^{.5}$$

Where, NCREW = Number of Crew Members

CIN = 1.0 for Turbo-Fan Engines

CIN = .883 for Turbo-Prop Engines

NENG = Number of Engines

FL = Fuselage Length (ft.)

BW = Wing Span (ft.)

(3) Air Conditioning

$$WAC = (6)\ (DELP + 5.)\ (VP)^{0.35}$$

Where, DELP = Design Pressure Differential (psi) = 8.0 for the present study.

VP = Pressurized Volume (cu. ft.)

(4) Furnishings

$$WFUR = 13.6\ (SF)^{.562} + .68\ (DNAC)(LNAC)(NENG) + 9.36\ (KFUR)(LCC)(WCC) + 70.5\ (KTP)(FW)$$

Where, SF = Fuselage Wetted Area (sq. ft.)

DNAC = Nacelle Diameter (ft.)

LNAC = Nacelle Length (ft.)

KFUR = Type of Furnishings Factor

= 0.7 for short-haul austere furnishings

= 1.0 for normal domestic furnishings

= 1.3 for plush furnishings used with long-haul aircraft (i.e., intercontinental).

LCC = passenger compartment length (ft.) including galleys and toilets.

WCC = passenger compartment width (ft.)

KTP = turbo-prop sound insulation factor

= 1.0 for turbo-prop; 0. for turbo-fan.

FW = Fuselage width (ft.)

(5) Operating Equipment

WOE = WCREW + WATTND + WFOOD + ENOIL + UNFUEL

Where,

WCREW	=	190 (NCREW)
WATTND	=	143 (NATTND)
NATTND	=	Number of Attendants
WFOOD	=	3 (NPASS) + 10 (NCREW)
ENOIL	=	.003 (THR) (NENG)
THR	=	thrust per engine (lbs.)
UNFUEL	=	.008 (FCAP)
FCAP	=	fuel capacity (lbs.)

The foregoing relationships yield comparable results for the 148 passenger, turbofan powered aircraft with mechanical flaps as was reported in Ref. 1.

3.1.4 Initial Sizing Data. The aerodynamic, propulsion, and weight data discused in the previous sections and the modified cost data of Section 2.1 were incorporated into the computer sizing program with which aircraft were sized for the combinations of parameters defined in the following table:

Field Length m (ft)	Cruise Mach No.	Aspect Ratio	Cruise Power Setting
457 (1500)			
610 (2000)	0.5	8	0.6
	0.55	10	through
914 (3000)	0.6	12	1.0
1067 (3500)			

All the airplanes have a passenger capacity of 100, a range of 926 km (500 n.mi.) and a cruise altitude of 7620 m (25,000 ft). Two- and 4-engined configurations were sized, all using rubberized T-56/quiet propeller data. The range of power settings was varied with the particular aircraft field length and Mach number.

The cruise sizing portion of the program is used to calculate aircraft size, weight and thrust characteristics for a range of wing loadings for each combination of Mach number, aspect ratio and power setting. Figure 3 shows an example plot of thrust to weight ratio (in terms of takeoff thrust and weight) required to cruise the airplanes plotted against wing loading for the three aspect ratios and three engine power settings.

The takeoff and landing portion of the program is used to calculate the thrust to weight ratio required for takeoff and landing as a function of wing loading for each field length and each aspect ratio. For each case flap angle is optimized to meet field length and climbout requirements. Figure 3 shows an example for the 4-engined data. Note that aspect ratio change has little effect on the landing capability and a single line represents all aspect ratios at each field length.

Airplanes just meeting cruise, takeoff and landing thrust to weight requirements are found at the intersection of the cruise, takeoff and landing lines for each aspect ratio; an example is identified by a square symbol for 910 m (3000 ft) field length. Airplanes can be selected at the intersection of the cruise and landing lines which will just meet the cruise and landing requirment while providing better than required takeoff performance; an example is identified by the circle symbol in the figure. Although the thrust to weight ratio for such an airplane is higher than that of the equally landing, takeoff and cruise critical airplane, it may be the better choice since its wing loading is higher and its DOC may be lower.

In the previous studies covered by this contract (Ref. 1, 5) the optimum designs were selected on the basis of DOC for a stage length of 926 km (500 n.mi.) or in some cases on the basis of minimum fuel consumption. In this study the criteria have been modified to select the optimum designs on the basis of DOC-2 for a stage length of 278 km (150 n,mi.) which is more typical of the average short-haul stage length. The 926 km (500 n.mi.) range is still retained as the design requirement. It was therefore necessary to modify the airplane sizing program to size for 926 km (500 n.mi.) but use 278 km (150 n.mi.) for selection of the optimum. The process is further complicated by the fact that for 926 km (500 n.mi.) the optimum cruise altitude is close to 7620 m (25000 ft) whereas for 278 km (150 n.mi.) the optimum DOC will probably be achieved at a lower cruise altitude and possibly at a different speed.

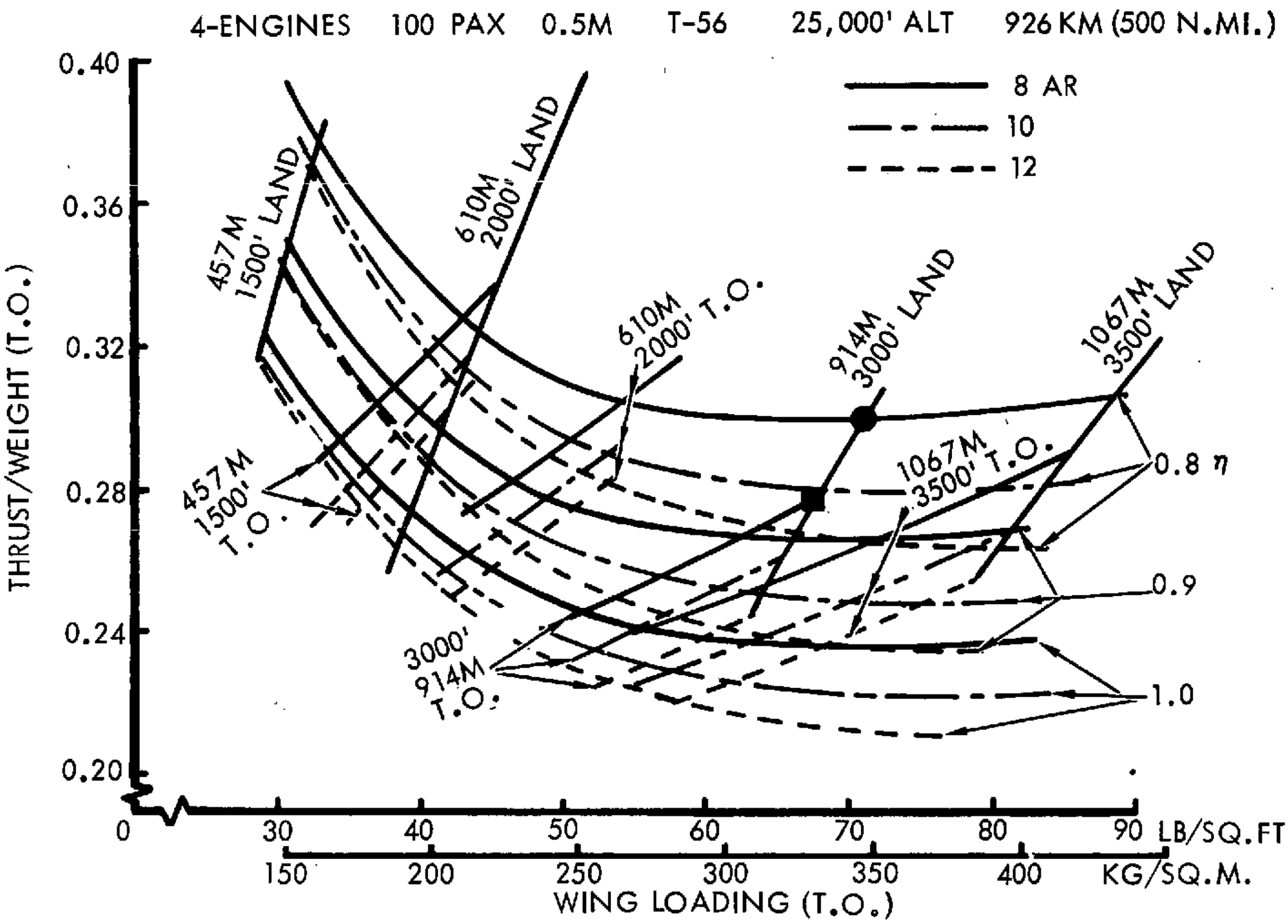


Figure 3 Example Thrust/Weight Ratio vs. Wing Loading (4-Engines)

The program was therefore modified to fly the sized airplanes at 3048, 4572, and 6096 m (10,000, 15,000 and 20,000 ft) cruise altitudes and at 3 cruise speeds at each altitude. The cruise speeds used vary with the design cruise Mach number as follows:

Mach No.	278 km (150 n.mi.) Cruise Speeds EAS			V_D
	KM/HR (KEAS)	KM/HR (KEAS)	KM/HR (KEAS)	KM/HR (KEAS)
0.5	389 (210)	426 (230)	463 (250)	556 (300)
0.55	444 (240)	482 (260)	506 (273)	598 (323)
0.6	482 (260)	519 (280)	556 (300)	648 (350)

Below 10,000 ft the FAA limits speed to 250 KEAS or less. Figure 4 shows an example of the computer print-out for this portion of the program and illustrates the data available for each speed and altitude combination. Only one aspect ratio at one power setting is shown in the figure. For each wing loading the minimum DOC-2 (identified as column CPM2 in the figure) can be selected which then identifies the best altitude and speed. In the figure for $W/S_{T.O.}$ = 150 kg/sq. m (30.8 lb/sq ft) the minimum DOC-2 is 4.22 c/ASSM at 3048 m (10,000 ft) altitude and 463 km/hr (250 KEAS). This process was repeated for all combinations of number of engines, Mach number, wing loading, aspect ratio, and power setting. From these data, plots of DOC-2 vs. wing loading such as those shown in Figure 5 have been prepared.

By transferring the wing loading value at which takeoff, landing and cruise requirements are met or exceeded for each field length from Figure 3 to Figure 5 the DOC-2 for that field length, aspect ratio, and power setting can be determined as shown by the short lines on Figure 5. It can be seen that for all aspect ratios and all field lengths the minimum DOC-2 was achieved with the airplane sized for 0.8 cruise power setting. At 457 and 610 m (1500 and 2000 ft) field length a smaller power setting (η = 0.7) would have produced a slight further reduction in DOC-2; at the longer field lengths the DOC-2 has minimized.

Figure 6 presents DOC-2 versus aspect ratio for each field length for the 4-engine, 0.5 M designs. It can be concluded that aspect ratio 8 is optimum for field lengths of 457 and 610 m (1500 and 2000 ft) while at 914 and 1066 m (3000 and 3500 ft) the aircraft operating cost is very insensitive to aspect ratio variation.

Figure 7 shows an example of DOC-2 at 926 km (500 n.mi.) versus aspect ratio. The choice of the higher aspect ratio is more apparent and occurs at a shorter field length than for the 278 km (150 n.mi.) case.

LOW W/S RUN NO. 3 MATRIX 9/12/74 NF0156/9 WHB

STOL DIST.= 30 .FT M=.50 RANGE= 50 .NM PAYLOAD= 205 .LB SEATS= 10.

SWE P= 5.0DEG CDC= .0 CDMISC= .0 D M=.050

IVER=1 IMACH=5 IENG= 56 I1985=0 IVEC=0 ITR=0 IGEAR=1 IVBAR=0

NO. ENG USED INITIAL CRUISE=4. ENG COST FACTOR=1.0 IRANGE=0

MACH	WSTO	RNG2	ALT	VT	FTM	CLID	ROC2	WSP2	CPM1	CPM2	CPM4	CPM10	ETA	FUEL
.3829	30.8	150.	10.	244.4	.72	12.7	2170.	30.6	4.0[illegible]	4.42	5.27	7.81	.596	4150.
.4194	30.8	150.	10.	267.6	.67	12.5	2179.	30.6	3.86	4.30	5.17	7.80	.730	4284.
.4558	30.8	150.	10.	290.9	.63	12.4	218[illegible].	30.6	3.76	4.22	5.15	7.92	.836	4528.
.4227	30.8	150.	15.	264.7	.69	22.5	1807.	30.4	3.95	4.41	5.32	8.06	.718	4467.
.4629	30.8	150.	15.	289.9	.65	22.5	1817.	30.4	3.84	4.31	5.26	8.1[illegible]	.875	4645.
.5032	30.8	150.	15.	315.2	.62	22.4	1825.	30.4	3.7[illegible]	4.27	5.28	8.32	1.069	4964.
.4684	30.8	150.	20.	287.7	.68	37.0	1438.	30.2	3.95	4.45	5.45	8.43	.871	4879.
.5130	30.8	150.	20.	315.1	.64	36.9	1447.	30.2	3.87	4.39	5.4[illegible]	8.57	1.064	5114.
.5576	30.8	150.	20.	342.5	.62	36.5	1456.	30.2	3.83	4.40	5.54	8.95	1.290	5578.
.3829	46.5	150.	10.	244.4	.72	17.8	1617.	46.1	3.32	3.60	4.15	5.79	.590	2676.
.4194	46.5	150.	10.	267.6	.67	17.8	1627.	46.1	3.20	3.48	4.04	5.71	.699	2714.
.4558	46.6	150.	10.	290.9	.63	17.9	1635.	46.1	3.11	3.39	3.97	5.69	.829	2804.
.4227	46.5	150.	15.	264.7	.70	33.6	1294.	45.8	3.30	3.60	4.21	6.05	.710	2984.
.4629	46.6	150.	15.	289.9	.6[illegible]	33.[illegible]	130[illegible].	45.9	3.20	3.51	4.13	6.00	.838	3049.
.5032	46.6	150.	15.	315.2	.63	3[illegible].5	131[illegible].	45.9	3.12	3.44	4.09	6.02	.99[illegible]	3151.
.4684	46.6	150.	20.	287.7	.70	57.0	966.	45.5	3.34	3.68	4.38	6.47	.860	3401.
.5130	46.6	150.	20.	315.1	.67	57.5	976.	45.5	3.26	3.61	4.32	6.44	1.017	3460.
.5576	46.6	150.	20.	342.5	.64	57.6	983.	45.5	3.20	3.57	4.31	6.52	1.205	3604.
.3829	62.6	150.	10.	244.4	.72	21.2	1419.	61.9	3.14	3.38	3.87	5.32	.587	2361.
.4194	62.6	150.	10.	267.6	.67	21.4	1429.	61.9	3.02	3.26	3.75	5.20	.674	2361.
.4558	62.6	150.	10.	290.9	.63	21.3	1437.	61.9	2.93	3.17	3.67	5.15	.780	2405.
.4227	62.6	150.	15.	264.7	.70	41.4	1093.	61.5	3.12	3.39	3.94	5.60	.705	2688.
.4629	62.6	150.	15.	289.9	.66	40.6	1103.	61.5	3.03	3.31	3.86	5.53	.806	2707.
.5032	62.6	150.	15.	315.2	.63	41.1	111[illegible].	61.5	2.95	3.23	3.80	5.49	.939	2752.
.4684	62.6	150.	20.	287.7	.70	73.8	765.	60.9	3.17	3.49	4.14	6.08	.851	3152.
.5130	62.6	150.	20.	315.1	.68	73.3	775.	60.9	3.11	3.43	4.08	6.03	.976	3166.
.5576	62.6	150.	20.	342.5	.65	73.9	784.	61.0	3.05	3.38	4.04	6.01	1.130	3216.
.3829	84.3	150.	10.	244.4	.72	23.9	1331.	83.3	3.05	3.29	3.76	5.17	.586	2290.
.4194	84.3	150.	10.	267.6	.67	24.0	1343.	83.4	2.94	3.17	3.63	5.02	.648	2260.
.4558	84.3	150.	10.	290.9	.63	23.5	1355.	83.4	2.84	3.08	3.54	4.94	.789	2273.
.4227	84.3	150.	15.	264.7	.69	47.7	982.	82.7	3.03	3.30	3.85	5.47	.702	2648.
.4629	84.3	150.	15.	289.9	.66	47.2	994.	82.7	2.94	3.21	3.75	5.37	.774	2631.
.5032	84.3	150.	15.	315.2	.63	47.0	1004.	82.7	2.87	3.14	3.68	5.31	.876	2642.
.4684	84.3	150.	20.	287.7	.69	89.7	636.	81.7	3.09	3.42	4.07	6.02	.844	3178.
.5130	84.3	150.	20.	315.1	.67	89.8	648.	81.8	3.03	3.35	3.99	5.93	.934	3148.
.5576	84.3	150.	20.	342.5	.65	88.4	658.	81.8	2.99	3.31	3.96	5.90	1.051	3161.
.3829	30.8	150.	10.	244.4	.72	12.4	2173.	30.5	4.10	4.53	5.40	8.02	.597	4269.
.4194	30.8	150.	10.	267.6	.67	12.5	2183.	30.5	3.96	4.41	5.31	8.02	.736	4419.
.4558	30.8	150.	10.	290.9	.63	12.4	2192.	30.5	3.86	[illegible]	5.29	8.16	[illegible]	4689.
.4227	30.8	150.	15.	264.7	.69	22.3	1826.	30.4	4.05	4.51	5.45	8.26	.720	4584.
.4629	30.8	150.	15.	289.9	.65	22.4	1835.	30.4	3.93	4.42	5.40	8.33	.883	4784.
.5032	30.8	150.	15.	315.2	.61	22.[illegible]	1843.	30.4	3.86	4.38	5.43	8.58	1.083	5136.
.4684	30.8	150.	20.	287.7	.68	36.4	1471.	30.2	4.04	4.5[illegible]	5.57	8.62	.874	4987.
.5130	30.8	150.	20.	315.1	.64	36.4	1480.	30.2	3.96	4.50	5.57	8.78	1.074	5250.
.5576	30.8	150.	20.	342.5	.61	36.0	148[illegible].	30.2	3.92	4.51	5.69	9.21	1.308	5764.
.3829	46.5	150.	10.	244.4	.72	17.7	1603.	46.0	3.34	3.61	4.15	5.76	.592	26[illegible]3.
.4194	46.5	150.	10.	267.6	.68	17.6	1[illegible]2.	46.0	3.2[illegible]	3.50	4.04	5.69	.709	2673.
.4558	46.5	150.	10.	290.9	.64	17.7	1620.	46.0	3.1[illegible]	3.41	3.98	5.69	.848	277[illegible].

V_{DIVE} = 300KEAS

10K

15K

20K

ALTITUDE

W/S

110 KEAS

130

150

AR = 8

λ = 1.0

10

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Figure 4 Example Computer Sizing Print-out

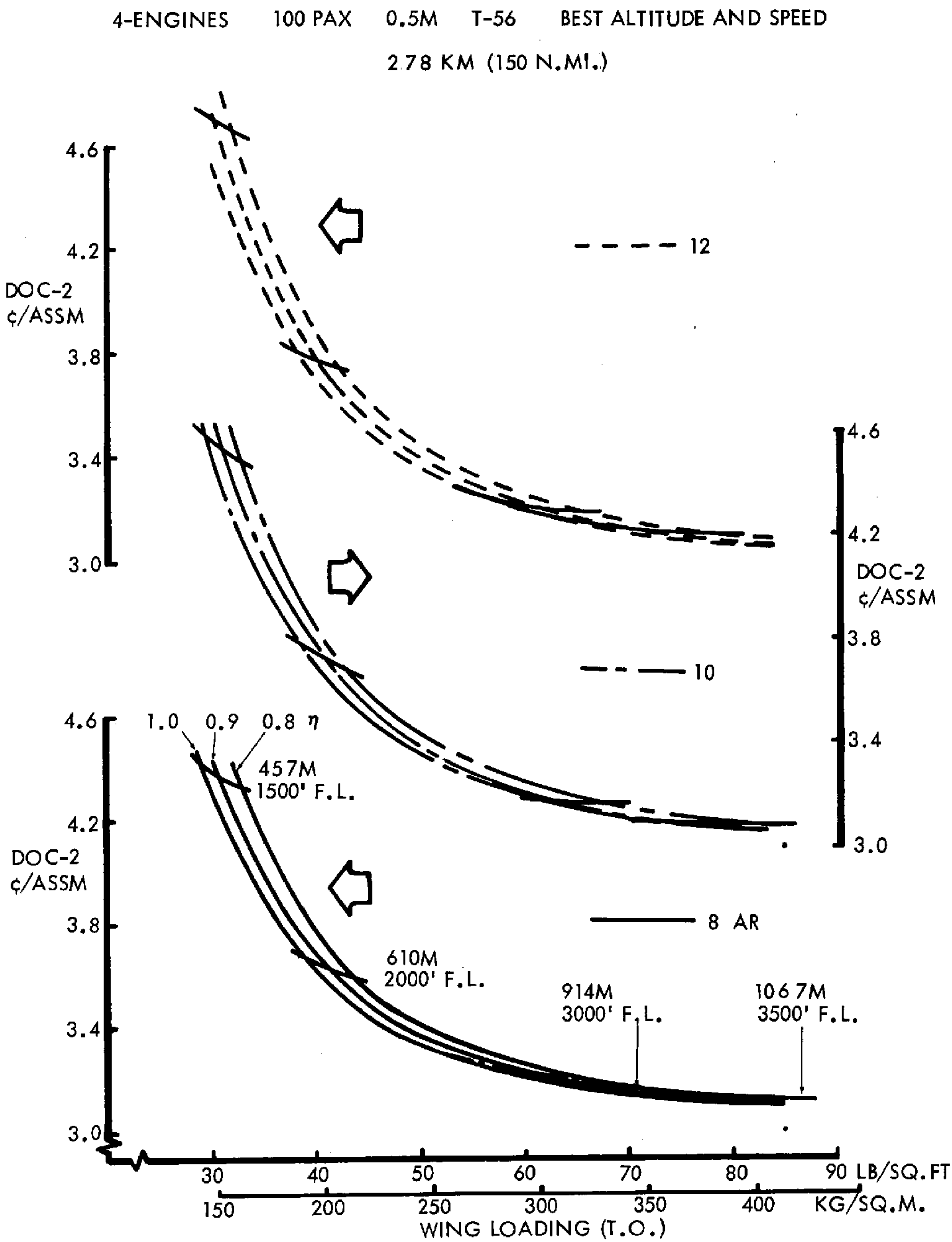


Figure 5 Example DOC-2 (150 n.mi.) vs. Wing Loading

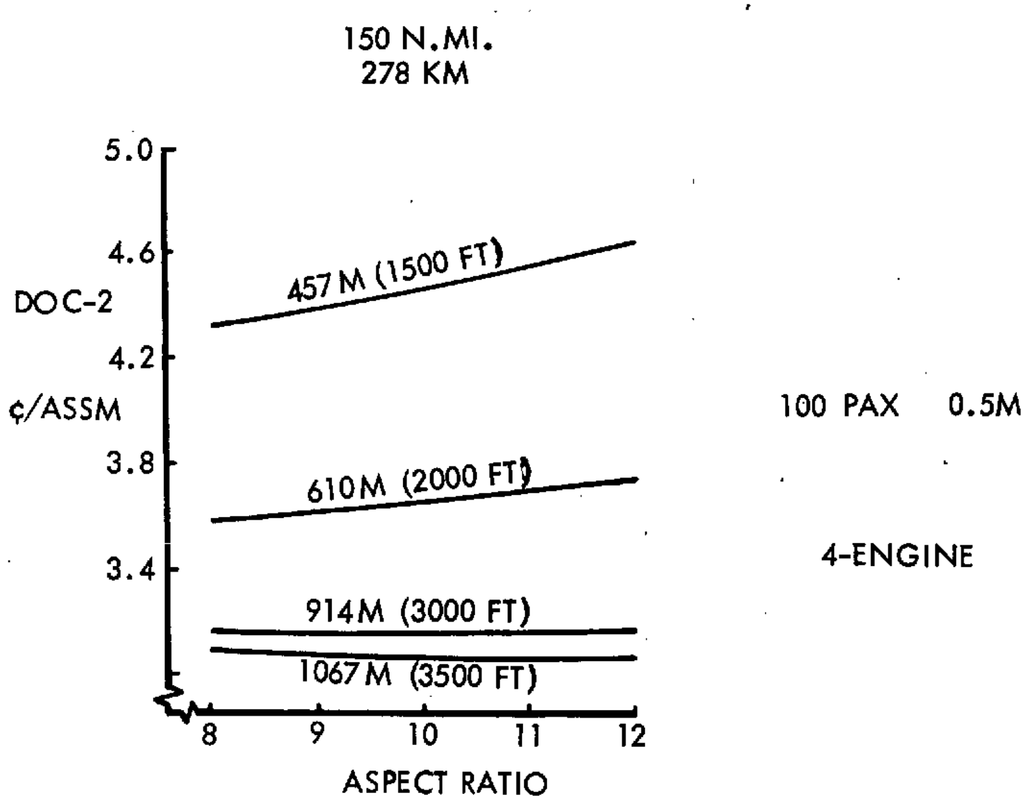


Figure 6 DOC-2 vs. Aspect Ratio (278 km; 150 n.mi)

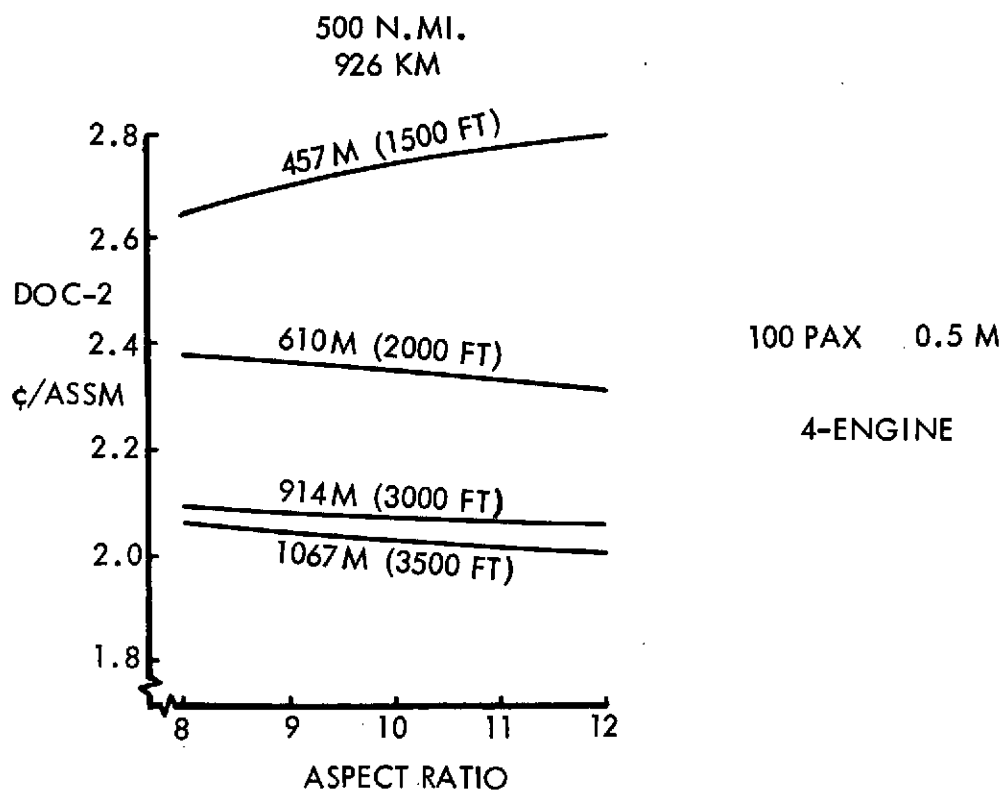


Figure 7 DOC-2 vs. Aspect Ratio (926 km; 500 n.mi)

Thrust to weight ratio versus wing loading data for 2-engined configurations are presented in Figure 8. Note the lower wing loadings, relative to the 4-engine deflected slipstream configurations of Figure 3 to achieve the same field performance. Also note the higher thrust to weight ratios required for a given field length which when intersected with the cruise requirement results in lower percent cruise power settings than for the 4-engined configurations.

From similar data for other Mach numbers, Figure 9 was prepared showing DOC-2 for 278 km (150 n.mi.) stage length versus field length for the 4-engine and 2-engine configurations at the different design cruise Mach numbers. The 4-engined deflected slipstream airplanes have equivalent DOC-2 to the 2-engined configurations at approximately 914 m (3000 ft) field length. As field length shortens DOC-2 increases but the deflected slipstream configuration rapidly becomes increasingly superior to the 2-engined configuration. At longer field lengths than 914 m (3000 ft) the 2-engined design should improve and be slightly superior to the 4-engined design due to its lower engine cost per unit of thrust overcoming the effect of the lower wing loading and higher thrust to weight effects on DOC.

Note that at this stage length the extra cost of meeting the higher cruise speeds results in poorer DOC at all field lengths shorter than approximately 914 m (3000 ft); this is due to the large wing areas of these airplanes. From these data the 0.5 Mach, 610 m (2000 ft) field length, 4-engine configuration and the 0.6 Mach, 914 m (3000 ft) field length, 2-engine configuration, indicated as "design point" on Figure 9, were selected as baseline design points for a more detailed analysis.

3.2 Baseline Airplane Configurations

The parametric study conducted in Section 3.1 was based on the 100 passenger size. However, it is considered that the airplane size required in the low/medium density market for operation into auxiliary short fields at major hubs is more likely to be smaller than 100 passengers. It was therefore decided to size the baseline airplanes at the small end of the passenger sizes being considered.

The selected baseline design points determined in Section 3.1 have the characteristics shown in Table VI. Baseline airplanes were sized with these characteristics for 44 passengers. Configuration arrangements for these airplanes are presented in Figures 10 and 11 while weight and economic data are presented in Table VII.

3.3 Ride Quality Analyses

This section describes the analyses conducted to determine the ride quality characteristics of the two baseline airplanes, and for comparison purposes, an airplane similar to the B737. The study was limited to the longitudinal axis for which the airplane derivatives are shown in Table VIII.

2-ENGINES T-56 QUIET PROP 0.5 M

926 KM (500 N.MI.); 7620 M (25,000')

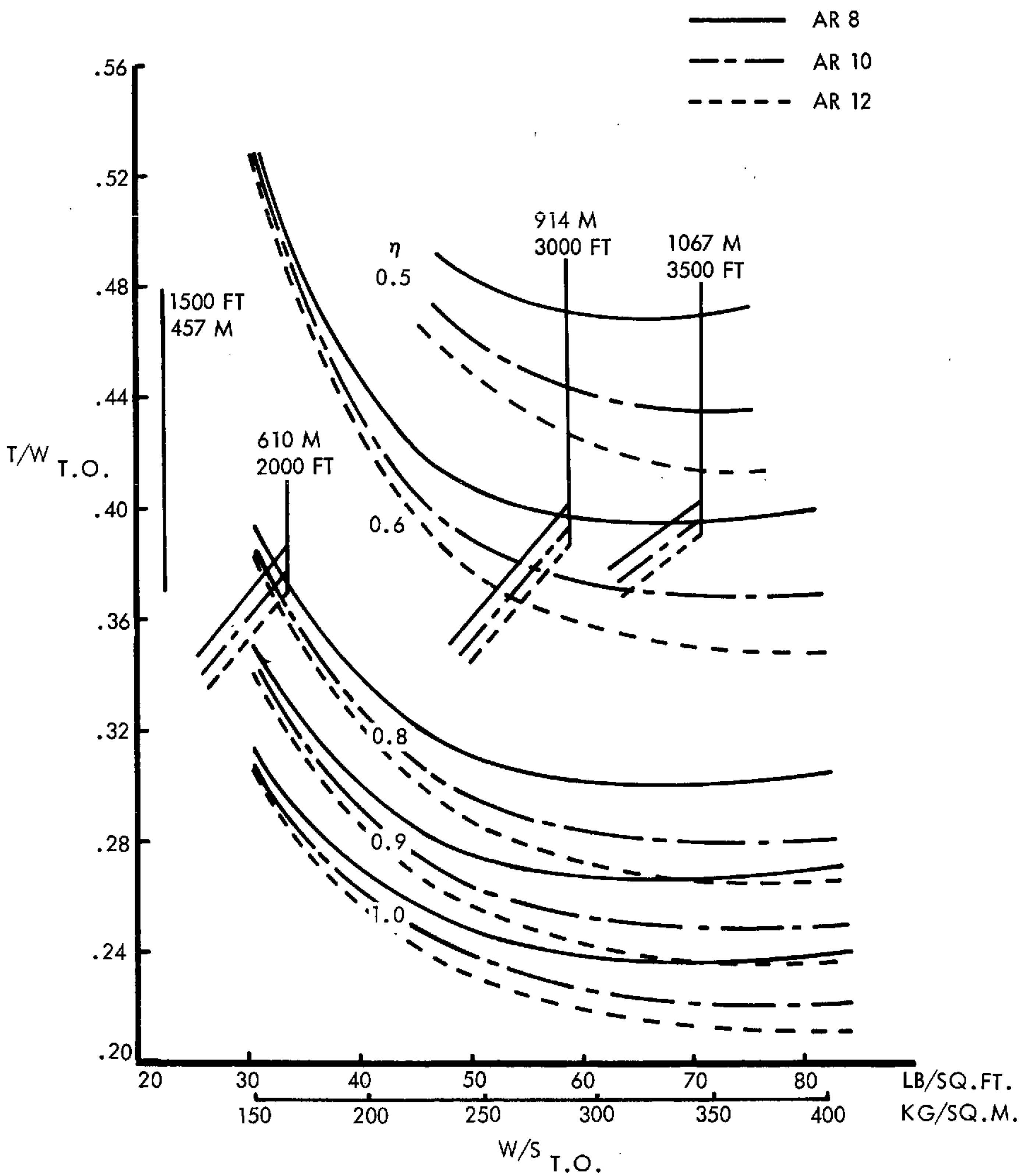


Figure 8 Example Thrust/Weight Ratio vs. Wing Loading (2-Engines)

100 PAX T-56 BEST ALTITUDE, SPEED AND AR FOR 278 KM (150 N.MI.)

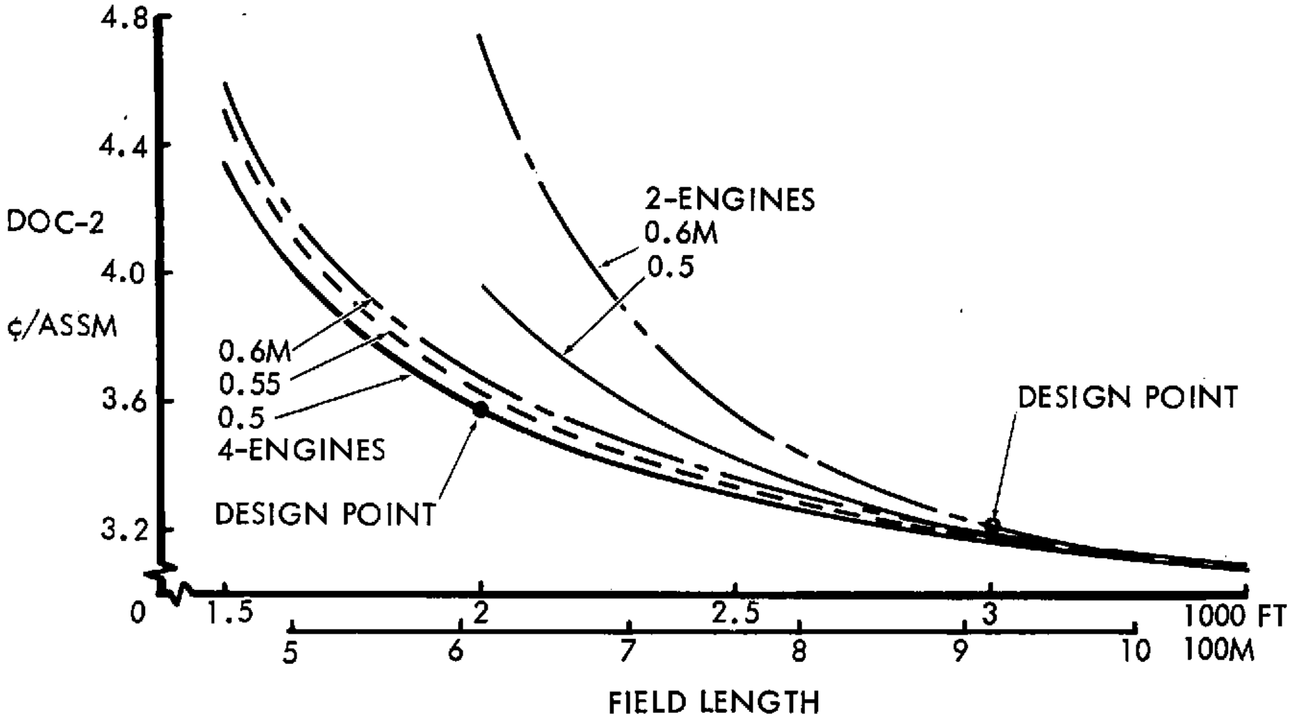
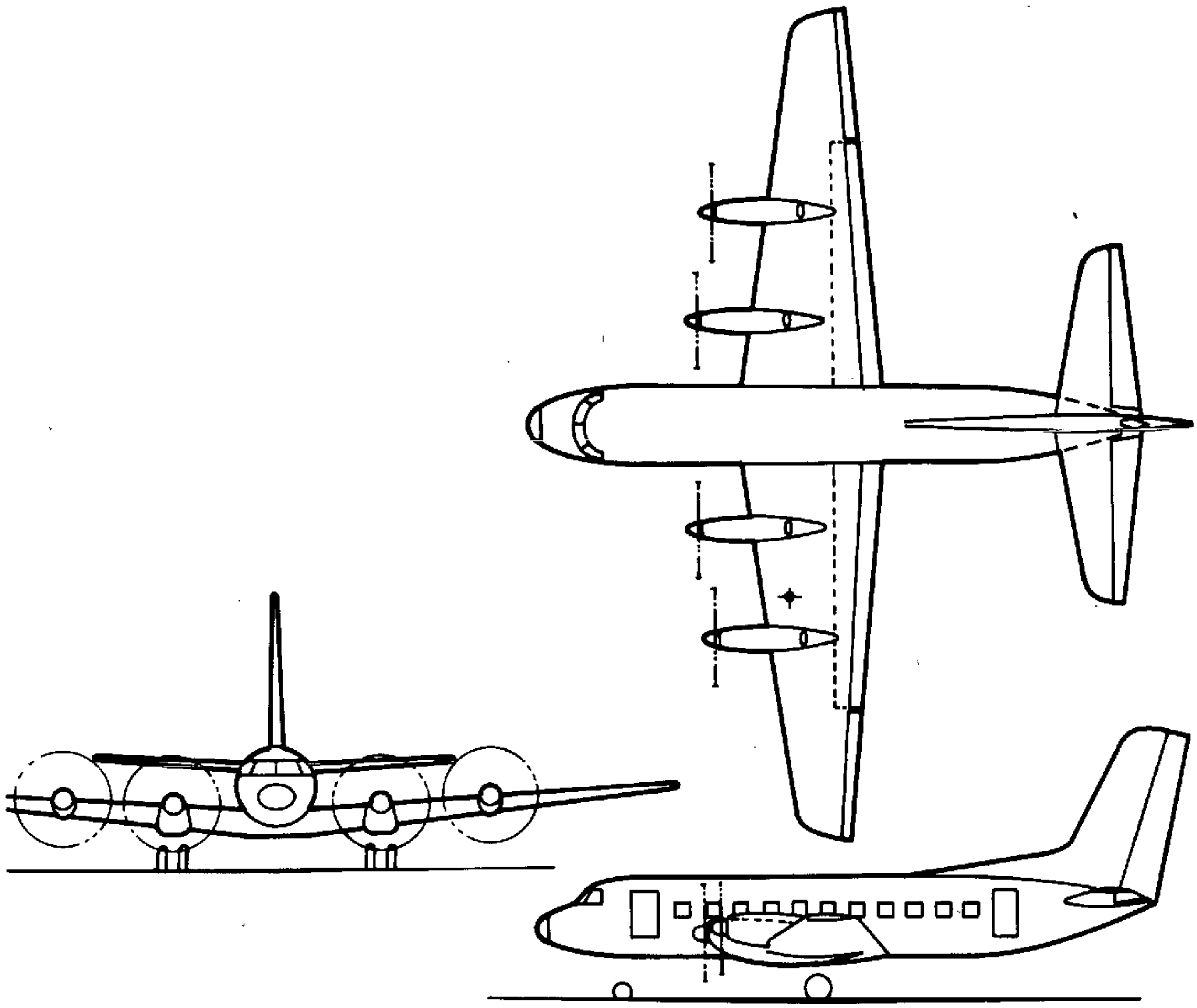


Figure 9 DOC-2 (278 km; 150 n.mi) vs. Field Length and Mach No. (No Active Controls)

FIELD LENGTH - m (FT)	610	(2000)	914	(3000)
NO. OF ENGINES	4		2	
W/S T.O kg/sq. m. (LB/SQ. FT)	215	(44.0)	287	(58.8)
T/W T.O.	.323		.40	
ASPECT RATIO	8		8	
926 km (500 N.MI.) CRUISE ALT. m (FT)	7620	(25,000)	7620	(25,000)
926 km (500 N.MI.) CRUISE SPEED M	0.5		0.6	
926 km (500 N.MI.) CRUISE POWER SETTING	0.8		0.78	
278 km (150 N.MI.) CRUISE SPEED - km/hr (KEAS)	463	(250)	556	(300)
278 km (150 N.MI.) CRUISE ALT. m (FT)	4572	(15000)	4572	(15000)

Table VI Selected Baseline Design Points



PAYLOAD: 44 PASSENGERS

RGW: 22,251 KG (49,055 LB)

OWE: 16,005 KG (35,285 LB)

WING AREA: 103.3 SQ.M. (1,112 SQ. FT.)

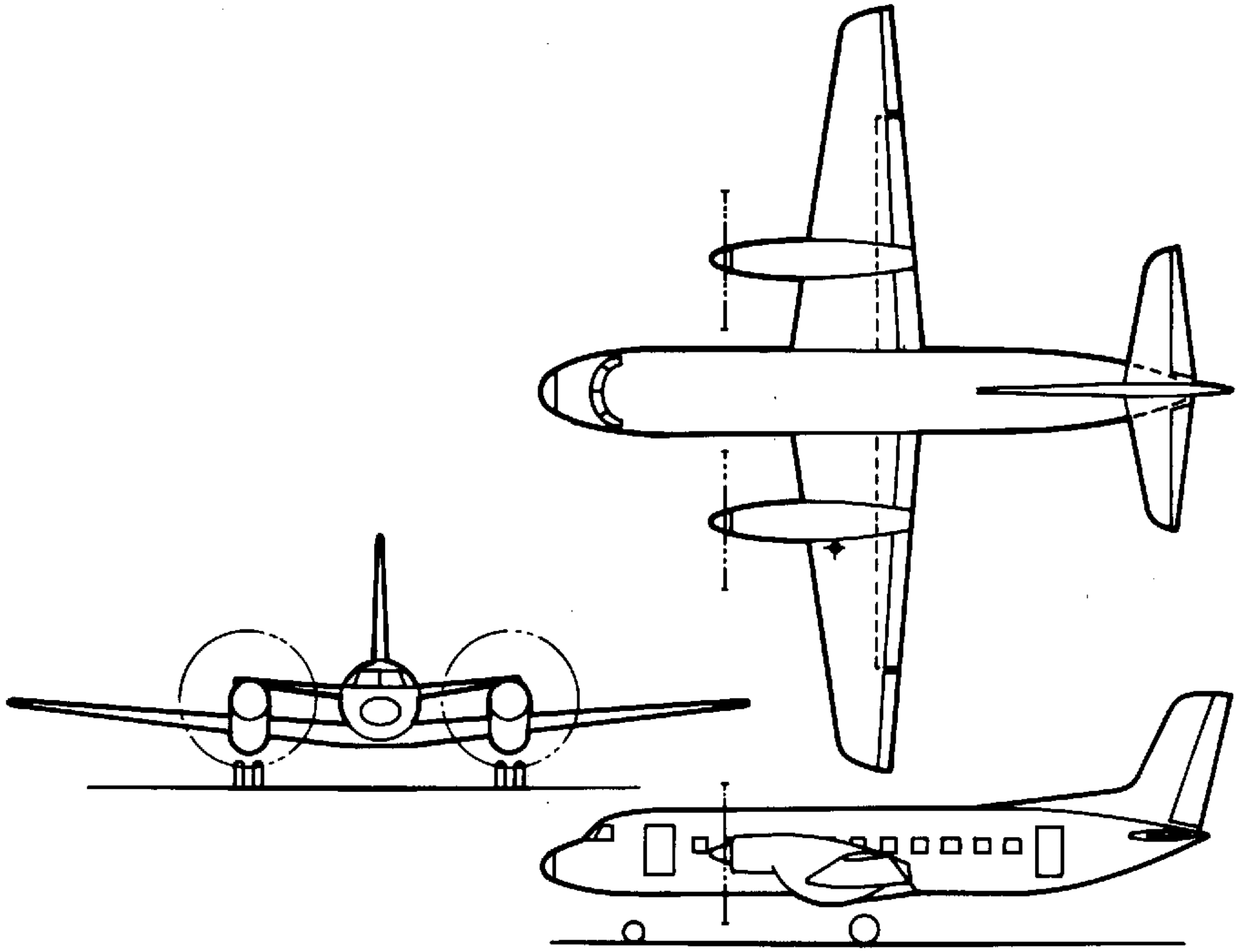
WING LOADING: 215 KG/SQ.M. (44.0 LB/SQ. FT.)

