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SUPPLEMENT TO FEASIBILITY OF V/STOL CONCEPTS FOR SHORT-HAUL TRANSPORT AIRCRAFT

by Bernard L. Fry

Prepared by
THE BOEING COMPANY
Morton, Pa.
for Ames Research Center

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SUPPLEMENT TO

FEASIBILITY OF V/STOL CONCEPTS FOR SHORT-HAUL TRANSPORT AIRCRAFT

By Bernard L. Fry
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SUMMARY

This report summarizes the results of additional work based on the short haul V/STOL feasibility study made by The Boeing Company under NASA Contract NAS2-3142. These additional studies cover some of the original work in more detail and revise other parts of the study in the light of the experience gained.

Examination of the aircraft designed to the ground rules of the original study showed the considerable influence on aircraft size, and therefore cost, of such parameters as flight profile and fixed equipment assumptions. A revised set of ground rules has been developed with respect to range, payload, reserves, flight profile, etc., and tilt wing and lift fan aircraft have been designed to these ground rules. More economical aircraft than those designed to the original rules have resulted.

One of the tradeoffs made in the original study investigated the effect of advanced propulsion technology. This report investigates the effect of advanced airframe and propulsion technology and shows that weight savings of more than 20 percent and direct operating cost (D.O.C.) reductions of 13 to 25 percent may be possible relative to 1970 aircraft designed to identical ground rules.

Originally, short haul V/STOL feasibility studies were made for NASA by three companies (References 1, 2, and 3).

In order to assist NASA in comparing on a common basis the various aircraft concepts designed by the three contractors, the most promising concepts have been resized using U.S. Navy Air Systems Command weight trends.

There has been little data generated to aid the prediction of lift engine installation weights, particularly for pod installations. Therefore, several types of lift engine pod have been compared, and one has been selected for more detailed study than was originally made for the jet lift VTOL. It is shown that turbojet lift engines are preferable to lift turbofan engines for wing mounted pod installations.

DEVELOPMENT OF REVISED GROUND RULES

Range and Cruise Speed

The design range of the aircraft was determined by considering the stage lengths of the major city pairs in the North East Corridor. It was assumed that initial V/STOL intercity services would not have the benefit of an exclusive enroute airways system completely divorced from the existing conventional traffic airways. Therefore, airways distances between cities were considered rather than straight line distances. The longest stage length likely to be flown by a nonstop service is the Boston to Washington run of 393 nautical miles (453 statute miles). This distance is considerably higher than any other North East Corridor stage length likely to generate sufficient traffic to warrant a nonstop service. Since one of the major problems with present short haul services is high operating costs for short stage lengths, it is necessary to reduce these costs as much as possible for V/STOL aircraft. This implies that the design range should be as short as possible, consistent with utility, so as to minimize aircraft weight and cost. It was therefore decided to select a design stage length which included a high speed cruise but which was below the Boston-Washington distance. This route would then be flown at reduced cruise speed and therefore increased specific range. The selected range with a high cruise speed is 400 statute miles. This gives the aircraft the following capability:

1. Fly the Boston-Washington route with reduction in cruise speed, for example, from 380 knots to 325 knots for the tilt wing. It will be seen in later discussion on design capacity that the traffic on the direct Boston-Washington route is quite small compared to that between other major centers, and therefore the speed compromise on this route is not a major shortcoming.

2. The tilt wing will serve city pairs up to 466 statute miles apart with full payload at cruise speed for best specific

range (280 knots). This would permit 100 percent load factor operation on the major West Coast routes, with the exception of Seattle-San Francisco and Portland-San Francisco, and all of the major Gulf Coast routes. The lift fan aircraft is operating very near to its best specific range at the design range. Its maximum range is 407 statute miles at 30 000 feet cruise altitude.

3. Permit unrefueled multihop operation of two segments of 110 statute mile stage length for the lift fan or tilt wing aircraft.

Payload

Reference 3 aircraft were studied with 60 and 120 passenger capacity. The NASA requested that The Boeing Company attempt to define the probable aircraft capacity required in the 1975 time period.

Table 1 shows the total number of air passengers per day for the major city pairs in the North East Corridor for 1975 as projected by The Boeing Company Commercial Airplane Division market forecast. This projection will not give a "cut and dried" solution to the problem of defining payload since the share of this market carried by V/STOL aircraft may vary from zero to perhaps fifty percent depending on the stimulation of the market. The problem should really be defined in terms of what is the correct size of aircraft to initiate and stimulate V/STOL intercity services. Certainly it should be as large as possible to avoid the well known trend of high direct operating cost of small capacity aircraft. On the other hand, it should not be so large that an attractive frequency of service cannot be maintained. The technical risk also increases with aircraft size.

It would seem reasonable to set 25 percent of the total short haul market as an initial target for V/STOL services. Table 1 shows the total number of passengers forecast to be carried between the major North East Corridor city pairs. This has then been converted to the number of daily flights in each direction assuming 25 percent of the total market and 60 percent load factors with 60, 90 and 120 passenger aircraft. City pairs with insufficient traffic (based on 25 percent of the total market) to support three sixty passenger aircraft per day each way at sixty percent load factor have been omitted from Table 1. It can be seen that the 120 passenger aircraft gives very poor service frequencies on all but the Boston-New York and New York-Washington routes. The 90 passenger aircraft gives minimally accepted frequencies on all but the Washington-Hartford and Boston-Baltimore routes, but the latter may be served by a Baltimore stop on some of the Boston-Washington flights. The 90 passenger aircraft would give a

TABLE 1

1975 TRAFFIC FORECAST FOR THE NORTHEAST REGION

City Pairs	Range St. Miles	Total Rev.Pass Miles/Yr Millions	Total Pass/ Day	25% V/STOL, 60% Load Factor Flights/Day Each Way		
				60 Pass	90 Pass	120 Pass
New York/Philadelphia	82	50.7	1 694	6	4	3
New York/Hartford	106	136.8	3 536	12	8	6
Philadelphia/Washington	122	81.2	1 824	6	4	3
New York/Albany	131	157.2	3 288	11	8	6
New York/Providence	153	154.6	2 769	10	6	5
Washington/Norfolk	153	137.7	2 466	9	6	4
New York/Baltimore	171	137.9	2 209	8	5	4
Boston/New York	188	1 207.7	17 602	61*	41*	31*
New York/Syracuse	193	254.8	3 617	13	8	6
New York/Washington	205	1 298.8	17 360	60*	40*	30*
New York/Rochester	249	254	2 795	10	6	5
Boston/Philadelphia	270	211	2 141	7	5	4
New York/Buffalo	291	558.7	5 260	18	12	9
Washington/Hartford	309	118.7	1 053	4	2	2
Boston/Baltimore	359	126.8	968	3	2	2
Boston/Washington	393	796.8	5 555	19	13	10

* Probably distributed between two terminals at each end

20 per day frequency between Boston, New York and Washington from and to two terminals in each city. This would give a very attractive half hourly service which should have little difficulty in diverting the 25 percent of the market required to justify such a service. The 60 passenger aircraft gives a reasonable frequency on the majority of the routes; however, the Boston-New York-Washington frequency is needlessly high, and the 60 passenger aircraft is difficult to justify considering the high direct operating cost shown in Figure 1 which gives a typical variation of D.O.C. with passenger capacity.

It is tentatively concluded that a 90 passenger aircraft would satisfy the conflicting needs of frequency and direct operating cost, and be a reasonable starting point for commercial V/STOL short haul transportation.

The original ground rules requirement to carry a revenue cargo amounting to 10 percent of the passenger payload has been dropped. This was done on the assumption that a 100 percent passenger load factor would be accompanied by a full volumetric baggage load, leaving no room for cargo. It is likely that cargo space would be sold to freight operators by the bin load (see discussion of baggage handling in the Fixed Equipment section) and carried mainly in off peak periods with a guaranteed maximum delivery time.

Reserves

In establishing the reserves required for a VTOL commercial transport aircraft, the following diversion causes have been considered:

1. VTOL system failure
2. Landing pad emergency
3. Enroute engine failure

It seems clear that the VTOL system failure is the worst case since this will require integration with the conventional ATC system, diversion to the nearest airport with sufficient runway length for the VTOL to make a conventional landing, and flying the conventional approach and landing pattern. The balanced field length requirements could be quite long for high wing loading VTOL's and therefore reduce the number of possible landing sites.

A landing pad emergency (i.e., landing pad inoperative due to approach aid failure, a disabled aircraft on the landing pad, etc.) would not give more severe requirements than the above. The worst possibility, where the nearest VTOL

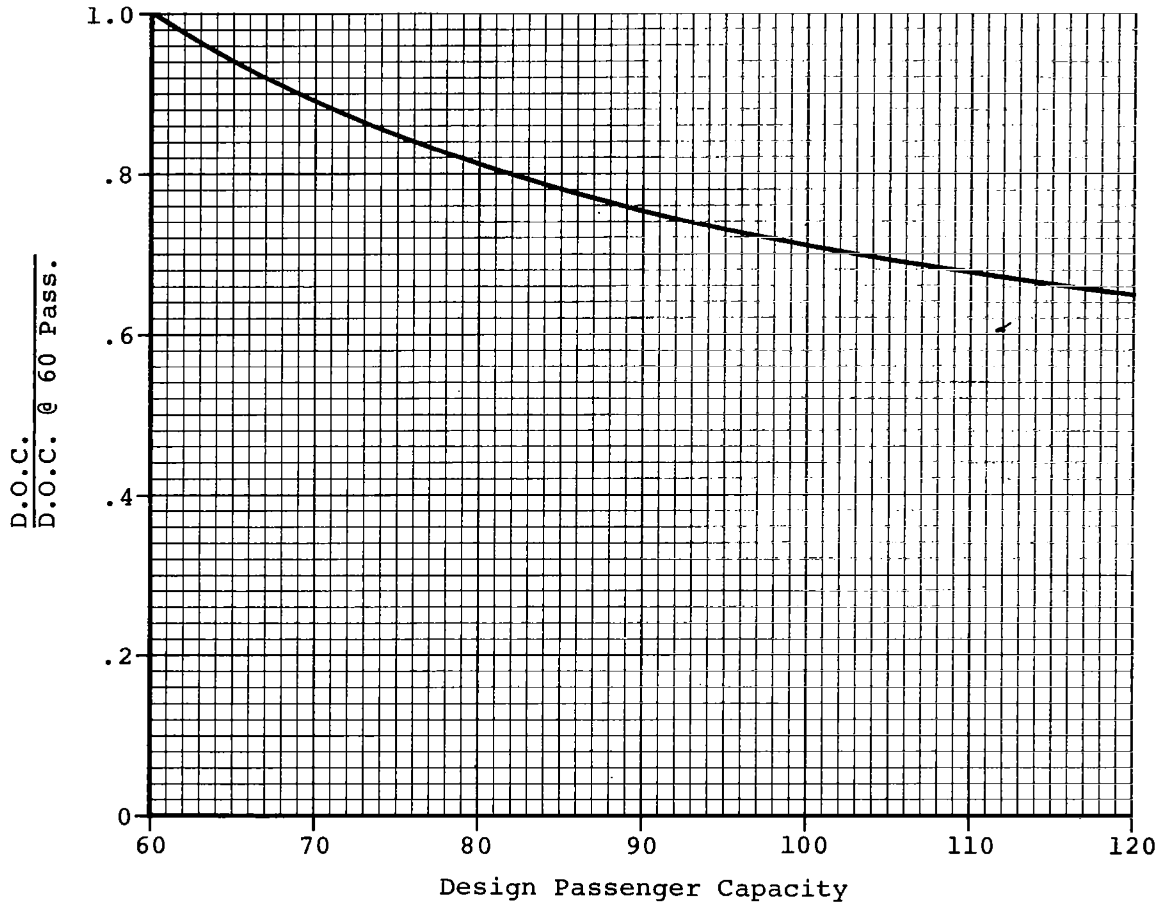


Figure 1. Typical Variation of Direct Operating Cost with Passenger Capacity.

facilities do not have space to handle diverted traffic, gives the requirements discussed above.

The enroute engine failure should be considered, but is unlikely to give a greater diversion distance than the above. Also, the fuel required to reach the original destination is available in addition to the reserve fuel. In view of the above arguments, the following reserves are suggested:

1. Five minutes at cruise power at 1 000 feet to rejoin conventional ATC system.

2. Climb to 5 000 feet, cruise at best specific range to nearest IFR airport and descend.

Fuel for conventional approach and landing is adequately covered by the unused fuel for the VTOL landing, since the emergency would be declared after attempted conversion.

The diversion distance has been determined on the assumption that the VTOL aircraft would require the runway lengths and approach aids found at major airports to make a conventional IFR landing. For the North East Corridor this distance is typically 150 nautical miles to the furthest of two alternates. For instance, a diversion from Norfolk would be to Washington or Baltimore (130 and 150 n.m.) and from Boston to any of the major New York airports (approximately 150 n.m.).

VTOL Thrust Margins and Control Criteria

The thrust margins and control criteria given in the original study ground rules (Reference 3) have not been changed with respect to the combinations of thrust margin, trim, percentages of full control power and engine out conditions which must be obtainable. The full control initial accelerations for 60 and 120 passenger aircraft given in the original ground rules have been interpolated for 90 passenger aircraft, giving the following required initial acceleration values:

Roll	0.55 Radians/sec^2
Pitch	0.27 Radians/sec^2
Yaw	0.23 Radians/sec^2

The design takeoff temperature has been increased from 86°F to 89°F to permit full payload-range operation on most days through the peak traffic summer months. For the New York-Philadelphia area 89° is exceeded, on average, fifteen days per year.

Flight Profile

The design flight profile,for computation of the fuel burned on the design stage length, has been changed considerably compared to the original ground rules. These changes stem from two main causes, the landing pattern and the inclusion of air traffic control restrictions in the vicinity of airports. The segments of the flight profile are discussed in detail below and are summarized in Figure 2.

Taxi at departure point. - One half minute has been allowed for engine starting and taxi from a dispersed loading point to the takeoff pad.

Takeoff. - The takeoff pattern established in the operational analysis section of Reference 3 has been used up to the 1 000 foot altitude point. The constant altitude acceleration to climb speed has been eliminated due to the climb speed restriction imposed by air traffic control considerations. No distance credit is allowed for takeoff.

Climb. - The initial climb up to 2 000 feet is made at 200 knots TAS. This is an existing ATC restriction which is unlikely to be removed for initial VTOL commercial operation since congestion in major airport control zones will almost certainly continue. The climb from 2 000 feet up to cruise altitude is at the speed for best rate of climb except as limited by V_{mo}, M_{mo} or a cabin angle limit of 15 degrees. This limit has been raised from 12 degrees in the original ground rules since angles of this order are reached by the newer short haul jet aircraft without adverse passenger reaction.

Cruise. - The cruise is made at maximum cruise speed, i.e., at cruise power, except where the reduction in propeller efficiency of the tilt wing would cause a high design gross weight, and thus increasing direct operating costs, to be encountered. The cruise speed-direct operating cost tradeoff conducted in the initial study (see Figure 4 of Reference 3) has been used as a guide.

Descent. - The descent to 10 000 feet is at the speed for maximum rate of descent with idle thrust or power except as restricted by V_{mo}, M_{mo} or a cabin angle limit of -6 degrees. Below 10 000 feet an ATC speed restriction of 250 knots TAS is applied and spoilers are deployed to avoid low sink rates, which typically fall to 800 feet per minute or less in the clean configuration. Spoilers increase the rate to around 1 500 feet per minute. Below 2 000 feet the speed restriction is lowered to 200 knots TAS. This descent technique is more realistic than the unrestricted (except by V_{mo} and M_{mo})

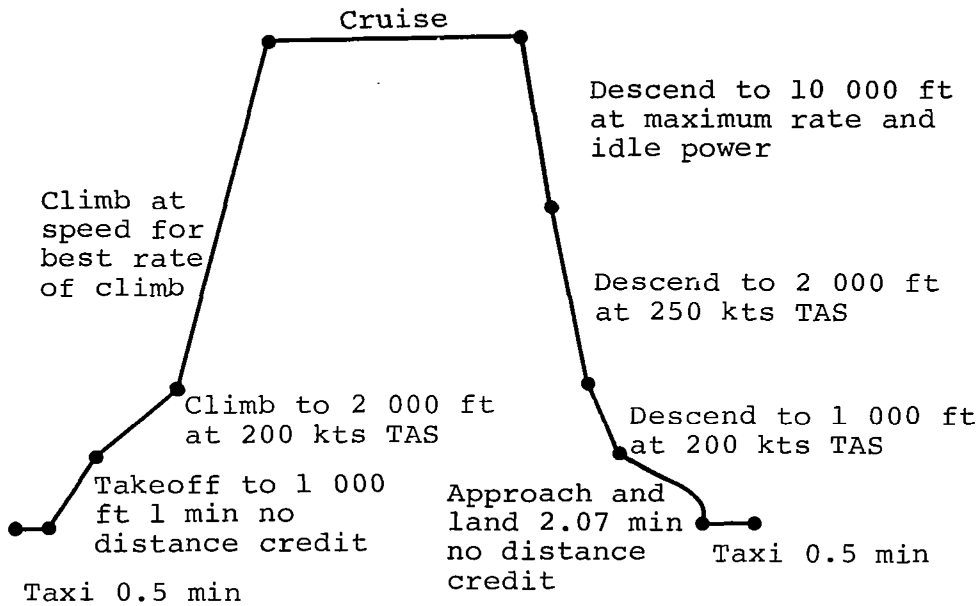


Figure 2. Flight Profile Summary.

technique used in the original ground rules which gave speed and descent rates of the order of 350 knots and 3 000 feet per minute respectively at a 1 000 foot altitude.

