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FEASIBILITY STUDY OF MODERN AIRSHIPS
(PHASE I)

Volume III - Historical Overview (Task I)

Contract NAS2-8643

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Prepared for

Ames Research Center, Moffett Field, California

by

Goodyear Aerospace Corporation, Akron, Ohio

FOREWORD

This final technical report was prepared for the Ames Research Center, Moffett Field, Calif., by Goodyear Aerospace Corporation, Akron, Ohio, under NASA Contract NAS2-8643, "Feasibility Study of Modern Airships." The technical monitor for the Ames Research Center was Dr. Mark D. Ardema.

This report describes work covered during Phase I (9 December 1974 to 9 April 1975) and consists of four volumes:

Volume I - Summary and Mission Analysis (Tasks II and IV)
Volume II - Parametric Analysis (Task III)
Volume III - Historical Overview (Task I)
Volume IV - Appendices

The report was a group effort headed by Mr. Ralph R. Huston and was submitted in May 1975. The contractor's report number is GER-16146.

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FEASIBILITY STUDY OF MODERN AIRSHIPS

VOLUME III - HISTORICAL OVERVIEW (TASK I)

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SUMMARY

The history of lighter-than-air (LTA) vehicles is reviewed in terms of providing a background for the mission analysis and parametric analysis tasks (see Volumes I and II, respectively), which were performed as part of the Goodyear Aerospace Corporation (GAC) feasibility study of modern airships. In addition, data from past airships and airship operations are presented that will be of interest in Phase II.

The following areas are detailed relative to past vehicles and operations:

1. Parameterization of design characteristics
2. Historical markets, missions, costs, and operating procedures
3. Indices of efficiency so that comparisons can be made from the parametric analysis of Volume II
4. Identification of critical design and operational characteristics
5. Definition of the 1930 state of the art, both technically and economically. A 1974 state of the art is defined from both a technical and an economic standpoint.

As a final portion of the historical overview, the more prominent concepts emerging in the current resurgent interest in LTA are briefly reviewed.

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INTRODUCTION

The essentials of free ballooning - including the gas-tight bag, the valve, the net, and the basket that carried the pilots - were all developed in Europe in the 18th century. Benjamin Franklin saw one of these earliest flights and wrote home to friends in America: "Among the pleasantries that conversation produces on this subject, some suppose flying to be now invented, and that since men may be supported in the air, nothing is wanted but some light handy instrument to give and direct motion."

Inventors worked for a century to verify Franklin's prophecy. In 1852, Henri Giffard, a French inventor, built the first power-driven balloon, a 45-ft-long dirigible*, which derived its motive power from a three-horsepower steam engine. The first rigid airship was constructed in 1898 by an Austrian named Schwartz. He used a framework consisting of 12 rings and 16 longitudinal aluminum girders and an outer covering of sheet aluminum.

At the turn of the century, Count Zeppelin completed and flew his first craft and thus laid the foundations for practicable commercial and military operations. Between 1900 and 1918, the German Zeppelin Company built more than 100 rigid airships. Ultimately, the Zeppelin Company built and operated two of the world's most notable airships, the Graf Zeppelin and the Hindenburg, the latter being the largest airship ever built.

Other notable airship constructors from 1900 to 1918 were the German Schutte-Lanz Company, which built 22 rigid airships from 1911 to 1918, and the German Luft-Fahrying-Gesellschaft Company, which built 27-Parseval-type non-rigid airships from 1906 to 1918. The Prussian Army Airship Works, also a German concern, manufactured about 10 semi-rigid airships, the majority of them for the Prussian Army.

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*A lighter-than-air aircraft, having its own motive power, that can be steered in any desired direction by its crew. Dirigible: of aircraft or airborne devices that can be directed or steered; dirigible balloon; a balloon, especially a non-spherical balloon, that can be steered. No specific structural type is implicit in the term "dirigible" in the U.S. Air Force Dictionary (1956)

The British became interested in rigid airships about 1910 and built a small ship, the Mayfly. After 1914, the British also became highly active in building non-rigid airships. The British R-100 and R-101 attest to their continued interest in the rigid design. Both France and Italy were active in building semi-rigid airships, the Roma and Norge being notable Italian configurations.

The American airship industry started in 1911, with Goodyear and Goodrich the principal early suppliers. During World War I, Goodyear became the major supplier and ultimately built and delivered more than 1000 balloons and close to 100 non-rigid airships for the United States, England, and France. Construction activities continued at Goodyear after the war, including building America's first semi-rigid ship, the RS-1.

In 1924, the Inter-Allied Air Commission forbade further German Zeppelin Company operations. With dismantling the huge zeppelin hangars on Lake Constance projected, The Goodyear Tire & Rubber Company agreed with Luftschiffbau-Zeppelin to form a new company, Goodyear Zeppelin Corporation, in which L-Z would have a one-third interest and GT&R two-thirds interest and in which the Zeppelin patents could be used. Dr. Karl Arnstein, chief engineer of Luftschiffbau-Zeppelin - along with 12 of his technical experts - came to Goodyear to assume the position of Vice-President of Engineering. With the combined expertise of the German Zeppelin Company and the American airship industry now available, the Goodyear Zeppelin Company a few years later designed and built the rigid airships Akron and Macon for the U. S. Navy - the largest airships built to that date.

The Goodyear Zeppelin Company, later renamed Goodyear Aircraft Company and known today as Goodyear Aerospace Corporation, continued to build non-rigid airships for military purposes and between 1941 and 1961 delivered nearly 220 units to the Navy.* In 1961, the last ZPG-3W airship - the largest non-rigid ever built - was delivered to the U. S. Navy. Goodyear Aerospace continues to build advertising airships today for its parent organization, The Goodyear Tire & Rubber Company.

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*Only supplier of airships to the Navy since 1930.

The conventional airship is a powered, streamlined body-of-revolution, air-displacement vehicle that derives its buoyancy from the difference in weight of the inflation gas within its hull or envelope and the weight of the ambient atmosphere thus displaced. Historically, two distinct structural types of airships have given rise to a definition of dirigibles based on these structural differences: (1) rigid (unpressurized) airships and (2) non-rigid (pressurized) airships. A third type, the semi-rigid, basically is a blend of these two.

The rigid type (see Figure 1) - such as the Akron, Macon, and Hindenburg - were built of aluminum bulkhead rings, aluminum transverse girders, and a network of pretensioned diagonal shear wires. An outer fabric (doped

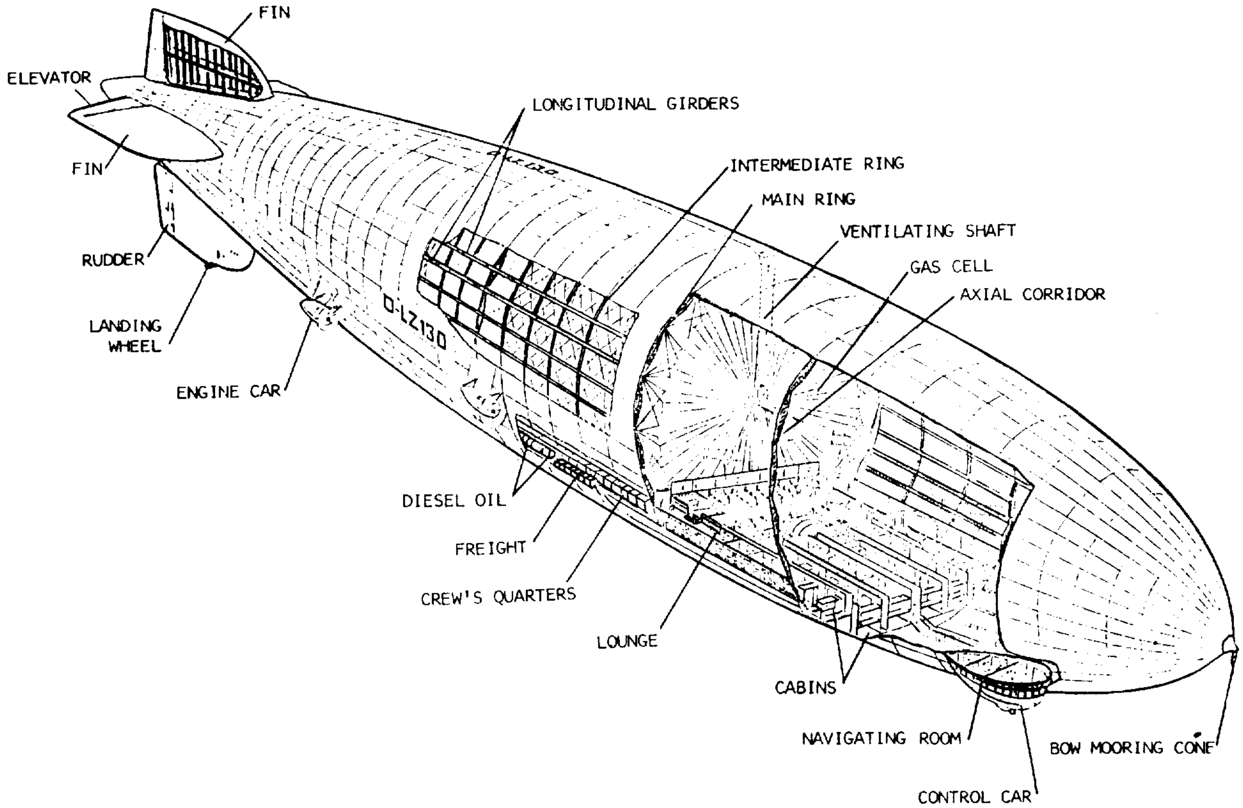

Figure 1 - Typical Rigid Airship

cotton cloth) provided a wind and weather cover. The lifting gas was contained in several independent gas-tight cells, which were supported between bulkhead ring nettings. The gas cells were partially filled at sea level, with pressure height being the altitude at which expansion of the gas completely filled the cells. Climb beyond pressure height, which normally was not undertaken, necessarily required valving and irrevocable loss of the lifting gas to prevent overpressuring and rupturing the cells. Generally, poppet valves with spring settings for overpressure protection provided automatic pressure valving at the pressure height with a manual capability also available. Both hydrogen and helium have been used as lifting gases, with the latter much preferred because of its inert character. Heavy takeoffs* were never accomplished with rigid airships.

The rigid airships manufactured by the German Schutte-Lanz Company used wood exclusively for structural members. During 1911 to 1917 and even prior to this, the German Zeppelin Company used aluminum in its rigid airships. The first rigid also was of an aluminum construction. It is not exactly clear why the Schutte-Lanz Company chose wood, but at the time of the World War I armistice the company was preparing to use aluminum in future construction.

The non-rigid (pressure) airship (see Figure 2) consists of a hull or envelope typically of a coated fabric filled with a lifting gas and pressured slightly above ambient. Earlier non-rigid envelopes were coated cotton fabric while the more recent configurations such as the ZPG-3W used a neoprene-coated dacron. Dacron has a higher strength-to-weight ratio than cotton.

In the non-rigid, several ballonets - or air compartments - are curtained off within the envelope. They normally are located forward, aft, and amid ship. The maximum ballonet capacity is a function of the design pressure height. The envelope is pressurized by ducting air for the ballonets from the propwash or pumping with electric blowers through an air distribution system to the ballonets. Dampers, air lines, and exhaust valves at the

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*Heavy takeoff denotes aerodynamic lift in addition to aerostatic lift required to accomplish takeoff.

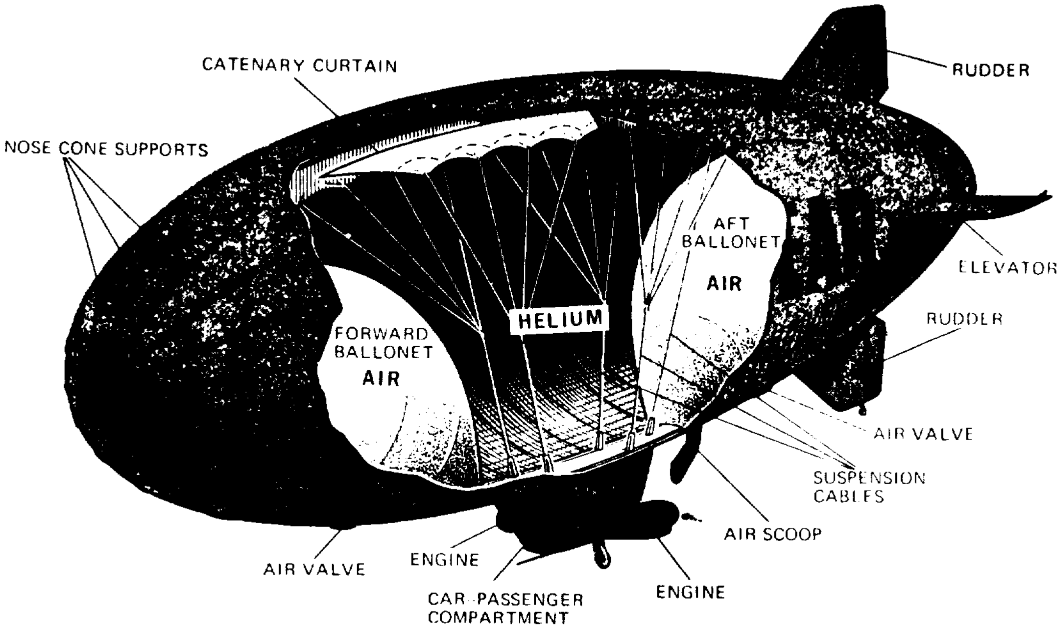

Figure 2 - Typical Non-rigid (Pressure) Airship

ballonets permit the envelope pressure to be controlled, and relative fullness of the fore and aft ballonets permit trimming in pitch. As the ship ascends, the lifting gas is expanded without gas being lost by deflation of the ballonets. Pressure height is the altitude at which the ballonets are completely deflated, the envelope at that point being 100 percent full of lifting gas. Further ascent can occur only with valving of the lifting gas. It is possible for an airship to be flown so high, with consequent valving of the lifting gas, that upon descent the ballonets are pumped full (of air) before the ground has been reached. At this point, the airship can descend with envelope pressurization only by pumping air directly into the lifting gas provided an emergency access route of air to the lifting gas is available. Both hydrogen and helium have been used as a lifting gas.

Rate of ascent with a pressure airship may be limited by engine power if the ship is "heavy" but is structurally limited by the ballonet valves' capacity to exhaust air. Conversely, rate of descent is limited by the air system's capacity to pump air into the ballonets as the helium contracts with increasing ambient pressure.

While the car structure and engine nacelles on a rigid airship are extended from convenient bulkhead rings and longitudinal girders, the car structure weight on a non-rigid is distributed to the fabric envelope by catenary systems. Usually, two identical internal catenary curtains, either side of the centerline on the top of the envelope, tie to the upper envelope along two fore and aft Y joints. Vertical tension cables from the roof of the car carry the weight to fitting points on the curtains. The curtains spread the load to the upper envelope, deforming it slightly "out-of-round" at the Y intersection. A catenary system around the car-lower envelope intersection distributes pitching or yawing loads to the envelope. Fins on a non-rigid are cable-braced to finger patches tangent to the cable-envelope intersections. Powerplant installations on a non-rigid always have been extensions from the hard car structure.

Pressurized metalclad airships have been considered throughout the history of LTA. The metalclad, as the name suggests, uses a thin metal covering (historically, only aluminum was ever seriously considered) rather than the conventional fabric covering.

The semi-rigid airship (see Figure 3) generally differed from the non-rigid by using a nose-to-tail rigid keel rather than the catenary curtains for distributing the car weight into the fabric envelope. It was still a pressure airship and required slight pressurization to permit resistance of hull bending moments without envelope wrinkling. Its cross-sectional shape tended more to a pear shape because the entire car weight was applied to the bottom of the envelope.

The following subsections of the historical overview relate to:

1. Parameterization of design characteristics for both conventional and unconventional LTA vehicles of interest to the current study.
2. Results of historical markets and missions, costs and operating procedures, and research relative to past LTA activities.

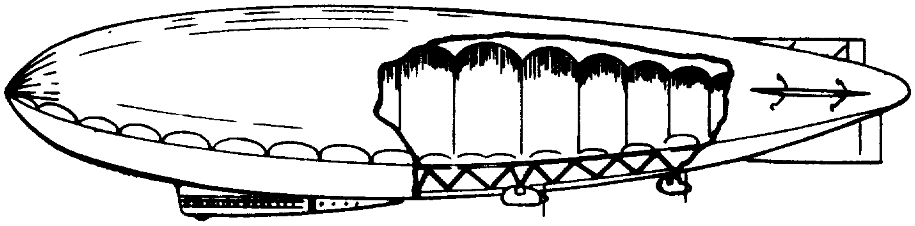

Figure 3 - Typical Semi-rigid Airship

3. Parameterization of the data presented in Item 1, above, into the indices of efficiency of interest to the current study.
4. Identification of critical design and operational characteristics of past LTA vehicles.
5. Definition of 1930 state of the art (SOA), technically and economically, relative to LTA vehicles.
6. Definition of 1974 SOA, technically and economically, relative to LTA vehicles.

PARAMETERIZATION OF DESIGN CHARACTERISTICS

Rigid Airships

German

Tables 1 and 2 give the more important characteristics of all German airships built up to and including 1920, except for a few built prior to 1910 that fall under miscellaneous types. These airships are omitted because of their

TABLE 1 - CHARACTERISTICS OF GERMAN ZEPPELIN RIGID AIRSHIPS
LZ-1 THROUGH LZ-121 (REFERENCES 1 AND 2)

Building Number	Building Shed	History	Class	Owned By	Capacity Cu. Ft.	No. of Cells	Length, Ft.	Diameter, Ft.	Total Load, Lbs.	Useful Load (0°-760 mm lbs)	Useful Total Percent	Power Cars No.	Engines No.	Engines Type	Engines H.P.	Total H.P.	Propellers - No. and Material	Speed, M.P.H.	Date - First Flight	Placed Out of Service	Life-Months	** Type Development
LZ-1 *	Manzell			Zeppelin	400,000	17	420	38.2	27,200			2	2	Daimler	14.7	29.4	4LZ Alum. Blade	18.0	Jul 2, 1900	Early 1901	7±	A
LZ-2 *	Manzell			Zeppelin	400,000	16	420	38.2	27,200	About 6,000	22.1	2	2	Daimler	85	170	4LZ Alum. Blade	24.5	Nov 30, 1905	Jan 17, 1906	2	B
LZ-3	Manzell			Zeppelin	400,000	16	420	38.2	27,200	6,000	22.1	2	2	Daimler	85	170	"	24.5	Oct 9, 1906		)	B
LZ-3	Manzell	Rebuilt	Z-1	Army	430,000	17	446	38.2	29,200	6,000	20.5	2	2	Daimler	100	200	"	27.3			)84)	
LZ-3	Manzell	Control Surfaces Rebuilt	Z-1	Army	430,000	17	446	38.2	29,200	6,000	20.5	2	2	Daimler	100	200	"	33.5		Autumn 1913	)	B
LZ-4 *	Manzell			Zeppelin	530,000	17	446	42.7	36,000	About 10,000	27.8	2	2	Daimler	100	200	"	28.0	Jun 20, 1908	Aug 5, 1908	2-	C
LZ-5	Manzell		Z-II	Army	530,000	17	446	42.7	36,000	10,000	27.8	2	2	Daimler	100	200	"	28.0	May 26. 1906	Apr 25. 1910	11	C
LZ-6 *	Friedrichshafen			Zeppelin	530,000	17	446	42.7	36,000	10,000	27.8	2	2	Daimler	115	230	7 "	29.0	Aug 25, 1909		)	D
LZ-6	Friedrichshafen	Rebuil5		Delag	562,000	18	473	42.7	38,200	About 8,800	23.0	2	3	2 Daimle 1 Maybch	2-115 1-140	370	"	34.5		Sep 14. 1910	)13-)	D
LZ-7	Friedrichshafen		Deutschland	Delag	680,000	18	486	45.9	46,500	About 14,300	30.7	2	3	Daimler	120	360	"	35.7	Jun 19. 1910	Jun 28. 1910	0.3	E
LZ-8	Friedrichshafen	Replaced LZ-7	"	Delay	680,000	18	486	45.9	46,500	14,300	30.7	2	3	Daimler	120	360	"	35.7	Mar 30. 1911	May 16, 1911	1.5	E
LZ-9 *	Friedrichshafen		Z-II	Army	592,000	16	433	45.9	40,200			2	3	Maybach	140	420	"	48.5	Oct 2, 1911		)	F
LZ-9	Friedrichshafen	Rebuilt	Z-II	Army	628,000	17	459	45.9	42,700	About 13,200	30.9	2	3	Maybach	140	420	"	47.0		Aug 1, 1914	)34)	F
LZ-10	Friedrichshafen		Schwaben	Delag	628,000	17	459	45.9	42,700	13,200	30.9	2	3	Maybach	140	420	"	47.0	Jun 26, 1911	Jun 28, 1912	12	F
LZ-11*	Friedrichshafen		Viktori-aluise	Delag	658,000	18	486	45.9	44,700	About 13,600	30.5	2	3	Maybach	140	420	"	47.0	Feb 14, 1912	Autumn 1915	32	G
LZ-12	Friedrichshafen		Z-III	Army	628,000	17	459	45.9	42,700	13,200	30.9	2	3	Maybach	140	420	"	47.0	Apr 25, 1912	Summer 1914	27	F
LZ-13	Friedrichshafen		Hansa	Delag	658,000	18	486	45.9	44,700	13,600	30.5	2	3	Maybach	165	495	"	47.0	Jul 30, 1912	Summer 1916	48	G
LZ-14*	Friedrichshafen		L-I	Navy	790,000	18	518	48.7	53,700	18,900	35.2	2	3	Maybach	165	495	"	47.4	Oct 7, 1912	Sept 9, 1913	11	H
LZ-15	Friedrichshafen	Replaced Z-1 (LZ-3)	Z-I	Army	686,000	16	466	48.7	46,600	15,500	33.3	2	3	Maybach	165	495	"	45.8	Jan 16, 1913	Mar 19, 1913	2	H
LZ-16	Friedrichshafen		Z-IV	Army	686,000	16	466	48.7	46,600	15,400	33.0	2	3	Maybach	165	495	"	46.7	Mar 14, 1913	Autumn 1916	43	H
LZ-17	Friedrichshafen		Sachsen	Delag	686,000	16	459	48.7	46,600	About 15,400	33.0	2	3	Maybach	165	495	"	47.0	May 3, 1913		)	H
LZ-17	Friedrichshafen	Length Increased	Sachsen	Delay	735,000	17	486	48.7	50,000	About 16,500	33.0	2	3	Maybach	165	495	"	44.7		Autumn 1916	)41)	H
LZ-18*	Friedrichshafen		L-2	Navy	9580,00	18	518	54.4	64,500	24,200	37.5	3	4	Maybach	165	660	"	47.0	Sep 9, 1913	Oct 17, 1913	1	I

*First airship of a type.