ENG/PROP S.L.S.T.: 19.12 KN (4,300 LB)

926 KM (500 N.MI.) CRUISE: 0.5M @ 7620 M (25,000 FT.)

278 KM (150 N.MI.) CRUISE: 463 KM/HR (250 KEAS) @ 4570 M (15,000 FT.)

Figure 10 610 m (2000 ft) Field Length Design Point Aircraft



PAYLOAD: 44 PASSENGERS

RGW: 22,262 KG (49,080 LB)

OWE: 15,940 KG (35,140 LB)

WING AREA: 77.3 SQ.M. (832 SQ. FT.)

WING LOADING: 287 KG/SQ.M. (58.8 LB/SQ.FT.)

ENG/PROP S.L.S.T.: 45.64 KN (10,261 LB)

500 N.MI. CRUISE: 0.6 M @ 7620 M (25,000 FT.)

150 N.MI. CRUISE: 556 KM/HR (300 KEAS) @ 4570 M (15,000 FT.)

Figure 11 914 m (3000 ft) Field Length Design Point Aircraft

No. of Engines	4		2	
Field Length m (ft)	610	(2000)	914	(3000)
Cruise Mach No.	0.5		0.6	
No. of Pax	44		44	
W/S $_{T.O}$ kg/sq.m (lb/sq ft)	215	(44.0)	287	(58.8)
Installed T/W	.325		.403	
Percent Cruise Power	78.0		75.5	
OWE kg (lb)	16,005	(35,285)	15,939	(35,139)
RGW kg (lb)	22,251	(49,055)	22,262	(49,078)
Rated Thrust kN (lb)	19.12	(4,299)	45.64	(10,261)
500 n.mi. Fuel kg (lb)	1,622	(3,575)	1,653	(3,645)
150 n.mi. Fuel kg (lb)	758	(1,671)	799	(1,762)
Airframe $ M	2.5158		2.6713	
Total Aircraft Price $M	3.4019		3.2687	
DOC-2 926 km 500 n.mi. ¢/ASSM	3.732		3.075	
DOC-4 926 km 500 n.mi. ¢/ASSM	4.235		3.583	
DOC-2 278 km 150 n.mi. ¢/ASSM	5.617		4.857	
DOC-4 278 km 150 n.mi. ¢/ASSM	6.398		5.675	

Table VII Design Point Aircraft Characteristics (No Active Controls)

No. of Engines	4			2		
W/S	215 kg/sq.m. (44 lb/sq. ft.)			287 (58.8)		
Flight Condition	Cruise	Descent	Approach	Cruise	Descent	Approach
C_{L_α} /RAD	5.3	4.85	4.6	5.4	4.85	4.6
C_{M_α} /RAD	-1.62					
C_D/C_L^2	.044					
C_{M_q} /RAD/SEC	-20					
C_M /RAD/SEC	-8					
$C_{M_{\delta e}}$ /RAD	-3.44					
$C_{L_{\delta f}}$ /RAD	1.60	1.49	2.1	1.08	1.00	1.66
$C_{M_{\delta f}}$ /RAD	-.332	-.298	-.400	-.223	-.200	-.322

Table VIII Baseline Aircraft Derivatives

The analyses were performed utilizing a linear 3 degrees-of-freedom digital computer program. The airplane mathematical model did not include any structural flexibility effects. Random atmospheric turbulence was modeled with a Lockheed developed power spectral density function which is similar to the Von Karman function. A vertical gust velocity exceedance probability level of 10^{-3} was selected for this study. Corresponding rms gust velocities for the selected cruise, descent and landing approach conditions are 1.74, 2.5 and 3.0 m/sec (5.7, 8.2 and 9.8 fps), respectively. These turbulence level values are based on data reported in NACA TN 4332 and ASD-TR-61-235 and are identical to the levels used in previous ride quality studies for NASA Ames and Langley.

The three flight conditions considered are shown in Table IX for the two aircraft wing loadings evaluated, and for the Boeing 737 type airplane.

	CRUISE		DESCENT		APPROACH	
Airplane	KM/HR V (KTAS)	M ALT (Ft)	KM/HR V (KTAS)	M ALT (Ft)	KM/HR V (KTAS)	M ALT (Ft)
W/S = 215 kg/sq.m (44 lb/sq ft)	556 (300)	7620 (25,000)	463 (250)	1524 (5000)	143 (77)	S.L.
W/S = 287 kg/sq.m (58.8 lb/sq ft)	667 (360)	7620 (25,000)	463 (250)	1524 (5000)	181 (98)	S.L.
737 Type	819 (442)	9140 (30,000)	463 (250)	1524 (5000)	222 (120)	S.L.

Table IX Flight Conditions

Figures 12 and 13 present the r.m.s. vertical acceleration and r.m.s. pitch rate evaluations for the cruise, descent and approach cases for the two baseline airplanes. The figures also show criteria levels for determining acceptability of ride qualities. These criteria are based on a r.m.s. vertical linear acceleration at three passenger compartment locations of 0.11 g's. This is an $\bar{A}$ criterion which is a similar to the $\bar{H}$ criterion developed by Rustenberg in Ref. 7, except that $\bar{A}$ does not include the human discomfort function of frequency.

The particular level of $\bar{A}$ used is based on ride qualities studies conducted for NASA Langley and is specified in the original work statement of this contract (NAS2-6995), Ref 5. The corresponding limit values on r.m.s. angular pitch rate are 0.5 deg/sec for cruise and descent and 1.0 deg/sec for landing approach. For this specific study however, the criterion used to define acceptable ride comfort is that provided by contemporary short/medium haul aircraft such as the B737, which have proven to be acceptable to a majority of passengers.

610 M (2000 FT) FIELD LENGTH
W/S = 215 KG/SQ. M. (44 LB/SQ.FT.)

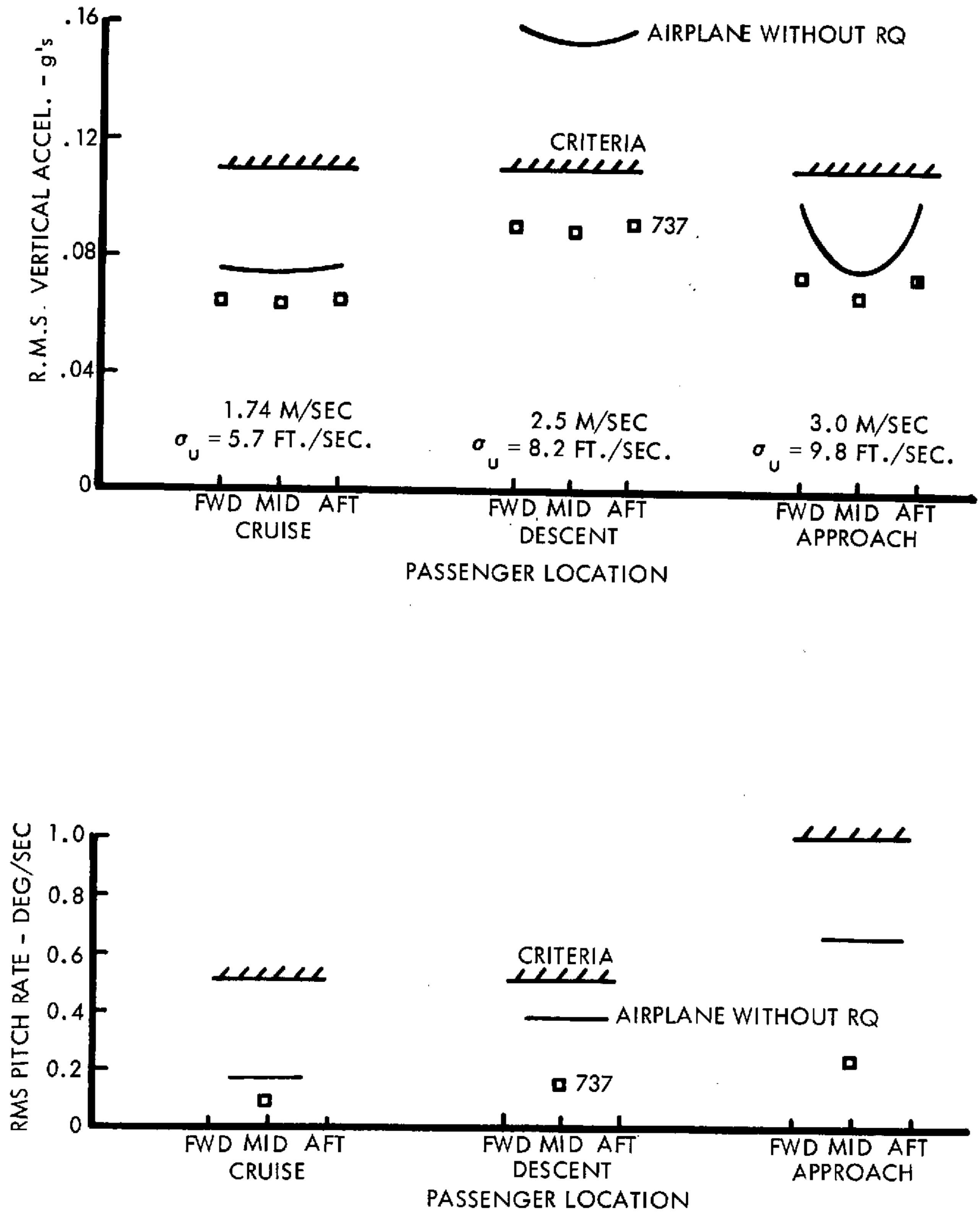


Figure 12 Ride Quality Evaluation (W/S = 215 kg/sq.m; 44 lb/sq.ft)

914 M (3000 FT) FIELD LENGTH
W/S = 287 KG/SQ.M. (58.8 LB/SQ.FT.)

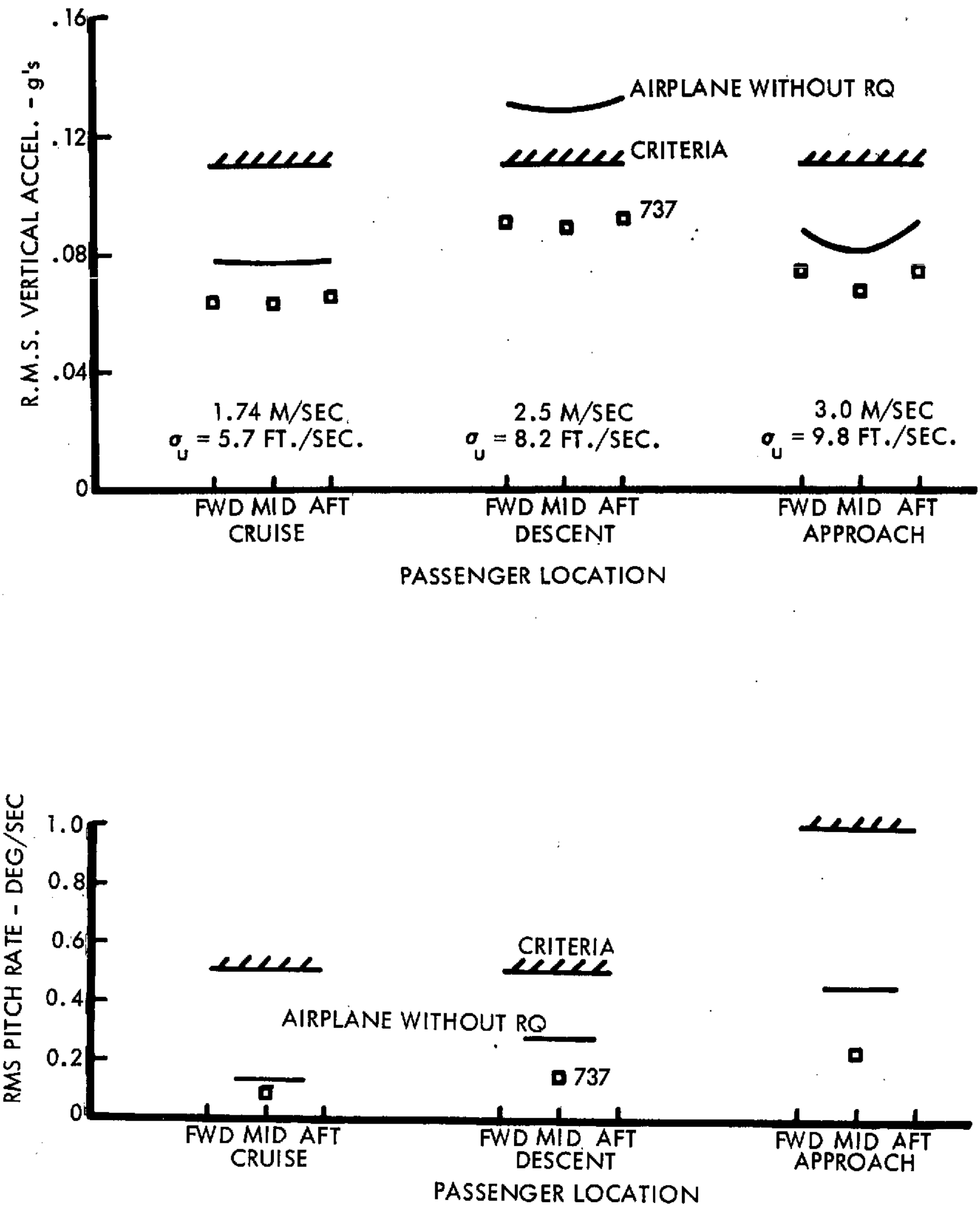


Figure 13 Ride Quality Evaluation (W/S = 287 kg/sq.m; 58.71 lb/sq. ft)

It has not been possible to obtain directly comparable ride quality data for The B737; it was therefore necessary to calculate ride qualities for a B737 type airplane using the same methodology as used for the baseline airplanes. For comparison purposes the B737 type data are shown on Figures 12 and 13 which illustrate that both baseline airplanes meet the ride quality criteria in cruise and approach conditions but do not meet the vertical acceleration criterion in the descent conditions; the B737 type airplane is better than the criteria in all flight conditions., The baseline airplane ride qualities are acceptably close to the B737 for the cruise and approach conditions but are unacceptably worse than the B737 in the descent case.

It was therefore necessary to define ride quality control systems which would improve the baseline airplanes to the standard of the B737, particularly for the descent condition.

3.4 Structural Analyses

The two baseline configurations described in Section 3.2 were used to conduct wing structural analyses to determine -

(1) the gust effects on the structure

(2) the fatigue effects on the structure

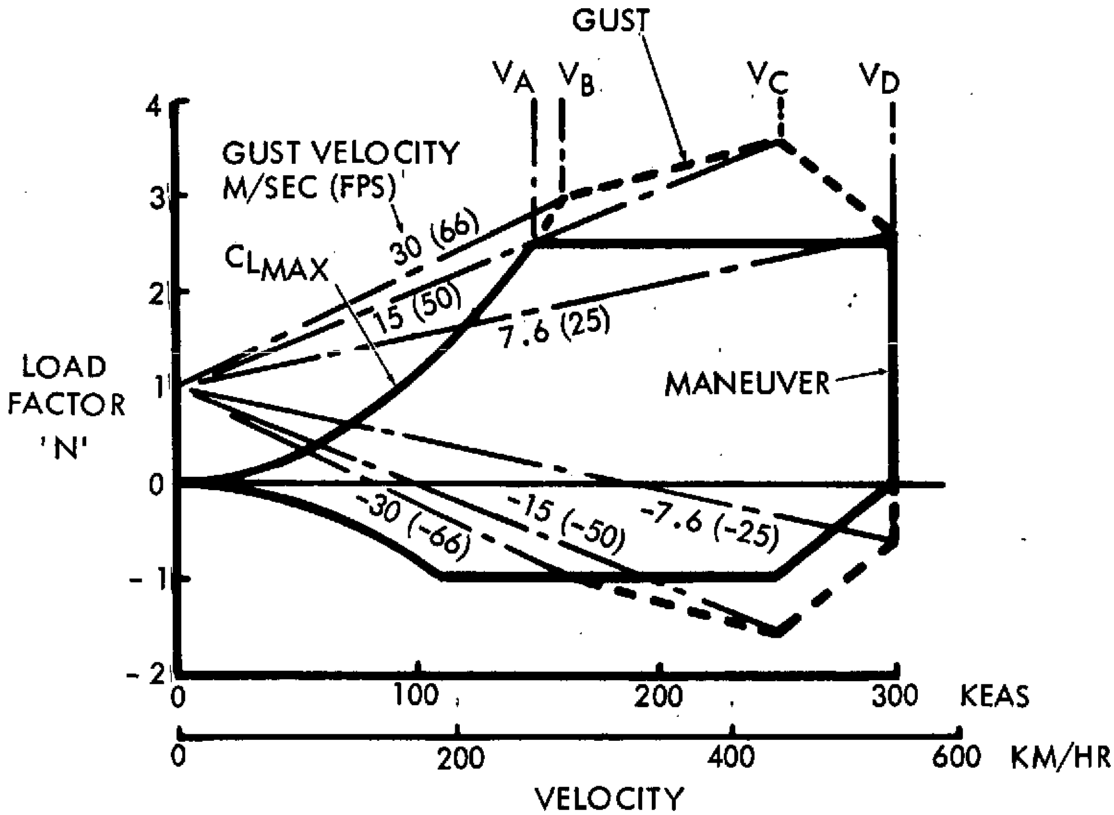
(3) modifications to the weight estimation logic.

These analyses were conducted using Lockheed-Georgia's "Wing Weight Analysis Program" which includes structural analysis procedures adapted for advanced design studies.

3.4.1 Gust Analyses – The wing gust loads were analyzed at gust velocities of ± 15.24 meters per second (± 50 fps) at cruise speed (Vc) and ± 20.12 meters per second (± 66 fps) at the airspeed (VB) corresponding to CL max (flaps up) in the presence of the gust. The gust load factor envelope corresponding to these conditions along with the conditions at dive speed (VD) is illustrated in Figure 14. Each of the baseline configurations was analyzed to determine the gust load factor and loads for the VB, VC, and VD speeds at their corresponding gust conditions. The gust load factors were computed in accordance with the formulae contained in FAR Parts 25 and XX (Ref. 3 & 4). The resulting gust load factors for each baseline configuration are as follows:

A. 44 Passengers, 610 m (2000 ft) Field-Length, 4 Engine Turbo-Prop, 0.5 Cruise Mach Number Configuration:

- o NG = 1 + Δ NG
- o @ VB = 296 km/hr (160 KEAS); Δ NG =± 1.92



W/S-PSF	44	58.8
V_B-KEAS	160	194
KM/HR	296	359
N_{V_B}	2.92	3.0
V_C-KEAS	250	300
KM/HR	463	556
N_{V_C}	3.52	3.52

Figure 14 Typical Load Factor Envelopes

- o @ VC = 463 km/hr (250 KEAS); Δ NG = ± 2.52

B. 44 Passengers, 914 m (3000 ft) Field-Length, 2 engine turbo-prop.
0.6 Cruise Mach Number Configuration:

- o NG = 1 + ΔNG
- o @ VB = 359 km/hr (194 KEAS); ΔNG = ±2.00
- o @ VC = 556 km/hr (300 KEAS); ΔNG = ± 2.52

These analyses indicated that, for these two configurations, the major designing load case would be the gust encounter at VC.

3.4.2 Fatigue Analysis – The wing structural analysis for the two baseline aircraft included consideration of their fatigue characteristics. A method for advanced design fatigue estimation was employed which related operational usage, design stress, and cyclic allowables to the fatigue life. Based upon passengers carried versus range data for the 1972 U. S. Domestic Regional Carriers, the average stage length between 0 and 926 km (0 and 500 n.mi.) was calculated to be 417 km (225 n.mi.) with a 40% passenger load factor. Considering a 30,000 hour fatigue life, average cruise speeds, and the foregoing average stage length and passenger load factor, 241,325 kN/sq.m (35000 psi) fatigue allowable was estimated.

This fatigue allowable is relatively insensitive to the parameter variations of the present study and, thereby, was assumed to be constant. Further detail study, of course, would undoubtedly show slight variations in this assessment and assumption since the Gust Load Alleviation System, in particular, should lower the cyclic rate of maximum load encounter. The benefits, however, would still be small for the low wing loading aircraft involved in this study.

3.4.3 Effects on Aircraft Weight – The wing weight for the two baseline aircraft were analyzed by the "Wing Weight Analysis Program" and the results are given in Table V in section 3.1.3. This program synthesizes the wing structure for a number of external loading conditions (e.g., maneuver, gust, taxi, etc.) along with constraints imposed by geometry, fatigue, stiffness and manufacturing requirements. As indicated in Section 3.1.3, the "Wing Weight Analysis Program" verified the results of the weight estimation logic, so that, modifications were not required for the airplane without active controls. The program was also manipulated to determine the degree of damping required from a gust load alleviation system to achieve the maximum structural weight saving. The application and formulation of the "Gust Load Alleviation System" weight estimation procedure is presented in Section 4.2.

3.5 Final Sizing of Airplanes Without Active Controls

The baseline airplane studies were used to confirm or update the parametric sizing routine before proceeding with the sizing of the following array of airplanes:

Turboprop Design

No. Of Passengers	4-Engines 0.5 MACH Field Length m (ft) 457 (1500)	610 (2000)	914 (3000)	2-Engines 0.6 MACH Field Length m (ft) 914 (3000)	1067 (3500)
44	O	O	O	O	O
100	O	O	O	O	O
148		O	O	O	O

Turbofan Mechanical Flap

148 passengers, 2-engined, 0.7 Mach, 910 m (300 ft) field length.

The scope of the program did not permit absolutely precise optimization of each of the above airplanes; airplanes close to the optimum were obtained by varying the cruise power setting until the design wing loading and thrust to weight ratios, optimized in Section 3.1.4, were closely matched.

Table X presents the principal characteristics of the turboprop airplanes sized without active controls. The turbofan data are presented in Section 6.2

Table X Airplane Characteristics (No Active Controls)

# ENGINES	4								2					
# PAX	44			100			148		44		100		148	
M	0.5			0.5			0.6				0.6		0.6	
F.L. - FT.	1,500	2,000	3,000	1,500	2,000	3,000	2,000	3,000	3,000	3,500	3,000	3,500	3,000	3,500
$W/S_{T.O.}$ - PSF	32.7	44.0	71.1	32.7	44.0	71.0	44.0	71.0	58.8	71.0	58.8	71.0	58.8	71.0
$T/W_{T.O.}$	.383	.325	.301	.383	.327	.300	.326	.298	.403	.405	.398	.406	.401	.402
500	.765	.780	.802	.760	.765	.788	.750	.782	.755	.725	.745	.705	.725	.696
RGW - LB	61,004	49,055	42,670	121,369	94,644	80,921	130,163	110,217	49,078	47,026	95,276	90,892	132,329	125,506
OWE - LB	45,406	35,285	29,635	87,794	65,072	52,907	87,514	69,765	35,139	33,364	65,401	61,775	89,091	83,145
SLST - LB	6,285	4,299	3,458	12,527	8,324	6,549	11,431	8,846	10,643	10,261	20,418	19,841	28,553	27,152
DOC-2 (500)	4.207	3.732	3.487	2.649	2.230	2.030	1.790	1.605	3.075	2.999	1.903	1.841	1.561	1.499
DOC-4 (500)	4.895	4.235	3.916	3.246	2.649	2.380	2.173	1.923	3.583	3.479	2.329	2.242	1.956	1.868
DOC-2 (150)	6.414	5.617	5.189	4.128	3.426	3.066	2.769	2.442	4.857	4.716	3.068	2.955	2.540	2.425
CR. ALT (DOC-2, 150)	15	15	15	15	15	15	15	15	15	15	15	15	15	15
KEAS (DOC-2, 150)	250	250	250	250	250	250	250	250	300	300	300	300	300	300
DOC-4 (150)	7.510	6.398	5.823	5.073	4.068	3.575	3.352	2.890	5.675	5.478	3.735	3.587	3.154	2.994
CR. ALT (DOC-4, 150)	15	15	15	10	10	10	10	10	15	15	10	10	10	10
500 N.M. FUEL - LB	4,913	3,575	3,042	9,751	6,822	5,696	9,264	7,665	3,645	3,443	6,957	6,557	9,571	8,936
150 N.M. FUEL (DOC-2)	2,352	1,671	1,353	4,678	3,202	2,537	4,346	3,420	1,762	1,641	3,368	3,132	4,639	4,269
WING AREA - FT^2	1,856	1,112	599	3,694	2,146	1,136	2,949	1,548	832	659	1,614	1,275	2,242	1,760
WING WEIGHT - LB	10,147	6,454	3,957	22,851	14,064	8,479	20,585	12,314	5,211	4,356	11,438	9,519	16,935	14,031
SURFACE CONTR. - LB	1,537	1,331	1,214	2,421	2,054	1,853	2,535	2,272	1,332	1,295	2,063	2,000	2,563	2,475
HYDRAULICS - LB.	512	444	405	807	685	618	845	757	444	432	688	667	854	825
HOR. STAB. $\overline{V}$	.789	.727	.770	.826	.779	.843	.842	.933	.625	.658	.676	.716	.739	.790
HOR. STAB AREA - FT^2	729	312	131	1,477	616	257	848	357	173	129	349	259	493	367
HOR. STAB WT - LB	1,946	1,005	524	3,922	1,974	1,021	2,716	1,410	778	624	1,549	1,241	2,179	1,742
VERT. STAB $\overline{V}$	.078	.069	.067	.112	.099	.097	.125	.123	.055	.056	.080	.082	.102	.104
VERT. STAB AREA - FT^2	533	218	84	1,486	582	219	922	351	114	82	308	219	504	357
AIRFRAME COST \$M	2.8926	2.5633	2.3711	4.4232	2.8136	3.4699	4.6846	4.2272	2.7187	2.6517	4.0720	3.9569	5.0305	4.8634
TOTAL COST \$M	3.8969	3.4494	3.1959	5.6837	4.9153	4.4879	5.9077	5.3512	3.3162	3.2418	4.8123	4.6903	5.8574	5.6766

AIRPLANES WITH MANUAL CONTROLS (COSTS REDUCED BY \$47,460)

AIRFRAME COST \$M	2.8451	2.5158	2.3236						2.6712	2.6042				
DOC-2 (500)	4.190	3.715	3.47						3.060	2.984				
DOC-4 (500)	4.879	4.219	3.899						3.569	3.464				
DOC-2 (150)	6.391	5.594	5.166						4.837	4.695				
DOC-4 (150)	7.487	6.376	5.800						5.655	5.458				

4.0 ACTIVE CONTROL SYSTEMS

The term "Active Control Technology" is of recent origin but it is worth noting that Orville Wright was awarded the Collier Trophy for his work in automatic stabilization in 1914. A significant recent application of active controls was the Lockheed-Georgia Company's incorporation of an Active Lift Distribution Control System into the C-5A in order to reduce wing bending loads in the short period and first wing mode frequency range. Other potential uses of active control technology include flutter control, envelope limiting, load control, relaxed static stability and ride quality control.

In this study, systems have been developed for the baseline airplanes to provide the following alternate capabilities:

(a) Passenger ride comfort equivalent to that of a B737 aircraft.

(b) The above ride comfort plus structural load alleviation due to gusts.

(c) The above ride quality and gust load alleviation capabilities, plus the use of a reduced static margin.

Systems for each of the above capabilities are described, their weights and costs defined and parametric weight and cost relationships determined for variations in wing loading, passenger size and the other related parameters. Table XI summarizes the capability and redundancy standard of the three systems.

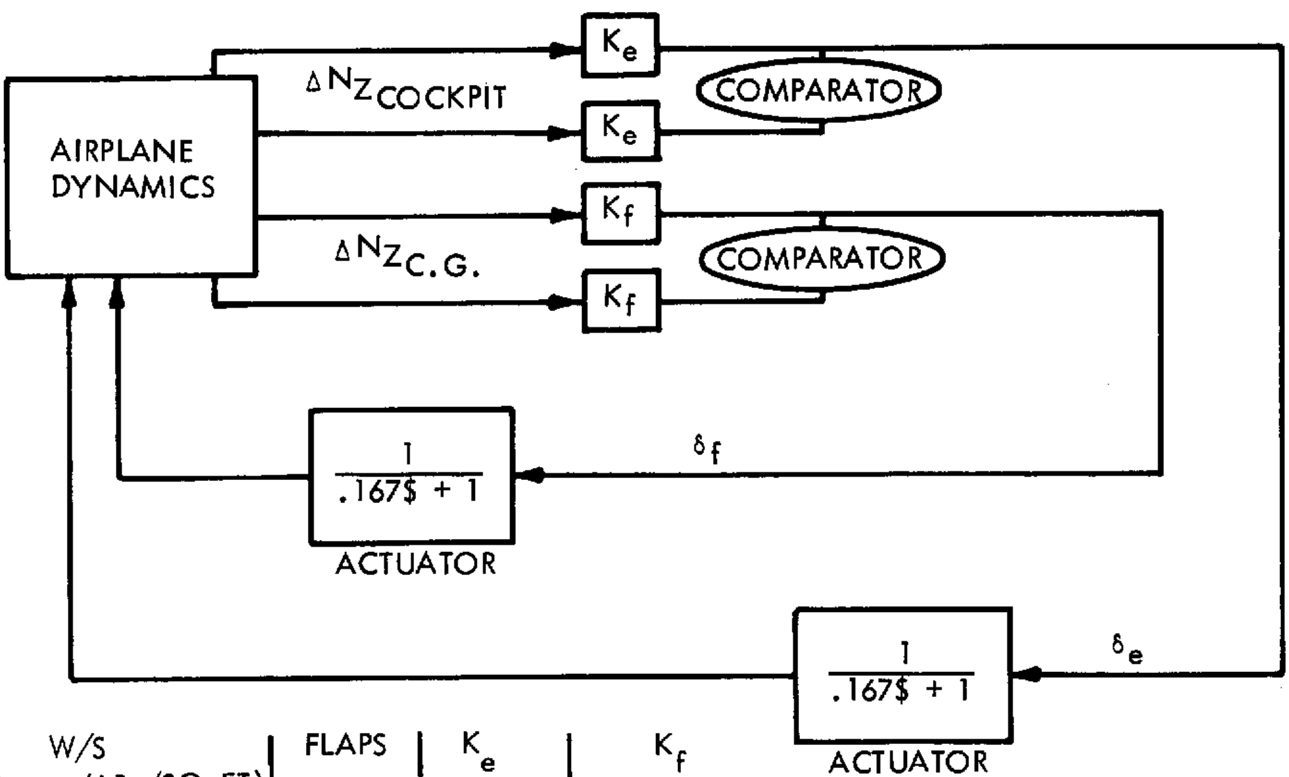
4.1 Ride Quality Control System

This section describes the ride quality control systems, together with the associated parametric system weight and cost data.

4.1.1 Ride Quality Control System Synthesis. Longitudinal ride quality control systems have been synthesized utilizing a linear 3-degree of freedom digital computer program to improve the ride comfort of the two baseline airplanes to that estimated for a contemporary jet transport such as the B737. The system finally developed is shown schematically in Figure 15 together with values of the gains determined for the 215 and 287 kg/sq.m (44 and 58.8 lb/sq. ft) wing loading baseline airplanes. The system consists of two feedback loops, the first being vertical acceleration at the center of gravity driving three aft-segment flap panels plus the aileron on each wing semi-span, and the second being vertical acceleration at the flight station driving the elevators. The acceleration feedback to the wing surfaces provides

Designation	Capability	Redundancy
Baseline	No Active Controls	Not Applicable
RQ (Ride Quality)	Ride Quality Control only	Multiple surfaces and hydraulic systems with individual actuators. Two electronic channels - FAIL SAFE
GLA (Gust Load Alleviation)	Ride Quality Control plus Gust Load Alleviation	As for RQ plus third electronic channel and duplicated hydraulic supplies to each surface - FAIL OPERATIVE
AS (Artificial Stability)	Ride Quality Control plus Gust Load Alleviation plus Artificial Stability	As for GLA plus fourth electronic channel and third hydraulic supply to pitch control - FAIL OPERATIVE after two identical failures.

Table XI System Designation, Capability and Redundancy



W/S KG/SQ.M.	(LB./SQ.FT)	FLAPS	K_e	K_f
215	(44)	UP	.023	-.40
215	(44)	DOWN	.10	-1.0
287	(58.8)	UP	.023	-.40
287	(58.8)	DOWN	.07	-1.0

(K_e & K_f UNITS ARE RAD./g)

Figure 15 Ride Quality Control System

ride smoothing but greatly increases the r.m.s. pitch rate levels. The addition of the flight station accelerometer permits the sensing of the vertical accelerations due to pitching moments generated by the ride control surfaces on the wing. This signal is then used to drive the elevators to counter these pitching moments. The acceleration feedback to the pitch control also reduces r.m.s. g's in the short period frequency range. The synthesis of the ride quality system did not include a consideration of the system filtering necessary for system/structural stability requirements. It was assumed that this consideration would not have a significant effect on the cost or weight of the ride quality system.

To meet handling qualities requirements for good pilot control during aircraft maneuvering it would be necessary to cancel out the ride control commands to the wing surfaces and elevator with a stick position function. The stick position function could be determined by an analysis of stick force per g characteristics. Other feedback parameters were evaluated such as angle of attack feedback to the flap/aileron lift control surfaces and pitch angular rate feedback to the elevator. In both cases there was no significant improvement in r.m.s. acceleration levels. However, for handling qualities requirements, which were not considered within the scope of this study, it would more than likely be necessary to include a pitch damping loop in the system.

For the cockpit acceleration feedback to the elevator, results indicated an optimum gain for attenuating r.m.s. pitch rate. Above or below the optimum gain the amount of pitch rate attenuation is reduced. In spite of the fact that the control flap effectiveness is significantly increased with flaps extended, it was necessary to increase the ride control system gains for the landing approach case in order to meet the Boeing 737 ride quality level.

Wing loading had a significant effect on the control flap size required to match 737 ride qualities. The wing loading of the 215 kg/sq. m (44 psf) airplane required the surfaces to have a 15% wing chord size while the 387 kg/sq. m (58.8 psf) wing loading airplane required full span 10% chord surfaces for wing lift control. Alternatively, 15% chord surfaces covering only part of the landing flap span can be used for the higher wing loading case; this is probably the more efficient method.

The ride quality system synthesis used an actuator bandpass of 6 rad/sec with a no load rate limit of 60 deg/sec. This no load rate limit under loaded conditions would be around 40 deg/sec. The effects of control surface actuator bandpass and deflection rate limit have not been evaluated but studies performed for NASA Langley (Ref 8)indicate that the bandpass and rate limit used are adequate. Furthermore, preliminary data just released by NASA Langley shows that even for higher speed jet aircraft most of the energy associated with aircraft vertical motion is at frequencies below 6 rad/sec.

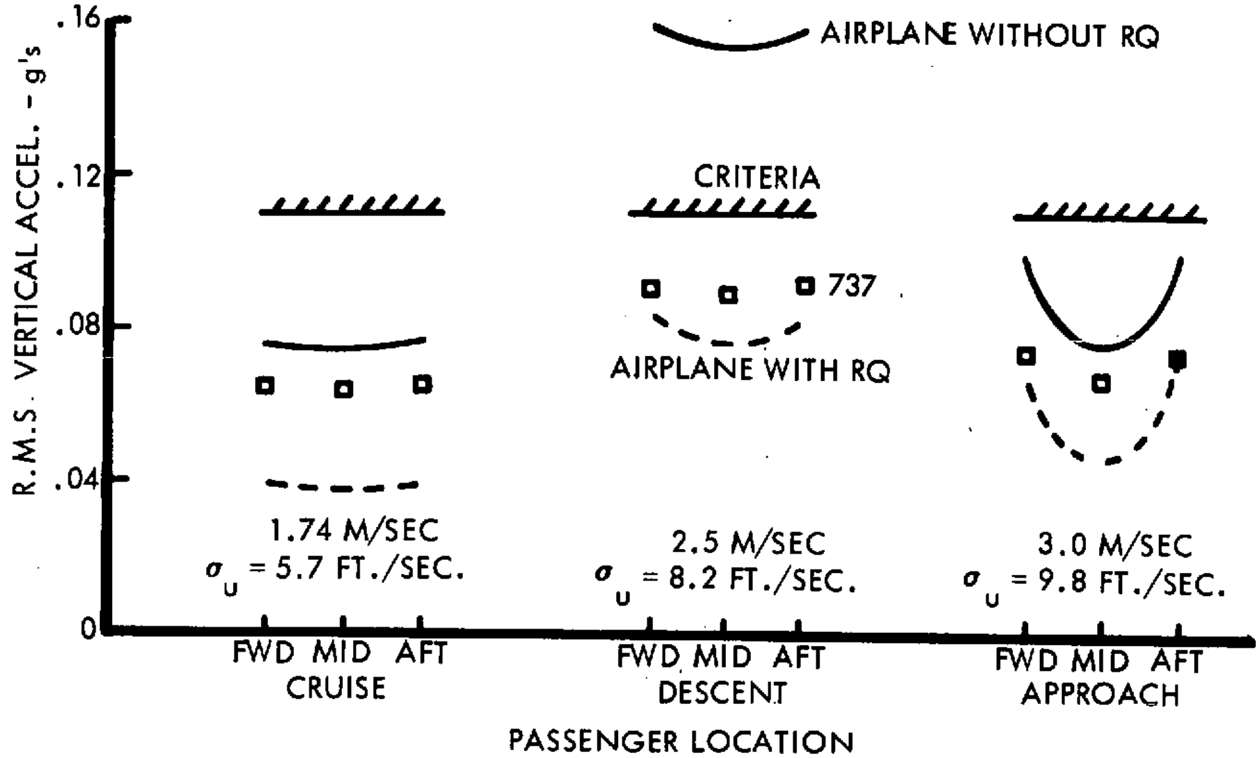
Figures 16 and 17 present r.m.s. vertical acceleration and r.m.s. pitch rate for the two baseline airplanes, with and without a ride quality system installed. Data are presented for the cruise, descent and approach cases. For both baseline airplanes the ride quality systems were designed to improve the ride in the descent case so that it was slightly better than the estimated B737 r.m.s. vertical acceleration. In doing this the cruise and approach ride qualities were generally better than required to equal the B737 estimate.

4.1.2 Ride Quality Control System Design. The lift changes required for ride control are provided by automatically controlling the angular position of the aileron and the aft segment of the double slotted trailing edge flap as shown in Figure 18. The design shown consists of a forward flap segment which travels aft on conventional flap tracks and an aft flap segment which pivots about point 'A' to provide the landing flap position. For ride quality control the aft flap segment pivots about point 'B' and is actuated by a hydraulic actuator 'C' which is attached to the flap carriage 'D'. The actuator piston-rod end is connected to the flap ride control operating lever at 'A', this point being coincident, with no ride control deflection, with the pivot point about which the aft segment rotates for normal landing flap operation. The aft flap segment can be actuated for ride quality control in the retracted or extended landing flap position through ± 15 degrees in the design shown. The pivot point, as arranged, provides the required chord (.15C) and allows the overhanging nose of the surface to be used for mass balancing purposes.

The lowest wing loadings examined required this aft segment of the flap, used for ride control, to extend the full span of the trailing edge flap. To avoid problems due to structural deflection under load this flap segment on each wing is split into 3 equal span sections, each operated by a single actuator and a single hydraulic supply. Each pair of flap segments is supplied by a different hydraulic system so that failure of a single hydraulic system still leaves the aileron and two flap sections on each wing available for ride quality control. As the wing loading increases the span of the control flap and the number of sections can be reduced until only the aileron is used. At high wing loadings, approaching that of the B737, ride quality control is unnecessary to meet the standards set for this study. On airplanes equipped with powered controls the elevator and aileron servo-actuators are modified to include an electrical input signal to the valves in addition to the manual pilot input.

In airplanes with manual controls, such as the smaller airplanes in the matrix being studied, it is necessary to change to powered controls on introduction of a ride quality system. This does not change the weight of the control systems but does increase the cost.

610 M (2000 FT) FIELD LENGTH
W/S = 215 KG/SQ. M. (44 LB/SQ.FT.)



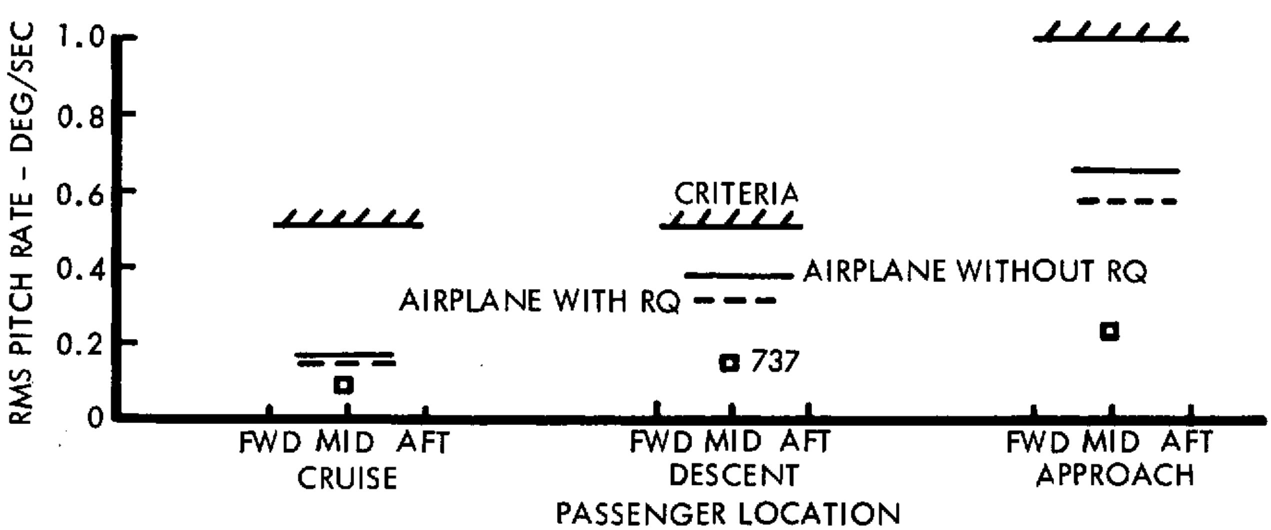


Figure 16 Ride Quality System Effects (610 m; 2000 ft. F.L.)