Landing. - The approach and landing pattern defined in the operational analysis section of Reference 3 has been used. This approach involves a steep descent (12 degrees) to minimize approach time and reduce noise levels in areas surrounding the VTOL airport. The practicability of steep approaches has not yet been established, but it appears likely that VTOL aircraft handling qualities will be sufficiently improved by the early 1970's to permit steep approaches. In fact, a high standard of handling qualities will be a prerequisite for certification of a VTOL commercial transport aircraft.

Taxi. - One half minute for taxi from the landing pad to the unloading area has been allowed.

Fixed Equipment

The fixed equipment weights for both 90 passenger aircraft designed to the original ground rules and the revised ground rules are summarized in Table 2. Very little change in total fixed equipment weight has been made for the revised ground rules, but the distribution of these weights, particularly in the furnishing and equipment group, has been changed considerably.

Discussion of an austere approach to V/STOL short haul transport design in Reference 3 suggested that gross weight could be reduced by eliminating the auxiliary power unit and airstairs from the aircraft and incorporating their functions in ground handling equipment at the landing pad. While this may be possible in the future when VTOL services become firmly established and sophisticated terminal facilities are built, it is probable that initial services in the early 1970's will operate from a mixture of new downtown facilities and existing facilities such as the Pan American Building in New York and conventional airports. Therefore, the APU and airstairs have been retained. The APU has been installed in the forward part of the right hand landing gear fairing in order to reduce installation weight. Previous designs in this study had rear fuselage installation which required more support structure and longer inlet and exhaust ducting than the gear fairing installation.

The original and revised furnishing and equipment weights are compared in detail in Table 3. The orgiginal weights reflected a furnishing standard equivalent to that of current transports, such as the Boeing 727, with a small reduction in seat weight. The new ground rules have a generally more austere

TABLE 2
FIXED EQUIPMENT WEIGHT COMPARISON
90 PASSENGER AIRCRAFT

Items	Original Ground Rules	Revised Ground Rules
	lbs	lbs
Auxiliary Power Unit	530	450
Instruments and Navigation	675	675
Hydraulics	490	450
Electrical	2125	1900
Electronics	750	750
Furnishings and Equipment	(6694)	(6434)
Flight Provisions	515	490
Passenger Accommodations	5200	4157
Cargo Handling	642	1470
Emergency Equipment	337	317
Air Conditioning and Anti-icing	1423	1423
TOTALS	12687	12082

TABLE 3
FURNISHINGS AND EQUIPMENT WEIGHT COMPARISON
90 PASSENGER AIRCRAFT

Items	Original Ground Rules lbs	Revised Ground Rules lbs
Flight Provisions	(515)	(490)
Pilots Seats	119	100
Instrument Board	63	63
Windshield Wipers	15	15
Rain Repellent System	12	12
Soundproofing and Attachments	172	200
Lining and Attachments	57	40
Partitions	50	50
Coat Rack, Sunvisors, etc.	27	10
Passenger Accommodations	(5200)	(4157)
Seats and Belts	2162	1440
Service Units	376	225
Hat Rack	300	350
Window Shades	30	30
Coat Compartments	43	30
Floor Coverings	240	200
Galley Partitions, etc.	44	44
Soundproofing and Attachments	529	700
Lining (Interior Trim)	903	903
Toilets	419	175
Washing and Drinking Facilities	94	30
Misc.	60	30
Cargo Handling	(642)	(1470)
Nets	40	-
Tiedowns	25	-
Conveyer and Locking Mechanism	-	70
Cargo Bins	-	840
Lining and Attachments	240	220
Soundproofing and Attachments	137	140
Partitions	70	70
Cargo Floor	125	125
Misc.	5	5
Emergency Equipment	(337)	(317)
Oxygen (Crew and Passengers)	154	134
Fire Extinguishers	31	31
Escape Provisions	55	55
Fire Detection and Extinguishing	97	97
TOTALS	6694	6434

approach to cabin furnishings with reductions in the weight of seats, passenger service units and floor coverings and elimination of one of the two toilets. The latter is justified on the basis that transcontinental jets have two toilets for the use of 100 economy class passengers, and therefore one should be sufficient for 90 passengers on flights of 1.5 hours duration. These weight savings in cabin furnishings are partially offset by increases in overhead rack weight to allow for closures to permit these racks to carry hand baggage, and increased soundproofing weight, which has been added to give a more realistic allowance for the higher noise generation of VTOL aircraft compared to conventional aircraft. However, there is still a net saving in the passenger accommodations group of over 1 000 pounds. The cargo handling system has been changed considerably. The original aircraft had a weight allowance for a conventional cargo compartment with nets and tie down points. The ground rules have been changed to give a baggage handling system which will permit rapid turnaround times for multihop short stage length operation. Weight has been allowed for 14 baggage bins tailored to the cargo compartment cross section and a system for conveying the bins along the compartments and locking them in place. The additional cargo handling group weight offsets most of the saving in the passenger accommodation group.

Aircraft Designed to the Revised Ground Rules

The NASA directed that tilt wing and lift fan aircraft be designed to the revised ground rules because these types were the most promising VTOL aircraft in the original study of Reference 3 and would possibly derive economic benefits from the revisions to the ground rules. Ninety passenger aircraft have been designed to the original ground rules for direct comparison. The revised ground rules aircraft follow the design philosophy, general configuration and basic parameters, such as wing loading aspect ratio, etc., used in designing the 60 and 120 passenger aircraft in the original study. Therefore, the general discussion in the Configuration Analysis section of Reference 3 applies to these aircraft. The only changes made with respect to the aircraft descriptions of Reference 3 were in the disc loading of the tilt wing, which was lowered slightly to maintain the power loading at the higher design takeoff temperature in the revised ground rules, and the reduced V_{mo} of the tilt wing. This V_{mo} was reduced from 390 to 344 knots E.A.S. because of the descent speed limit imposed by air traffic control requirements at altitudes below 10 000 feet. The 390 knot figure was originally established to permit high speed descents in the original ground rules. The lift fan V_{mo} has not been changed because its high cruise speed capability allows

400 knots E.A.S. to be reached when cruising at 10 000 feet altitude. The lower V_{mo} of the tilt wing has also lowered the gust load factor such that the aircraft is no longer gust critical.

Three view drawings of the aircraft designed to the new ground rules are shown in Figures 3 and 4. Tables 4 and 5 give comparisons of the tilt wing aircraft weights and general characteristics ,and Tables 6 and 7 show similar data for the lift fan aircraft. These tables compare the 60, 90 and 120 passenger aircraft designed to the original ground rules and the new 90 passenger aircraft. It can be seen that application of the revised ground rules results in considerable weight reductions. Figures 5 and 6 compare the sizes of the tilt wing and lift fan aircraft respectively. Included in these comparisons are the advanced technology aircraft discussed in the next section of the report. The payload versus range characteristics of the tilt wing and lift fan aircraft designed to the revised ground rules are shown in Figure 7. This data is given for the high speed cruise case and the best range cruise speed.

The breakdown of fuel for the various mission segments is given in Table 8. The net effect of the revised ground rules is to reduce the total fuel required for both aircraft types by 18 percent. The lift fan fuel burned does not reduce by quite as high a percentage as the tilt wing due to the more severe effect of the revised descent speed restrictions. However, this is offset by the reduction in lift fan reserve fuel; this part of the fuel load increases in the tilt wing. This is due to the removal of the go-around in the VTOL mode required in the original reserves, which obviously had a more severe effect on the lift fan than the tilt wing.

The sensitivity of gross weight to design range, which was derived from the aircraft sizing process with the revised ground rules, is shown in Figure 8. It can be seen that this sensitivity is small. This is due to the fact that a small percentage increase in total available fuel (and therefore gross weight) gives a larger percent increase in cruise fuel and therefore a significant increase in range.

The D.O.C. of the 90 passenger aircraft designed to the revised ground rules are presented in Figures 9 and 10. They are compared with the 60, 90 and 120 passenger aircraft designed to the original ground rules. Figures 9 and 10 have been cross-plotted at 100 miles stage length in Figure 11 to show the sensitivity of D.O.C. to passenger capacity directly. All of the data for original ground rule aircraft is given for the "short pattern" nonproductive time, i.e., one minute each for taxi out, takeoff, land and taxi in.

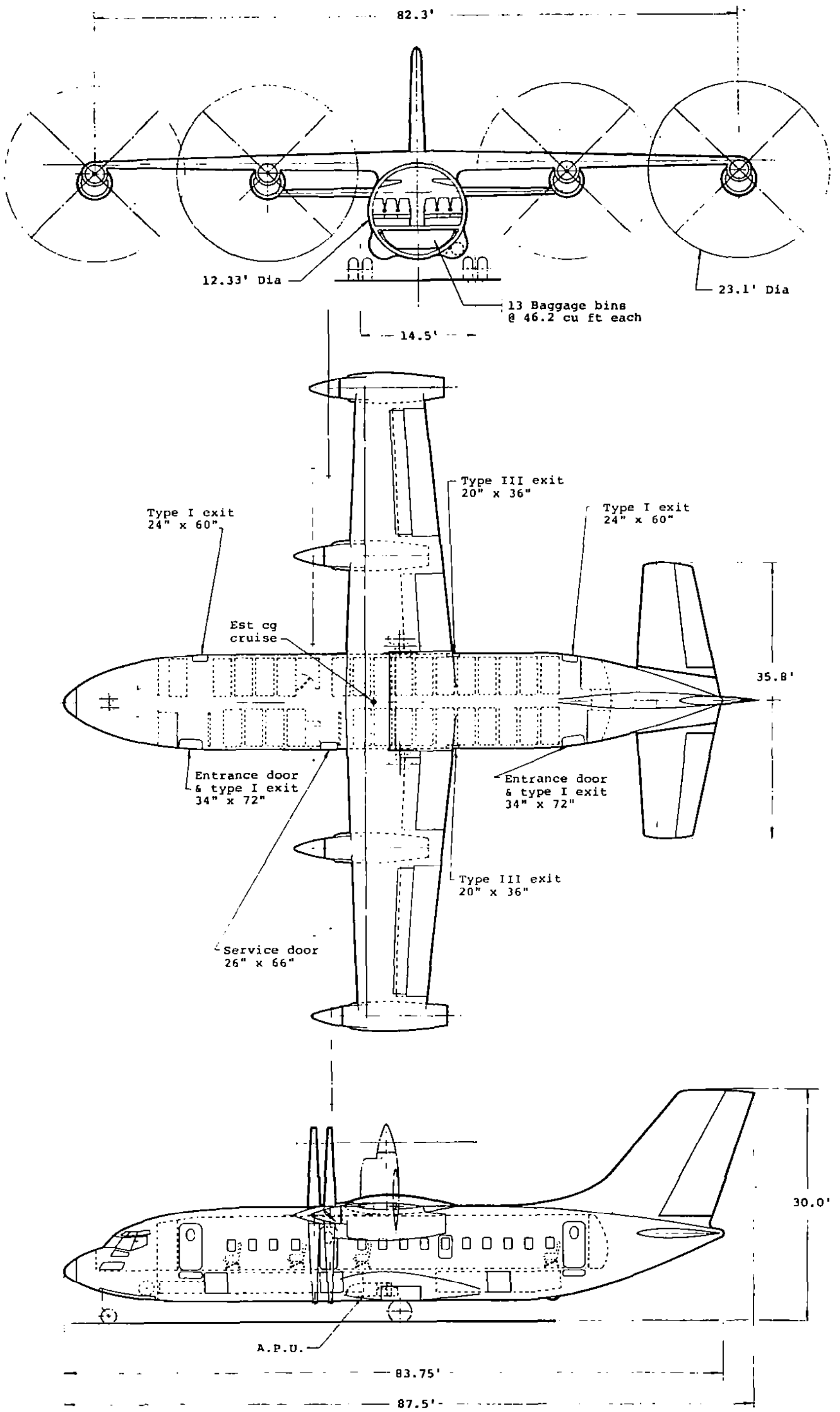


Figure 3. Tilt Wing VTOL General Arrangement.

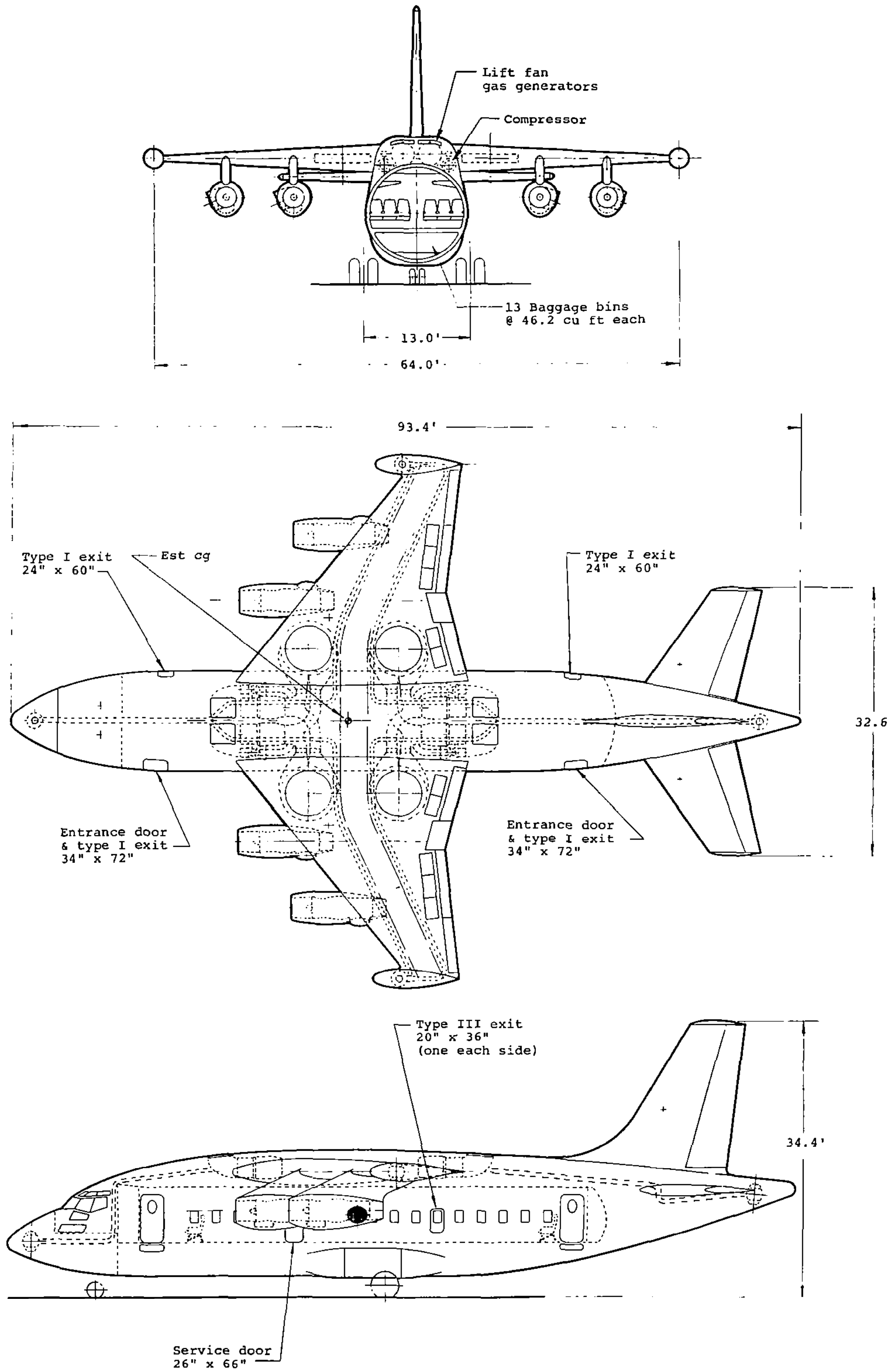


Figure 4. Lift Fan VTOL General Arrangement.