**Indexes development status. Figure 4 refers to this index (see top of figure). Note: 1.0 ft = 3.048 × 10^{-1} m, 1.0 lbm = 4.536 × 10^{-1} kg, 1.0 HP = 7.457 × 10^{2} watts, 1.0 mph = 4.470 × 10^{-1} m/s

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TABLE 1 - (CONTINUED)

Building Number	Building Shed	History	Class	Owned By	Capacity Cu. Ft.	No. of Cells	Length, Ft.	Diameter, Ft.	Total Load, Lbs.	Useful Load (0°-760 mm lbs)	Useful Total Percent	Power Cars No.	Engines No.	Engines Type	Engines H.P.	Total H.P.	Propellers - No. and Material	Speed, M.P.H.	Date - First Flight	Placed Out of Service	Life - Months	Type Development
LZ-19	Friedrichshafen	Replaced Z-I (LZ-15)	Z-I	Army	686,000	16	459	48.7	46,000	15,400	33.0	2	3	Maybach	165	495	4LZ Alum. Blade	45.6	Jun 6, 1913	Jun 13, 1914	1?	H
LZ-20	Friedrichshafen		Z-V	Army	686,000	16	459	48.7	46,600	15,400	33.0	2	3	Maybach	165	495	"	45.8	Jul 8, 1913		)13.5	H
LZ-20	Friedrichshafen	Length Increased	Z-V	Army	735,000	17	486	48.7	50,000	16,300	32.6	2	3	Maybach	165	495	"	44.7		Aug 27, 1914	)	H
LZ-21*	Friedrichshafen		Z-VI	Army	735,000	17	486	48.7	50,000	16,500	33.0	2	3	Maybach	165	495	"	45.4	Nov 10, 1913	Aug 6, 1914	9	K
LZ-22*	Friedrichshafen		Z-VII	Army	780,000	18	512	48.7	53,000	17,600	33.2	2	3	Maybach	175	525	"	45.8	Jan 8, 1914	Aug 23, 1914	7.5	L
LZ-23	Friedrichshafen		Z-VIII	Army	780,000	18	512	48.7	53,000	17,600	33.2	2	3	Maybach	175	525	"	45.2	Feb 21, 1914	Aug 23, 1914	6	L
LZ-24*	Friedrichshafen		L-3	Navy	792,000	18	518	48.7	53,800	19,100	35.5	2	3	Maybach	210	630	"	48.0	May 11, 1914	Feb 17, 1915	9	M
LZ-25	Friedrichshafen		Z-IX	Army	792,000	18	518	48.7	53,800	19,100	35.5	2	3	Maybach	210	630	"	47.8	Jul 29, 1914	Oct 8, 1914	2	M
LZ-26*	Frankfurt am Main		Z-XII	Army	880,000	15	529	52.4	60,000	24,200	40.3	2	3	Maybach	210	630	4LZ Alum. later 3 Lorenzen Wood	49.6	Dec 14, 1914	Aug 8, 1917	32	N
LZ-27	Friedrichshafen		L-4	Navy	792,000	18	518	48.7	53,800	19,100	35.5	2	3	Maybach	210	630	4LZ Alum.	48.0	Aug 28, 1913	Feb 17, 1915	17.5	M
LZ-28	Friedrichshafen		L-5	Navy	792,000	18	518	48.7	53,800	19,100	35.5	2	3	Maybach	210	630	4LZ Alum.	48.0	Sep 22, 1913	Aug 6, 1915	23	M
LZ-29	Friedrichshafen		Z-X	Navy	792,000	18	518	48.7	53,800	19,100	35.5	2	3	Maybach	210	630	4LZ Alum.	49.2	Oct 13, 1914	May 21, 1915	7	M
LZ-30	Potsdam		Z-XI	Army	792,000	18	518	48.7	53,800	19,100	35.5	2	3	Maybach	210	630	4 LZ Alum.	49.2	Nov 11, 1914	May 20, 1915	6	M
LZ-31	Friedrichshafen		L-6	Navy	792,000	18	518	48.7	53,800	19,100	35.5	2	3	Maybach	210	630	4LZ Alum.	49.2	Nov 3, 1914	Sep 19, 1916	22.5	M
LZ-32	Friedrichshafen		L-7	Navy	792,000	18	518	48.7	53,800	19,100	35.5	2	3	Maybach	210	630	4LZ Alum.	49.2	Nov 20, 1914	May 4, 1916	17.5	M
LZ-33	Friedrichshafen		L-8	Navy	792,000	18	518	48.7	53,800	19,100	35.5	2	3	Maybach	210	630	4 LZ Alum.	49.2	Dec 17, 1914	Mar 5, 1915	2.7	M
LZ-34	Potsdam		LZ-34	Army	792,000	18	518	48.7	53,800	19,100	35.5	2	3	Maybach	210	630	4LZ Alum.	49.2	Jan 6, 1915	May 21, 1915	4.5	M
LZ-35	Friedrichshafen		LZ-35	Arm6	792,000	18	518	48.7	53,800	19,100	35.5	2	3	Maybach	210	630	4LZ Alum.	49.2	Jan 11, 1915	Apr 13, 1915	3	M
LZ-36*	Friedrichshafen		L-9	Navy	880,000	15	530	52.4	60,000	22,000	36.7	2	3	Maybach	210	630	3 Lorenzen Wood	49.2	Mar 8, 1915	Sept 16, 1916	18.2	O
LZ-37	Potsdam		LZ-37	Army	792,000	18	518	48.7	53,800	19,100	35.5	2	3	Maybach	210	630	4LZ alum	49.2	Feb 28, 1915	Jun 7, 1915	3.3	M
LZ-38*	Friedrichshafen		LZ-38	Army	1,128,000	16	536	61.3	76,800	33,000	43.0	2	4	Maybach	210	840	4 Lorenzen	56.0	Apr 3, 1915	Jun 7, 1915	2	P
LZ-39	Friedrichshafen		LZ-39	Army	880,000	15	530	52.4	60,000	About 22,000	36.7	2	3	Maybach	210	630	3 Lorenzen Wood	48.0	Apr 24, 1915	Dec 18, 1915	8	O

TABLE 1 - (CONTINUED)

Building Number	Building Shed	History	Class	Owned By	Capacity Cu. Ft.	No. of Cells	Length, Ft.	Diameter, Ft.	Total Load, Lbs.	Useful Load (0°-760 mm lbs)	Useful Total Percent	Power Cars No.	Engines No.	Engines Type	Engines H.P.	Total H.P.	Propellers - No. and Material	Speed, M.P.H.	Date - First Flight	Placed Out of Service	Life - Months	Type Development
LZ-40	Friedrichshafen		L-10	Navy	1,128,000	16	536	61.3	76,800	33,000	43.0	2	4	Maybach	210	840	4 Lorenzen	about 56.0	May 13, 1915	Sep 3, 1915	4.3	P
LZ-41	Loewenthal		L-11	Navy	1,128,000	16	536	61.3	76,800	33,000	43.0	2	4	Maybach	210	840	4' Lorenzen	56.0	Jun 7, 1915	Apr 1917	22	P
LZ-42	Potsdam		LZ-72	Army	1,128,000	16	536	61.3	76,800	33,000	43.0	2	4	Maybach	210	840	4 Lorenzen	56.0	Jun 15, 1915	Feb 16, 1917	20	P
LZ-43	Friedrichshafen		L-12	Navy	1,128,000	16	536	61.3	76,800	33,000	43.0	2	4	Maybach	210	840	4 Lorenzen	56.0	Jun 21, 1915	Aug 10, 1915	1.6	P
LZ-44	Loewenthal		LZ-74	Army	1,128,000	16	536	61.3	76,800	33,000	43.0	2	4	Maybach	210	840	4 Lorenzen	56.0	Jul 8, 1915	Oct 8, 1915	3	P
LZ-45	Friedrichshafen		L-13	Navy	1,128,000	16	536	61.3	76,800	33,000	43.0	2	4	Maybach	210	840	4 Lorenzen	56.0	Jul 23, 1915	Apr 1917	21	P
LZ-46	Loewenthal		L-14	Navy	1,128,000	16	536	61.3	76,800	33,000	43.0	2	4	Maybach	210	840	4 Lorenzen	56.0	Aug 9, 1915	Jul 1919	47	P
LZ-47	Friedrichshafen		LZ-77	Army	1,128,000	16	536	61.3	76,800	33,000	43.0	2	4	Maybach	3-210 1-240	870	4 Lorenzen	56.0	Aug 24, 1915	Feb 21, 1916	6	P
LZ-48	Loewenthal		L-15	Navy	1,128,000	16	536	61.3	76,800	33,000	43.0	2	4	Maybach	240	960	4 Lorenzen	56.0	Sep 9, 1915	Apr 1, 1916	7	P
LZ-49	Potsdam		LZ-79	Army	1,128,000	16	536	61.3	76,800	33,000	43.0	2	4	Maybach	240	840	4 Lorenzen	56.0	Aug 2, 1915	Jan 30, 1916	6	P
LZ-50	Friedrichshafen		L-16	Navy	1,128,000	16	536	61.3	76,800	33,000	43.0	2	4	Maybach	240	960	4 Lorenzen	56.0	Sep 23, 1915	Oct 19, 1917	25	P
LZ-51	Loewenthal		LZ-81	Army	1,128,000	16	536	61.3	76,800	33,000	43.0	2	4	Maybach	240	960	4 Lorenzen	56.0	Oct 7, 1915		)	P
LZ-51	Loewenthal	Lengthened LZ-51	LZ-81	Army	1,262,000	18	586	61.3	85,800	38,500	44.9	2	4	Maybach	240	960	4 Lorenzen	about 56.0		Sep 27, 1916	)11.7)	P
LZ-52	Loewenthal		L-18	Navy	1,128,000	16	536	61.3	76,800	33,000	43.0	2	4	Maybach	240	960	4 Lorenzen	56.0	Nov 3, 1915	Nov 17, 1915	0.5	P
LZ-53	Friedrichshafen		L-17	Navy	1,128,000	16	536	61.3	76,800	33,000	43.0	2	4	Maybach	240	960	4 Lorenzen	56.0	Oct 20, 1915	Dec 28, 1916	14.3	P
LZ-54	Friedrichshafen		L-19	Navy	1,128,000	16	536	61.3	76,800	33,000	43.0	2	4	Maybach	240	960	4 Lorenzen	56.0	Nov 27, 1915	Feb 2, 1916	2.1	P
LZ-55	Potsdam		LZ-85	Army	1,128,000	16	536	61.3	76,800	33,000	43.0	2	4	Maybach	240	840	4 Lorenzen	56.0	Sep 12, 1915	May 5, 1916		
LZ-56	Potsdam		LZ-86	Army	1,128,000	16	536	61.3	76,800	33,000	43.0	2	4	Maybach	210	840	4 Lorenzen	56.0	Oct 10, 1915		)	P
LZ-56	Potsdam	Lengthened LZ-56	LZ-86	Army	1,262,000	18	586	61.3	85,800	38,500	44.9	2	4	Maybach	210	840	4 Lorenzen	56.0		Sep 4, 1916	)10.8	P
LZ-57	Loewenthal		LZ-87	Army	1,128,000	16	536	61.3	76,800	33,000	43.0	2	4	Maybach	240	960	4 Lorenzen	56.0	Dec 6, 1915		) 20	P
LZ-57	Loewenthal	Lengthened LZ-57	LZ-87	Army	1,262,000	18	586	61.3	85,800	38,500	44.9	2	4	Maybach	240	960	4 Lorenzen	56.0		July 28, '17	)	P
LZ-58	Potsdam		LZ-88	Army	1,228,000	16	536	61.3	76,800	33,000	43.0	2	4	Maybach	210	840	4 Lorenzen	56.0	Nov 14, 1915		)	P
LZ-58	Potsdam	Lengthened LZ-58	LZ-88	Army	1,262,000	18	586	61.3	85,800	38,500	44.9	2	4	Maybach	240	960	4 Lorenzen	56.0		Sep 15, 1917	)23)	P
LZ-59*	Friedrichshafen		L-20	Navy	1,262,000	18	586	61.3	85,800	38,500	44.9	4	4	Maybach	240	960	4 Lorenzen	56.0	Dec 21, 1915	May 3, 1916	5.4	Q

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TABLE 1 - (CONTINUED)

Building Number	Building Shed	History	Class	Owned By	Capacity Cu. Ft.	No. of Cells	Length, Ft.	Diameter, Ft.	Total Load, Lbs.	Useful Load (0°-760 mm lbs)	Useful Total Percent	Power Cars No.	Engines No.	Engines Type	Engines H.P.	Total H.P.	Propellers - No. and Material	Speed, M.P.H.	Date - First Flight	Placed Out of Service	Life-Months	Type Development
LZ-60	Potsdam		LZ-90	Army	1,128,000	16	536	61.3	76,800	33,000	43.0	2	4	Maybach	240	960	4 Lorenzen	56.0	Jan 1, 1916		)11.2	P
LZ-60	Potsdam	Lengthened LZ-60	LZ-90	Army	1,262,000	18	586	61.3	85,800	38,500	44.9	2	4	Maybach	240	960	4 Lorenzen	56.0		Dec 7, 1916	)	P
LZ-61	Loewenthal		L-21	Navy	1,262,000	18	586	61.3	85,800	38,500	44.9	2	4	Maybach	240	960	4 Lorenzen	56.0	Jan 10, 1916	Dec 28, 1916	10.5	P
LZ-62*	Friedrichshafen		L-30	Navy	1,940,000	19	649	78.4	132,000	63,200	47.9	4	6	Maybach	240	1440	6 Lorenzen	62.2	May 28, 1916	Summer 1920	50	P
LZ-63	Potsdam		LZ-93	Army	1,128,000	16	536	61.3	76,800	33,000	43.0	2	4	Maybach	240	840	4 Lorenzen	56.0	Feb 23, 1916		)17	P
LZ-63	Potsdam	Lengthened LZ-63	LZ-93	Army	1,262,000	18	586	61.3	85,800	38,500	44.9	2	4	Maybach	240	960	4 Lorenzen	56.0		Summer 1917	)	P
LZ-64	Loewenthal		L-72	Navy	1,262,000	18	586	61.3	85,800	38,500	44.9	2	4	Maybach	240	960	4 Lorenzen	56.0	Mar 3, 1916	May 14, 1917	14.3	Q
LZ-65	Friedrichshafen		LZ-95	Army	1,262,000	18	586	61.3	85,800	38,500	44.9	2	4	Maybach	240	960	4 Lorenzen	56.0	Jan 31, 1916	Feb 22, 1916	0.7	Q
LZ-66	Potsdam		L-23	Navy	1,262,000	18	586	61.3	85,800	38,500	44.9	2	4	Maybach	240	960	4 Lorenzen	56.0	Apr 8 1916	Aug 22, 1917	16.5	Q
LZ-67	Loewenthal		LZ-97	Army	1,262,000	18	586	61.3	85,800	38,500	44.9	2	4	Maybach	240	960	4 Lorenzen	56.0	Apr 4, 1916	Jul 5, 1917	15	Q
LZ-68	Loewenthal		LZ-98	Army	1,262,000	18	586	61.3	85,800	38,500	44.9	2	4	Maybach	240	960	4 Lorenzen	56.0	Apr 28 1916	Aug 1917	16	Q
LZ-69	Potsdam		L-24	Navy	1,262,000	18	586	61.3	85,800	38,500	44.9	2	4	Maybach	240	960	4 Lorenzen	56.0	May 20 1916	Dec 28 1916	7.2	Q
LZ-70	Loewenthal		L-26	Navy	1,262,000	18	Building discontinued in order to provide space for building of 1,940,000 cu. ft. airship (LZ-72)															
LZ-71	Potsdam		LZ-101	Army	1,262,000	18	586	61.3	85,800	38,500	44.9	2	4	Maybach	240	960	4 Lorenzen	56.0	Jun 29, 1916	Sep 1917	14.5	Q
LZ-72	Loewenthal		L-31	Navy	1,940,000	19	649	78.4	132,000	66,000	50.0	4	6	Maybach	240	1440	6 Lorenzen	60.3	Aug 12, 1916	Oct 2, 19	1.7	R
LZ-73	Potsdam		LZ-103	Army	1,262,000	18	586	61.3	85,800	38,500	44.9	2	4	Maybach	240	960	4 Lorenzen	56.0	Aug 8, 1916	Aug 1917	12	Q
LZ-74	Friedrichshafen		L-32	Navy	1,940,000	19	649	78.4	132,000	66,000	50.0	4	6	Maybach	240	1440	6 Lorenzen	60.3	Aug 4, 1916	Sep 24, 1916	1.7	R
LZ-75	Staaken		L-37	Navy	1,940,000	19	649	78.4	132,000	66,000	50.0	4	6	Maybach	240	1440	6 Lorenzen	60.3	Nov 9, 1916	Summer 1920	44	R
LZ-76	Friedrichshafen		L-33	Navy	1,940,000	19	649	78.4	132,000	66,000	50.0	4	6	Maybach	240	1440	6 Lorenzen	60.3	Aug 30, 1916	Sep 24, 1916	0.8	R
LZ-77	Potsdam		LZ-107	Army	1,262,000	18	586	61.3	85,800	38,500	44.9	2	4	Maybach	240	960	4 Lorenzen	56.0	Oct 16, 1916	July 1917	9	Q
LZ-78	Loewenthal		L-34	Navy	1,940,000	19	649	78.4	132,000	68,200	51.6	4	6	Maybach	240	1440	6 Lorenzen	60.3	Sep 22, 1916	Nov 28, 1916	2.2	R
LZ-79	Staaken		L-41	Navy	1,940,000	19	649	78.4	132,000	68,200	51.6	4	6	Maybach	240	1440	6 Lorenzen	60.3	Jan 15, 1917	July 1919	30	R
LZ-80	Friedrichshafen		L-35	Navy	1,940,000	19	649	78.4	132,000	68,200	51.6	4	6	Maybach	240	1440	6 Lorenzen	60.3	Oct 12, 1916	Summer 1918	21	R
LZ-81	Potsdam		LZ-111	Army	1,262,000	18	586	61.3	85,800	38,500	44.9	2	4	Maybach	240	960	4 Lorenzen	56.0	Dec 20, 1916	Aug 10, 1917	7.7	Q

TABLE 1 - (CONTINUED)

Building Number	Building Shed	History	Class	Owned By	Capacity Cu. Ft.	No. of Cells	Length, Ft.	Diameter, Ft.	Total Load, Lbs.	Useful Load (0°-760 mm lbs)	Useful Total Percent	Power Cars No.	Engines No.	Engines Type	Engines H.P.	Total H.P.	Propellers - No. and Material	Speed, M.P.H.	Date - First Flight	Placed Out of Service	Life- Months	Type Development
LZ-82	Friedrichshafen		L-36	Navy	1,940,000	19	649	78.4	132,000	70,400	53.3	4	6	Maybach	240	1440	6 Lorenzen	60.3	Nov 1, 1916	Feb 7, 1917	3.2	R
LZ-83	Staaken		LZ-113	Army	1,940,000	19	649	78.4	132,000	70,400 to 71,500	53.3	4	6	Maybach	240	1440	6 Lorenzen	62.5	Feb 22, 1917	Oct 8, 1920	43.5	R
LZ-84	Loewenthal		L-38	Navy	1,940,000	19	649	78.4	132,000	71,500	54.2	4	6	Maybach	240	1440	6 Lorenzen	62.5	Nov 22, 1916	Dec 29, 1916	1.2	R
LZ-85	Staaken		L-45	Navy	1,940,000	19	649	78.4	132,000	71,500	54.2	4	6	Maybach	240	1440	6 Lorenzen	62.5	Apr 2, 1917	Oct 20, 1917	6.5	R
LZ-86	Friedrichshafen		L-39	Navy	1,940,000	19	649	78.4	132,000	71,500	54.2	4	6	Maybach	240	1440	6 Lorenzen	62.5	Dec 11, 1916	Mar 17, 1917	3.2	R
LZ-87	Staaken		L-47	Navy	1,940,000	19	649	78.4	132,000	71,500	54.2	4	6	Maybach	240	1440	6 Lorenzen	62.5	May 1, 1917	Jan 5, 1918	8	R
LZ-88	Friedrichshafen		L-40	Navy	1,940,000	19	649	78.4	132,000	71,500	54.2	4	6	Maybach	240	1440	6 Lorenzen	62.5	Jan 3, 1917	Jun 17, 1917	5.5	R
LZ-89	Staaken		L-50	Navy	1,940,000	19	649	78.4	132,000	71,500	54.2	4	6	Maybach	240	1440	6 Lorenzen	62.5	Jun 9, 1917	Oct 20, 1917	4.3	R
LZ-90	Loewenthal		LZ-120	Army	1,940,000	19	649	78.4	132,000	71,500	54.2	4	6	Maybach	240	1440	6 Lorenzen	62.5	Jan 31, 1917			R
LZ-91*	Friedrichshafen		L-42	Navy	1,960,000	18	645	78.4	133,000	79,200	59.5	4	5	Maybach	240	1200	5 Lorenzen	60.3	Feb 21, 1917	July 1919	29	S
LZ-92	Friedrichshafen		L-43	Navy	1,960,000	18	645	78.4	133,000	79,200	59.5	4	5	Maybach	240	1200	5 Lorenzen	60.3	Mar 6, 1917	Jun 14, 1917	3.2	S
LZ-93*	Loewenthal		L-44	Navy	1,970,000	18	645	78.4	134,000	82,500	61.5	4	5	Maybach	240	1200	3 Lorenzen 1 Jaray-LZ	60.3	Apr 1, 1917	Oct 20, 1917	6.7	T
LZ-94	Friedrichshafen		L-46	Navy	1,970,000	18	645	78.4	134,000	82,500	61.5	4	5	Maybach	240	1200	3 Lorenzen 1 Jaray-LZ	60.3	Apr 24, 1917	Jan 5, 1918	8.3	T
LZ-95*	Friedrichshafen		L-48	Navy	1,970,000	18	645	78.4	134,000	85,800	61.5	4	5	Maybach	240	1200	4 Jaray-LZ	about 66.0	May 22, 1917	Jun 17, 1917	0.8	U
LZ-96	Loewenthal		L-49	Navy	1,970,000	18	645	78.4	134,000	85,800	61.5	4	5	Maybach	240	1200	4 Jaray-LZ	66.0	Jun 13, 1917	Oct 20, 1917	4.2	U
LZ-97	Friedrichshafen		L-51	Navy	1,970,000	18	645	78.4	134,000	85,800	61.5	4	5	Maybach	240	1200	4 Jaray-LZ	66.0	Jul 6, 1917	Jan 5, 1918	6	U
LZ-98	Staaken		L-52	Navy	1,970,000	18	645	78.4	134,000	85,800	61.5	4	5	Maybach	240	1200	4 Jaray-LZ	66.0	Jul 4, 1917	August 1919	25	U
LZ-99	Staaken		L-54	Navy	1,970,000	18	645	78.4	134,000	85,800	61.5	4	5	Maybach	240	1200	4 Jaray-LZ	66.0	Aug 13, 1917	Jul 19, 1918	11.2	U
LZ-100*	Friedrichshafen		L-53	Navy	1,975,000	14	645	78.4	134,300	88,000	65.6	4	5	Maybach	240	1200	4 Jaray-LZ	67.0	Aug 18, 1917	Aug 11, 1918	12	V
LZ-101	Loewenthal		L-55	Navy	1,975,000	14	645	78.4	434,300	88,000	65.6	4	5	Maybach	240	1200	4 Jaray-LZ	67.0	Sep 1, 1917	Oct 20, 1917	1.7	V