914 M (3000 FT) FIELD LENGTH
W/S = 287 KG/SQ.M. (58.8 LB/SQ.FT.)

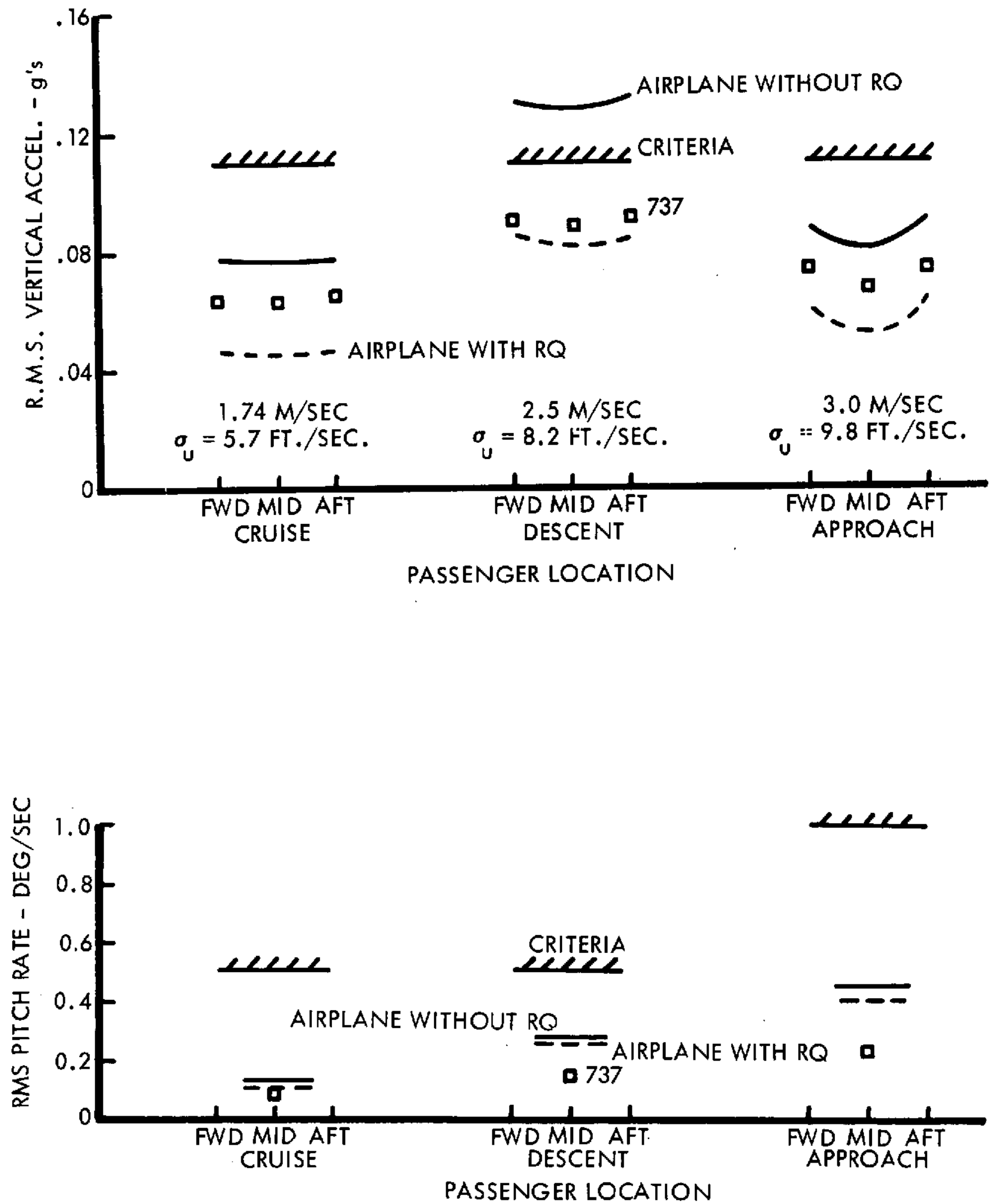
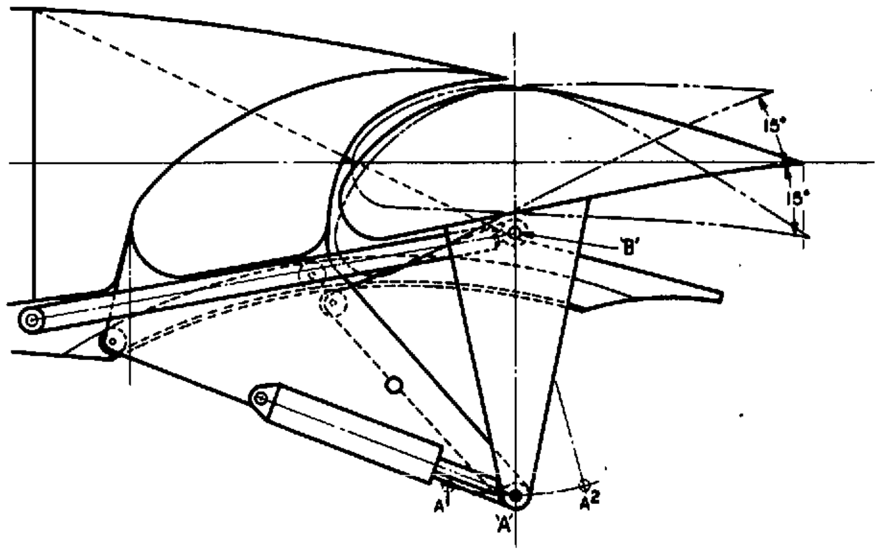
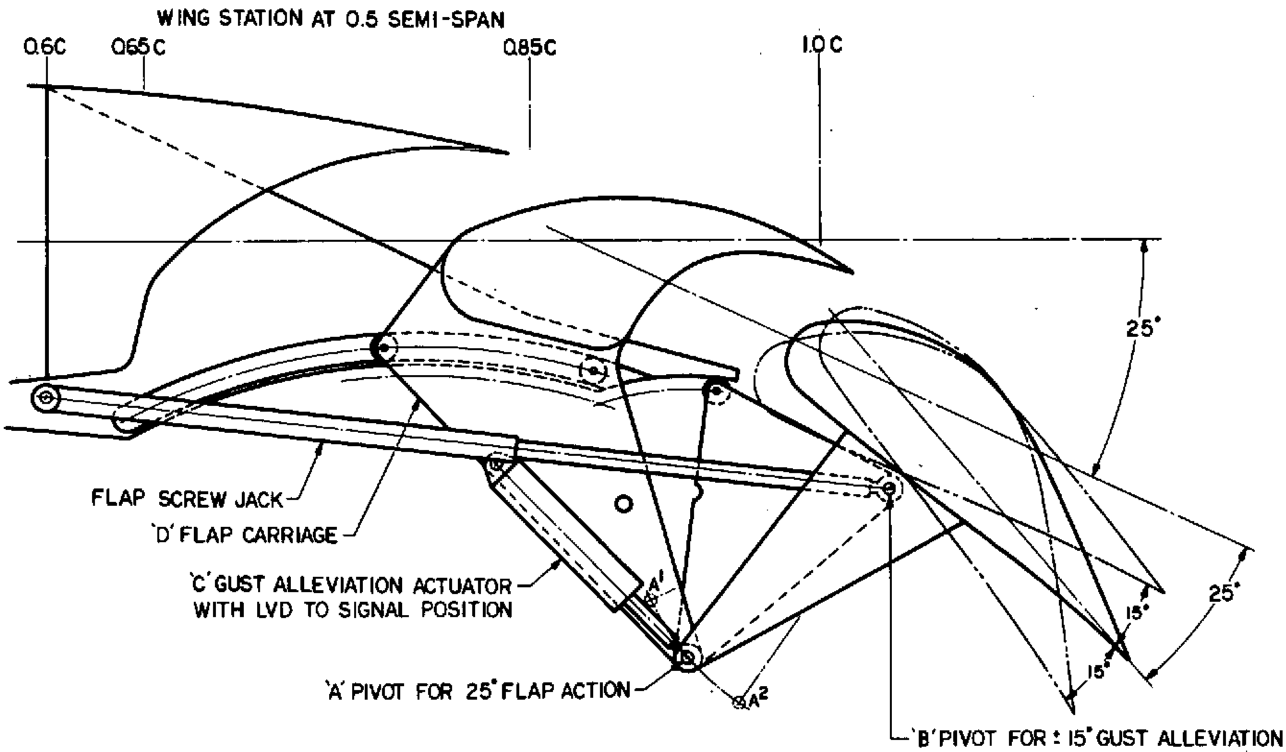


Figure 17 Ride Quality System Effects (914 m; 3000 ft. F.L.)



TRAILING EDGE FLAP - RETRACTED



TRAILING EDGE FLAP - EXTENDED

Figure 18 Ride Quality and Gust Alleviation Control Flap

The hydraulic power provided in the airplane is not increased, relative to the airplanes without the ride quality system, since it is not considered an essential system in an emergency condition; priority valves are included in the hydraulic system so that in an emergency or under exceptional demand conditions the ride quality system will momentarily stop functioning until priority services have been satisfied.

While failure of a single actuator or hydraulic system is considered to be acceptable, a false signal from the sensors to all actuators is considered not acceptable. To prevent such an occurrence the sensing and electronics components are completely duplicated and arranged so that their signals to the actuators are compared. If these signals do not agree with each other the ride quality control system is shut down. In the event of a hard-over of a single control flap surface, position indicators in the cockpit will alert the pilot to switch off power to that surface and its twin on the opposite wing.

4.1.3 Ride Quality Control System Weight and Cost – The components and systems affected by the incorporation of a Ride Quality (RQ) Control System include the control surfaces, control servo actuators, control system, hydraulic system and the electronics systems. The weights and costs of the two design point airplanes were estimated using the system design descriptions from Section 4.1.2; Table XII summarizes the data for one of the airplanes. Parametric curves summarizing the weight and cost effects for a range of airplanes are presented in Section 5.1. The following describes the logic utilized for each major component to formulate and quantify these effects.

Control Surfaces - The aileron and the second segment of the trailing edge flap act as the ride quality control surfaces. Since these surfaces are also used for maneuver (the ailerons) and during landing and take-off, the surface weight and cost is not expected to change to any appreciable degree.

Surface Controls – The surface controls effects include the addition of servo-actuators for the RQ segment of the trailing edge flaps and the addition of aileron and elevator servo-actuators with automatic electrical input capability in lieu of actuators without this capability. On the smaller aircraft (set arbitrarily at below 70 passengers) without RQ, the aileron and elevator will probably be operated by manual controls. Addition of RQ would require installation of full power aileron and elevator controls for these smaller aircraft. The weight difference between manual and powered controls was assessed to be negligible for this study; the cost difference, however, was evaluated and included in the cost estimation logic. For the 44 passenger baseline airplane, the cost of powered versus manual primary controls was estimated to be $42,000 before the inclusion of profit. For all sizes of airplanes, addition of electro-hydraulic valves to the aileron and elevator servo actuators cost an additional $18,500 per airplane.

610 M (2000 FT) BASELINE
W/S - 215 KG/SQ.M. (44 PSF)

	Δ WEIGHT LB	Δ WEIGHT KG	Δ COST - $
Δ SURFACE CONTROLS	(77)	(35)	(96,960)
* POWERED AILERON AND ELEVATOR	0	0	47,460
AILERON AND ELEV. E-H VALVES	15	6.8	49,500
CONTROL FLAP ACTUATION	62	28.2	
Δ HYDRAULIC SYSTEM	(36)	(16.3)	(2,200)
Δ ELECTRONICS	(100)	(45.3)	(67,800)
2 AILERON/FLAP CHANNELS	30	13.6	
2 ELEVATOR CHANNELS	30	13.6	
ACCELEROMETERS AND INDIC.	10	4.5	
WIRING AND MISC.	30	13.6	
Δ TOTAL	(213)	(96.6)	(166,960)

* MANUAL CONTROLS IN BASELINE

Table XII Weight and Cost - RQ System

The 44 passenger baseline airplane with 215 kg/sq.m (44 psf) wing loading requires the full span of the trailing edge flap for ride quality control. Assuming the surface is divided into 3 sections per wing side, 6 actuators would be required and each was estimated to weigh 4.1 kg (9 lb) and cost $4000. The aileron and elevator electro-hydraulic servo actuator weight increment for this baseline was estimated to be 1.8 kg (4 lb) per actuator; 5.4 kg (12 lb) per airplane. The baseline airplane surface controls weight, therefore, was estimated to be

(1) flap servo-actuators and installation (6 x 9 x 1.15) = 62 lbs. (28 kg)

(2) aileron and elevator servo-actuator modification (3 x 4x 1.25) = 15 lbs. (6.8 kg)

The above weight estimates total to 35 kg (77 lbs.) per airplane for the 215 kg/sq.m (44 psf) wing loading, 44 passenger, baseline.

Parametric scaling of these weight and cost data was based upon evaluation of the degree of ride quality control required. The basis for ride quality acceptability was based upon the ride quality level of the B737 type airplane. That is, rough air damping requirements were predicated upon the airplane wing loading relative to that for the B737; approximately 488 to 576 kg/sq.m (100 to 118 psf). The trim requirements for the aft flap segments, therefore, are inversely proportional to the airplane wing loading relative to a 488 kg/sq.m, (100 psf) wing loading assuming that the aileron alone will provide adequate ride control at 488 kg/sq.m (100 psf). This trim requirement is expressed by the following proportionality:

$$\Delta C_L/C_L \propto (S/W - .01) \propto \text{No. of Actuators}$$

This relationship was used to establish the required span, and hence the number of actuators, using the 215 kg/sq.m (44 psf) baseline with six actuators and 488 kg/sq.m (100 psf) for zero actuators. The flap RQ actuator weight and cost was evaluated as being proportional to the surface hinge moment which was in turn proportional to the product of airplane gross weight and the wing average chord. The aileron and elevator surface controls were assumed constant for wing loadings below 488 kg/sq.m (100 psf).

Electronics — The additional electronics required for RQ control is composed of surface position indicators, two aileron and RQ flap channels of electronics for the surfaces and two for the elevator RQ operation, and aircraft acceleration sensors. These items are considered to be invariant with airplane size below a wing loading of 488 kg/sq.m (100 psf) and were considered constant for airplanes employing RQ control. The weight and cost for electronics was estimated to be as follows:

o	Surface Position Indicators	1.8 kg (4 lbs.)	$ 2,400
o	Four Electronic Channels	27 kg (60 lbs.)	$60,000
o	Accelerometers, Wiring, & Misc.	16 kg (36 lbs.)	–
	TOTAL	45 kg (100 lbs.)	$62,400*

*** Profit not included.**

Hydraulics – Additional hydraulic system weight for RQ control was assumed to consist of flex-hoses running between the primary control main plumbing lines and the second-segment flap actuators with flow being controlled by added priority valves. The weights of these components were estimated for the baseline aircraft and related to the number of actuators and wing geometric parameters. The cost of the additional hydraulics was evaluated using the sizing program's hydraulic cost estimating relationship.

4.2 Gust Load Alleviation System

This section describes the Gust Load Alleviation (GLA) System, together with the associated parametric system weight and cost data.

4.2.1 Gust Load Alleviation System Synthesis. Systems were synthesized for the baseline airplanes to reduce the gust loading conditions to be equivalent in criticality to the maneuver cases. From the analyses described in Section 3.4, the following requirements were obtained for the system synthesis.

	W/S	
15 mps (50 fps) Vertical Gust	215 kg/sq.m (44 PSF)	287 kg/sq.m (59 PSF)
kg G. Wt. (Lb.)	21,092 (46,500)	20,965 (46,220)
kN/sq.m q (PSF)	10.1 (211.1)	14.56 (304.1)
m Alt. (ft)	4,572 (15,000)	4.572 (15,000)
Δg Required from System	± 1.5	± 1.5
C_L TRIM	.191	:177

20 mps (66 fps) Vertical Gust	W/S 215 kg/sq.m (44 PSF)	287 kg/sq. m (59 PSF)
kg Wt (Lb.)	21,092 (46,500)	20,965 (46,220)
kN/sq.m q (PSF)	4.14 (86.5)	6.09 (127.1)
Alt. (ft)	0 (0)	0 (0)
Δ g Required from System	±.9	±1.0
C_L TRIM	.465	.422

Results of the synthesis show that the ride quality control system described in Section 4.1.1 for the W/S = 215 kg/sq.m (44 psf) airplane will meet the gust load alleviation system requirement if the wing control surface deflection capability is increased 3.0 degrees to a maximum of 18.0 degrees. There is no increased hinge moment requirement along with the increased surface deflection. For the W/S = 287 kg/sq m (58.8 psf) airplane however the ride quality system will not meet the gust load needs and therefore had to be increased in chordwise length of the gust flap to 15% chord or extended in span if 15% chord is used for the ride quality system. For this case, the hinge moments are significantly larger than those for the ride quality system. The maximum surface deflection had to be increased to 18.0 degrees. The flap/aileron and elevator gains are not changed from the values used in the ride quality system for the W/S = 215 kg/sq.m (44 psf) airplane. For the W/S = 287 kg/sq.m (58.8 psf) airplane however the ride quality requirements would not determine gain magnitude because the gust load alleviation system places a higher requirement on the feedback gains.

4.2.2 Gust Load Alleviation System Design. The system is basically similar to the ride quality control system described in Section 4.1.2. However since the structural integrity of the airplane is dependent on the operation of this system it is necessary to reconsider the failure cases involved.

The general arrangement, splitting of the surfaces and the use of single actuators for the flap sections are retained as for the ride quality system. Single actuators are acceptable, since in the unlikely event of a surface or actuator failure in severe gust conditions, the flaps can be extended to the approach condition and the airplane speed reduced. However it is considered necessary to provide duplicated electro-hydraulic valves and duplicated hydraulic supplies to each actuator since these components are more likely to fail than the actuators.

On failure of a hydraulic system, a shuttle valve, located at the actuator, senses the differential pressure between the two systems and automatically closes off the ports from the failed system. Only one of the two electro-hydraulic control valves is used during normal operation of the gust load alleviation system. If this control valve fails it will be detected by comparison of the surface position feedback signal and the input signal to the valve, and/or comparison with signals from the other surfaces. A discrepancy will automatically signal a solenoid-operated shuttle-valve to redirect the hydraulic supplies through the standby control valve.

It was accepted in the previous section that the ride quality system would momentarily stop functioning under exceptionally high hydraulic system demand by the priority systems. This situation is not acceptable for the gust load alleviation system since it is itself a priority system.

It is therefore necessary to increase the hydraulic power system and the distribution pipes feeding the flight controls and flaps along the wing rear spar.

An additional electronics channel and associated wiring have been incorporated, making a total of 3 channels. On failure of one channel, comparison of the 3 channels automatically identifies and disconnects the faulty channel.

Arguments can be advanced for over-designing the total system to avoid reducing speed after failure of an actuator, and for further redundancy to cater for double failures (e.g., failure of two electronic systems); it was decided to take an optimistic approach for the purposes of this study.

4.2.3 Gust Load Alleviation System Weight and Cost

From the structural analyses in Section 3.4 and the system description given by Section 4.2.2, a computerized estimation technique was developed for determining the GLA system parametric and weight relationships. The cost estimating relationships are similar to those employed for the RQ system and are evaluated on a weight basis for the added actuators, surface controls system modifications, additional electronic components, increased hydraulic system capacity, and decreased wing structural weight. Weight and cost data for one of the design point airplanes are summarized in Table XIII while variations as a function of airplane size parameters are given in Section 5.2.

The GLA computerized estimation technique developed for this study consists of a set of logic in the sizing program which includes estimation of:

- o Gust load factors at V_B and V_C
- o Wing box weight increment due to gust loads
- o Trim lift coefficients required from the GLA system
- o Determination of the required size of a gust flap for use with the aileron
- o System weight increments for the gust flap, aileron, and elevator actuators; for the additional hydraulic capacity and components; and for the additional electronic components.

The logic incorporated in the sizing program for the GLA system is based upon analysis of the design basepoints and parametric correlation described in the paragraphs which follow.

Gust Load Factor Estimation

o $N_G = 1 + \Delta N_G$

o $N_G = \pm K_G \; U_{DE} \; V_E \; C_{L_\alpha} / (498 \times W/S)$

where $K_G = 1.76 \; W/S \; / \; (5.3 \; w_a \; C_{L_\alpha} \; \bar{C} + 2 \; W/S)$

U_{DE} = Gust Velocity (fps)

= ± 50 at V_c; ± 66 at V_B

V_E = Equivalent Airspeed (knots)

= V_C or V_B

610 M (2000 FT) BASELINE
W/S - 215 KG/SQ.M. (44 PSF)

	ΔWEIGHT LB	KG	Δ COST - $
Δ SURFACE CONTROLS	(137)	(62.1)	(122,910)
* POWERED AILERON AND ELEVATOR	0	0	47,460
AILERON AND ELEV. E-H VALVES	20	9.0	
CONTROL FLAP ACTUATION	72	32.7	75,450
SHUTTLE VALVES AND MISC.	45	20.4	
Δ HYDRAULIC SYSTEM	(204)	(92.5)	(12,240)
PUMPS	34	15.4	
POWER TRANSFER UNITS	13	5.9	
RESERVOIRS	27	12.2	
PLUMBING	130	59.0	
Δ ELECTRONICS	(155)	(70.3)	(90,400)
3 AILERON/FLAP CHANNELS	45	20.4	
3 ELEVATOR CHANNELS	45	20.4	
ACCELEROMETERS AND INDIC.	10	4.5	
WIRING AND MISC.	55	25.0	
Δ TOTAL	(496)	(225.0)	(225,550)

* MANUAL CONTROLS IN BASELINE

Table XIII Weight and Cost - GLA System

44 PAX AR = 8 RWG = 51,000 LB (23,134 KG)

W/S - PSF (KG/SQ.M.)		WITH GUST		NO GUST	
MAX	MIN	N_G	WING WEIGHT LB (KG)	WING WEIGHT LB (KG)	WING WEIGHT CHANGE LB (KG)
44 (215)	40.25 (197)	3.52	6,577 (2983)	6,080 (2758)	-497 (-225)
59 (287)	53.8 (263)	3.04	5,148 (2335)	4,914 (2229)	-234 (-106)
71 (347)	64.75 (316)	2.77	4,415 (2002)	4,309 (1955)	-106 (-48)
100 (488)	91.2 (445)	2.35	3,454 (1567)	3,451 (1565)	- 3 (-1.36)

Table XIV Wing Weight Change due to Gust Loading

V_C = Cruise Speed

V_B = Speed with max gust at $C_{L\ MAX}$.

W/S = minimum wing loading (psf)

w_a = air density at altitude (pcf)
(15,000 ft. used in the logic where w_a = 0.0481 pcf)

C_{L_α} = lift curve slope (per radian)

$\bar{C}$ = wing average chord (ft)

$C_{L\ MAX}$ = 1.4 (Assumed for V_B definition)

Wing Box Weight Change

The "Wing Weight Analysis Program" was used to analyze various wing parameters to arrive at gust load factors and potential wing structural weight reduction with GLA. In preparing this estimate, four aircraft were analyzed with wing loading variation from 215 to 488 kg/sq. m (44 to 100 psf) at the maximum gross weight condition. Wing loading variation at constant aspect ratio was used since wing loading is the major influencing parameter on the gust loads. The four configurations analyzed were assumed to have the same gross weight with wing loading changes obtained by wing area and each was analyzed with and without gust loads to determine the weight penalty due to gust. The results of the "Wing Weight Analysis" for these cases are shown in Table XIV. Examination of these analyses indicated that a 2g gust load factor (ΔN_G = 1) produced equivalent loads to those with a 2.5 g maneuver load factor; therefore, a criteria was selected based upon ΔN_G being greater than 1.0 to indicate gust criticality. As was indicated in Section 3.1.3, the parametric wing weight relationship predicts fairly accurate weights for a gust critical wing at low wing loadings. A parametric relationship, therefore, was developed for the wing weight change with GLA and applied as a weight reduction to the weight from the basic wing weight equation.

Gust Flap Size Derivation

The gust flap was sized in the GLA computerized technique by determining the maximum amount of ΔC_L trim required. This required trim was then compared with allowable trim available from the aileron to determine the trim required from the aft segment of the trailing edge flaps. With the gust flap required trim identified, the inboard end of the gust flaps was derived for a 15 percent chord gust flap deflected 18 degrees. With this information, the gust flap hinge moment was determined for use in sizing the actuators and other system components.

System Weight Estimates

For the baseline aircraft in Table XIV, the gust flap was determined to run the full span of the trailing edge flaps. Systems analysis yielded the following for the baseline configuration:

(a) Surface Controls,+ 62 kg (+137 lb.)

o	Flap Actuators & Installation (6)	=	32.7 kg (72 lb.)
o	Aileron & Elevator Actuator Mod.	=	6.8 kg (15 lb.)
o	Shuttle Valves (9)	=	12.2 kg (27 lb.)
o	Miscellaneous	=	10.4 kg (23 lb.)

(b) Electronics, + 70 kg (+155 lb.)

o	Accelerometers and Surface Position Indicators	=	4.5 kg (10 lb.)
o	Three Electronic Channels	=	40.8 kg (90 lb.)
o	Wiring and Installation	=	25 kg (55 lb.)

(c) Hydraulics, + 92.5 kg (204 lb.)

o	Hydraulic Pump Increase	=	15.4 kg (34 lb.)
o	Power Transfer Units	=	5.9 kg (13 lb.)
o	Reservoirs	=	12.2 kg (27 lb.)
o	Main Line Plumbing and Fluid	=	23.1 kg (51 lb.)
o	Gust Flap Plumbing and Fluid	=	10.4 kg (23 lb.)
o	Hoses and Valves at Actuators	=	25.4 kg (56 lb.)

The above baseline represented a gust flap hinge moment of 45,920 M-N (33,879 ft. - lb) per aircraft and added hydraulic flow rate amounting to 0.009 cu.m/min. (2.7 gpm) to each of the six gust flap actuators. Since the gust flaps will be primary controls for GLA, added hydraulic capacity and redundancy is required. From this baseline analysis, parametric relationships were derived for each system component and incorporated into the sizing program.

Costs

The arrangement of the system and the costing of the actuators is similar to the RQ system, however size and number of actuators may vary. Additional electro-hydraulic valves have been incorporated at the control flap, aileron and elevator actuator installation which for the baseline amounts to:

6 E-H valves for control flaps @ $2750	=	$16,500
2 E-H valves for aileron @ $4500	=	9,000
1 E-H valve for pitch control @ $5500	=	5,500
13% profit	=	4,000
TOTAL		$35,000

The additional electronic channel amounts to $20,000 for a total of $80,000 + 13% profit - $90,400.

The increased hydraulic system and the installation of all systems is calculated within the sizing program costing routine and cannot be separated readily into individual costs.

4.3 Artificial Stability System

This section describes the system which provides ride quality control, structural gust load alleviation and permits the relaxation of the static stability margin, which results in smaller horizontal stabilizers than required for the baseline airplanes.

In order to determine the effects on airplane size and cost of this reduced static margin it was necessary to include in the parametric sizing program an automatic horizontal stabilizer sizing routine which included static margin as a variable. Section 4.3.1 describes the routine developed and used for all the airplanes in this report except the initial designs described in Section 3.1.

Section 4.3.2 describes the system design while Section 4.3.3 discusses the weights and costs associated with the system.

4.3.1 Horizontal Stabilizer Sizing – The horizontal stabilizers were sized to perform three major functions:

1. Provide trim capability throughout the operational envelope.

2. Provide sufficient longitudinal control capability during commanded (plus inadvertent) speed and altitude excursions in smooth and turbulent air to meet operational requirements.

3. Provide sufficient longitudinal stability throughout the operational envelope for pilot control of the aircraft during maneuvers and in steady flight.

The critical conditions for these functions for horizontal stabilizer sizing are:

1. (a) Trim at the landing approach speed with most forward center of gravity.

   (b) Flare in Ground effect during the landing maneuver.

2. Sufficient pitch acceleration capability at the most forward center of gravity so that all necessary maneuvers, including go-around, can be performed during landing.

3. Adequate static margin at the most aft center of gravity during landing or high speed, low altitude cruise.

A trimmable incidence horizontal stabilizer was used in conjunction with a 30 percent chord elevator to provide the required trim and control capabilities. Horizontal tail sizing to provide these capabilities requires definition of the following parameters:

C_{MO}	= tail off pitching moment coefficient
R	= required center of gravity range
$\frac{\delta C_M}{\delta C_L}$	= minimum allowable static margin
$C_{LT_{MAX}}$	= max tail lift coefficient (a function of elevator deflection)

C_L	= lift coefficient at a given speed
$C_{L_{\alpha T}} = a_1$	= tail lift curve slope
$C_{L_\alpha} = a$	= wing lift curve slope
$\frac{d\epsilon}{d\alpha}$	= rate of change of downwash with incidence
k_{yy}	= radius of gyration in pitch
g	= gravitational constant
$\bar{c}$	= wing mean aerodynamic chord
$\Delta\ddot{\theta}$	= change in angular pitching

Figure 19 illustrates the primary parameters involved in sizing the horizontal stabilizer by presenting tail volume coefficient (V_H) versus C.G. position. The solid sloping line originating at h_N (neutral point-tail off) defines the tail size (V_H) required for neutral stability as the C.G moves aft from "h_N". The other solid line, originating at C_{MO}/C_L (trim position - tail off) defines the tail size for the airplane to remain trimmed as the C.G is moved forward. The point where the two solid lines intersect each other identifies the tail-size and the C.G location for the airplane to be both trimmed and neutrally stable. This is a point and therefore no C.G travel is available. To provide C.G travel the tail size must be increased still further. The dashed line identified as "stability line" provides an acceptable positive static margin ($\delta C_M / \delta C_L$) relative to the neutral stability line, while the dashed line identified as "trim line" provides control power for maneuver ($K\ddot{\theta}$) relative to the basic trim requirement. Note that the point of intersection of the two dashed lines increases the tail size required. To provide a range of C.G locations (R) which can be trimmed and stable the tail size must be increased; the larger the required C.G range, the larger the required tail size.

The slope of the "stability line" is a function of lift curve slopes of the wing and tail and the wing downwash. Powered lift systems increase the slope which results in a larger tail being required for a given C.G. range. The slope of the "trim line" is a function of the wing and tail lift coefficients; the higher the lift coefficient available from the tail (flying-tail, inverted camber, slotted leading edge, etc.) the lower the slope and hence the smaller the tail size required for a given C.G range.

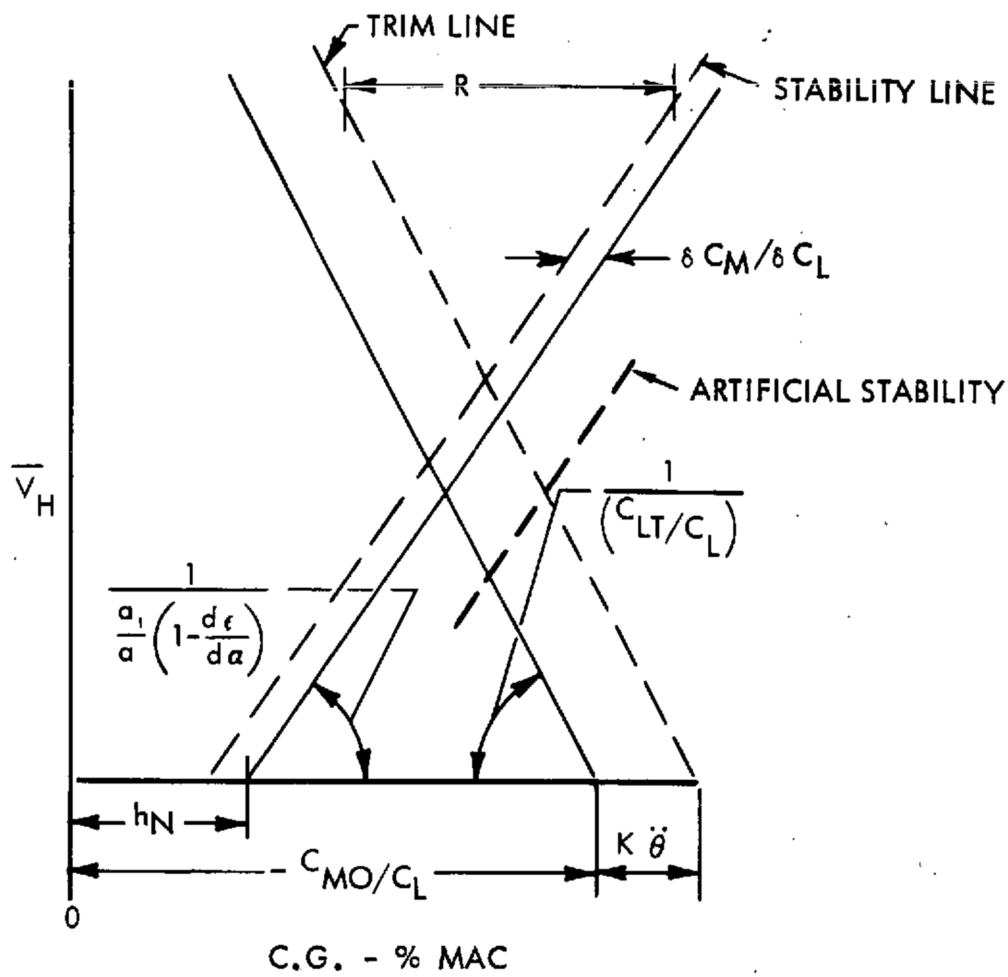


Figure 19 Horizontal Tail Sizing

Of primary importance to the present study is the "static margin" ($\delta C_M/ \delta C_L$) which is shown in the figure to have a positive value of 3% MAC and is provided by increasing the tail size relative to the neutral stability requirement. By the use of active controls a negative stability margin can be accepted, which places the stability line in the position identified as "artificial stability." This has the effect of reducing the tail size for a given C.G range which results in a weight saving and possibly a cost saving due to active controls.

A computer routine which included the above parameters was developed and incorporated into the main sizing program. Thus by the input of the correct value of $\delta C_M/ \delta C_L$, the static margin could be modified, the horizontal stabilizer resized and the effect of these changes on the complete airplane automatically computed. A similar type of routine was also developed for sizing the vertical stabilizer.

The $\Delta \ddot{\theta}$ level required to cover all maneuvers, over and above trim, has been shown in Ref. 9 to be a function of the desired landing field length. The real parameter involved is the approach speed which can be shown to be a single value for a given field length and set of landing criteria. The level of $\Delta \ddot{\theta}$ required from the control will also be a function of the technique used for controlling the approach and flare to touchdown. Thus the actual value of $\Delta \ddot{\theta}$ was chosen for each configuration and will depend upon the glide path control characteristics and requirements for that configuration. The suggested levels recommended in Refs. 10, 11, 12 and 13 were used as guides in selecting the $\Delta \ddot{\theta}$ level.

4.3.2 Artificial Stability System Design – The system is identified as an "Artificial Stability" (AS) system for convenience. It is in fact a combined gust load alleviation system and artificial stability system. The gust load alleviation system is identical to that described in Section 4.2 and meets the same redundancy considerations. This system is modified to provide artificial stability in the pitching plane by the addition of a third electro-hydraulic valve, and a fourth electronic channel in the pitch system, and miscellaneous switching logic and additional sensors. The artificial stability system utilizes these additional components with the actuators, electro-hydraulic valves, electronics, sensors and wiring provided for the gust load alleviation system.

The redundancy thus provided permits the failure of any two critical components while providing a fully functioning artificial stability system. The reduction in hinge moment if two actuators fail is probably acceptable as an emergency condition.

4.3.3. Artificial Stability System Weights and Costs – The additional components for this system do not vary with wing loading or aircraft size. These components weigh 13.6 kg (30 lb.) and add an additional $39,550 to the aircraft cost. The effects of the gust load alleviation portion of the system on wing weight and system weight are similar to those described in Section 4.2.3.

5.0 TURBOPROP AIRPLANE CHARACTERISTICS WITH ACTIVE CONTROLS

The matrix of airplanes defined and sized without active controls in Section 3.5 were resized with the effects of the three levels of active control systems included. This section describes the characteristics of these airplanes while the following section, 6.0, compares the effects of the various systems.

5.1 Characteristics of Airplanes Incorporating Ride Quality Systems

This system increases the weight and cost of the airplanes and slightly improves the fatigue life. Large wing weight savings are not expected and it is unlikely that the optimum aspect ratio would differ because of the introduction of this system. The airplanes sized with ride quality systems therefore retain the aspect ratios, wing loadings and thrust to weight ratios of the airplanes sized without active controls.

Table XV presents the primary size and economic characteristics of the matrix of airplanes. Included for convenience in the lower portion of this table are weight and cost changes relative to the airplanes without active controls. These data are discussed in Section 6.0. Figure 20 illustrates the variation of the ride quality system weight with wing loading for the 4-engined, 100 passenger size. Note that the weights for the individual systems, e.g., surface controls, are the additional weights due to the ride quality system. Figure 21 presents similar data to illustrate the variation of system weight with passenger size. The example shown is for the 610 m (2000 ft.) field length; data for the other field lengths are included in Table XV.

Figure 22 presents system cost variations with wing loading and passenger size. The steps in the "surface controls" and "total RQ system" curves at 70 passengers are due to the necessity of incorporating powered aileron & elevator controls into the basic airplane. The weight and cost trends are as expected, increasing with reduction of wing loading and increase of passenger size except for the electronics values which remain constant.

5.2 Characteristics of Airplanes Incorporating Gust Load Alleviation Systems

Since the gust load alleviation system will reduce the wing box weight, it can favor the use of higher wing aspect ratios. The degree of change in aspect ratio will vary with field length and it was therefore necessary with this system to reoptimize the aspect ratio for each of the

# ENGINES	4								2					
# PAX	44			100			148		44		100		148	
M	0.5			0.5			0.5		0.6		0.6		0.6	
F.L. - FT.	1,500	2,000	3,000	1,500	2,000	3,000	2,000	3,000	3,000	3,500	3,000	3,500	3,000	3,500
$W/S_{T.O.}$ - PSF	32.7	44.0	71.1	32.7	44.0	71.0	44.0	71.0	58.8	71.0	58.8	71.0	58.8	71.0
$T/W_{T.O.}$	.382	.325	.300	.383	.326	.300	.326	.298	.403	.405	.398	.405	.401	.402
η_{500}	.765	.780	.802	.760	.765	.788	.750	.782	.755	.725	.745	.705	.725	.705
RGW - LB	61,778	49,459	42,903	122,534	95,163	81,180	130,765	110,493	49,379	47,275	95,637	91,150	132,736	125,812
OWE - LB	46,105	35,657	29,852	88,841	65.550	53,149	88,067	70,022	35,419	33,597	65,736	62,029	89,468	83,430
SLST - LB	6,356	4,326	3,470	12,639	8,361	6,563	11,475	8,862	10,696	10,295	20,472	19,877	28,617	27,197
DOC-2 (500)	4.280	3.785	3.527	2.688	2.256	2.048	1.808	1.617	3.114	3.034	1.922	1.857	1.573	1.510
DOC-4 (500)	4.977	4.292	3.958	3.291	2.677	2.399	2.193	1.936	3.624	3.516	2.348	2.259	1.969	1.879
DOC-2 (150)	6.522	5.694	5.246	4.186	3.463	3.092	2.796	2.459	4.916	4.769	3.095	2.979	2.559	2.441
CR. ALT (DOC-2, 150)	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000
KEAS (DOC-2, 150)	250	250	250	250	250	250	250	250	300	300	300	300	300	300
DOC-4 (150)	7.631	6.480	5.883	5.141	4.109	3.602	3.382	2.909	5.738	5.534	3.764	3.612	3.175	3.012
CR. ALT (DOC-4, 150)	15,000	15,000	15,000	10,000	10,000	10,000	10,000	10,000	15,000	15,000	10,000	10,000	10,000	10,000
500 N.M. FUEL - LB	4,970	3,599	3,055	9,840	6,854	5,710	9,301	7,680	3,661	3,455	5,977	6,571	9,594	8,952
150 N.M. FUEL (DOC-2)	2,379	1,682	1,358	4,720	3,217	2,543	4,363	3,427	1,770	1,647	3,378	3,138	4,650	4,277
WING AREA - FT^2	1,879	1,120	602	3,728	2,157	1,139	2,962	1,551	836	662	1,620	1.278	2,249	1,764
WING WT. - LB.	10,296	6,514	3,980	23,107	14,152	8,509	20,694	12,347	5,246	4,381	11,487	9,549	16,994	14,069
SURFACE CONTR. - LB	1,687	1,414	1,249	2,649	2,173	1,896	2,678	2,320	1,383	1,330	2,132	2,045	2,645	2,527
HYDRAULICS - LB	574	480	423	888	729	638	895	778	468	450	716	687	885	847
HORIZ. STAB. $\bar{V}$	.787	.726	.769	.825	.778	.843	.842	.933	.624	.657	.675	.715	.739	.789
HORIZ. STAB. AREA - FT	740.8	315	131		620	258	853	358	174	129	350	260	495	367
HORIZ. STAB. WT. - LB	1,976	1,015	527	3,967	1,986	1,024	2,730	1,414	783	627	1,556	1,245	2,186	1,747
VERT. STAB. $\bar{V}$	.078	.069	.067	.112	.099	.097	.125	.123	.055	.056	.080	.082	.102	.104
VERT. STAB. AREA - FT^2	544	221	328	1,509	587	220	939	352	115	82	310	220	506	358
A/F COST - $M	3.0540	2.6920	2.4746	4.6070	3.9514	3.5751	4.8287	4.3337	2.8316	2.7563	4.1891	4.0630	5.1509	4.9714
TOTAL COST - $M	4.0620	3.5799	3.3004	5.8712	5.0546	4.5938	6.0533	5.4583	3.4299	3.3411	4.9301	4.7968	5.9783	5.7850
WSCR - LB	150	83	35	228	119	43	143	48	51	35	69	45	82	52
WSCRA - LB	138	76	31	214	111	39	135	45	46	32	64	41	77	48
CSCRA - $	72,624	49,493	29,166	89,844	57,559	31,188	62,959	32,544	36,090	29,395	40,222	31,580	43,140	33,156
WAVR - LB	100	100	100	100	100	100	100	100	100	100	100	100	100	100
CAVR - $	67,800	67,800	67,800	67,800	67,800	67,800	67,800	67,800	67,800	67,800	67,800	67,800	67,800	67,800
WHR - LB	62	36	18	81	44	20	50	21	24	18	28	20	30	22
Δ A/F COST - %	5.58	5.02	4.51	4.16	3.61	3.63	3.01	2.52	4.15	3.94	2.88	2.68	2.39	2.22
Δ TOTAL COST	.1651	.1305	.1045	.1975	.1393	.1059	.1456	.1071	.1137	.1053	.1178	.1065	.1209	.1084
Δ OWE - LB	699	372	217	1,047	478	242	553	257	280	233	335	254	377	285
Δ RGW - LB	774	404	233	1,165	519	259	602	276	301	249	361	258	407	306
% DOC-2 (500)	1.7	1.4	1.15	1.41	1.17	.89	1.0	.75	1.27	1.17	1.0	.81	.9	.75
% DOC-4 (500)	1.68	1.35	1.07	1.39	1.06	.8	.92	.68	1.14	1.06	.86	.76	.72	.6
% DOC-2 (150)	1.68	1.37	1.1	1.4	1.08	0.85	0.96	0.7	1.2	1.12	0.88	0.81	0.75	0.66
% DOC-4 (150)	1.61	1.28	1.03	1.34	1.01	0.76	0.89	0.66	1.11	.102	0.78	0.70	0.67	0.60
% 500 NM FUEL	1.16	0.67	0.43	0.91	0.47	0.25	0.40	0.20	0.44	0.35	0.29	0.21	0.24	0.18
% 150 NM FUEL	1.15	0.66	0.37	0.90	0.47	0.24	0.39	0.20	0.45	0.37	0.30	0.19	0.24	0.19
% OWE CHANGE	1.54	1.05	0.73	1.19	0.73	0.46	0.63	0.37	0.80	0.70	0.51	0.41	0.42	0.34
RELATIVE TO MANUAL CONTROLS														
% AF COST	7.22	6.87	6.37						5.9	5.7				
% DOC-2 (500)	2.15	1.88	1.64						1.76	1.68				
% DOC-4 (500)	2.01	1.73	1.51						1.54	1.5				
% DOC-2 (150)	2.05	1.79	1.55						1.63	1.58				
% DOC-4 (150)	1.92	1.63	1.43						1.47	1.39				

