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APPLICATION OF ADVANCED TECHNOLOGY
TO FUTURE LONG-RANGE AIRCRAFT

by Owen E. Schrader

May 24, 1976

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16. Abstract

The objective of this paper is to provide an overview assessment of three separate programs at Langley Research Center that have incorporated advanced technology into the design of long-range passenger and cargo aircraft. The first technology centers around the use of a span-loaded cargo aircraft with the payload distributed along the wing. The second technology is the application of laminar flow control (LFC) to the aircraft to reduce the aerodynamic drag. The last program evaluates the production of alternate aircraft fuels from coal and the use of liquid hydrogen as an aircraft fuel.

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APPLICATION OF ADVANCED TECHNOLOGY TO FUTURE LONG-RANGE AIRCRAFT

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SUMMARY

The objective of this paper is to provide an overview assessment of three separate programs at Langley Research Center that have incorporated advanced technology into the design of long-range passenger and cargo aircraft. The first technology centers around the use of a span-loaded cargo aircraft with the payload distributed along the wing. This concept has the potential for reduced structural weights. The second technology is the application of laminar flow control (LFC) to the aircraft to reduce the aerodynamic drag. The use of LFC can reduce the fuel requirements during long-range cruise. The last program evaluates the production of alternate aircraft fuels from coal and the use of liquid hydrogen as an aircraft fuel. Coal-derived hydrogen as an aircraft fuel offers both the prospect for reduced dependence on petroleum fuels and improved performance for long-range aircraft.

INTRODUCTION

This paper was presented at the 35th Annual Conference of the Society of Allied Weight Engineers, Inc., Philadelphia, Pennsylvania, May 24-26, 1976, to provide an overview assessment of three distinct program efforts at Langley Research Center. The purpose was to show the impact on aircraft weight due to the application of advanced technology into the design of long-range passenger and cargo aircraft. Each of the programs will be discussed separately followed by a general discussion of items of common interest.

The first program is the Very Large Aircraft Systems Technology Program. The discussion on this program will center around the results of recent studies on Technical and Economic Assessment of Span-Loaded Cargo Aircraft Concepts (Refs. 1-4). The next program is the Laminar Flow Control Technology Program. A recent study of the Application of Advanced Technologies to Laminar Flow Control Systems for Subsonic Transports will provide the basis for the discussion (Refs. 5 and 6). The third program is the Hydrogen Fueled Aircraft Technology Program. Areas of discussion will be on the Application of Hydrogen Fuel to Long-Range Subsonic Transport Aircraft (Refs. 7 and 8), and of the Conversion of Coal to Hydrogen, Methane, and Liquid Fuels for Aircraft (Refs. 9, 10, and 11).

SYMBOLS

ACLS	air cushion landing system
ALT	altitude
AR	aspect ratio
Btu	British thermal unit
Bend M.	bending material
C.G.	center of gravity
CO	carbon monoxide
CO_2	carbon dioxide
$C_{(s)}$	carbon-solid
C.S.	control surfaces
Deg	degree
DOC	direct operating cost
EAS	equivalent air speed
EMP	empennage
FAR	federal air regulations
F.E.	fixed equipment
FeO	iron (II) oxide
Fe_3O_4	iron (II, III) oxide
F.L.	field length
GTM	gross ton miles
GW	gross weight
H_2	hydrogen
H_2O	water
IC	investment cost

LFC	laminar flow control
lb	pound
L/D	lift/drag
L.E.	leading edge
LH_2	liquid hydrogen
M	Mach number
N_2	nitrogen
NAC	nacelle
NSF	National Science Foundation
O_2	oxygen
OWE	operating weight empty
P	pressure
PAX	passenger
ROI	return on investment
S	second
SFC	specific fuel consumption
SHR	shear
SLS	sea level static
STR	structure
Sw	wing area
S km/m^3	seat - km/m^3
SS mi/gal	seat - statute mi./gallon
T	temperature
TE	trailing edge
TF	turbulent flow
TOFL	takeoff field length
TOGW	takeoff gross weight
t/c	thickness/chord
V_{App}	velocity approach
Λ	wing sweep angle

DISCUSSION

Large Aircraft

The Very Large Aircraft Systems Technology Program is a broad program. Major elements of the program are shown in Figure 1. Under the configuration studies, the most recent data are the results from the studies of the application of advanced technologies to span-distributed loading cargo aircraft. The application of comparable advanced technologies was also applied on conventional fuselage-loaded cargo aircraft. The studies were conducted with the following general ground rules: nominal range of 5,556 km (3,000 n. mi.); balanced field length of 3,657 meters (12,000 ft); container size of 2.44 x 2.44 x 6.1 meters (8 x 8 x 20 ft); cargo density of 112 to 192 kg/meter^3 (7 to 12 lb/ft^3); and appropriate technology for a 1990 system introduction date. The technology could include composites, active controls, and thick supercritical wings with winglets.

The Boeing study of the distributed-load concept (Fig. 2) was limited to unswept wings of constant chord with the tail supported by twin booms from the wing trailing edge. The McDonnell Douglas study concentrated on an unswept wing configuration (Fig. 3) that had a small nonpayload-carrying fuselage. Douglas also performed a brief analysis of a swept wing spanloader and a cargo hybrid seaplane (Figs. 4 and 5). The Lockheed study configuration (Fig. 6) has a swept wing with provision for outsized cargo 4.12 m (13.5 ft) in the fuselage. All three studies developed a conventional reference configuration for comparison (Figs. 7, 8, and 9). Table 1 lists various elements for comparison between the selected distributed load concept (spanloader) and the conventional fuselage-loaded reference configuration.

The distributed-load airplanes with a straight wing and constant chord have a large number of common parts compared to conventional airplanes. This increase in the number of common parts allows the manufacturing man-hours to be reduced because of the lower position on the learning curve. The data in Table 1 present the cost difference in terms of dollars per kg (dollars per pound) of empty weight. The Boeing configuration cost was $304 per kg ($137.9 per pound) of empty weight compared to $355 per kg ($161.2 per pound) for their conventional configuration. The Douglas configuration cost was $325 per kg ($147.5 per pound) of empty weight compared to $396 per kg ($179.7 per pound) for their conventional configuration.

The Boeing distributed-load airplane with a straight wing was not as fuel efficient as the conventional configuration. This resulted in a higher direct operating cost (DOC), but when aircraft investment cost is added to the DOC, the distributed load aircraft has an economic advantage. This is an ROI that is a simple return on the cost of the investment added to operating cost; it is not a profit derived ROI. A breakdown of these costs is shown in Figure 10.

The Boeing and Douglas straight-wing distributed-load airplanes (Figs. 2 and 3), when confined to a 272,155 kg (600,000-lb) payload, did not have as efficient aerodynamic performance as the conventional aircraft (L/D: 16.6 vs 21.9 and 18.8 vs 21.5). This was due to the fallout during the design of a trade between aspect ratio, wing thickness ratio, and number of cargo bays. When the study aircraft were projected to 453,600 kg (1,000,000 lb) payload, both the aspect ratio could be increased and the wing thickness ratio improved by the addition of additional cargo bays. This resulted in a configuration that was 20 to 25 percent better than the reference conventional configuration. It is also apparent from the study results by Lockheed that the use of a tailless, the production of liquid methane over liquid hydrogen and synthetic jet fuel from coal. The choice for an alternative fuel is not obvious because it is necessary to take other factors into consideration, such as: the efficiency of each when used as fuel on the airplane; the potential capability of production of hydrogen from other sources of energy by electrolysis, the potential restriction on the use of our coal supplies to chemical uses; the comparative cost of each fuel; and the problems of storage, handling, and tankage of cryogenic fuels.

Another of the studies, under the hydrogen-fueled aircraft technology program, assessed the use of LH_2 (liquid hydrogen) as an aircraft fuel. The title was the Study of the Application of Hydrogen Fuel to Long-Range Subsonic Transport Aircraft. The study was performed by Lockheed Aircraft Company. The objectives of the study were to: (1) assess the feasibility and potential advantages of using LH_2 as fuel in long-range, subsonic transport aircraft (both passenger and cargo types), (2) identify the problems and technology requirements peculiar to such aircraft, and (3) outline a program for development of necessary technology on a timely basis. The technical guidelines included supercritical aerodynamics, composite materials, active controls, advanced engines, and initial operation in 1990-1995.

A number of candidate passenger configurations, shown in Figures 21 and 22, were reviewed. Two configurations were selected for detail analysis, while the others were rejected for the reasons shown. One of the configurations (Fig. 23) has all of the fuel located in two tanks fore and aft in the fuselage, while the other (Fig. 24) has external fuel tanks on the wing. There was not a clearly significant safety advantage with either configuration. The decision to select the internal tank configuration offered the potential for both lower weight and better performance.

The requirement for large tankage volume results from the difference in the available energy per unit weight and volume between conventional hydrocarbon jet fuel and LH_2. On an energy per unit weight basis, the LH_2 is higher by a factor of 2.8, but on an energy per unit volume basis, the LH_2 is lower by a factor of 3.78. Therefore, for the same onboard energy, it required 3.78 times the volume of LH_2 to be equivalent to the volume of 2.8 times more weight of jet fuel.

The results of the comparison are shown in Tables 3 and 4 for the 400-passenger, 5,560 km (3,000 n. mi.), $M = 0.85$ aircraft and 400-passenger, 10,190 km (5,500 n. mi.), $M = 0.85$ aircraft. The results of the comparison of the selected LH_2 configurations to the reference jet-fueled configurations are shown in Tables 5 and 6.

A similar review of cargo configurations was conducted and the selected configurations are shown in Figures 25 and 26. The mission fuel is contained in an area above the cargo bay and in the unpressurized aft fuselage section. The upper tank area is separated from the cargo area by a horizontal bulkhead, and the area is pressurized by engine bleed air entering from the front and venting out the rear of the aircraft to provide continuous purging.

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A corresponding hydrocarbon jet-fueled airplane was developed for each mission of 56,700 kg payload, 5,560 km range (125,000 lb, 3000 n. mi.), and M = 0.85 small cargo aircraft; and 113,400 kg payload, 10,190 km range (250,000 lb, 5,500 n. mi.), and M = 0.85 large cargo aircraft. The jet-fueled airplane was used as a reference airplane for comparison with the LH_2 fueled cargo airplanes. The results of the comparison are shown in Tables 7 and 8. The combination of the low density of LH_2 and the requirement for a blanket of insulation around the tanks and plumbing to maintain the fuel at its cryogenic temperature, present design requirements that are reflected in the weight and performance of the airplane. As the tables show, the fuel weight required is about one-third of the conventional fueled airplane while the operating weights are nearly the same. The performance for the fat fuselage LH_2 in terms of L/D ratio is lower, but because of the reduced take-off weight, the onboard energy utilization is slightly better with LH_2. The use of LH_2 as a fuel for transport aircraft does require technology development but is not dependent upon either a breakthrough in present capability or the invention of new products. It has been considered technically feasible that hydrogen-fueled aircraft can be developed and begin commercial operations by 1990.

The advantage of using LH_2 fueled aircraft increases with the amount of fuel or energy needed to perform the mission. The apparent crossover point, shown in Figures 27 and 28, where LH_2 can be used to an advantage appears to also vary with passenger load. The 130-passenger LH_2 configuration appears to have a crossover point at 2,780 km (1,500 n. mi.), while the 400-passenger LH_2 appears to have its crossover point just under 3,700 km (2,000 n. mi.). The weight difference for LH_2 fueled aircraft becomes significant (266,430 kg vs 450,200 kg or 587,370 lb vs 992,520 lb) for the 19,000+ km (10,000 + n. mi.) when compared to a kerosene-fueled configuration.

CONCLUDING REMARKS

This paper has reviewed three technology programs that have the potential for the improvement in efficiency of transport airplanes. The first program, Span-Loaded Cargo Aircraft Concepts, identified the gains that are possible with this concept and also that these gains would tend to increase with both aircraft size and configuration refinements. The need for aircraft of this size will have to be paced with the development of large markets for air freight operations between selected hub cities that have the special runways and facilities.

The efforts at aircraft fuel conservation are being actively pursued by the laminar-flow control technology project. This is a technology that has been demonstrated in actual flight test with the X-21 in the 1960's. The current effort is to demonstrate economic and practicality of LFC. The potential gains of LFC are significant. It will require the development of a number of technologies to meet the structural, material, systems, maintenance, and operational requirements of LFC.

As we enter into the late 20th century and the numerous efforts of the type described in the two preceding programs cannot meet the fuel conservation requirements placed on air transportation, the alternative of LH_2 as an airplane fuel can be used. The efforts of the Hydrogen Fueled Aircraft Technology Program are aimed at providing a technology readiness so that the aircraft and the air transportation industry can convert to LH_2 fueled configurations in a more orderly manner with the arrival of the so-called "hydrogen economy." The results of the initial studies on LH_2 fueled airplanes have shown that the performance is improved over kerosene-fueled airplanes for design ranges over 2,780 km (1,500 n. mi.). The advantages in performance alone are not adequate to justify the conversion to LH_2 for aircraft fuel at this time. The hydrogen production, distribution, and storage would also require extensive parallel development to meet the fuel needs of the air transportation industry.