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TABLE 1 - (CONTINUED)

Building Number	Building Shed	History	Class	Owned By	Capacity Cu. Ft.	No. of Cells	Length, Ft.	Diameter, Ft.	Total Load, Lbs.	Useful Load (0°-760 mm lbs)	Useful Total Percent	Power Cars No.	Engines No.	Engines Type	Engines H.P.	Total H.P.	Propellers - No. and Material	Speed, M.P.H.	Date - First Flight	Placed Out of Service
LZ-102	Friedrichshafen		L-57	Navy	2,416,680	16	743	78		14,400			5	Maybach	240	1200		63	9-26-17	10-7-17
LZ-103	Staaken		L-56	Navy	1,475,680	14	644	78		88,000			5	Maybach	240	1200		67	9-24-17	8-19
LZ-104	Staaken		L-59	Navy	2,416,680	16	743	78		14,400	65.6		5	Maybach	240	1200		63	10-10-17	4-7-18
LZ-105	Friedrichshafen		L-58	Navy	1,975,680	14	644	78		88,000			5	Maybach	290	1450		72	10-29-17	1-5-18
LZ-106	Friedrichshafen		L-61	Navy	1,975,680	14	644	78		88,000			5	Maybach	290	1450		72	12-12-17	8-29-18
LZ-107	Lowenthal		L-62	Navy	1,975,680	14	644	78		88,000			5	Maybach	290	1450		72	1-19-18	8-10-18
LZ-108	Staaken		L-60	Navy	1,975,680	14	644	78		88,000			5	Maybach	290	1450		72	12-18-17	7-19-18
LZ-109	Staaken		L-64	Navy	1,975,680	14	644	78		88,000			5	Maybach	290	1450		72	3-11-18	7-22-20
LZ-110	Friedrichshafen		L-63	Navy	1,975,680	14	644	78		88,000			5	Maybach	290	1450		72	3-4-18	7-19
LZ-111	Lowenthal		L-65	Navy	1,975,680	14	644	78		88,000			5	Maybach	290	1450		72	4-17-18	7-19
LZ-112	Friedrichshafen		L-70	Navy	2,404,332	15	743	78		96,800			7	Maybach	290	2030		81	7-1-18	8-5-18
LZ-113	Friedrichshafen		L-71	Navy	2,404,332	15	743	78		96,800	65.8		7	Maybach	290	2030		81	7-29-18	7-1-20
LZ-114	Lowenthal		L-72	-	2,404,332	15	743	78		96,800	65.8		7	Maybach	290	2030		81	7-9-20	-
LZ-115-119 Not Built																				
LZ-120	Bodensee				700,300	11	394	61		22,046	43.1		4	Maybach	240	960		83	8-20-19	-
LZ-121	Nordstern				785,759	12	427	61		24,250				Maybach						

TABLE 2 - GERMAN SCHUTTE-LANZ AIRSHIPS (RIGID)

Building Number	Building Shed	Class	Owned by	Capacity Cu. Ft.	Number of Gas Cells	Length, Ft.	Diameter, Ft.	Total Load, Pounds	Useful Load, at 0°-760 Mm Pounds	Useful Total, Percent	Engines, No.	Engines, Make	Engines, Hp.	Engines, Total, H.P.	Speed, M.P.H.	Date First Flight	Placed Out of Service	Life, Months
SL-1	Rheinau	SL-1	Schutte Lanz	724,000	11	430	60.3	49,200	9,900	20.1	2	Mercedes	240	480	44.0	Oct. 17, 11	Jul 17,'13	21
SL-2	Rheinau	SL-2	Army	883,000	15	473	59.7	60,000	17,000	20.3	4	Maybach	180	720	55.0	Feb 28, 14		
Rblt. SL-2	Rheinau	SL-2	Army	968,000	16	512	59.7	65,800	23,000	34.9	4	Maybach	210	840			Jan 10, 16	22.5
SL-3	Rheinau	SL-3	Navy	1,144,000	17	503	64.8	77,800	29,000	37.3	4	Maybach	210	840	52.5	Feb 4, 15	May 1, 16	15
SL-4	Sandhofen	SL-4	Navy	1,144,000	17	503	64.8	77,800	30,700	39.4	4	Maybach	210	840	53.0	Apr 25, 15	Dec 15, 15	8.3
SL-5	Darnstadt	SL-5	Navy	1,144,000	17	503	64.8	77,800	31,400	40.4	4	Maybach	210	840	51.5	Jun '15	Jul 5, 15	1
SL-6	Leipzig	SL-6	Navy	1,240,000	18	532	64.8	84,500	34,800	41.2	4	Maybach	210	840	57.5	Sept 19,15	Nov 18, 15	2
SL-7	Rheinau	SL-7	Navy	1,240,000	18	532	64.8	84,500	34.200	40.5	4	Maybach	210	840	56.0	Sept 3, 15	Mar 6, 17	18
SL-8	Leipzig	SL-8	Navy	1,240,000	18	572	66.0	84,500	41,100	48.6	4	Maybach	240	960	57.5	Mar 30, 16	Nov 20, 17	19.7
SL-9	Leipzig	SL-9	Navy	1,240,000	18	572	66.0	84,500	43,600	51.6	4	Maybach	240	960	57.5	May 24, 16	Mar 30, 17	10.2
SL-10	Rheinau	SL-10	Army	1,370,000	19	572	66.0	93,300	46,200	49.5	4	Maybach	240	960	56.0	May 17, 16	Jul 28, 16	2.3
SL-11	Leipzig	SL-11	Army	1,370,000	19	572	66.0	93,300	About 46,200	49.5	4	Maybach	240	960	57.0	Aug 2, 16	Sept 3 16	1
SL-12	Zeesen	SL-12	Navy	1,370,000	19	572	66.0	93,300	45,800	49.1	4	Maybach	240	960	53.5	Nov 9, 17	Dec 28, 16	1.7
SL-13	Leipzig	SL-13	Arny	1,370,000	19	572	66.0	93,300	Over 44,000	Over 47.2	4	Maybach	240	960	About	Oct 19, 16	Feb 8, 17	3.7
SL-14	Rheinau	SL-14	Navy	1,370,000	19	572	66.0	93,300	About 45,100	About 48.4	4	Maybach	240	960	56.0	Aug 23, 16	May 11, 17	8.5
SL-15	Rheinau	SL-15	Army	1,370,000	19	572	66.0	93,300	45,100	48.4	4	Maybach	240	960	56.0	Nov 9, 16	Summer 17	8
SL-16	Leipzig	E-9	Army	1,370,000	19	572	66.0	93,300	45,100	48.4	4	Maybach	240	960	56.0	Jan 18, 17	Summer 17	7
SL-17	Zeesen	E-10	Army	13,70,000	19	572	66.0	93,300	45,100	48.4	4	Maybach	240	960	56.0	Mar 22, 17	Summer 17	4
SL-18	Leipzig	E-11	Army	13,70,000	19	572	66.0	93,300			4	Maybach	240	960			Feb 8, 17	

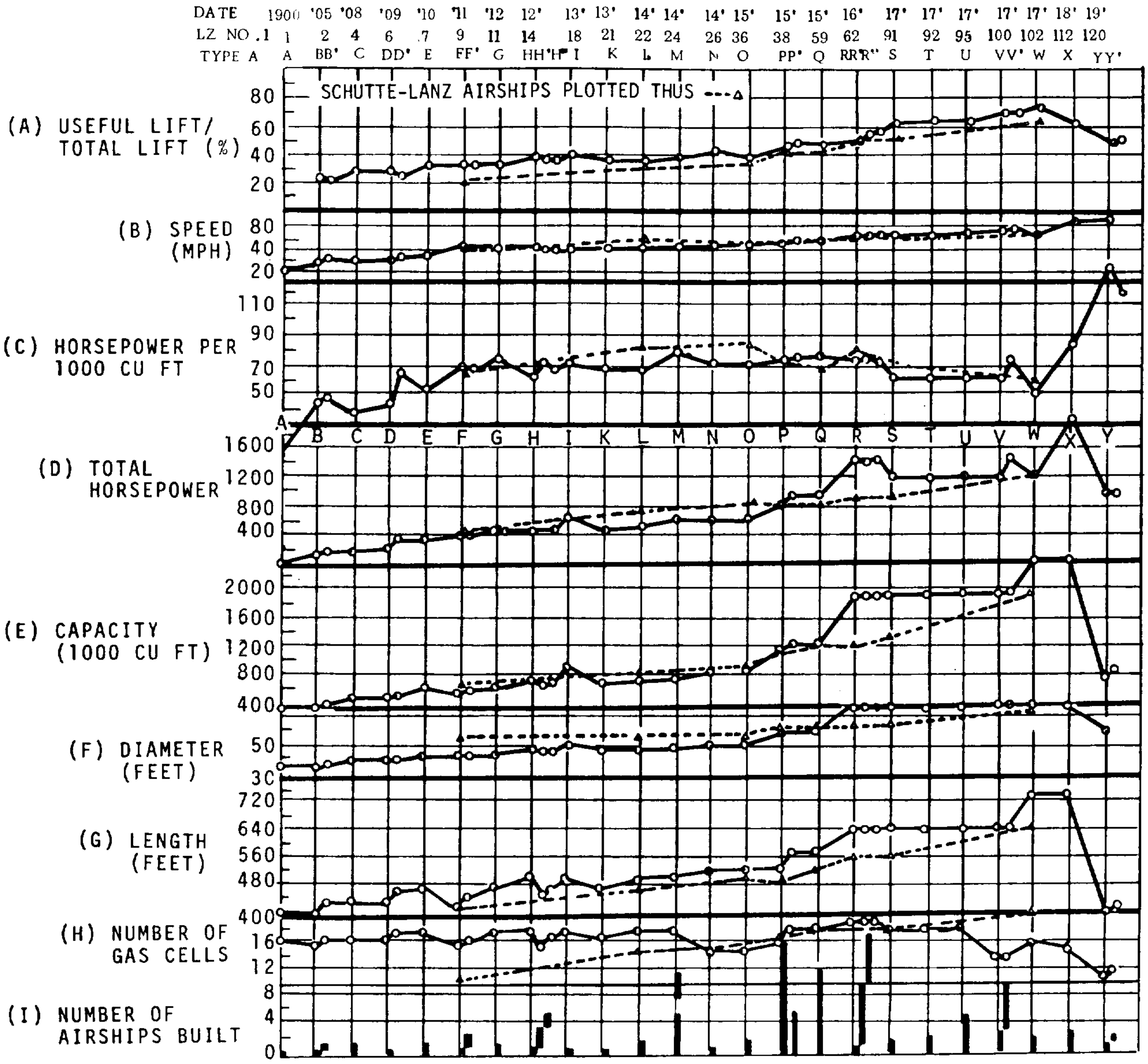
Note: 1.0 ft = 3.048 x 10^{-1} m, 1.0 lbm = 4.536 x 10^{-1} kg 1.0 HP = 7.457 x 10^{2} watts, 1.0 mph = 4.47 x 10^{-1} m/s relative unimportance, since they cannot be classified as successful or important in influencing the development of German airships. From this data, Figure 4 has been prepared to show the technological evolution of both the Zeppelin (rigid) and Schutte-Lanz (rigid) airships during this period.

At the extreme top of Figure 4, the year the first airship of a particular Zeppelin type appeared and the L-Z number of that ship are given. Type letters assigned to the various classes of ships are given in the third heading at the top of the figure. Where several types include airships that have different characteristics, these types have been plotted separately on each curve (see H, H', H"; P, P'; and R, R', and R"). For instance, airships H, H', and H" are the same particular letter type, but they had to be plotted separately since their characteristics varied and showed development within the type. The designation of the Schutte-Lanz airships is included with the various plots.

Curve A of Figure 4 shows the improvement that occurred in the important useful load-to-total load (gross weight) index. Improvement in the Zeppelins from a 20 percent factor in 1900 to a 65 percent factor at the close of World War I represented a very substantial improvement. Later airships, German Zeppelins included, did not have useful load-to-gross weight ratios approaching the 65 percent factor of the earlier Zeppelins. The early Zeppelin airships had higher useful load-to-gross weight ratios for the following reasons:

1. They were designed to much less severe strength criteria, especially with regard to aerodynamic loads on the hull and tail surfaces.
2. They carried no electronic gear except a small radio.
3. Crew accommodations were extremely meager.
4. They carried no landing gear to speak of, no hydraulic systems, no bow mooring, and no power boost for control.
5. Their gas valve complement permitted a rate of ascent of only 6 meters per second.

Curve B of Figure 4 indicates that maximum speed capabilities rose from 8.94 to 37.01 m/s (20 to 82.8 mph), with more than half this increase occurring



*1.0 FT = 3.048 x 10^{-1} m, 1.0 HP = 7.457 x 10^{2} WATTS, 1.0 mph = 4.470 x 10^{-1} m/s

Figure 4 - Characteristics of German Zeppelin and Schutte-Lanz Rigid Airships*

between 1914 and 1918. Accompanying this increase in speed was a similar increase in horsepower. The increase in horsepower is shown in Curve C in horsepower per 1000 cu ft. Curves B and C show that, when airship type R is compared with types S, T, U, and V, better aerodynamic efficiencies are obtained for the latter configurations.

Curve D shows the increase in horsepower that resulted in the increase in speed portrayed in Curve B. Curves E, F, and G show the general evolution to larger capacity ships, with increases in both diameter and length occurring. Curve H shows the number of gas cells as a function of airship type. Curve I depicts the number of each type of airship built.

General data and characteristics relative to the two most notable German airships, the Graf Zeppelin and Hindenburg, have been included in Table 3, which lists all major rigid airships. Table 4 gives a detailed weight breakdown of these two German airships and the other notable rigids.

British

The designers of Vickers Limited produced Britain's first rigid airship for the British Navy in 1911. This ship had a 19,994 cu m (706,000 cu ft) capacity, was framed of aluminum and incorporated swiveling propellers, and had water recovery apparatus and mooring mast provisions. This ship was wrecked through inexperience in ground handling, which resulted in halting all rigid airship development in Britain.

In 1913, the admiralty again contracted for another rigid airship from Vickers. After ordering work on it suspended once in 1914, the airship R-9 was finally completed and successfully flown in April 1917. The R-9 had a 22,656 cu m (800,000 cu ft) capacity and was used extensively in training crews and developing the swiveling propellers and mooring mast inventions. The R-9 established the "23" class airships, and several 25,488 cu m (900,000 cu ft) airships were built.

The "33" class rigid airships built by the British took the name from the German airship L-33 (brought down in Scotland in 1916) and were directly copied from it. These ships had a 56,640 cu m (2,000,000 cu ft) capacity, and one of them (the R-34) made the Trans-Atlantic flight to New York in May 1919. The class "33" airships were the only successful rigids the British ever built, and their success is reportedly due to the Zeppelin design.

The next attempt, a much larger ship - the R-38, was lost with all hands in 1921 and stopped the airship program for another eight years, at which time Britain designed and built the R-100 and the R-101.

TABLE 3 - CHARACTERISTICS OF RIGID AIRSHIPS (REFERENCES 3, 4, and 5)*

Item	R-34 Beardmore (1918)	ZR-2 British R-38 (1921)	ZR-1 Shenan-doah (1923)	ZR-3 (LZ-126) LosAngeles (1924)	LZ-127 Graf Zeppelin (1298)	R-100 British (1929)	R-101 British (1929)	ZRS-4 Akron (1931)	ZRS-5 Macon (1933)	LZ-129 Hindenburg (1936)
Total Volume - ft^3	2,130,000	2,940,000	2,290,000	2,800,000	4,200,000	5,570,000	5,970,000	7,400,000	7,400,000	7,650,000
Gas Volume - ft^3	2,000,000	2,760,000	2,148,000	2,600,000	3,900,000 ****	5,150,000	5,510,000	6,850,000	6,850,000	7,060,000
Length - ft	643	699	680	660	776	709	777	785	785	814
Diameter - ft	78.7	85.2	78.7	90.7	100	133	132	132.9	132.9	135.2
Fineness Ratio	8.17	8.20	8.7	7.3	7.8	5.3	5.9	5.9	5.9	6.02
Lifting Gas	Hydrogen	Hydrogen	Helium	Hydrogen Helium	Hydrogen	Hydrogen	Hydrogen	Helium	Helium	Hydrogen
Gross Weight ** - lb	129,200	178.296	126,517	167,960 H_2 153,140 He	260,300	332,690	355,946	403,465	403,465	456,076
Weight Empty - lb	67,200	86,000	80,400	86,400 H_2 89,239 He	137,000	233,000	264,000	237,844 *****	236,493 *****	249,000
Useful Lift - lb	62,000	92,296	46,117	81,560 H_2 63,900 He	123,300	99,690	91,946	165,621	166,972	207,076
Max. Speed - knots	58	61.4	58	66.7 H_2 65.2 He	69	71.2	67.2	69	72.2	72
Endurance *** - hrs	93	104	55	138 H_2 89 He	183	88	100	138	159	200
Fuel Comp *** - lb/hr	485	625	505	420 H_2 450 He	490	770	600	895	780	660
Fuel Capacity - lb	45,000	65,000	28,000	58,000 H_2 40,000 He	90,000	66,000	60,000	124,000	124,000	132,000
Total Propulsive Power - HP	1,375	2,100	1,500	2,000	2,800	4,020	5,500	4,480	4,480	4,400

* 1.0 ft = 3.048×10^{-1} m, 1.0 lbm = 4.536×10^{-1} kg, 1.0 HP = 7.457×10^{2} watts, 1.0 knot = 5.144×10^{-1} m/s, 1.0 cu ft = 2.832×10^{-2} cu m

** Gross Weight and Gross Lift are used interchangeably; Note that in the case of past rigids gross lift is entirely aerostatic in that "heavy" take offs were not utilized; Lift of helium at 59°F, 29.92 in Hg, 94% purity is used and is 0.062 lbs/ft^3; corresponding lift for hydrogen is 0.068 lbs/ft^3; fuel gas is

*** 50 knots

**** Total gas volume (2,800,000 cubic ft. was H_2); 1,100,000 was fuel gas)

***** Minus airplane compartment of 2664 Kg

TABLE 4 - DETAILED WEIGHTS FOR NOTABLE RIGID AIRSHIPS (REFERENCE 6)*

	Los Angeles		Graf Zeppelin		Macon		Hindenburg		1944 Goodyear Design	
	Weight (Pounds)	Percent of Gross Lift	Weight (Pounds)	Percent of Gross Lift	Weight (Pounds)	Percent of Gross Lift	Weight (Pounds)	Percent of Gross Lift	Weight (Pounds)	Percent of Gross Lift
1. Hull Structure	31,299	20.44	61,117	23.48	94,320	23.38	110,435	24.21	149,000	24.68
2. Empennage	2,750	1.80	6,998	2.69	14,116	3.50	16,669	3.65	20,000	3.31
3. Gas Cells	8,769	5.73	12,822	4.93	21,769	5.40	25,524	5.60	30,500	5.05
4. Outer Cover (Doped) Including Empennage	7,401	4.83	10,836	4.16	12,606	3.12	18,753	4.11	20,000	3.31
5. Gas Valves, Hoods and Ventilation	781	0.51	1,047	0.40	3,102	0.77	2,605	0.57	4,000	0.66
6. Nettings	671	0.44	715	0.27	570	0.14	1,043	0.23	1,200	0.20
7. Fuel and Oil System	2,651	1.73	4,275	1.64	5,546	1.37	5,625	1.23	7,000	1.16
8. Ballast and Water System	950	0.62	1,229	0.47	3,430	0.85	3,126	0.69	4,000	0.66
9. Control Car	1,399	0.91	1,604	0.62	1,718	0.43	1,874	0.41	2,000	0.33
10. Controls	550	0.36	693	0.27	1,672	0.41	1,562	0.34	1,900	0.31
11. Electrical System	1,199	0.78	1,923	0.74	2,688	0.67	4,167	0.91	4,000	0.66
12. Heating and Ventilation	251	0.16	535	0.21	738	0.18	728	0.16	1,000	0.17
13. Crew Quarters	2,499	1.63	3,205	1.23	6,450	1.60	3,645	0.80	3,500	0.58
14. Instruments	251	0.16	267	0.10	255	0.06	1,043	0.23	1,000	0.17
15. Radio and Communication	900	0.59	1,067	0.41	572	0.14	2,083	0.46	2,500	0.41
16. Mooring and Handling	1,399	0.91	1,453	0.56	3,425	0.85	4,168	0.91	4,700	1.16
17. Power Plant	21,199	13.84	21,102	8.11	49,759	12.33	36,465	8.00	31,000	5.13
18. Water Recovery	4,000	2.61	5,876	2.26	12,922	3.20	8,336	1.83	10,000	1.66
19. Miscellaneous	319	0.21	236	0.09	839	0.21	1,149	0.25	1,700	0.28
20. Contingency		-		-		-		-	6,000	0.99
21. Total	89,239	58.27	137,000	52.63	236,497	58.62	249,000	54.60	305,000	50.90
22. Airplane Compt. Plus Trapeze					5,861					
GROSS LIFT **	153,140	100.0	260,300	100.0	403,465	100.0	456,076	100.00	574,275	100.00
23. Breakdown of Hull Structure Weight										
a. Longitudinals	11,298	-	19,873	-	22,867	-	28,129	-	38,000	-
b. Wiring (Main. & Gas Cells)	2,400	-	4,274	-	8,930	-	10,149	-	16,080	-
c. Intermediate Frames	4,824	-	9,724	-	12,361	-	15,627	-	20,000	-
d. Main Frames (Rings, Bulkheads, Cruciforms, and Axial Beams)	8,776	-	19,980	-	37,374	-	43,758	-	58,000	-
e. Misc. Reinf. (Bow Cap, Stern Cap, Outer Cover Support Wires)	1,900	-	3,313	-	4,631	-	5,731	-	7,500	-
f. Keels (Gangways)	2,101	-	3,953	-	8,157	-	6,772	-	9,500	-
SUBTOTAL	31,299	-	61,117	-	94,320	-	110,435	-	149,000	-

*1.0 lbm = 4.536×10^{-1} kg

**95 percent inflation with gas and lift given in Table 3.

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These ships had a 144,432 cu m (5,100,000 cu ft) capacity and a radical design that used a few heavy longitudinal members instead of many light stringers. The outer covering was unstable in the large flat areas between these members and had to be pulled inward, which gave the ship a peculiar fluted effect. This also limited the gas capacity and reputedly resulted in an overweight design.