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Table XV Characteristics of Airplanes with RQ System

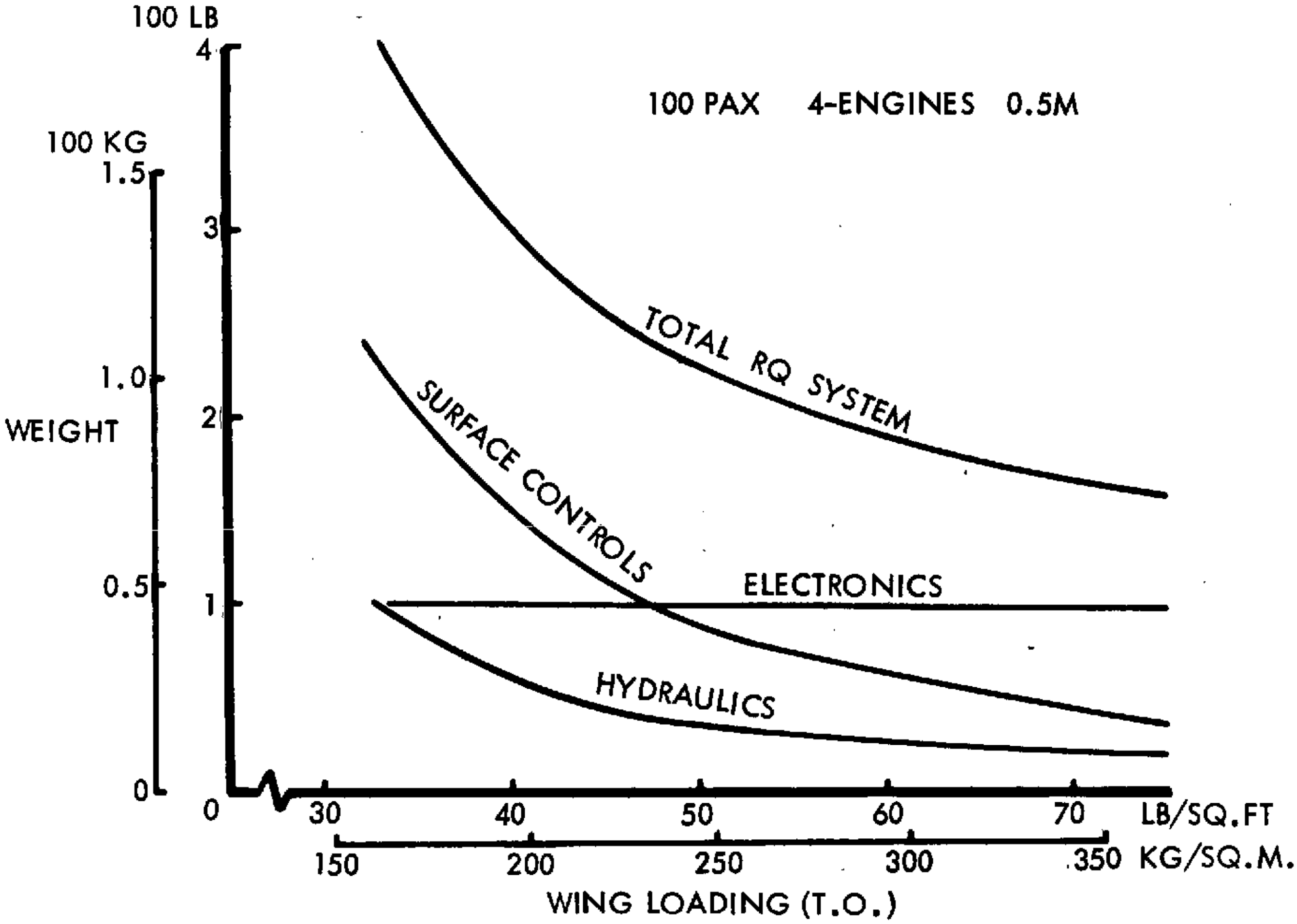

Figure 20 RQ System Weights vs. Wing Loading

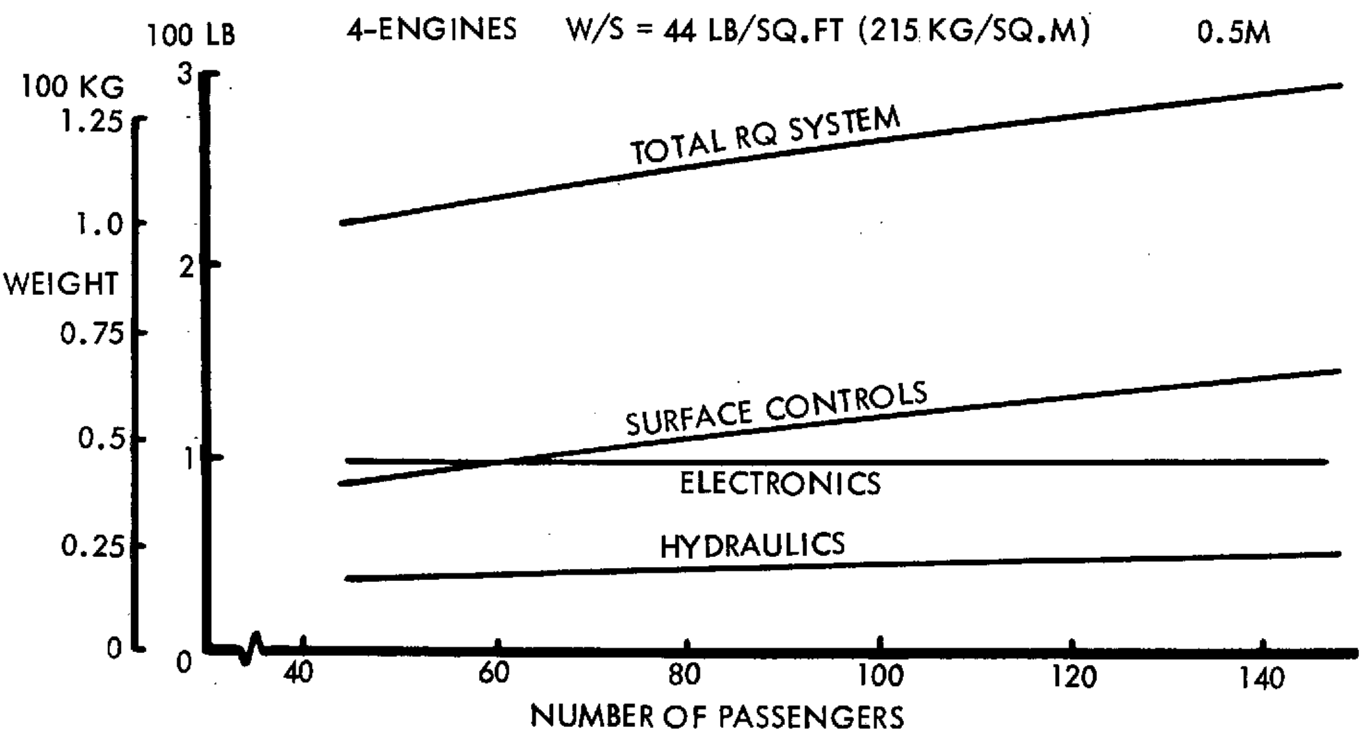

Figure 21 RQ System Weights vs. Number of Passengers

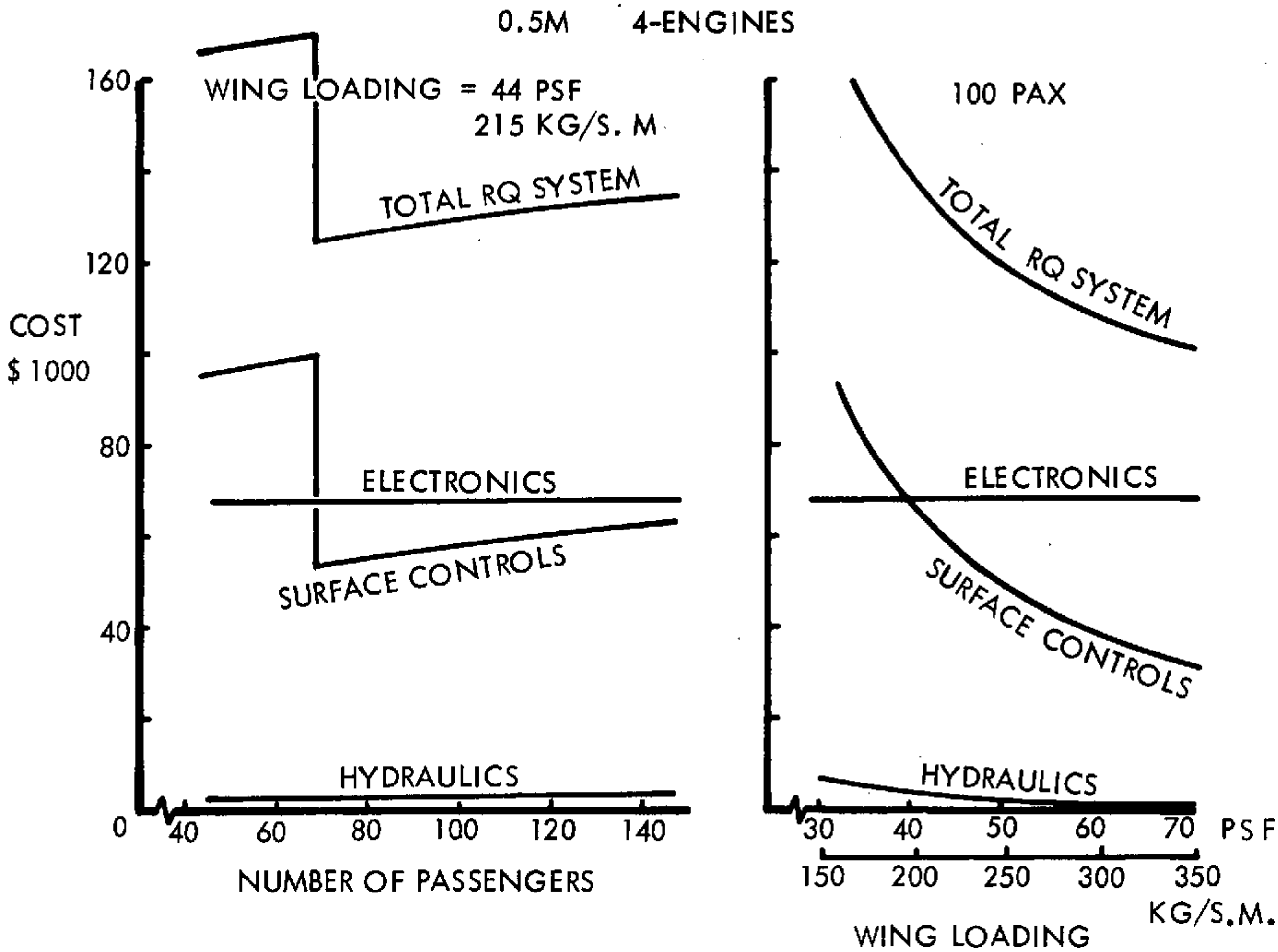

Figure 22 RQ System Costs (Scaled)

2- and 4-engine turboprop configurations and for the turbo-fan design. This reoptimization of aspect ratios was conducted for the 100 passenger size for each field length. From consideration of the initial parametric data discussed in Section 3.1.4, it was determined that the optimum altitude and speed would probably remain as 4570 m (15,000 ft.) and maximum EAS for the 278 km (150 n.mi.) stage length. The reoptimized aspect ratios were therefore selected for minimum DOC-2 at these conditions. Table XVI presents the size and economic characteristics of the 100 passenger airplanes for each field length and the selected ranges of aspect ratios. The best value of each fuel and economic characteristic from the range of aspect ratios is underlined for each field length in the table and from these data the optimum aspect ratios were selected. From the table it can be seen that in some cases it was necessary to make compromises in selecting the overall optimum. The following aspect ratios were selected for sizing the airplanes with the gust load alleviation system installed.

<u>4-engine configurations</u>

Field length - m (Ft)	457 (1500)	610 (2000)	914 (300)	1067 (3500)
Aspect ratio	8	8	12	14

<u>2-engine configurations</u>

Field length - m (Ft)	914 (3000	1067 (3500)
Aspect ratio	8	10

The scope of the program did not permit the reoptimization of the aspect ratio for each of the three passenger sizes; it was therefore assumed that the values obtained for the 100 passenger size would be close to optimum for the other two sizes.

The characteristics of the matrix of airplanes, incorporating gust load alleviation are presented in Table XVII. For convenience, the lower portion of this table contains comparison type data which are discussed in Section 6.0.

Figure 23 presents an example of the variation of gust load alleviation subsystem weights as a function of wing loading and passenger size. Similar data in terms of initial Δ airframe cost as a function of wing loading and passenger size are presented in Figure 24. Equivalent weight and cost data for the complete matrix of passenger sizes and field lengths are provided in Table XVII. Note the sharp increase in weight for the hydraulic system relative to that required for the RQ system. This is due to the provision of additional hydraulic

100 PAX

4-ENG. CASES

F.L. - FT	1,500		2,000		3,000				3,500	
AR	8	10	8	10	8	10	12	14	12	14
$W/S_{T.O.}$ - PSF	32.0	31.1	44.0	43.5	68.5	67.5	66.0	65.0	80.3	78.7
$T/W_{T.O.}$	.369	.357	.325	.320	.280	.274	.264	.257	.262	.251
η_P	.80	.837	.770	.763	.840	.807	.804	.804	.803	.806
DOC-2 (150)	4.00	4.050	3.426	3.448	3.098	3.096	3.097	3.110	3.025	3.029
DOC-4 (150)	4.896	4.969	4.071	4.096	3.614	3.601	3.596	3.606	3.499	3.497
DOC-2 (500)	2.576	2.601	2.235	2.244	2.056	2.042	2.039	2.042	1.998	1.995
DOC-4 (500)	3.138	3.170	2.648	2.654	2.407	2.375	2.364	2.362	2.312	2.300
FUEL (150) - LB	4,391	4,498	3,151	3,167	2,519	2,464	2,431	2,423	2,312	2,281
FUEL (500) - LB	9,154	9.280	6,714	6,662	5.699	5,413	5,264	5,183	5,095	4,959
A/C PRICE - \$M	5.6388	5.6764	5.033	5.0712	4.6089	4.6283	4.6406	4.6558	4.5500	4.5535
A/F PRICE - \$M	4.4211	4.4665	3.9395	3.9777	3.6156	3.6400	3.6622	3.6834	3.5843	3.5999
WING WT - LB	18,533	19,494	12,514	13,468	8,370	9.282	10,111	10,818	8,850	9,559
Δ WING WT - LB										
ΔW GLA - LB	-1986	-3,925	-576	-1,290	+201.2	+57	-161	-433	+167	+37
OWE - LB	80,937	82,283	63,626	64,954	52,479	53,439	54,179	54,898	51.776	52,290
RGW - LB	113,695	115,226	93,042	94,301	80,461	81,053	81,593	82,202	78,963	79,290
REL. TO AIRPLANES WITHOUT ACTIVE CONTROLS										
% Δ DOC-2 (500)	-2.76		0.22				0.44			8.37
% Δ DOC-4 (500)	-3.33		-0.04				-0.67			2.59
% Δ DOC-2 (150)	-3.10		0.00				1.01			2.50
% Δ DOC-4 (150)	-3.49		0.07				0.59			-2.51
% Δ OWE	-7.81		-2.22				2.4			-15.35

2-ENG. CASES

F.L. - FT	3,000				3,500			
AR	8	10	12	14	8	10	12	14
$W/S_{T.O.}$ - PSF	58.8	58.8	58.8	58.8	71.0	71.0	71.0	71.0
$T/W_{T.O.}$	.400	.392	.386	.382	.403	.397	.390	.386
η_P	.742	.740	.742	.745	.709	.693	.689	.686
DOC-2 (150)	3.088	3.094	3.102	3.116	2.987	2.995	3.006	3.017
DOC-4 (150)	3.773	3.775	3.782	3.800	3.628	3.632	3.642	3.654
DOC-2 (500)	1.918	1.920	1.924	1.928	1.862	1.863	1.863	1.872
DOC-4 (500)	2.342	2.338	2.339	2.343	2.264	2.257	2.252	2.261
FUEL (150) - LB	3,361	3,342	3,340	3,357	3,146	3,127	3,121	3,126
FUEL (500) - LB	6,929	6,830	6,787	6,784	6,565	6,447	6,369	6,350
A/C PRICE - \$M	4.9538	4.9752	4.9933	5.0100	4.8414	4.8702	4.8903	4.9143
A/F PRICE - \$M	4.2136	4.2386	4.2592	4.2770	4.1089	4.1393	4.1620	4.1867
WING WT - LB	10,520	11,324	11,935	12,388	9,147	10,026	10,761	11,414
Δ WING WT - LB	-777	-1,216	-1,733	-2,324	-362	-569	-816	-1,102
ΔW GLA - LB	-271	-685	-1,186	-1,764	+72	-113	-347	-621
OWE - LB	64,905	65,630	66,237	66,767	61,810	62,773	63,475	64,256
RGW - LB	94,747	95,336	95,883	96,412	91,147	91,950	92,543	93,288

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Table XVI Optimization of Aspect Ratio with GLA System

# ENGINES	4									2					
# PAX	44			100			148			44		100		148	
M	0.5			0.5			0.5			0.6		0.6		0.6	
F.L. - FT	1,500	2,000	3,000	1,500	2,000	3,000	1,500	2,000	3,000	3,000	3,500	3,000	3,500	3,000	3,500
$W/S_{T.O.}$ - PSF	32.0	44.0	66.0	32.0	44.0	66.0	32.0	44.0	66.0	58.8	71.0	58.8	71.0	58.8	71.0
$T/W_{T.O.}$	.368	.325	.265	.369	.325	.264	.369	.324	.264	.400	.397	.400	.397	.400	.397
η_{500}	.806	.782	.818	.80	.770	.804	.790	.756	.780	.761	.713	.742	.693	.729	.678
RGW - LB	58,556	48,832	43,177	113,695	93,042	81,593	157,958	127,297	111,120	48,987	47,604	94,747	91,950	130,608	126,637
OWE - LB	43,204	35,083	30,445	80,937	63,626	54,179	110,701	84,920	71,571	35,067	34,021	64,905	62,773	87,521	84,472
SLST - LB	5,799	4,272	3,082	11,280	8,151	5,808	15,693	11,123	7,907	10,552	10,165	20,411	19,642	28,106	27,044
DOC-2 (500)	4.192	3.783	3.535	2.576	2.235	2.039	2.106	1.783	1.600	3.119	3.047	1.918	1.863	1.561	1.513
DOC-4 (500)	4.854	4.284	3.934	3.138	2.648	2.364	2.629	2.158	1.891	3.625	3.519	2.342	2.257	1.952	1.876
DOC-2 (150)	6.371	5.685	5.288	4.00	3.426	3.097	3.297	2.754	2.456	4.921	4.802	3.088	2.995	2.538	2.455
500 NM FUEL - LB	4,729	3,560	2,824	9,154	6,714	5,264	12,632	9,067	7,009	3,633	3,385	6,929	6,447	9,455	8,789
150 NM FUEL - LB	2,263	1,665	1,304	4,391	3,151	2,431	6,055	4,263	3,257	1,756	1,639	3,361	3,127	4,591	4,274
% Δ 500 FUEL	-3.75	-0.42	-7.17	-6.12	-1.58	-7.58		-2.13	-8.56	-0.33	-1.68	-0.40	-1.68	-1.21	-1.65
% Δ 150 FUEL	-3.78	-0.36	-3.62	-6.14	-1.59	-4.18		-1.91	-4.77	-0.34	-0.12	-0.2	-0.16	-1.03	+0.12
WING AREA - FT^2	1,823	1,107	653	3,535	2,109	1,232	4,920	2.883	1.679	830	688	1,604	1,289	2,213	1,776
WING WEIGHT - LB	8,545	5,877	4,779	18,534	12,514	10,111	27,413	18,163	14,614	4,855	4,624	10,520	10,026	15,408	14,664
SURFACE CONTR - LB	1,640	1,453	1,329	2,483	2,177	1,985	3,050	2,653	2,415	1,442	1,408	2,184	2,134	2,677	2,616
HYDRAULICS - LB	776	616	510	1,320	1,013	825	1,733	1,306	1,055	556	525	908	854	1,167	1,096
HOR. STAB. $\overline{V}$	.779	.728	.837	.822	.782	.927	.870	.848	1.031	.625	.713	.678	.782	.742	.864
HOR. STAB. AREA - FT^2	701	310	132	1,375	603	261	1,886	826	364	173	127.2	346	258	485.4	363.6
HOR. STAB. WT. - LB	1,871	1,000	530	3,657	1,934	1,034	5,037	2,648	1,433	776	621	1,539	1,240	2,147	1,737
VERT. STAB. $\overline{V}$	.076	.069	.062	.109	.099	.090	.136	.125	.114	.055	.056	.080	.082	.102	.103
VERT. STAB. AREA - FT^2	506	217	109	1,354	567	283	2,187	902	448	114	93.2	305	250	494	403
AIRFRAME COST $M	2.9986	2.7225	2.5538	4.4211	3.9395	3.6622	5.4328	4.7839	4.4284	2.8740	2.8272	4.2136	4.1343	5.1453	5.0506
TOTAL COST $M	3.9766	3.6067	3.3479	5.6388	5.0336	4.6406	6.7905	5.9960	5.5115	3.4696	3.4156	4.9538	4.8702	5.9679	5.8628
AR	8	8	12	8	8	12	8	8	12	8	10	8	10	8	10
Δ WT. SYSTEM - LB	576	454	362.5	931	637	481	1163	782	580	379.7	347.5	506	456	611	548
Δ W BOX - LB	-1,266	-514	-265	-2,917	-1,213	-642	-4,346	-1,812	-982	-317	-228	-777	-569	-1,193	-881
Δ W GLA - LB	-690	-60.3	+97.5	-1986	-576	-161	-3,183	-1,030	-402	+62.7	+119.5	-271	-113	-582	-333
% DOC-2 (500)	-0.36	1.37	1.38	-2.76	0.22	0.44		-0.39	-0.31	1.43	1.60	0.79	1.20	0.00	0.93
% DOC-4 (500)	-0.84	1.16	0.46	-3.33	-0.04	-0.67		-0.69	-1.66	1.17	1.15	0.56	0.67	-0.20	0.43
% DOC-2 (150)	-0.67	1.21	1.91	-3.10	0.00	1.01		-0.54	0.57	1.32	1.82	0.65	1.35	-0.08	1.24
% DOC-4 (150)	-1.12	1.03	1.32	-3.49	0.07	0.59		-0.30	0.55	1.07	1.55	1.02	1.25	0.51	1.64
% OWE	-4.85	-0.57	2.73	-7.81	-2.22	2.4		-2.96	2.59	-0.20	1.97	-0.76	1.62	-1.76	1.60
% A/F COST	3.66	6.21	7.70	-0.05	3.30	5.54		2.12	4.75	5.71	6.62	3.48	4.48	2.28	3.85
Δ WSCR - LB	150	125	105	228	146	122	235	155	131	112	103	128	119	136	127
Δ CSCR - $	81,220	75,447	66,362	90,000	75,224	67,636	95,000	74,084	67,810	66,939	62,664	66,687	63,348	65,936	63,193
Δ WHYD - LB	277	173	102	547	336	204	773	473	294	113	90	223	182	320	266
WACT - LB	85	60.3	39.867	150	80.742	56.4	154	89.62	65.82	46.53	38.1	63.3	53.77	71.07	61.65
DNGB (CRUISE)	3.1197	2.5495	2.0099	2.8158	2.3909	1.9438	2.6547	2.3000	1.9058	2.5745	2.3180	2.4492	2.2354	2.3799	2.1877
DCLG	.51382	.48038	.46280	.42214	.42185	.43197	.36769	.38706	.41361	.40966	.40286	.36601	.37064	.33945	.35133
ETAIGF	.15476	.20566	.29408	.2825	.29036	.33570	.36776	.34310	.36350	.31636	.36065	.38519	.40725	.42533	.43707
DNGB (U_B)	2.1556	2.0414	1.9845	1.8608	1.8600	1.8898	1.7104	1.7621	1.8362	1.8249	1.8057	1.7060	1.7182	1.6385	1.6683
VEB - KEAS	138.93	160.77	196.07	132.41	155.96	193.15	128.81	153.43	191.46	178.96	196.41	175.35	193.48	173.15	191.77
VEC - KEAS	250	250	250	250	250	250	250	250	250	300	300	300	300	300	300
REL. TO MANUAL CONTROLS															
% A/F PRICE	5.4	8.22	9.91							7.59	8.56				
% DOC-2 (500)	+.05	1.83	1.87							1.93	2.11				
% DOC-4 (500)	-0.51	1.54	0.90							1.57	1.59				
% DOC-2 (150)	-0.31	1.63	2.36							1.74	2.28				
% DOC-4 (150)	-0.81	1.38	1.72							1.43	1.92				

WAVR = 155 LB
CAVR = 90,400

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Table XVII Characteristics of Airplanes with GLA System.

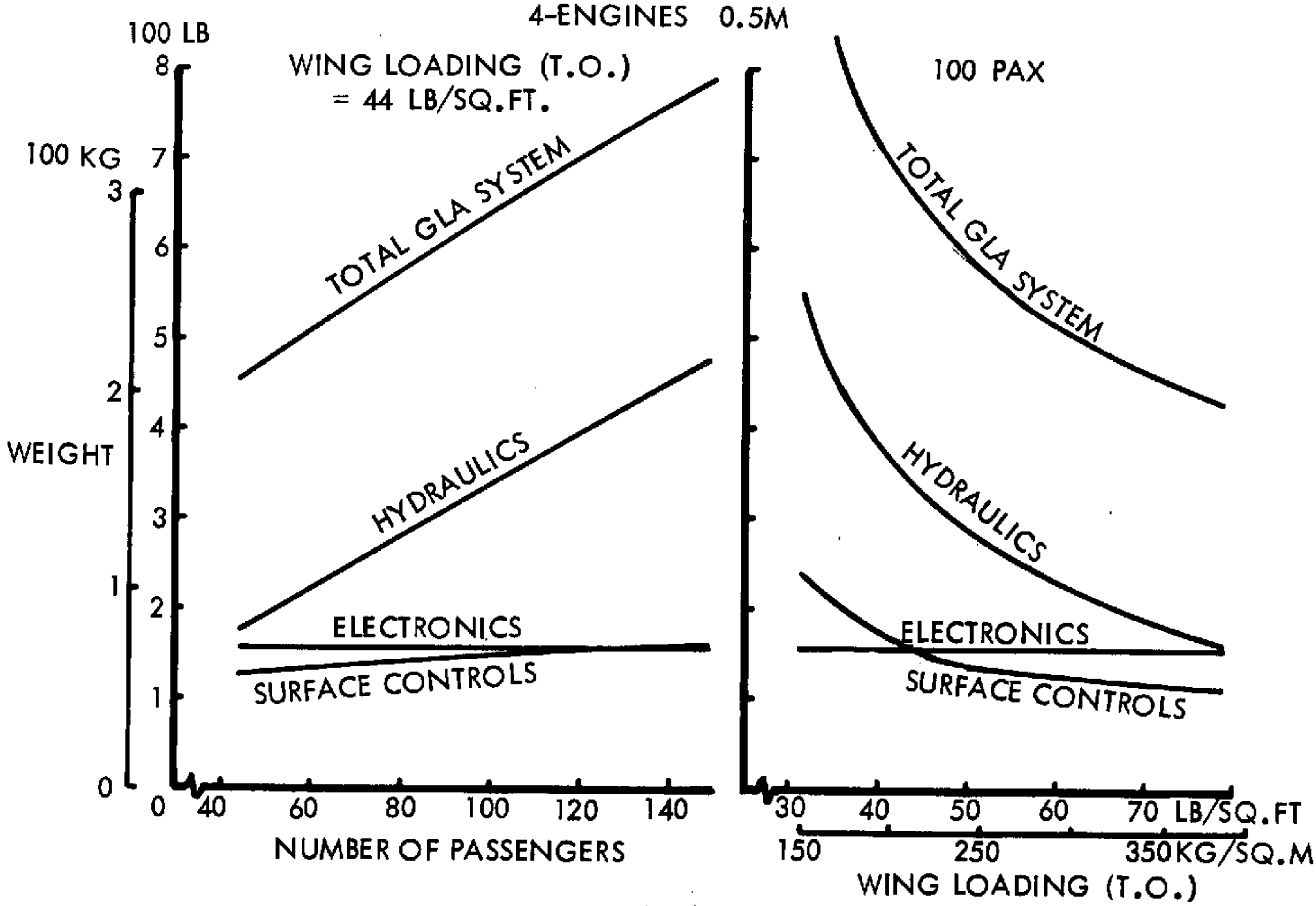

Figure 23 GLA System Weights – Scaled

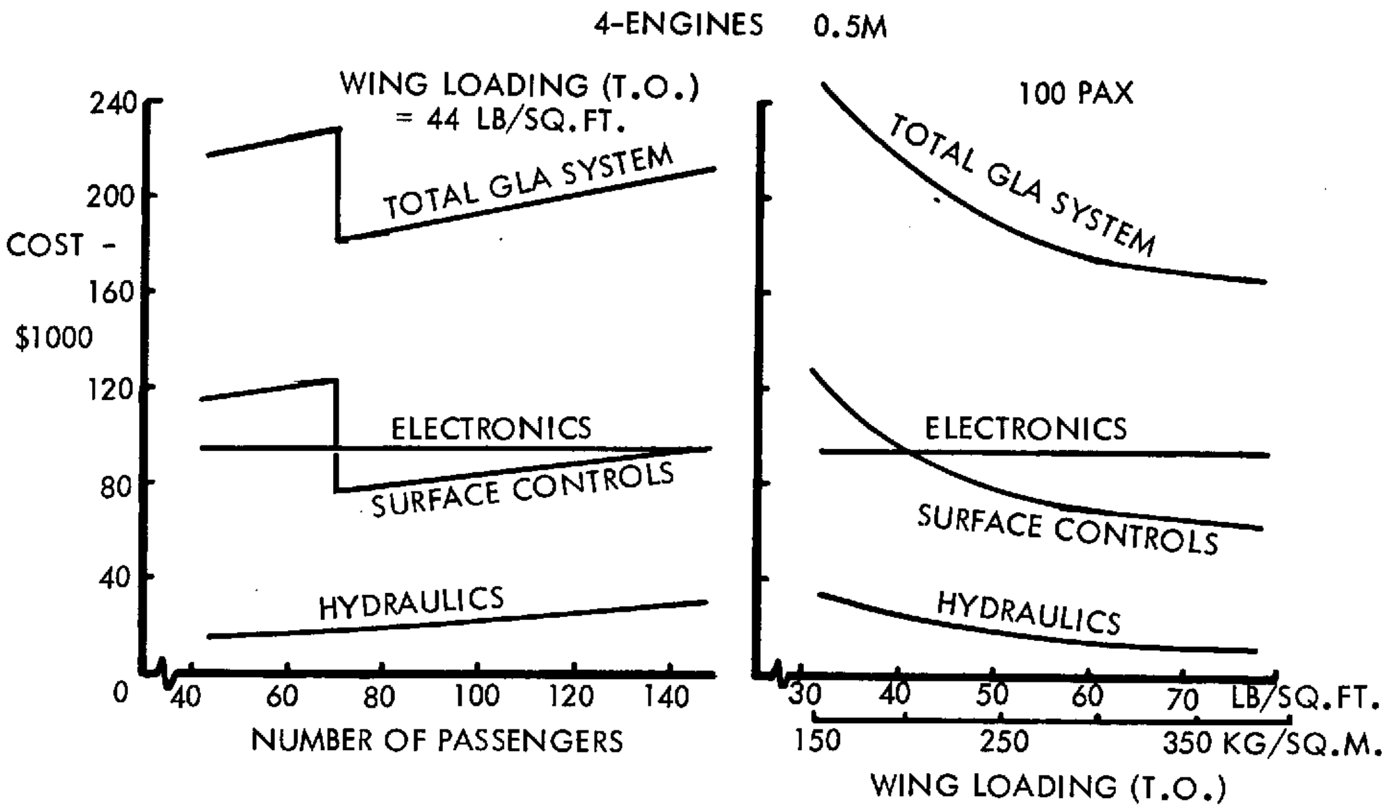

Figure 24 GLA System Costs – Scaled

capacity for the GLA system. The cost/kg (lb) of hydraulic components is lower than that of surface controls and electronics and this sharp increase in weight does not therefore reflect so strongly in the costs.

The variation of the "rough-airspeed" V_B with field length is shown in Figure 25 for airplanes without GLA. This speed corresponds to $C_{L\ MAX}$ (flaps up) in the presence of a 20.12 m/sec (66 fps) gust. The shorter field length airplanes have a much lower V_B than the longer field length airplanes due to the difference in wing loading. In fact, at the longer field lengths, V_B is approaching the cruise speed for 4570 m (15,000 ft) altitude. The effect of this variation of V_B can be seen in Figure 26 which presents load factor as a function of field length. The maneuver load factor is shown constant for all field lengths at 2.5. The 15.25 m/sec. (50 fps) gust at cruise speed is shown to produce greater load factors than the 20.12 m/sec (66 fps) gust at speed V_B at the shorter field lengths. This is due to V_C being much greater than V_B. As V_B approaches V_C, with increase in field length, so the effect of the higher gust velocity increases the gust load factor at V_B relative to V_C. Although the load factor is higher at V_C than at V_B for the shorter field lengths, it is the lower speed which actually determines the ΔC_L required from the gust alleviation system and therefore designs the size of the GLA surfaces.

The effect of the gust load alleviation system on wing weight is illustrated in Figure 27 which shows the wing-box weight saving due to the gust load alleviation system plotted against field length. The weight saving is defined as the difference in weight between the weight of the wing sized for airplanes with GLA incorporated and the weight of the wing with the same geometry but without gust load alleviation, This non-alleviated wing does not include the weight increase required by resizing to make the heavier airplane meet the required performance and the weight savings presented are therefore conservative.

5.3 Characteristics of Airplanes Incorporating Artificial Stability Systems

The term "artificial stability system" in this report includes the gust load alleviation capabilities of the systems discussed in Section 5.2. When considering the resizing of the matrix of airplanes with the artificial stability system included it was assumed that the optimum wing aspect ratios would be determined by the gust load alleviation effects rather than the resizing of the horizontal stabilizer. This means that the optimum aspect ratios determined in Section 5.2 are close to optimum for airplanes with artificial stability systems and were therefore used when resizing.

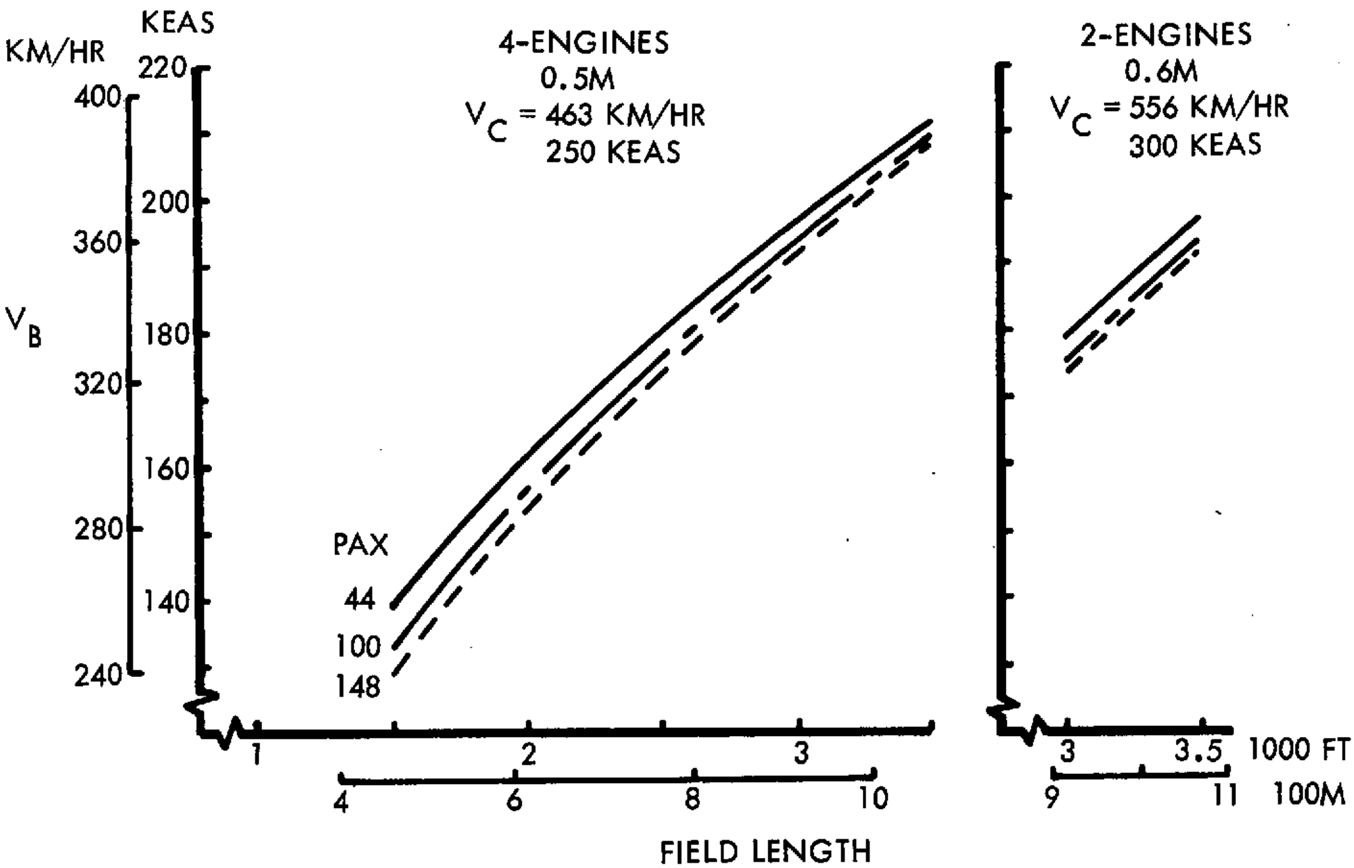

Figure 25 V_B Speed vs. Field Length

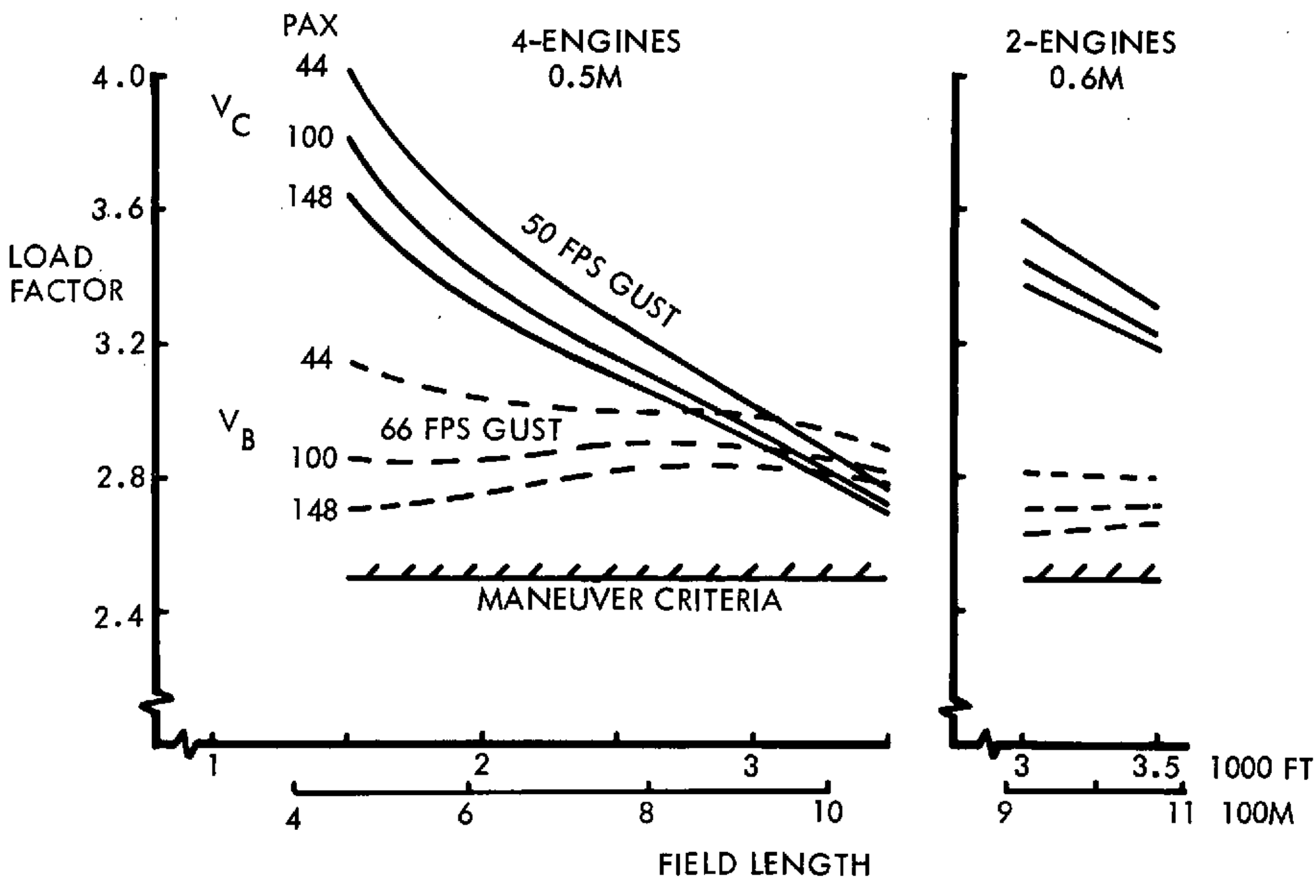

Figure 26 Gust Load Factor vs. Field Length

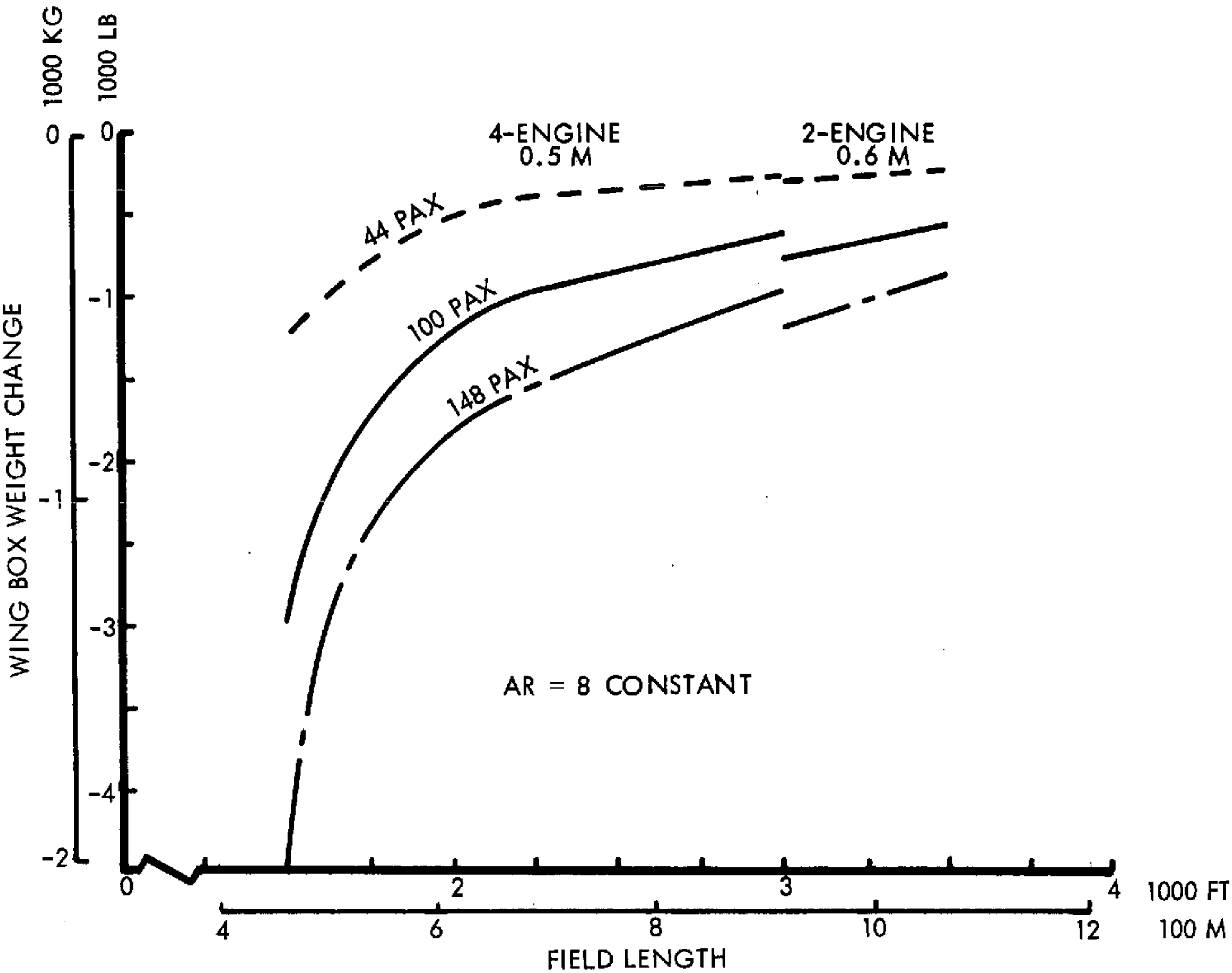

Figure 27 Wing Box Weight Change Due to GLA

The effects of the relaxed stability on horizontal stabilizer size were achieved by modifying the stability margin input to the sizing program as described in Section 4.3.1 and by including the subsystem weight and cost changes described in Section 4.3.3.