TABLE 4
SUMMARY OF TILT WING VTOL WEIGHTS (POUNDS)

Passenger Capacity:				
Original Ground Rules	60	90		120
Revised Ground Rules			90	
Wing	5250	6700	6075	8119
Tail	1937	2350	2160	2854
Body	9620	11329	11000	13196
Alighting Gear	2775	3320	3080	3900
Flight Controls	4172	5160	4750	6130
Power Plant Installation	(15605)	(20285)	(18515)	(24771)
Engine Section	1250	1580	1420	1920
Engine Installation	3820	4920	4500	5956
Drive System	5310	7080	6420	8802
Fuel System	350	450	430	475
Engine Controls	100	100	100	100
Starting System	170	180	175	190
Propeller Installation	4605	5975	5470	7328
Auxiliary Power Unit	530	530	450	530
Instruments & Navigation	675	675	675	675
Hydraulics	450	490	450	525
Electrical	2000	2125	1900	2250
Electronics	750	750	750	750
Furnishings & Equipment	5120	6694	6434	8278
Air Conditioning Anti-Icing	1370	1423	1423	1495
WEIGHT EMPTY	50254	61831	57662	73473
Crew and Crew Luggage	520	660	660	660
Unusable Fuel & Oil	175	175	175	175
Engine Oil	100	100	100	100
Passenger Service Items	655	703	653	750
OPERATING WEIGHT EMPTY	51704	63469	59250	75158
Passengers & Luggage	12000	18000	18000	24000
Revenue Cargo	1200	1800	-	2400
Fuel	6800	8731	7250	10400
TAKEOFF GROSS WEIGHT	71704	92000	84500	111958

TABLE 5
SUMMARY OF TILT WING GENERAL CHARACTERISTICS

Passenger Capacity:				
Original Ground Rules	60	90		120
Revised Ground Rules			90	
Physical Data				
Wing				
Area	787	998	946	1 200
Span (ft)	79.5	88.8	82.3	97.2
Aspect Ratio	8.03	7.91	7.16	7.86
Sweep at 1/4 Chord (degrees)	0	0	0	0
(t/c) Root Fuselage	0.18	0.18	0.18	0.18
(t/c) Tip	0.09	0.09	0.09	0.09
Horizontal Tail Area (sq ft)	238	283.5	280	310
Vertical Tail Area (sq ft)	79.5	86.4	83.75	102.75
Design Cruise Conditions				
Cruise Speed (kt TAS)	380	380	380	380
Cruise Altitude (ft)	30 000	30 000	30 000	30 000
Structural Limits				
V_{MO} (kts EAS)	390	390	344+	390
M_{MO}	0.72	0.72	0.72	0.72
V_D (kts EAS)	425	425	390	425
N_{LIMIT}	3.09*	3.05*	2.5	3.0*
Propellers				
Diameter (ft)	21.05	23.85	23.2	26.33
Number of Blades	4	4	4	4
Solidity	0.25	0.25	0.25	0.25
Maximum Tip Speed (fps)	850	850	850	850
Cruise Powerplants				
Number	4	4	4	4
Maximum Power/Engine (ESHP)	6 741	8 650	7 820	10 487
Pressure Ratio	14	14	14	16
T_4 °R	2 600	2 600	2 600	2 600

* Gust critical.
\+ Lowered due to ATC speed restriction below 10 000 feet

TABLE 6
SUMMARY OF LIFT FAN VTOL WEIGHTS (POUNDS)

Passenger Capacity:				
Original Ground Rules	60	90		120
Revised Ground Rules			90	
Wing	5774	7460	6600	9559
Tail	2557	2940	2625	3447
Body	11890	12733	12043	14060
Alighting Gear	3155	3885	3400	4489
Flight Controls	2000	2100	2035	2210
Reaction Controls	2030	2400	2250	2660
Power Plant Installation	(15411)	(18200)	(16670)	(21824)
Engine Section - Cruise	1344	1600	1500	2100
Engine Installation - Cruise	5000	6000	5500	7026
Lift Gas Generators	2660	3110	2700	3720
Fan and Ducting Installation	5452	6450	6000	7858
Fuel System	475	550	490	610
Engine Controls	300	300	300	310
Starting System	180	190	180	200
Auxiliary Power Unit	530	530	450	530
Instruments & Navigation	700	700	675	700
Hydraulics	450	500	490	529
Electrical	2000	2100	1860	2250
Electronics	750	750	750	750
Furnishings & Equipment	5182	6694	6434	8318
Air Conditioning and De-Icing	1430	1450	1420	1535
WEIGHT EMPTY	53859	62442	57696	72871
Crew and Crew Luggage	520	660	660	660
Unusable Fuel & Oil	175	175	175	175
Engine Oil	100	100	100	100
Passenger Service Items	655	703	653	750
OPERATING WEIGHT EMPTY	55309	64080	59284	74556
Passenger & Luggage	12000	18000	18000	24000
Revenue Cargo	1200	1800		2400
Fuel	10720	13120	10910	14541
TAKEOFF GROSS WEIGHT	79229	97000	88194	115497

TABLE 7

SUMMARY OF LIFT FAN VTOL GENERAL CHARACTERISTICS

Passenger Capacity:				
Original Ground Rules	60	90		120
Revised Ground Rules			90	
Physical Data				
Wing				
Area (sq ft)	1 055	1 260	1 146	1 455
Span (ft)	58.6	67	63.33	75
Aspect Ratio	3.20	3.5	3.5	3.90
Sweep at 1/4 Chord (Degrees)	35	35	35	30
(t/c) Root Fuselage	.145	.145	.145	.145
(t/c) Tip	.10	.10	.10	.10
Horizontal Tail Area (sq ft)	360	352	311	410
Vertical Tail Area (sq ft)	188	211	181	240
Fuselage Length (ft)	82.5	96	93.4	106
Design Cruise Conditions				
Cruise Speed (kt TAS)	466	466	466	466
Cruise Altitude (ft)	30 000	30 000	30 000	30 000
Structural Limits				
V_{MO} (kts EAS)	400	400	400	400
M_{MO}	.83	.83	.83	.83
V_D (kts EAS)	450	450	450	450
N_{LIMIT}	2.5	2.5	2.5	2.5
Cruise Powerplants				
Number	4	4	4	4
Maximum Thrust (lbs)	6 060	8 525	7 760	10 110
Bypass Ratio	3	3	3	3
Pressure Ratio	20	20	20	20
T_4	2 600	2 600	2 600	2 600
Lift Powerplants				
Number	4 Gas Gen., 4 Lift Fans			
Maximum Thrust (lbs) per fan	17 600	21 530	19 570	25 250
Fan Bypass Ratio/Pressure Ratio	8/1.3	8/1.3	8/1.3	8/1.3
Pressure Ratio (Gas Generators)	12	12	12	12
T_4 °R	2 600	2 600	2 600	2 600
Fan Diameter (ft)	6.45	6.88	6.65	7.37
Effective Thrust Augmentation Ratio	2.5	2.5	2.5	2.5

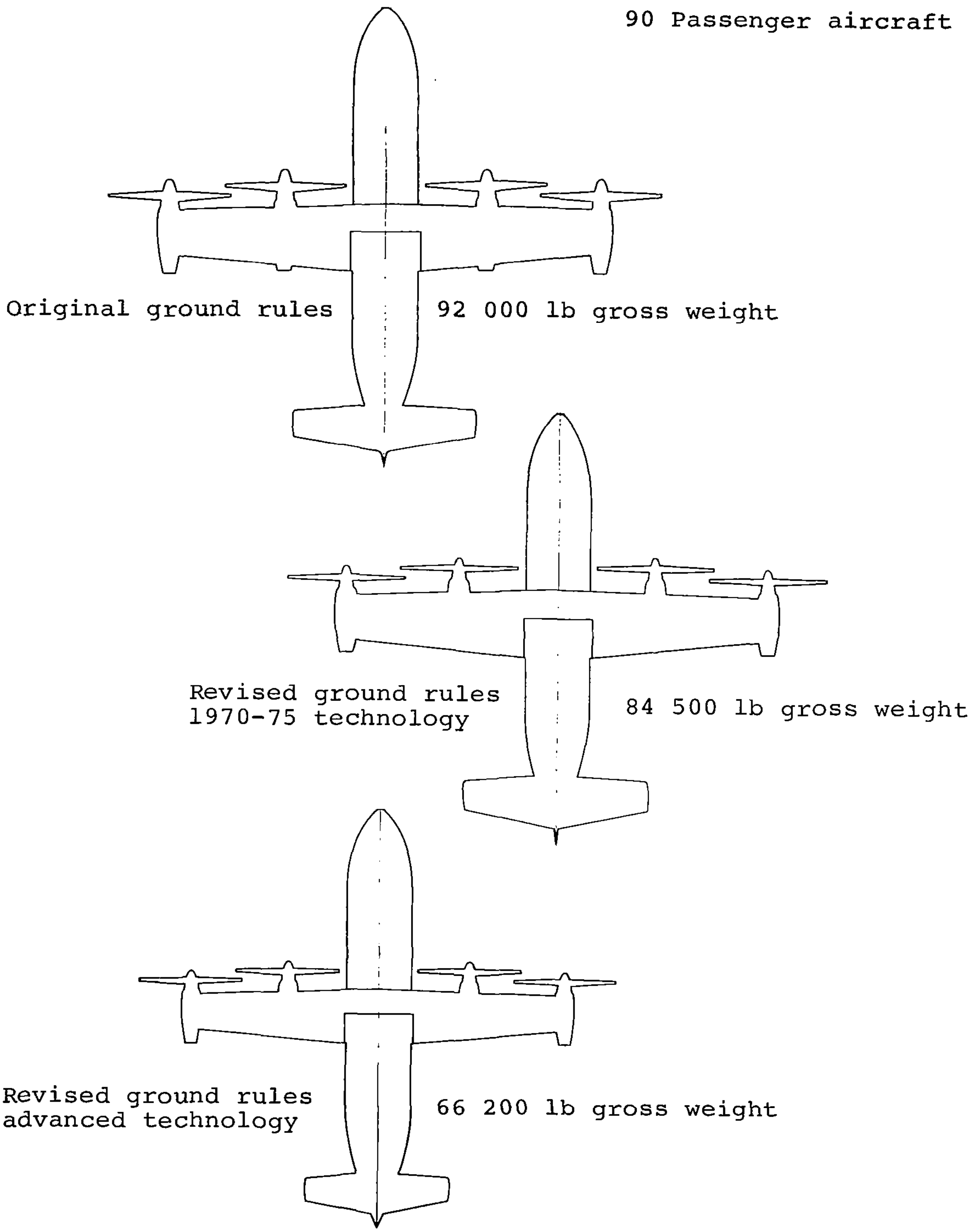


Figure 5. Tilt Wing VTOL Size Comparison.

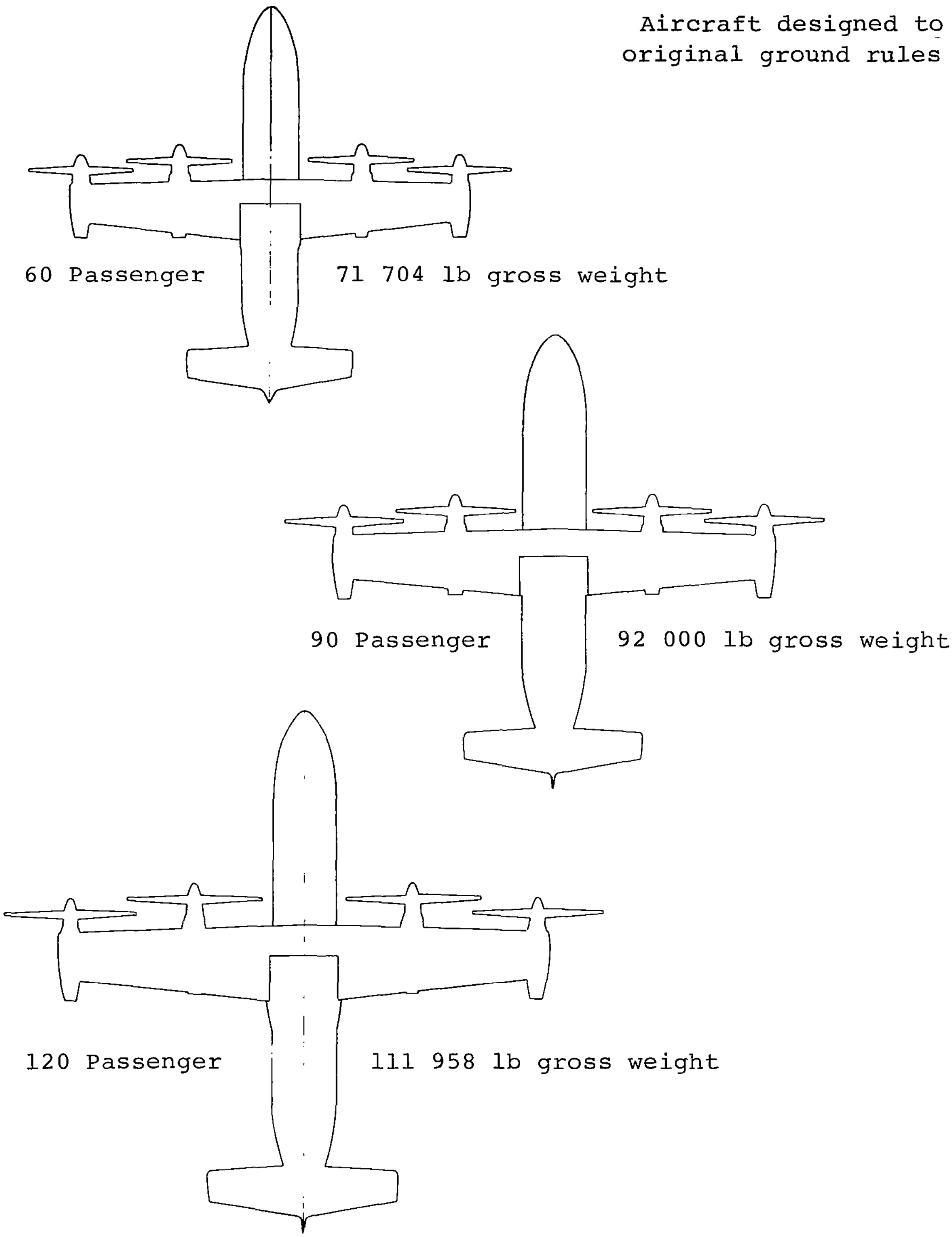


Figure 5. - Concluded.

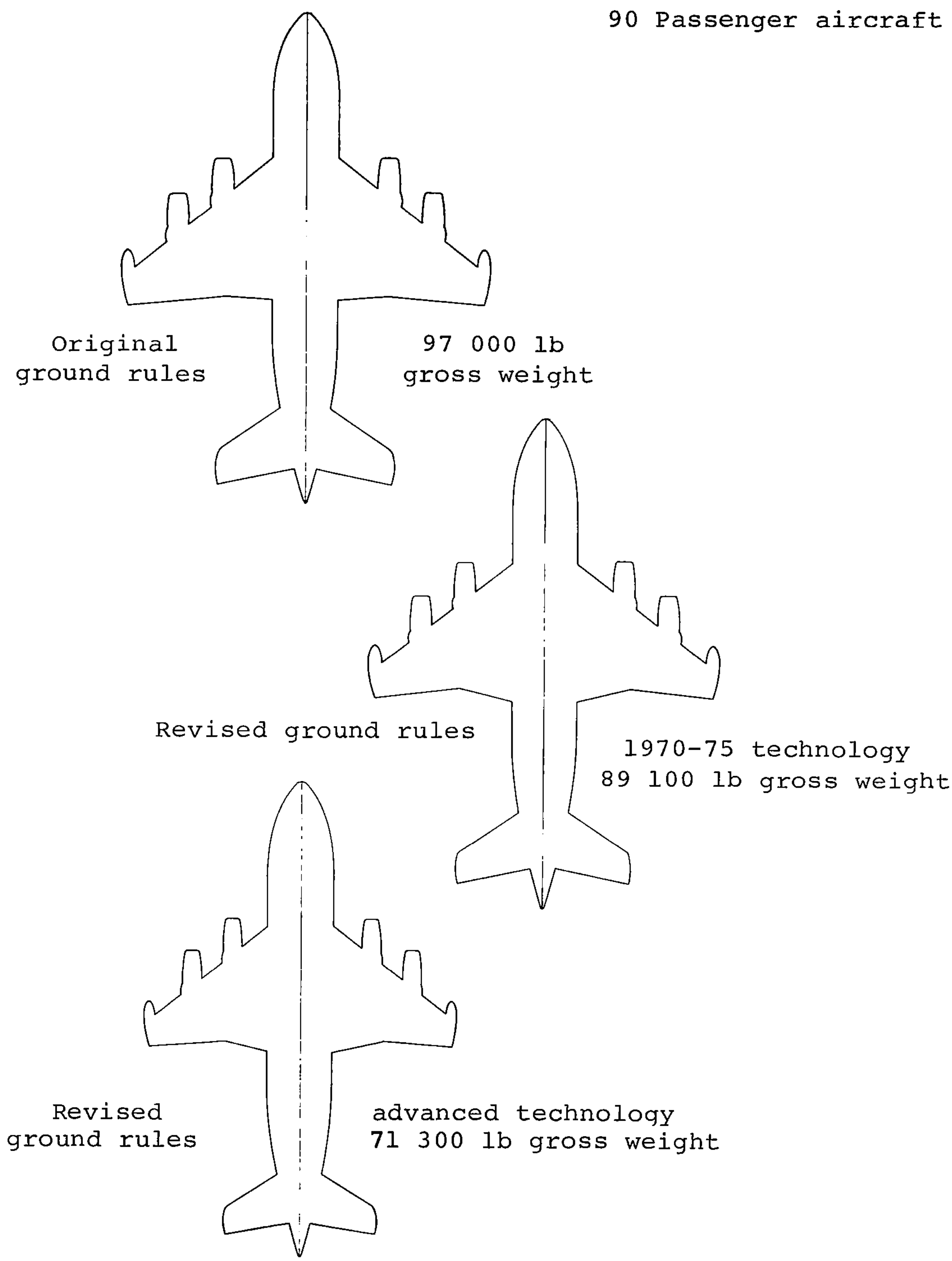


Figure 6. Lift Fan VTOL Size Comparison.