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TABLE 1 - COMPARISON OF SPAN LOADER CONFIGURATIONS VS REFERENCE CONFIGURATIONS
SI UNITS

	BOEING		DOUGLAS		LOCKHEED	
	Span Loader	Reference	Span Loader	Reference	Span Loader	Reference
TOGW kg	759177	467018	612349	571602	700013	781164
OWE kg	238771	179713	179860	181667	248754	313894
GROSS PL* kg	316516	194772	280428	267619	272155	272155
PL DENSITY kg/m^3	.128	.128	.128	.128	.128	.128
FUEL kg	203889	92532	152060	122314	179103	430154
RESERVE %	14.4	19.1	18.8	14.9	18.4	18.0
LAND F.L. m	1889	1859	3035	1588		
T.O.F.L. m	2133	3566	3272	3657	2206	3360
OWE/TOGW	.3145	.3848	.294	.318	.3553	.4018
CRUISE MACH NO.	.68	.78	.655	.784	.75	.75
ALT. m	8534	10058	9601	8778	10668	10668
L/D	16.6	21.9	18.8	21.5	19.66	20.05
BLOCK FUEL / PAYLOAD	.5512	.3843	.4402	.3889	.5368	.5878
PAYLOAD / GW	.2836	.3235	.2999	.3671	.2916	.2613
PAY LOAD / BLOCK FUEL x Range km	5.04	7.23	6.30	7.13	5.17	4.73
V_{APP} m/s	67.4	66.8	86.9	68.9		
RANGE km	5556	5556	5556	5556	5556	5556
ASPECT RATIO	6.5	10.5	4.45	9.2	5.9	8.5
Sw m^2	1730	790	1701	743	1724	1287
Gw/Sw kg/m^2	439	591	360	769	392	591
Λ DEG	0	20	0	28	40	20
t/c %	21.5	14	20	14	21.77	13.6
PAYLOAD / TOGW	.4169	.4171	.4579	.4681	.3888	.3484
PRICE (MILLION) $	72.6	63.9	58.5	72.0	134.08	156.58
$/kg of OWE	304	355	325	396	539	499
$/kg of PAYLOAD	229	328	208	269	493	575
DOC ¢/kg-km	.00303	.00297	.00230	.00222	.00351	.00397
NO. OF BAYS	4		3		2	

*Gross PL includes container weight

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TABLE 1 - COMPARISON OF SPAN LOADER CONFIGURATIONS VS REFERENCE CONFIGURATIONS
CONVENTIONAL UNITS

		BOEING		DOUGLAS		LOCKHEED	
		SPAN LOADER	REFERENCE	SPAN LOADER	REFERENCE	SPAN LOADER	REFERENCE
TOGW	LB	1,673,700	1,029,600	1,350,000	1,260,167	1,543,266	1,722,172
OWE	LB	526,400	396,200	396,525	400,509	548,410	692,019
GROSS PL*	LB	697,800	429,400	618,240	590,000	600,000	600,000
PL DENSITY	LB/FT^3	10	10	10	10	10	10
FUEL	LB	449,500	204,000	335,235	269,658	394,856	430,154
RESERVE	%	14.4	19.1	18.8	14.9	18.4	18.0
LAND FL.	FT	6,200	6,100	9,960	5,210		
TOFL	FT	7,000	11,700	10,737	12,000	7,240	11,024
OWE/TOGW		.3145	.3848	.294	.318	.3553	.4018
CRUISE MACH		.68	.78	.655	.784	.75	.75
CRUISE ALT	FT	20,000	33,000	31,500	28,800	35,000	35,000
CRUISE L/D		16.6	21.9	18.8	21.5	19.66	20.05
$\frac{\text{BLOCK FUEL}}{\text{PAYLOAD}}$		.5512	.3843	.4402	.3889	.5368	.5878
$\frac{\text{PAYLOAD}}{\text{GW}}$ X MACH NO.		.2836	.3235	.2999	.3671	.2916	.2613
$\frac{\text{PAYLOAD}}{\text{BLOCK FUEL}}$ X RANGE	NMI	2.72	3.90	3.40	3.85	2.79	2.55
V_{APP}	KT	131	130	169	134		
RANGE	NMI	3,000	3,000	3,000	3,000	3,000	3,000
ASPECT RATIO		6.5	10.5	4.45	9.2	5.9	8.5
Sw	FT^2	18,620	8,500	18,314	8,000	18,559	13,880
Gw/Sw	LB/FT^2	90	121	73.7	157.5	80.3	121
Λ	DEG	0	20	0	28	40	20
t/c	%	21.5	14	20	14	21.77	13.6
$\frac{\text{PAYLOAD}}{\text{TOGW}}$		.4169	.4171	.4579	.4681	.3888	.3484
PRICE (MILLION)	$	72.6	63.9	58.5	72.0	134.08	156.58
$/LB OF OWE		137.9	161.2	147.5	179.7	244.5	226.3
$/LB OF PL		104.0	148.8	94.6	122.0	223.5	260.9
DOC COST	¢/GTM	5.1	5.0	3.863	3.734	5.89	6.67
NO. OF BAYS		4		3		2	

*Gross PL includes container weight

TABLE 2 - COMPARISONS OF 200-PASSENGER TF AND LFC AIRCRAFT

CHARACTERISTIC	TF-200	LFC-200-R
CRUISE M. NO.	0.80	0.80
CRUISE ALTITUDE m (FT)	10972.(36000)	11582.(38000)
WING SWEEP, DEG	25.0	22.7
ASPECT RATIO	12.5	14.0
WING LOADING, kg/m^2 (LB/FT^2)	672.(133.5)	658.(131.0)
WING T/C RATIO	.1075	.1088
WING AREA, m^2 (FT^2)	258.(2779)	232.(2494)
CRUISE L/D	22.63	28.76
ENGINE THRUST kg(LB)	11720.(25840)	9882.(21788)
BYPASS RATIO	6.00	6.00
CRUISE POWER RATIO	0.87	0.87
GROSS WEIGHT, kg(LB)	173431.(382351)	152685.(336612)
EMPTY WEIGHT, kg(LB)	81906.(166006)	80384.(162990)
BLOCK FUEL, kg(LB)	67756.(129604)	48532.(93028)
FLYAWAY COST, $\$10^6$	23.218	23.503

TABLE 3-COMPARISON OF INTERNAL VS EXTERNAL TANK LH_2 AIRCRAFT

[400 PAX; 5560 km (3000 nmi); M = 0.85]

			EXTERNAL TANKS		INTERNAL TANKS	
	SI	CUSTOMARY	SI	CUSTOMARY	SI	CUSTOMARY
Gross Weight	kg	lb	159,800	352,300	153,500	338,500
Fuel Weight	kg	lb	18,500	40,700	16,300	36,300
Operating Empty Weight	kg	lb	101,400	223,600	97,300	214,500
Wing Area	m^2	ft^2	294	3170	286	3077
Span	m	ft	48.7	160	50.6	166
Fuselage Length	m	ft	60	197	64	210
FAR T.O. Field Length	m	ft	1536	5040	1788	5860
FAR Landing Field Length	m	ft	1760	5780	1770	5810
L/D (Cruise)	-	-	13.1	13.1	15.2	15.2
SFC (Cruise)	$\frac{kg}{hr}/daN$	$\left(\frac{lb}{hr}\right)/lb$	.203	.200	.203	.200
Thrust per Engine	N	lb	135,000	30,390	111,000	24,960
Energy Utilization	$\frac{kJ}{seat\ km}$	$\frac{Btu}{seat\ nmi}$	814	1430	680	1196
Airplane Price	$\$10^6$	$\$10^6$	25.0	25.0	23.6	23.6
DOC*	$\frac{¢}{seat\ km}$	$\frac{¢}{seat\ nmi}$	.612	1.134	.554	1.026

*LH_2 Fuel Cost = \$3/1.054 GJ = \$3/10^6 BTU = 15.48 ¢/lb

TABLE 4 - COMPARISON OF INTERNAL VS EXTERNAL TANK LH_2 AIRCRAFT

[400 PAX; 10,190 km (5500 nmi); M = 0.85]

	SI	CUSTOMARY	EXTERNAL TANKS		INTERNAL TANKS	
			SI	CUSTOMARY	SI	CUSTOMARY
Gross Weight	kg	lb	198,100	436,800	177,700	391,700
Fuel Weight	kg	lb	36,700	81,000	27,900	61,600
Operating Empty Weight	kg	lb	121,300	267,800	109,900	242,100
Wing Area	m^2	ft^2	338	3640	312	3360
Span	m	ft	52.1	171	53	174
Fuselage Length	m	ft	60	197	66.8	219
FAR T.O. Field Length	m	ft	1610	5290	1900	6240
FAR Landing Field Length	m	ft	1770	5810	1770	5810
L/D (Cruise)	-	-	13.4	13.4	16.1	16.1
SFC (Cruise)	$\frac{kg}{hr}/daN$	$\left(\frac{lb}{hr}\right)/lb$	.202	.199	.202	.199
Thrust per Engine	N	lb	172,100	38,760	127,500	28,690
Energy Utilization	$\frac{kJ}{seat\ km}$	$\frac{Btu}{seat\ nmi}$	930	1634	705	1239
Airplane Price	$\$10^6$	$\$10^6$	30.2	30.2	26.9	26.9
DOC*	$\frac{¢}{seat\ km}$	$\frac{¢}{seat\ nmi}$	.688	1.277	.576	1.079

*LH_2 Fuel Cost = \$3/1.054 GJ - \$3/10^6 BTU = 15.48 ¢/lb

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TABLE 5 - COMPARISON OF LH_2 VS JET A PASSENGER AIRCRAFT

[400 PAX; 5560 km (3000 nmi): M = 0.85]

	SI	CUSTOMARY	LH_2 SI	LH_2 CUSTOMARY	JET A SI	JET A CUSTOMARY
Takeoff Gross Weight	kg	lb	152,000	335,200	183,200	404,300
Operating Empty Weight	kg	lb	96,500	212,900	95,500	210,600
Block Fuel Weight	kg	lb	12,700	28,000	37,400	82,400
Total Fuel Weight	kg	lb	15,600	34,300	47,800	105,700
Wing Area	m^2	ft^2	283	3,047	301	3,235
Wing Loading, Takeoff	kg/m^2	lb/ft^2	537	110	610	125
Landing	kg/m^2	lb/ft^2	488	100	488	100
Span	m	ft	50.5	165.6	52	170.6
Fuselage Length	m	ft	64	210	60	197
Lift/Drag (Cruise)			14.86	14.86	16.66	16.66
Specific Fuel Consumption (Cruise)	$\frac{kg}{hr}/daN$	$\left(\frac{lb}{hr}\right)/lb$	.203	0.200	.592	0.582
Thrust per Engine (SLS)	N	lb	110,000	24,720	114,500	25,770
Thrust/Weight (SLS)	N/kg	-	2.90	.295	2.51	0.255
FAR T.O. Distance	m	ft	1,790	5,860	2,437	7,980
FAR Landing Distance	m	ft	1,770	5,804	1,760	5,760
Approach Speed (EAS)	m/s	knots	69.5	135	69	134
Weight Fractions	percent	percent				
Fuel			10.2	10.2	26.2	26.2
Payload			26.3	26.3	21.8	21.8
Structure			31.7	31.4	27.8	27.8
Propulsion			10.7	10.7	6.7	6.4
Equipment and Operation Items			21.7	21.4	17.8	17.8
Energy Utilization	$\frac{kJ}{seat\ km}$	$\frac{Btu}{seat\ nmi}$	685	1,204	717	1,260

TABLE 6 - COMPARISON OF LH_2 VS JET A PASSENGER AIRCRAFT

[400 PAX; 10,190 km (5500 nmi); M = 0.85]

			LH_2		JET A	
	SI	CUSTOMARY	SI	CUSTOMARY	SI	CUSTOMARY
Takeoff Gross Weight	kg	lb	177,800	391,700	237,200	523,200
Operating Empty Weight	kg	lb	110,000	242,100	110,800	244,400
Block Fuel Weight	kg	lb	24,000	52,900	75,000	165,500
Total Fuel Weight	kg	lb	27,900	61,600	86,500	190,800
Wing Area	m^2	ft^2	313	3,363	389	4,186
Wing Loading, Takeoff	kg/m^2	lb/ft^2	569	116.5	610	125
Landing	kg/m^2	lb/ft^2	493	101	518	106
Span	m	ft	53	174	59.2	194.1
Fuselage Length	m	ft	66.7	219	60	197
Lift/Drag (Cruise)			16.07	16.07	17.91	17.91
Specific Fuel Consumption (Cruise)	$\frac{kg}{hr}/daN$	$\left(\frac{lb}{hr}\right)/lb$	.203	0.199	.590	0.581
Thrust per Engine (SLS)	N	lb	127,700	28,700	145,400	32,700
Thrust/Weight (SLS)	N/kg	-	2.88	0.293	2.45	0.25
FAR T.O. Distance	m	ft	1,900	6,240	2,435	7,990
FAR Landing Distance	m	ft	1,770	5,810	1,590	5.210
Approach Speed (EAS)	m/s	knots	69.5	135	63.7	124
Weight Fractions	percent	percent				
Fuel			15.7	15.7	36.5	36.5
Payload			22.5	22.5	16.8	16.8
Structure			30.7	30.7	26.0	26.0
Propulsion			12.3	12.3	6.4	6.4
Equipment and Operating Items			18.8	18.8	14.3	14.3
Energy Utilization	$\frac{kJ}{seat\ km}$	$\frac{Btu}{seat\ nmi}$	705	1,239	788	1,384

TABLE 7. COMPARISON OF LH_2 VS JET A SMALL CARGO AIRCRAFT

[56,700 kg (125,000 lb); 5560 km (3000 nmi); M = 0.85]

			LH_2		JET A	
	SI	CUSTOMARY	SI	CUSTOMARY	SI	CUSTOMARY
Takeoff Gross Weight	kg	lb	135,760	299,300	161,480	356,000
Operating Empty Weight	kg	lb	64,640	142,500	63.730	140,500
Block Fuel Weight	kg	lb	11,860	26,140	33,880	74,700
Total Fuel Weight	kg	lb	14,470	31,900	41,100	90,600
Wing Area	m^2	ft^2	240.1	2584	263.2	2833
Wing Loading, Takeoff	kg/m^2	lb/ft^2	565	115.8	613	125.6
Landing	kg/m^2	lb/ft^2	536	109.7	536	109.7
Span	m	ft	46.5	152.5	51.3	168.3
Fuselage Length	m	ft	52.0	170.7	50.8	166.5
Lift/Drag (Cruise)			16.3	16.3	17.9	17.9
Specific Fuel Consumption (Cruise)	$\frac{kg}{hr}/daN$	$\frac{lb}{hr}/lb$	0.213	0.209	0.619	0.608
Thrust per Engine (SLS)	N	lb	106,310	23,890	112,980	25,400
Thrust/Weight (SLS)	N/kg	-	0.32	0.32	0.29	0.29
FAR T.O. Distance	m	ft	1786	5800	2207	7240
FAR Landing Distance	m	ft	2231	7320	2216	7270
Approach Speed (EAS)	m/s	knots	69.5	135	69.5	135
Weight Fractions	percent	percent				
Fuel			11	11	26	26
Payload			42	42	35	35
Structure			29	29	25	25
Propulsion			10	10	7	7
Equipment and Operating Items			8	8	7	7
Energy Utilization	$\frac{kJ}{Mg\ km}$	$\frac{Btu}{ton\ n\ mi}$	4502	7181	4596	7330

TABLE 8. COMPARISON OF LH_2 VS JET A LARGE CARGO AIRCRAFT

[113,400 kg (250,000 lb); 10,190 km (5500 nmi); M = -.85]

	SI	CUSTOMARY	LH_2 SI	LH_2 CUSTOMARY	JET A SI	JET A CUSTOMARY
Takeoff Gross Weight	kg	lb	300,060	661,500	400,890	883,800
Operating Empty Weight	kg	lb	138,670	305,700	138,850	306,100
Block Fuel Weight	kg	lb	41,300	91,100	129,200	285,000
Total Fuel Weight	kg	lb	47,990	105,800	148,650	327,700
Wing Area	m^2	ft^2	483.4	5203	658.1	7084
Wing Loading, Takeoff	kg/m^2	lb/ft^2	620.5	127.5	609.3	124.8
Landing	kg/m^2	lb/ft^2	535.6	109.7	412.5	84.5
Span	m	ft	66	216.4	77	252.5
Fuselage Length	m	ft	77.0	252.7	72.0	236.0
Lift/Drag (Cruise)			18.0	18.0	19.5	19.5
Specific Fuel Consumption (Cruise)	$\frac{kg}{hr}/daN$	$\frac{lb}{hr}/lb$	0.213	0.209	0.619	0.608
Thrust per Engine (SLS)	N	lb	212,170	47,700	258,430	58,100
Thrust/Weight (SLS)	N/kg	-	0.29	0.29	0.26	0.26
FAR T.O. Distance	m	ft	2185	7170	2438	8000
FAR Landing Distance	m	ft	2304	7560	2143	7030
Approach Speed (EAS)	m/s	knots	69.5	135	61.2	119
Weight Fractions	percent	percent				
Fuel			16	16	37	37
Payload			38	38	28	28
Structure			31	31	23	23
Propulsion			10	10	7	7
Equipment and Operating Items			5	5	5	5
Energy Utilization	$\frac{kJ}{Mg\ km}$	$\frac{Btu}{ton\ nmi}$	4286	6835	4782	7627

CARGO TRANSPORTATION SYSTEMS

- MARKET SYSTEMS ANALYSIS
- TECHNOLOGY IMPACT ASSESSMENT (WITH N.S.F.)