The characteristics of the matrix of airplanes, incorporating gust load alleviation and relaxed static stability, are presented in Table XVIII.

The weight and cost changes of the subsystems associated with the artificial stability system follow similar trends as those presented for the gust load alleviation system but include the additional increment defined in Section 4.3.3.

# ENGINES	4									2					
# PAX	44			100			148			44		100		148	
M	0.5			0.5			0.5			0.6		0.6		0.6	
F.L. - FT.	1,500	2,000	3,000	1,500	2,000	3,000	1,500	2,000	3,000	3,000	3,500	3,000	3,500	3,000	3,500
$W/S_{T.O.}$ - PSF	32.0	44.0	66.0	32.0	44.0	66.0	32.0	44.0	66.0	58.8	71.0	58.8	71.0	58.8	71.0
$T/W_{T.O.}$	.368	.325	.264	.369	.325	.264	.369	.325	.264	.400	.397	.400	.397	.399	.397
η_{500}	.783	.768	.812	.780	.758	.798	.772	.744	.774	.751	.705	.734	.686	.721	.672
RGW - LB	57,585	48,402	43,022	111,771	92,175	81,292	155,017	126,280	110,759	48,652	47,414	94,045	91,541	129,710	126,074
OWE - LB	42,447	34,754	30,329	79,406	62,939	53,947	108,362	84,108	71,288	34,806	33,874	64,339	62,447	86,799	84,017
SLST- LB	5,709	4,232	3,064	11,090	8,065	5,781	15,385	11,038	7,879	10,470	10,128	20,222	19,559	27,890	26,919
DOC-2 (500)	4.154	3.769	3.539	2.544	2.224	2.039	2.074	1.774	1.600	3.115	3.050	1.911	1.861	1.555	1.510
DOC-4 (500)	4.794	4.260	3.934	3.088	2.629	2.360	2.579	2.144	1.888	3.614	3.518	2.329	2.252	1.940	1.870
DOC-2 (150)	6.306	5.669	5.283	3.945	3.405	3.096	3.248	2.740	2.454	4.913	4.804	3.076	2.992	2.527	2.450
DOC-4 (150)	7.325	6.434	5.888	4.812	4.037	3.591	4.055	3.319	2.901	5.717	5.559	3.750	3.625	3.151	3.033
500 N.M. FUEL - LB	4,568	3,483	2,794	8,857	6,581	5,212	12,198	8,913	6,950	3,579	3,354	6,830	6,387	9,330	8,712
150 N.M. FUEL - LB	2,186	1,633	1,289	4,244	3,092	2,412	5,858	4,195	3,236	1,732	1,625	3,312	3,104	4,533	4,239
WING AREA - FT^2	1,794	1,097	650	3,482	2,088	1,228	4,830	2,862	1,674	824	665	1,592	1,284	2,198	1,769
WING WEIGHT - LB	8,387	5,820	4,760	18,196	12,377	10,070	26,835	18,001	14,562	4,818	4,602	10,433	9,976	15,289	14,591
SURF. CONT. - LB	1,623	1,445	1,326	2,457	2,164	1,980	3,014	2,639	2,410	1,436	1,405	2,174	2,128	2,665	2,609
HYDRAULICS - LB	767	612	509	1,303	1,005	823	1,707	1,297	1,052	553	523	903	851	1,161	1,092
HOR. STAB. $\bar{V}$	.610	.563	.674	.652	.619	.764	.701	.684	.868	.481	.563	.534	.632	.598	.715
HOR. STAB. AREA - FT^2	536	237	105.5	1,066	470	213.5	1,480	658	305	131.4	100	270	207	387	299
HOR. STAB. WT. - LB	1,542	826	453	3,045	1,620	898	4,227	2,253	1,265	639	523.4	1,291	1,062	1,829	1,512
VERT. STAB. $\bar{V}$	.076	.069	.062	.109	.099	.090	.136	.125	.114	.055	.056	.080	.082	.102	.103
VERT. AREA - FT^2	493	214	108.7	1,320	559	281	2,124	891	446	113	92.6	302	248	489	401
AIRFRAME COST - $M	3.0113	2.7495	2.5887	4.4164	3.9579	3.6941	5.4115	4.8004	4.4594	2.9031	2.8607	4.2351	4.1680	5.1638	5.0769
TOTAL COST - $M	3.9842	3.6311	3.3813	5.6273	5.0481	4.6710	6.7603	6.0095	5.5413	3.4972	3.4483	4.9731	4.8979	5.9842	5.8876
AR	8	8	12	8	8	12	8	8	12	8	10	8	10	8	10
Δ WT SYSTEM - LB	601.1			952		510									
Δ W BOX - LB	-1,240	-508.4	-263	-2,868	-1,196	-639	-4,265	-1,795	-978	-314	-226	-770	-566	-1,183	-876
Δ W GLA - LB	-638.9	-26.3	128.2	-1,916	-533	-129	-3,100	-986	-370	94.8	151	-236	-81	-545	-300
% DOC-2 (500)	-1.26	0.99	1.49	-3.96	-0.27	0.44		-0.89	-0.31	1.30	1.70	0.42	1.09	-0.38	0.73
% DOC-4 (500)	-2.06	0.59	0.46	-4.87	-0.76	-0.84		-1.33	-1.82	0.87	1.12	0.00	0.45	-0.82	0.11
% DOC-2 (150)	-1.68	0.93	1.81	-4.43	-0.61	+0.98		-1.05	0.49	1.15	1.87	0.26	1.25	-0.51	1.03
% DOC-4 (150)	-2.46	0.56	1.12	-5.14	-0.76	+0.45		-0.98	0.38	0.74	1.48	0.40	1.06	-0.10	1.30
% OWE	-6.52	-1.50	2.34	-9.56	-3.28	+1.97		-3.89	2.18	-0.95	1.53	-1.62	1.09	-2.57	1.05
% A/F COST	4.10	7.26	9.18	-0.15	+3.78	+6.46		2.47	5.49	6.78	7.88	4.0	5.33	2.65	4.39
Δ WSCR - LB	150	125	105	228	145	122	235	154	131	111	103	128	119	136	127
Δ CSCR - $	81,260	75,438	66,348	90,000	75,203	67,621	95,000	74,103	67,796	66,914	62,632	66,677	63,333	75,938	63,182
Δ WHYD - LB	273	172	102	539	332	203	758	469	293	112	89	221	181	318	265
WACT - LB	85	60	39.8	150	80.4	56.7	154	89.4	65.7	46.3	38	63.1	53.6	70.9	61.5
GLF	4.1232	3.5496	3.0095	3.8236	3.3901	2.9436	3.6617	3.3013	2.9057	3.5734	3.3165	3.4496	3.2353	3.3805	3.1877
DCLG	.51546	.48081	.4628	.42451	.42242	.43205	.37069	.38783	.41372	.40972	.40271	.36639	.37076	.33988	.35151
ETAIGF	.15237	.2051	.2941	.27893	.28955	.33560	.36339	.34193	.36337	.31730	.3609	.38468	.40711	.42464	.43681
% FUEL 500	-7.02	-2.57	-8.15	-9.17	-3.53	-8.5		-3.79	-9.33	-1.81	-2.58	-1.83	-2.59	-2.52	-2.5
% FUEL 150	-7.06	-2.27	-4.73	-9.28	-3.44	-4.93		-3.47	-5.38	-1.70	-0.98	-1.66	-0.89	-2.28	-0.70
RELATIVE TO MANUAL CONTROLS															
% A/F COST	5.84	9.29	11.41							8.68	9.85				
% DOC-2 (500)	-0.86	1.45	1.99							1.80	2.21				
% DOC-4 (500)	-1.74	0.97	0.90							1.26	1.56				
% DOC-2 (150)	-1.33	1.34	2.26							1.57	2.32				
% DOC-4 (150)	-2.16	0.91	1.52							1.10	1.85				

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Table XVIII Characteristics of Airplanes with AS System

6.0 COMPARISON OF AIRPLANE CHARACTERISTICS WITH AND WITHOUT ACTIVE CONTROLS

The characteristics of the turboprop powered airplanes contained in Sections 3.5, 5.1, 5.2 and 5.3 are first compared to illustrate the effects on such parameters as direct operating cost, mission fuel, weights and initial price, due to incorporating the three types of active control system. The effects of these systems on a turbofan powered MF configuration are then illustrated and the effects of these systems on the competitiveness of the aircraft with a powered lift concept are discussed.

6.1 Comparison of Turboprop Airplane Characteristics

6.1.1 Direct Operating Cost Comparisons — Direct operating cost at DOC-2 and DOC-4 fuel prices as a function of field length are presented in Figures 28, 29 and 30 for the 44, 100 and 148 passenger baseline airplanes respectively. The data are presented for the 2- and 4-engine configurations and for 278 and 926 km (150 and 500 n.mi,) stage lengths. The expected large reduction in DOC due to increase in passenger capacity is apparent by comparing the figures. Note also the rapid increase in DOC as the shortest field length is approached.

It is interesting to compare the 2- and 4-engine configurations at 914 m (3000 ft) field length. The 2-engine designs are heavier, cost more and use more fuel but in some cases the higher speed results in a lower DOC than for the 4-engine designs. For 44 passengers, 2-engines provides minimum DOC for both fuel prices and both stage lengths. For the 100 passenger case, 2-engines are better at 926 km (500 n.mi.), the two configurations are equal at DOC-2 and 278 km (150 n.mi.), while the 4-engine design is better for DOC-4 and 278 km (150 n.mi.). For 148 passengers, the 4-engine design is best except for 926 km (500 n.mi.) and DOC-2.

The effects of incorporating the three active control systems on 278 km (150 n.mi.), DOC-2 are presented in Figures 31, 32, and 33 for the 44, 100 and 148 passenger capacity configurations. It can be seen that the RQ system increases DOC at all field lengths and all passenger sizes. The GLA and AS systems reduce DOC at the shorter field lengths but increase DOC at the longer field lengths except in the case of the 148 passenger airplane. These figures are adequate to show the general trends of the data but are difficult to use for determining quantitative effects; a series of figures have therefore been prepared showing percentage change in DOC due to introduction of the active controls as a function of field length.

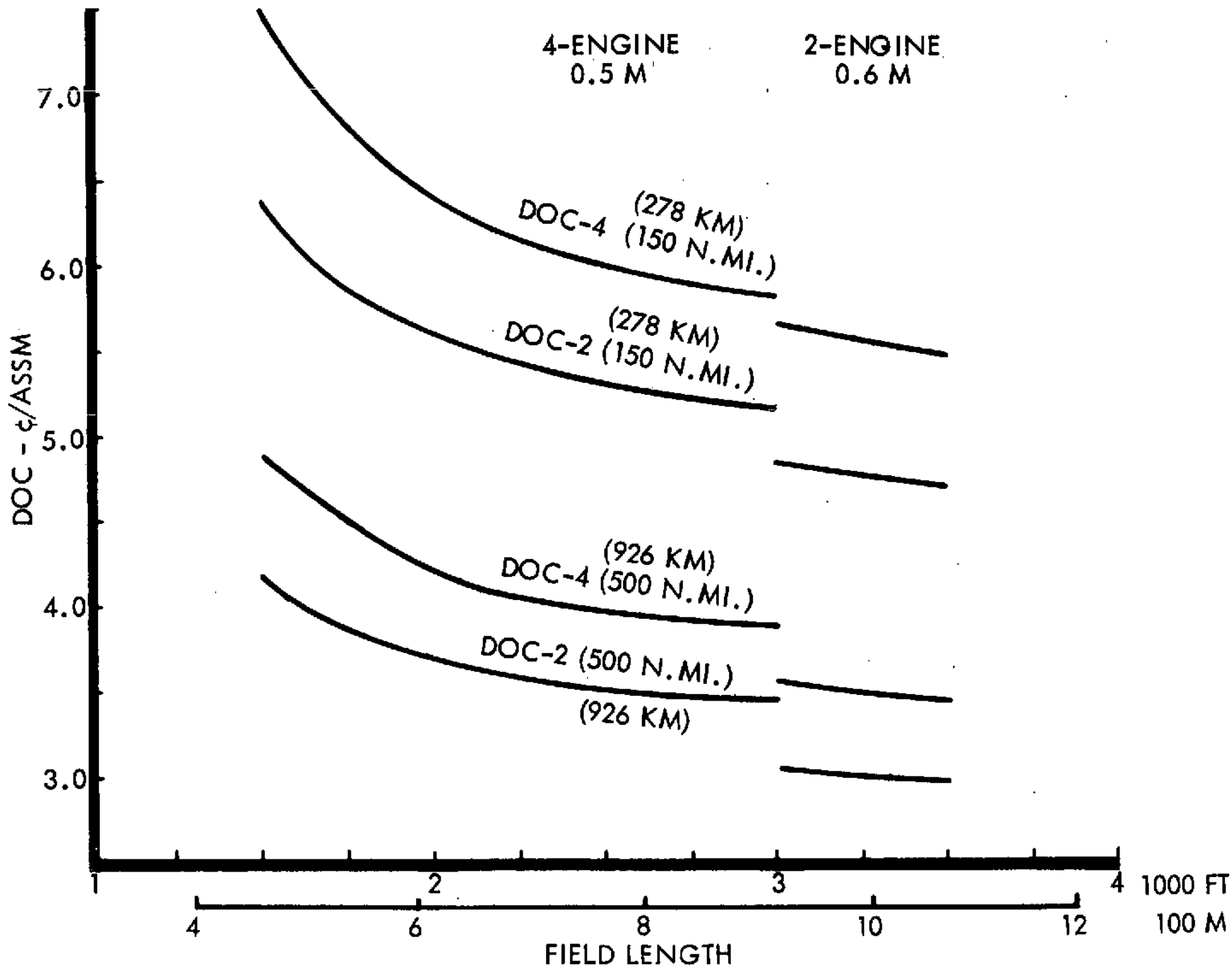

Figure 28 Direct Operating Cost vs. Field Length (44 Pax - Without Active Controls)

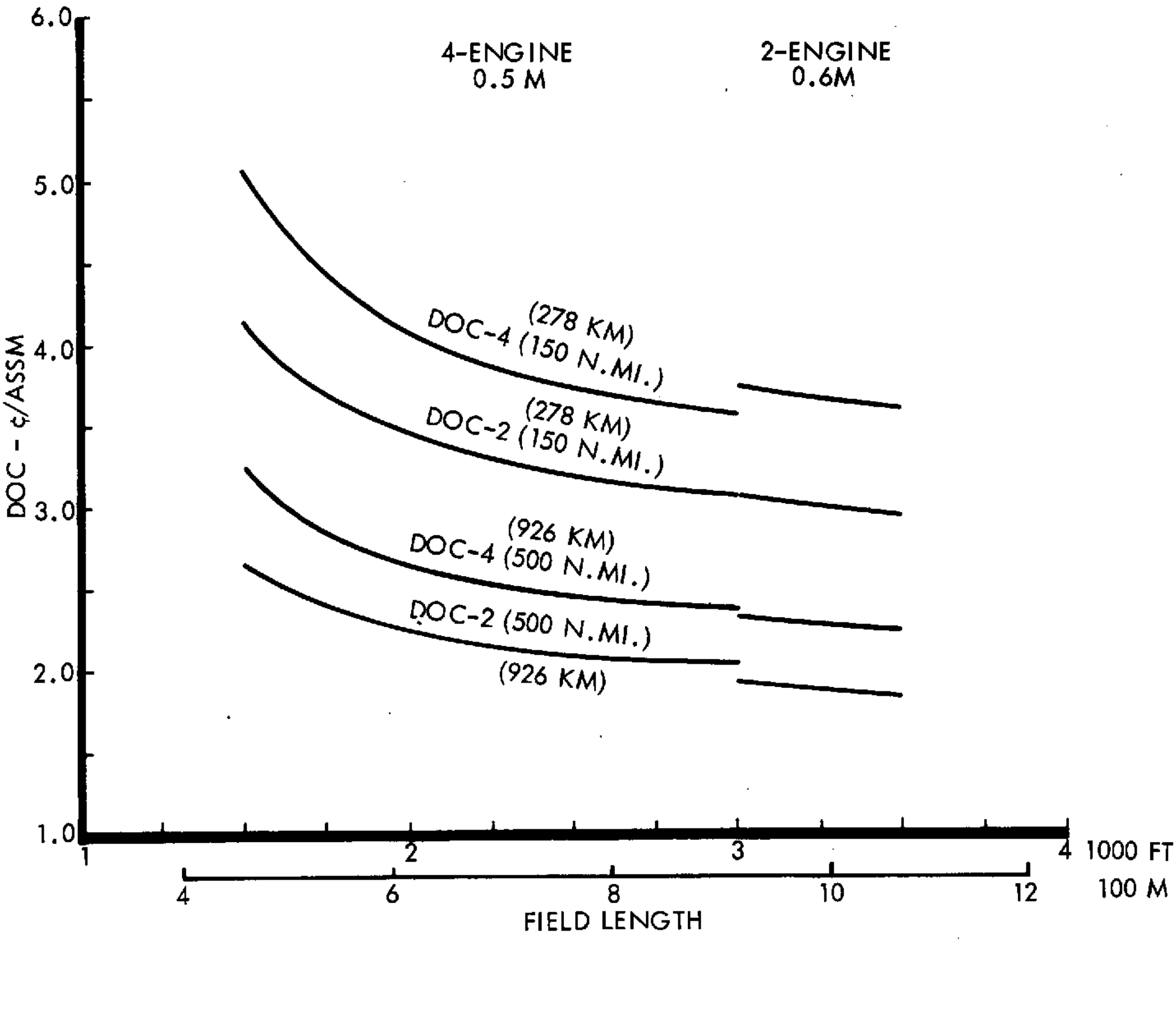

Figure 29 Direct Operating Cost vs. Field Length (100 Pax - Without Active Controls)

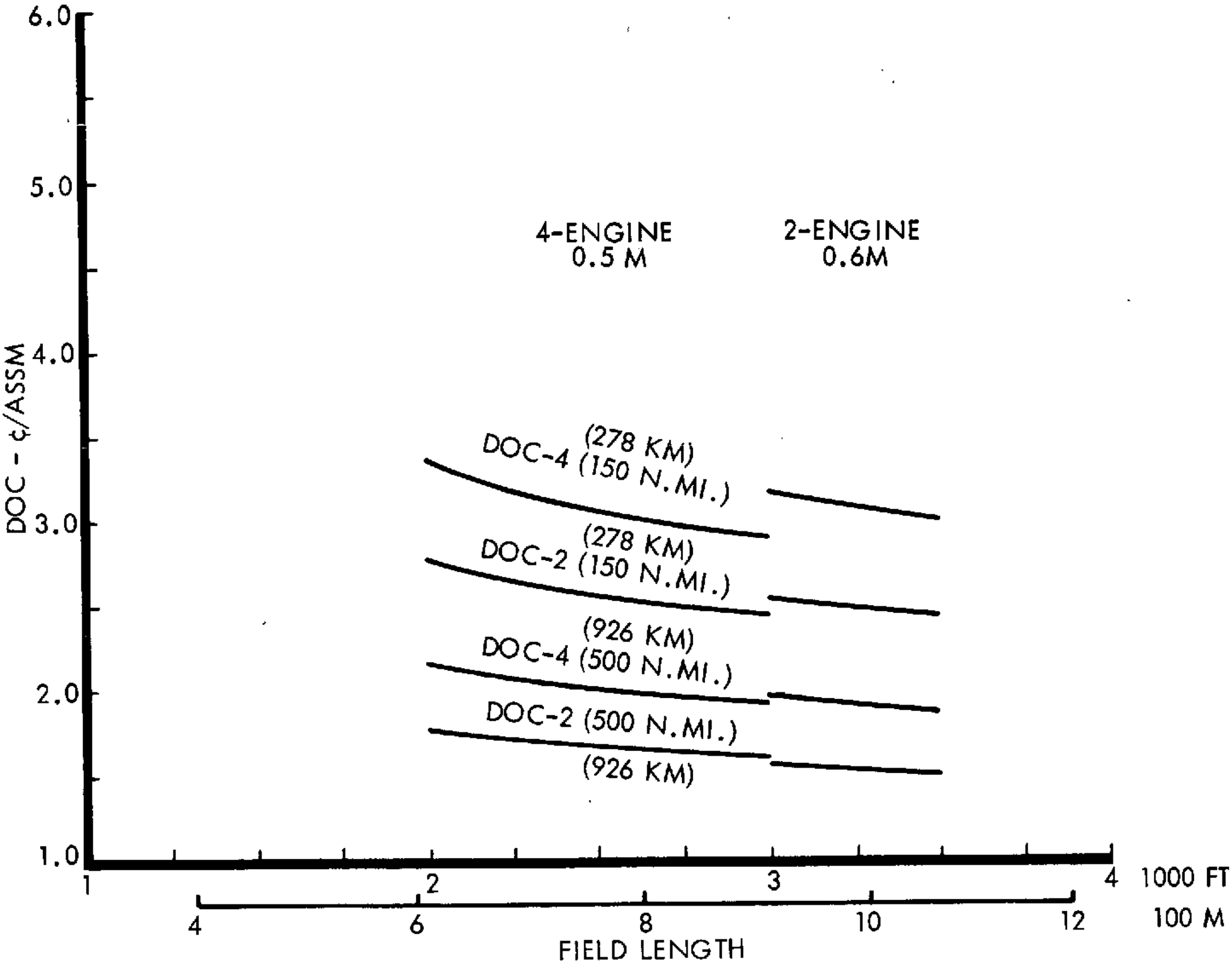

Figure 30 Direct Operating Cost vs. Field Length (148 Pax - Without Active Controls)

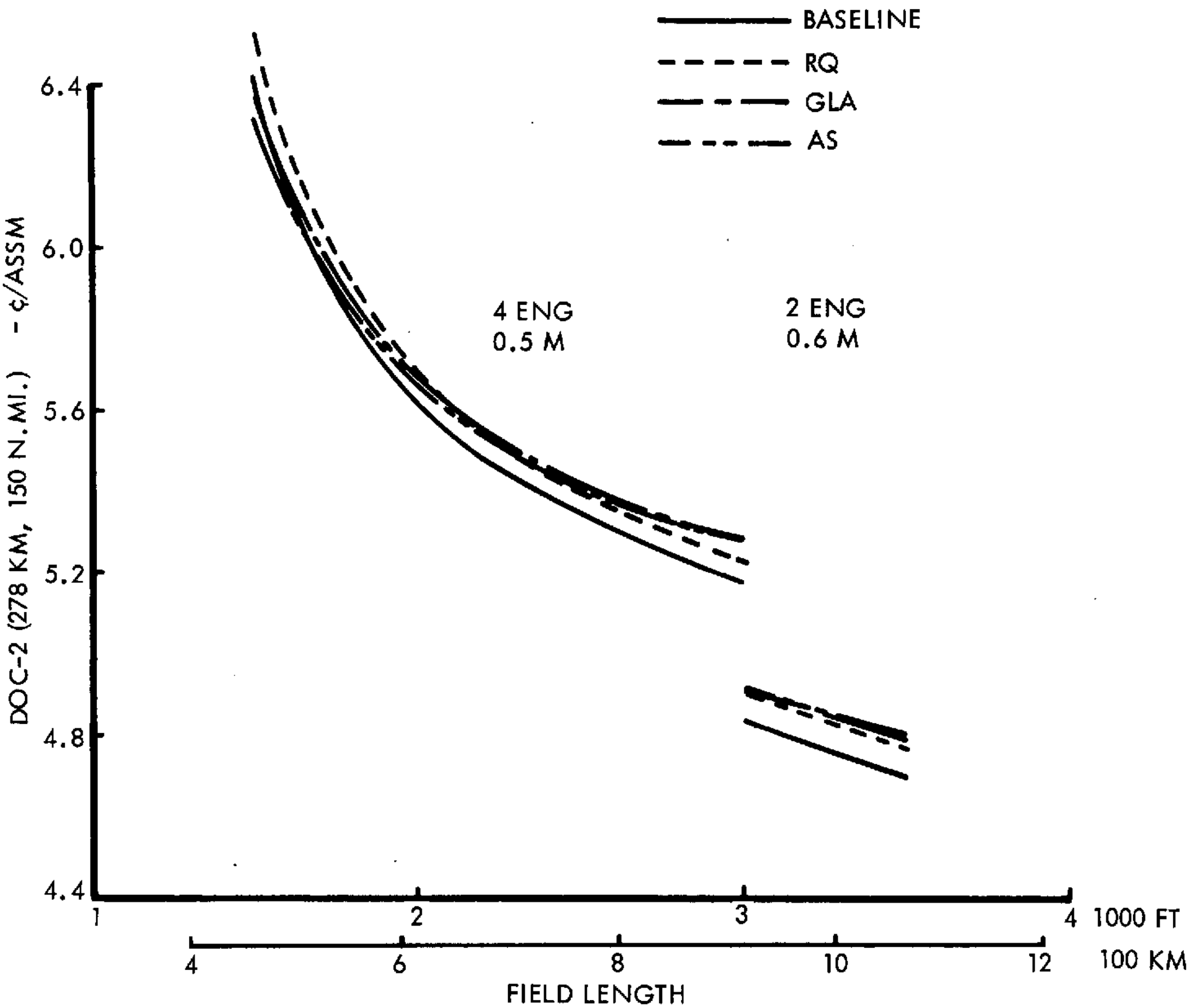

Figure 31 DOC-2 (278 km, 150 n.m) vs. Field Length (44 Pax)

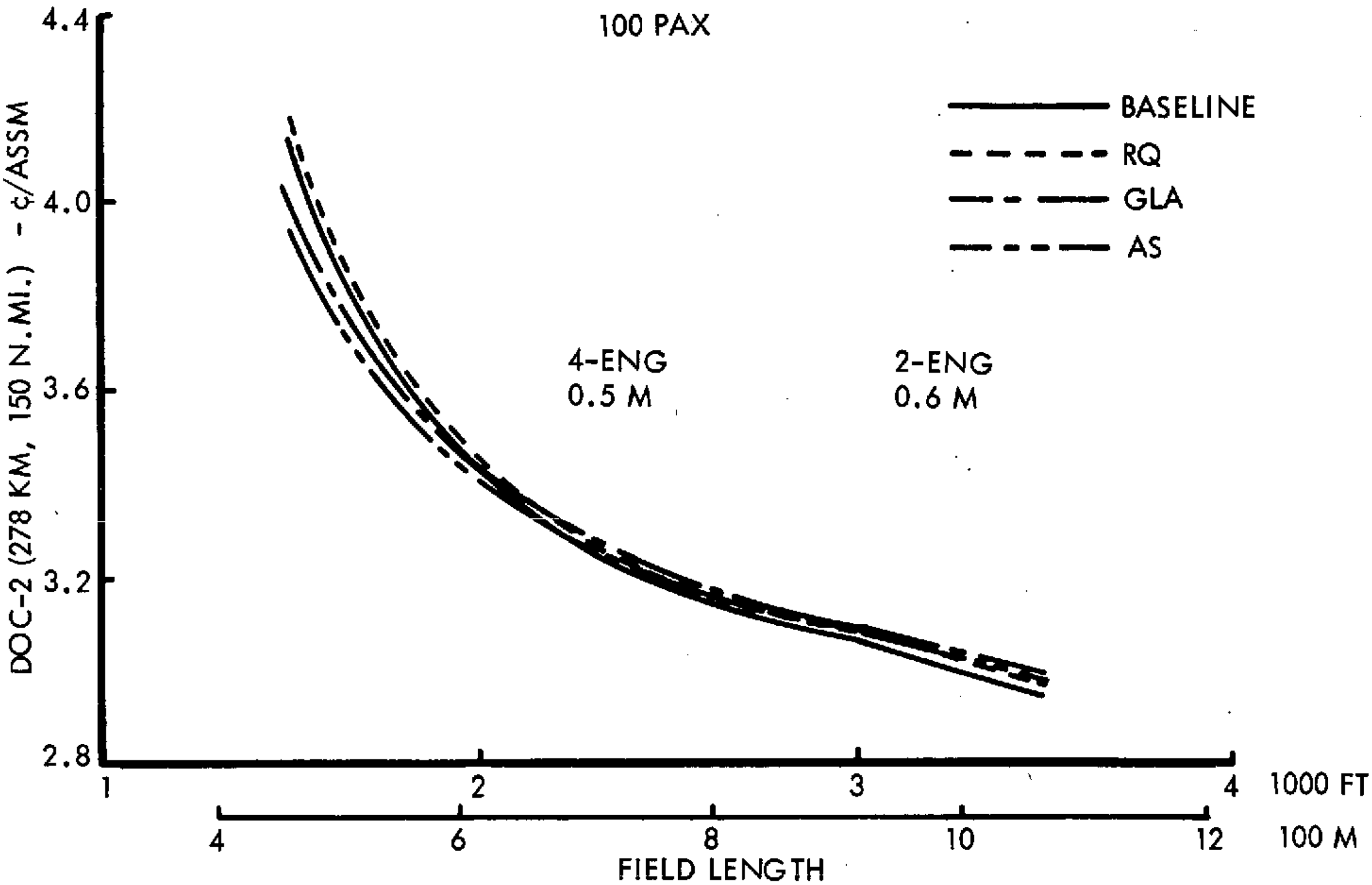

Figure 32 DOC-2 (278 km, 150 n.m) vs. Field Length (100 Pax)

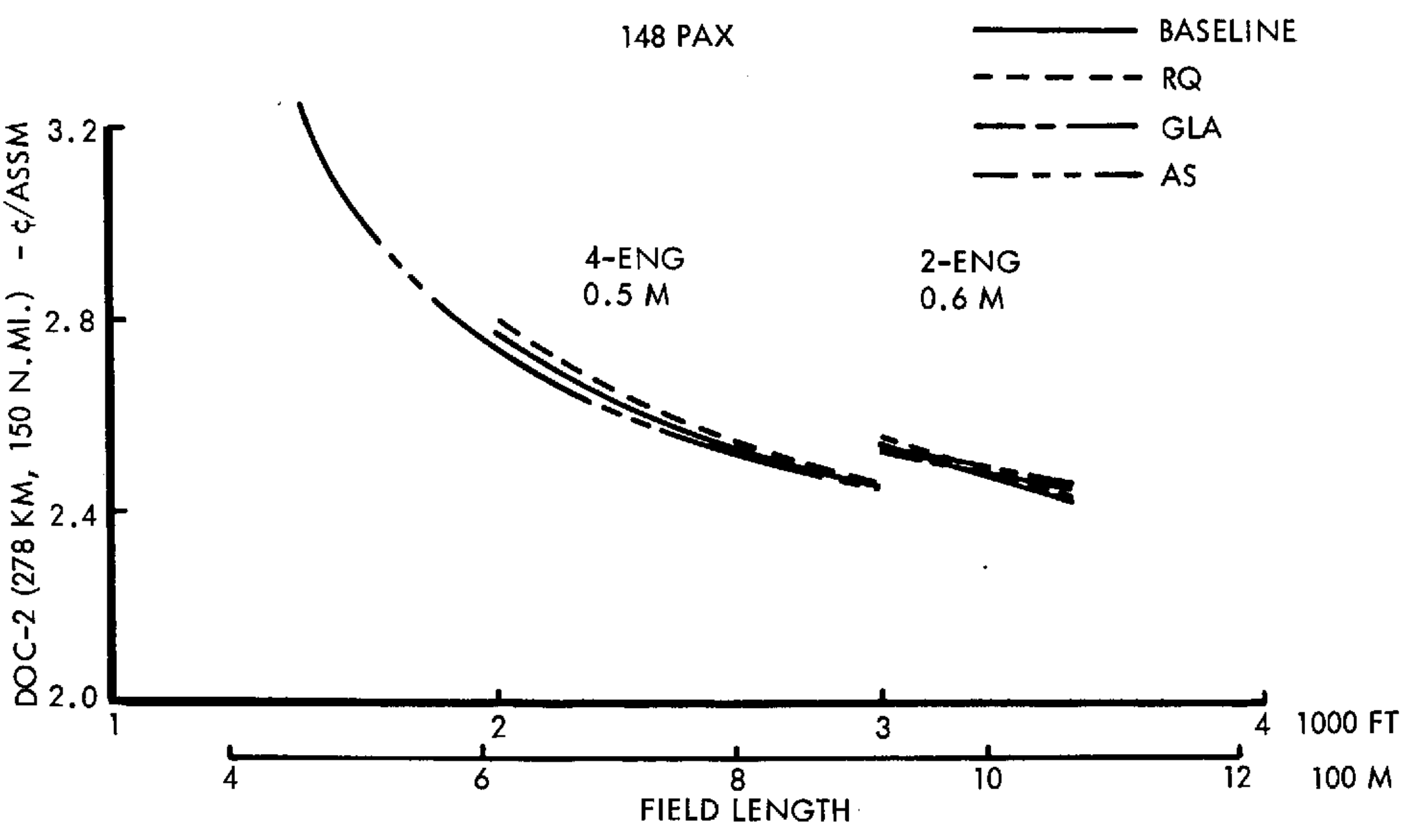

Figure 33 DOC-2 (278 km, 150 n.m) vs. Field Length (148 Pax)

Figure 34, for example, illustrates percentage change in DOC-2 for 278 km (150 n.mi.) stage length. The RQ system can be seen to increase DOC by 0.65 to 2.0 percent dependent on field length and passenger size, with the largest increase being for the shortest field length. The effects of the GLA and AS systems in improving aircraft efficiency, particularly at the shorter field lengths, can be seen for all but the 44 passenger aircraft at the longer field lengths. For the 44 passenger airplane DOC can be reduced below that of the baseline at field lengths below 579 m (1900 ft) but increases above that of the RQ design at field lengths longer than 686 m (2250 ft). In other words, GLA or AS systems should not be incorporated into the 44 passenger size vehicle at field lengths longer than 686 m (2250 ft). The 100 passenger size with a GLA or AS system can be provided with excellent ride quality at the shortest field length while achieving a reduction in DOC of 3 to 4 percent. At approximately 610 m (2900 ft.), the RQ system is more desirable than the GLA or AS systems for the 4-engine configurations. For the 2-engine configuration the RQ system is most desirable for field lengths greater than about 1036 m (3400 ft). The 148 passenger aircraft should be provided with the GLA or AS system in preference to the RQ system at all field lengths below 991 m (3250 ft); lower DOC's than the baseline are achieved at field lengths below 701 to 792 m (2300 to 2600 ft).

Similar data are provided in Figures 35 through 37 for DOC-4, 278 km (150 n.mi.); DOC-2, 926 km (500 n.mi.); and DOC-4, 926 km (500 n.mi.). Figures 38 and 39 present percent change in DOC-2 and DOC-4 for the three active control systems as a function of passenger size for the 4-engine configuration at 610 m (2000 ft.) field length. At all sizes benefits are provided by the GLA and AS systems relative to the RQ system. Except at the smallest size the AS system has a lower DOC than the GLA system. Figures 40 and 41 present similar data for the 2-engine configuration at 914 m (3000 ft.) field length and illustrate the passenger sizes above which the GLA and AS systems are more desirable than the RQ system and when the systems provide lower DOC than the baseline aircraft without active controls.

6.1.2 Fuel Consumption Comparisons – The effects on 278 km (150 n.mi.) mission fuel of the active control systems are shown in Figures 42 through 44 for the 44, 100 and 148 passenger airplanes respectively. As expected, the RQ system incurs a penalty while the GLA and AS systems provide fuel savings. The savings at the shortest field length are because of the reduction in airplane size through GLA, and at the longer field lengths because of the increase in aspect ratio provided by the GLA system. An additional increment of saving is provided by the AS system due to the reeuction in horizontal stabilizer area and consequent reduction in airplane size. Note the large increase in mission fuel required by the 2-engine configuration. This is partly due to the speed difference and partly due to the lower wing loading and hence larger airplane required to meet the field performance.