Great Britain finally discontinued further rigid airship development after the R-101 was lost in a flight across France; the flight was started immediately after an extra bay for increased lift had been added. The evidence brought forward by the court of inquiry investigating the crash disclosed that the lift still was not favorable and that the cell wires were slackened to further increase volume before the last flight, which permitted the cells to chafe on the longitudinal girders. The airship crashed due to a sudden loss of lift. The R-100 was scrapped shortly after the loss of the R-101, thus ending Great Britain's rigid airship efforts.

Table 3 compares the British R-34, R-38, R-100, and R-101 with the other rigid airships of major interest.

American

American rigid airship programs started with the launching of the Shenandoah from Lakehurst Naval Air Station in 1923 and with a research project in 1922, which was to result in the ZMC-2 metalclad airship.

The most notable American rigid airships were the Akron and Macon. Table 3 compares the general characteristics of these airships with other notable rigid airships. Table 4 compares the detailed weight breakdown of the Akron and Macon (Macon data presented)* with detailed weight breakdowns of other notable rigids.

Extensive technical data, analysis, design information, and test results are available at Goodyear relative to the Akron and Macon airships but seemingly are not of general interest and accordingly are not included in this historical overview. Should any of this data be used subsequently, it will be presented at that time.

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*Akron was slightly heavier.

Figure 5 summarizes the development of the rigid airship and shows that various rigid airship projects have continued at Goodyear. The detailed weight breakdown resulting from extensive design and cost analyses conducted in the mid-1940's by Goodyear relative to a 283,200 cu m (10 million cubic foot) airship for both passenger and cargo transportation is included in Table 4.

Non-rigid Airships

German

Table 5 summarizes the characteristics of the major German non-rigid airships, which were all constructed prior to or during World War I. The Wullenkemper organization has recently designed and built non-rigid airships.

French

Appendix A of Volume IV summarizes the characteristics of several French non-rigid airships.

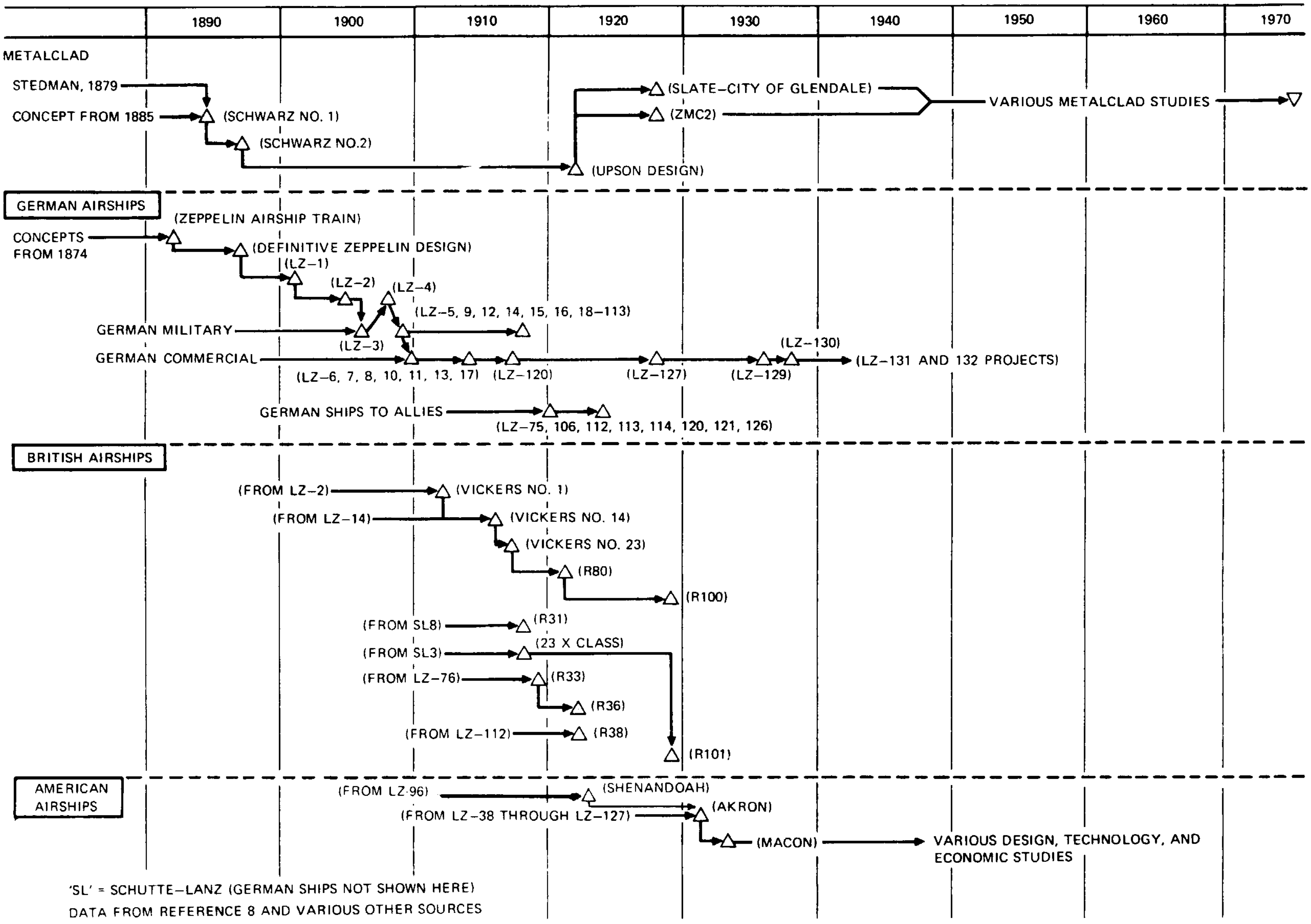
British

Although the British preceded the United States to some extent in the development of non-rigid airships, there appears to be no significant differences in the configurations; thus, British data are not presented.

American

America, by far, has been the major builder of non-rigid airships and, with minor exception, the only builder of them since the close of World War I. Appendix B of Volume IV summarizes the non-rigid airships manufactured by Goodyear, which has been the major supplier. Table 6 summarizes the characteristics of various types of American non-rigids.

Another American non-rigid airship of interest is the metalclad ZMC-2 built by the Aircraft Development Corporation for the Navy. The characteristics of this configuration are also summarized in Table 6, with added detail in Table 7. As pointed out in several references to the ZMC-2, it does not compare favorably with the conventional construction because for smaller sizes the minimum gage restriction relative to the thickness of the metal covering severely penalizes the metalclad.



'SL' = SCHUTTE–LANZ (GERMAN SHIPS NOT SHOWN HERE)
DATA FROM REFERENCE 8 AND VARIOUS OTHER SOURCES

Figure 5 - Summary of Significant Rigid Airship History

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TABLE 5 - GERMAN NON-RIGID AIRSHIPS (REFERENCE 1)*

Airship Designation	Capacity, Cu. Ft.	Length, Feet	Diameter, Feet	Total Load, Pounds	Useful Load, Pounds	Useful Total, Per Cent	Engine, Number	Engines, Make	Engines, Total H.P.	Propellers Number	Propellers Material	Speed, M.P.H.	Number of Passengers and Crew	Placed in Service	History
Clouth	65,000	138	27.8	4,400	. . . .	. .	1	Adler	50	2-2 Bladed	Wooden	19.0	4	1909	Keel girder type
Siemens Schuckert	475,000	394	44.3	32,000	. . . .	. .	4	Daimler	480	2-4 Bladed 4-2 Bladed	Steel	44.5		Jan 23, 1911	)Rebuilt and)dismantled
Suchard	353,000	246	55.7	24,200	. . . .	. .	2	N.A.G.	220	2-4 Bladed	Fabric	22.5	6	Early 1912	Motor board car
PV	81,000	164	29.2	5,500	2,200	40.0	1	Daimler	85	1-4 Bladed	Fabric	27.0	6	May 26, 1906	
PL-1	120,000	197	30.8	7,600	2,850	37.5	1	Daimler	85	1-4 Bladed	Fabric	27.0	6 to 8	Sept. 21, 1909	
PL-2	141,000	197	34.1	9,600	3,500	36.5	1	Daimler	85	1-4 Bladed	Fabric	28.0	6	Aug 13, 1908	
PL-3	233,000	229	40.4	15,800	4,100	27.9	2	N.A.G.	220	1-4 Bladed	Fabric	32.0	12 to 16	Feb 18, 1909	
PL-4	89,000	164	28.2	6,050	2,200	36.4	1	Austro Daimler	70	1-3 Bladed	Fabric	26.0	5	1909	
PL-5	51,000	131	26.3	3,460	1,320	38.1	1	Daimler	25	1-3 Bladed	Fabric	20.0	4	Dec. 8, 1909	
PL-6	240,000	229	40.4	16,300	6,600	40.5	2	N.A.G.	220	2-4 Bladed	Fabric	33.5	12 to 16	Jan 30, 1910	
PL-7	268,000	236	45.9	18,200	4,840	26.6	2	N.A.G.	220	2-4 Bladed	Fabric	36.5	12 to 16	Oct. 30, 1910	
PL-8	290,000	253	50.9	19,700	6,160	31.3	2	Maybach	340	2-4 Bladed	Plate Steel	41.8		Dec 24, 1912	
PL-9	60,000	131	26.3	4,080	2,420	59.4	1	N.A.G.	50	1-2 Bladed	Wooden	24.6	4	Oct 10, 1910	
PL-11	353,000	276	50.9	24,000	6,780	28.2	2	Korting	400	2-4 Bladed	Plate Steel	40.2	7 to 12	Dec 13, 1911	
PL-12	282,000	269	45.9	19,200	6,600	34.4	2	N.A.G.	220	2-4 Bladed	Plate Steel	33.5	12 to 16	May 11, 1912	
PL-13	282,000	259	47.6	19,200	4,840	25.2	2	Maybach	300	2-4 Bladed	Plate Steel	41.2	7	Apr 3, 1912	
PL-14	353,000	269	52.5	24,000	. . . .	. . .	2	Maybach	360	2-4 Bladed	Plate Steel	41.3		Feb 27, 1913	
PL-16	353,000	308	50.9	24,000	7,840	31.2	2	Maybach	360	2-4 Bladed	Wooden	18.0		Aug, 1914	
PL-17	353,000	279	52.5	24,000	6,160	25.7	2	Maybach	340	2-4 Bladed	Plate Steel	40.2		Sep 13, 1912	
PL-18	311,000	275	49.2	21,200	6,160	29.0	2	Maybach	360	2-4 Bladed	Plate Steel	40.2		Apr 23, 1913	
PL-19	363,000	308	51.2	24,700	7,270	29.4	2	Maybach	360	2-4 Bladed	Wooden	47.8		Summer 1914	
PL-21	353,000	302	49.2	24,000			2	Maybach	360	2-4 Bladed	Wooden	47.5			
PL-25	470,000	369	53.8	32,000	13,200	41.2	2	Maybach	420	2-4 Bladed	Wooden	43.5		Jan 1915	
PL-26	1,060,000	512	62.7	72,000	About 35,200	48.9	4	Maybach	840	4-2 Bladed	Wooden	50.5		Oct 26, 1915	
PL-27	1,100,000	518	64.3	74,700	39,600	53.0	4	Maybach	960	4-2 Bladed	Wooden	56.0		Mar 8, 1917	

PL-22-23-24 Never Completed

*1.0 ft = 3.048×10^{-1} m, 1.0 lbm = 4.536×10^{-1} kg, 1.0 HP = 7.457×10^{2} watts, 1.0 mph = 4.470×10^{-1} m/s

TABLE 6 - AMERICAN NON-RIGID AIRSHIP CHARACTERISTICS

Characteristics	A (1915)	B (1916)	C (1918)	G (1935)	AA (1919)	K-1 to -135 (1931 - 1945)	L (1938-1943)	M-1,2,3,4 (1943-1944)
Total Volume (cu ft)	110,000	84,000	181,000	183,000	35,350	319,000[a] to 456,000	123,000	647,000 to 725,000
Max Ballonet Volume(cu ft)	---	19,250	55,250	39,200	7,000	104,400 to 119,500	29,249	193,000 to 210,000
No. of Ballonets	---		2	2	---	2 2	2	4 4
Gross Lift - Stabic(lb)	7,438	5,440	11,650	11,350	2,440	20,560 to 27,400	7,400	40,150 to 44,950
Weight Empty (lb)	6,188	3,600	7,600	7,235	1,556	12,876 to 20,300	5,700	29,800 to 31,500
Useful Lift - Static(lb)	1,250	1,840	4,050	4,115	884	7,684 to 7,100	1,700	10,350 to 13,450
Dynamic Lift (lb)	---	---	---	1,000	---	--- 2,500	500	3,500 to 3,500
Total Lift (lb) (Static + Dynamic)	7,438	5,440	11,650	12,350	2,440	20,560 to 29,900	7,900	43,650 to 48,450
Normal Fuel (lb)	---	700	1,440	---	---	--- 5,500	650	7,350 to 10,450
Horsepower	140	100	300	420	40	600 to 1,200	290	1,110
Speed(knots) - Max	---	41	52	56.5	33	55 to 67.5	52	69
- Cruise	---	30	35	47.8	---	40 to 50	40	50
Endurance(hr) -Top Speed	---	10.9	14.8	10.6	---	41 to 59	7.65	10.2 to 14.4
-Cruise	---	26.5	31.2	16.7	---	at 35 knots	---	35.5 to 50.5
Weight Empty / Volume	0.056	0.043	0.042	0.0395	0.044	0.0405 to 0.0445	0.046	0.046 to 0.0435
100% Ballonet Volume / Envelope Volume x 100	---	23	30,5	21.4	20	33 to 26 16 (Fuel Gas)	24	30 to 29 Articulated Car
Max Altitude(ft)(Ballonet) 100% full at take-off	---	8,500	11,800	8,000	7,300	13,000 to 10,000	9,000	11,800 to 11,400

[a] Total volume includes 51,700 cu ft for fuel gas

[b] Numbers in parenthesis indicate basic weight,i.e., stripped of all electronic and military equipment

[c] Without electrical night sign on envelope

[d] Heavy take-off

[e] Metalclad

NOTE: (1) Gross lift values do not correspond to any single value of healium lift (purity) or percent inflation as various values were actually utilized in acutal mission

(2) Data from References 4 and 7. Goodyear supplied ships to Navy except Type A - and ZMC-2 Metalclad

(3) 1.0 ft = 3.048×10^{-1} m, 1.0 lbm = 4.536×10^{-1} kg, 1.0 HP = 4.457×10^{2} watts, 1.0 knot = 5.144×10^{-1} m/s, 1.0 cw ft = 2.832×10^{-2} cu m

TABLE 6 - (CONTINUED)

Characteristics	N, ZPG-1 (1951)	ZPG-2[b] (1953-1957)	ZPG-2W[b] (1955-1957)	ZPG-3W[b] (1959-1960	ZWG-1[b] Design Study	GT&R GZ-19A Columbia II (1963-)	GZ-20 [c] America (1968-)	ZMC-2[e] (1929)
Total Volume (cu ft)	875,000	975,000	975,000	1,490,000	2,800,000	147,300	202,700	202,200
Max Ballonet Volume(cu ft)	203,000	247,300	247,300	383,200	750,790	38,600	41,950	50,600
No. of Ballonets	4	4	4	4	3	2	2	2
Gross Lift - Stabic(lb)	52,622	61,913	61,913	94,615	177,800	8,776	11,900	12,242
Weight Empty (lb)	40,152	46,302(38,006)	47,779(37,297)	67,566(56,582)	116,940(90,484)	6,400	8,250	9,115
Useful Lift - Static(lb)	12,470	15,611(23,907)	14,134(24,616)	27,049(38,033)	60,860(87,316)	2,376	3,650	3,127
Dynamic Lift (lb)	6,000	6,000	6,000	10,500	15,000	350	430	---
Total Lift (lb) (Static + Dynamic)	58,622	67,913	67,913	105,115	192,800	9,126	12,330	11,910
Normal Fuel (lb)	6,680 12,680 [d]	7,019 12,900 [d]	4,695 10,700[d]	5,372 15,872[d]	22,955 37,240[d]	1,100	1,800	1,400
Horsepower	1,600	1,600	1,600	2,550	3,050	350	420	440
Speed (knots) - Max	74	73	70.5	82	72	48.5	50.0	60.8
- Cruise	40	40	40	---	35	36	45.5	48.6
Endurance (hr) - Top Speed - Cruise	85	59.0	55.7 at 38 kts	80	10 hrs at 50 kts 120 hrs at 35 kts 10 hrs at 50 kts	--- 17.5	8.8 13.0	--- 10.9
Weight Empty / Volume	0.046	0.0475(0.039)	0.049(0.0383)	0.0455(0.032)	0.040(0.032)	0.0435	0.0408	0.0451
100% Ballonet Volume / Envelope Volume x 100	28	25.4	25.4	25.7	26.9	26.2	20.6	25
Max Altitude(ft) (Ballonet) 100% full at take-off	10,800	9,500	9,500	9,600	10,000	10,000	7,500	8,000

[a] Total volume includes 51, 700 cu ft for fuel gas

[b] Numbers in parenthesis indicate basic weight, i.e., stripped of all electronic and military equipment

[c] Without electrical night sign on envelope

[d] Heavy take-off

[e] Metalclad

NOTE: (1) Gross lift values do not correspond to any single value of helium lift (purity) or percent inflation as various values were actually utilized in actual mission

(2) Data from References 4 and 7. Goodyear supplied ships to Navy except Type A and ZMC-2 Metalclad

TABLE 7 - ZMC-2 CHARACTERISTICS (REFERENCE 7)*

Length of Hull	149 ft. 5 in.
Diameter of Hull (max.)	52 ft. 8 in.
Fineness Ratio	2.83
Displacement of Hull	202,200 cu. ft.
Total Ballonet Displacement	50,600 cu. ft.
Front Ballonet Displacement	22,600 cu. ft.
Rear Ballonet Displacement	28,000 cu. ft.
Ratio of Ballonet Volume to Hull Volume	25%
Thickness of Skin	0.0095 in.
Length of Car	24 ft.
Width of Car	6 ft. 6 in.
Number of Air Valves	3
Number of Gas Valves	2
Number of Fins	8
Total Fin Area	440 sq. ft.
Total Elevator Area	190 sq. ft.
Total Rudder Area	95 sq. ft.
Total Automatic Rudder Area	95 sq. ft.
Engines (Wright Whirlwind J-5	2
Power at 1,800 r.p.m.	440 h.p.
Propeller Diameter (all metal)	9 ft. 2 in.
Lineal Feet of Seam	17,600 ft.
Surface Area	19,436 sq. ft.

PERFORMANCE DATA OF THE ZMC-2 METALCLAD

Gross lift (100 per cent, inflation with 92 per cent, pure helium at 60 deg. Fahr. and 29.92 in. Hg.).		12,242 lb.
Weight Empty		9,115 lb.
Useful Load		3,127 lb.
Crew (three)	600 lb.	
Fuel (200 gal.)	1,200 lb.	
Oil (25 gal.)	200 lb.	
Ballast (50 gal.)	420 lb.	
Passengers and Cargo	707 lb.	
Range with 250 gal. (Cruising Speed)		760 mi.
Maximum Possible Range (still air)		1,120 mi.
Maximum Speed at 440 h.p.		70 m.p.h.
Cruising Speed at 220 h.p.		56 m.p.h.
Static Ceiling		9,000 ft.

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*1.0 ft = 3.048×10^{-1} m, 1.0 lbm = 4.536×10^{-1} kg, 1.0 mi = 1.852×10^{3} m, 1.0 mph = 4.470×10^{-1} m/s, 1 sq ft = 0.0929 sq m, 1.0 cu ft = 2.832×10^{-2} cu m

This minimum gage penalty disappears with increasing size. The Aircraft Development Corporation in the 1930's prepared proposed configurations for a variety of applications and compared notable rigid airships as illustrated in Table 8. The data of this table indicates the MC-72 metalclad compares favorably with the Akron.

In Reference 9, C. P. Burgess compares the Aircraft Development Corporation's proposed MC-74* with the Akron. Burgess terms the MC-74 estimate "an honest and careful piece of work" but states in light of experience that he believes the actual empty weight would be about 15 percent over the estimate. This would bring the 209,568 cu m (7,400,000 cu ft) MC-74 to essentially 107,049.6 kg (236,000 lb). Burgess then shows that the reason

TABLE 8 - COMPARISON OF AKRON (ZRS-4) AND PROPOSED MC-72 METALCLAD [a]

ITEM	COMPARATIVE DATA	
	ZRS-4[b]	MC-72
Displacement (Air), $ft.^3$	7,250,000	7,260,000
100% Gas Volume, $ft.^3$	6,850,000	7,080,000
Total Lift, Helium Lifting .062 $lb./ft.^3$, 95% full, lb.	403,000	417,000
Weight Empty, lb.	233,000	249,000
Useful Load, lb.	170,000	168,000
Useful Load/Total Lift	42.2	40.3
Useful Load per 1,000 $ft.^3$ Displacement, lb.	23.5	23.2
Motors	Maybach (8)	Maybach (8)
Horse-Power	4,480	4,480
Maximum Speed, m.p.h.	84	84
Useful Load per Horse-Power, lb.	38.0	37.5
Number of Gas Cells	12	11
Lift of Largest Cell, 95% full, lb.	57,000	49,000
Lift of Largest Cell/Useful Load	33.5	29.1
Lift of Largest Cell/Total Lift	14.1	11.7

[a] 1.0 ft = 3.048×10^{-1} m, 1.0 lbm = 4.536×10^{-1} kg, 1.0 HP = 7.457×10^{2} watts
1.0 mph = 4.470×10^{-1} m/s, 1.0 cu ft = 2.832×10^{-2} cu m

[b] Data from reference 7 which recognized the Akron data as unofficial. Akron data not changed from values of reference 7 since differences are not substantial.

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[*] The MC-74 (slightly larger than the MC-72) has the same air volume as Akron.

for the MC-74 empty weight being less than the Akron (110,147.69 kg, or 242,830 lb, is the value Burgess uses) is not due to inherent advantages in the metalclad design. He states that they differ because of such items as lighter engines. In Table 9, Burgess compares the weight estimate of the Aircraft Development Corporation with his own relative to what is basically termed nonpropulsive structural weight.