AIRCRAFT SYSTEMS TECHNOLOGY STUDY

- IN-HOUSE ANALYSES
- INDUSTRY SURVEYS
- INDUSTRY SYSTEMS STUDY

AIRCRAFT RESEARCH AND TECHNOLOGY

- PROPULSIVE LIFT STUDIES - ANALYSES AND EXPERIMENTS
- THICK AIRFOIL PROGRAM - ANALYSES AND EXPERIMENTS
- CONFIGURATION STUDIES
- SUPPORT FOR ACLS PROGRAM
- COMPOSITE STRUCTURES DEVELOPMENT
- ACTIVE CONTROL DEVELOPMENT

SIMULATION/DEMONSTRATION

- SIMULATOR STUDIES
- SUB-SCALE FLIGHT TESTS - NEEDS ASSESSMENT

Figure 1. Representative elements of NASA proposed very large aircraft systems technology program.

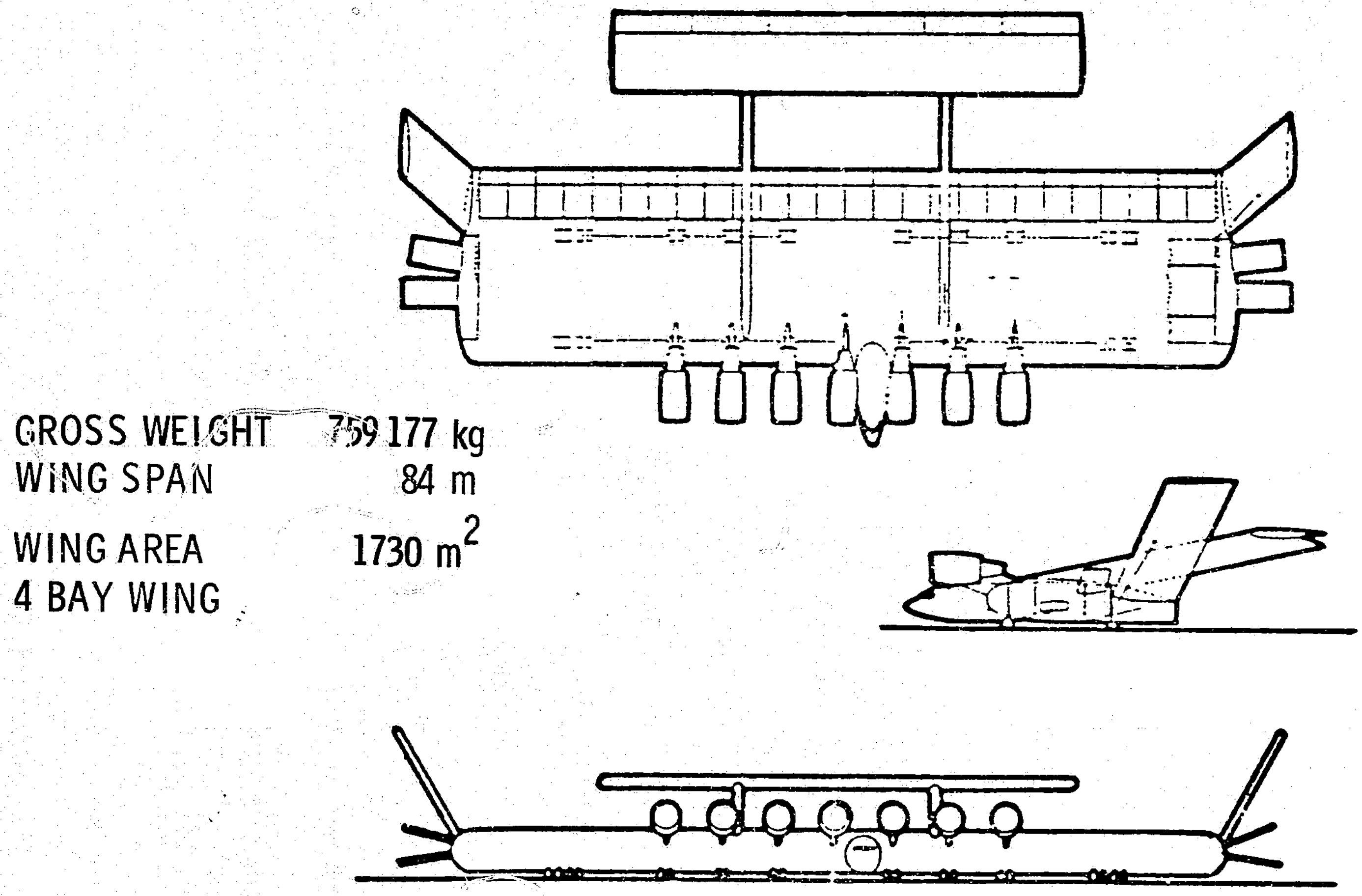

Figure 2. Boeing spanloader configuration.

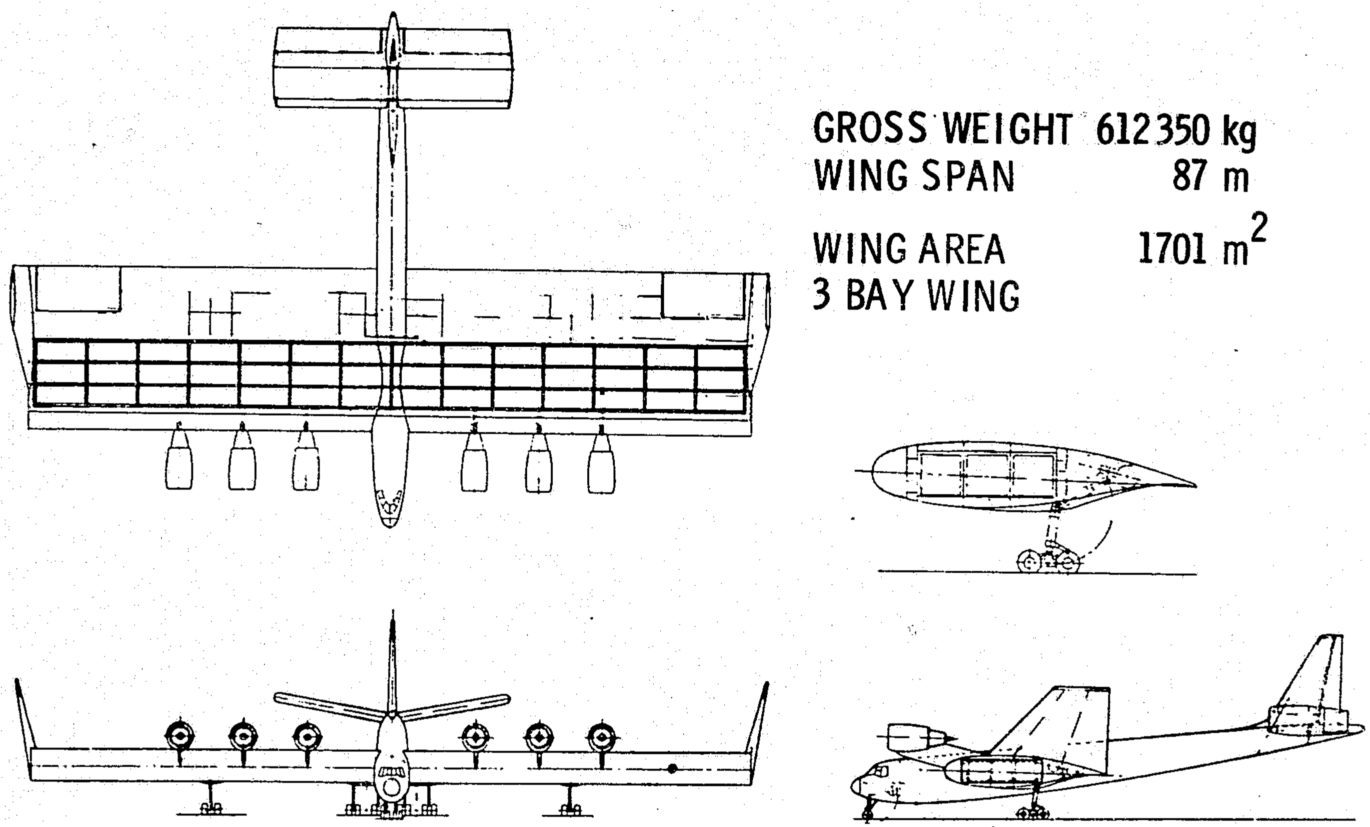

Figure 3. McDonnell Douglas spanloader configuration.

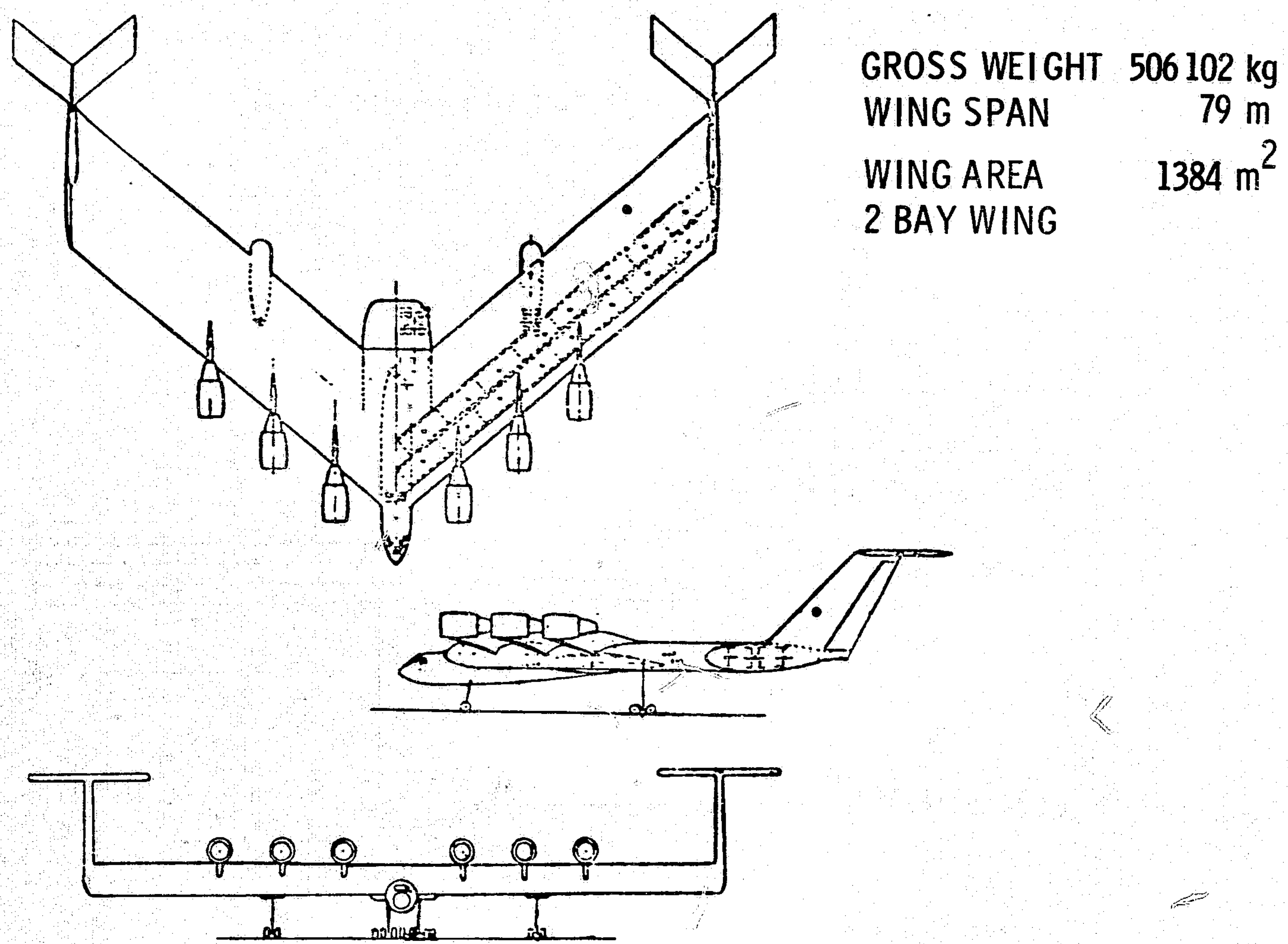

Figure 4. McDonnell Douglas swept wing spanloader configuration.

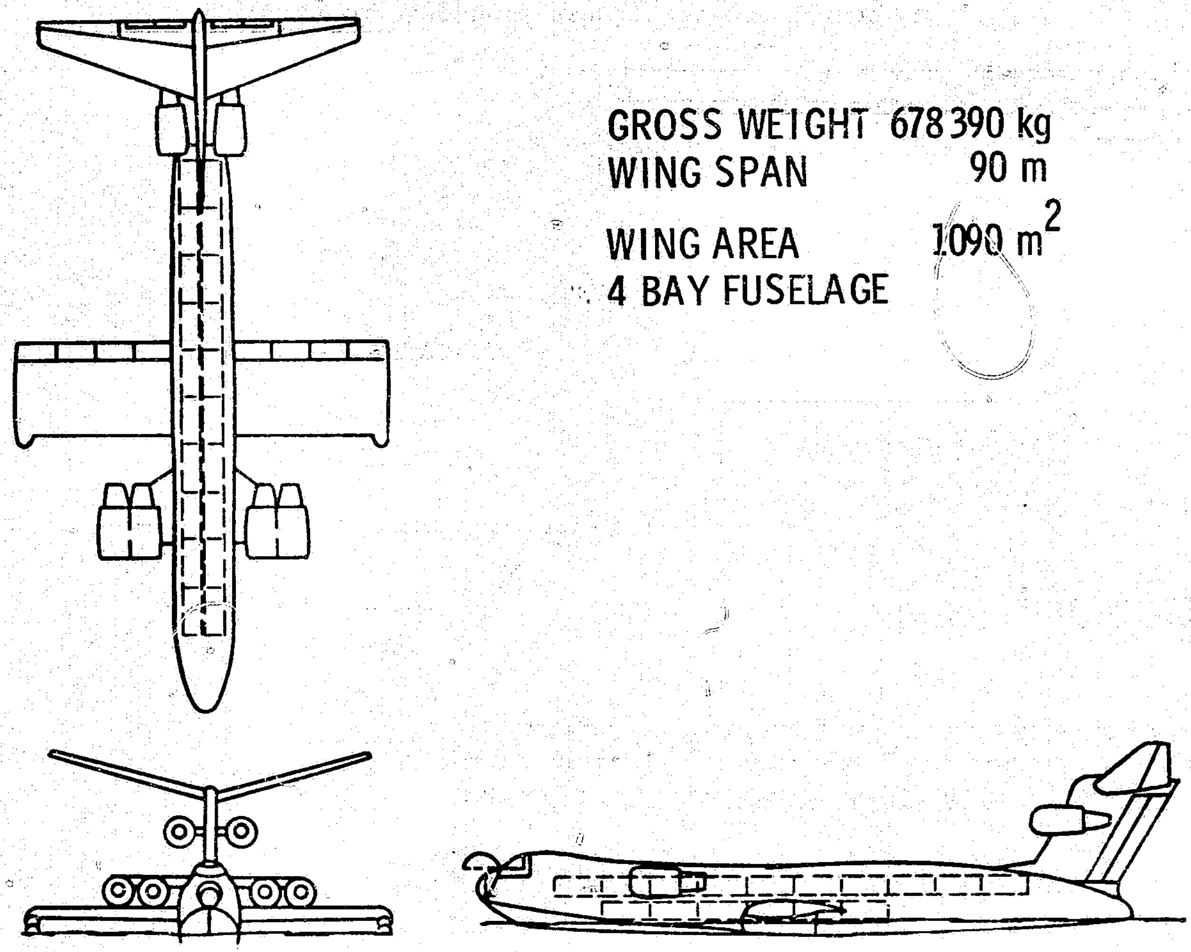

Figure 5. McDonnell Douglas hybrid seaplane configuration.