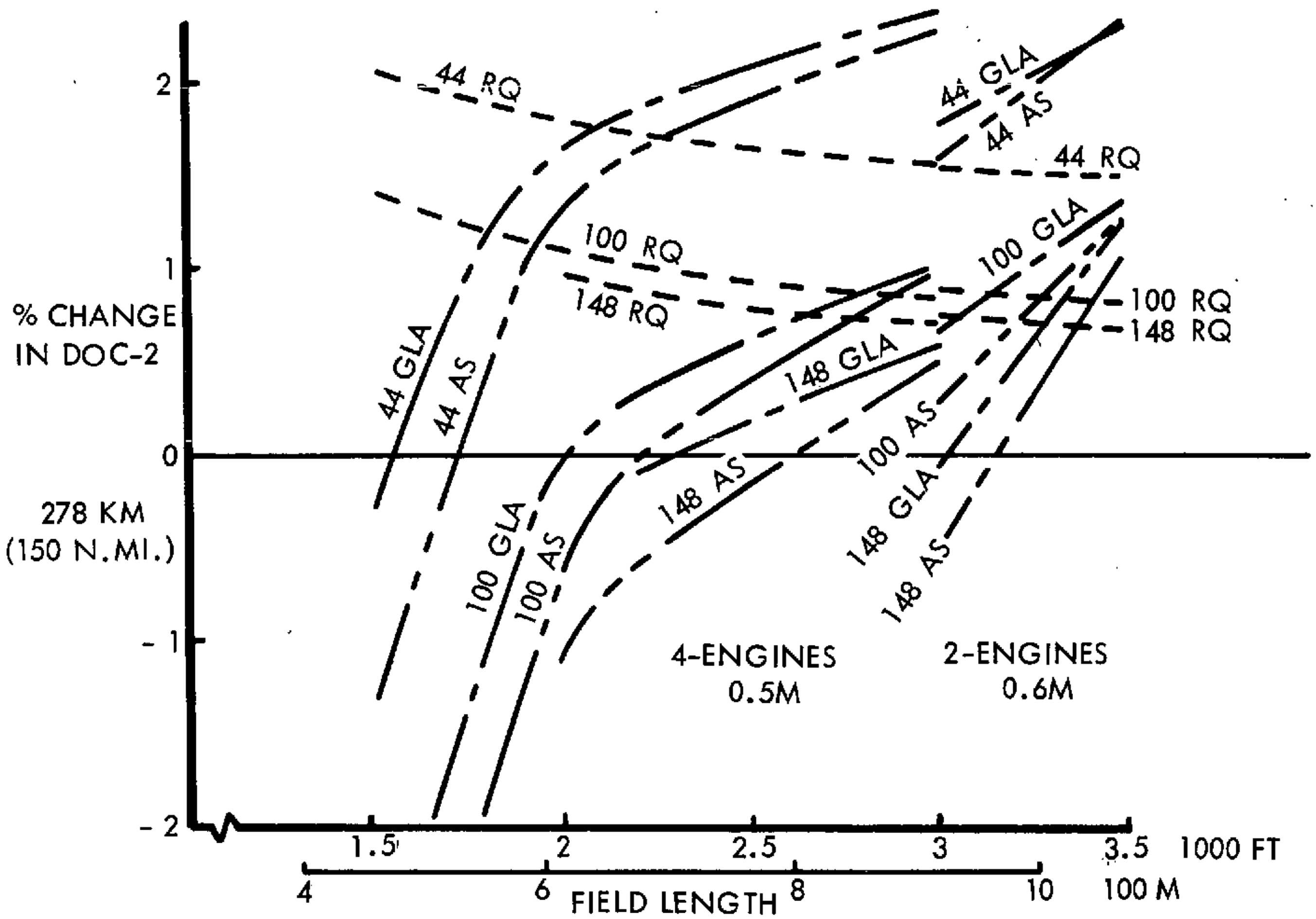

Figure 34 Percent Change in DOC-2 (278 km, 150 n.m) Due to Active Controls

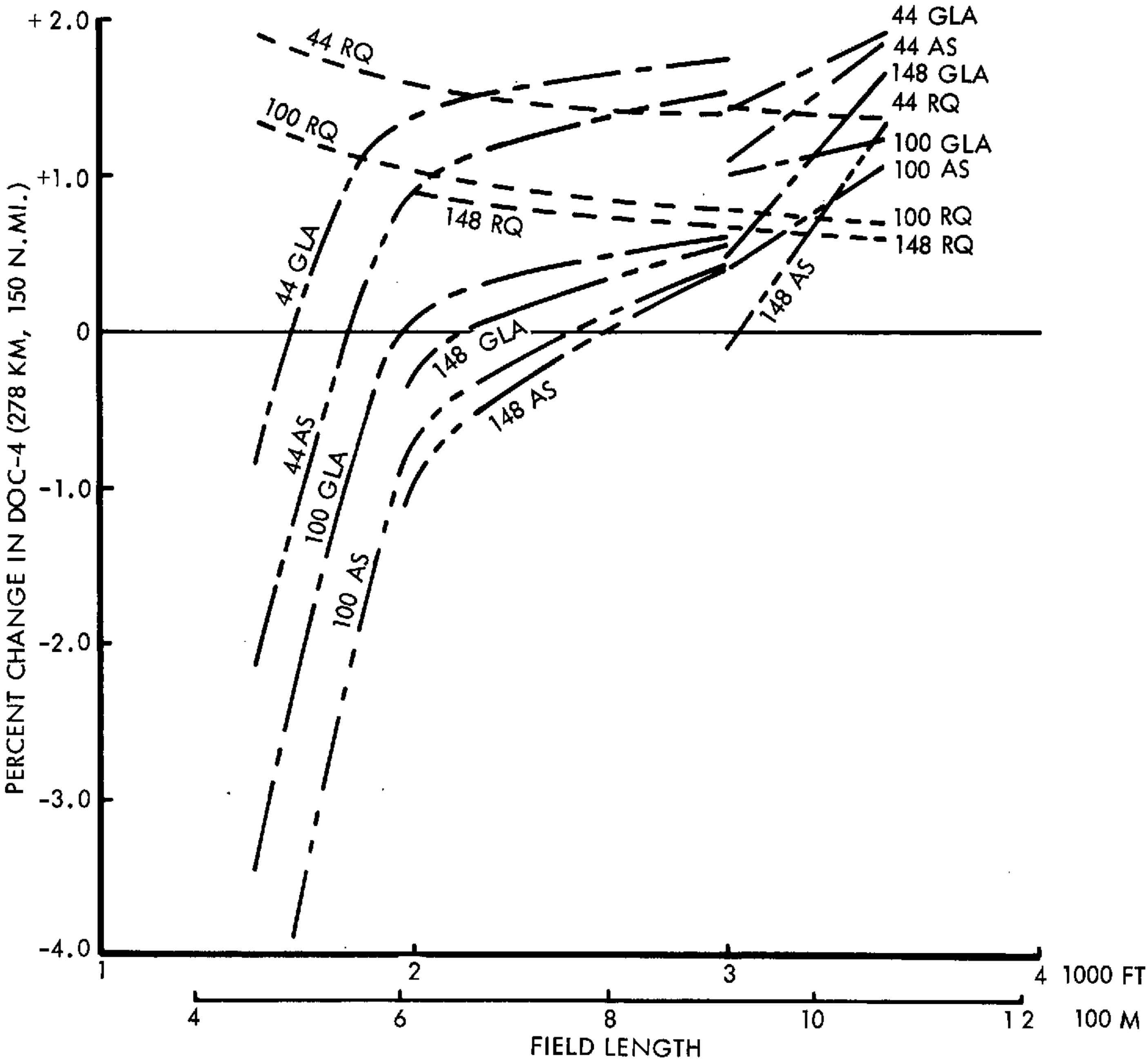

Figure 35 Percent Change DOC-4 (278 km, 150 n.m) Due to Active Controls

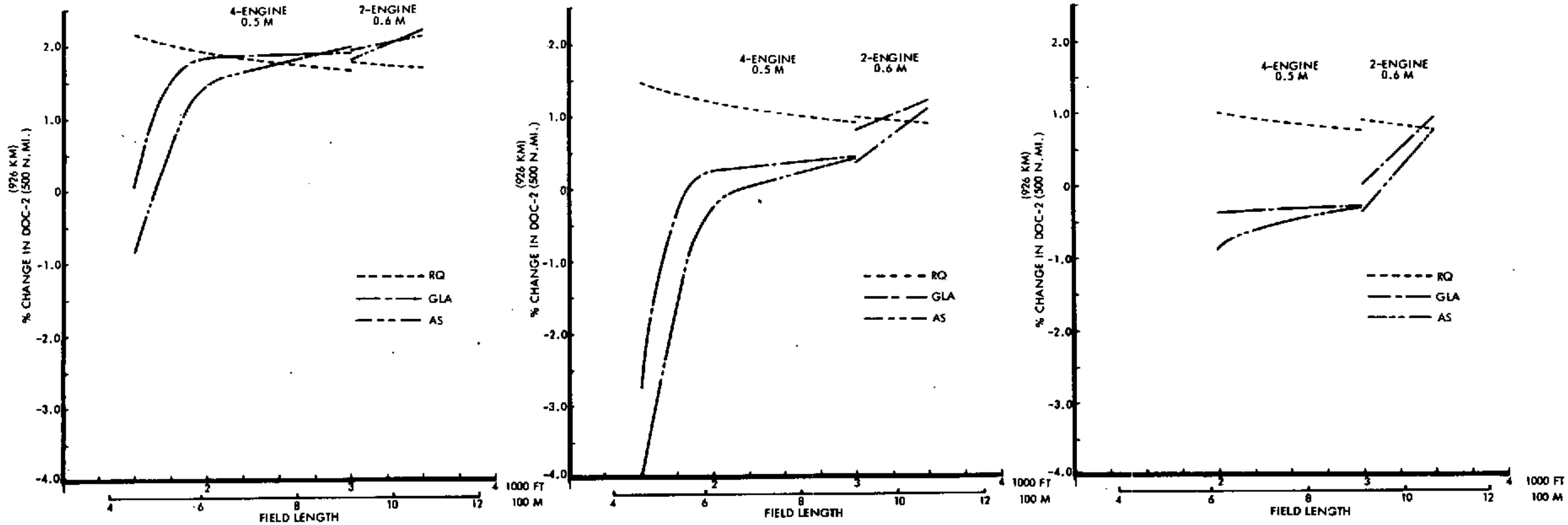

Figure 36 Percent Change in DOC-2 (926 km, 500 n.m) Due to Active Controls

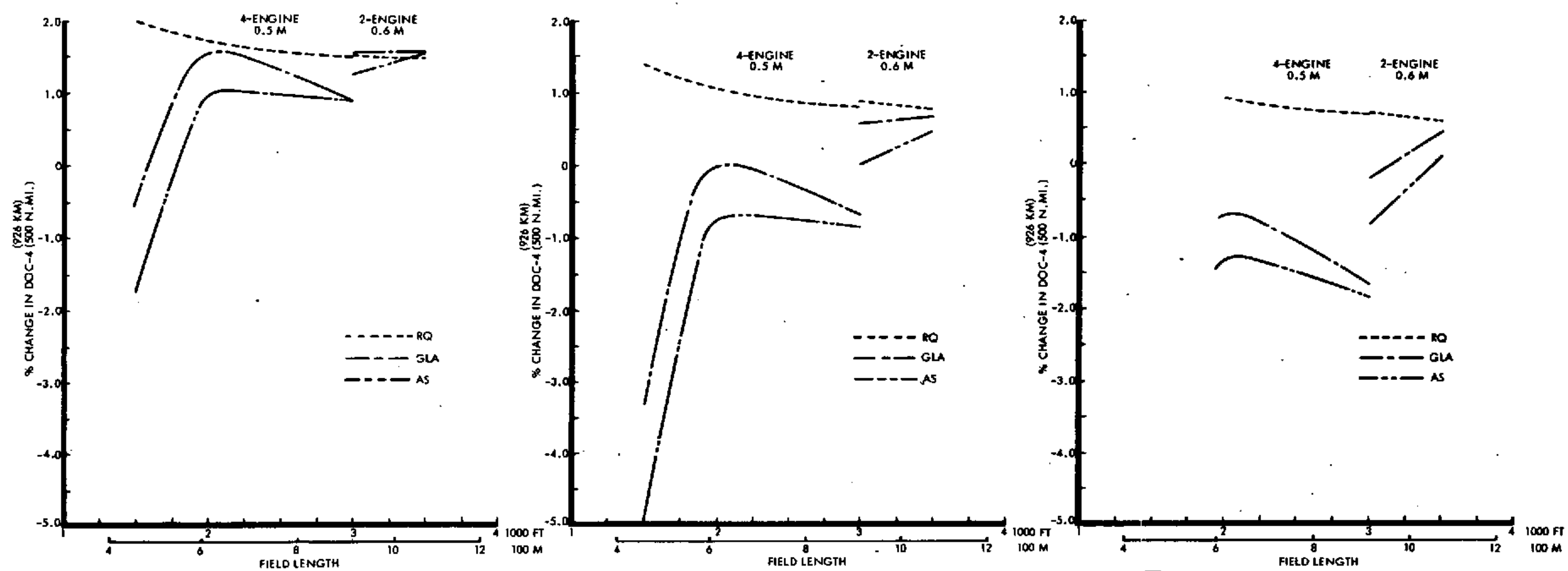

Figure 37 Percent Change in DOC-4 (926 km, 500 n.m) Due to Active Controls

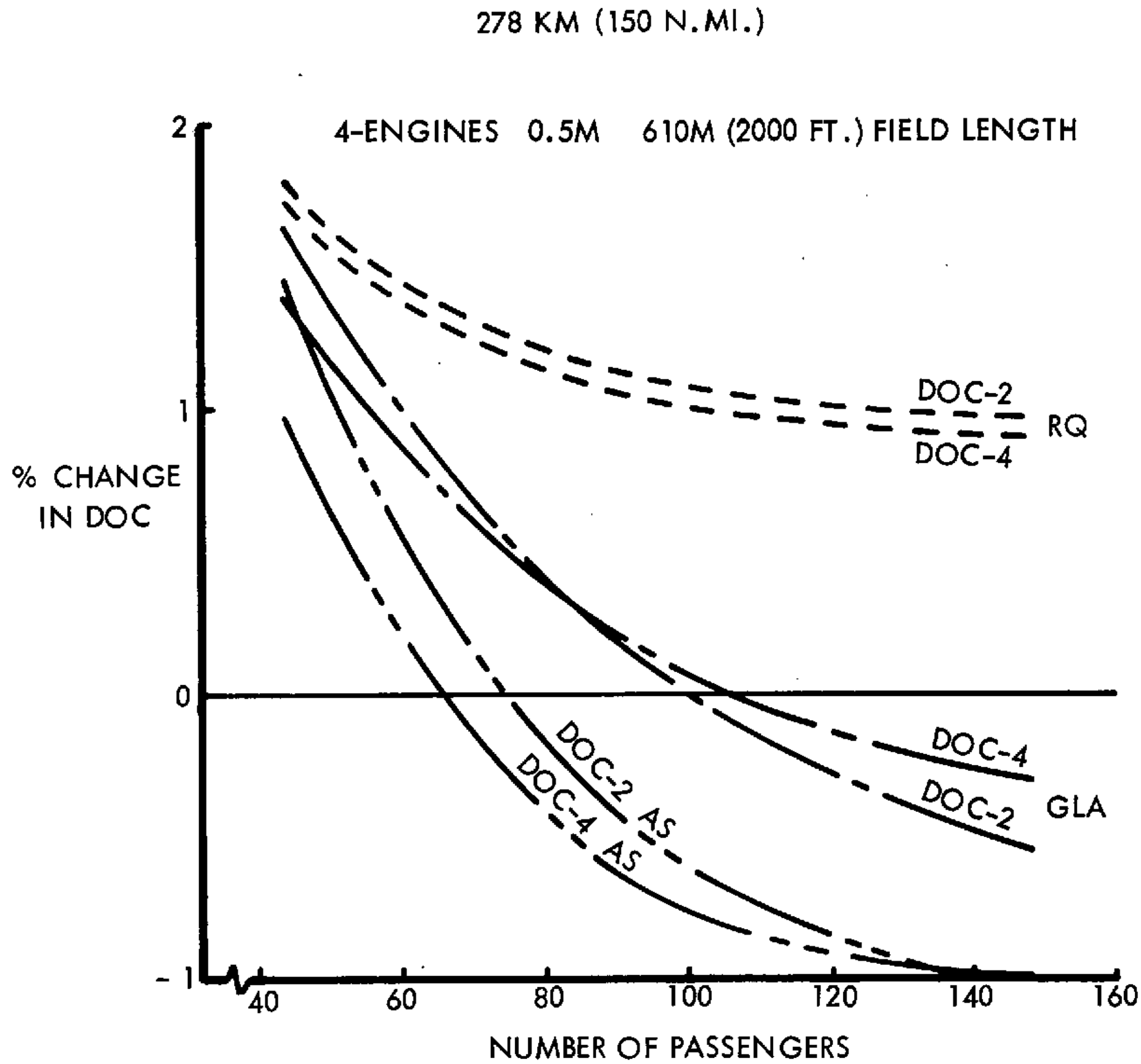

Figure 38 Percent Change in DOC (278 km, 150 n.m) vs. Passenger Size - 610 m (2000 ft) F.L.

4-ENG 0.5M 610M (2000 FT) F.L.

926 KM (500 N.MI.)

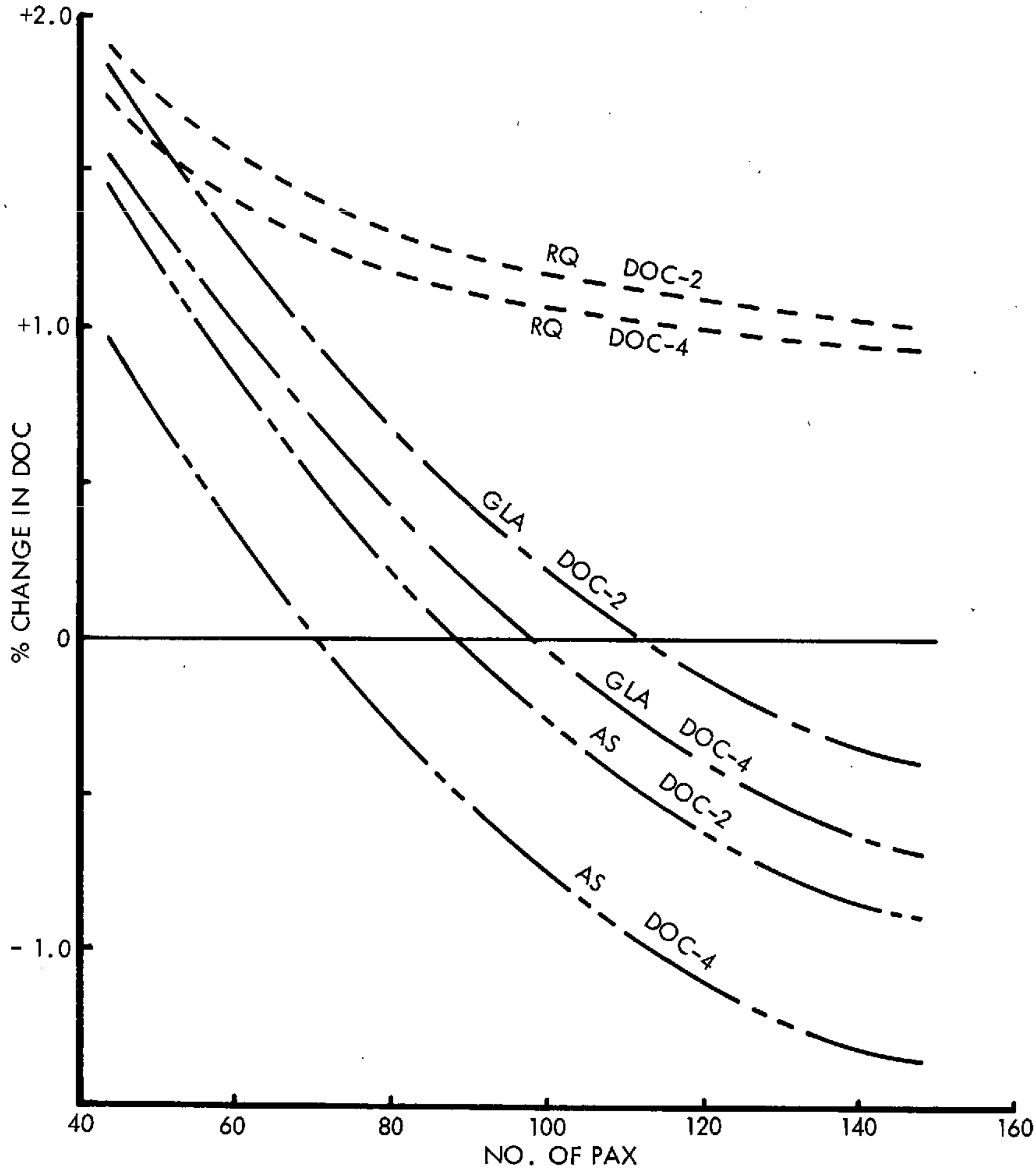

Figure 39 Percent Change in DOC (926 km, 500 n.m) vs. Passenger Size - 610 m (2000 ft) F.L.

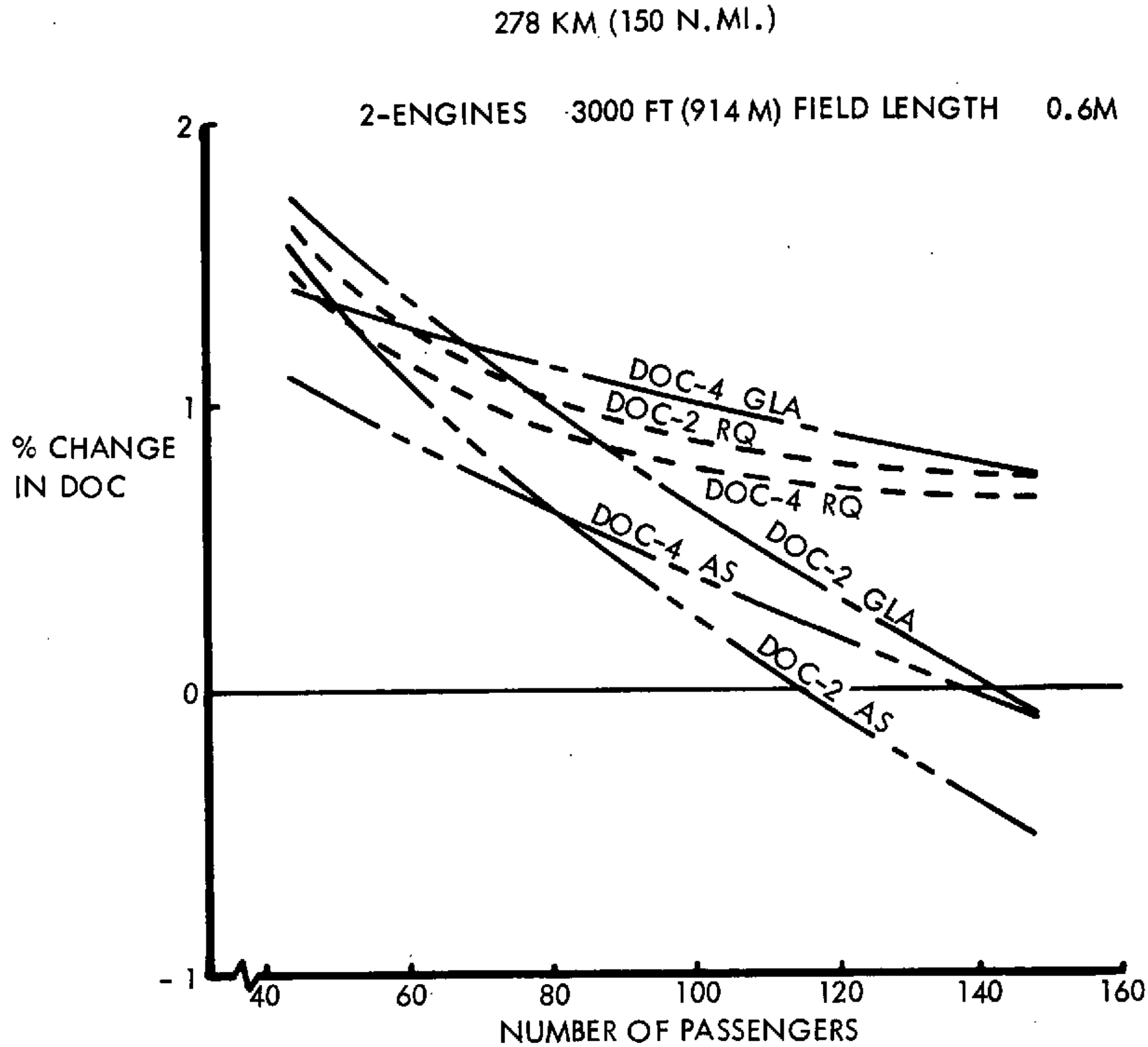

Figure 40 Percent Change in DOC (278 km, 150 n.m) vs. Passenger Size - 914 m (3000 ft) F.L.

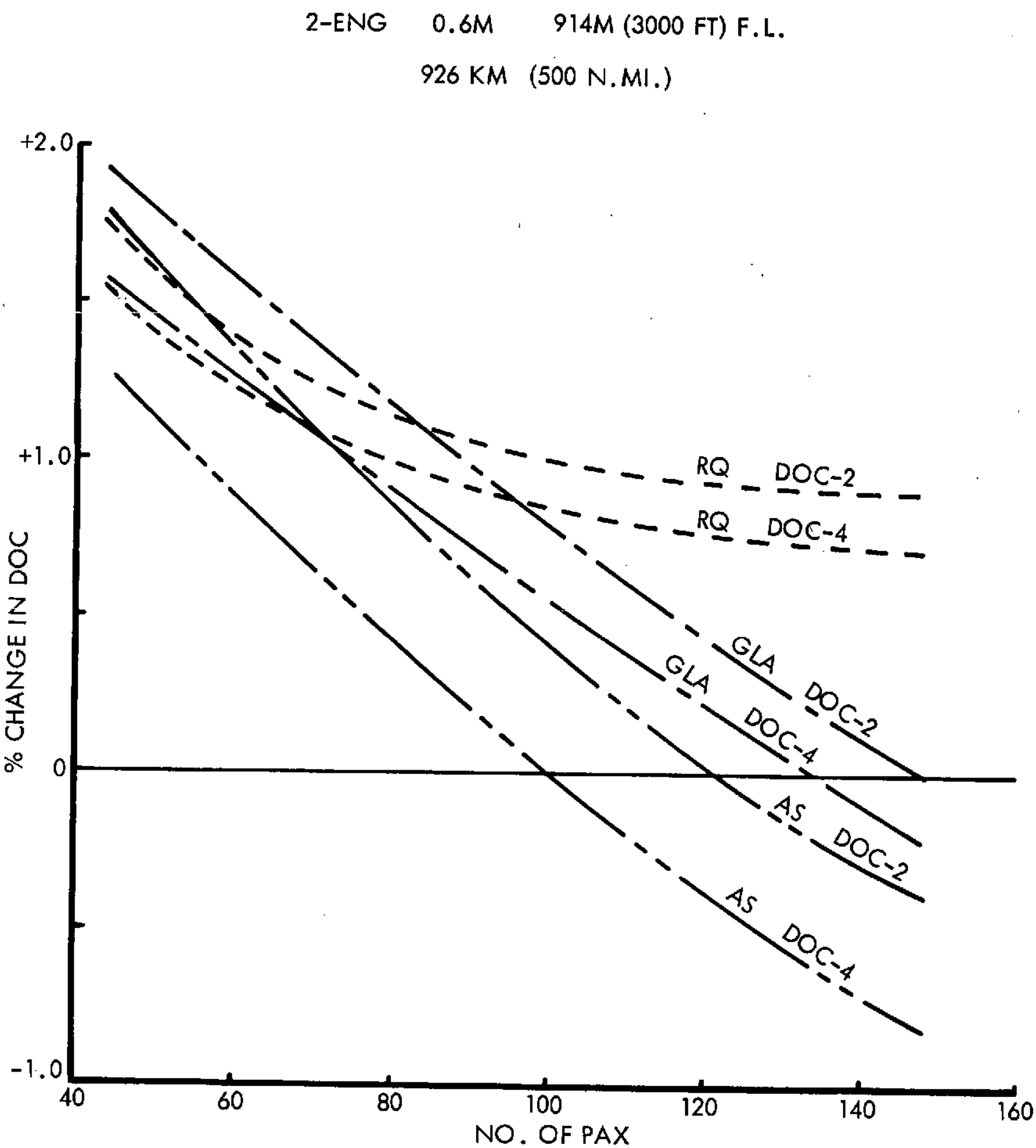

Figure 41 Percent Change in DOC (926 km, 500 n.m) vs. Passenger Size - 914 m (3000 ft) F.L

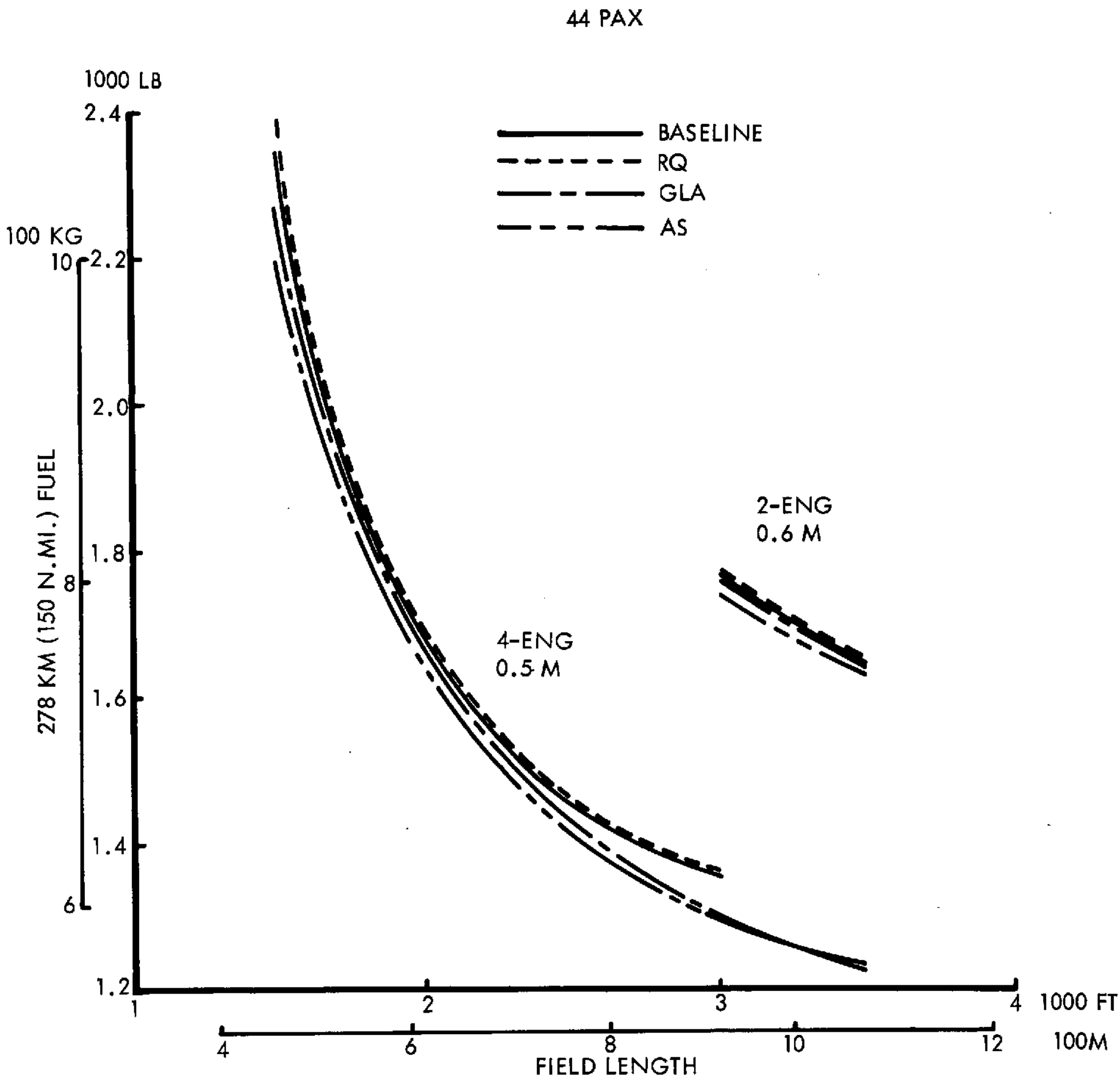

Figure 42 Effect of Active Controls on Mission Fuel (278 km, 150 n.m) - 44 Pax

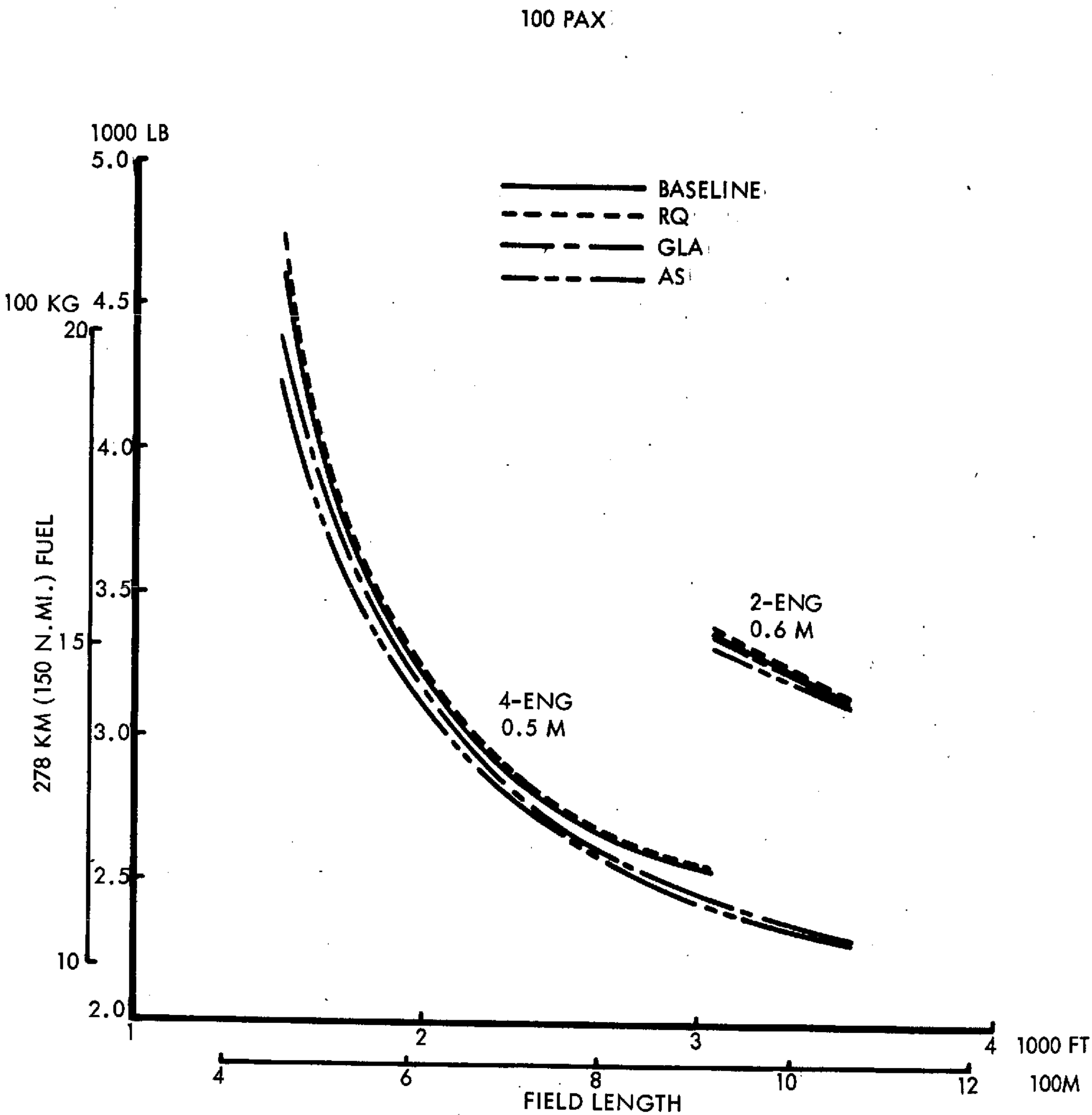

Figure 43 Effect of Active Controls on Mission Fuel (278 km, 150 n.mi) - 100 Pax

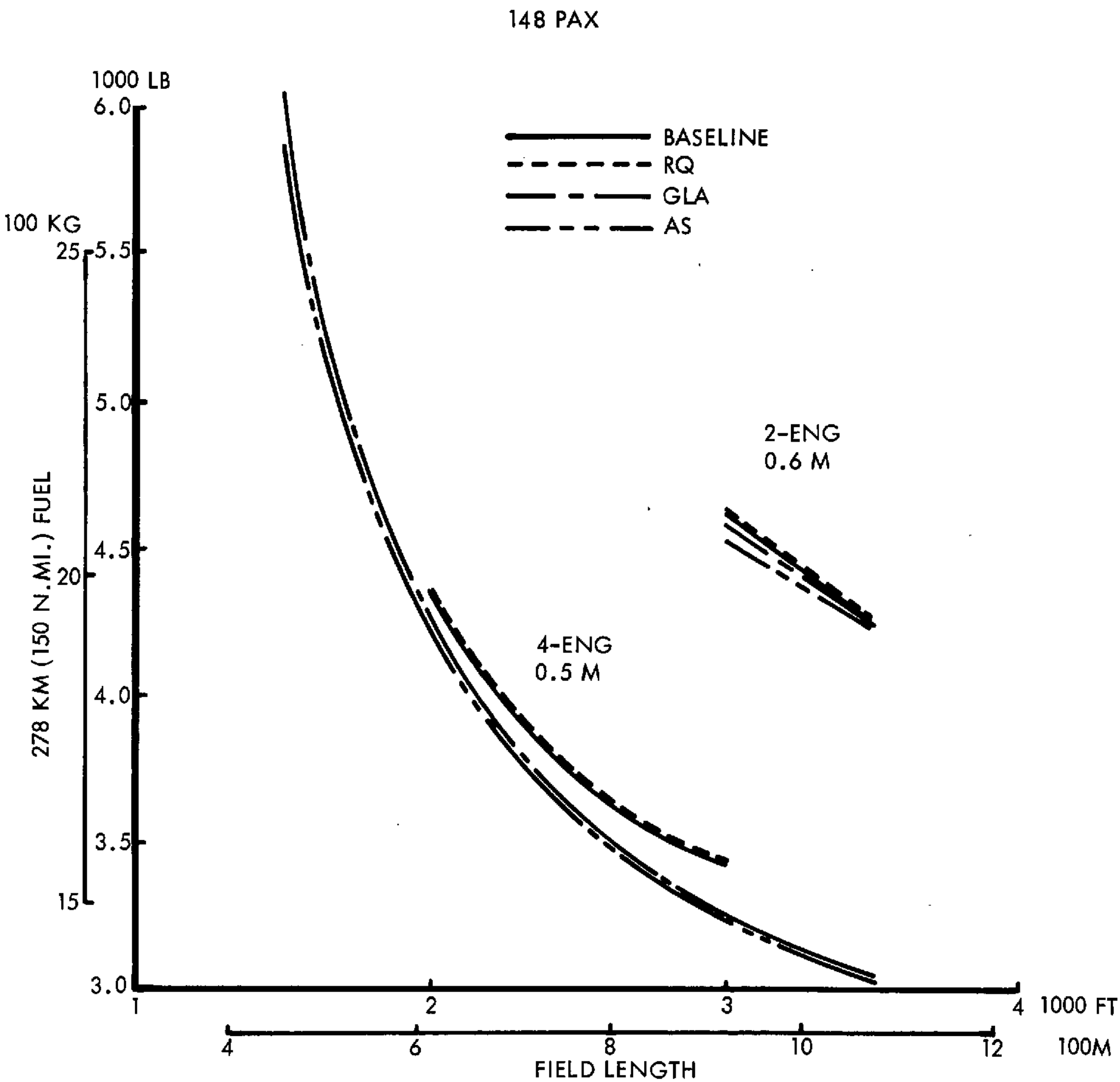

Figure 44 Effect of Active Controls on Mission Fuel (926 km, 500 n.m) - 148 Pax

Figures 45 through 47 present data for the 926 km (500 n.mi.) stage length. The trends are similar to the shorter stage length but the savings provided by the GLA and AS systems are of course much greater. As a measure of fuel efficiency, Figure 48 presents seat km/kg (seat statute miles/gallon) for the aircraft with the extremes of fuel consumption, i.e., those with the RQ and AS systems. Note again the poor fuel efficiency of the 2-engine designs and the drastic reduction in fuel efficiency associated with the shortest field lengths. As would be expected, the largest passenger capacity, 4-engined airplanes incorporating the AS system have the best fuel efficiency and at the same time provide excellent ride quality.

6.1.3 Weight Comparisons – Figures 49, 50 and 51 compare ramp gross weight as a function of field length for the 44, 100 and 148 passenger sizes. As would be expected the 2-engined airplanes are heavier than the equivalent 4-engine design, partly because of the higher cruise speed and partly because of the engine-out performance requirements demanding lower wing loading and higher thrust to weight ratio.

The provision of ride quality incurs a weight penalty at all field lengths and for all passenger sizes while the adoption of gust load alleviation with or without the relaxed static stability portion of the system does offer weight saving benefits which are highest at the lowest wing loadings and increase with increase in passenger size as will be seen by comparing the figures. This weight saving benefit is not provided in all cases, as can be seen from Figure 49 where the gust load alleviation system actually penalizes the weight of the 4-engine airplane at 914 m (3000 ft) and the 2-engine vehicle at 1067 m (3500 ft). This weight penalty is due to the subsystem weight and the weight of the higher aspect ratio wing exceeding the saving in fuel and other weights. Note similar trends with the larger passenger capacities but at longer field lengths. Figure 52 for the 610 m (2000 ft) field length, 4-engine and Figure 53 for the 914 m (3000 ft) field length, 2-engine configuration further illustrate the variations of RGW and OWE with passenger capacity.

The percentage change in OWE due to the various active control systems is shown in Figure 54 as a function of field length for each passenger size. The ride quality system increases OWE by 1.0 to 1.5 percent at the shortest field length compared to 0.4 to 0.75 percent at the longest field lengths. Of course, a much greater improvement in ride quality is provided at the shortest field length than at the longest. Since much of the subsystem weight is not greatly affected by passenger size, it follows that the greatest percentage savings would be expected to be provided by the largest passenger size; this is confirmed in the figure. The airplanes with the benefits of GLA or AS system break-even with the baseline aircraft in terms of OWE at field lengths of around 701 m (2300 ft) for the 4-engine configuration and 960 m (3150 ft) for the 2-engine configuration. Below these field lengths OWE benefits are provided, while above them OWE penalties will be encountered.