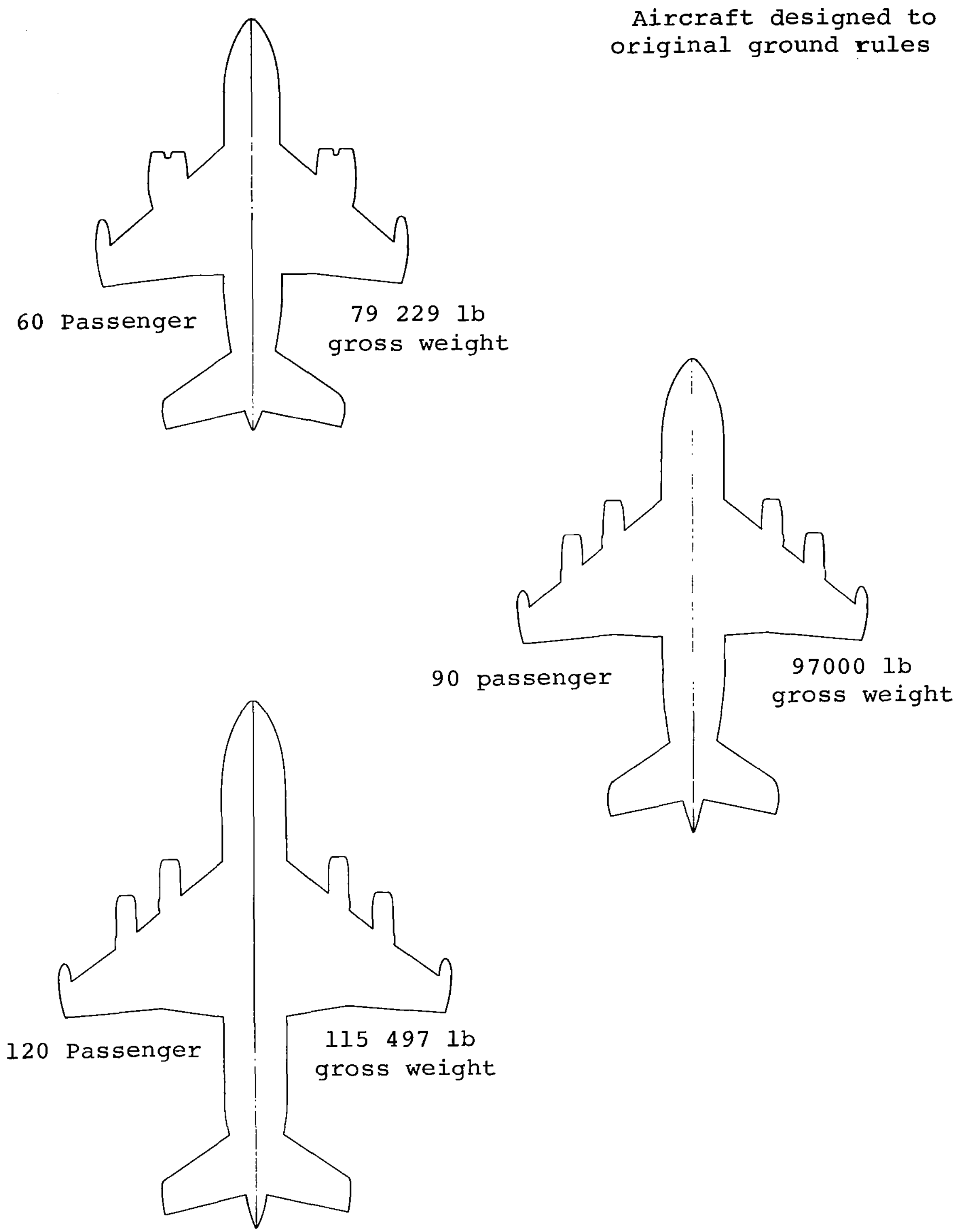


Figure 6. - Concluded.

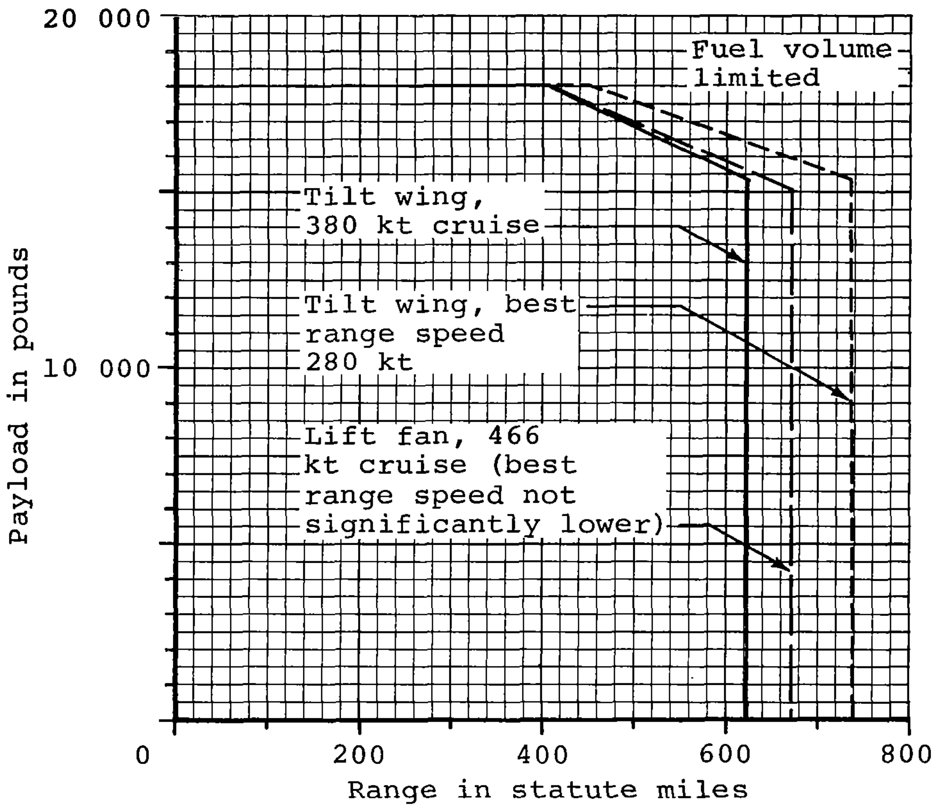


Figure 7. Payload Range Characteristics of Revised Ground Rule Aircraft.

TABLE 8
COMPARISON OF FUEL BREAKDOWNS
Pounds of Fuel for Design Range

Tilt Wing

Passenger Capacity	60	90	90	120
Ground Rules	Original	Original	Revision	Original
Taxi Out	86	110	25	134
Takeoff	140	180	178	224
Climb	740	950	868	1 116
Cruise	3 287	4 221	3 008	4 844
Descent	331	425	439	565
Approach and Land	430	552	349	683
Taxi In	86	110	25	134
Total Fuel Burned	5 100	6 548	4 892	7 700
Loiter	1 310	1 685	-	2 030
Go-around	390	498	-	670
Diversion	-	-	2 358	-
Total Reserves	1 700	2 183	2 358	2 700
Total Fuel	6 800	8 731	7 250	10 400

Lift Fan

Passenger Capacity	60	90	90	120
Ground Rules	Original	Original	Revision	Original
Taxi Out	92	110	20	128
Takeoff	576	705	674	810
Climb	2 040	2 497	2 426	2 700
Cruise	3 272	3 921	2 871	4 288
Descent	228	279	407	310
Approach and Land	1 565	1 910	1 207	2 200
Taxi In	40	48	10	55
Total Fuel Burned	7 813	9 470	7 615	10 491
Loiter	2 072	2 610	-	2 900
Go-around	835	1 040	-	1 150
Diversion	-	-	3 295	-
Total Reserves	2 907	3 650	3 295	4 050
Total Fuel	10 720	13 120	10 910	14 541

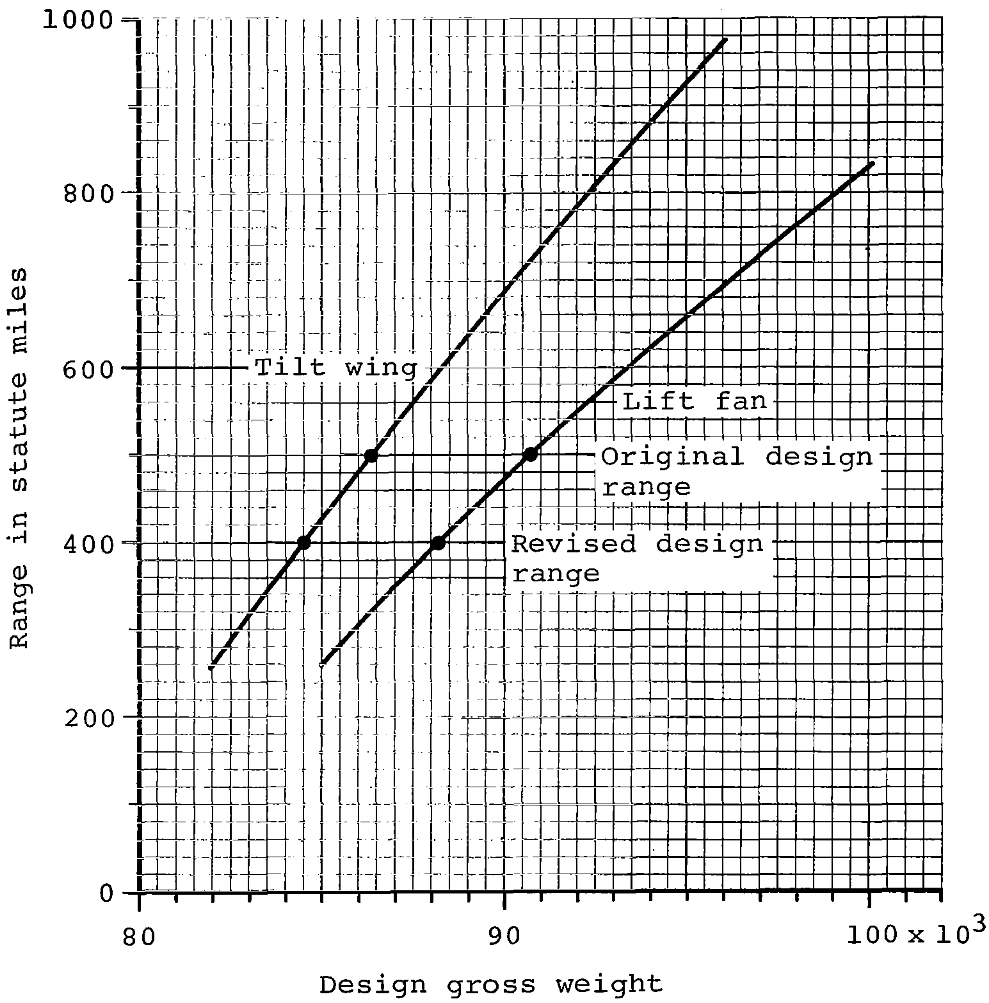


Figure 8. Sensitivity of Gross Weight to Design Range.

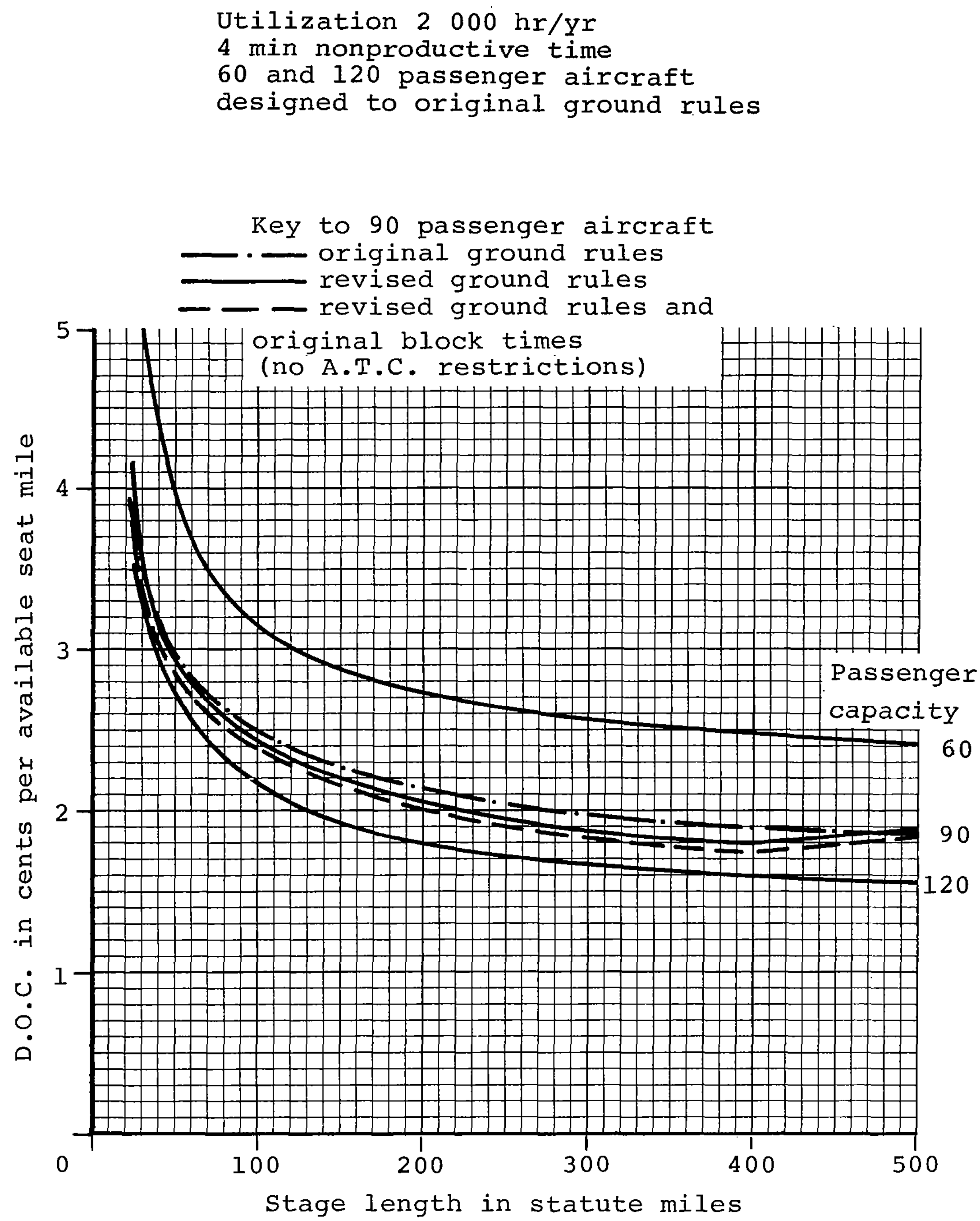


Figure 9. Comparison of Tilt Wing Direct Operating Costs.

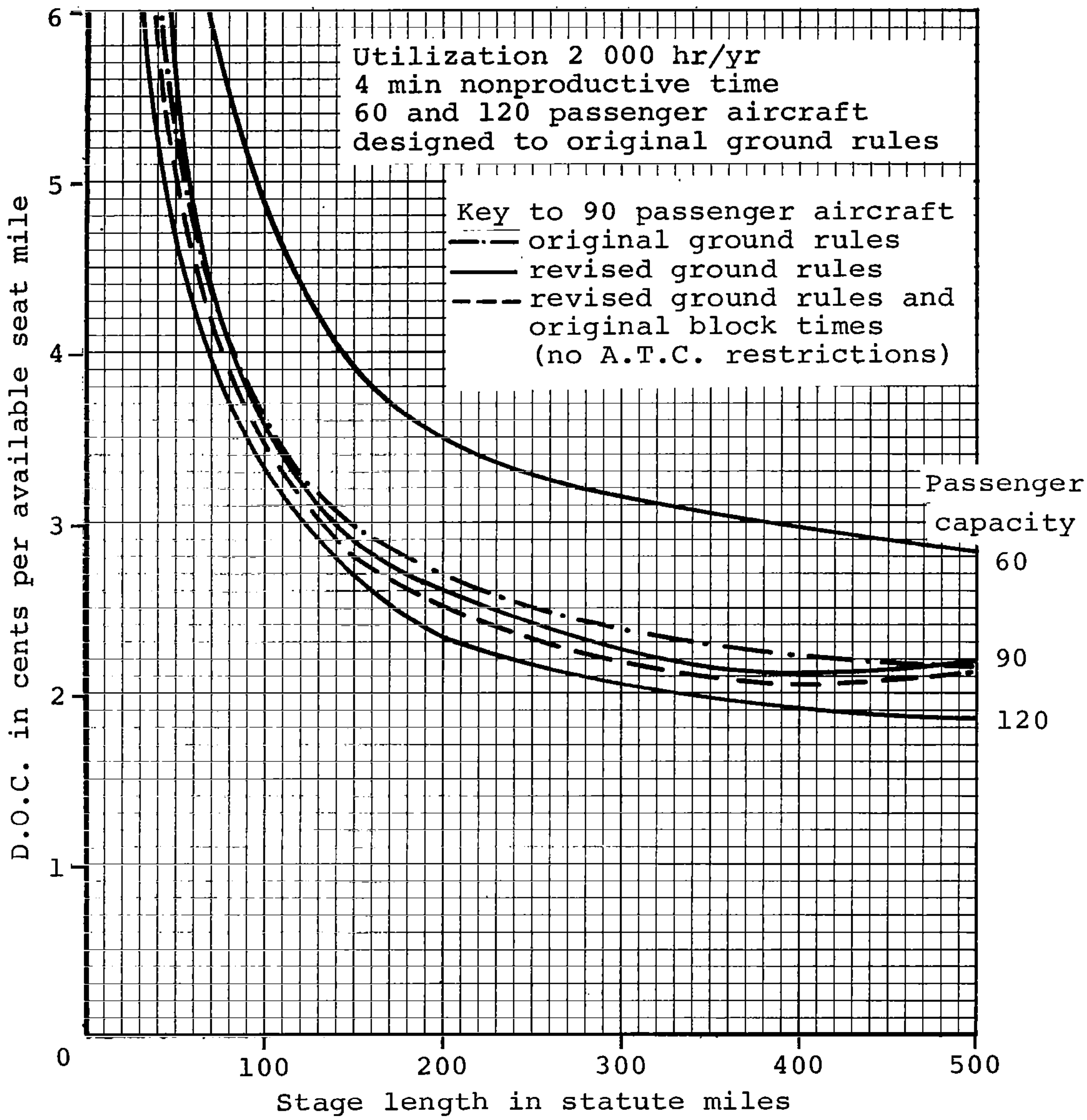


Figure 10. Comparison of Lift Fan Direct Operating Costs.