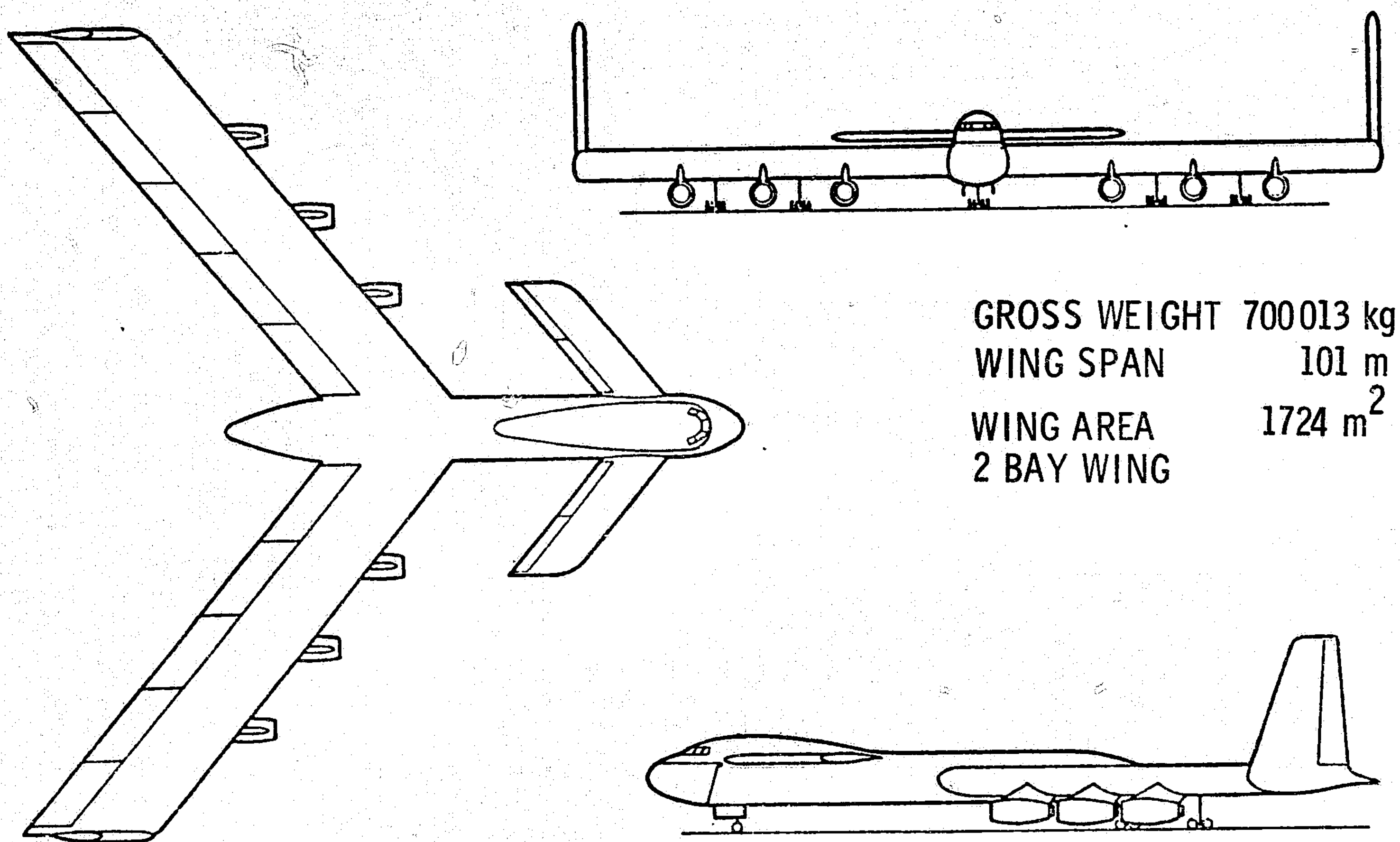

Figure 6. Lockheed spanloader configuration.

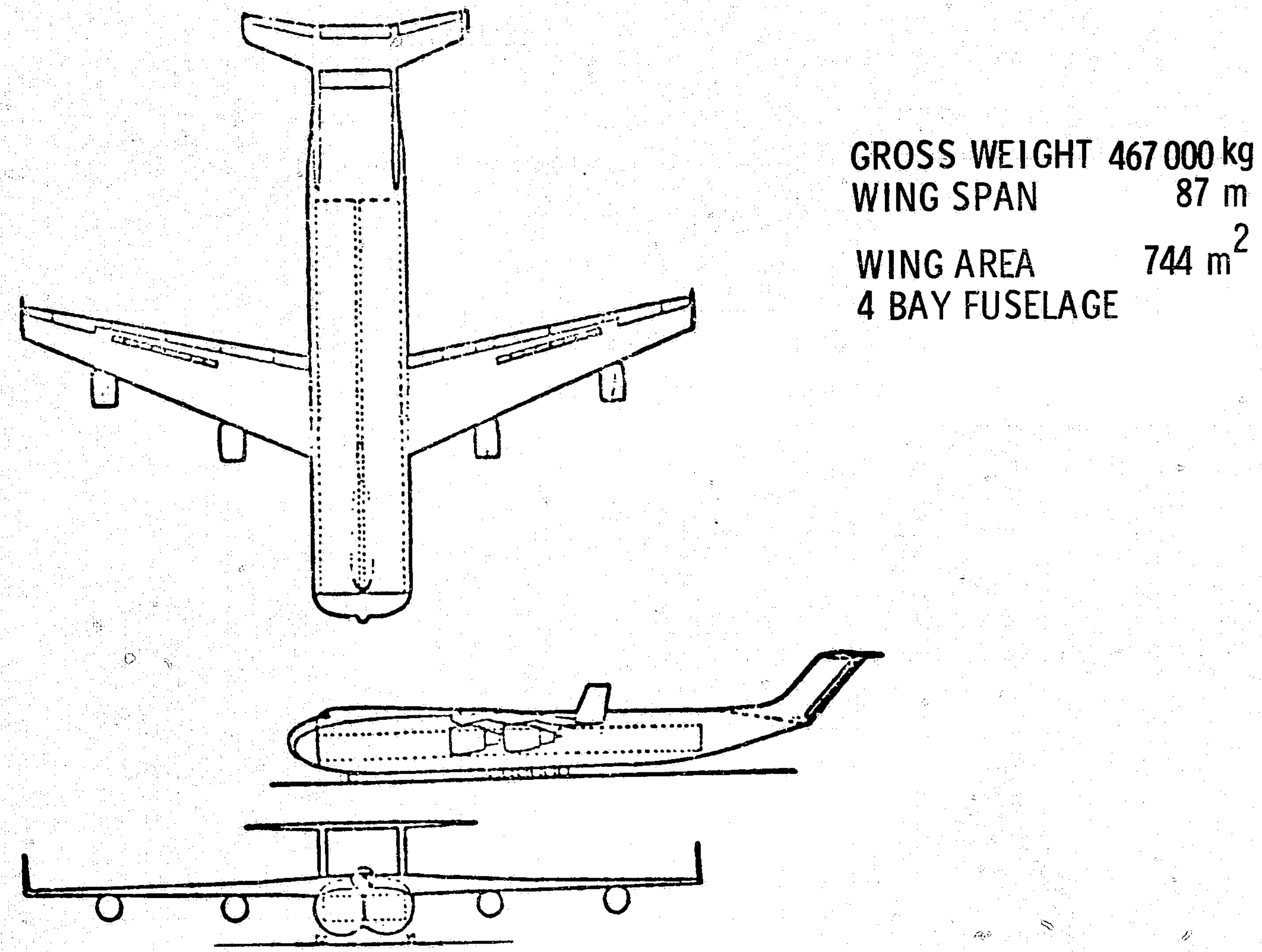

Figure 7. Boeing conventional reference configuration.

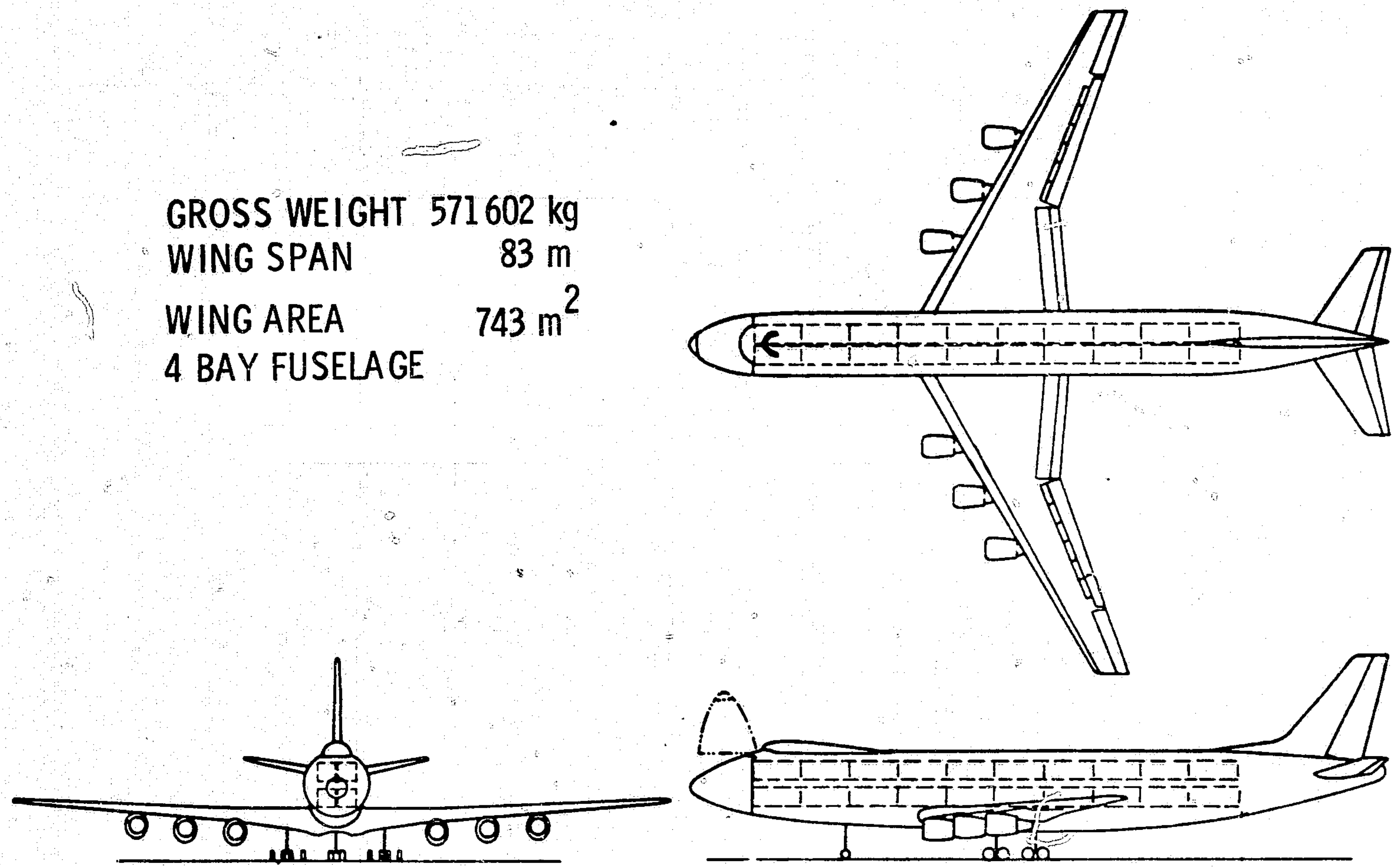

Figure 8. McDonnell Douglas conventional reference configuration.

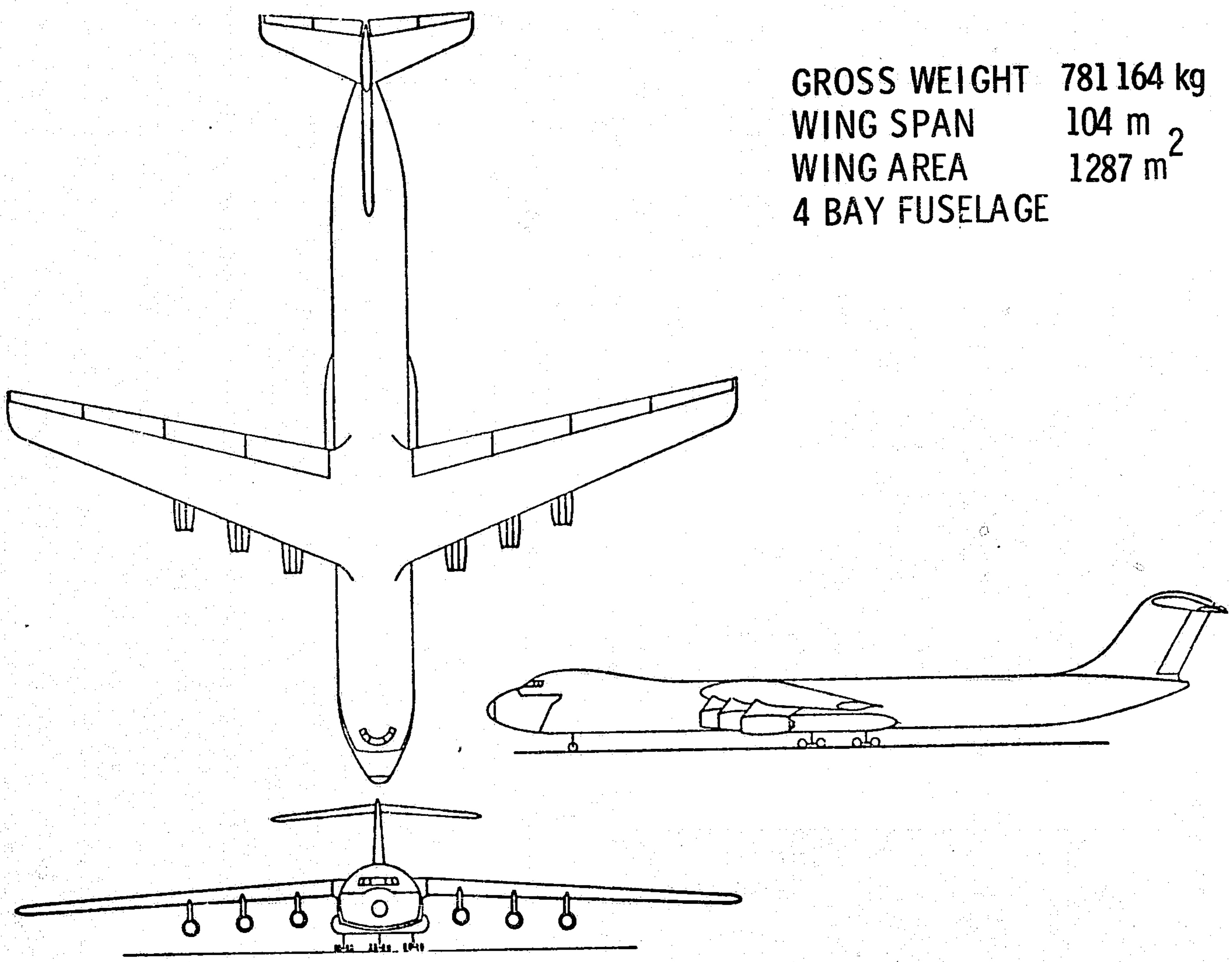

Figure 9. Lockheed conventional reference configuration.