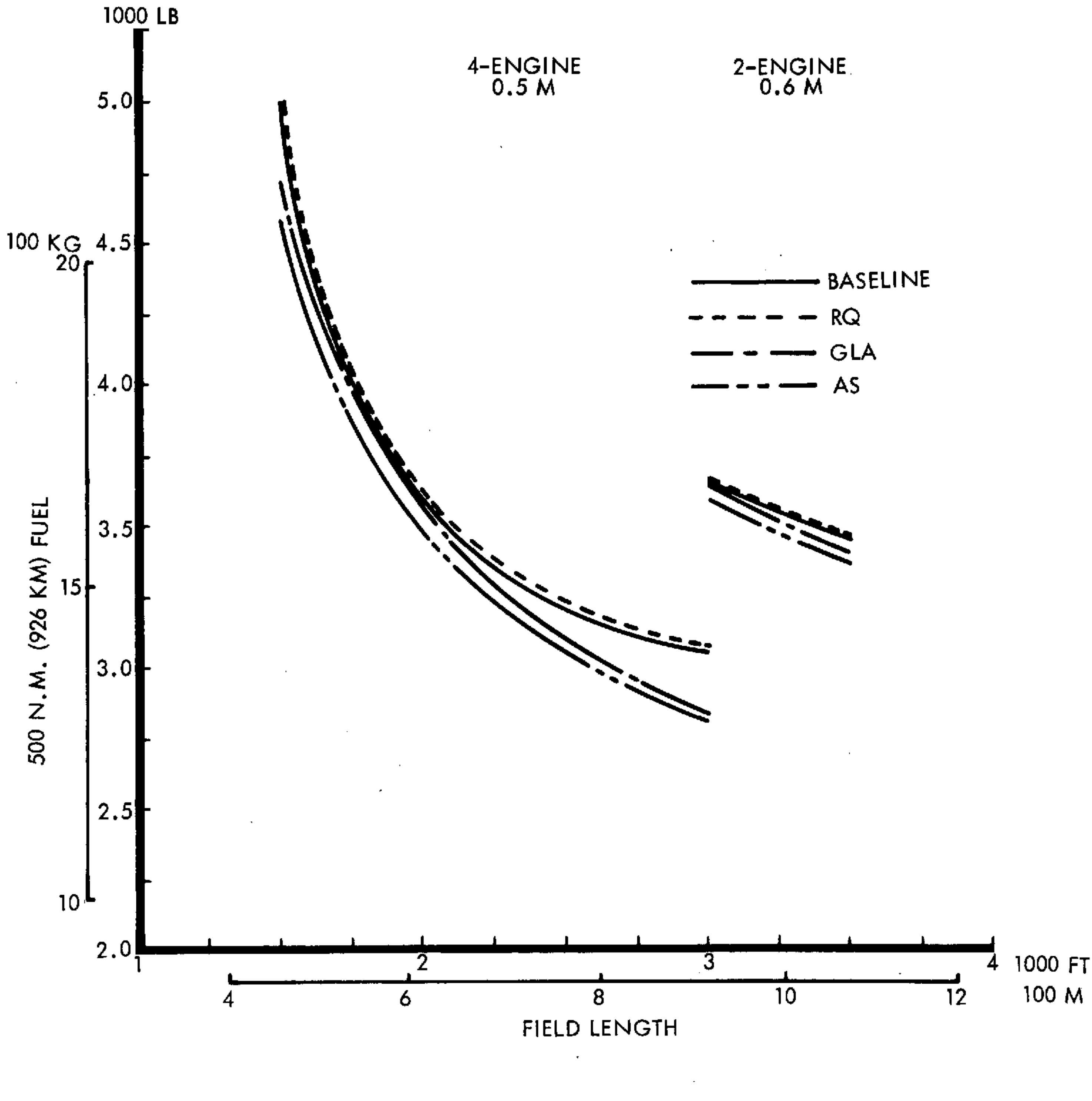

Figure 45 Effect of Active Controls on Mission Fuel (926 km, 500 n.m)- 44 Pax

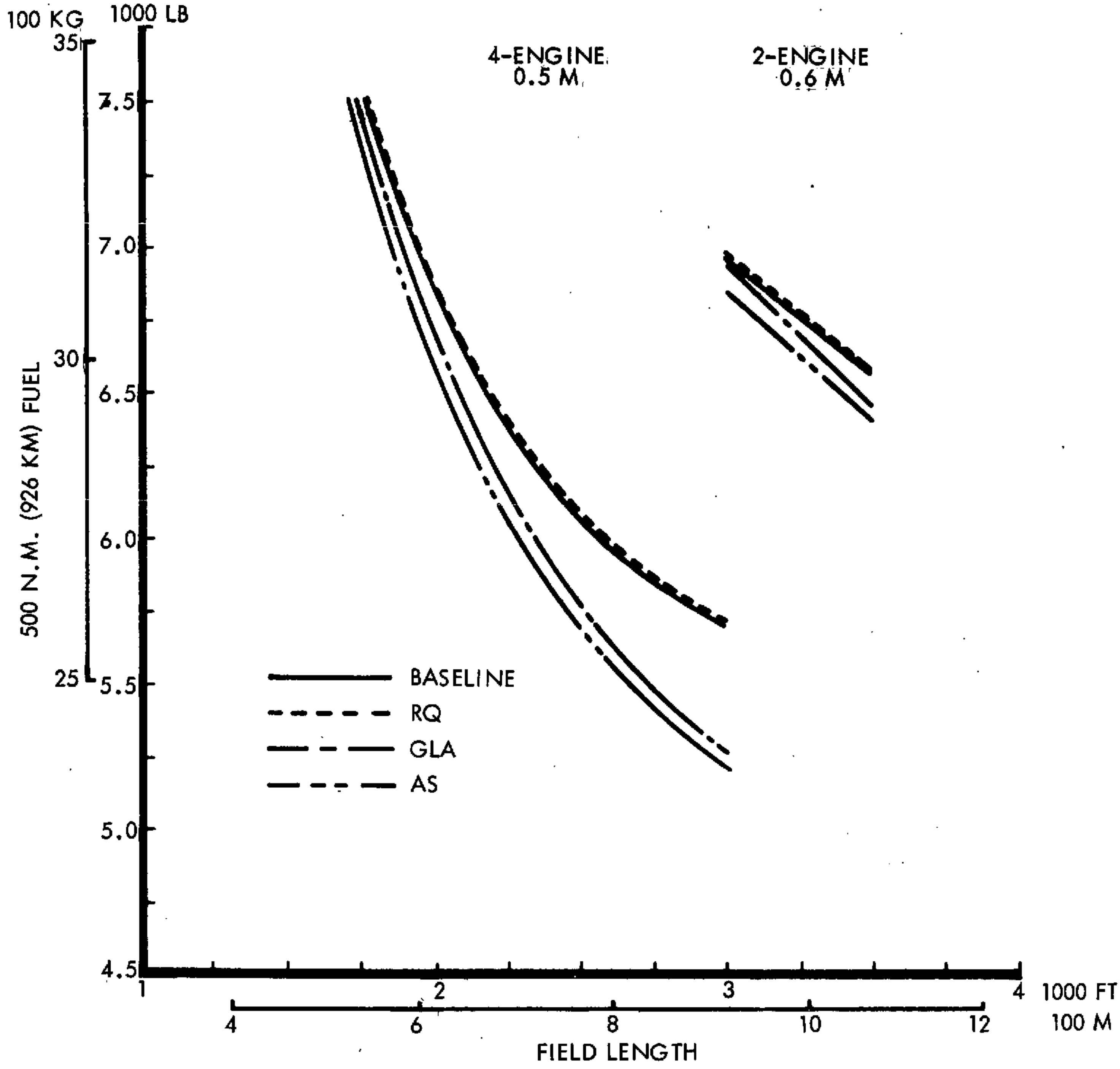

Figure 46 Effect of Active Controls on Mission Fuel (926 km, 500 n.m) - 100 Pax

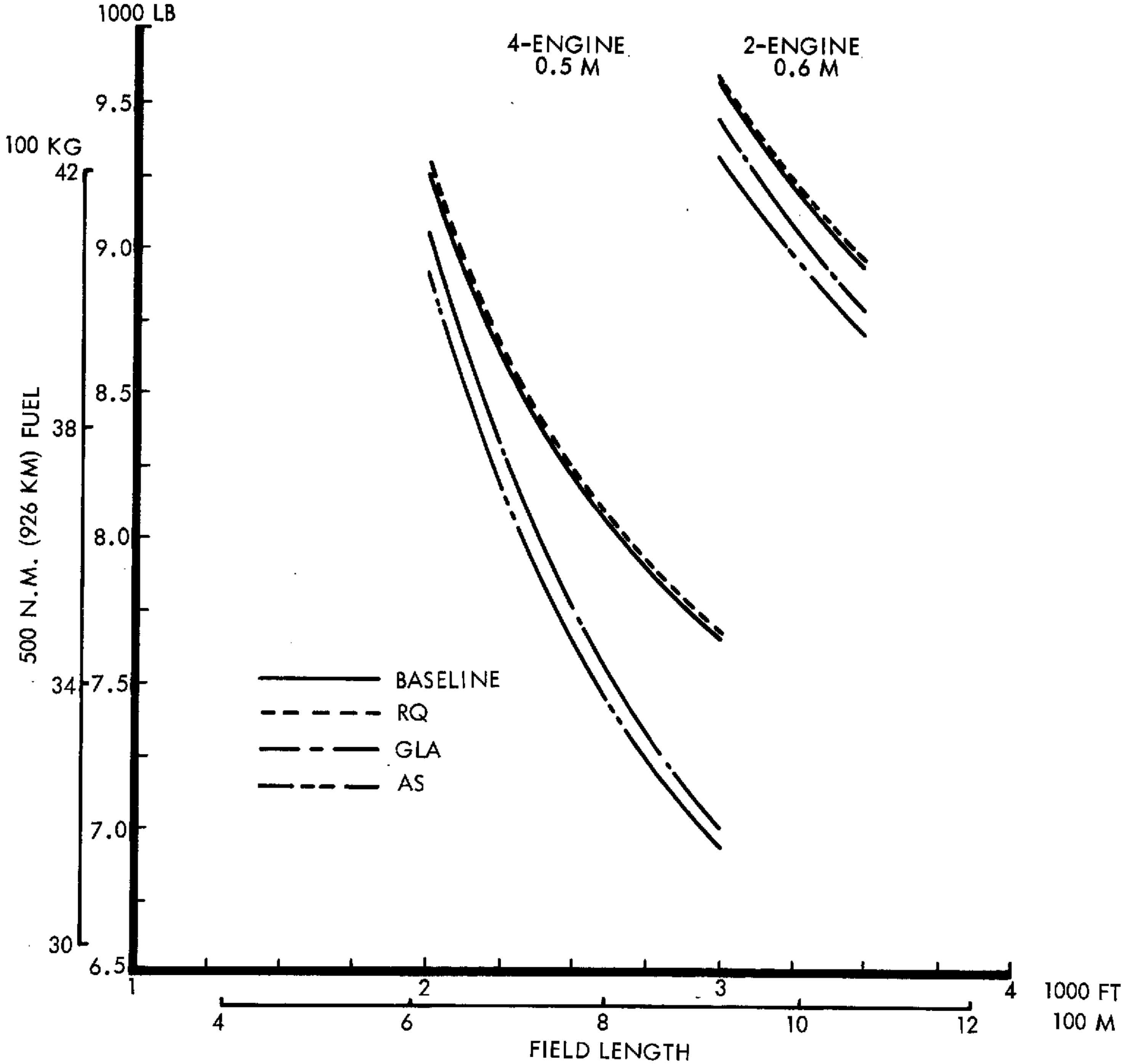

Figure 47 Effect of Active Controls on Mission Fuel (926 km, 500 n.m) - 148 Pax

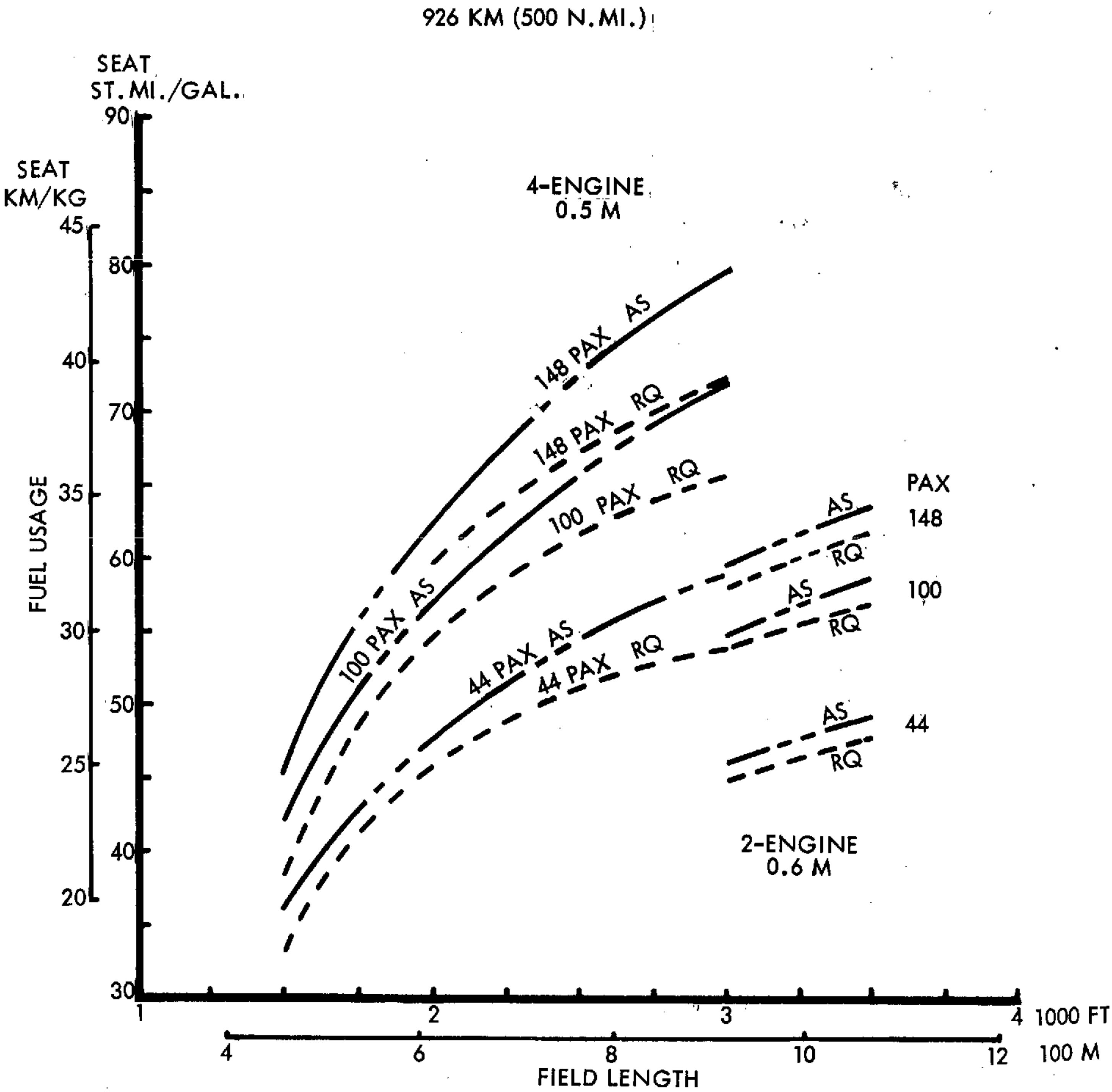

Figure 48 Effect of Active Controls on Fuel Usage Per Passenger

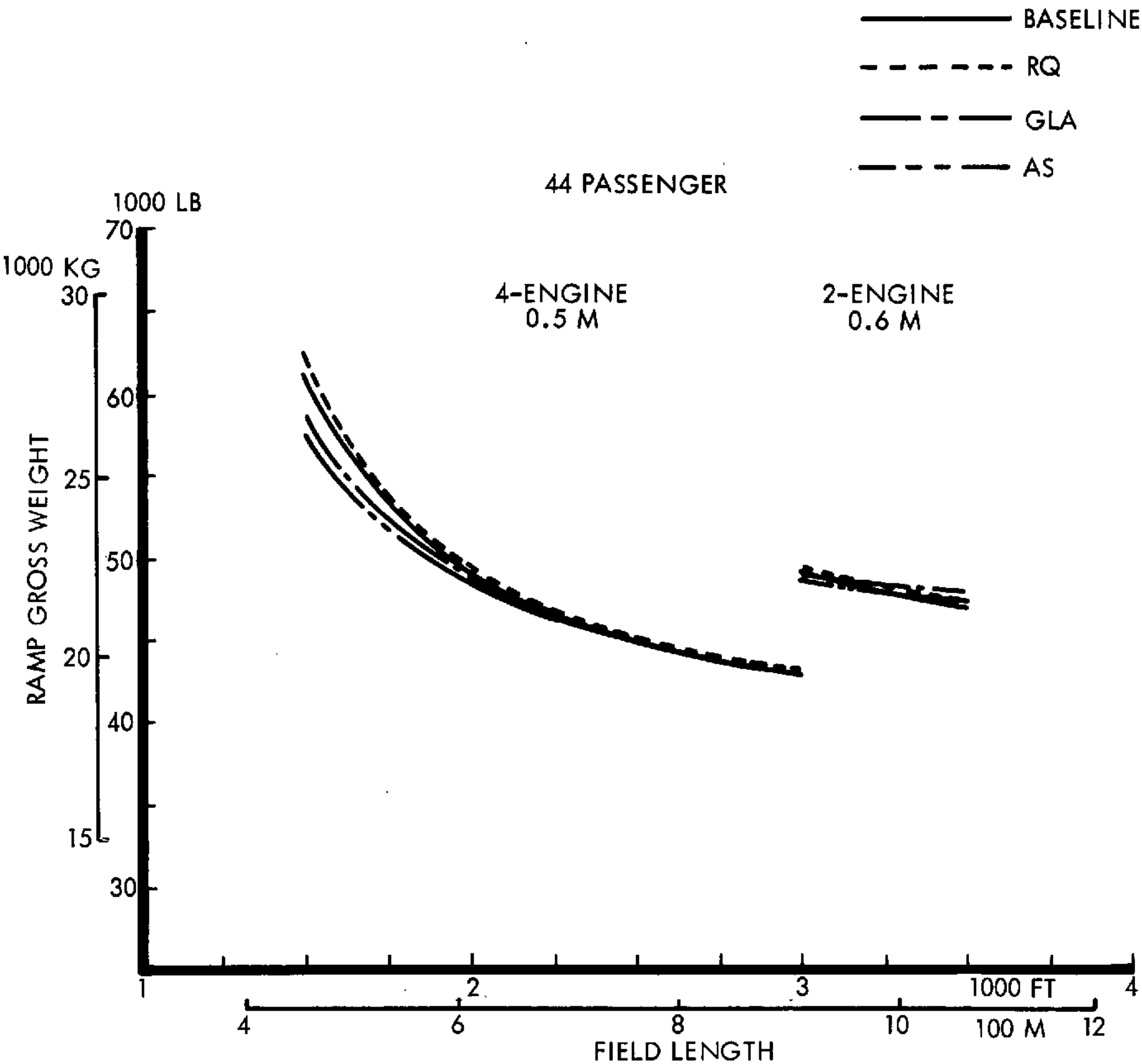

Figure 49 Effect of Active Controls on RGW - 44 Pax

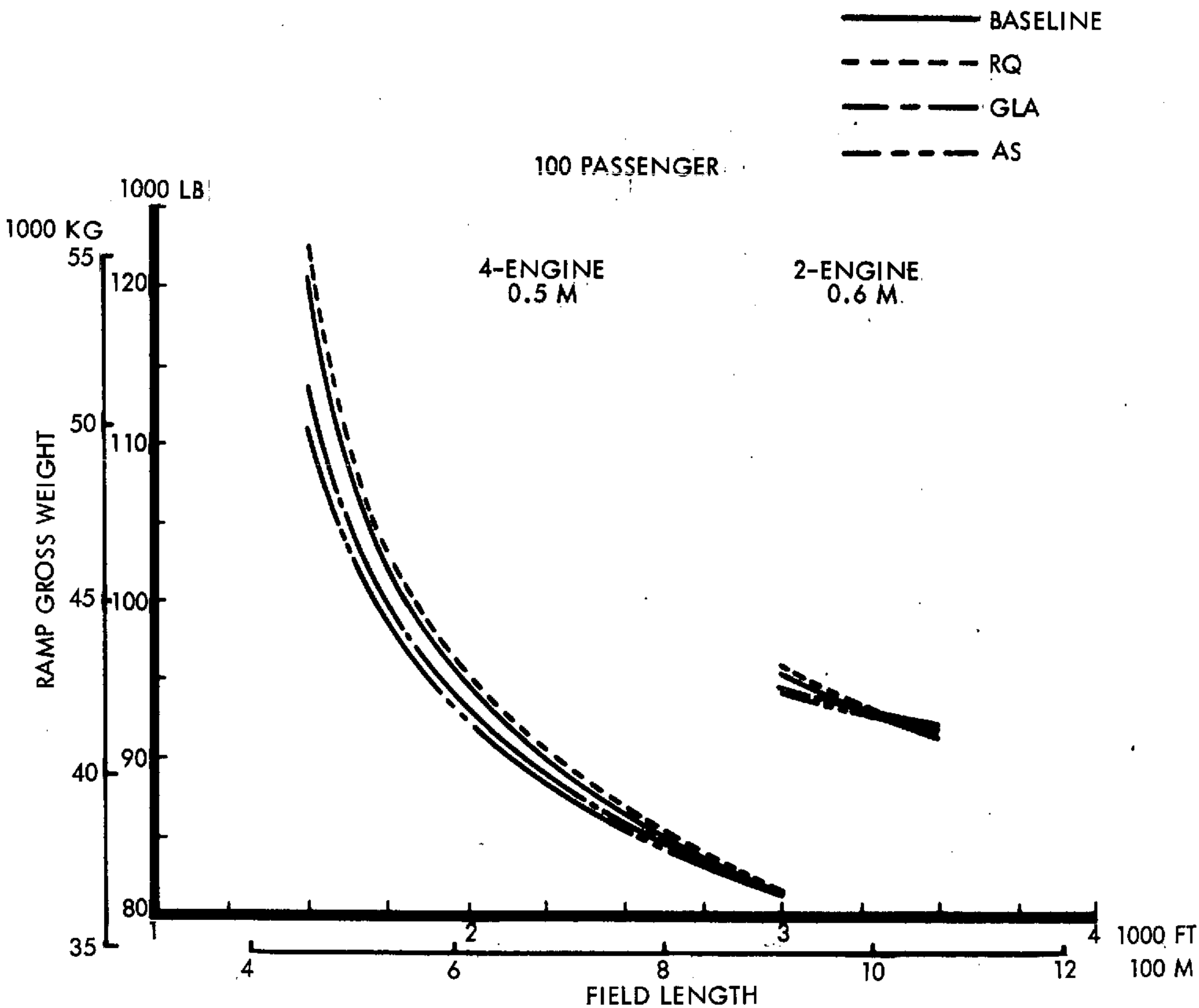

Figure 50 Effect of Active Controls on RGW - 100 Pax

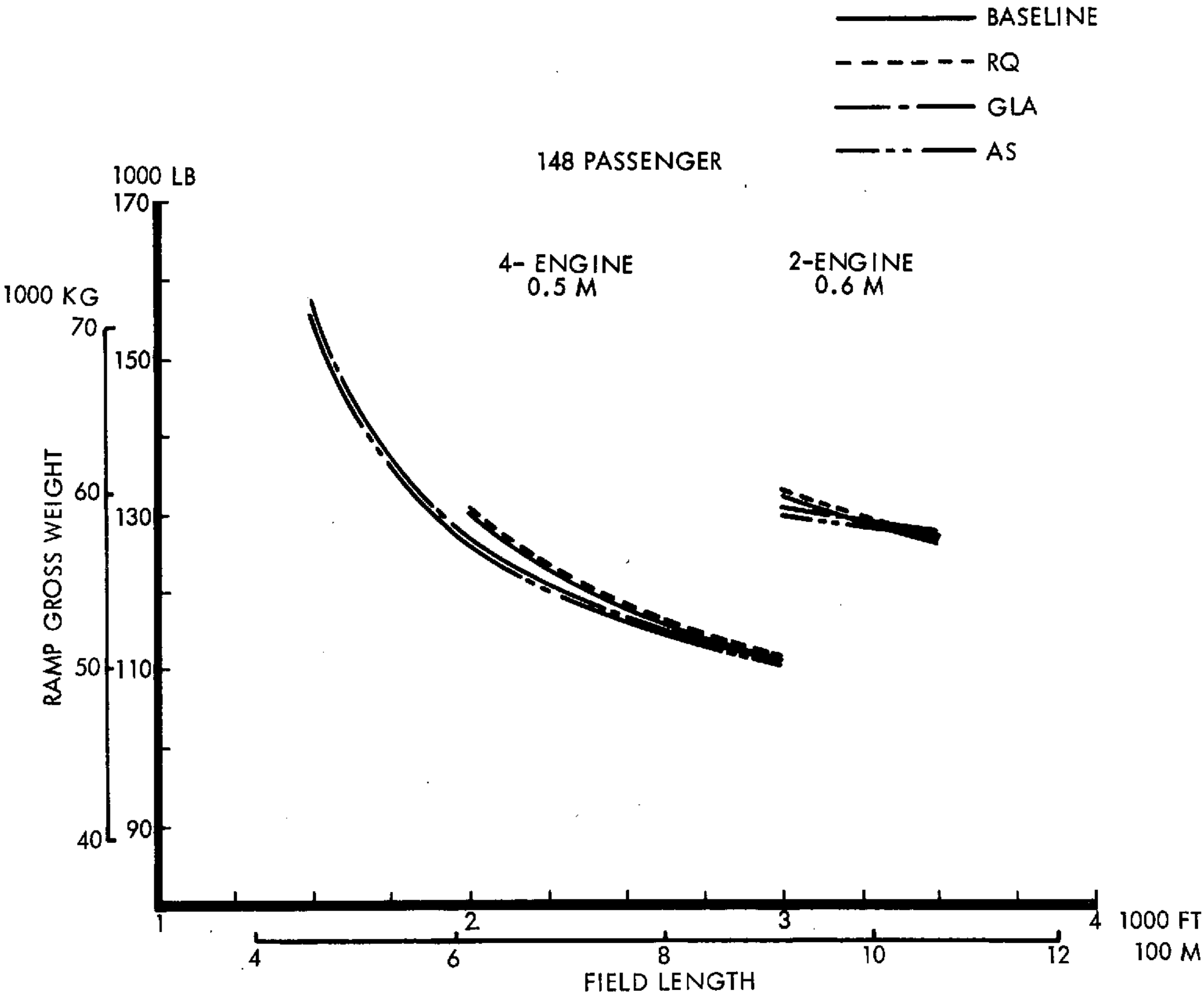

Figure 51 Effect of Active Controls on RGW - 148 Pax

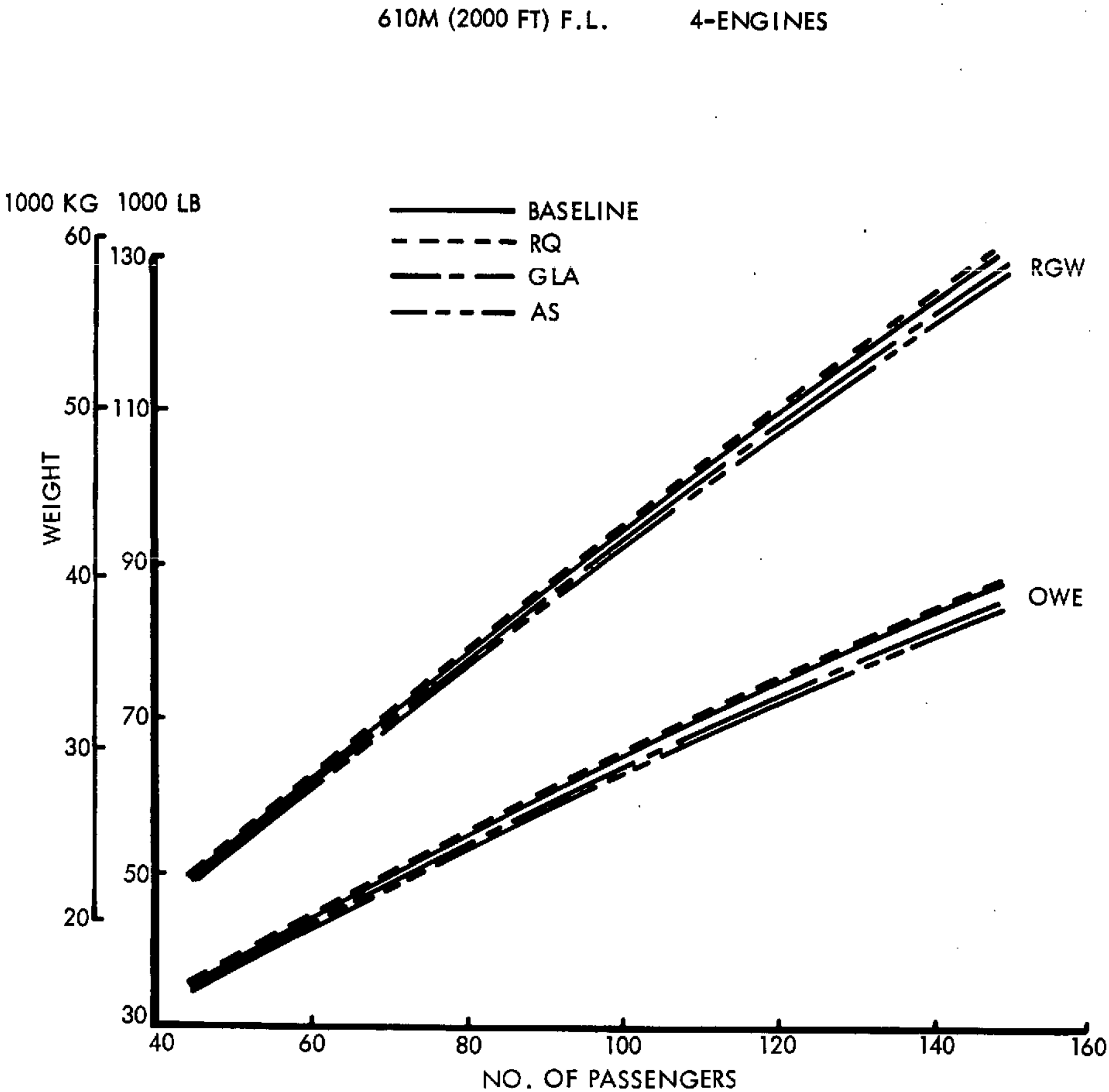

Figure 52 RGW and OWE vs. Passenger Capacity - 4 Engines, 610 m (2000 ft) F.L

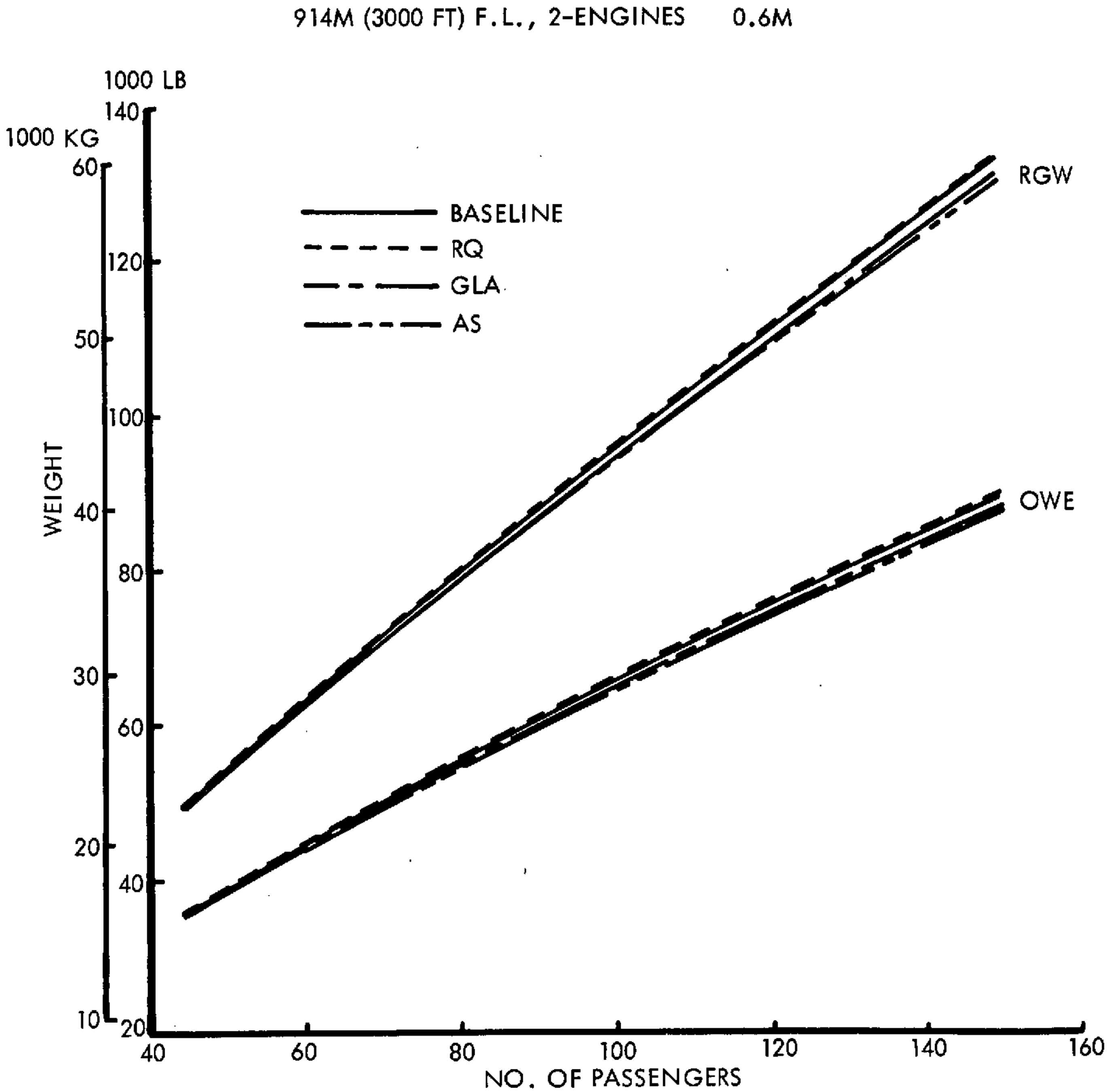

Figure 53 RGW and OWE vs. Passenger Capacity - 2 Engines, 914 m (3000 ft) F.L

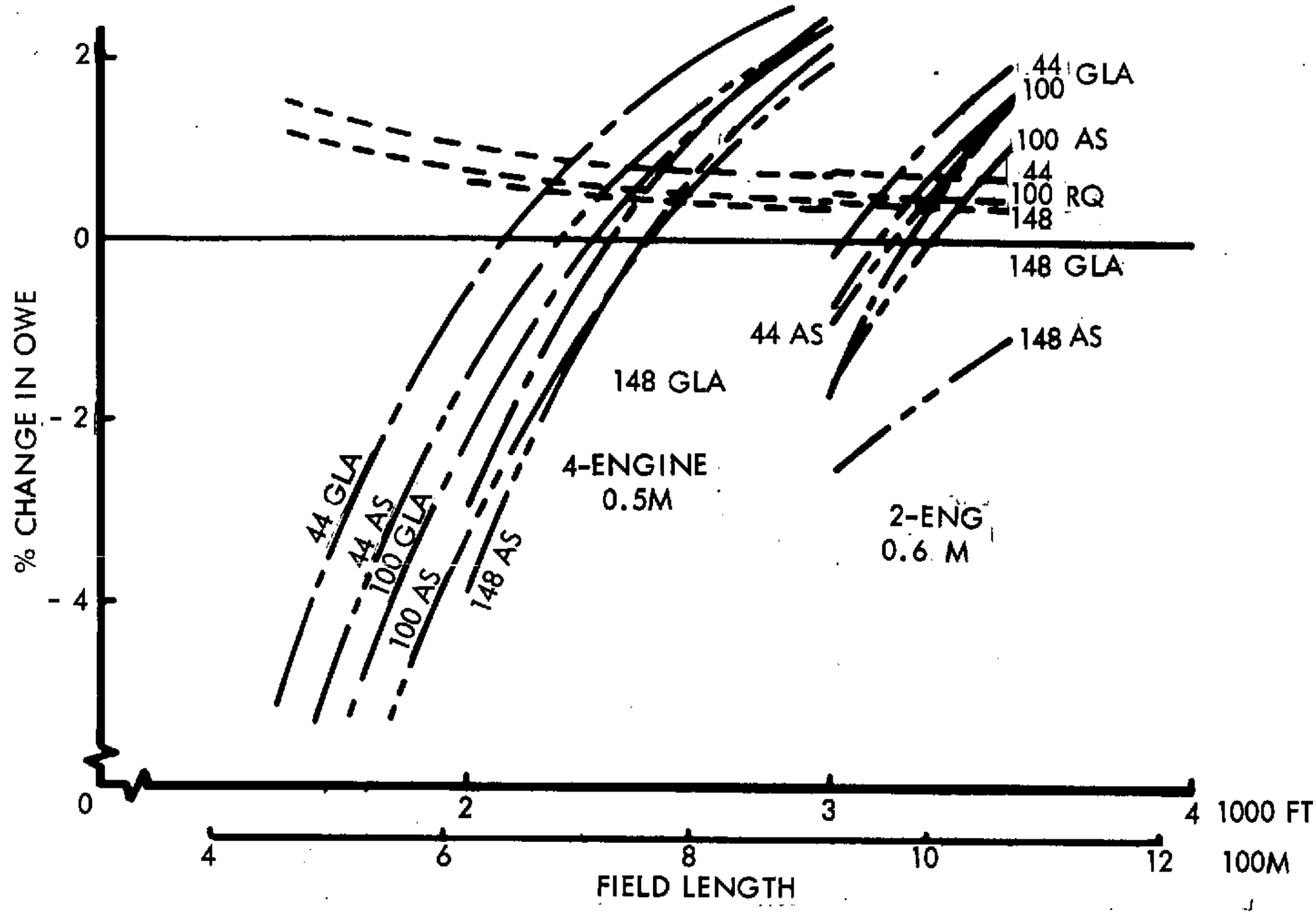

Figure 54 Percent Change in OWE due to Active Controls

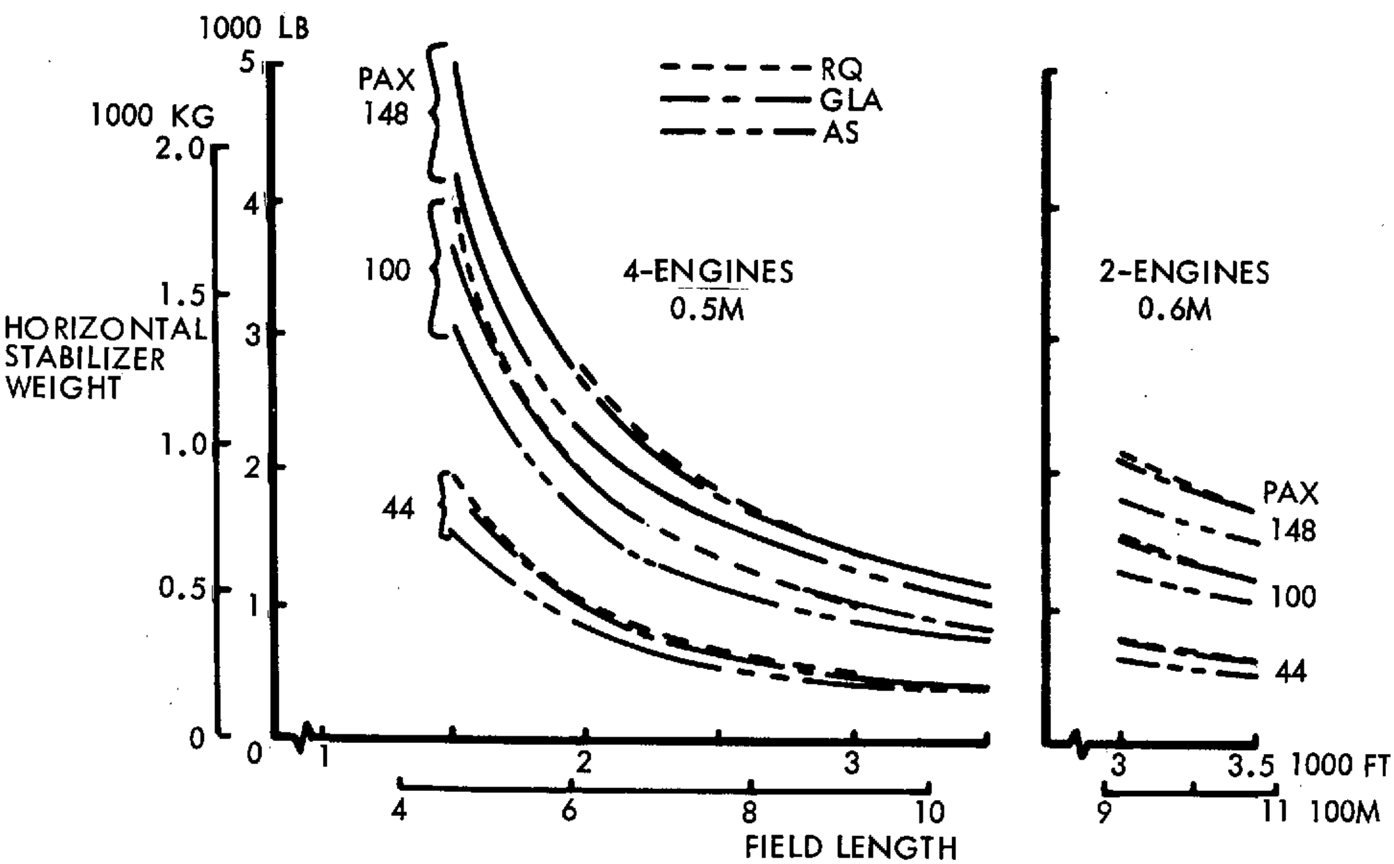

Figure 55 Effect of Active Controls on Horizontal Stabilizer Weight

The largest OWE benefits are generally provided by the AS system which can amount to 6.5 to 11 percent at the shortest field lengths. In addition to the effects of gust load alleviation the relaxation of the static stability with the AS system results in a reduction of horizontal stabilizer area and weight as shown in Figure 55 as a function of field length and passenger size. It will be noted that the GLA weights are lower than the RQ weights at the shorter field lengths due to the reduction in airplane size with GLA at the lower wing loadings. At the longer field lengths the optimization at higher wing aspect ratios results in relatively smaller wing chords and larger percent c.g. limits in terms of mean aerodynamic chord which in turn increases the required size of horizontal stabilizer. The sizing program reacts to these effects as shown in Figure 55 by the GLA weights actually being slightly higher than the RQ system weights.

The effect of relaxed static stability on stabilizer weight is shown clearly in Figure 55 by reductions of up 386 kg (850 lb). These effects are for the application of active controls while retaining the same type of stabilizer, in this case, trimmable with elevators. It is possible to obtain further reductions in horizontal stabilizer by the use of flying tails and geared elevators combined with active control systems. This further reduction has not been quantified in this program.

6.1.4 Airplane Price — The incorporation of active controls in the airplanes introduces an increase in subsystem cost for all passenger sizes and field lengths. However, in some cases, due to weight saving and resizing to smaller, more efficient airplanes, the total airplane price is actually reduced below that of the basic airplane. Figures 56 through 60 present initial airframe and total aircraft price as a function of field length and passenger size for airplanes with and without active controls. It can be seen that in almost all cases the initial price increase due to the active control system is not offset by the weight saving and resizing of the vehicle. It must be remembered however that when reoptimizing with the GLA and AS systems, the wing aspect ratio increases with a resulting improvement in efficiency, but it is also generally associated with increased weight and cost. Only at the lowest wing loadings (i.e., shortest field lengths) does the weight saving due to GLA translate into a cost reduction. This occurs because, in this case, the optimum aspect ratio is unchanged by the introduction of GLA.