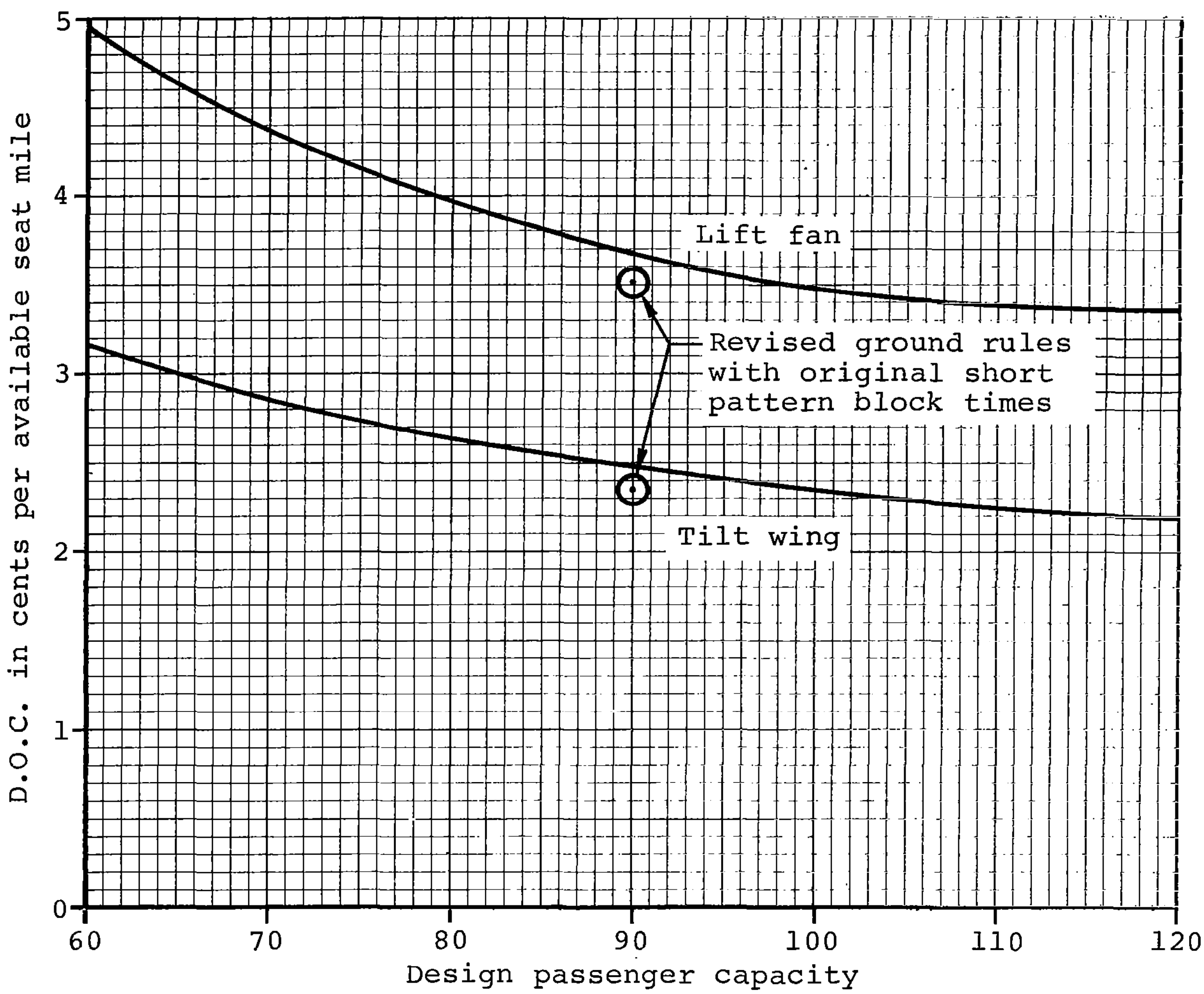


Figure 11. Sensitivity of Direct Operating Cost to Design Passenger Capacity, 100 Statute Miles Stage Length.

The new ground rule nonproductive time of 4.07 minutes is closely comparable and is made up of 1/2 minute for taxi at each end, one minute for landing and 2.07 minutes for approach and landing. The revised ground rules give a small reduction in D.O.C. compared to the original rules. This reduction is not as large as might be expected from the considerable design gross weight differences. This is due to the increased block times under the revised ground rules (Figure 12) caused by the slower descent below 10 000 feet using the air traffic control restrictions adopted in the new rules.

To illustrate the effect of these increased block times on direct operating cost, Figures 9 and 10 show the direct operating cost of the 90 passenger aircraft designed to the revised ground rules but operated at the block speeds obtained with the original ground rules. It can be seen that the reduction in D.O.C. relative to the original ground rules aircraft is of the order of eight percent compared to five percent when the block times conforming to the revised ground rules are used. A breakdown of these direct operating costs is given in Table 9. The acquisition costs of the various aircraft are compared in Table 10.

There is no significant difference in the distribution of direct operating cost for aircraft of differing passenger capacity but of the same concept. The most striking difference is in the maintenance cost of the lift fan and tilt wing aircraft. This difference accounts for the bulk of the increased direct operating cost of the lift fan relative to the tilt wing. Most of this increased maintenance cost is due to the rather complex lift propulsion system of the lift fan aircraft compounded by the short life of some of the lightweight components and a general lack of accessibility.

The overhaul life of the lift fan system gas generators was assumed to be 5 000 cycles (a cycle is defined as a start and a stop) rather than the more familiar T.B.O. (time between overhauls). Obviously with running times varying between one and five minutes, the thermal cycling effects on engine wear and tear are likely to predominate over the running duration effects. Twenty-five hundred flights between overhauls represents 750 cruise engine operating hours for 100 mile stage lengths and 2 180 hours for 400 mile stage lengths. Therefore a cruise engine T.B.O. of 5 000 hours with two intermediate hot section inspections (i.e., every 1 670 hours) implies removal and overhaul of the lift system gas generators at roughly the same interval as cruise engine hot section inspections. This seems logical since the hot gas ducting of the lift system and the bleed and burn nozzle of the reaction control system could be inspected at the same time. The maintenance cost of the lift fans was based on manufacturers data which assumes that they are as trouble free as airframe components.

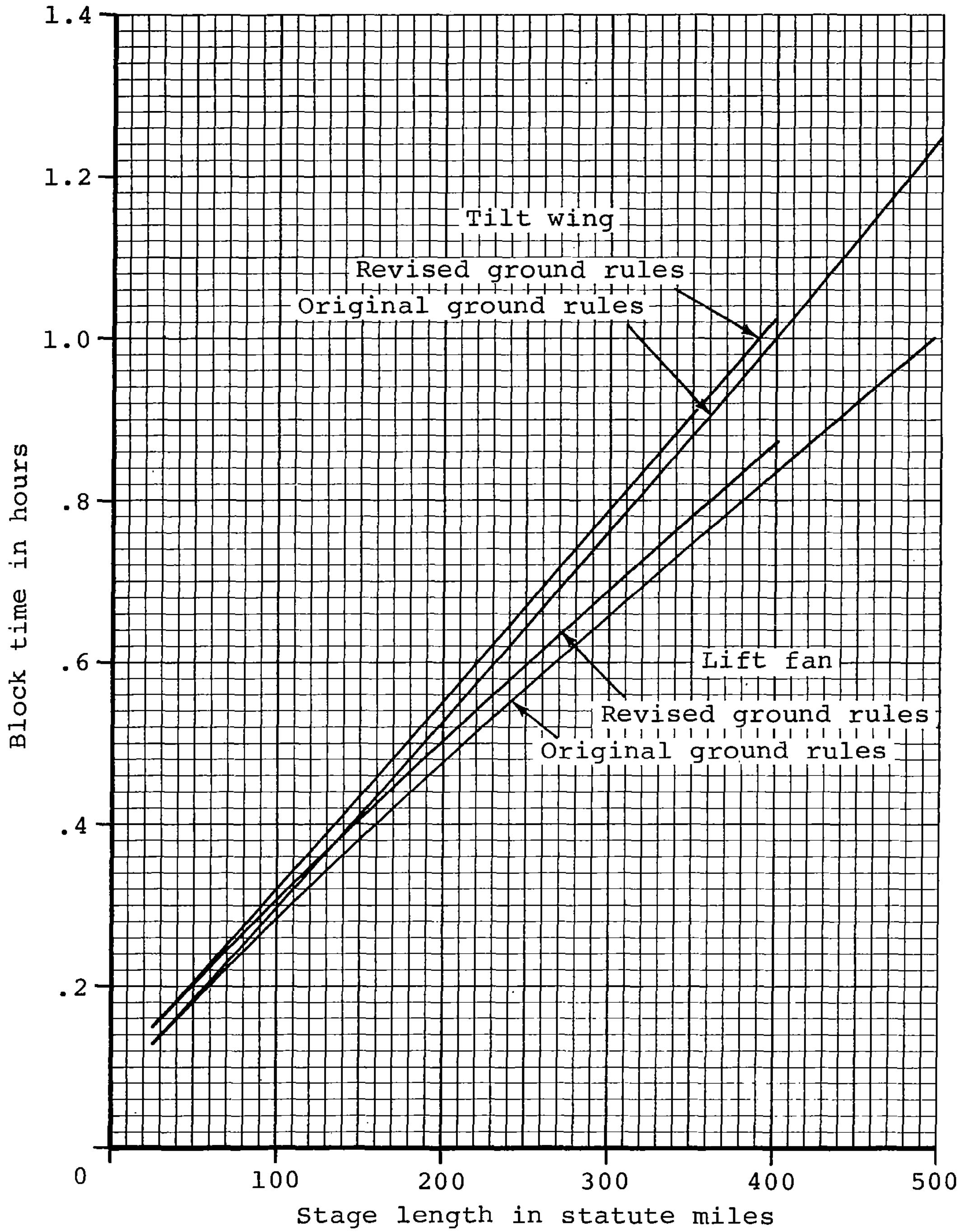


Figure 12. Block Time Comparison.

TABLE 9
DIRECT OPERATING COST BREAKDOWN
$/AIRCRAFT - MILE

Aircraft	Tilt Wing				Lift Fan			
Passenger Capacity	60	90	90	120	60	90	90	120
Design Ground Rules	Orig.	Orig.	Rev.*	Orig.	Orig.	Orig.	Rev.*	Orig.
	25 Statute Miles Stage Length							
Flying Operations	1.295	1.329	1.290	1.620	1.807	2/037	2.000	2.378
Maintenance (incl. burden)	.858	.966	..940	1.145	3.574	4.347	4.252	5.157
Depreciation	1.007	1.313	1.230	1.457	1.409	1.582	1.508	1.775
TOTAL	3.160	3.608	3.460	4.222	6.792	7.967	7.760	9.311
	250 Statute Miles Stage Length							
Flying Operations	.574	.682	.654	.775	.681	.745	.695	.874
Maintenance (incl. burden)	.408	.470	.434	.524	.670	.806	.745	.948
Depreciation	.613	.679	.626	.744	.637	.715	.665	.797
TOTAL	1.595	1.832	1.714	2.043	1.988	2.266	2.105	2.621

* Original short pattern block times

TABLE 10
COMPARISON OF ACQUISITION COSTS
RECURRING AND NONRECURRING EXCLUDING SPARES

Passenger Capacity		60	90	90	120
Ground Rules		Orig.	Rev.	Orig.	Orig.
Cost in Millions of 1965 Dollars	Tilt Wing	4.1	4.5	4.7	5.3
	Lift Fan	4.5	4.9	5.2	5.8

It may well be that heavier but longer life components in the lift propulsion system would give lower direct operating costs. However, this could not be reliably investigated due to the lack of data pertaining to the tradeoff between component weights and overhaul lives.

ADVANCED TECHNOLOGY

The aircraft designed to the revised ground rules reflect the airframe and propulsion technology of the 1970 time period. While this technology level represents some improvement in engine weight, size and performance over currently available power-plants, due mainly to increases in permissible turbine inlet temperatures and attainable pressure ratios, the structure weights used are typical of current aluminum and steel fabrication techniques, with allowance for increased use of titanium and glass fiber in relevant components.

One of the tradeoff exercises made earlier in this study, and reported in Reference 3, showed the effect of advanced propulsion technology on design gross weight and direct operating cost. These advances in propulsion technology have been combined with the foreseeable reductions in airframe weight, due to advanced materials and processes, to give an overall picture of the reduction in aircraft weight which might be expected in the future. A tentative assessment of the cost benefits which might accrue from advanced technology has also been attempted.

Advanced Airframe Technology

Under this heading, improvements in fuselage, wing, and tail structure weights are discussed, and a reassessment of transmission system and rotor weights, based on more recent information than that available earlier in the study, is made.

The major improvement expected in future structure weights will be primarily due to the very high strength and stiffness of new fiber reinforced composite materials. An extensive review of current information on fiber reinforced composite material has been conducted by The Boeing Company to project the future characteristics of these materials. The tensile strength, modules of elasticity and density of boron and carbon fibers have been projected and, together with the characteristics of various matrix materials, have been used to determine the characteristics of composite materials. These data are presented in Figures 13, 14 and 15 which show the tensile strength, modulus of elasticity and strength to density ratio of current materials, boron and carbon filaments

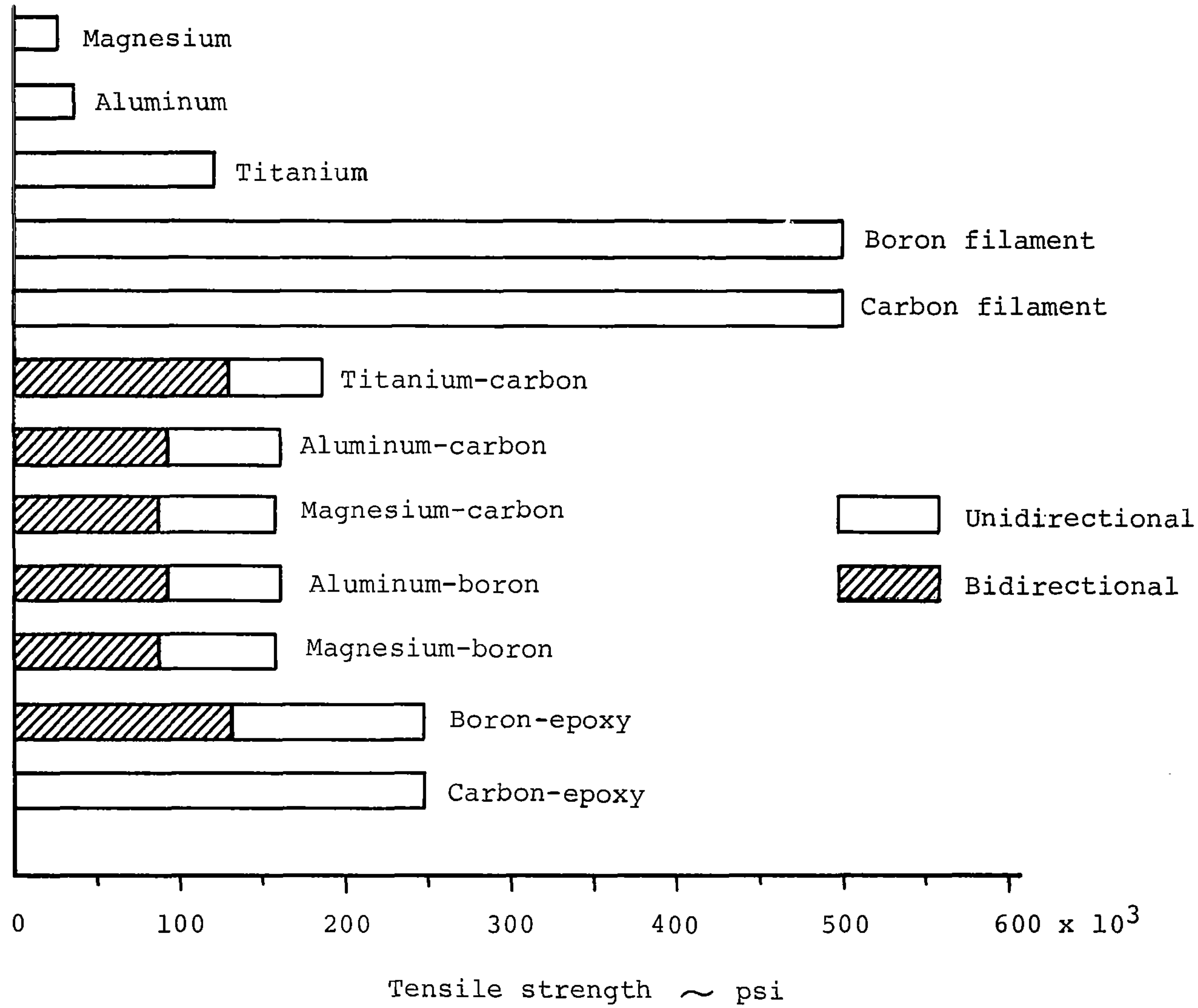


Figure 13. Tensile Strength Comparison of Composite Materials.