Burgess believes the comparisons favor the conventional rigid construction by about 1416 kg (5000 lb) but the metalclad has a slight advantage in empty weight-to-gross lift ratio. In any event, Burgess' comparison supports the basic

TABLE 9 - STRUCTURAL WEIGHT (POUNDS) OF AKRON AND MC-74 (REFERENCE 9)*

	AKRON (actual)	MC-74 (estimate)	MC-74 (+15%)
Hull plating or cover	11,721	42,032	48,337
Longitudinals	22,641	12,613	14,505
Main frames	37,101	27,548	31,680
Intermediate and splicing frames ...	12,067	3,974	4,570
Corridors	8,217	5,485	6,308
Shear wiring	5,200	---	---
Gas cell wiring	3,750	---	---
Cover wiring	1,905	---	---
Miscellaneous structure	2,820	2,713	3,120
Total hull structure	105,402	94,365	108,520
Gas cells, valves, etc.	25,127	19,239	22,125
Blower system	---	4,065	4,675
Total comparative weights	130,529	117,669	135,320
Comp. weight/gross lift	32.4%	27.4%	31.6%

*1.0 lbm = 4.536×10^{-1} kg

contention that the disadvantage that smaller metalclads have due to minimum gage considerations all but disappear when considering airships of the Akron and Macon size.*

Although the ZMC-2 metalclad was used for 12 years, the airship never flew an extensive number of hours (about 2250 total). There are perhaps two reasons for this:

1. Extreme unsteadiness in rough air due to exceedingly low slenderness ratio (in order to attain maximum structural efficiency) and the small size of the fins
2. Available funds in the Navy were apparently being directed to the more conventional rigid LTA configurations rather than "experimenting" with new innovations.

In a later article (see Reference 10), Burgess suggests altering the slenderness ratio to attain a compromise between structural efficiency and aerodynamic performance. In this same article, Burgess establishes the approximate weights and principal characteristics (see Table 10) of what he terms an ultimate airship (for 1939) that has the same air volume as the Akron and Macon.

Burgess's suggestions relative to the nature of the ultimate airship include:

1. Using the metalclad construction with no compartmentalization.
2. Using 15 percent ballonet volume.**
3. Reducing drag of the Akron and Macon by 30 percent by such approaches as placing the car in the nose of the airship and the air scoops for the ballonets in the nose area;

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*Based on material properties of that point in time.

**25% ballonet volume is more typical for non-rigids, but Burgess suggests that during descent following an emergency ascension above pressure height that air be pumped directly into the helium with subsequent purification of the helium being required. This emergency provision also is normally available on non-rigid designs.

TABLE 10 - PRINCIPAL CHARACTERISTICS AND APPROXIMATE WEIGHTS OF ULTIMATE AIRSHIP (1939) BY BURGESS (REFERENCE 10)*

PRINCIPAL CHARACTERISTICS	
Air Volume	7,400,000 ft.^{3}
Total gas volume	7,200,000 ft.^{3}
Gross lift, 95% full of gas lifting 0.062 lb./ft.^{3}	425,000 lbs.
Weight empty	143,600 lbs.
Service load	42,400 lbs.
Disposable load	239,000 lbs.
Length	618 ft.
Diameter	154.5 ft.
Maximum hp	3100
Maximum speed	75 kts.
Hp at 60 kts.	1640
Fuel consumption at 60 kts.	740 lb./hr.
Economic range at 60 kts.	7450 naut. mi. 8580 stat. mi.

APPROXIMATE WEIGHTS		
Item	Weight, lbs.	% Gross
Shell	30,400	7.15
Framing	30,400	7.15
Fins and control surfaces	12,000	2.82
Miscellaneous structure	2,000	0.47
Total structure	74,800	17.60
Ballonets and pressure system	8,000	1.88
Power plant	24,800	5.84
Fuel and ballast system	20,000	4.71
Electrical system	2,000	0.47
Quarters and control comp't.	8,000	1.88
Mooring and handling	4,000	0.94
Miscellaneous	2,000	0.47
Weight empty	143,600	33.79
Useful load	281,400	66.21
Gross weight	425,000	100.00

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*1.0 ft = 3.048×10^{-1} m, 1.0 lbm = 4.536×10^{-1} kg,
1.0 kt = 5.144×10^{-1} m/s, 1.0 HP = 7.457×10^{2} watts,
1.0 nauti mi = 1.852×10^{3} m, 1.0 statute mi = 1.609×10^{3} m,
1.0 cu ft = 2.832×10^{-2} cu m

using the metal hull for cooling the helium, which in turn is used to cool the radiators and water recovery apparatus.

4. Some minor improvements in specific fuel consumption and propeller efficiency that have since been realized.

Since the Burgess configuration has an empty weight of about 60 percent that of the Akron (which has the same total displacement) and a 75 percent greater useful load capacity, the configuration should be considered in the conventional LTA parametric weight studies.

Burgess was clearly impressed with the potential of the metalclad airship but expressed concern relative to manufacturing costs of the larger metalclads. Estimates by the Aircraft Development Corporation during the 1930's (Reference 7), however, do not indicate excessive manufacturing costs.

In Reference 11, Adm. Rosendahl states that flying the ZMC-2 was a "very tricky" proposition due to sudden changes in buoyancy resulting from the rapid transmission of heat to and from the helium by the metal hull, which was in direct contact with the helium. Other considerations tend to moderate the thinking that the metalclad is a concept without fault or shortcoming; these considerations are discussed in the parametric analysis subsection of this report. This is not to say that there are not viable solutions for those problems of which we are aware or for those problems that are unknown. With the metalclad, however, all aspects of its design, manufacture, and operation must be carefully considered.

Table 11 gives a detailed weight breakdown for the ZPG-3W as configured for its aircraft early warning (AEW) military mission and with its military equipment stripped.

Semi-rigid Airships

Table 12 summarizes the characteristics of the German semi-rigid airships. As in the rigids, a general evolution to larger, faster, and at the same time more efficient configurations can be seen in this table.

TABLE 11 - DETAILED WEIGHTS FOR ZPG-3W WITH AND WITHOUT MILITARY EQUIPMENT (REFERENCE 13)*

Item	Weight (pounds)		
Weight empty (total)			67,566[+] (56,582)[‡]
Envelope group (dacron):		21,986 (21,986)	
Envelope	12,690		
Ballonets	2,211		
Airlines	514		
Car suspension	1,414		
Bow stiffening and mooring	1,559		
Fin suspension	377		
Car fairing	484		
Access shaft and walkway	441		
Miscellaneous	2,296		
Tail group		3,701 (3,701)	
Car group		4,570 (4,570)	
Alighting gear group		1,190 (1,190)	
Pressure group		2,076 (2,076)	
Ballast group		750 (750)	
Surface control group		1,230 (1,230)	
Outrigger group		880 (880)	
Engine section and nacelle group		1,446 (1,446)	
Propulsion group:		8,307 (8,307)	
Engine installation	3,527		
Accessory gear boxes and drives	207		
Air induction system	34		
Exhaust system	135		
Cooling system	322		
Lubricating system	484		
Fuel system	2,160		
Engine controls	106		
Starting system	75		
Propeller installation	1,527		
Auxiliary power unit		760 (0)	
Instruments and navigation equipment group:		580 (580)	
Instruments	486		
Navigational equipment	94		
Hydraulic group		430 (430)	
Electrical group		3,176 (794)	
Electronics group		12,162 (4,320)	
Furnishings and equipment group		2,164 (2,164)	
Air conditioning and anti-icing group:			
Equipment group		1,363 (1,363)	
Air conditioning	1,307		
Anti-icing	56		
Auxiliary gear		795 (795)	

[+] Numbers without parenthesis refer to the ZPG-3W as configured for military mission.

[‡] Numbers with parenthesis refer to the ZPG-3W without military equipment.

*1.0 lbm = 4.536×10^{-1} kg

TABLE 12 - CHARACTERISTICS OF GERMAN SEMI-RIGID AIRSHIPS (REFERENCE 1)*

Airship Designation	Capacity, Cu. Ft.	Length, Feet	Diameter, Feet	Total Load, Pounds	Useful Load, Pounds	Useful Total, Per Cent	Engine, Number	Engines, Make	Engines, Total H.P.	Propellers Number	Propellers Material	Speed, M.P.H.	Number of Passengers and Crew	Placed in Service	History
Ruthenberg I	42,000	131	21.3	2,860			1	Benz	24	1-4 Bladed	Plate Steel	22.4	3	Sept. 1909	Keel Girder type
Ruthenberg II	60,000	151	24.3	4,080			1	Fiat	75	1-4 Bladed	Plate Steel	28.0		Early 1911	Keel Girder type
Vech	247,000	249	43.0	16,800			2	Schneeweis	180	4-2 Bladed	Wooden	35.0		Oct. 1913	
Erbsloh	102,000	174	32.8	6,950			1	Benz	125	1-2 Bladed	Wooden	30.0	5	Oct. 1909	
MV	63,000	131	26.9	4,280	1,030	24.1	1	Caggenau	24	2-3 Bladed	Metal	20.0		May 7, 1907	Built by the Prussian Army Airship Works to the design of Major Gross and Her Basenach.
M-1	176,000	215	36.4	12,000	3,000	25.0	2	Korting	150	2-3 Bladed	Metal	28.7		June 30, 1908	
Replaced M-1	194,000	235	39.3	13,200	3,640	27.6	2	Korting	150	2-2 Bladed	Wooden	28.1		Feb. 26, 1913	
M-II	176,000	215	36.4	12,000	3,000	25.0	2	Korting	150	2-3 Bladed	Metal	28.7		Apr. 26, 1909	
Replaced M-II	198,000	237	39.7	13,500	3,740	27.7	2	Korting	150	2-3 Bladed	Metal	28.0		Aug. 12, 1911	
M-III	275,000	267	42.6	18,700	5,350	28.6	4	Korting 3	300	2-4 Bladed	Wooden	36.7		Dec. 31, 1909	
Replaced M-III	318,000	274	42.6	21,600	6,160	28.5	4	Korting	300	2-2 Bladed	Wooden	42.2		Aug. 1912	
M-IV	390,000	317	45.9	26,500	5,940	22.4	2	Korting	400	4-4 Bladed	Wooden	38.0		Mar. 11, 1911	
Replaced IV	475,000	323	50.2	32,300	7,050	21.8	3	Maybach	480	2-4 Bladed 2-2 Bladed	Wooden	51.2		Aug. 11, 1913	
Rebuilt replaced M-IV	687,000	396	52.8	46,700	15,400	33.0	3	Maybach	480	2-4 Bladed 2-2 Bladed	Wooden	50.2		Sept. 7, 1914	

*1.0 ft = 3.048×10^{-1} m, 1.0 lbm = 4.536×10^{-1} kg, 1.0 HP = 7.457×10^{2} watts, 1.0 mph = 4.470×10^{-1} m/s, 1.0 cu ft = 2.832×10^{-2} cu m

Table 13 summarizes the characteristics of two notable Italian configurations, the Roma and the Norge, as well as the American RS-1. The historic flight from Rome to the North Pole in 1926 by the Norge is reported in Reference 12. Appendix A of Volume IV summarizes the characteristics of other Italian semi-rigid configurations.

Analysis of Data (Rigid, Non-rigid, Semi-rigid)

The rigid airship data from Tables 1, 3, and 4 have been plotted in Figure 6 in the form of useful lift-to-gross lift ratio as a function of air volume. Figure 6 also shows the same ratio for the airship that Burgess in Reference 3 refers to as the ultimate airship, as well as the 1944 Goodyear design for a 290,280 cu m (10,250,000 cu ft) rigid

Several factors are apparent from Figure 6:

1. The British R-100 and 101 do not compare favorably with the other configurations, which is why they are often reported as being overweight.

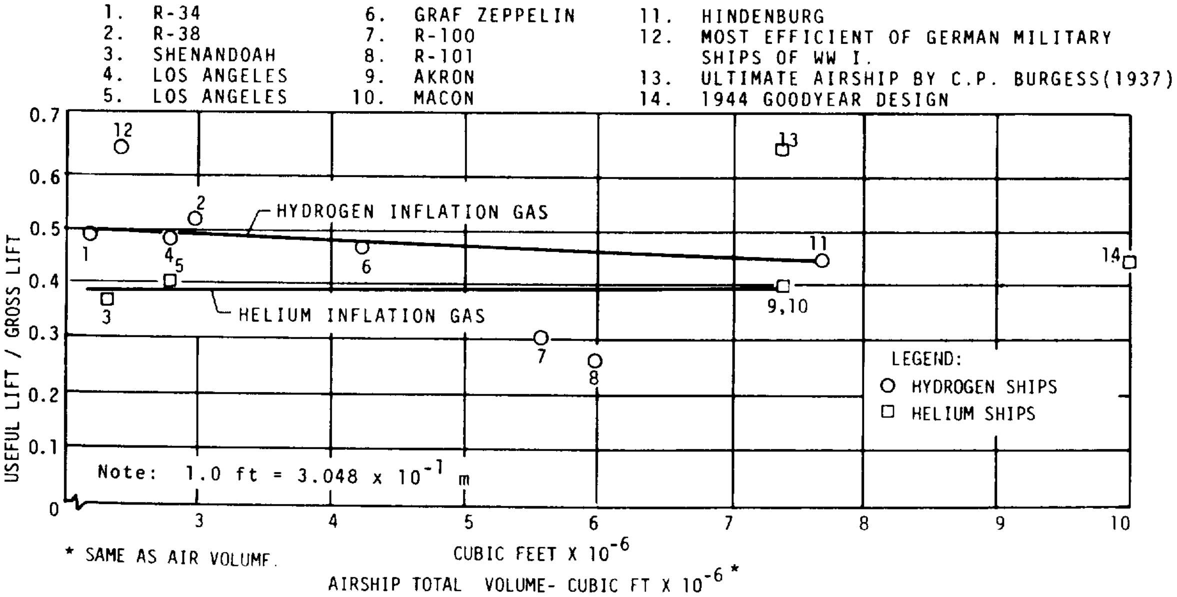


Figure 6 - Useful Lift-to-Gross Lift Ratio vs Airship Volume (Past Rigid Airship Configurations)

TABLE 13 - CHARACTERISTICS OF RS-1, ROMA, AND NORGE SEMI-RIGID AIRSHIPS (REFERENCE 3)*+

Designation	Type	Builder	Date	Volume (cu ft)	Length (ft)	Diameter (ft)	Height (ft)	No. of ballonets	Lifting gas	Gross lift (lb)	Dead weight (lb)
RS-1	Semirigid	Goodyear	1925	753, 000	282	70	93	4	Helium	44, 300	29, 400
Roma	Semirigid	L/A Constr. Rome	1919	1, 240, 000	410	74.6	92	6	Hydrogen	80, 000	47, 200
Norge	Semirigid	L/A Constr. Rome	1923	654, 000	348	64	78.7	8	Hydrogen	42, 200	26, 600

Designation	Useful lift (lb)	Useful/ gross	Ballonet volume (cu ft)	Ballonet/ gross	No.	Engine type	Total hp	Full speed (knots)	Fuel capacity (lb)	Consumption at 40 knots (lb/hr)	Range at 40 knots (nauti mi)
RS-1	14, 900	.336	30, 000	.398	4	Liberty	1200	64	7, 000	175	1600
Roma	32, 800	.410	. . .	. . .	6	Liberty	1800	64	14, 000	262	2140
Norge	15, 600	.369	. . .	. . .	3	Maybach	750	60	8, 700	133	2620

*Standard lift of gases: hydrogen .068 lb/ft^3; helium .062 lb/ft^3; gross lift taken at 95 percent inflation with gas of standard lift.

+1.0 ft = 3.048×10^{-1} m, 1.0 lbm = 4.536×10^{-1} kg, 1.0 HP = 7.457×10^{2} watts,
1.0 kt = 5.144×10^{-1} m/s, 1.0 naut mi = 1.852×10^{3} m, 1.0 cu ft = 2.832×10^{-2} cu m

2. German military rigids at the end of World War I exhibited much higher useful lift-to-gross lift ratios than any airships that followed.
3. The significant technology advancements incorporated in the Akron, Macon, and Hindenburg rigids are not apparent because the hulls of these configurations were noticeably stronger (and accordingly heavier) than prior designs. The necessity for the added strength resulted from flight experience with the earlier rigids and the wind tunnel testing associated with these most recent airships. The relative hull strengths of the more notable rigid airships are provided in a subsequent subsection of this overview.
4. Hydrogen-filled airships have a superior useful lift-to-gross lift ratio than helium-filled airships.
5. While the two lines portraying the "average" useful lift-to-gross lift ratios for hydrogen- and helium-filled airships are not exact, they generally illustrate:
    a. Hydrogen filled airships generally have exhibited useful lift-to-gross lift ratios ranging from 0.45 to 0.50.
    b. Helium-filled airships generally have exhibited a useful lift-to-gross lift ratio of about 0.40.

    The ratio of these values is slightly greater than the ratio of the lift of the gases although not significantly so.
6. The proposed 1944 Goodyear design has a useful lift-to-gross lift ratio comparable to prior experience but is somewhat improved in view of interim technology advances. The column entitled "Percent of Total" in Table 4 basically shows the areas of the design in which these improvements took place.
7. The improvement associated with C. P. Burgess' ultimate airship is readily apparent.

The empty weight-to-gas volume ratio better attests to the efficiency of a given past configuration than the useful lift-to-gross lift ratio. This volume ratio measures efficiency in that it considers the total "cost" to achieve a lifting capability (empty weight) as well as measures the total lifting capability achieved (the gas volume). This parameter also removes the effect of the differences in lifting gases and conditions of comparison (percent inflation, purity of lifting gas, and temperature of lifting gas). It also is one of the better methods to compare past rigid, non-rigid, and semi-rigid configurations. It is, however, somewhat unfair to the recent non-rigid configurations in that it does not account for the benefits derived by heavy takoffs but does account for the penalty paid in terms of the increased landing gear weight required to perform a heavy takeoff, since the gear increases the empty weight. The lower the empty weight-to-total gas volume ratio the more efficient is the configuration.

In Figure 7, the empty weight-to-gas volume ratio is a function of airship gas volume for the rigid airships of Figure 6. Some of the same conclusions in Figure 6 are still discernible but generally speaking the hydrogen- and helium-filled airships are very comparable in Figure 7.

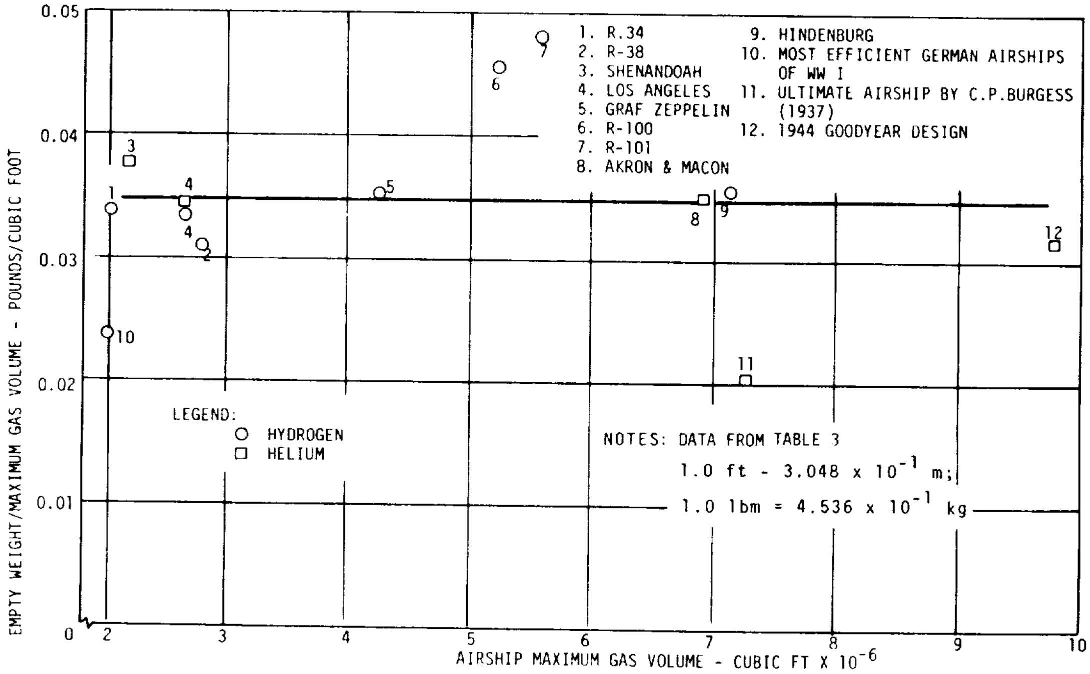


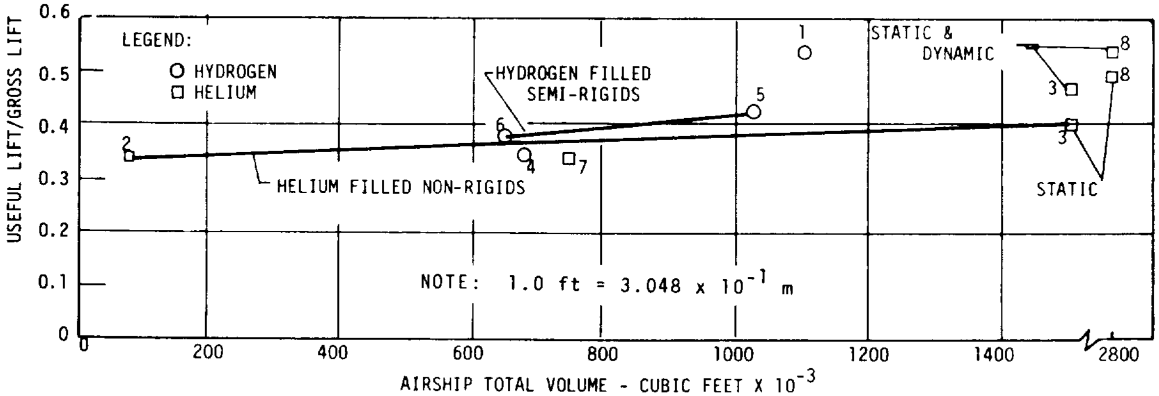
Figure 7 - Empty Weight-to-Gas Volume Ratio as a Function of Gas Volume (Past Rigid Airship Configurations)

These data reflect different design criteria such as design velocities. Note, however, that the hull strength of the Akron, Macon, and Hindenburg is very similar (see Page 110).

The non-rigid and semi-rigid data from Tables 5, 6, 12, and 13 have been plotted in Figure 8 in the form of useful lift-to-gross lift ratio as a function of total volume. Figure 8 shows the following:

1. Early German non-rigid configurations exhibited a greater useful lift-to-gross lift ratio than subsequent configurations for essentially the same reasons cited for the early German rigids.
2. The improvement within the helium-filled non-rigid airships is technology related and not size related. As in the rigid airships, the technology impact is not readily apparent due to corresponding increases in strength criteria. In addition, the increase in design velocity (which converts to a factor of four in terms of dynamic

1. MOST EFFICIENT GERMAN MILITARY NON-RIGID (1917)
2. EARLY AMERICAN NON-RIGID - B TYPE (1916)
3. RECENT AMERICAN NON-RIGID - ZPG-3W (1959)
4. MOST EFFICIENT GERMAN MILITARY SEMI-RIGID (1914)
5. ROMA SEMI-RIGID (1919)
6. NORGE SEMI-RIGID (1923)
7. RS-1 SEMI-RIGID (1925)
8. GOODYEAR NON-RIGID DESIGN STUDY



* STATIC EXCEPT AS NOTED

Figure 8 - Useful Lift*-to-Gross Lift Ratio versus Airship Volume (Past Non-rigid and Semi-rigid Configurations)

pressure for doubling the design velocity) between the ZPG-3W and the 1919B nonrigid tends to prevent improvement recognition.