Figures 61 through 63 present percent change in airframe cost due to each of the three active control systems as a function of field length for the 44, 100 and 148 passenger sizes respectively. As already mentioned, only in special cases does the cost decrease below the basic airframe cost. Note that at the shortest field lengths the GLA and AS systems cost less

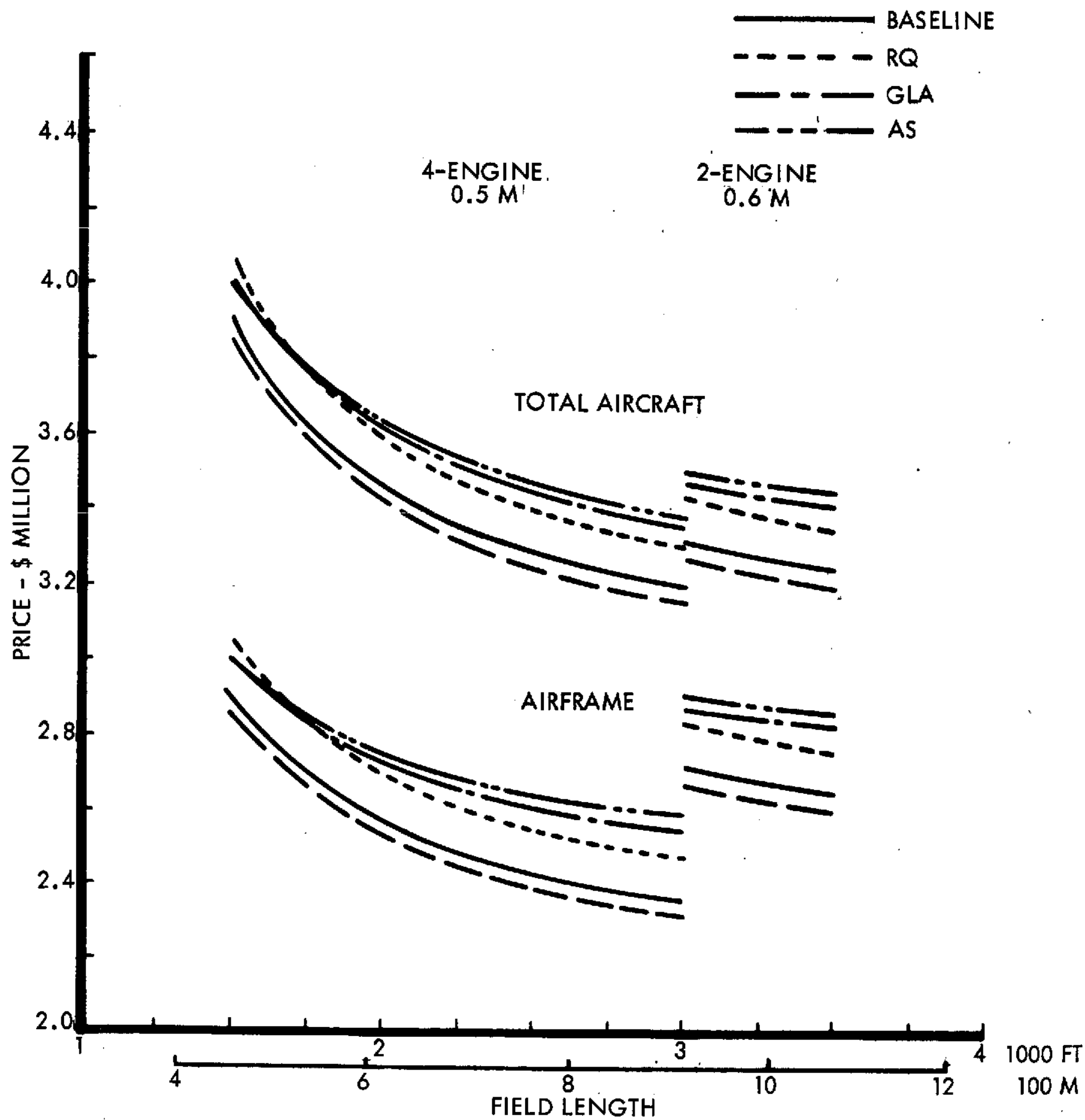

Figure 56 Effect of Active Controls on Airframe and Aircraft Price — 44 Pax

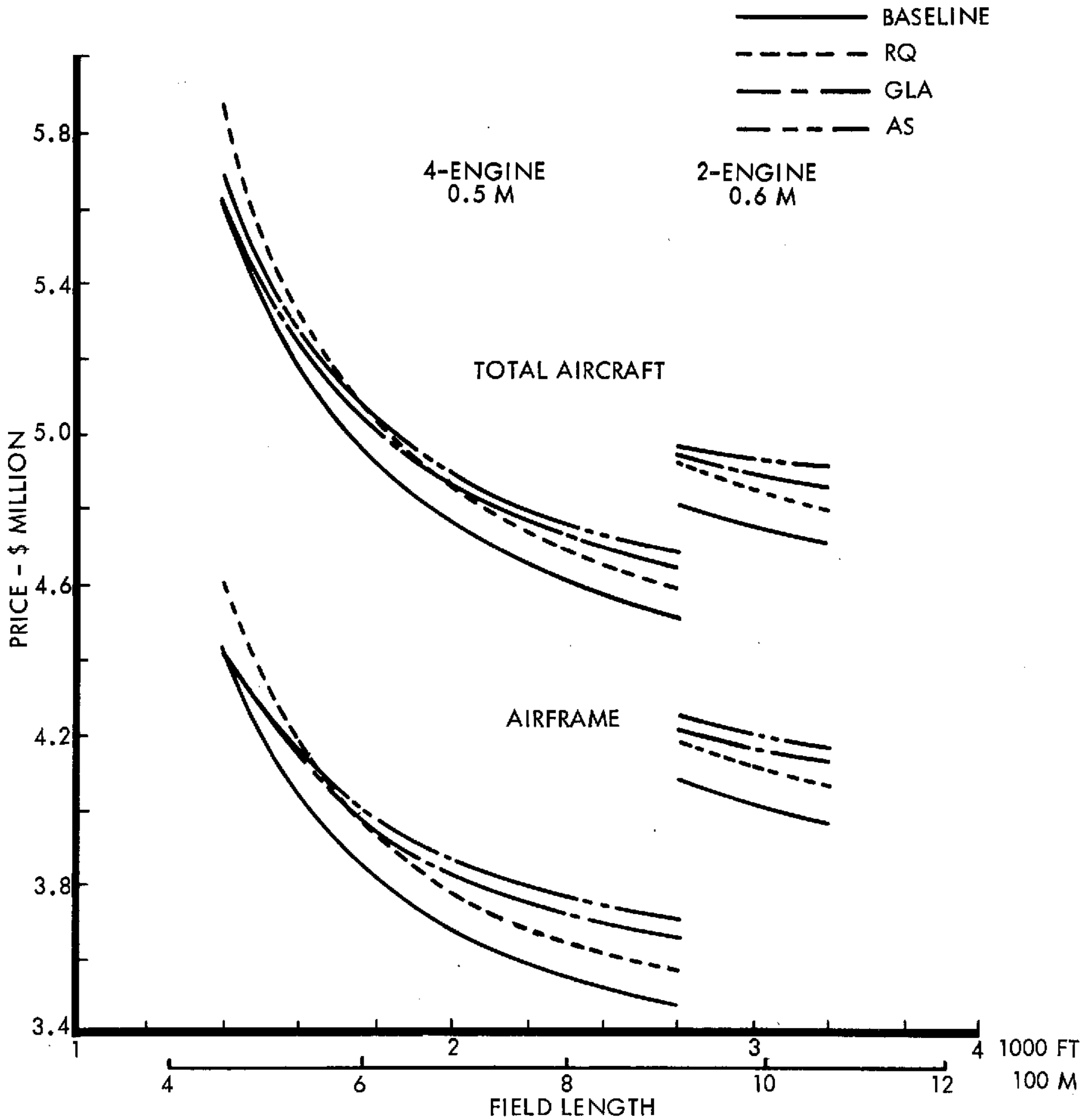

Figure 57 Effect of Active Controls on Airframe and Aircraft Price — 100 Pax

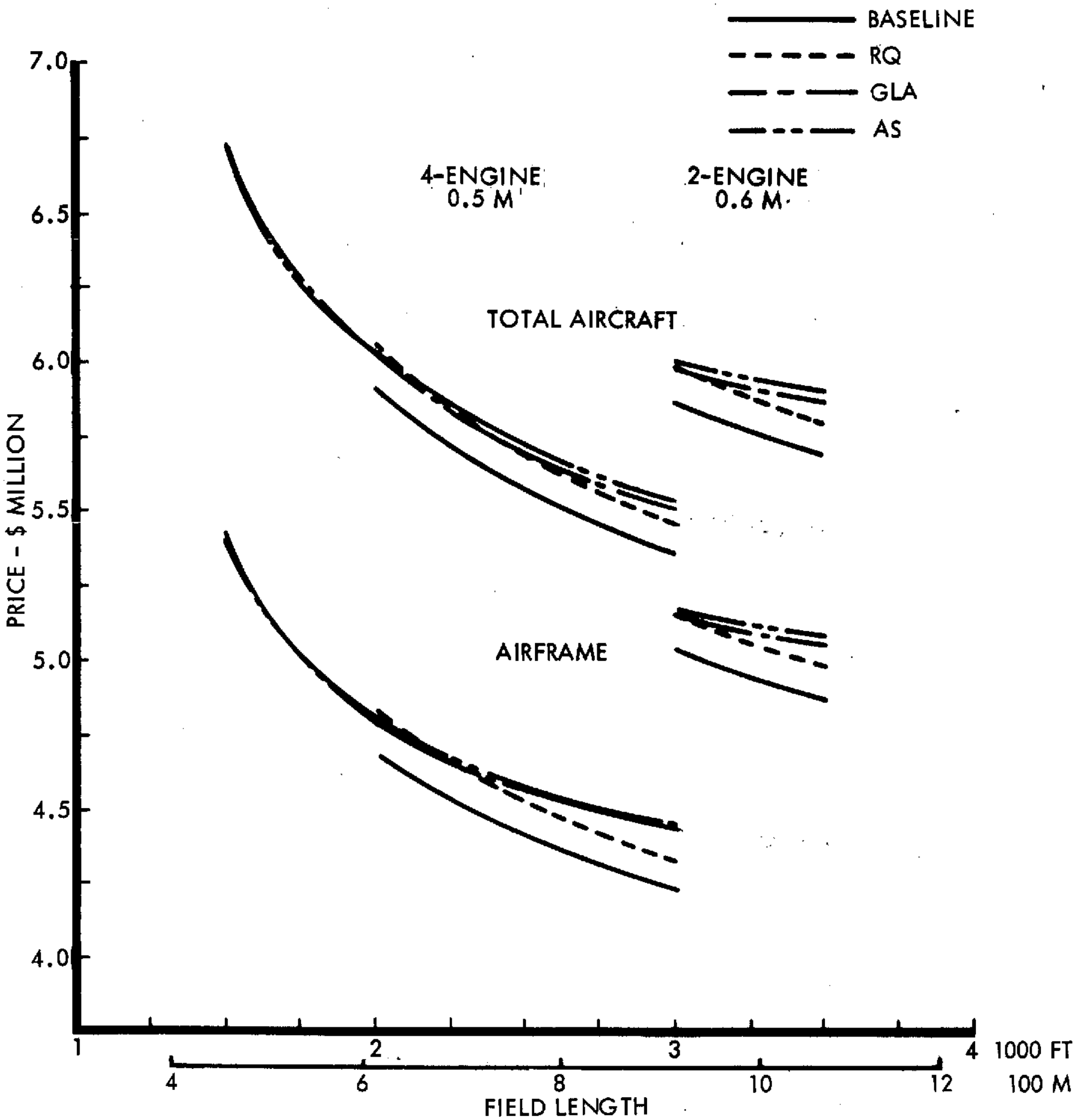

Figure 58 Effect of Active Controls on Airframe and Aircraft Price — 148 Pax

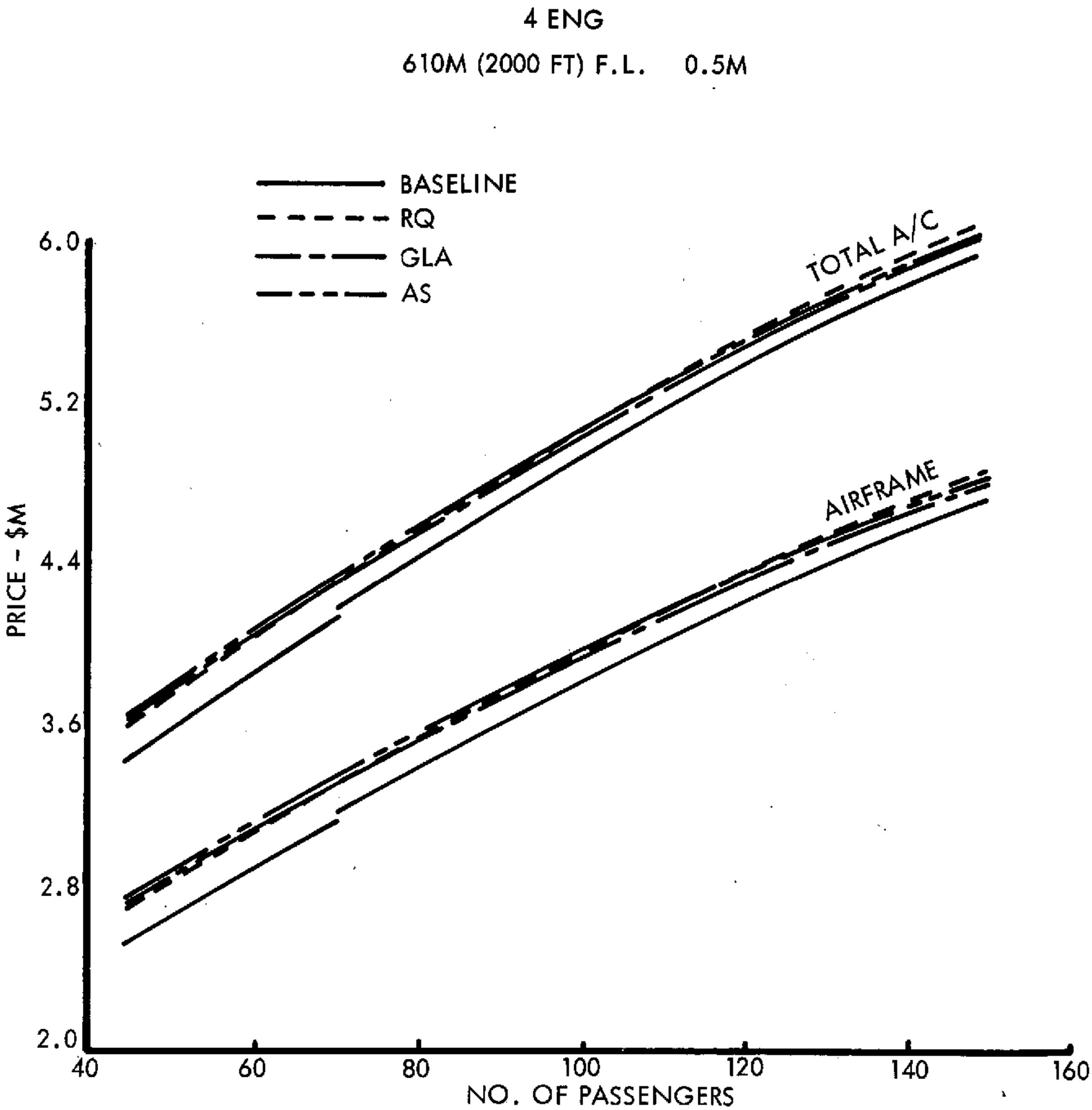

Figure 59 Airframe and Aircraft Price vs. Passenger Capacity - 4 Engines, 610 m (2000 ft) F.L

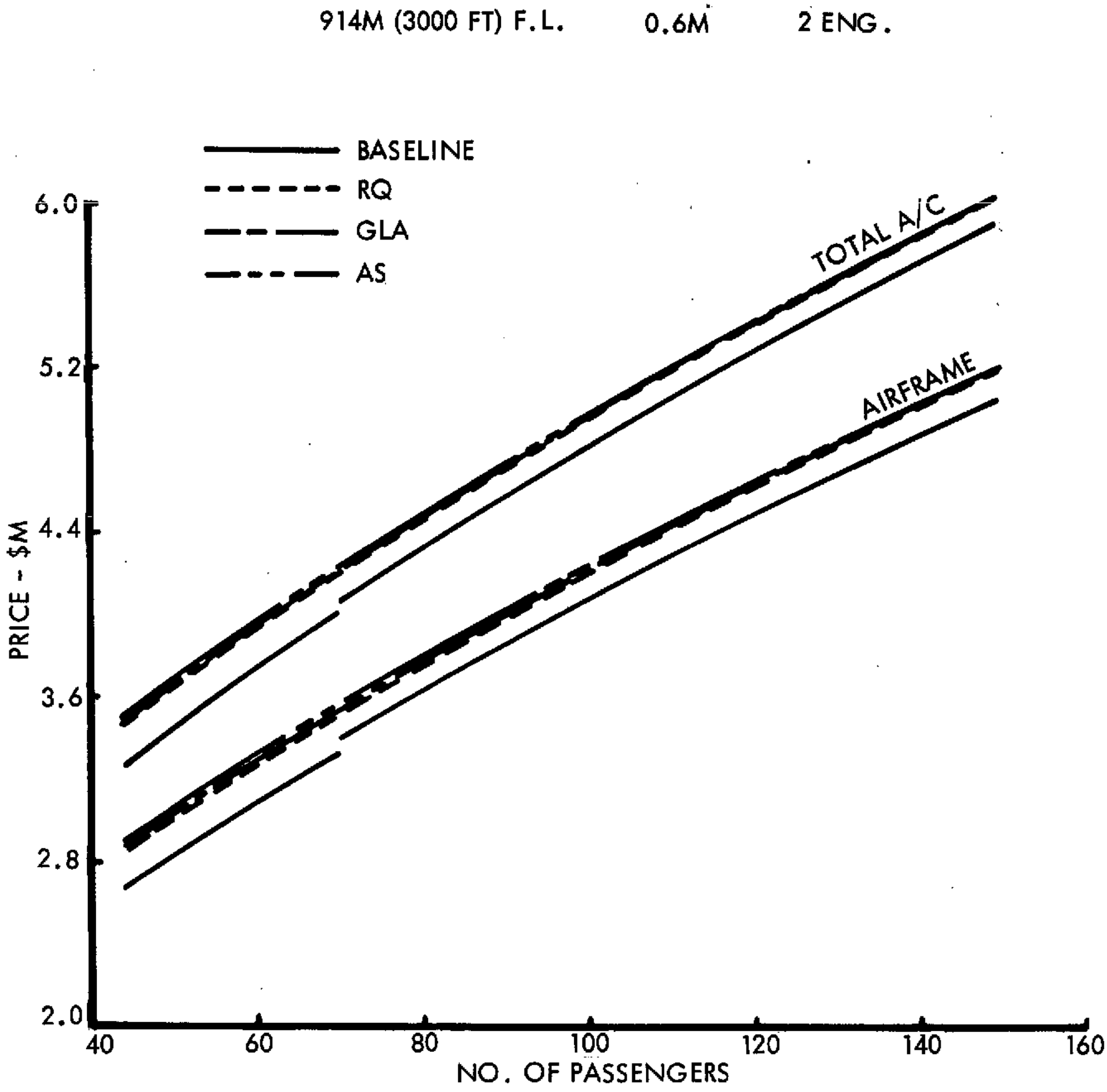

Figure 60 Airframe and Aircraft Price vs. Passenger Capacity - 2 Engines, 914 m (3000 ft) F.L

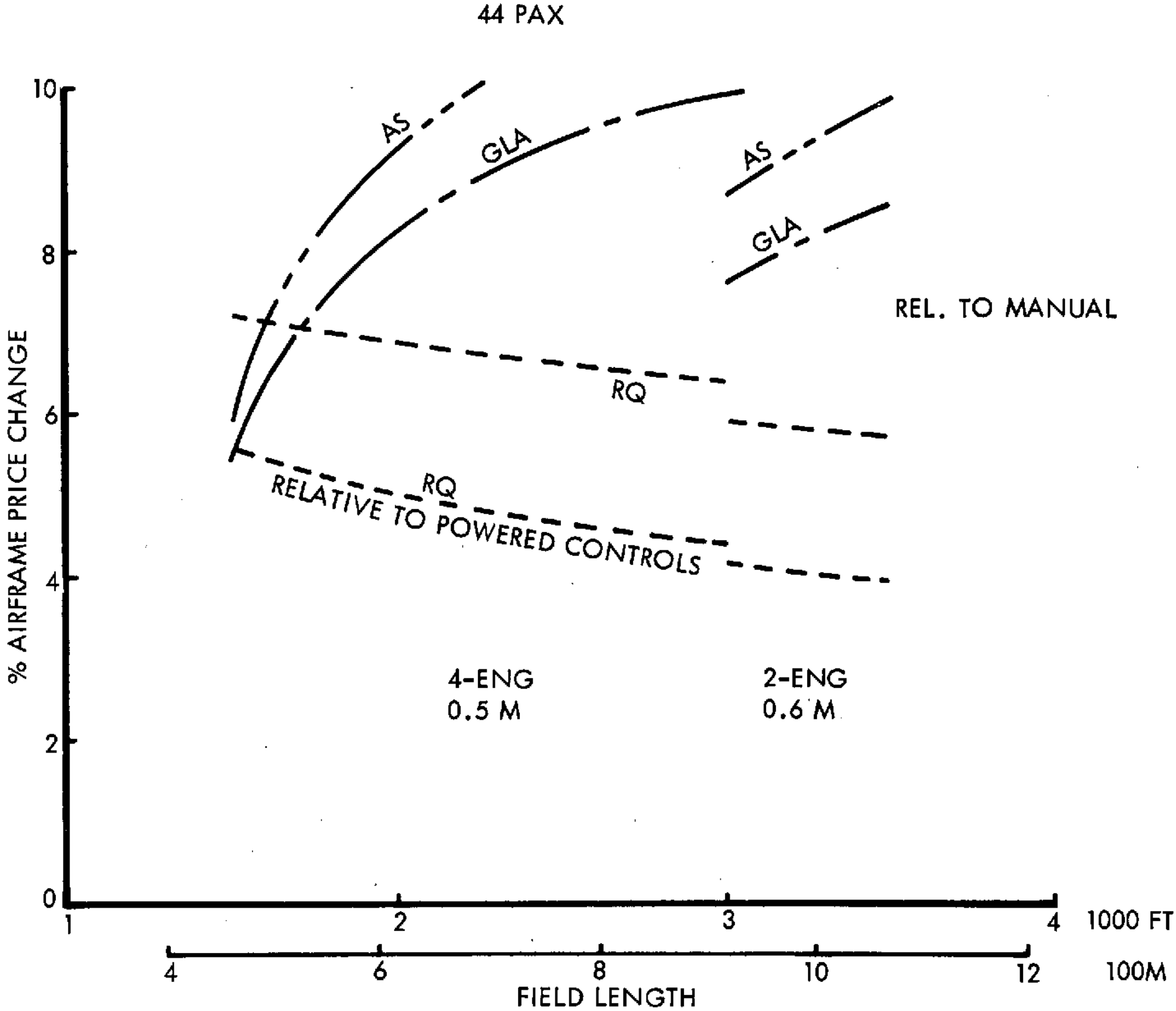

Figure 61 Percent Change in Airframe Price due to Active Controls - 44 Pax

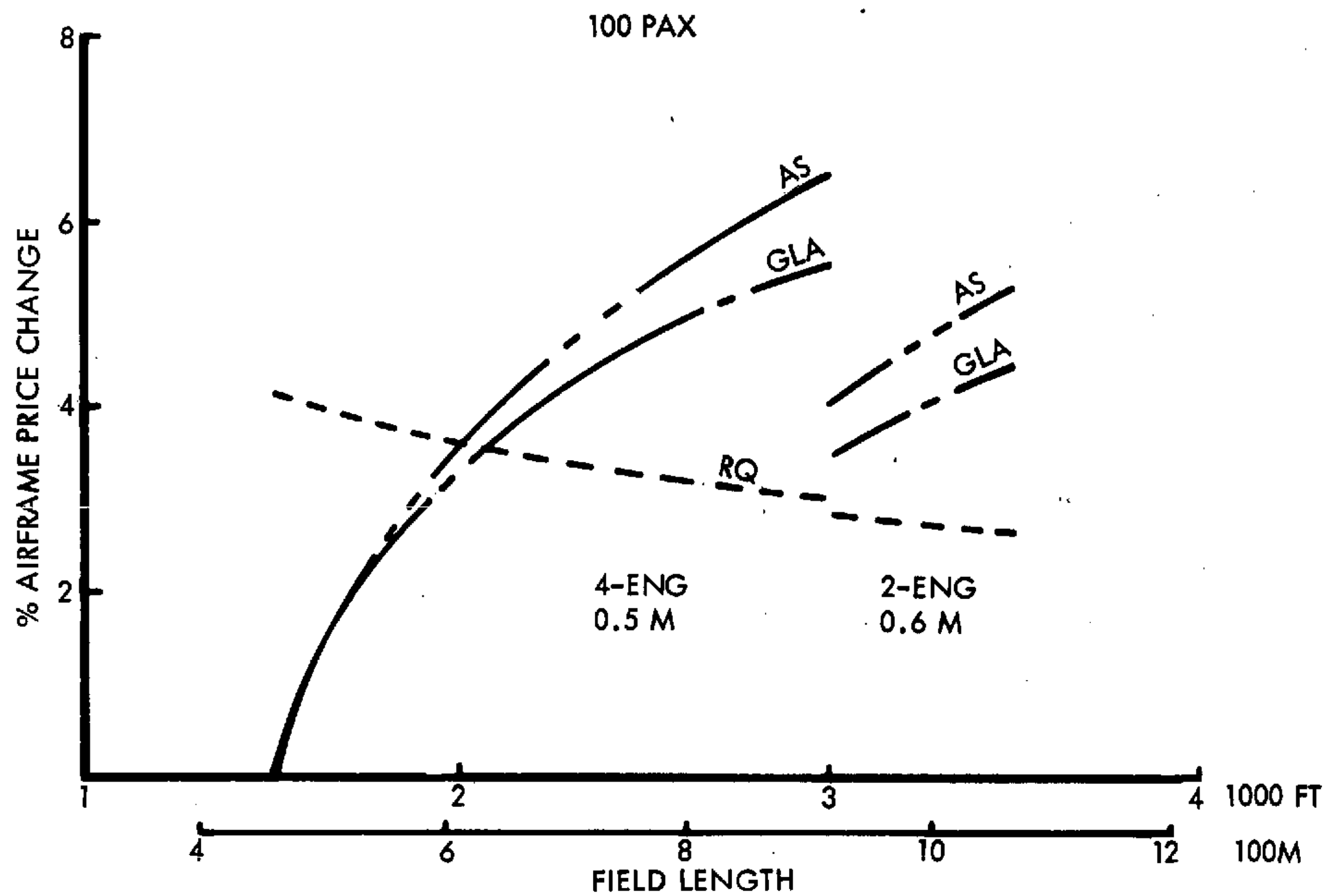

Figure 62 Percent Change in Airframe Price due to Active Controls - 100 Pax

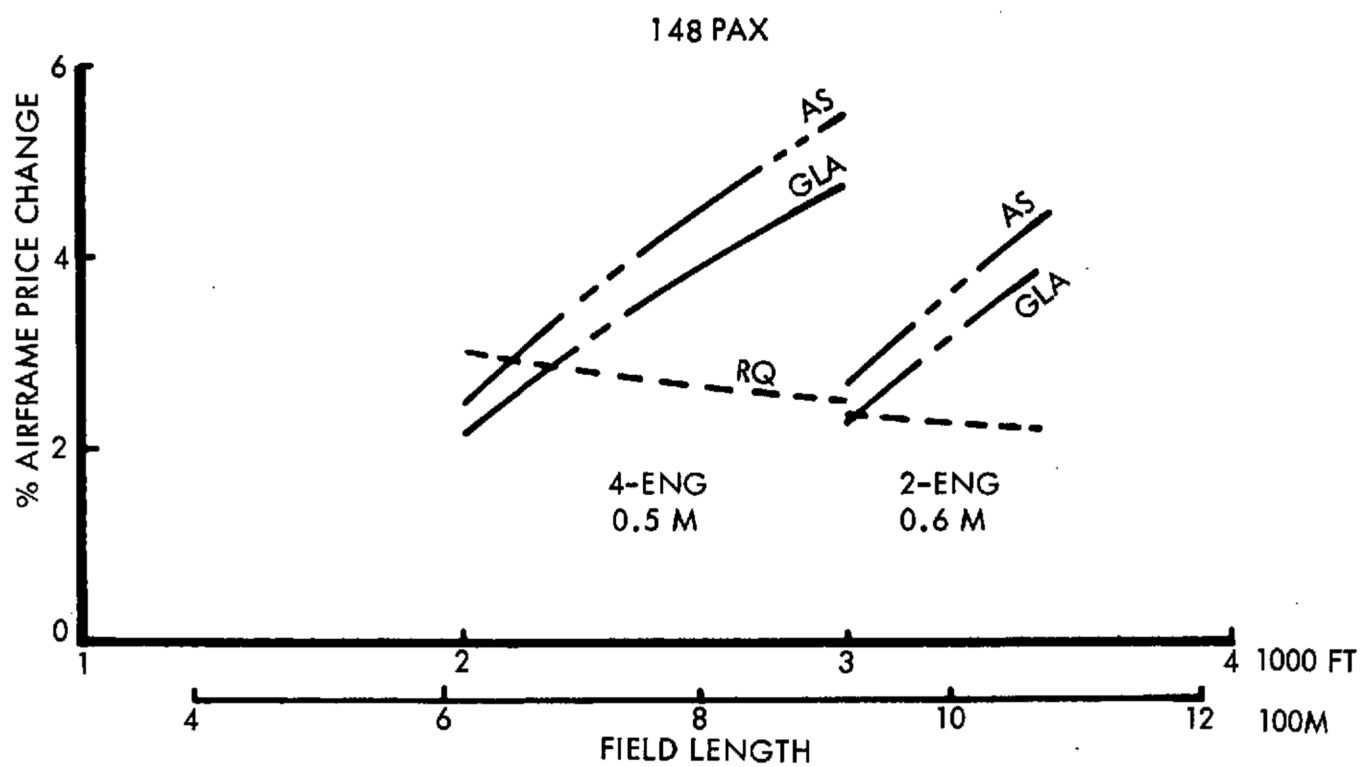

Figure 63 Percent Change in Airframe Price due to Active Controls - 148 Pax

than the RQ system while at the longer field lengths the cost effects of these systems exceed that of the RQ system. These increased costs may however be offset by the improved efficiency and result in lower direct operating costs.

Figure 64 presents percentage airframe cost change as a function of passenger capacity for the 4-engine configurations. In all cases the percentage change relative to the baseline airplane reduces with increase in passenger size. It is noteworthy that the percentage change for the RQ system airplanes increases with reduction in field length, but it reduces with reduction in field length for the GLA and AS systems.

6.2 Turbofan-Powered MF Airplane Characteristics and Comparison of Concepts

During the Ref. 1 study it was determined that the 914 m (3000 ft) field length mechanical flap (MF) concept powered by two advanced 1.35 fan pressure ratio (FPR) turbofans provided optimum DOC-2 for a 926 km (500 n.mi.) stage length at 0.7M. The wing loading of this airplane, which is illustrated in Figure 65, was 287 kg/sq. m. (58.8 lb./sq. ft.) which gives poor ride quality compared to B737 type aircraft. The methodologies discussed in the previous sections for determining the effects of active control systems on the turboprop concept have been applied to this turbofan-powered concept for the 148 passenger, 914 m (3000 ft) field length configuration.

The previous study airplanes were configured and analyzed with 1972 costs as the basis; the present study has been conducted with 1974 costs. Additionally, a very austere furnishing standard and reduced crew costs have been used in the present study for the turboprop designs with a view to obtaining the absolute minimum DOC for short-haul operation. In order to present a true comparison of the concepts, both the turbofan-powered and turboprop-powered aircraft have been resized and analyzed using consistent ground rules. The characteristics of the resulting airplanes are presented in Table XIX together with equivalent data for the over-the-wing/internally blown flap (OTW/IBF) powered lift concept. This concept, illustrated in Figure 66, was shown in Ref. 1 to have minimum DOC-2 at 0.75M when powered by four 1.35 FPR turbofan engines. The data for this airplane have been updated to 1974 costs but since its wing loading is sufficiently high to provide excellent ride quality it has not been resized with active controls.

The turboprop configuration is shown in Table XIX to have the lowest fuel consumption, DOC-2 and DOC-4 of the three concepts. It should be noted that the turboprop engine performance and cost data are based on a rubberized Detroit Diesel Allison T-56 engine. It

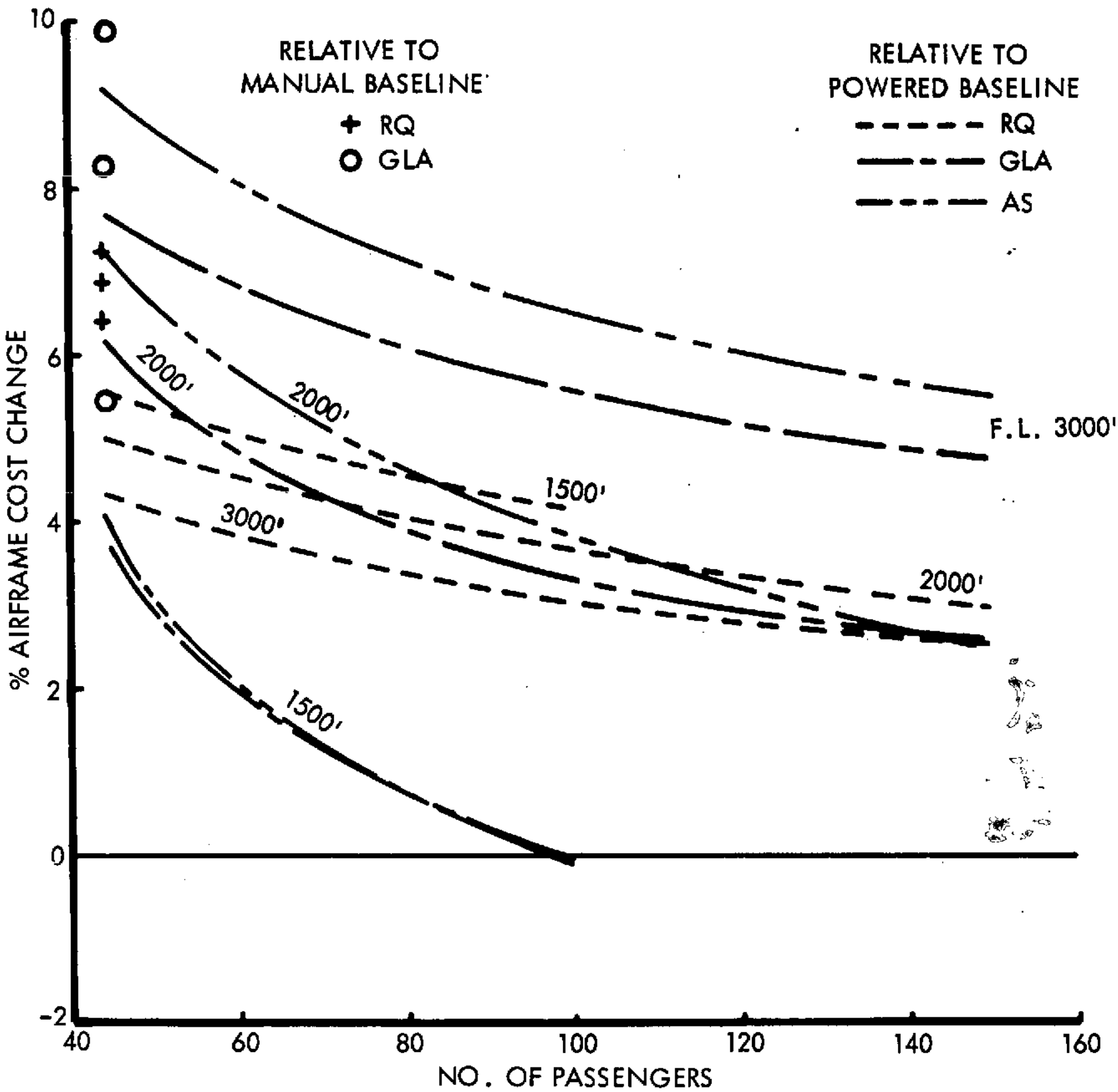

Figure 64 Percent Change in Airframe Price due to Active Controls vs. Passenger Capacity

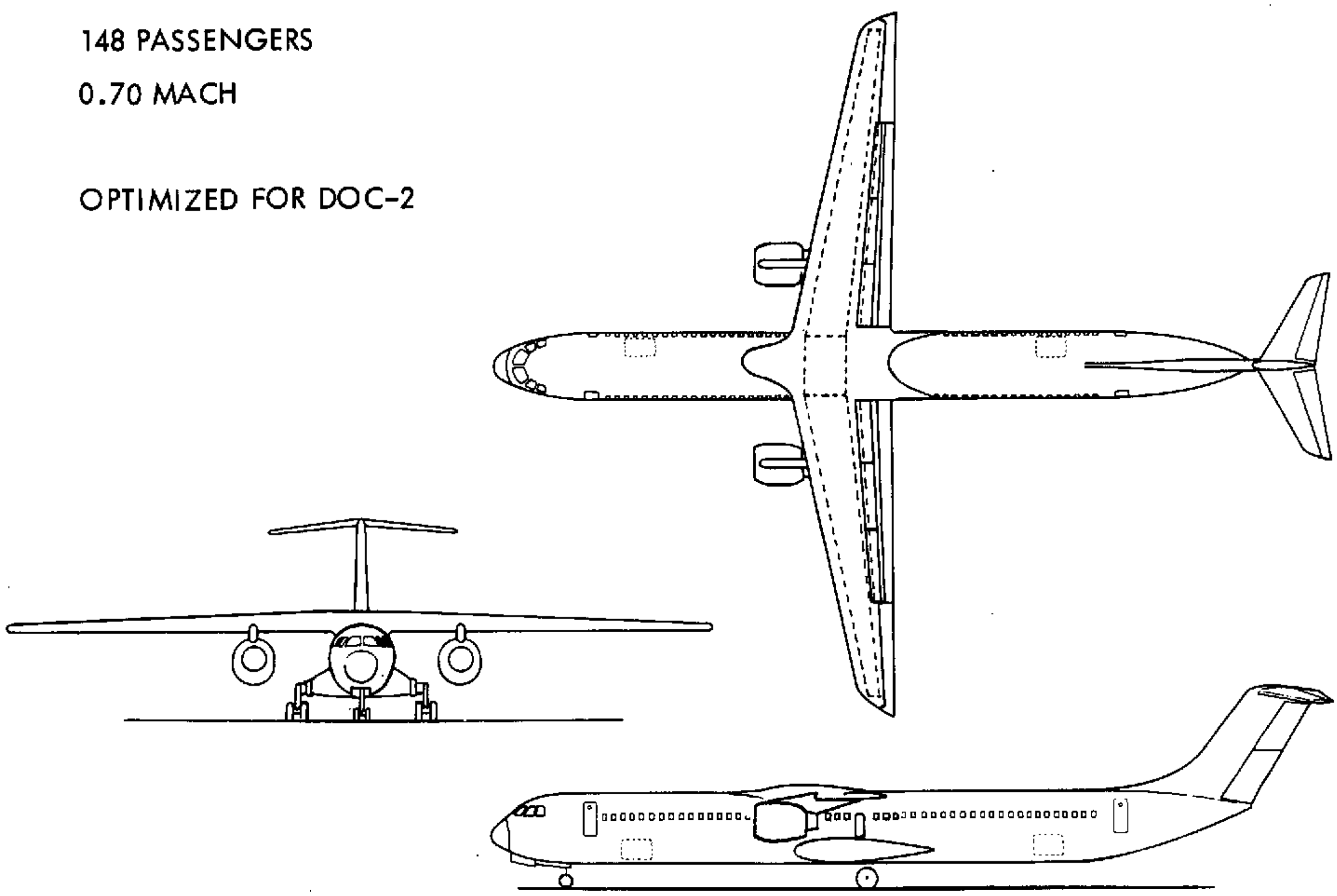

Figure 65 MF Vehicle

Table XIX Comparison of Concepts

A/C OPTIMIZED FOR DOC-2, 914M (3000 FT.) F.L., 926 KM (500 N.MI.)

CONCEPT	OTW/IBF 1.35 FPR	MF 1.35 FPR				TURBOPROP D.S.			
ACTIVE CONTROL	NONE	NONE	RQ	GLA	AS	NONE	RQ	GLA	AS
NO. OF ENG.	4	2	2	2	2	4	4	4	4
MACH NO.	0.75	0.70	0.70	0.70	0.70	0.5	0.5	0.5	0.5
OWE - KG	36,510	39,687	39,850	39,189	38,970	34,179	34,303	35,135	34,981
(LB)	80,490	87,494	87,853	86,396	85,913	75,351	75,623	77,458	77,119
RGW - KG	56,446	59,848	60,026	59,387	59,110	52,694	52,828	53,278	53,084
(LB)	124,440	131,940	132,332	130,924	130,314	116,168	116,464	117,457	117,028
RATED THRUST - KN	55.33	119.6	119.9	112.8	107.8	41.5	41.59	37.19	37.05
(LB)	12,440	26,890	26,948	25,365	24,231	9,330	9,350	8,355	8,332
MISSION FUEL - KG	4,400	4,790	4,802	4,749	4,708	3,601	3,609	3,335	3,304
(LB)	9,700	10,560	10,586	10,470	10,380	7,938	7,956	7,352	7,285
$W/S_{T.O}$ - KG/SQ.M	554	287	287	287	287	347	347	322	322
(LB/SQ.FT)	113.5	58.8	58.8	58.8	58.8	71.0	71.0	66.0	66.0
AR	12	8	8	10	10	8	8	12	12
DOC-2 ¢/ASSM	1.911	1.897	1.909	1.884	1.876	1.7866	1.799	1.793	1.788
DOC-4 ¢/ASSM	2.326	2.333	2.347	2.336	2.304	2.117	2.129	2.097	2.090
A/C PRICE $M	9.103	8.2736	8.3984	8.4015	8.3778	5.5163	5.6248	5.7253	5.7143

148 PASSENGERS

0.75 MACH

OPTIMIZED FOR DOC-2

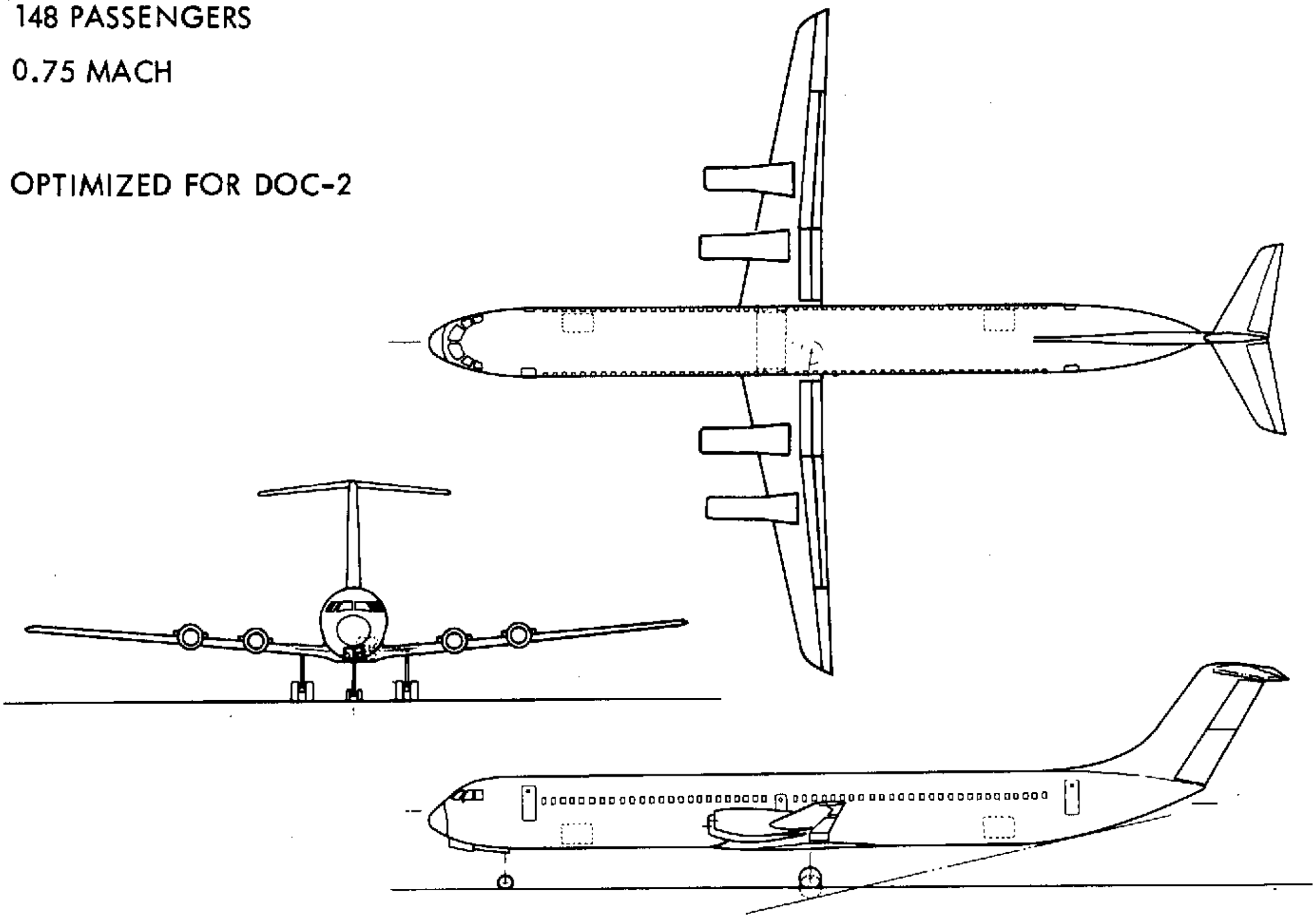

Figure 66 OTW/IBF Vehicle

is only possible to achieve these costs at the actual size of the T-56 which would result in a 200 passenger airplane with 4-engines at 914 m (3000 ft.) field length or a 48 passenger design with 2-engines at 0.6 M and 1067 m (3500 ft) field length. Alternate sizes are possible for other speeds and field lengths and by using other existing engines. It is expected that the results would be similar to the data generated using the rubberized T-56.

If a new, advanced turboprop engine having a higher cost and lower fuel consumption (Ref. 1) is used the DOC-2 and DOC-4 values are increased by 11 and 6.5 percent respectively. The turboprop is then not competitive with the other concepts at DOC-2 which suggests that a new turboprop airplane should be designed to use an existing engine unless fuel costs increase to DOC-4 values or above.

The turbofan powered MF with a ride quality system and the OTW/IBF are almost identical in DOC-2 value but the OTW/IBF has the advantage of a 9 percent lower fuel consumption. The incorporation of either the GLA or AS system improves the MF DOC-2, but it should be noted that a slight improvement in OTW/IBF DOC-2 could also be achieved by incorporating just the relaxed stability portion of the AS system. In order to match the OTW/IBF on DOC-4, the MF must incorporate the AS system.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The ride quality of short-haul airplanes with low wing loading can be improved to the standard of contemporary high wing loading airplanes by the use of active control systems. The direct operating cost penalty for improved ride quality is 2 percent or less for all cases; incorporation of gust load alleviation and augmented stability overcomes this penalty and gives better DOC than aircraft without active controls in all the very low wing loading airplanes (457 m (1500 ft) field length) and in the 100 and 148 passenger airplanes at 610 m (2000 ft) and 914 m (3000 ft) field length. For small aircraft (44 passengers) a GLA or AS system is recommended for very short field lengths but for field lengths of 610 m (2000 ft) and longer the simpler RQ system results in a smaller DOC penalty. For larger airplanes (100-148 passengers) the GLA and AS systems generally provide smaller DOC penalties than the RQ system for field lengths of less then 914 m (3000 ft). Above this field length the RQ system appears to minimize DOC effects except at the longer ranges and higher fuel prices where the increased aspect ratio of the GLA and AS systems results in improved fuel consumption and an advantage in DOC. Fuel savings of 11% were obtained by use of active controls in a 148 passenger airplane at 914 m (3000 ft) field length and 347 kg/sq. m (71 lb/sq ft) wing loading.

Weight savings were obtained with the GLA and AS system at the lower wing loadings where reoptimization did not increase wing aspect ratio. At longer field lengths and higher wing loadings the best economics of aircraft with active controls were obtained at increased aspect ratios. Fuel consumption was improved but small weight and cost penalties were incurred compared to baseline aircraft. Generally, the active control systems increased the initial cost of the airplane; the only exception being the largest aircraft at the shorter field lengths.

Due to the favorable fuel consumption and competitive direct operating costs, the turboprop-powered configuration with active controls must be considered a major contender for the short-haul low/medium density market, particularly for the shorter route segments where the time increase due to low speed is negligible. It must be stressed however that these turboprop aircraft, to be competitive, must be designed to match existing turboprop engines. The increased cost of a new turboprop engine will nullify most of the advantage of this configuration.

It may be that the low s.f.c. of a diesel engine might make consideration of this engine cycle worthwhile. Similarly since the development of a new turboprop engine is questionable it may be that a new very high bypass ratio fan would be advantageous at these speeds and field lengths., The incorporation of active controls in the turbofan MF airplane results in it being equal to the OTW/IBF hybrid in terms of DOC and ride quality. However, the OTW/IBF, because of its higher wing loading, retains its advantage of lower fuel consumption.

This study has been limited to short-haul; it is likely that larger fuel savings are available by the use of active control systems on long haul aircraft which stand to gain so much more from higher aspect ratio wings providing the wing weight increases can be minimized. Active control systems combining features such as ride quality improvement, gust load alleviation, flutter control and relaxed static stability could result in very efficient high aspect ratio wings. It is recommended that such a program be considered with the final step being the flight demonstration of the wing design.

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