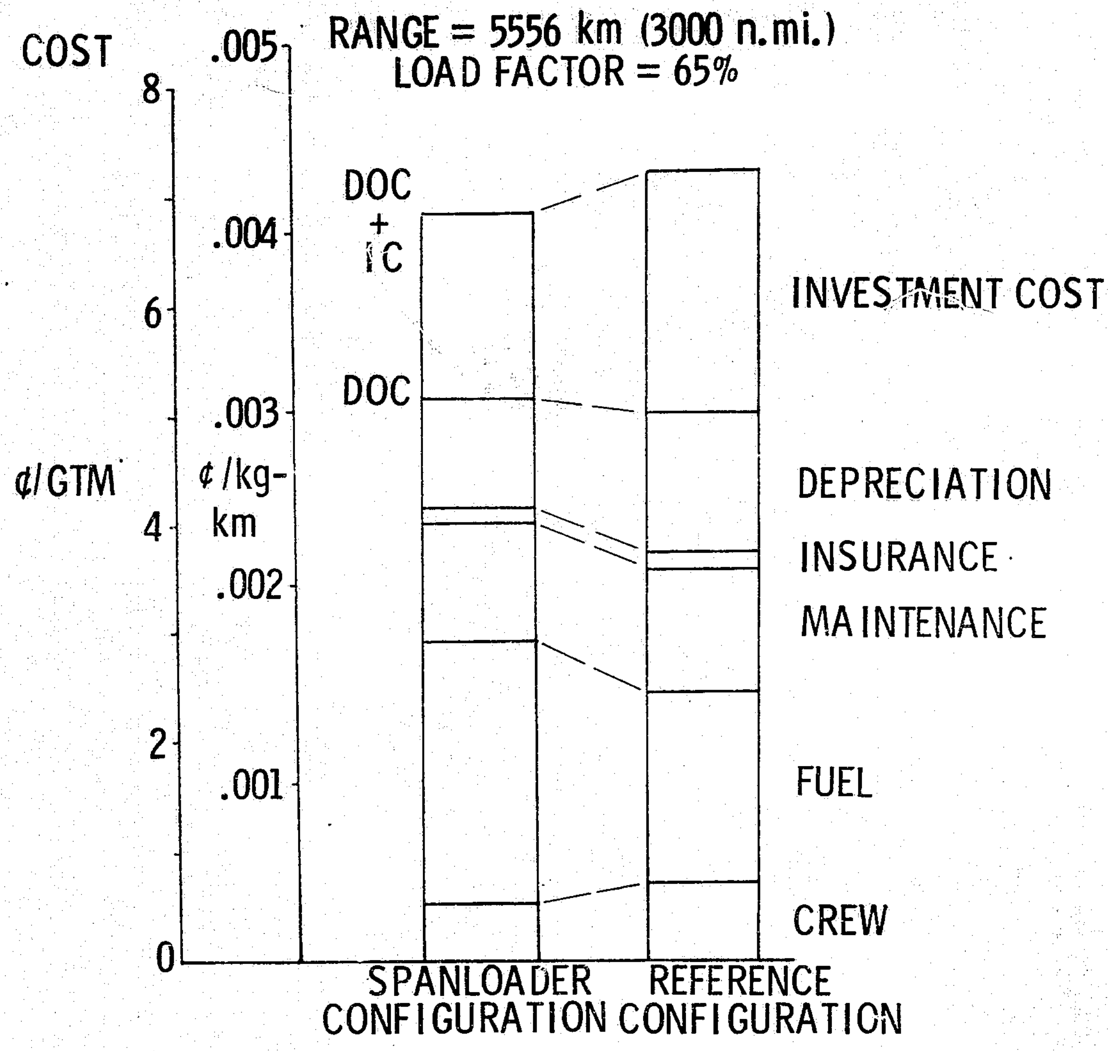

Figure 10. Cost comparison of the Boeing spanloader versus reference configuration.

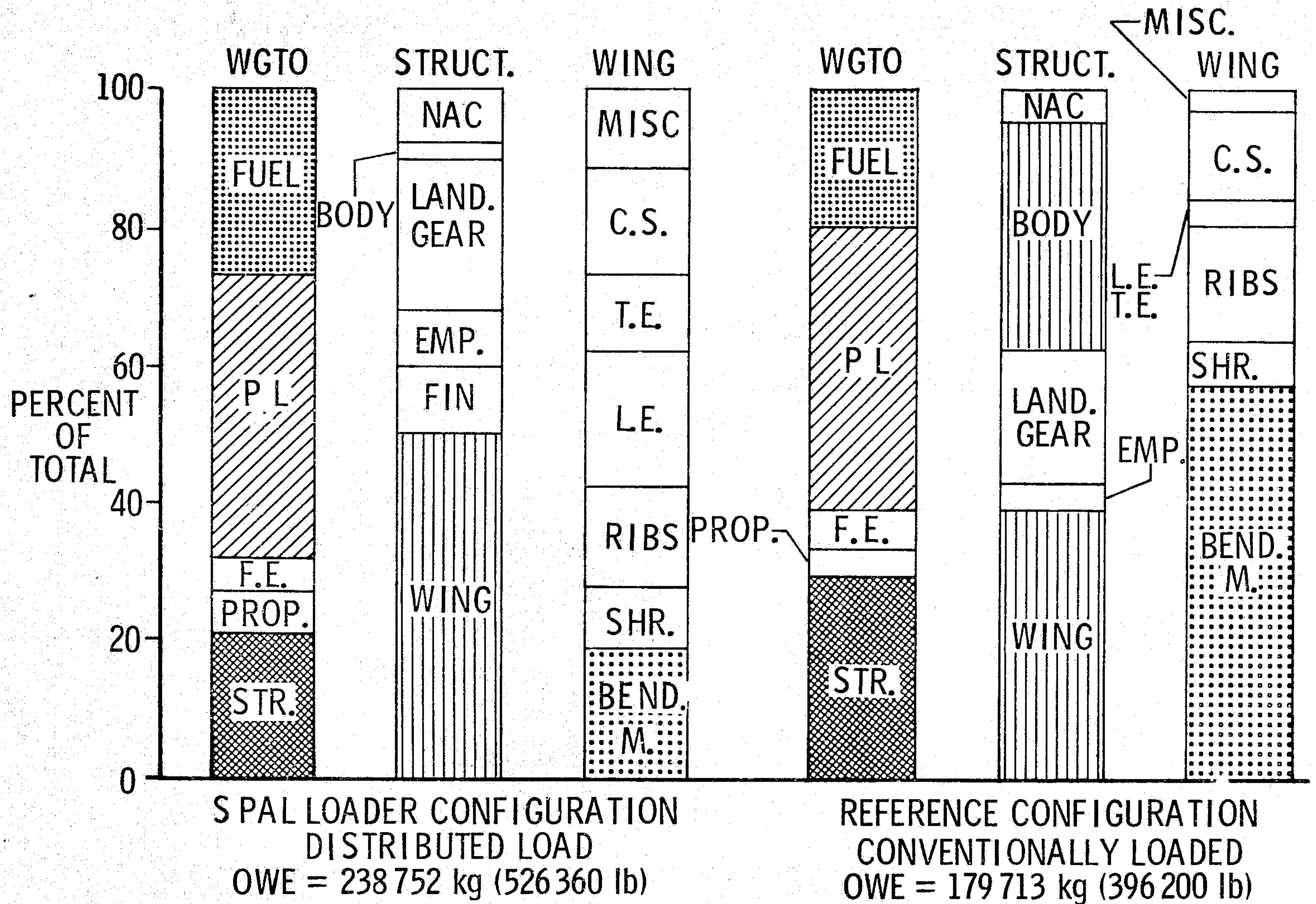

Figure 11. Weight distribution comparison of the Boeing spanloader versus reference configuration.

PHASE I

- TRANSPORT SYSTEMS DEFINITION
- DEVELOP TOOLS & REQUIREMENTS
- EVALUATE LEADING-EDGE CONTAMINATION
- DEVELOP LFC AIRFOILS

PHASE II

- FLIGHT TEST ADVANCED LFC AIRFOIL
- WTT SWEPT AIRFOIL SURFACE EFFECTS
- SYSTEM DESIGN
- SYSTEMS DEVELOPMENT
- PRELIMINARY DESIGN 1990 TRANSPORT
- DEFINE VALIDATOR AIRCRAFT

PHASE III

- DESIGN VALIDATOR AIRCRAFT
- AIRCRAFT MODIFICATION
- FLIGHT TEST

Figure 12. Representative elements of the Laminar Flow Control Technology Program.

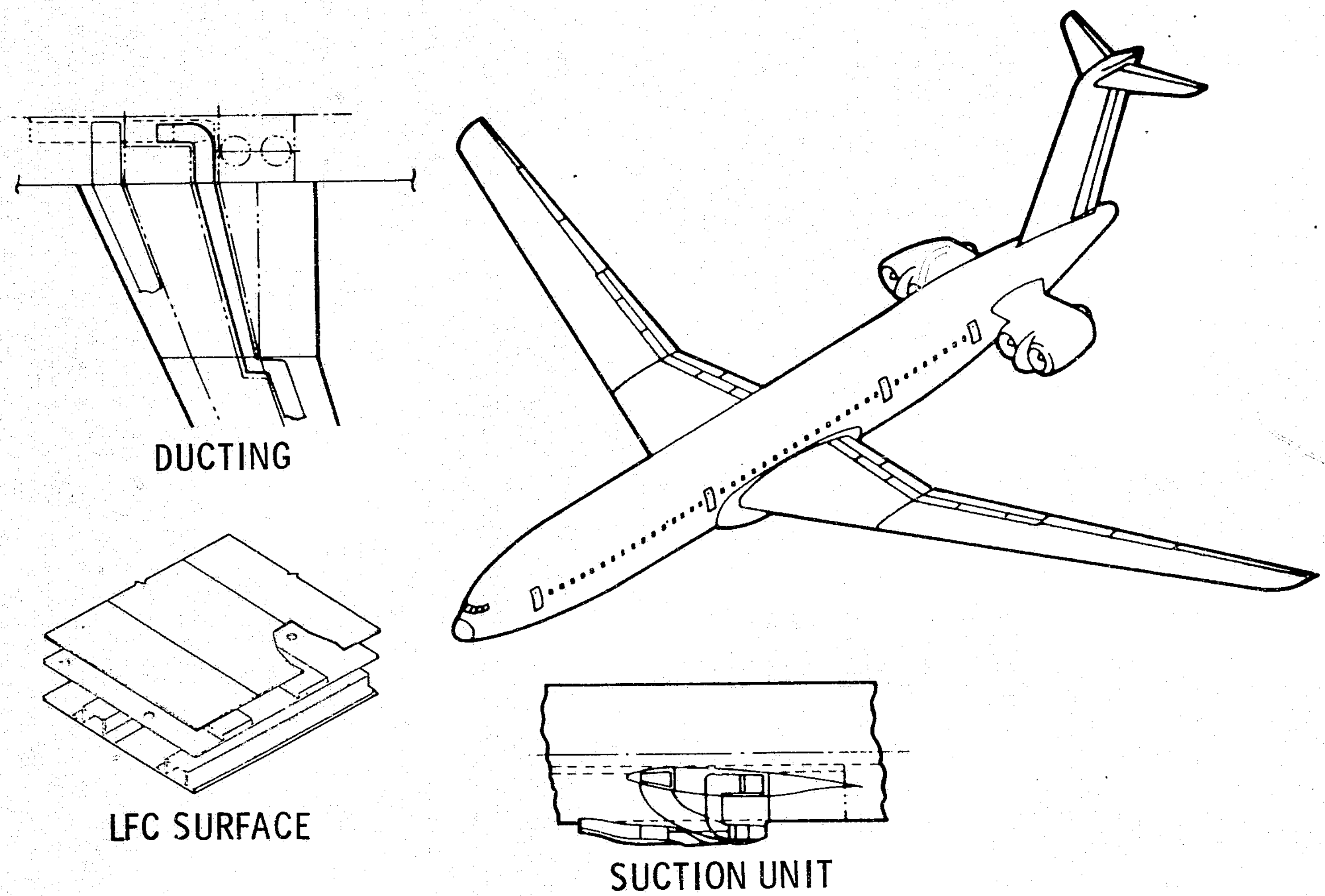

Figure 13. Laminar flow control configuration characteristics.