3. The semi-rigid airships do not appear significantly different in terms of the parameter plotted than the non-rigids for a similar period in time.
4. The benefit of dynamic lift has been included in Figure 8 with respect to the ZPG-3W and the ZPW-1 design study configuration.

Figure 9 represents a comparison between past rigids, non-rigids, and semi-rigids. The parameter used for the comparison is empty weight-to-maximum gas volume ratio. The following comments are offered relative to Figure 9:

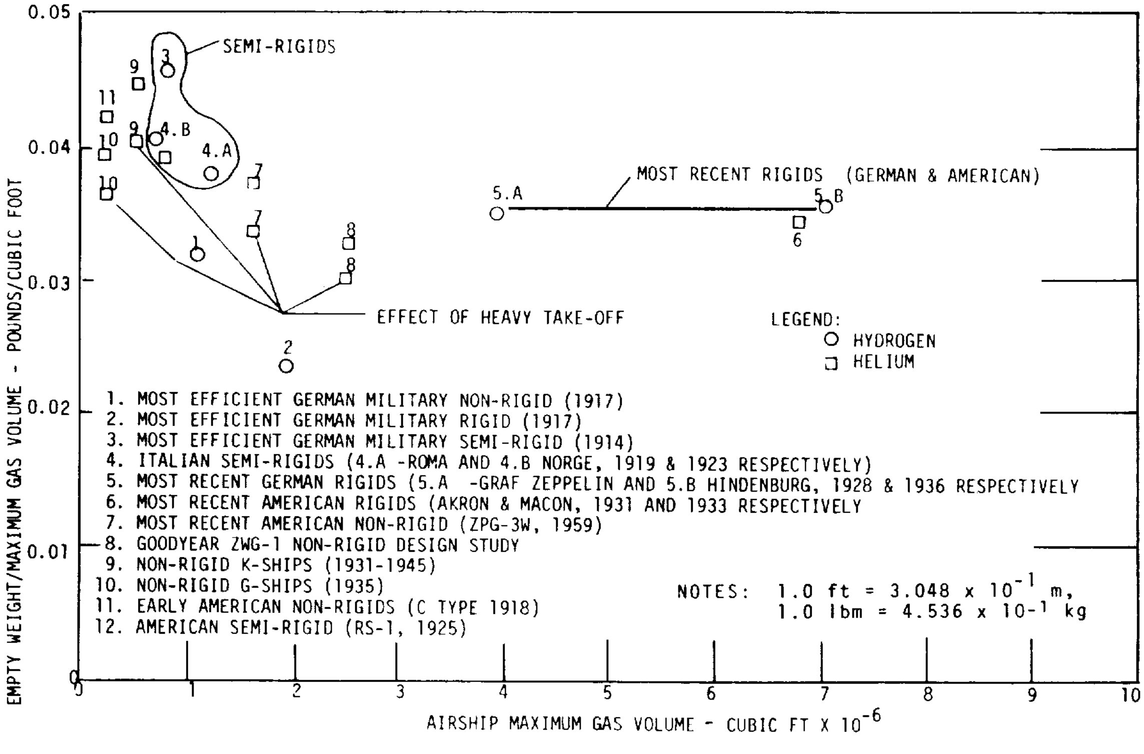


Figure 9 - Comparison of Past Rigid, Non-rigid, and Semi-rigid Airship Configurations

1. Semi-rigids and non-rigids for a comparable period in time (1916 to 1925) do not appear to differ significantly in terms of efficiency*, based on comparing data points 3, 4.A, 4.B, 11, and 12. In general, the design criteria, velocity, and materials were comparable in these designs and the sizes were similar.
2. The most recent rigids (data points 5.A, 5.B, and 6) have relatively the same efficiency. All these configurations have essentially the same design velocity and were of similar sizes. The Akron, Macon, and Hindenburg used a more severe hull strength criteria than the Graf Zeppelin. However, this was offset by the Akron, Macon, and Hindenburg using improved materials and the Hindenburg using an improved powerplant.
3. The ability of the non-rigid designs to perform heavy takeoffs has been translated to an increase in efficiency; this has been done by converting the dynamic lift into an effective increase in gas volume using a lift value for helium of 0.993 kg/cu m (0.062 lb/cu ft). Volume II assesses the "real gain" in efficiency resulting from heavy takeoffs.**
4. An increase in efficiency in the rigid design over certain size ranges also can be realized by heavy takeoff as discussed in Volume II.
5. The rigids and non-rigids of data points 5.A, 5.B, 6, 9, and 10 from a comparable period in time (1928 to 1936) indicate that the rigid configuration is historically somewhat between 12 and 25 percent more efficient than

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[*] Meaningful comparisons cannot be made over large periods in time generally due to changes in strength criteria based on experience and wind tunnel testing, technological improvements, and general trend to higher-speed designs as time passed.

[**] This is accomplished by defining the relative gain in useful lift versus the relative increase in empty weight due to increased landing gear weight.

the non-rigid.* Again, the reader must refer to Volume II to compare the two configurations precisely.

6. A comparison between the ZPG-3W and the rigid airships of the 1930 era is probably meaningless.

Figure 10 shows the effect that altitude has on useful lift. It can be seen from Figure 10 why airships have historically been considered relatively low-altitude vehicles. It is reasonable to suggest on the basis of the plot that, as a rule, commercial operations with a modern airship vehicle (MAV) should be limited to about 1524 m (5000 ft) above sea level to maximize productivity. Inherent in that statement is the general conclusion that commercial operations would not be suited to routes passing over mountainous terrain.

Use of the airship in military applications requiring high-altitude capability is not nearly such a significant concern. The "penalty" paid to attain an operational capability of 6096 m (20, 000 ft) can quickly be offset in a high-priority military need situation when it is realized the airship may be the only viable approach for meeting the need.

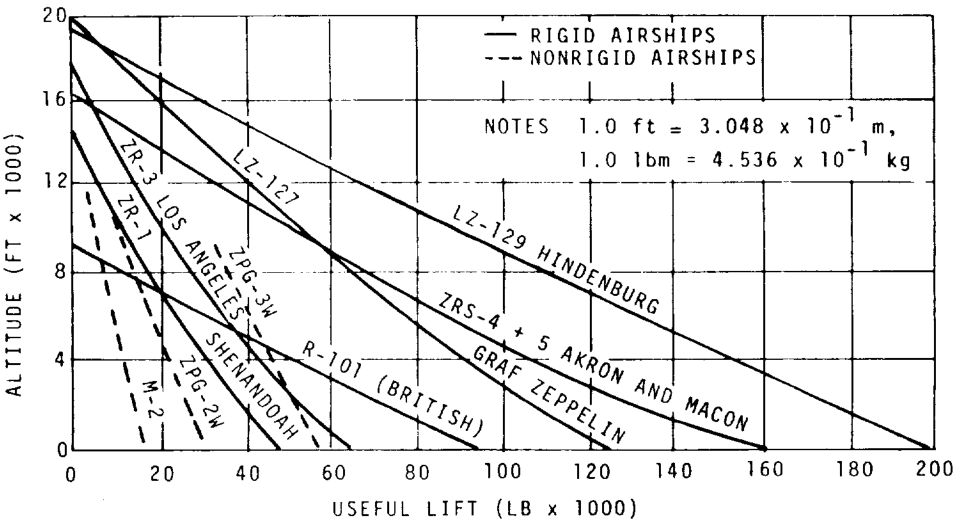

Figure 10 - Altitude versus Useful Lift

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* This conclusion does not suggest that rigids are categorically preferable over non-rigids since such a determination involves many factors. In addition, as shown in Volume II, the efficiency gain indicated in the rigids is principally due to their larger size.

Figure 11 shows the relationship between structural weight and volume of past rigid airships. The data of the figure is for airships that used different aerodynamic loading criteria, used different load factors and factors of safety, considered military versus commercial criteria in their design, exhibited different maximum speeds, and used different component material strength-to-weight ratios.

Thus, while the data have been interpreted linearly to facilitate an appraisal of the data trend, the relationship between wieght and volume is not necessarily linear for a given set of the above considerations. The parametric analysis subsection of this report illustrates the actual trend that exists between weight and volume for given sets of variables.

Figure 12 presents one figure of merit (FOM) of interest and shows payload ton-miles per hour as a function of gross weight for various notable rigid airships of the past. The British rigid data have not been plotted since they do not fit the trends shown because of the structure's rather excessive weight. Payload is defined as useful load minus fuel load required to traverse

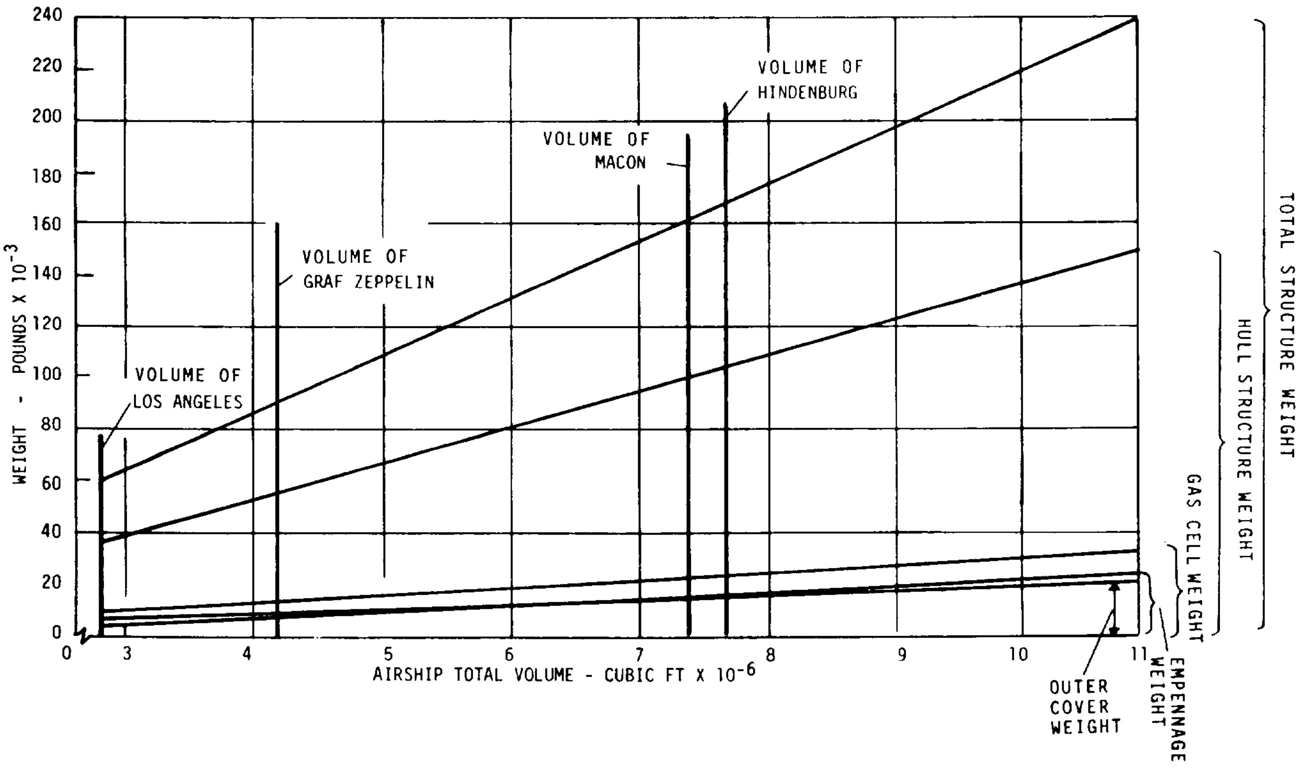


Figure 11 - Rigid Structural Weight versus Airship Air Volume

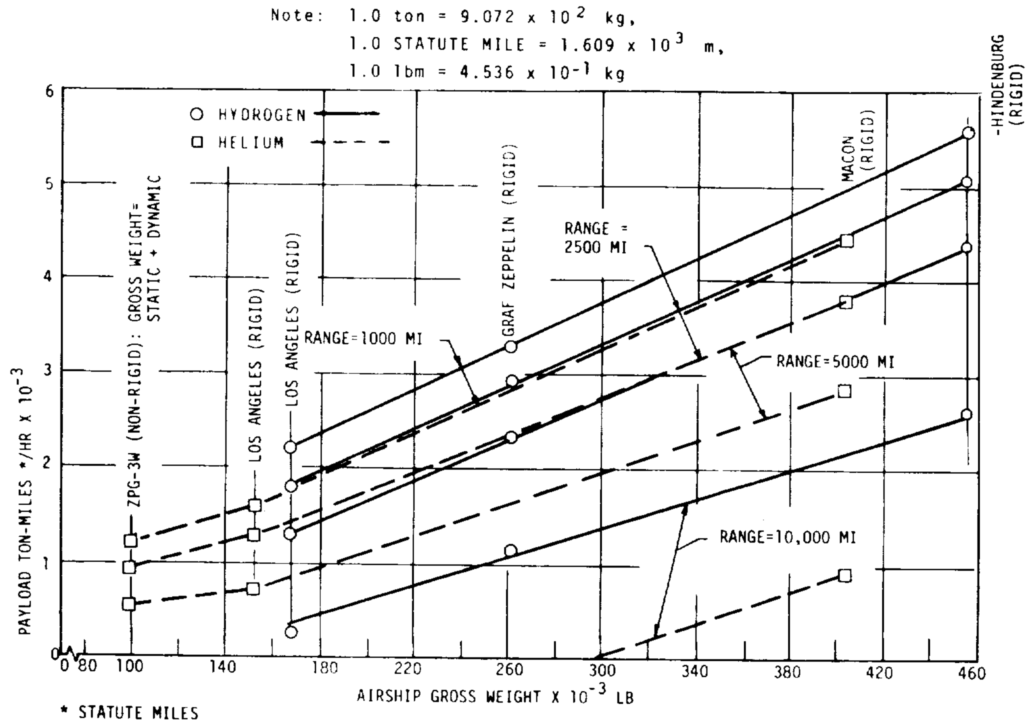
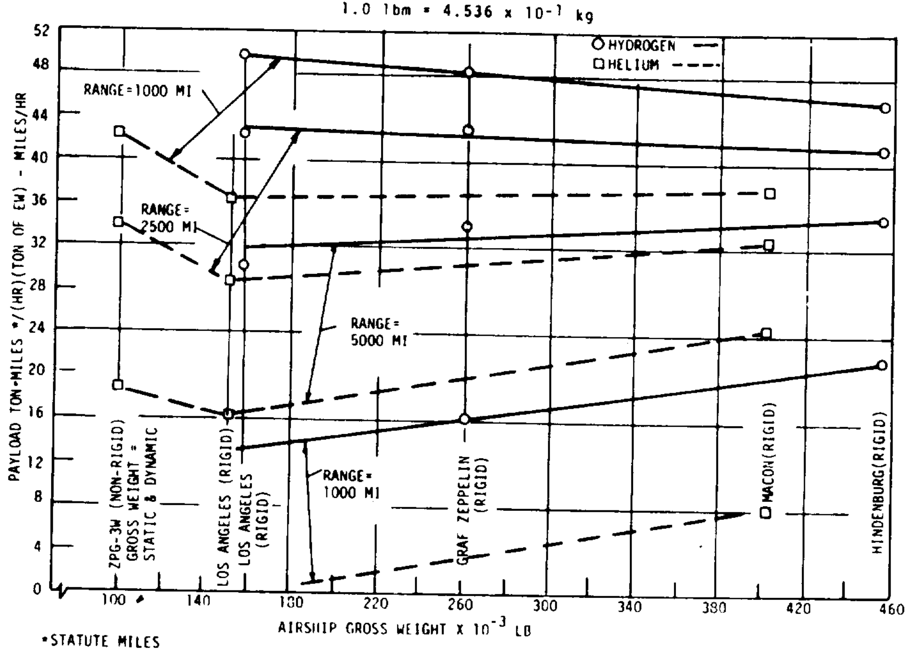


Figure 12 - Payload Ton-Miles per Hour versus Gross Weight (Rigids)

the range indicated at a velocity of 50 knots in a zero headwind condition. The curves provide a base so productivity can be compared with past rigids and those emerging from the parametric study. The results cannot be used to compare data available on other forms of transportation unless similar ground rules are adopted to define the relation between useful lift, payload, and fuel load. Fifty knots was not necessarily the optimal speed in terms of the FOM plotted but was a velocity at which data were available for all configurations. There is a variety of design criteria represented; accordingly, the linearized interpretations are not necessarily representative.

Figure 13 presents the FOM of payload ton-miles/(hours) (empty weight) as a function of gross weight for past rigids. The definitions in Figure 12 also apply to Figure 13, with generally the same qualifications applying. The parametric data are compared with these data in the parametric study.

The ZPG-3W non-rigid airship data point is included so that the parametric results of Volume II can be compared. Any specific comparisons



Note: 1.0 ton = 9.072×10^2 kg,
1.0 STATUTE MILE = 1.609×10^3 m,
1.0 lbm = 4.536×10^{-1} kg

Figure 13 - Payload Ton-Miles/(Hours)(Empty Weight) versus Gross Weight (Rigids)

between the ZPG-3W and the remainder of the data of Figures 12 and 13 are for the most part meaningless due to differing specifications to which the airships were built.

HISTORICAL MARKETS, MISSION COSTS, AND OPERATING PROCEDURES

General

The historical missions and markets have been broadly grouped as commerical and military. The following military and commercial operations are discussed in this subsection:

1. German military missions during World War I (rigid airship operation)
2. Seasonal pleasure flying in Germany between 1910 and 1914 (rigid airship operation)

3. Scheduled commercial service between Friedrichshafen, Germany, and Berlin during 1919 (rigid airship operation)
4. Scheduled seasonal service between Friedrichshafen and South America between 1932 and 1937 (rigid airship operation)
5. Scheduled seasonal service between Friedrichshafen and Lakehurst, N. J., between 1936 and 1937 (rigid airship operation)
6. American military missions since 1916 (rigid and non-rigid airship operation)

Operations and Economics

German Military Activities

At the outset of World War I, the German military had a fleet of approximately 12 Parseval and Siemens-Schuret non-rigid airships. These airships had little practical use during the war because of their limited size and speed. The commercial rigid airships of the Zeppelin Delag fleet were immediately pressed into service; thus, commercial services were suspended.

Zeppelin-type rigids totaled nine at the outset of hostilities. Ultimately, 88 airships were built by the Zeppelin Company for the German war effort. The Schutte-Lanz Company provided an additional 18 rigids. These airships were ultimately abandoned, however, in favor of the Zeppelin type because moisture caused the wooden structural members of the Schutte-Lanz airships to deteriorate.

Bombing by airship started in earnest during the siege of Antwerp, Belgium, with bombs improvised from artillery shells. The Zeppelins were employed extensively on the Russian front until that front collapsed. Raids on London started in 1915 and grew in intensity through 1916.

In some cases, fleets of as many as 16 airships were used. Table 14 summarizes pertinent characteristics of selected bombing missions. Later

TABLE 14 - SELECTED WORLD WAR I GERMAN BOMBING RAIDS*

Airship	Gas capacity cu.m.	Date of Raid	Object of raid	Crew	Fuel kg.	Water Ballast kg.	Bombs kg.	Altitude of Attack m.	Maximum altitude m.	Distance flown km.	Time	
											Hr.	Min.
Z 4	19500	9/9/14	Russian camp at Insterburg	10	1075	1950	900	2100	2575	365	8	40
Sachsen	20870	9/2/14	Antwerp	11	1600	1625	950	1950	2500	661	11	25
Z 9	22500	8/24/14	Antwerp	13	2270	1320	1750	2000	2400	562	8	--
Z 10	22500	3/20/15	Paris	12	2440	2720	995	2000	2400	433	8	32
		3/17/15	Paris, Calais	15	2605	2080	3000	2200	2675	708	10	1
		5/16/15	Calais	14	1970	3380	1600	3050	3150	450	7	42
Z 12	25000	7/22/15	Malkin	11	1350	3480	1650	3000	3300	491	5	59
		8/11/15	Bialystok	11	1420	3300	2000	3000	3600	608	9	34
LZ 35	22500	3/20/15	Paris	11	2555	2810	818	2000	2450	760	11	7
38	32000	4/29/15	Harwich, Ipswich	14	3200	4200	2447	3200	3550	800	12	47
		5/31/15	London	12	3080	6620	1357	3300	3900	685	9	37
39	25000	12/17/15	Rowno	10	2850	3000	975	2000	2200	478	12	50
74	32000	9/7/15	London	14	3060	4050	2000	3100	3500	1063	14	43
77	32000	2/1/16	Paris	13	2050	7100	2600	2900	3600	900	15	--
79	32000	1/31/16	Paris	12	2820	7100	1500	3100	3900	780	10	50
85	32000	1/31/16	Saloniki	16	3440	6090	2000	2900	3900	1425	18	29
86	32000	4/2/16	Minsk	15	2400	6300	2060	2750	3500	600	10	43
90	32000	3/31/16	Norwich	14	3550	4460	2450	2500	3275	1496	18	33

*1.0 ft = 3.048×10^{-1} m, 1.0 lbm = 4.536×10^{-1} kg, 1.0 cu ft = 2.832×10^{-2} cu m raids were carried out at altitudes in excess of 6400.8 m (21,000 ft) and bomb loads were in excess of 5443.2 kg (12,000 lb). The bombing raids became reasonably effective, with many large munition factories disabled for extended periods (Reference 14). The raids began to decrease in 1917 when the altitude capability and incendiary ammunition of the airplanes improved.

After 284 raids, of which 188 were considered successful under Army operation, the Zeppelins were transferred to naval service in the North Sea. These airships played an important scouting role in the famous battle of Jutland, the only large-scale naval battle of World War I. Reportedly, without the Zeppelins in this battle, the German fleet would have been eliminated.

The Zeppelins were used in a wide variety of ways by the Germany Navy. Forty Zeppelins in the latter stages of the war broke up extensive mine fields, stopped enemy merchant ships at sea, and bombed out enemy locks and drydocks.

During World War I, German Army and Navy airships flew approximately 26 000 hours, or nearly 2.315×10^9 m (1,250,000 m), during approximately 5000 flights. About 51 airships were lost (References 15 and 16):

1. 17 downed by incendiary projectiles from artillery or airplanes
2. 19 heavily damaged by artillary
3. 7 stranded in enemy territory
4. 8 destroyed in hangars by enemy action

At the end of the war, Germany resumed commercial passenger and freight services with the airship, a service abandoned in 1914 so that all efforts could be focused on providing airships to the military.

German Commercial Activities

Between 1910 and 1937, German Zeppelins were used for four different sustained commercial operations.