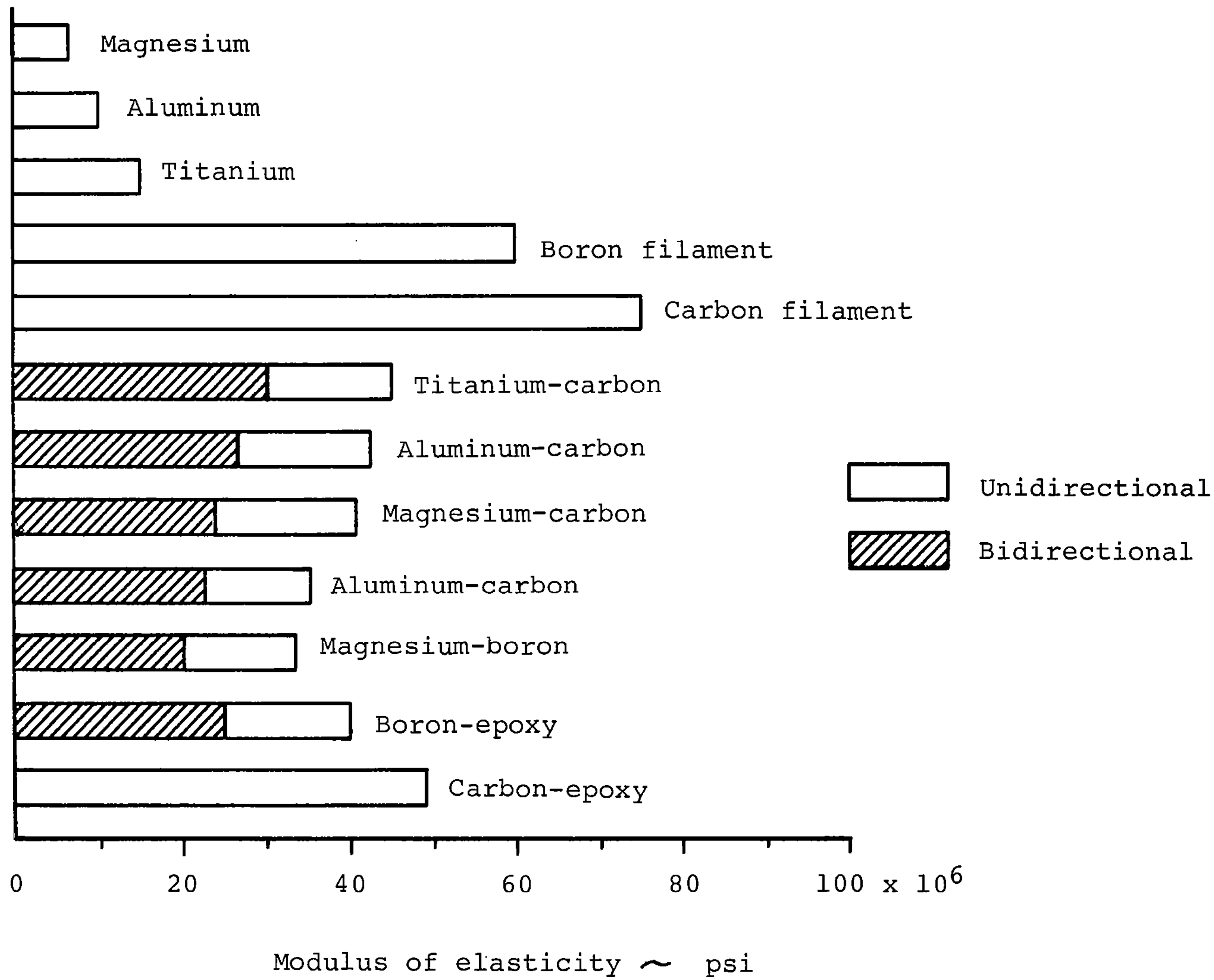


Figure 14. Modulus of Elasticity Comparison of Composite Materials.

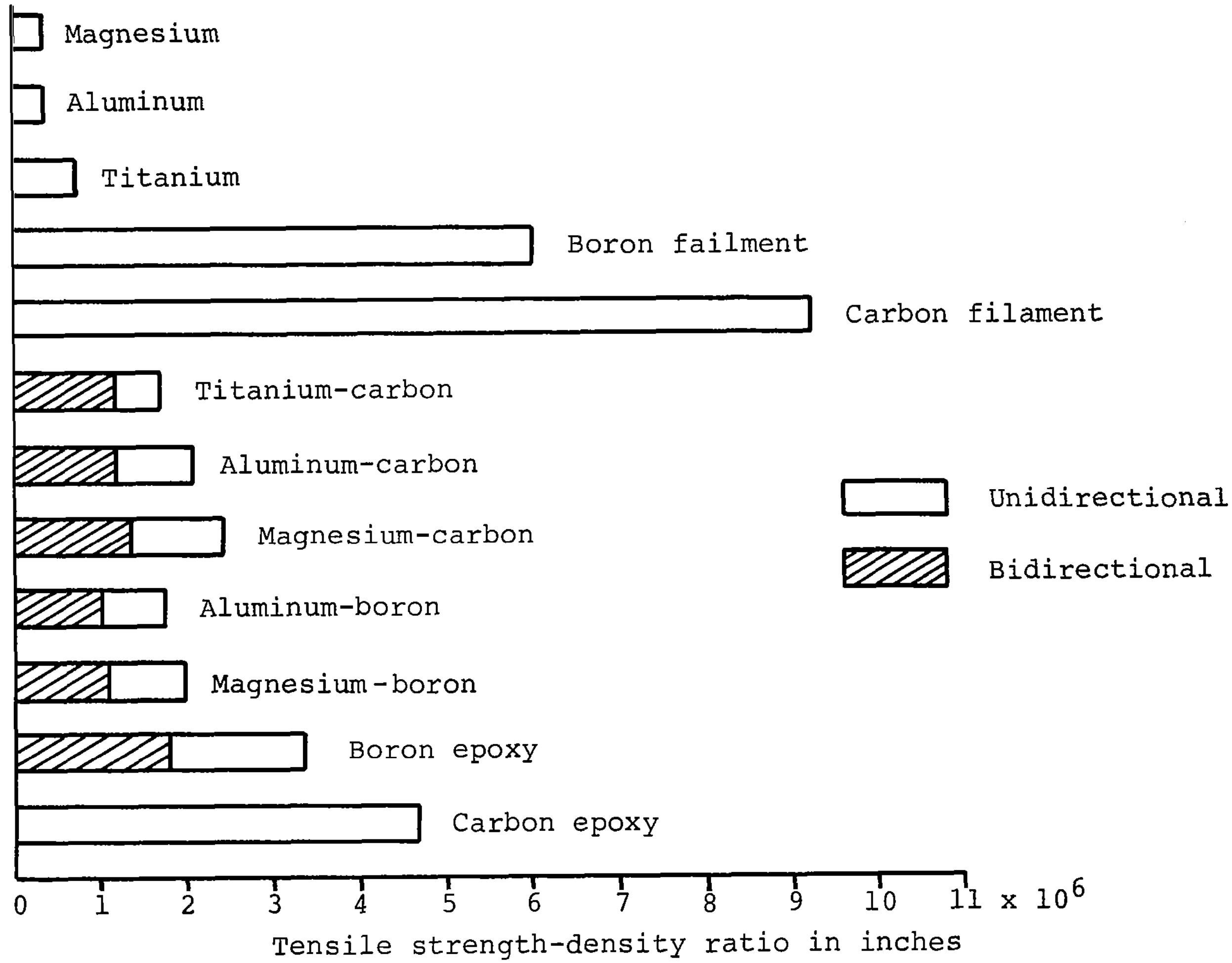


Figure 15. Tensile Strength - Density Ratio.

and various composite materials. The composite material characteristics are given for unidirectional and bidirectional filament layup for pure tension/compression and shear applications respectively.

These composite material characteristics have been used to predict possible reductions in airframe weights. The airframe components have been examined with respect to the typical amounts of bending, shear and torsion material contained in each, and therefore the need for unidirectional or bidirectional filament composites. The practicability of replacing conventional parts with the new materials has also been considered, taking into account such factors as ease of maintenance and repair and design flexibility. Major components such as wing skins are assumed to be made of boron-epoxy composite with metal matrix composites being used for small fittings, joining of epoxy matrix materials to all metal structure and for landing gear parts. Secondary structure, such as fairings and flap shrouds, is assumed to remain as aluminum, since loads on these parts are small with material thickness being determined by minimum gages for handling. Parts such as access doors and covers will also be unchanged. A typical wing structure weight breakdown with forecast weight reductions is given below. All numbers are percentages of original structure weight.

Item	Original Structure	Remaining as Aluminum	Boron Composite Material	Total
Spar Caps	9	1.0	4.35	5.35
Rib Shear	7	1.0	3.25	4.25
Spar Webs & Skins	59	19	22	41
Secondary Structure	25	25		25
	100	46	29.60	75.6

The revised wing is then composed of 39 percent composite structure and 61 percent aluminum, and is 24.4 percent lighter than an all aluminum wing. It is anticipated that a similar saving would be realized in tail weights and that fuselages could be fabricated with 50 percent of the aluminum structure replaced by composite materials for a weight saving of 21.5 percent. A further weight saving of 10 percent may be possible with carbon filament composite materials. However, the boron technology is more firmly established and the weight savings quoted above have been used in this study.

Substantial savings in the weight of rotor blades and gear boxes will be realized in future years from advances in materials, lubricants and metallurgical techniques. The use of single crystal gears and improved lubricants will allow higher induced stresses in gearing which in turn will result in a reduction in weight and/or increased component life.

Figure 16 presents the increase in Hertz stress levels with time over the last twenty years and the probable future gains. These stress levels will permit weight savings of the order of twenty percent in the foreseeable future. Rotor blade weights will be significantly reduced by using advanced filament composite materials in place of the current metal and fiberglass structure. Table 11 compares the weight of a conventional CH-47 blade with a boron composite blade and shows that a saving of 32 percent is possible.

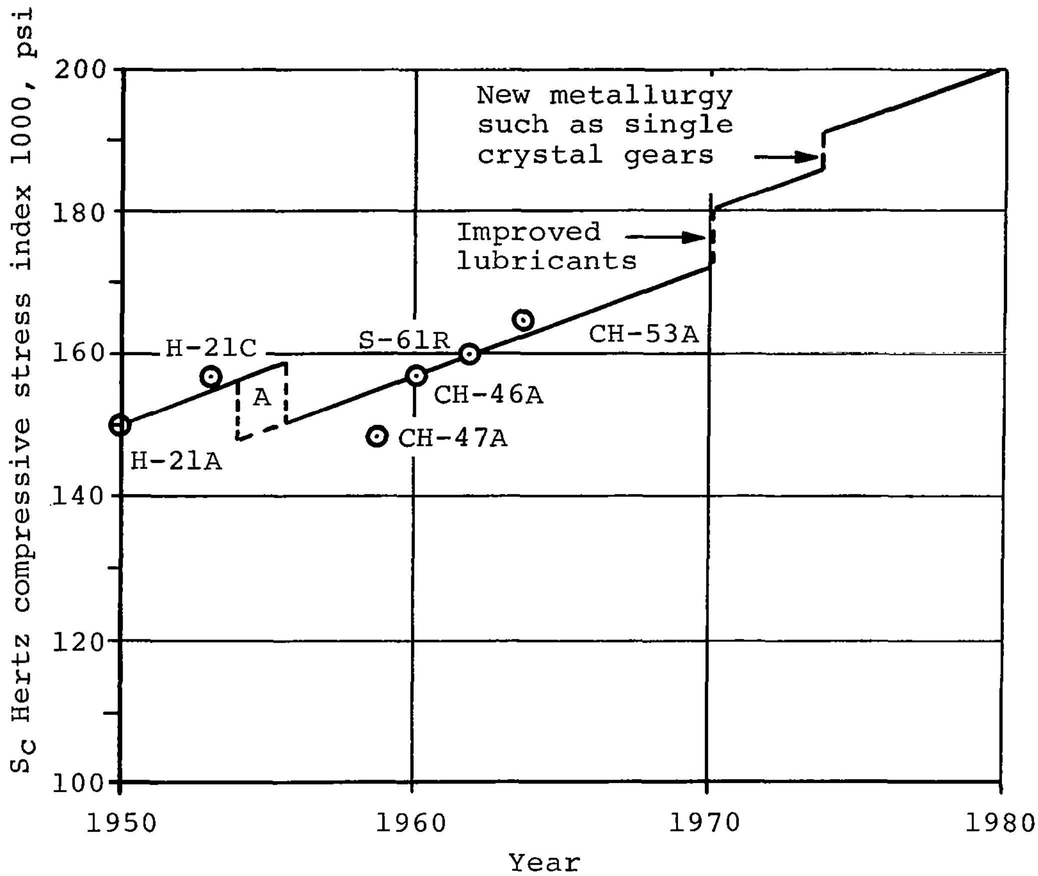
TABLE 11
EFFECT OF BORON COMPOSITE MATERIAL ON CH-47 ROTOR BLADE WEIGHT

COMPONENTS	WT. PER BLADE LBS. CURRENT CH-47	WT. PER BLADE LBS. BORON CH-47
Spar	140.0	61.7
Leading Edge	40.0	40.0
Trailing Edge	5.7	3.0
Skin & Ribs	25.8	25.8
Bal. & Tracking Wts.	15.1	11.1
Root End	31.0	31.0
Joints, Splices & Misc.	10.5	10.5
TOTAL WEIGHT PER BLADE	268.1	183.1
TOTAL WEIGHT PER AIRCRAFT	1 608.6	1 098.6

Effect of Advanced Technology on Aircraft Size and Cost

The 90 passenger tilt wing and lift fan aircraft designed to the revised ground rules have been resized to show the effect of advanced airframe and propulsion technology. The basic configurations and aerodynamic technology have not been changed so that the comparison shows the direct effect of these advances. Tables 12 and 13 compare the 90 passenger aircraft weights and general characteristics respectively. The advanced technology lift fan aircraft is reduced in weight by 20 percent and the tilt wing by 21 percent.

It is not possible to forecast the cost of advanced structural materials and propulsion systems with any degree of certainty. Presently,boron costs 500 dollars per pound; however, other materials such as titanium were extremely costly when produced in experimental quantities but reduced rapidly in price when production quantities were required by industry. However, this is a slow process and even now titanium is only used for applications where weight saving is of more than usual importance. It is obvious that advanced



NOTES: 1. During interval A, turbine engine introduction led to use of turbine engine oil in gearboxes, thus decreasing S_c at this time.

2. The constant slope represents minor improvements such as shot peening, forged teeth, improved surface finish, improved carburizing, etc.

Figure 16. Improvements in Allowable Hertz Stresses.