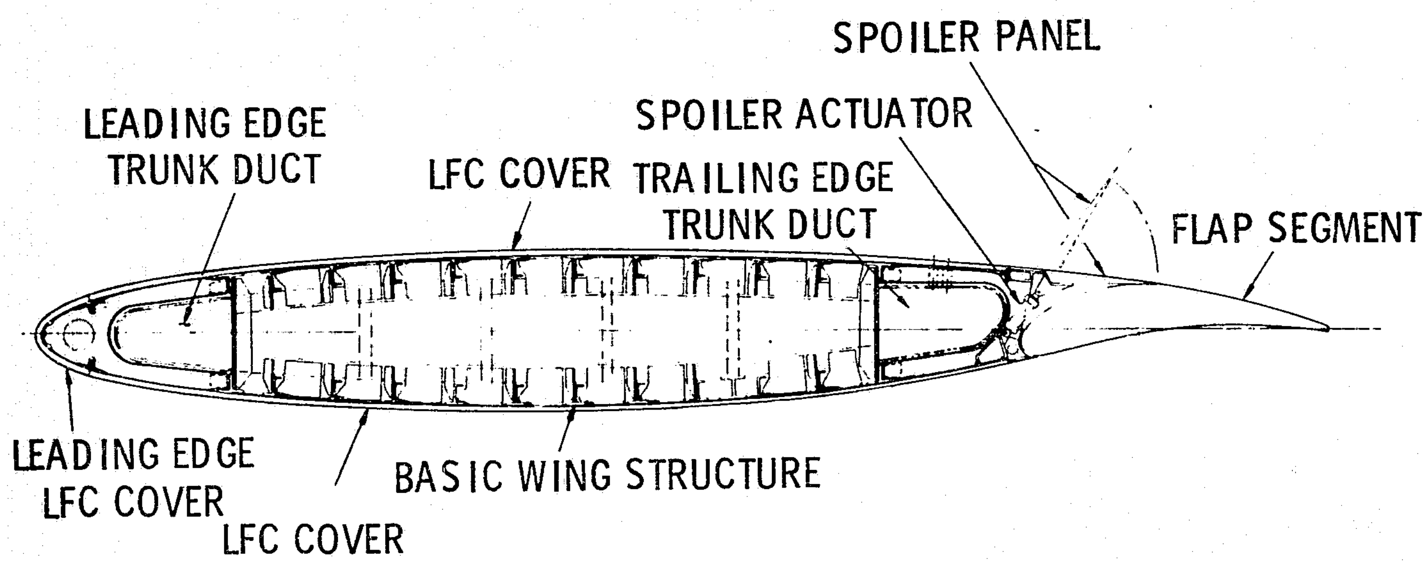

Figure 14. Typical laminar flow control wing section.

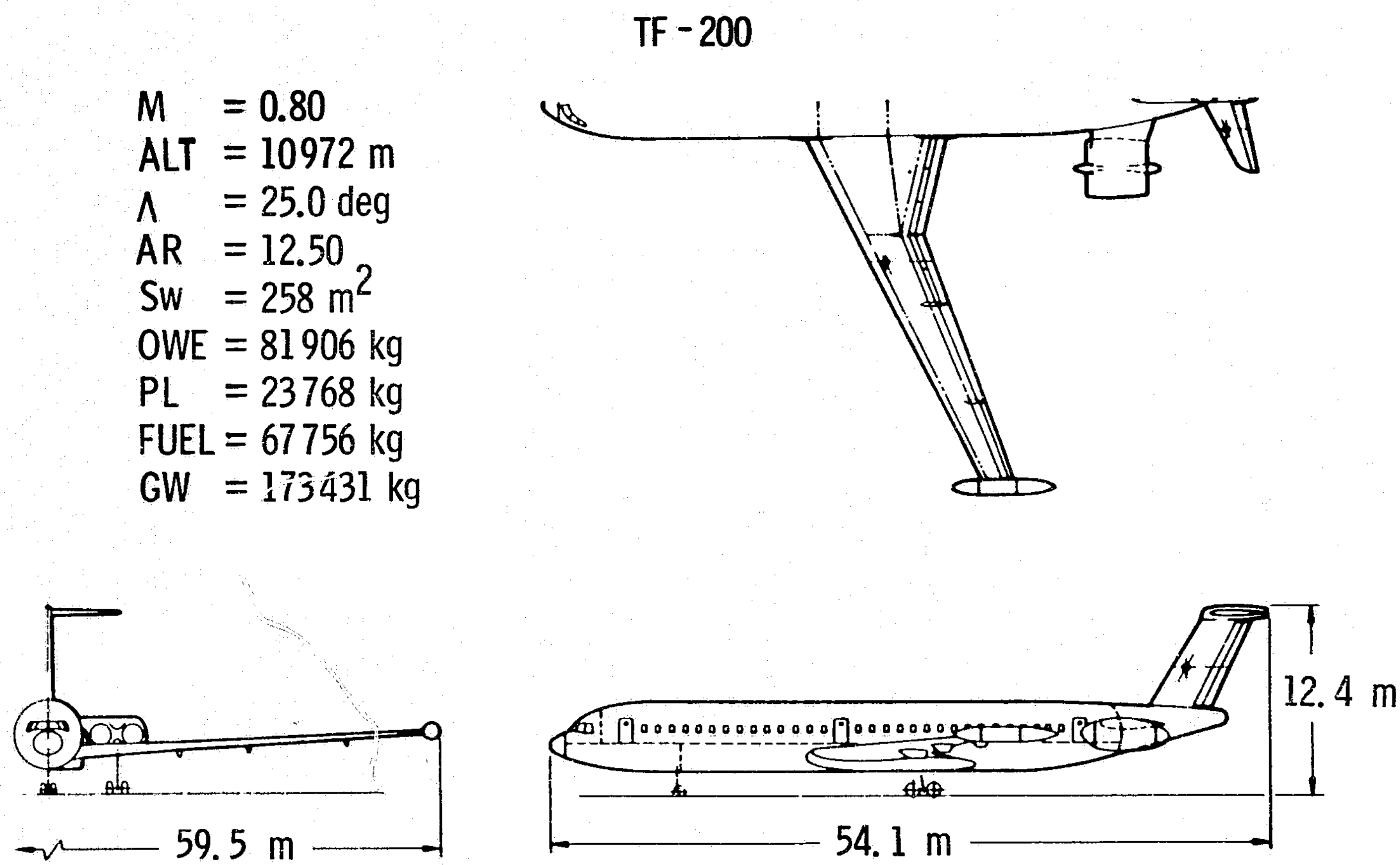

Figure 15. Conventional turbulent flow configuration.

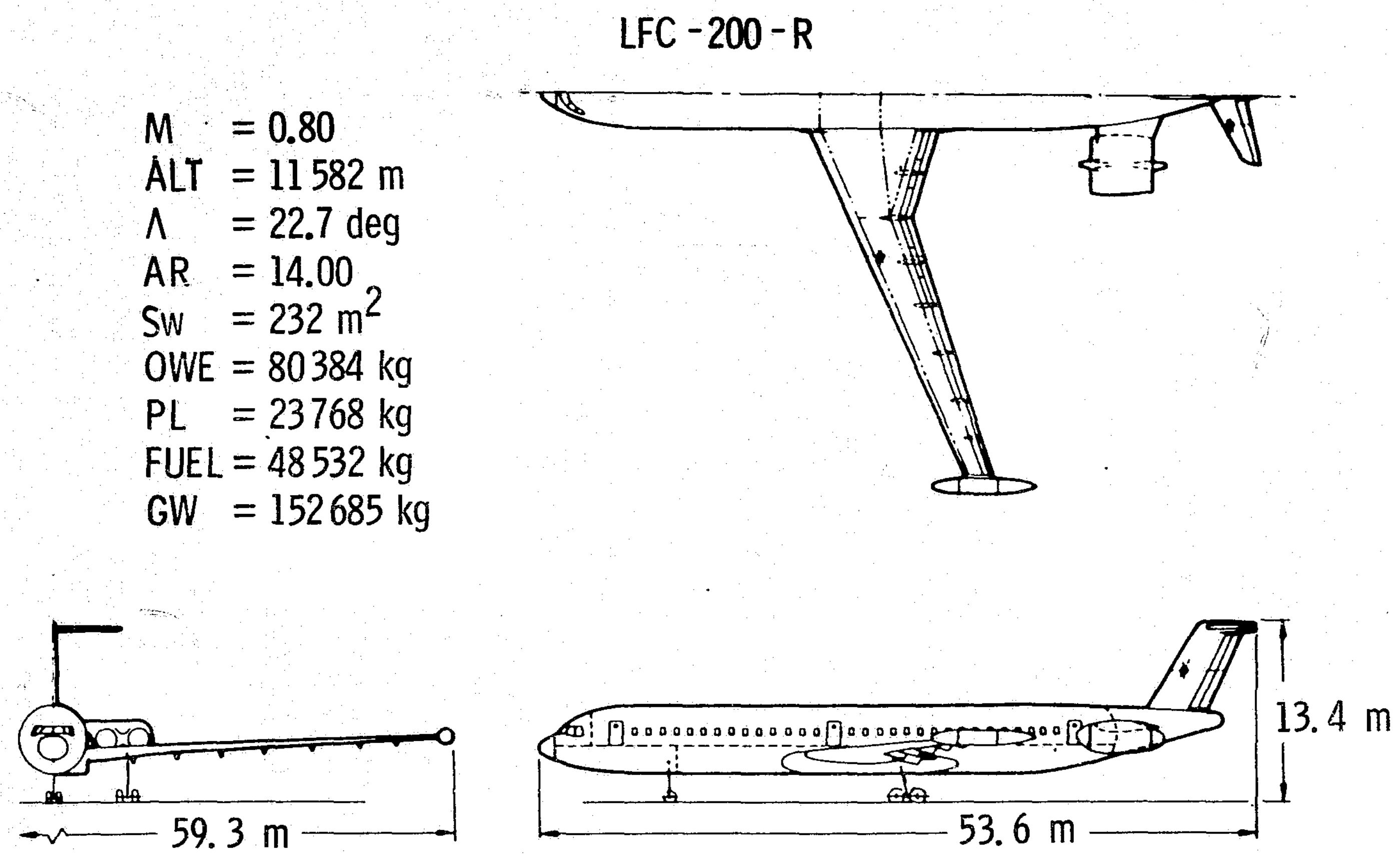

Figure 16. Laminar flow control configuration.

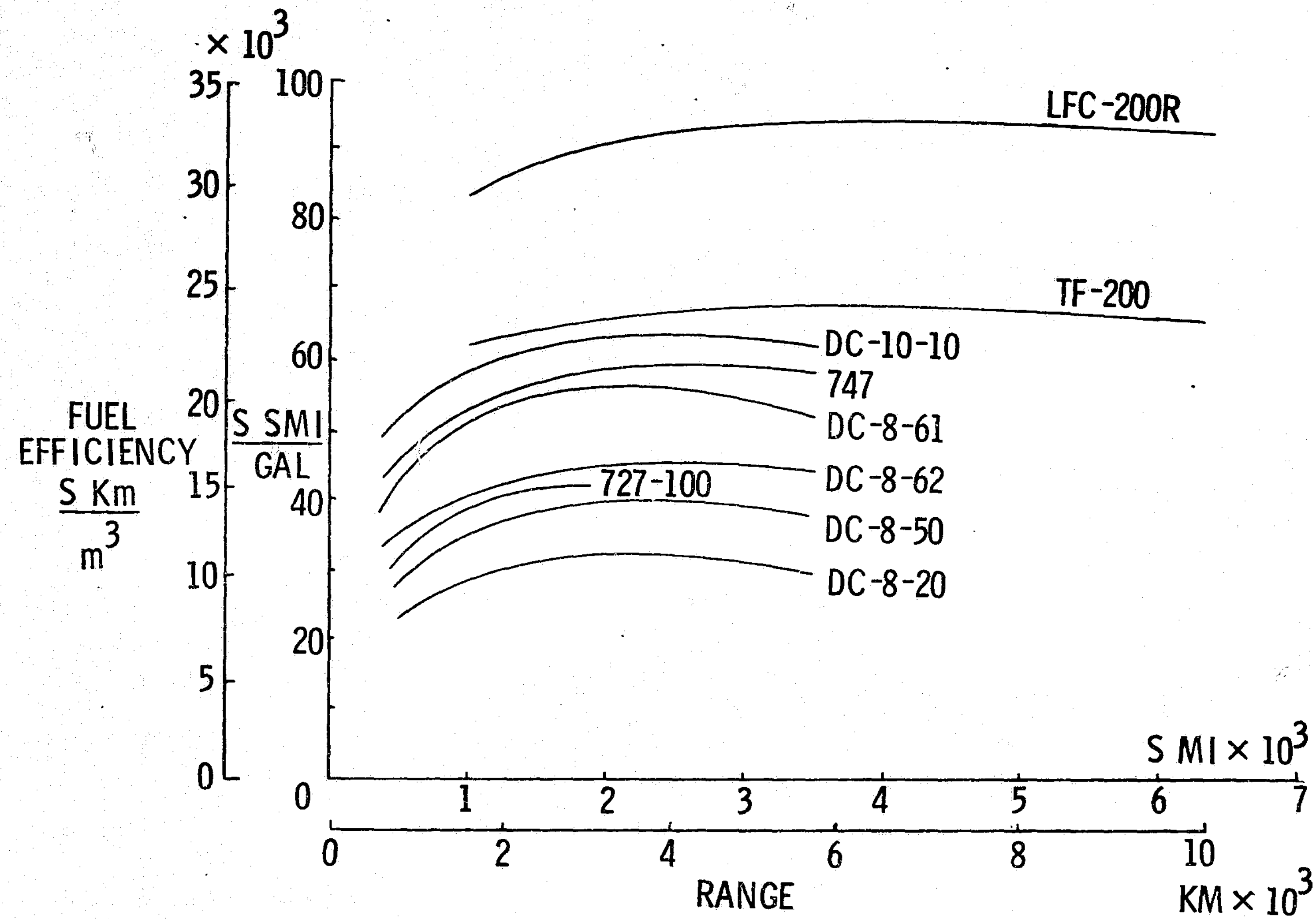

Figure 17. Comparison of fuel efficiency.

PRODUCTION OF ALTERNATE FUELS

- THERMAL EFFICIENCY AND ECONOMICS OF HYDROGEN LIQUEFACTION CONVERSION
- CONVERSION OF COAL TO H_2, CH_4, AND LIQUID FUELS FOR AIRCRAFT
- POTENTIAL FOR IMPROVING LH_2 PRODUCTION FROM COAL

RELATIVE PERFORMANCE OF AIRCRAFT - JP vs LH_2

- APPLICATION OF LH_2 TO LONG-RANGE SUBSONIC AIRCRAFT

INTERACTION OF LH_2 AIRCRAFT WITH AIRPORT/GROUND REQUIREMENTS

- DETERMINATION OF INTEGRATED TECHNOLOGICAL AIR TRANSPORT SYSTEM GROUND REQUIREMENTS IF LONG-HAUL
- LH_2 FIRE AND EXPLOSION HAZARDS

LH_2 AIRCRAFT FUEL SYSTEMS

- DEVELOPMENT AND VALIDATION OF THERMAL PROTECTION SYSTEMS FOR LH_2 FUEL TANKS
- EVALUATION OF MECHANICAL PROPERTY DATA ON 2219 AND APPLICATION TO LH_2 TANKAGE

THERMAL INSULATION OF AIRBORNE LH_2 FUEL TANKS

Figure 18. Representative elements of the Hydrogen-Fueled Aircraft Technology Program.