TABLE 15 - LUFTSCHIFFBAU ZEPPELIN COMMERCIAL SERVICE (1910 TO 1937)

Airship	Period of service	Number of days in service	Number of days flown	Number of-flights	Number of hours flown	Miles flown	People carried	
							Revenue Passengers	Other
Deutschland (LZ-7)	6/19/10 to 6/28/10	10	5	7	20.3	643	142	78
LZ-6	8/21/10 to 9/14/10	23	18	34	66.1	1,943	723	377
Ersta Deutschland (LZ-8)	3/23/11 to 5/16/11	53	17	22	47.1	1,485	129	329
Schwaben (LZ-10)	6/26/11 to 6/28/12	362	143	218	479.3	16,972	1,553	2,801
Viktoria-Luise (LZ-11)	2/16/12 to 7/31/14	1244	316	489	981.2	33,749	2,995	6,743
Hansa (LZ-13)	7/16/12 to 7/31/14	735	255	399	840.4	27,613	2,187	6,134
Sachsen (LZ-17)	5/3/13 to 7/31/14	447	233	419	740.6	24,806	2,465	7,372
Bodensee (LZ-120)	8/24/19 to 12/1/19	98	88	103	532	32.313	2,253	4,050
Graf Zeppelin (LZ-127)								
1928	9/18/28			11	269.1	15,385	365	-
1929				39	917	57,295	1,200	-
1930				109	1,155.5	71,934	2,656	7,070
1931				73	1,186	73,566	2,056	4,959
1932				59	1,770.2	112,521	1,309	3,781
1933				64	2,064.8	131,936	1,314	4,070
1934				68	2,495.4	159,958	1,600	4,420
1935				82	3,519.3	220,734	1,429	5,219
1936				73	2,964.3	183,205	930	-
1937	6/18/37			12[2]	836.4	26,908	251	-
Total				590	17,178	1,053,442	13,110	34,000
Hindenburg (LZ-129)								
1936	3/4/36			56	2,810.4	191,592	2,656	-
1937	5/6/37			7	277.6	15,102	403	-
Total				63	3,088	206,694	3,059	7,305

[1] Data from transmittals from officers of Luftschiffbau Zeppelin to officers of Goodyear Zeppelin and Reference 8.

[2] **Three round trips to South America; remainder apparently to Germany at a reduced speed prior to its being retired.**

Note: 1.0 Statute Mile = 1.609×10^3 m

TABLE 15 - (CONTINUED)

Airship	Freight carried (lb)	Mail carried (lb)	Average distance per flight (mi) statute	Average load factor (%)	Projected maximum utilization rate[2]	Average block time (hr)	Average block velocity (mph)	Maximum velocity of ship[3] (mph)	Passenger capacity	Number in crew (average)
Deutschland (LZ-7)	-	-	92.0	-	1482	2.9	31.7	35.7		
LZ-6	-	-	57.2	-	1340	1.9	29.4	34.5		
Ersta Deutschland (LZ-8)	-	-	67.5	-	1010	2.14	31.5	35.7		
Schwaben (LZ-10)	-	-	77.9	-	1222	2.20	35.4	47.0		
Viktoria-Luise (LZ-11)	-	-	69.0	-	1134	2.01	34.4	47.0		
Hansa (LZ-13)	-	-	69.2	-	1202	2.11	32.9	47.0		
Sachsen (LZ-17)	-	-	59.2	-	1159	1.77	33.5	44.7		
Bondensee (LZ-120)	6,600	11,000	313	100	2206	5.17	60.6	82.7	22	20
Graf Zeppelin (LZ-127)										
1928	-	-	1399	See Table 16	-	24.5	57.2	79.4	20	40.5
1929	-	-	1469		1375	23.5	62.5			
1930	-	-	660		1734	10.6	62.2			
1931	-	-	1008		1779	16.25	62.0			
1932	-	-	1907		2655	30.0	63.6			
1933	-	-	2062		3098,	32.3	63.9			
1934	-	-	2352		3743	36.7	64.1			
1935	17,982	13,200	2692		5279	42.9	62.7			
1936	11,770	15,017	2510		4446	40.6	61.8			
1937	-	-	2242			69.7	32.14			
Total	66,981	86,282	1785							
Hindenburg (LZ-129)										
1936	19,903	18,247	3421	94	4215	50.2	68.2	82.8	50	56
1937	1,565	1,265	2157	80	-	39.7	54.4		72	
Total	21,468	19,512	3281	93						

[1] Data from trasmittals from officers of Luftschiffbau Zeppelin to officers of Goodyear Zeppelin and Reference 8.

[2] Projected maximum utilization rate = $(365)\left(\frac{\text{number of hours flown per year}}{\text{days flown per year}}\right)$

[3] Still air

Seasonal Pleasure - The initial service operated by the Deutsche Luftschiffahrts-Aktien-Gesellschaft (Delag), which was a subsidiary of the Luftschiffbau Zeppelin (L-Z) Company, operated sightseeing and intercity trips during 1910. Available data from the 1910 service is given in Table 15, along with data pertinent to the entire German commercial service.

Figure 14 shows the utilization rate for the entire L-Z commercial history (1910 to 1937). The airship in the L-Z service was seasonal and within a season may have been periodic due to weather, especially from 1910 to 1914. If a modern commercial airship would not be subject to any significant schedule alteration as a result of seasonal effects (if it were, it never would

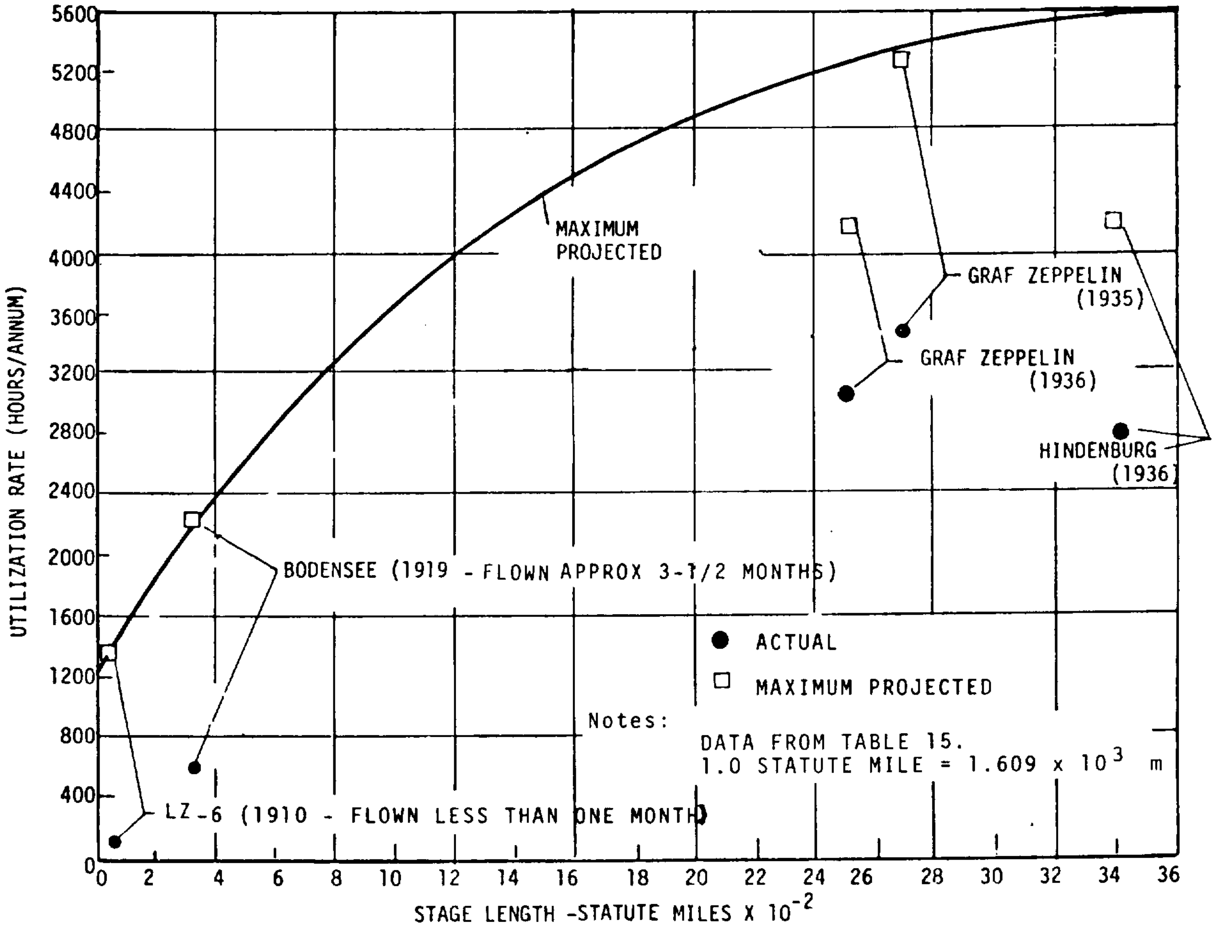


Figure 14 - Utilization Rate as a Function of Stage Length for German Commercial Service (1910 to 1937)

exist other than as a novelty), the demonstrated utilization can be modified by factoring out seasonal and periodic interruptions of the past rigids; this has been done in the cure labeled "projected maximum." The projected maximum utilization rate in hours per day is calculated as follows:

$$(365)\left(\frac{\text{number of actual hours flown in year}}{\text{number of days actually flown per year}}\right)$$

The value of this parameter is included in Table 15 for each airship of the commercial L-Z service.

The ratio of the average block velocity-to-airship maximum velocity ratio, plotted in Figure 15, also can be obtained from Table 15. This curve accounts for the effects of head wind, tail wind, weather avoidance maneuvers, and holding pattern for better landing conditions. The same ratio also has been presented for modern-day commercial passenger jets and passenger helicopters.

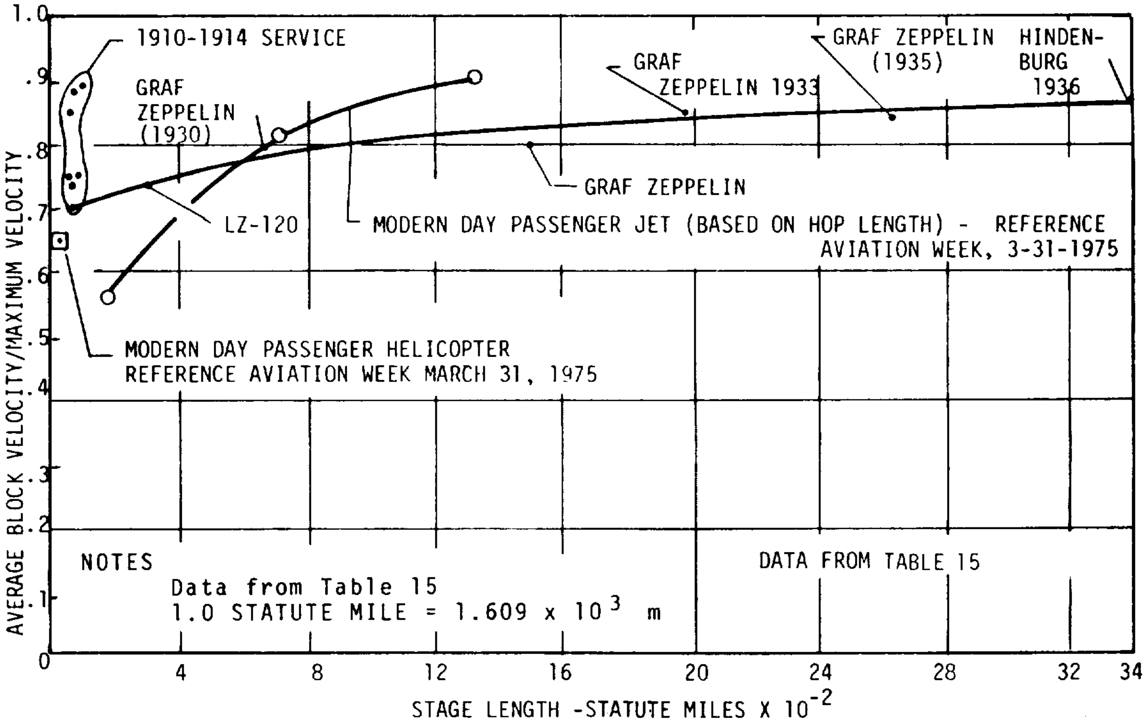


Figure 15 - Average Block Velocity Maximum Velocity Ratio

Similar sightseeing and intercity flights were conducted in 1911 with LZ-8 and LZ-10 airships. The LZ-11, LZ-13, and LZ-17 were operated until the outbreak of World War I, at which time the Delag ships were placed into military service. Reference 8 reports that the total operating costs between 22 June 1910 and 31 July 1914 for the Delag operations were 4,260,000 reich marks ($1,700,000 at an exchange rate of RM 1.00 = $0.40); this reportedly covered 47.7 percent of the expenditure, with the balance apparently more than covered by the German government. In return, the naval and other military crews were trained during the commercial flights, and the airships were required to meet certain limited military requirements.

<u>Scheduled Commercial Service (Germany)</u> - The commercial service was resumed after the war with the Bodensee (LZ-120), which flew between Friedrichshafen and Berlin from 24 August 1919 to 1 December 1919, with an intermediate stop at Munich during part of the service. The service reportedly operated at a loss despite a load factor of 100 percent on essentially all flights. * The service was extremely popular as evidenced by the load factor; accordingly, L-Z planned to introduce additional ships with flights beyond the German borders. The Bodensee was lengthened in December 1919 so that the passenger load could be increased from 22 to 30; undoubtedly, this was undertaken to resolve the reported loss situation. The Nordstern (LZ-121) was build between October and December of 1919 and had characteristics essentially identical to the lengthened Bodensee. With these two ships carrying 30 passengers each, it was intended to open an airship line in the spring of 1920 between Switzerland and Stockholm by way of Berlin and to Italy and Spain. The Inter-Allied command forbade further commercial operations, and the Bodensee was turned over to Italy and the Nordstern to France.

<u>Scheduled Commercial Service (South America)</u> - Commercial operations were resumed by L-Z in 1928 with the Graf Zeppelin. Table 16 summarizes readily available data on the Graf Zeppelin. Operations with the Graf were suspended shortly after the loss of the Hindenburg on 6 May 1937 since helium

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*The Bodensee (approximately 198,240 cu m (700,000 cu ft) was the largest airship that the Inter-Allied Command would permit Germany to build. This factor, coupled with the severe inflation of that time, no doubt contributed to and was possibly responsible for the reported loss.

TABLE 16 - DATA RELATIVE TO GRAF ZEPPELIN TRANSOCEANIC FLIGHTS AND PASSENGER LOAD FACTORS

I. TRANSOCEANIC CROSSING HISTORY

Year	So. Atlantic		No. Atlantic	Pacific	Total
	Pass.	Mail			
1928-9			5	1	6
1930	1		1		2
1931	6				6
1932	18				18
1933	17		1		18
1934	24				24
1935	32	* 6			38
1936	24		2		26
1937	6				6
TOTAL	128	6	9	1	144

*These 6 crossings represent regular scheduled mail crossings from Pernambuco to Africa and return without landing in Africa. The mail was dropped by parachute and taken aboard with a line. Three such round trips were made, yielding 6 crossings. Naturally no passengers were carried.

II. SOUTH AMERICAN SERVICE LOAD FACTORS (1932-1935)

Year	Crossings	Passengers	Pass/Flight	% Capacity
1932	18	185	10.3	51.5
1933	17	215 *212	12.6 12.5	63.0 62.5
1934	24	429 *401	17.9 16.7	89.5 83.5
1935	32	572 *568	17.9 17.7	89.5 89.0

*On a few flights during 1933, 1934, and 1935 all passenger accommodations were sold out and additional passengers were accomodated in the keel of the ship. The figures designated with * give the number of passengers after deducting the number of passengers carried in the keel. In all cases 100% capacity has been taken as 20.

Three round trips to South America were made in 1931 before establishing the service which was first scheduled in 1932.

In 1935, several mail flights were also made across the So. Atlantic, but as these flights were purely for mail carrying and no passengers were carried, they have not been entered here.

A crossing may be designated as a transoceanic flight, either Friedrichenafen to Pernambuco, Seville to Pernambuco, or the reverse.

was unavailable to Germany and the Hindenburg experience had made commercial airship operation without it difficult to promote. The LZ-130 (Graf Zeppelin II), which first flew on 14 September 1938, was intended to be a strictly commercial ship, but was never used in that capacity because an agreement for the United States to provide helium could not be reached.

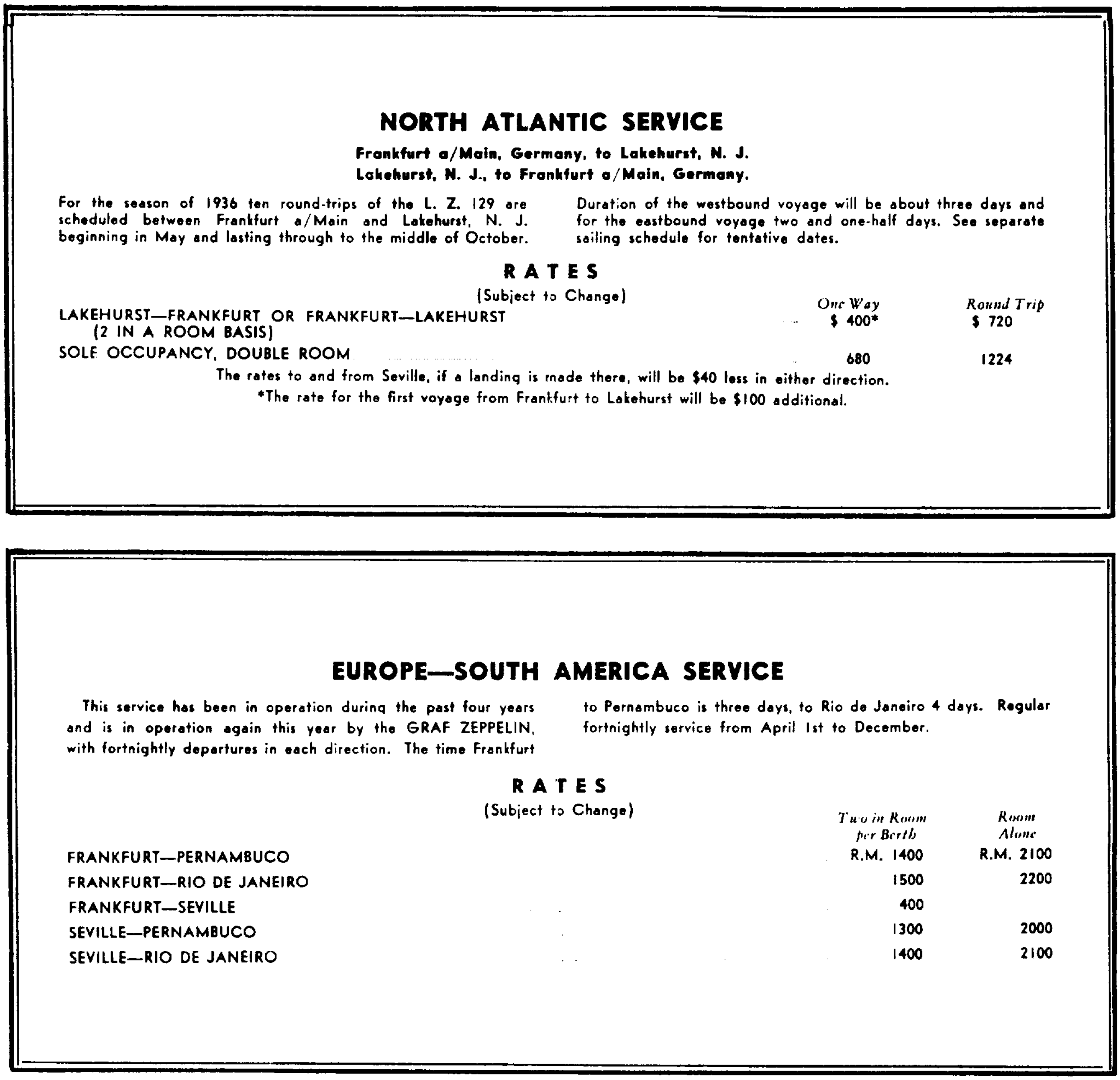
Among its accomplishments, the Graf Zeppelin traveled around the world in an elapsed time of 20 days, 4 hours, and 14 minutes. It covered 3.419×10^7 m (21,249 mi) in a flying time of 300 hours and 20 minutes, an average of nearly 31.74 m/s (71 mph). The four nonstop stages of the trip were as follows:

1. August 15 to 19, 1929 - Friedrichshafen to Tokyo, nonstop, 1.028×10^7 m (6386 mi) in 101 hours and 49 minutes, over Berlin, Stettin, Danzig, Estonia, Wologda (Russia), Yakutsk, and Siberia. A crew of 40 plus 20 passengers.
2. August 23 to August 26, 1929 - after refueling and gasing, Tokyo to Los Angeles, nonstop, 9.651×10^6 m (5998 mi) in 79 hours and 3 minutes. A crew of 41 plus 18 passengers.
3. August 27 to August 29, 1929 - Los Angeles to Lakehurst, nonstop, 4.821×10^6 m (2996 mi) in 51 hours and 57 minutes, via El Paso, Kansas City, Chicago, Detroit, and New York. A crew of 34 plus 16 passengers.
4. September 1 to 4, 1929 - Lakehurst to Friedrichshafen, last nonstop stage, 8.475×10^6 m (5267 mi) in 67 hours and 31 minutes, via Azores, Santander, and Bordeaux. A crew of 40 plus 22 passengers.

The engine was refueled at Tokyo, Los Angeles, and Lakehurst. Only plugs and several valves were changed on the entire trip. Passengers included noted men and women and journalists from various countries flying one or more or all stages. U. S. naval officers made the trip from Lakehurst.

The transoceanic crossing of the Graf Zeppelin for its entire period of service along with the load factors attained on the South Atlantic service from 1928 through 1935 are summarized in Table 16.

The fare schedule for the 1936 season is present in Figure 16. Reference 8 reports that the 1932 service required a total expenditure of $19,500 per



NORTH ATLANTIC SERVICE

Frankfurt a/Main, Germany, to Lakehurst, N. J.
Lakehurst, N. J., to Frankfurt a/Main, Germany.

For the season of 1936 ten round-trips of the L. Z. 129 are scheduled between Frankfurt a/Main and Lakehurst, N. J. beginning in May and lasting through to the middle of October. Duration of the westbound voyage will be about three days and for the eastbound voyage two and one-half days. See separate sailing schedule for tentative dates.

RATES

(Subject to Change)

	One Way	*Round Trip*
LAKEHURST—FRANKFURT OR FRANKFURT—LAKEHURST (2 IN A ROOM BASIS)	$ 400*	$ 720
SOLE OCCUPANCY, DOUBLE ROOM	680	1224

The rates to and from Seville, if a landing is made there, will be $40 less in either direction.