TABLE 12

EFFECT OF ADVANCED TECHNOLOGY ON WEIGHT 90 PASSENGER AIRCRAFT DESIGNED TO REVISED GROUND RULES

	WEIGHT POUNDS			
	Tilt Wing VTOL		Lift Fan VTOL	
Item	1970 Tech- nology	Advanced Tech- nology	1970 Tech nology	Advanced Tech- nology
Wing	6 075	3 680	6 600	3 910
Tail	2 160	1 360	2 625	1 450
Body	11 000	8 400	12 034	9 065
Alighting Gear	3 080	2 650	3 400	2 750
Flight Controls	4 750	3 290	2 035	1 700
Reaction Controls	-	-	2 250	1 950
Power Plant Installation	(18 515)	(11 390)	(16 670)	(10 662)
Engine Section - Cruise	1 420	1 100	1 500	1 052
Engine Installation - Cruise	4 500	2 490	5 500	3 440
Lift Gas Generators	-	-	2 700	1 510
Fans and Ducting	-	-	6 000	3 800
Drive System	6 420	3 805	-	-
Fuel System	430	330	490	400
Engine Controls	100	100	300	300
Starting System	175	165	180	160
Propeller Installation	5 470	3 400	-	-
Auxiliary Power Unit	450	400	450	400
Instruments and Navigation	675	505	675	505
Hydraulics	450	320	490	320
Electrical	1 900	1 575	1 860	1 575
Electronics	750	670	750	670
Furnishings and Equipment	6 434	6 005	6 434	6 005
Air Conditioning and De-Icing	1 423	1 350	1 423	1 350
WEIGHT EMPTY	57 662	41 595	57 696	42 312
Crew and Crew Luggage	660	660	660	660
Unusable Fuel & Oil	175	175	175	175
Engine Oil	100	100	100	100
Passenger Service Items	653	653	653	653
OPERATING WEIGHT EMPTY	59 250	43 183	59 284	43 900
Passengers and Luggage	18 000	18 000	18 000	18 000
Fuel	7 250	5 300	10 910	8 300
TAKEOFF GROSS WEIGHT	84 500	66 488	88 194	70 200

TABLE 13
COMPARISON OF 1970 TECHNOLOGY AND ADVANCED TECHNOLOGY AIRCRAFT GENERAL CHARACTERISTICS

	Tilt Wing		Lift Fan	
	1970 Technology	Advanced Technology	1970 Technology	Advanced Technology
Physical Data				
Wing				
Area (sq ft)	946	720	1 146	911
Span (ft)	82.3	73	63.33	56.5
Aspect Ratio	7.16	8.25	3.5	3.5
Sweep at 1/4 Chord (degrees)	0	0	35	35
(t/c) Root Fuselage	0.18	0.18	.145	.145
(t/c) Tip	0.09	0.09	.10	.10
Horizontal Tail Area (sq ft)	280	180	311	230
Vertical Tail Area (sq ft)	216	140	181	140
Fuselage Length (ft)	83.75	83.75	93.4	93.4
Design Cruise Conditions				
Cruise Speed (kt TAS)	380	380	466	466
Cruise Altitude (ft)	30 000	30 000	30 000	30 000
Structural Limits				
V_{MO} (kts EAS)	344	344	400	400
M_{MO}	0.72	0.72	0.83	0.83
V_D (kts EAS)	390	390	450	450
N_{LIMIT}	2.5	2.5	2.5	2.5
Propellers				
Diameter (ft)	23.2	20.2	-	-
Number of Blades	4	4	-	-
Solidity	0.25	0.25		
Maximum Tip Speed (fps)	850	850	-	-
Cruise Powerplants				
Number	4	4	4	4
Maximum Power/Thrust per Engine	7 820 SHP	6 130 SHP	7 760 LBS	6 180 LBS
Bypass Ratio	-	-	3	3
Pressure Ratio	14	22	20	26
T_4° R	2 600	3 200	2 600	3 200
Lift Powerplants				
Number	-	-	4 Gas Gen, 4 Fans	
Maximum Thrust (lbs) per fan	-	-	19 490	15 600
Fan Bypass Ratio/Pressure Ratio	-	-	8/1.3	11/1.3
Pressure Ratio	-	-	12	16
T_4° R	-	-	2 600	3 200
Fan Diameter (ft)	-	-	6.65	6.05
Effective Thrust Augmentation Ratio			2.5	2.93

composite materials will not be used unless the cost per unit weight of airframe is comparable to that of current aircraft. It is equally obvious that engine weight and fuel flow improvements due to increased turbine inlet temperatures and pressure ratios will be of no value unless reliability and maintenance costs are unimpaired. Therefore, it can be assumed that the current acquisition and direct operating cost methods and data will apply to the advanced technology aircraft, and that the ability to meet these costs will play a large part in determining the time period when the degree of technological advancement postulated above is incorporated in production aircraft. With these assumptions the acquisition costs of the advanced technology aircraft would be 13 percent lower than comparable aircraft of the 1970 time period. The corresponding direct operating costs are given in Figure 17 which shows that these costs are reduced by 13 to 17 percent for the tilt wing and by 19 to 25 percent for the lift fan.

LIFT ENGINE POD DESIGN

In this phase of the study, it was intended to make a comprehensive evaluation of the turbofan lift engine pod incorporated in the 60 passenger jet lift VTOL designed for the original concept comparison exercise described in Reference 3. The purpose of the evaluation was to obtain more accurate lift engine installation weight data than was possible with the initial preliminary design data. When the turbofan engine (bypass ratio 2.5) pod was laid out to a large scale with adequate engine swivel nozzle movement, it was found that a larger pod than that originally conceived would be necessary. Although a ± 25 degree thrust deflection is required, according to Rolls Royce data, it is necessary to swivel the nozzle ± 30 degrees to obtain this deflection. This is a result of the nozzle deflecting the fan air, while the higher velocity primary flow tends to exhaust parallel to the engine spin axis. Figure 18 shows the resulting increase in pod size from the preliminary work to a corrected engine pitch based on realistic nozzles.

Because of the large increase in pod size, which would tend to invalidate drag and weight data for the preliminary design, it was decided that a variety of lift engine installations should be investigated rather than detailing the turbofan lift engine pod as originally intended. It was obvious that turbojet lift engines would give a smaller pod, but these had been excluded in the initial study on the grounds of high noise level. An analysis of the noise signatures indicated that the noise difference between turbofan and turbojet lift engines could be small due to an equal exchange of fan noise for jet noise. The results are given in Figure 19 for

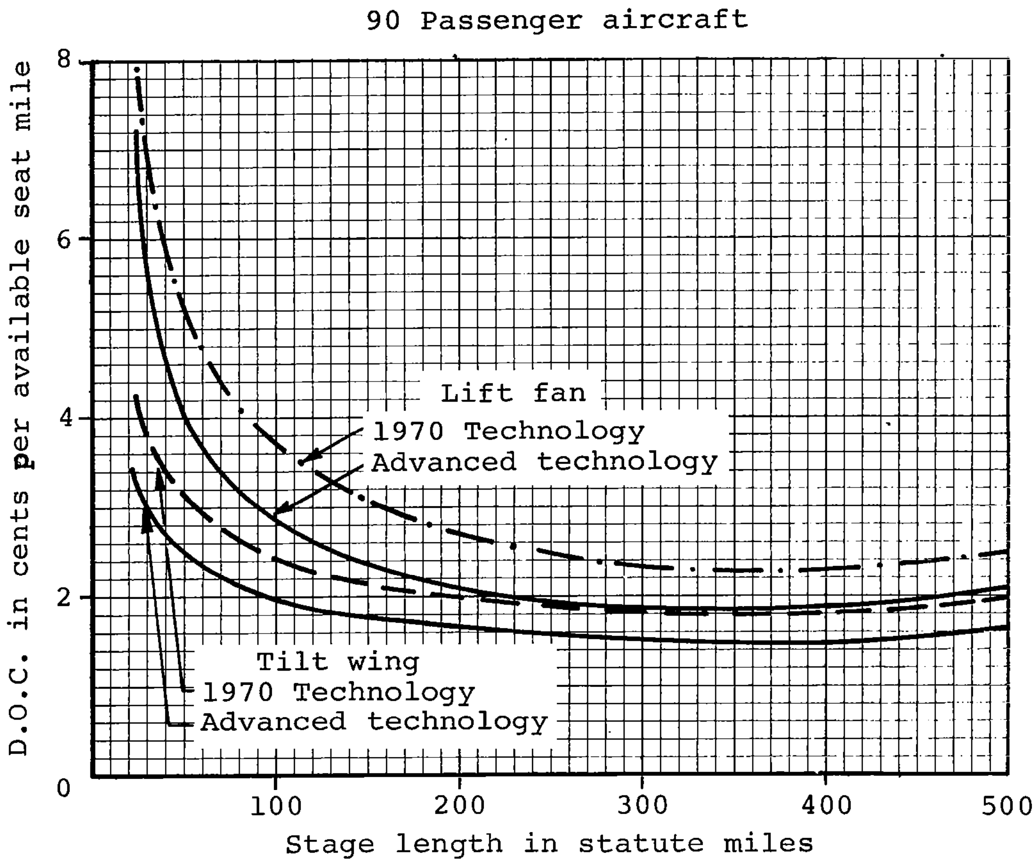
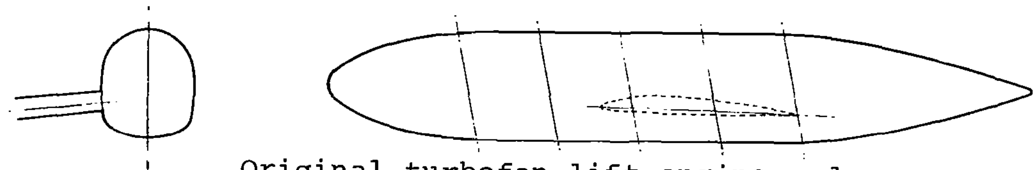
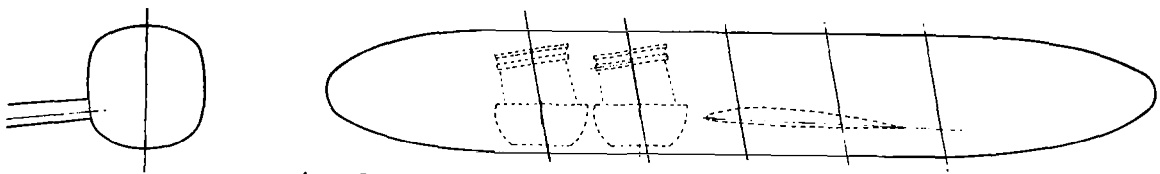


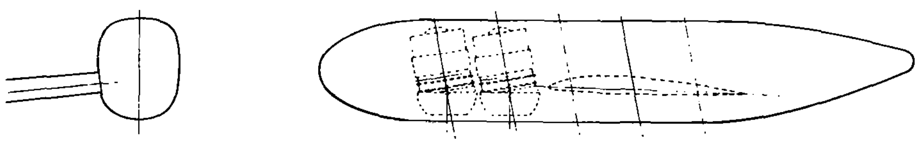
Figure 17. Effect of Advanced Technology on Direct Operating Cost.



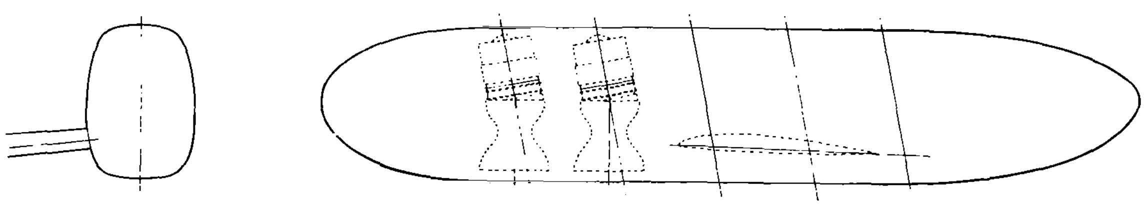
Original turbofan lift engine pod,
swivelling nozzle $\pm 25°$



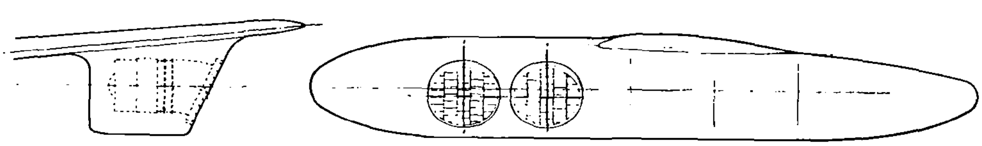
Revised turbofan lift engine pod,
swivelling nozzle $\pm 30°$



Turbojet lift engine pod,
swivelling nozzle $\pm 25°$



Turbojet lift engine pod, swivelling
multitubular nozzle $\pm 25°$



Turbojet lift engine pod, rotating
cascaded deflector

Figure 18. Comparison of Lift Engine Pod Arrangements.

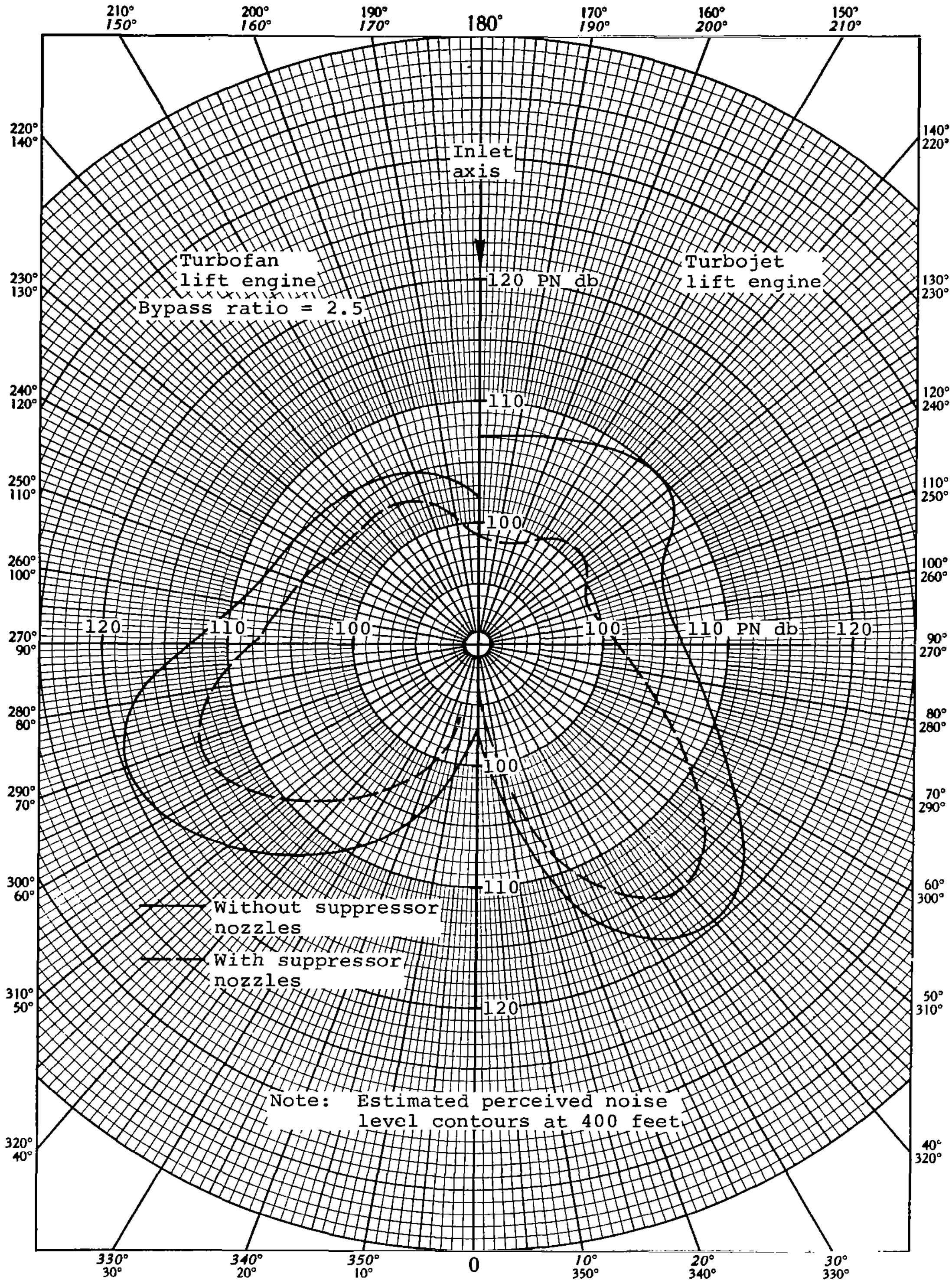


Figure 19. Comparison of Turbofan and Turbojet Lift Engine Noise.

one engine of 10 000 pounds thrust. This figure shows that the noise difference is indeed small, and it was therefore decided that turbojet installations would be examined. Figure 18 shows the various layouts which were considered. The most simple installation has turbojet engines with swivel nozzles, and it can be seen that the smaller engines and the reduced nozzle movement (due to 100 percent turning efficiency) results in a considerably smaller pod than with the turbofan engines. The installation of multitubular sound suppression nozzles, giving a noise reduction of approximately five Pn db, results in an impractically large engine pod, the problem being aggravated by the need to swivel the nozzles. This installation is also shown in Figure 18. The last pod configuration examined has turbojet engines oriented in the spanwise direction with cascade type nozzles on the outboard face of the pod. This layout was looked at because of the advantages which accrue from the ability to obtain large thrust deflection angles (up to ± 90 degrees), such as higher transition flexibility and lift engine run-up without ground erosion or lift force.

After considering the four alternatives shown in Figure 18 and discussed above, the turbojet layout with the "plain" swivelling nozzles was selected for detailed study on the basis that its simplicity and small size outweighed the advantages of the other configurations.