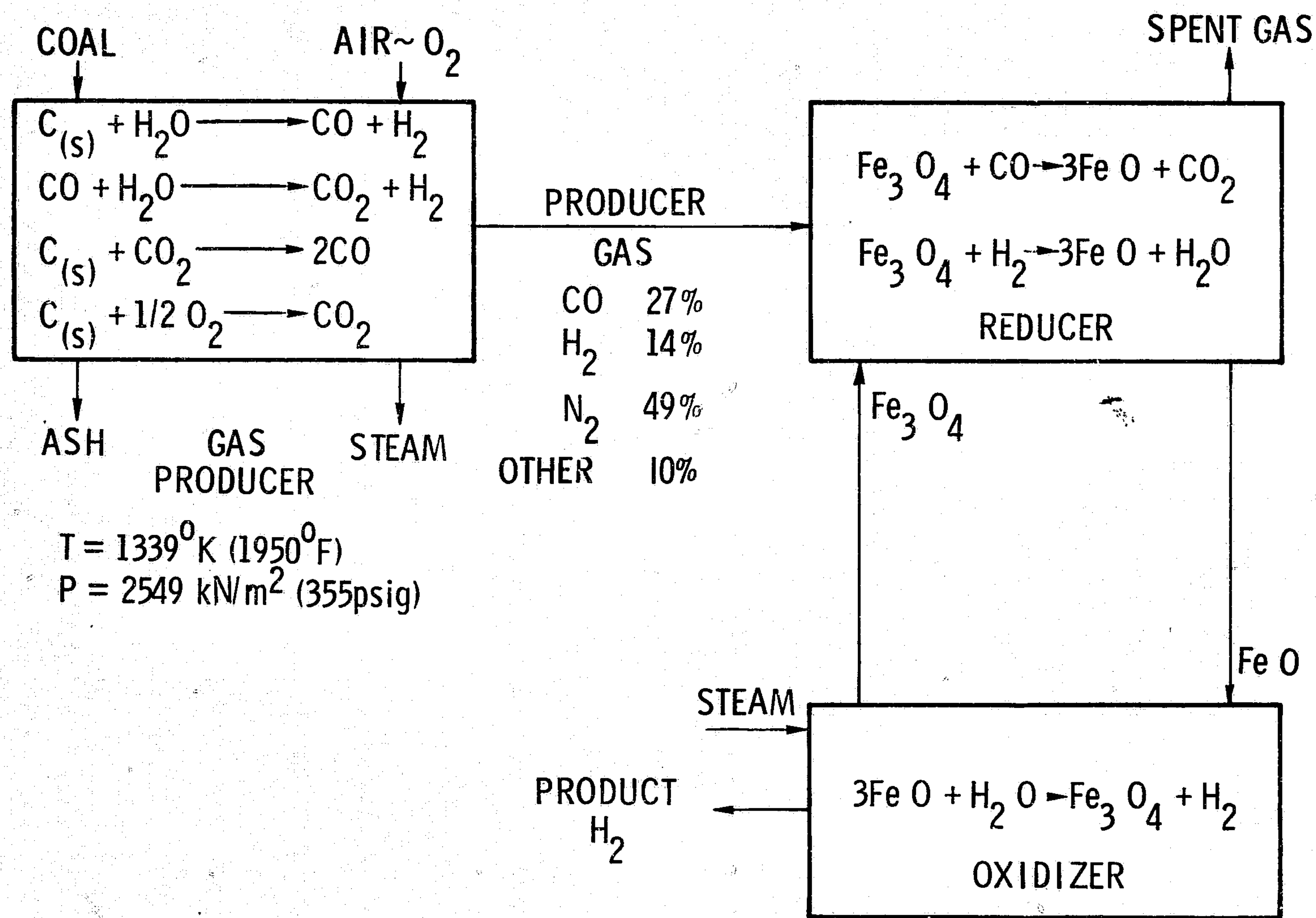

Figure 19. Steam-iron process for producing hydrogen from coal.

	HYDROGEN PROCESSES			METHANE	JET FUEL
	U-GAS™	STEAM-IRON	KOPPERS-TOTZEK	HYGAS®	
COAL INPUT / PRODUCER GAS %	66.2	44.6	56.8	70.0	
+ BY-PRODUCT %	.2	18.0/(36.9)[a]	.2	4.0	
GAS PRODUCTION %	66.4	62.6/(81.5)[a]	57.0	74.0	
LIQUID PRODUCTION %	44.9	61.6[a]	38.9	64.8	52.7

(a) ON SITE ELECTRICAL POWER GENERATION

Figure 20. Thermal efficiency of fuel production from coal by various processes.

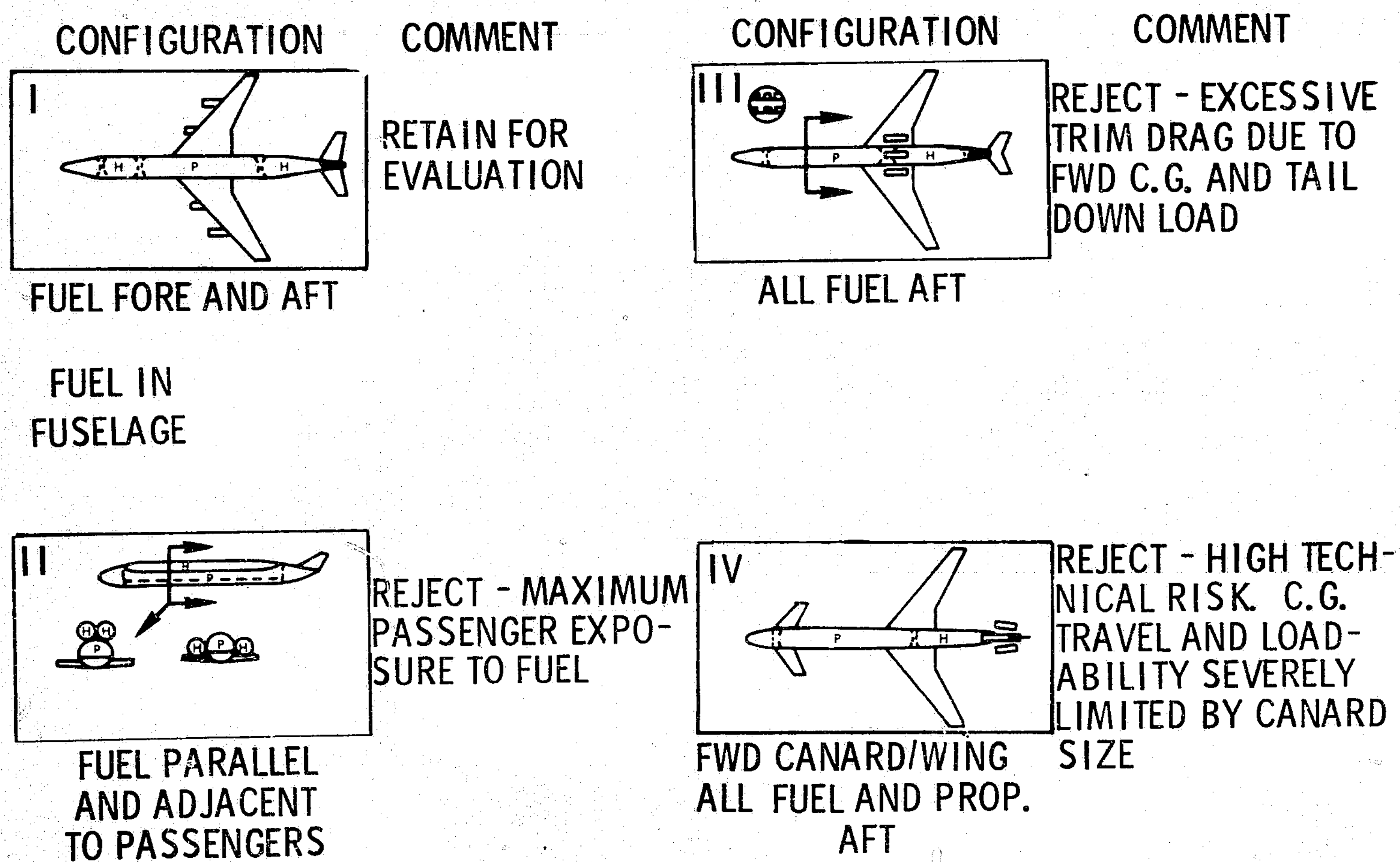

Figure 21. Candidate configurations.

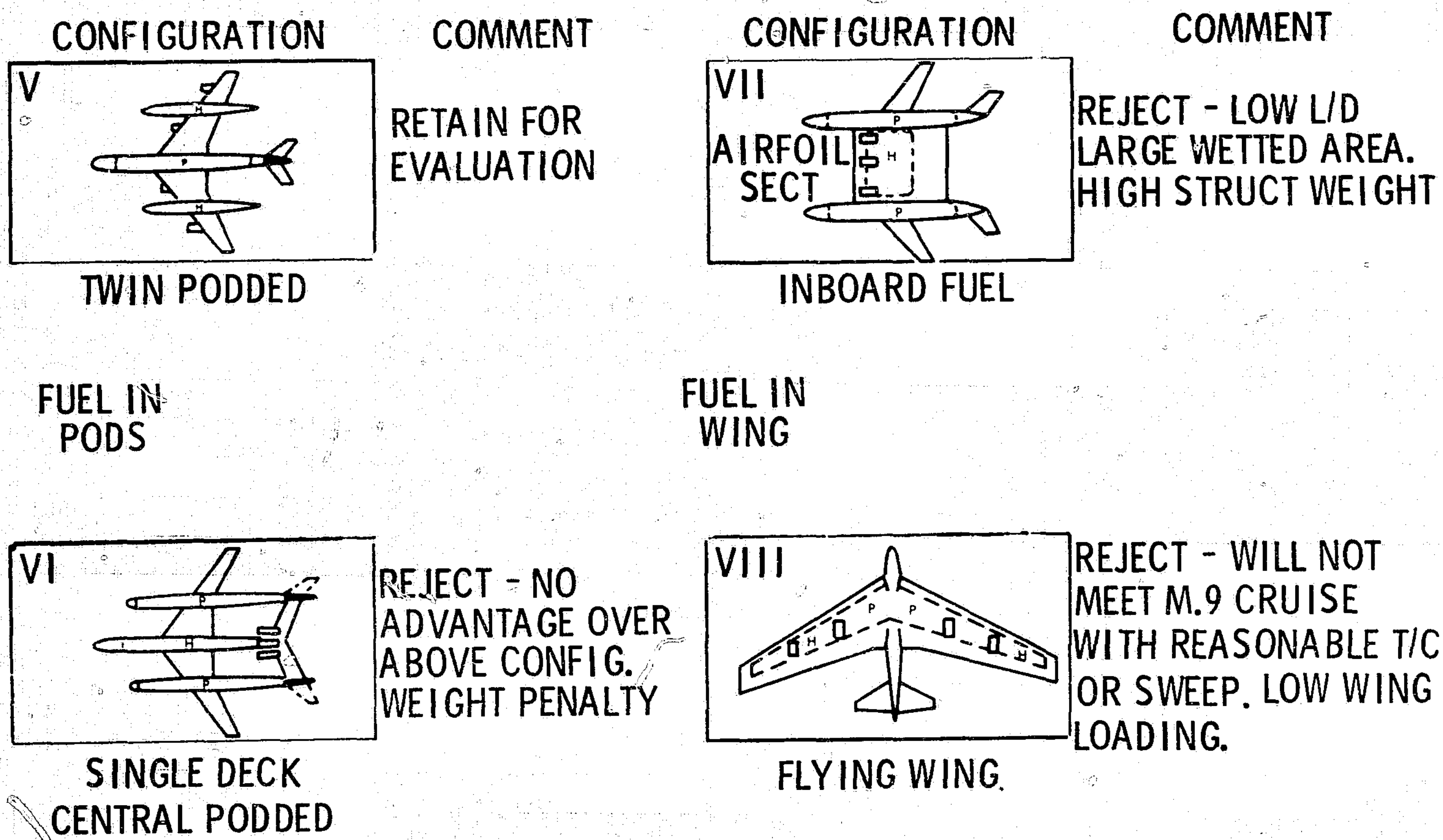

Figure 22. Candidate configurations.

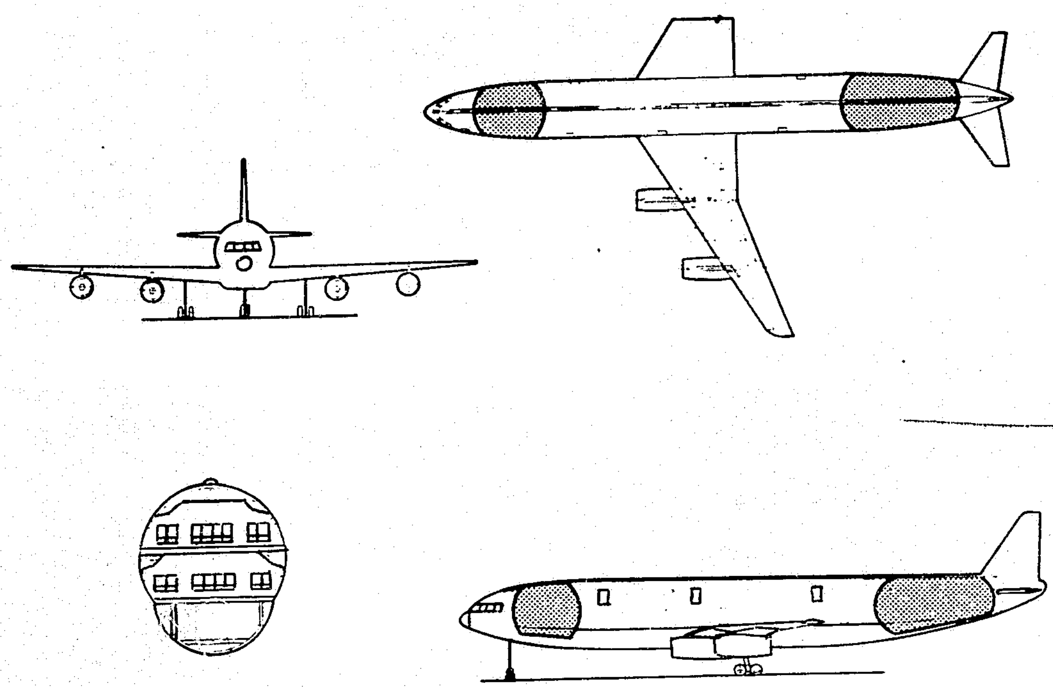

Figure 23. 400 passenger internal LH_2 tank configuration.