A drawing of the selected configuration, sufficiently detailed to permit component weight estimation, is shown in Figure 20. A noteworthy feature of this pod design is the spoiler in front of the forward engine on the lower side. This spoiler ensures a favorable pressure gradient across the engines for in-flight engine starting and prevents the reverse spin-up which can occur when total head is higher beneath the pod than above. The inlet doors are of the side folding type. Reference 4 indicates that this type of door, combined with individual bellmouth inlets for each engine, gives good pressure recovery and low inlet pressure distortion. The engines are mounted on forged yoke structures which are attached to a longitudinal beam on the inboard side of the pod and carry through to the outboard side to support the outer wall. Between each of these yokes, and at the front and back of the engine bay, there are stiffened sheet metal bulkheads which carry the door loads and provide attachment for the fiberglass nose and tail fairings and inlet bellmouths. The bulkheads are fabricated of stainless steel in the area of the engine hot sections and therefore form integral firewalls. The inboard longitudinal beam is a fabricated structure and is attached to the machined skins and spars of the wing by laminated angle beams.

Table 14 gives a detailed weight breakdown of the pod including attachment and engines. The total weight per aircraft is 8 242 pounds compared to 10 796 for the original turbo-

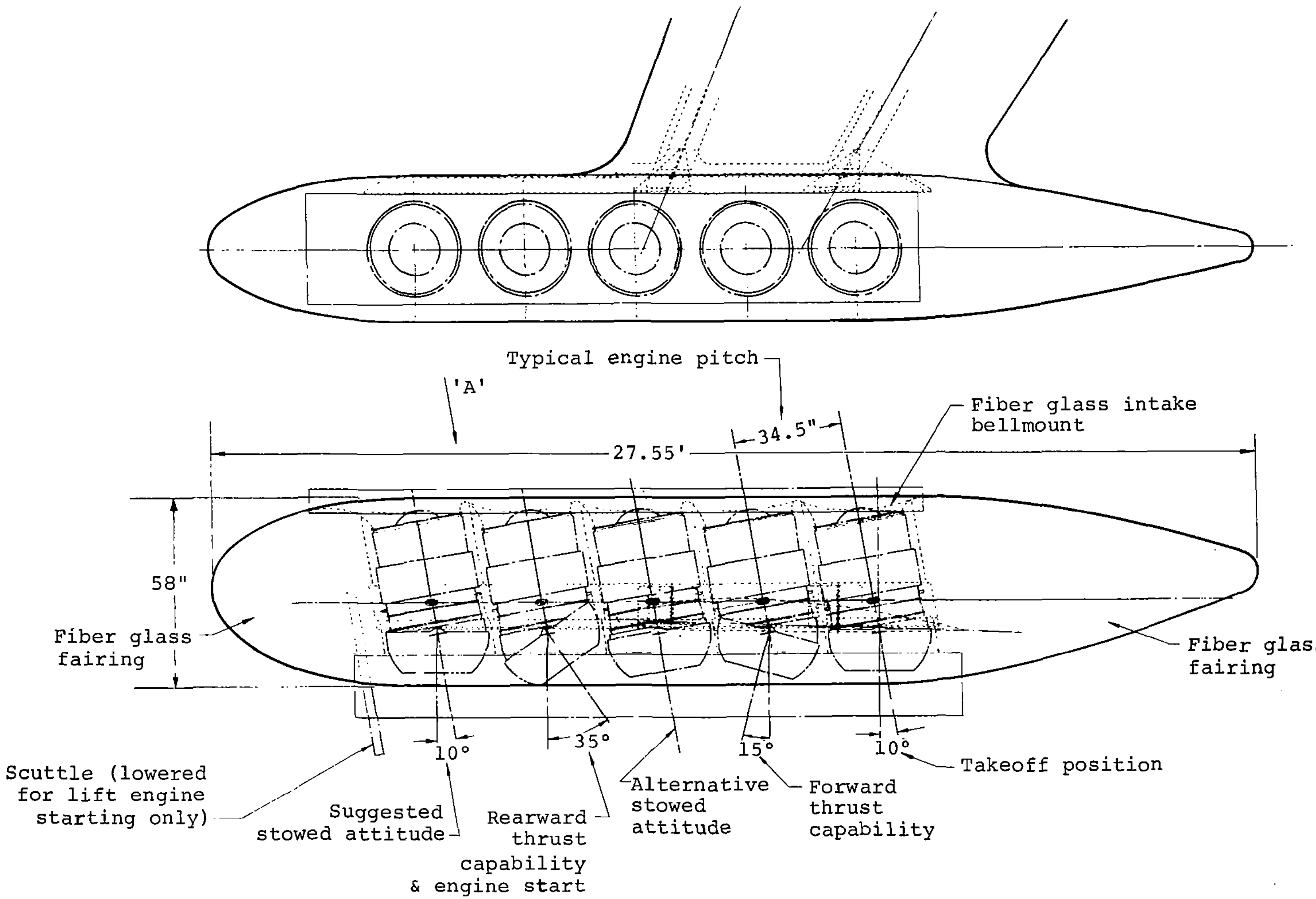
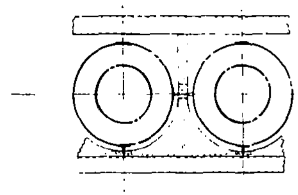
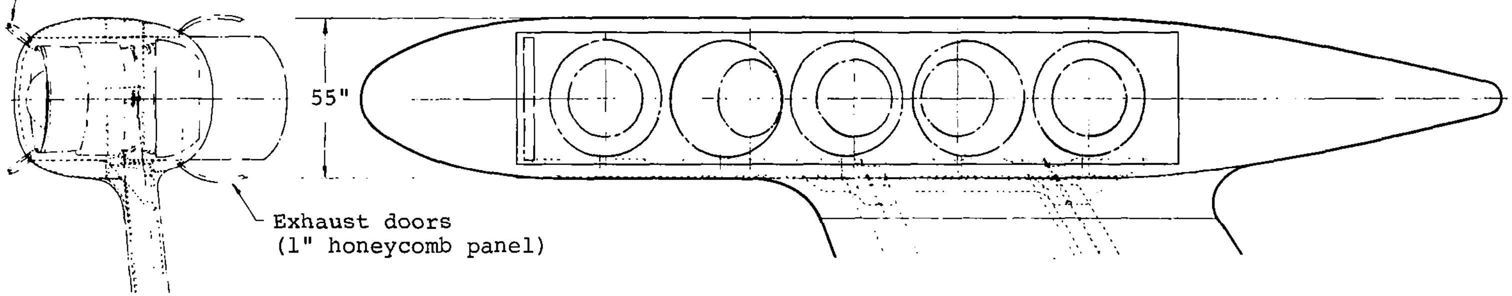


Figure 20. Turbojet Lift Engine Pod Layout.

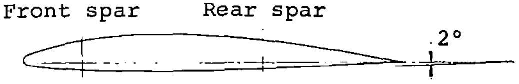


Part view an arrow 'A'
omitting intake.



Suggested pipe sizes leading from wing to lift pod:

- ⊕ Air 3 1/4" dia
- ⊕ Fuel 2 3/4" dia
- + Hydraulics 1" dia



Wing section at intersection
with lift pod

Figure 20. - Concluded.

TABLE 14

TURBOJET LIFT ENGINE POD WEIGHT SUMMARY

Item	Weight lb
Engines and Nozzles	2500
Inboard Support Beam	236
Attachments to Wing	27
Engine Mtg. Yokes	148
Outboard Beam	41
Structural Firewall Bulkheads	74
Side structure and Firewalls	147
Door Support Angles	30
Upper Doors and Hinges (inc. Actuation)	96
Lower Doors and Hinges (" ")	173
Fiberglass Fairings (nose, tail & side)	338
"Scuttle" Spoiler	32
Fiberglass Intake Bellmouths	75
Engine and Nozzle Controls	27
Fuel System Plumbing	7
Hydraulic and Electrical Plumbing and Wiring	40
Bleed Air Starting Ducts	15
3% Allowance for Misc. Hardware	45
5% Contingency	75
	4121

fan installation. The difference of 2 527 pounds would be almost entirely absorbed by the increased lift engine fuel (2 950 pounds to 4 920 pounds) necessary because of the increased s.f.c. of the turbojet lift engines over that of the turbofans, and the increased fuel system weight due to the increased fuel capacity. Therefore, the engine change does not significantly affect the design gross weight of the jet lift VTOL aircraft.

These conclusions should not be construed as being generally true. They apply only to lift engines of bypass ratios of 0 to 3 and of 1970 technology. More advanced technology lift turbofan engines with higher bypass ratios and/or noise suppression design features such as low fan tip speeds, elimination of inlet guide vanes and acoustically absorptive materials on inlet duct walls promise to be significantly quieter than lift turbojet engines. This is especially true of the concentric gas generator lift fans with bypass ratios of the order 8 to 10 presently being investigated. These engines will be applicable to lift fan aircraft of the type shown in Figure 4, and should, incidentally, give substantially reduced maintenance cost compared to the tip turbine lift fans with their associated ducting and remote gas generators.

STANDARDIZATION OF WEIGHT TRENDS

NASA V/STOL short haul transport studies were made by three contractors. Although fairly comprehensive ground rules were stipulated for the aircraft designed in the study, it was inevitable that different philosophies would be used by the three contractors in determining the weight of fixed equipment items and assessing the weight penalties associated with the many unique features of V/STOL aircraft. To assist NASA in evaluating the various concepts studied by each contractor on a common basis, all of the aircraft selected as being the most promising in the initial study have been resized to weight trends determined by the U.S. Navy Air Systems Command. In general, these trends have increased propulsion system weights and decreased the airframe weights. The Boeing Company was not given the weight equations used by USNASC and has, therefore, used scaling factors to iterate to new design gross weights for the aircraft. The only deviation from the weights given to NASA by USNASC is in the fuel systems. This deviation was agreed to by USNASC after further explanation of the systems concepts. The original Boeing weights, the USNASC assessment based on the same useful load and the final iterated weights are compared in Table 15. The effect of the total weight changes on physical characteristics is shown in Table 16. The lift fan aircraft weights are not presented since USNASC made no overall change to the weight of this airplane.

TABLE 15
EFFECT OF USNASC EVALUATION ON 60 PASSENGER AIRCRAFT WEIGHTS

	JET LIFT			TILT-WING			TURBOFAN STOL		
Groups	Boeing	US NASC	Final	Boeing	US NASC	Final	Boeing	US NASC	Final
Wing	7000	6790	6730	5250	5300	5450	5895	5770	4955
Tails	2023	1700	1550	1937	1590	1775	1765	1250	1050
Body	10450	8200	8031	9620	8500	8555	9990	8060	7525
Landing Gear	3230	3400	3260	2775	3000	3100	2591	2750	2380
Flt Conts & Hyds.	2349	1740	1740	4622	3670	3916	2600	2090	1920
Power Plant Instl.	(18321)	(20040)	(19169)	(15605)	(18570)	(18724)	(7638)	(8380)	(7065)
*Engs & Nacelles	17801	19480	18649	5340	7720	7974	7273	7920	6700
Drive System	-	-	-	4605	4800	4710	-	-	-
Propellers	-	-	-	5310	5380	5570	-	-	-
Fuel System	520	560	520	350	670	470	365	460	365
A.P.U.	530	500	500	530	500	500	530	500	500
Instr. & Navig.	770	590	590	675	510	510	675	460	460
Elec. & Electronics	2755	2640	2640	2750	2590	2590	2750	2360	2360
Furn. & Equip.	5220	5380	5380	5120	5430	5430	5120	4780	4780
Air Cond. & De-Ice	1450	1340	1340	1370	1610	1610	1370	1370	1370
WEIGHT EMPTY	54098	52320	50930	50254	51270	52160	40924	37770	34365
(G.W.Structure Adjust)		-180			+154			-385	
Crew & Crew Baggage	520 ←								→ 520
Unusable Fuel & Oil	295	530	530	275	500	500	275	170	170
Pass. Service Items	655	700	700	655	700	700	655	700	700
OPER. WT. EMPTY	55568	53890	52680	51704	53144	53880	42374	38775	35755
Pass. & Luggage (60)	13200 ←								→ 13200
Fuel	11990	11990	11790	6800	6800	7060	7250	7250	6900
Take-Off G.W.	80758	79080	77670	71704	73144	74140	62824	59225	55855

*This weight includes: Engine section (nacelle & eng. mts.) engines, air induction, exhaust, cooling, lubrication, engine controls & starting systems.

TABLE 16

EFFECT OF USNAC WEIGHT EVALUATION ON GENERAL AIRCRAFT CHARACTERISTICS

	JET LIFT		TILT WING		TURBOFAN STOL	
	Original	Final Adjusted Wt	Original	Final Adjusted Wt	Original	Final Adjusted Wt
Physical Data						
Wing						
Area (sq ft)	712	683	787	814	749	667
Span (ft)	55	53.9	79.5	80.5	67	63.2
Aspect Ratio	4.25	4.25	8.03	7.97	6.0	6.0
Horizontal Tail Area	186	182	238	242	180	170
Vertical Tail Area	177	173	178	182	146	137
Propeller Diameter	-	-	21.05	21.4	-	-
Cruise Powerplants						
Maximum Thrust or Power per engine	6950 lb	6800 lb	6740 SHP	6970 SHP	7500 lb.	6670 lb
Lift Powerplants						
Maximum Thrust	9970	9520	-	-	-	-

The changes in direct operating cost which would result from these changes in design gross weight are shown in Figure 21 as a function of stage length.

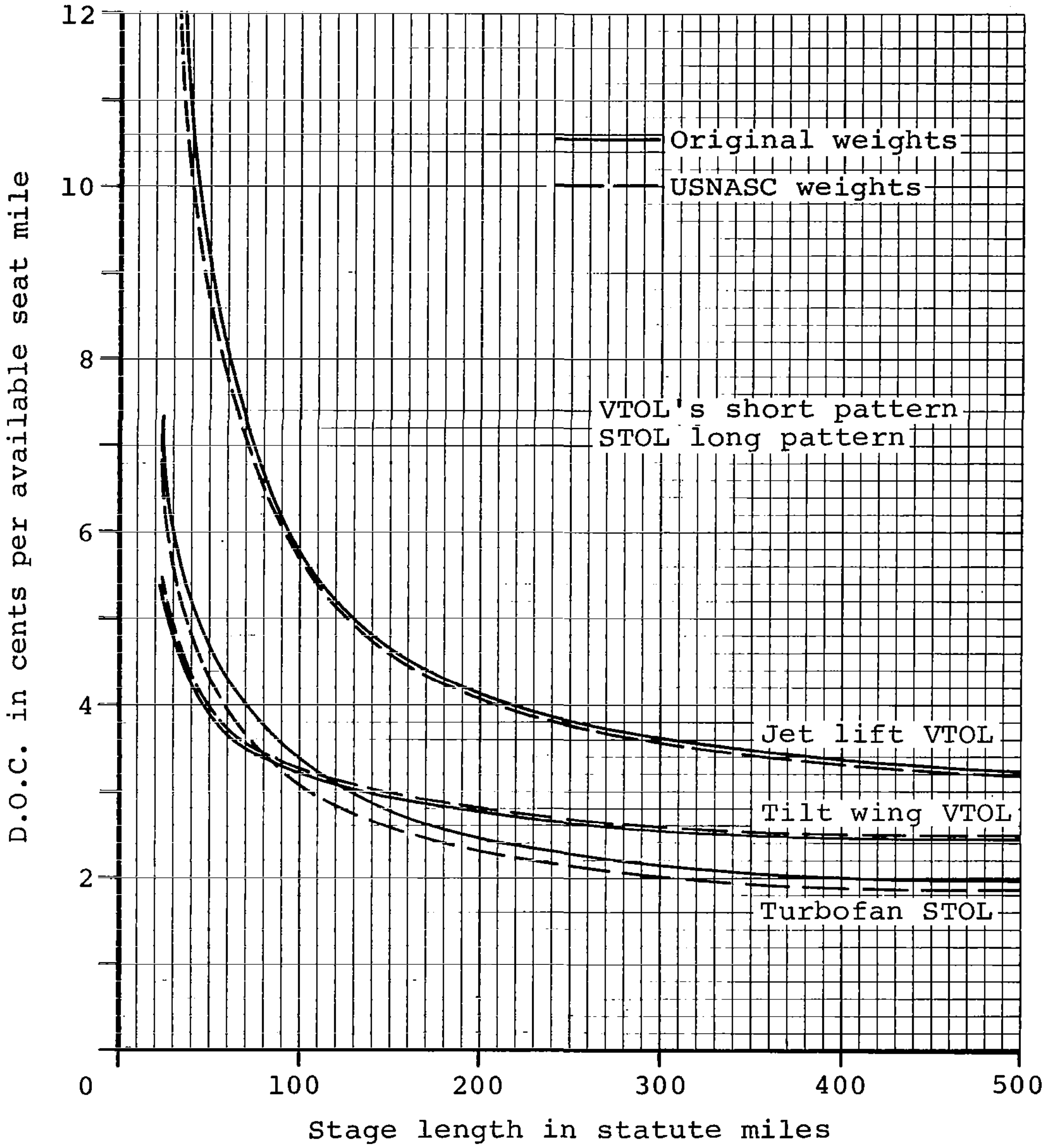


Figure 21. Effect of USNASC Weight Trends on Direct Operating Cost.

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