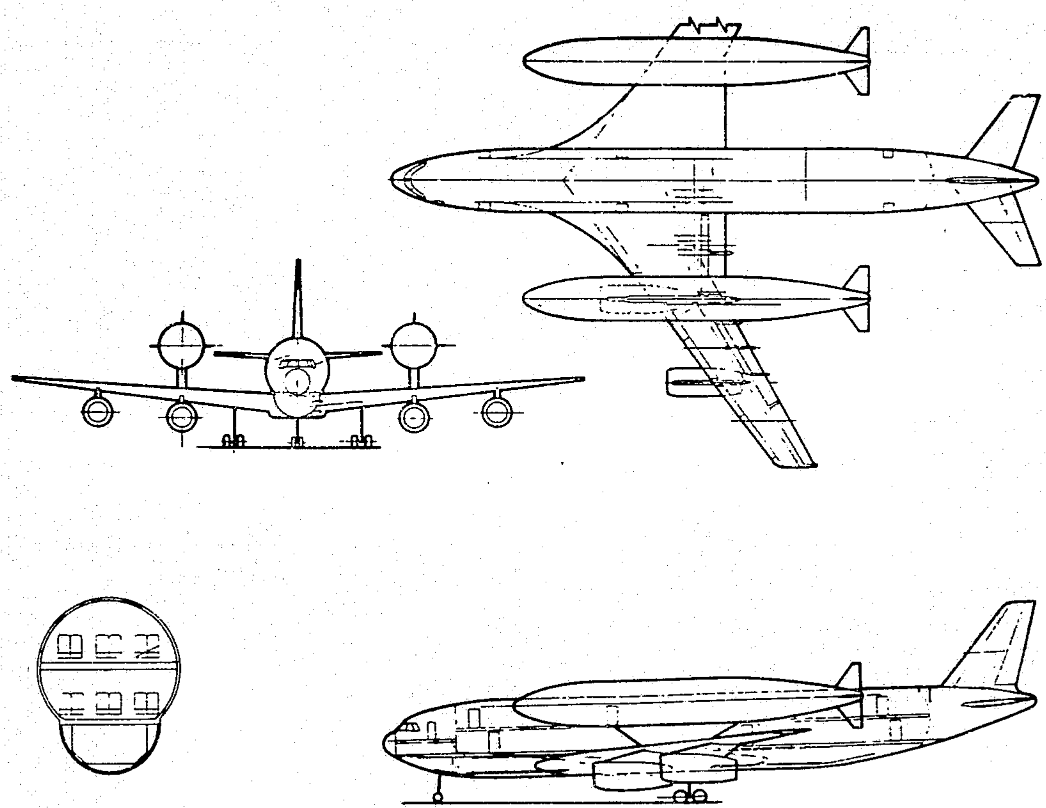

Figure 24. 400 passenger external LH_2 tank configuration.

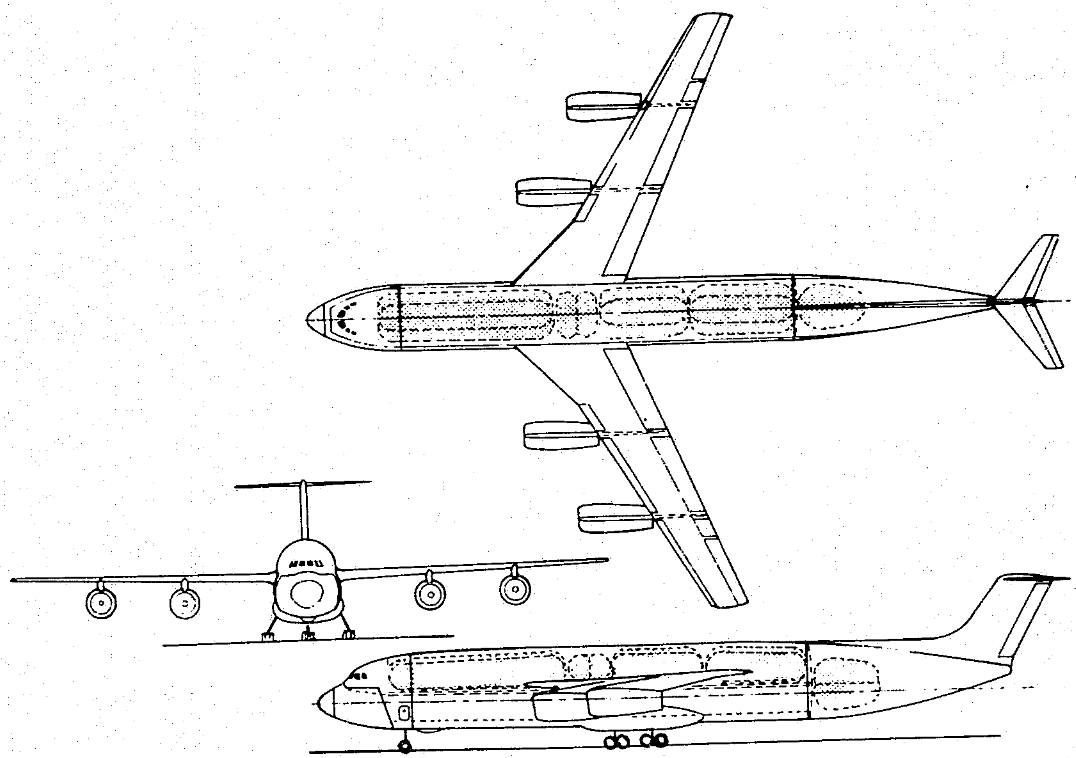

Figure 25. LH_2 cargo configuration — 113,400 kg payload (250,000 lb).

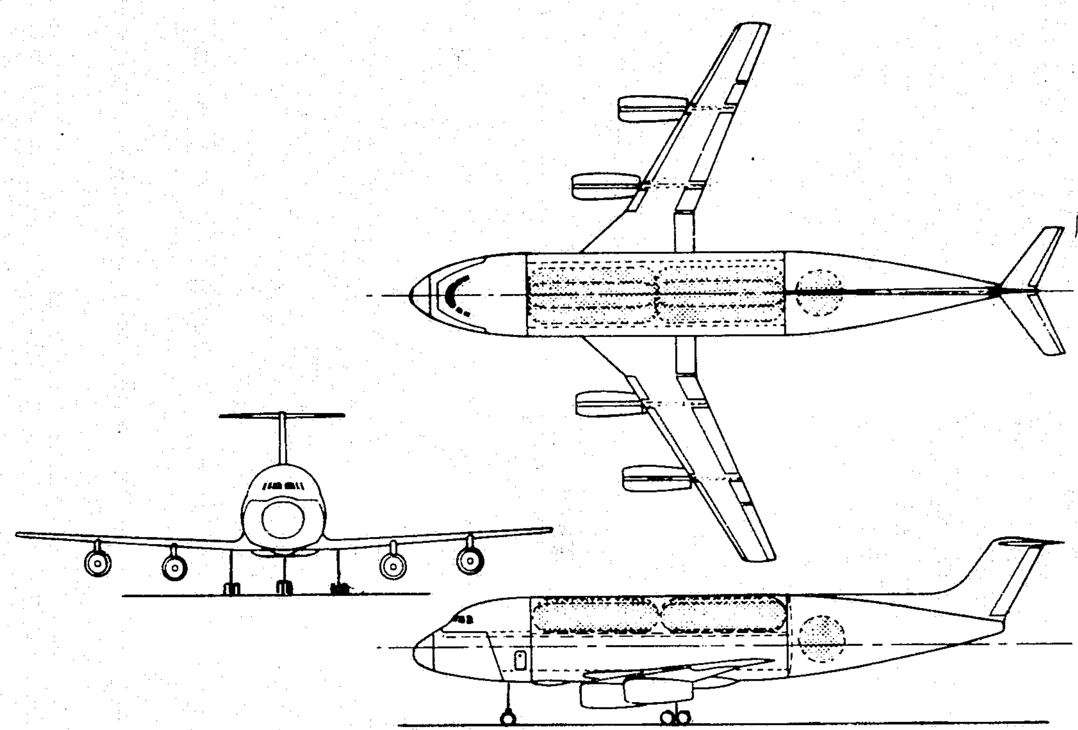

Figure 26. LH_2 cargo configuration — 56,700 kg payload (125,000 lb).

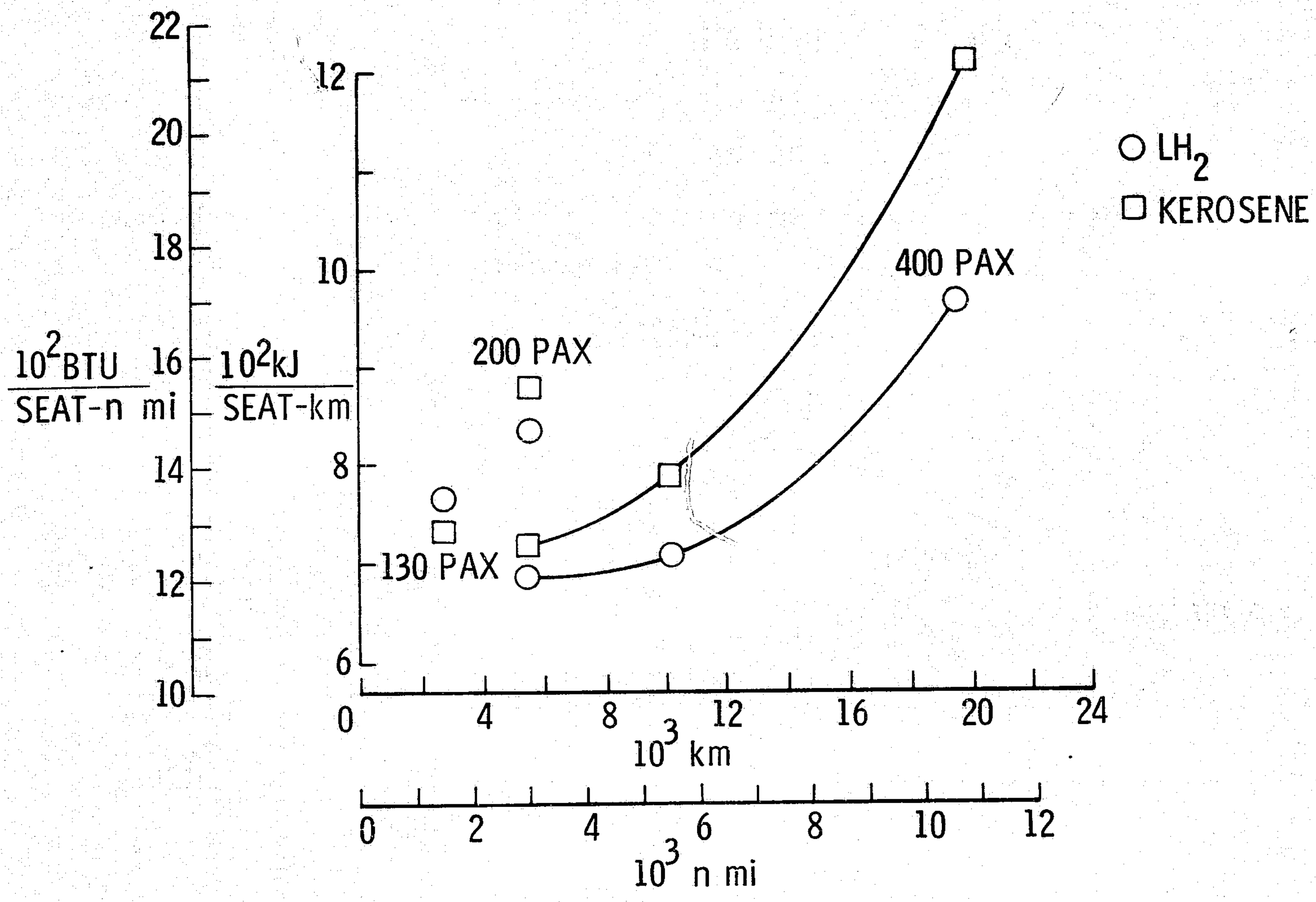

Figure 27. Energy utilization — LH_2 versus kerosene-fueled aircraft.

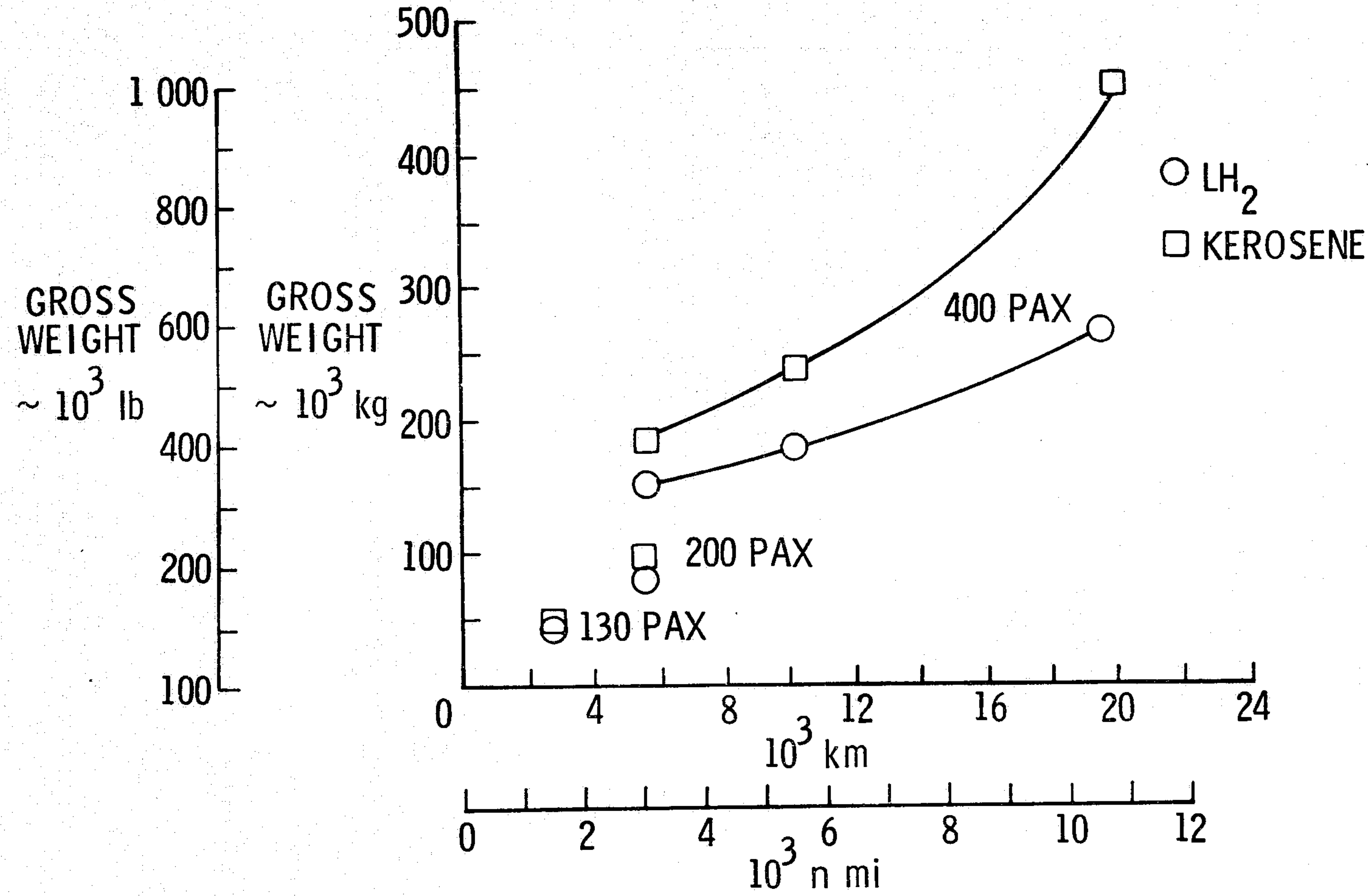

Figure 28. Growth characteristics — LH_2 versus kerosene-fueled aircraft.