*The rate for the first voyage from Frankfurt to Lakehurst will be $100 additional.

EUROPE—SOUTH AMERICA SERVICE

This service has been in operation during the past four years and is in operation again this year by the GRAF ZEPPELIN, with fortnightly departures in each direction. The time Frankfurt to Pernambuco is three days, to Rio de Janeiro 4 days. Regular fortnightly service from April 1st to December.

RATES

(Subject to Change)

	Two in Room per Berth	*Room Alone*
FRANKFURT—PERNAMBUCO	R.M. 1400	R.M. 2100
FRANKFURT—RIO DE JANEIRO	1500	2200
FRANKFURT—SEVILLE	400	
SEVILLE—PERNAMBUCO	1300	2000
SEVILLE—RIO DE JANEIRO	1400	2100

Figure 16 - Fare Schedule for Graf Zeppelin and Hindenburg (1936$)

trip (1932$), which appears reasonable on the basis of the Hindenburg's 1936 per-trip expenses. Using the 1936 fare schedule (which does not appear significantly different from the 1932 rates) and the load factor information from Table 16, the passenger revenue (in 1932$) per trip in 1932 averaged $4820[*] (all passages round trip, Seville to Pernambuco and return, double occupancy). The maximum average revenue (in 1932$) would have been $9064 (all one-way passages, Frankfurt to Rio, single occupancy). Reference 8 reports the mail revenue (in 1932$) at $11,330 per trip for 1932.[**] Freight revenue was small as was the amount of freight carried per trip. From this, then, the minimum average revenue (in 1932$) per trip was $16,120 and the maximum average revenue (in 1932$) was $20,394. This would indicate that the first year's expenses were probably not covered by mail and passenger revenue.

Scheduled Commercial Service (North Atlantic) - The Hindenburg was used on the North Atlantic route due to the fact that its cruise speed was higher than the Graf Zepplin. Operating costs for the North Atlantic flights of the Hindenburg for 1936 are determined below from the performance data of Tables 17 and 18.[***] The operating costs of the Hindenburg during 1936 over the North Atlantic route are given below:

1. Total annual expense (1936$)

a.	Twelve and one-half percent amortization of ship ($2,300,000)	$287,500
b.	Twenty percent amortization of five engines (four on ship, one spare)	$ 60,000
c.	Overhaul, alterations, new parts, maintenance, and repairs (including amortization of tools and equipment)	$120,000

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[*] Reich mark = $0.40 (1932).

[**] The extent of a subsidy, if any, is not known.

[***] Data contained in this analysis transmitted in personnel correspondence of officers of Luftschiffbau Zeppelin to officers of Goodyear Zeppelin.

d.	Insurance		
	All risk on ship (five percent)	$130,000	
	Crew accident	$ 11,600	
	Third-party liability	$ 2,000	
	Engine breakdown	$ 5,600	
	Crew baggage	$ 250	$149,450
e.	Crew's wages (three flight watches and reserves)		$110,000
f.	Administrative, engineering, and selling overhead applicable to the airship		$ 45,000
	Total fixed charges (1936$)		$771,950

TABLE 17 - SUMMARY OF HINDENBURG'S 1936 NORTH ATLANTIC SERVICE (WESTWARD CROSSINGS)*

Flight No.	Date of Departure	Flight Time	Distance Nau.Miles	Passengers	Crew	Mail Kg	Freight Kg	Fuel Oil Kg	Lub.Oil Kg
1	May 6	61:40	3880	50	55	1059	134	50,350	4,000
2	May 16	78:50	3920	40	54	135	26	54,160	3,400
3	June 19	61:20	3692	43	54	156	58	50,600	3,015
4	June 30	52:49	3667	21	55	146	178	55,280	3,200
5	July 10	63:37	3679	50	53	123	105	54,000	3,582
6	Aug. 5	75:26	4372	50	57	195	385	55,500	2,659
7	Aug. 15	71:00	4132	58	58	170	165	52,100	3,100
8	Sept. 17	62:54	3616	72	59	112	61	51,100	3,850
9	Sept. 26	63:12	3729	44	57	190	16	51,600	3,810
10	Oct. 5	55:35	3620	56	60	79	29	50,000	3,800
Total		646:03	38307	484		2265	1057		
Average		64:36	3831	48.4	56	226.5	105.7		

*1.0 naut mi = 1.852×10^{3} m, 1.0 lbm = 4.536×10^{-1} kg

TABLE 18 - SUMMARY OF HINDENBURG'S 1936 NORTH ATLANTIC SERVICE (EASTWARD CROSSINGS) *

Flight No.	Date of Departure	Flight Time	Distance Nau.Miles	Passengers	Crew	Mail Kg	Freight Kg	Fuel Oil Kg	Lub.Oil Kg
1	May 11	49:13	3600	50	55	824	75	59,230	4,000
2	May 20	48:08	3560	57	54	185	1096	55,330	3,400
3	June 23	61:05	3504	57	54	207	106	55,800	2,800
4	July 3	45:39	3448	54	55	140	180	55,250	2,800
5	July 14	60:58	3918	57	53	156	68	46,200	3,552
6	Aug. 9	42:52	3633	54	57	140	650	50,250	3,840
7	Aug. 19	43:49	3532	57	58	140	136	50,000	3,435
8	Sept. 21	55:36	3628	48	59	128	55		
9	Sept. 30	58:02	3590	39	57	236	70	51,000	3,810
10	Oct. 9	52:17	3570	49	60	156	55		
Total		517:39	35983	522		2312	2391		
Average		51:45 hrs	3598	52.2	56	231.2	239.1		

*1.0 naut mi = 1.85×10^{3} m, 1 lbm = 4.536×10^{-1} kg

2. Total expense for North Atlantic flights (1936\$)
    a. From Table 15, the total distance flown in 1936 was 308,323 km; therefore, the fixed charge per mile for 1936 was \$771,950/(3.083×10^{8} meter), or \$0.0025 per meter.
    b. The total fixed charge for the North Atlantic flights (a distance of 1.38×10^{8} m) was

    (1.38×10^{8} m) (\$0.0025/m) = \$345,000

3. Total variable charges westbound (1936\$)

a.	223,532 cubic meters of hydrogen	\$ 14,960
b.	367,792 kg of diesel oil	\$ 10,136
c.	15,240 kg of lubricating oil	\$ 5,400
d.	Food for crew and passengers	\$ 13,200
e.	Ground crew at Frankfurt, ground transportation of payload, miscellaneous expenses and terminal fees	\$ 48,400
	Total	\$ 92,096

4.	Total variable charges eastbound (1936$)		
	a.	282, 463 cubic meters of hydrogen	$ 20, 850
	b.	399 cubic meters of diesel oil	$ 9, 495
	c.	14. 2 cubic meters of lubricating oil	$ 1, 875
	d.	Food for passengers and crew	$ 10, 000
	e.	Terminal fees paid to U. S. Navy for use of Lakehurst facilities, including bases of tank cars and freight for hydrogen shipments and alterations to equipment at NAS	$ 40, 810
	f.	Civilian ground crew costs	$ 1, 474
	g.	Administrative costs including office, traveling, insurance, publicity and other miscellaneous expenses at Lakehurst, and in New York during 1936; also, ground transportation of payloads	$ 20, 583
		Total	$105, 087
5.	Miscellaneous expenses (1936$)		
	a.	Passenger insurance	$ 4, 152
	b.	Flight pay for crew	$ 38, 640
	c.	Advertising	$ 5, 000
	d.	Expenses charged by passenger agents	$ 5, 000
		Total	$ 52, 792
6.	Total North Atlantic expenses (1936$)		
	a.	Fixed charges	$345, 000
	b.	Variable charges (westbound)	$ 92, 096
	c.	Variable charges (eastbound)	$105, 087
	d.	Miscellaneous charges	$ 52, 792
		Total	$594, 975

The total expense (in 1936$) on the North Atlantic route per one-way trip was $29, 749. In 1936, the passenger revenue was a minimum of $18, 108 (1936$) and a maximum of $34, 204 one way. Freight and mail revenues (principally mail) undoubtedly covered the total expense of $29, 749 (1936$), assuming that passenger revenue did not.

Table 19 summarizes the operating costs for the 1932 Graf Zeppelin and 1936 Hindenburg commercial service. Reference 17 indicates that the cost per available seat mile for the LZ-129, which apparently is based on not considering mail revenues[a], is $0.16; this is the same value obtained from the above data when mail revenues are neglected.

TABLE 19 - ZEPPELIN COMMERCIAL PASSENGER SERVICE OPERATING COSTS*

ITEM	1932 GRAF ZEPPELIN SOUTH AMERICAN SERVICE (1932$)		1936 HINDENBURG NORTH ATLANTIC SERVICE (1936$)	
	Discounting Mail & Freight Revenue	Accounting for Mail & Freight Revenue	Discounting Mail & Freight Revenue	Accounting for Mail & Freight Revenue (Est)
1. Block Speed** (MPH)	63.3	63.3	64.1	64.1
2. Stage Length** (Statute Miles)	5487	5487	3715	3715
3. Available seats	20	20	50	50
4. Total Operating Expense for Given Stage Length ($)	19,500	7,920	29,749	29,749
5. Cost/Average Seat Mile ($/Statute Mile)	0.18	0.07	0.16	0.10
6. Cost/Hour ($/Hr)	225	91.37	513	312
7. Cost/Mile ($/Statute Mile)	3.55	1.44	8.01	4.87

*1.0 mph = 4.470×10^{-1} m/s, 1.0 statute mile = 1.609×10^{3} m

**See Appendix C of Volume IV for added details on commercial service from which South American and North Atlantic block speeds and stage lengths have been determined.

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[a] Mail revenues were subsidized, the exact extent of which has not been established during this overview exercise.

It is impractical to determine by analyzing raw data what the cost per ton-mile of cargo for the Graf Zeppelin and Hindenburg would have been had they been cargo transporters rather than passenger ships. The detailed weight statements of the airships must be analyzed and passenger-related equipment, accommodations, and allowances removed. In addition, the impact of providing a cargo hold capability must be accounted for. The realization that passenger meals, entertainment, and stewards would not be required also must be considered in terms of reduced crew size and labor as well as resulting increases in payload. Additional costs also would be incurred in loading and unloading.

As to what the cost might have been per ton mile, an analysis by Goodyear in 1944 and 1945 that is based directly on the Hindenburg operating expenses indicates that a cost of $0.16 per ton-mile (1945 dollars) would have been reasonable for a 2.832×10^5 cu m (10,000,000 cu ft) helium ship.

Members of the International Zeppelin Transport Corporation (Reference 18) include Goodyear Zeppelin Corporation; G.M.-P. Murphy and Company; Lehman Brothers; United Aircraft and Transport Corporation; Aluminum Company of America; Carbide and Carbon Chemicals Corporation; and National City Company. On 24 March 1930, an agreement was signed by Dr. Hugo Eckener, president of Luftschiffbau Zeppelin, P. W. Litchfield, president of The Goodyear Tire & Rubber Company; J. C. Hunsaker, vice president of Goodyear Zeppelin; and J. P. Ripley, vice president of National City Company, to cooperatively pursue the study, development, establishment, and operation of a North Atlantic airship transport line.

During an October 1930 conference in Friedrichshafen between Mr. Hunsaker and Dr. Eckener, it was decided to halt construction of a 40-passenger 141,600 cu m (5,000,000 cu ft) hydrogen-filled airship (LZ-128) and redesign a larger airship, the LZ-129 (Hindenburg), that could be operated with helium. During this same conference, Dr. Eckener stated he favored diesel engines and later announced the new ship would definitely have diesel engines.

However, the Helium Act of 1925, which stated that helium could not be exported as a rare military asset, was expected to be relaxed but wasn't and accordingly the Hindenburg of necessity had to use hydrogen. After the Hindenburg loss in 1937 due to combustion of leaking hydrogen, the German government suspended further commercial operations until helium could be obtained.

Thus, LZ-128 (Graf Zeppelin) and LZ-130 (Graf Zeppelin II) were idled (LZ-130 was used by the military on a limited basis with hydrogen). Meanwhile, L-Z's plans for LZ-131 and LZ-132 continued to develop. It appeared at first that Congress would liberalize the Helium Act. Hitler's march into Austria in 1938, however, eliminated the possibility of the Germans receiving helium from America. The two remaining airships in Germany, the LZ-127 Graf Zeppelin and the LZ-130 Graf Zeppelin II, were taken over by the military and scrapped in order to use the aluminum in World War II aircraft.

As noted earlier, the metalclad is of interest in the context of a modern airship configuration. Rather in-depth economic analyses performed by the Detroit Aviation Company (Reference 7) are available for detailed consideration in Phase II; therefore, this subject is not discussed.

Manufacturing

Rigid Airships

Rigid airships were the first large aircraft. As a result, many problems encountered later in the manufacture of heavier-than-air (HTA) vehicles were first revealed during the German rigid airship program. Certain classes of the Zeppelin World War I airship approached production quantities. Enough were manufactured so that learning curve effects were identifiable. Near the end of the war, the Zeppelin Company was building 56,640 cu m (2,000,000 cu ft) rigid airships at a rate of one every six weeks.

Development times for past airships have depended upon a variety of interrelated considerations such as the current state of the art as related to the design objectives of the project, the particular expertise and experience of the agency designing the vehicle, and the size of the engineering and design team applied (which was often dependent upon national priorities). In general, programs like the Akron and the Hindenburg, which were first units of a given design, required three to four years prior to first flight. The Germans during World War I had reduced this time from two to six months. However, their new designs were somewhat an extension of prior proven vehicles.

Reference 8 points out that the Zeppelin World War I production experience would suggest an 80 percent learning curve as being applicable to large rigid airships. This value is somewhat typical of HTA manufacturing experience. It is also similar to the 83 percent factor applied by Goodyear in their 1944 - 1945 cost estimate of six 2.832 x 10^5 cu m (10,000,000 cu ft) commercial airships. This estimate reflected increased use of tooling and jigging than in the Zeppelin construction; accordingly, a slightly higher factor was applicable. Although, less learning takes place when increased mechanization is introduced, the average cost of a given lot size is reduced due to lower cost of the initial unit.

Table 20 gives a detailed breakdown of the actual hours and costs associated with the Akron and Macon rigid airship programs. Far greater than an 80 percent effect occurred between the Akron and Macon airships. However, this effect should not be regarded as typical because, at the time of the construction of the Akron, manufacturing expertise was not available in this country. Thus, the Akron was constructed on a less productive basis than would have occurred if the new design of the Akron had been the only variable for an experienced manufacturing team.

TABLE 20 - DETAILED BREAKDOWN OF ACTUAL AKRON AND MACON PROJECT HOURS AND DOLLARS (AS OF DATE INCURRED)

	HOURS		LABOR $		OVERHEAD $		MATERIAL		TOTAL $	
	AKRON	MACON	AKRON	MACON	AKRON	MACON	AKRON	MACON	AKRON	MACON
Fabrication	1,500,000	938,190	1,343,320	678,104	718,547	504,886	1,244,097	911,344	3,305,964	2,094,334
Design	408,000	119,740	482,231	146,757	235,331	35,311	19,845	17,775	737,407	199,843
Research & Tests	138,750	48,300	152,623	48,167	128,670	28,186	86,775	9,368	368,068	85,720
Inflation	6,940	4,855	5,213	3,039	6,361	2,265	2,072	8,943	13,646	14,247
Trial Flights	9,842	17,873	9,842	15,505	13,288	8,356	28,550	29,426	51,680	53,288
Unused Stores							-0-	26,290	-0-	26,290
Tools & Devices					254,190	136,262			254,190	136,262
Taxes					38,415	30,750			38,415	30,750
Equipment Depreciation					90,113	96,905			90,113	96,905
Insurance					60,060	41,668			60,060	41,668
Perf. Bond					2,687	1,225			2,687	1,225
Dock Depreciation					1,224,267	-0-			1,224,267	
Total	2,163,532	1,128,908	1,993,229	891,572	2,771,929	885,813	1,381,339	1,003,146	6,146,497	2,780,531
Admin. Exp.						129,970			148,433	129,970
Total Cost						1,015,783			6,294,930	2,910,501

Table 21 summarizes rigid airship manufacturing data.

Figure 17 shows the data of Table 21 relative to the direct construction man-hours per pound of empty weight as a function of gas volume (total). As noted in Table 21, all data are for the first unit of a new design. All commercial and many of the military airships fall near the suggested "historical averabe" value that has been included in the figure. The only noticeable departures would include: German Zeppelin LZ-38; German Zeppelins LZ-62, LZ-91, LZ-95, and LZ-100; and British R-100.

As to why this departure occurred, Reference 1 suggests that the LZ-38 type was the first airship sufficiently developed for war in terms of altitude, armament, and speed. Reference 1 also reports that the LZ-38 was very successful from the summer of 1915 to the spring of 1916.

The increase in man-hours per pound that the ever-increasing military requirements resulted in is clearly stated in Reference 1. In Reference 1, when referring to prior Zeppelins in comparison to LZ-62, the statement is made that "in this connection the main advantage of the former type (prior to LZ-62), namely the employment of a large number of similar cells and the rapid quantity production of the transverse frames or rings, was relinquished in favor of greater airship speed." Other military demands such as quieter exhaust systems, multimachine gun locations, more elaborate bomb releases, improved structural techniques (requiring more hand labor) to permit higher altitudes, and navigational improvements required to traverse greater distances all added to the man-hours or cost per pound.

The military airships of other nations never performed these "strategic missions"; accordingly, their construction man-hours per pound never approached the value of the elaborate German warships.

The 1944 Goodyear estimate for direct construction man-hours for the initial unit of its proposed 1944 design of a 2.832×10^5 cu m (10,000,000 cu ft) commercial airship agreed closely with the suggest historical average. The fabrication man-hours per pound for this airship were somewhat lower than the historical average; however, the estimate reflected added tooling and jigging with respect to that used in prior programs. Accordingly, a lower initial unit estimate and an 83 percent learning curve were used as opposed to the historical 80 percent curve.

TABLE 21 - SUMMARY OF RIGID AIRSHIP MANUFACTURING DATA[1]

Airship[2] Designation	Date of First Flight	Gas Volume (Cubic Feet)	Empty Weight (Pounds)	Development Time (Months)	Direct Design Manhours	Direct Construction Manhours[3] Total	Per Pound	Cost When Built [4]	Number Built	Use
LZ-1	7-2-00	400,000	21,200	25	13,500	86,250	4.54	DM 200,000	1	Experimental
LZ-6	8-25-09	530,000	26,000	7	-	150,700	5.80	DM 560,000	1	Commercial (DELAG)
LZ-7	6-19-10	680,000	32,200	9	-	176,000	5.47	DM 600,000	2	Commercial (DELAG)
LZ-14	10-7-12	790,000	34,800	6	-	143,000	4.11	DM 716,000	7	Military (Navy)
SL-2	2-28-14	883,000	43,000	12	-	148,500	3.45	DM 1,000,000	1	Military (Army)
LZ-38	4-3-15	1,128,000	43,800	8	-	385,000	8.79	DM 1,360,000	24	Military (Army)
LZ-59	12-21-15	1,262,000	47,300	2	-	281,600	5.95	DM 1,460,000	12	Military (Army)
LZ-62	5-28-16	1,940,000	68,800	10	-	1,100,000	15.98	DM 2,800,000	17	Military (Navy)
LZ-91	1-21-17	1,960,000	53,800	1	-	880,000	16.36	DM 3,264,000	2	Military (Navy)
LZ-95	5-22-17	1,970,000	48,200	4	-	1,161,600	24.10	DM 3,264,000	5	Military (Navy)
LZ-100	8-18-17	1,975,000	46,000	7	-	1,347,500	29.29	DM 3,264,000	10	Military (Navy)
SL-20	9-10-17	1,978,000	56,700	26	-	90,750	16.01	DM 2,000,000	3	Military (Navy)
Vickers No. 23	9-19-17	997,790	57,365	25	81,000	302,500	6.15	£ 125,000	4	Military (British)
LZ-126	8-27-24	2,600,000	86,400	25	-	-	-	DM 3,600,000	1	Military (Allies)
LZ-127	9-18-28	3,685,000	137,000	20	-	-	-	DM 6,000,000	1	Commercial (DZR)
ZRS-4 (Akron)	9-23-31	6,850,000	243,654	35	408,000	1,500,000	6.16	$ 6,294,930[5]	1	Military
LZ-129 (Hinden-burg)	3-4-36	7,060,000	249,000	53	-	1,500,00	6.02	$ 3,600,000	1	Commercial (DZR)
LZ-130 (Graf Zeppelin II)		7,000,000	240,224	-	-	1,200,000	5.00	-	1	

[1] Data from Reference 8 and Goodyear Files for Akron and Hindenburg

[2] Airship listed is first unit of a given design

[3] Reference 8 qualifies data as rough estimates and states subsequent unit of same type approximately follow an 80% Learning Curve.

[4] Cost are to first flight including contractor profit (costs are as of date incurred)

[5] Includes building dock depreciation of $1,224,267

Note: 1.0 lbm = 4.536×10^{-1} kg, 1.0 cu ft = 2.832×10^{-2} cu m

Table 21 compares data for the LZ-129 and LZ-130, which were essentially the same design. This table lends further credence to the 80 percent learning curve effect experienced with the World War I Zeppelin.

Thus, the historical average suggested in Figure 17 is a reasonable point of departure for Phase II in establishing future rigid airship acquisition costs. Readily available information relative to existing materials, existing propulsion systems, and existing avionics costs will provide realistic information for other facets of the acquisition cost estimate.

It is important to realize that, given today's technology in HTA and the historical foundation up through the 1940's in LTA, Goodyear envisions a modern rigid airship that would not require any state-of-the-art advances. Certain factors such as compliance with today's certification standards and substantial aerodynamics and structural verification testing must be considered. Certain costs typical of many new HTA programs are avoidable because of the off-the-shelf component philosophy, which seems realistically adaptable, and more importantly because in no area must the state-of-the-art be advanced.

Non-rigid Airships

Two periods of manufacturing activity illustrate the approximate fabrication costs of past military non-rigid airships: (1) the World War II years during which the K-type airships were built and (2) 1950 to 1960, during which the more elaborate ZSG-4, ZS2G-1, ZPG-2, and ZPG-3W were built.

Prototype airships (one each) were built of the ZSG-4, ZSG-1, and the ZPG-2 with follow-on production orders of 14, 17, and 15, respectively. Four ZPG-3W configurations were delivered. Table 22 summarizes pertinent cost data relative to these configurations. Based on the fabrication dollars* and empty weight data of Table 22, a cost per pound factor is given for both the prototype and production quantities. A learning curve factor also is given and was derived on the basis of the prototype cost, the average production cost per unit, and the number of units produced. The learning factors are higher (less learning is indicated) because material dollars are included in the cost-per-pound information. Material dollars vary little from unit to unit. All ZPG-3W units are considered prototype due to limited quantity manufactured.

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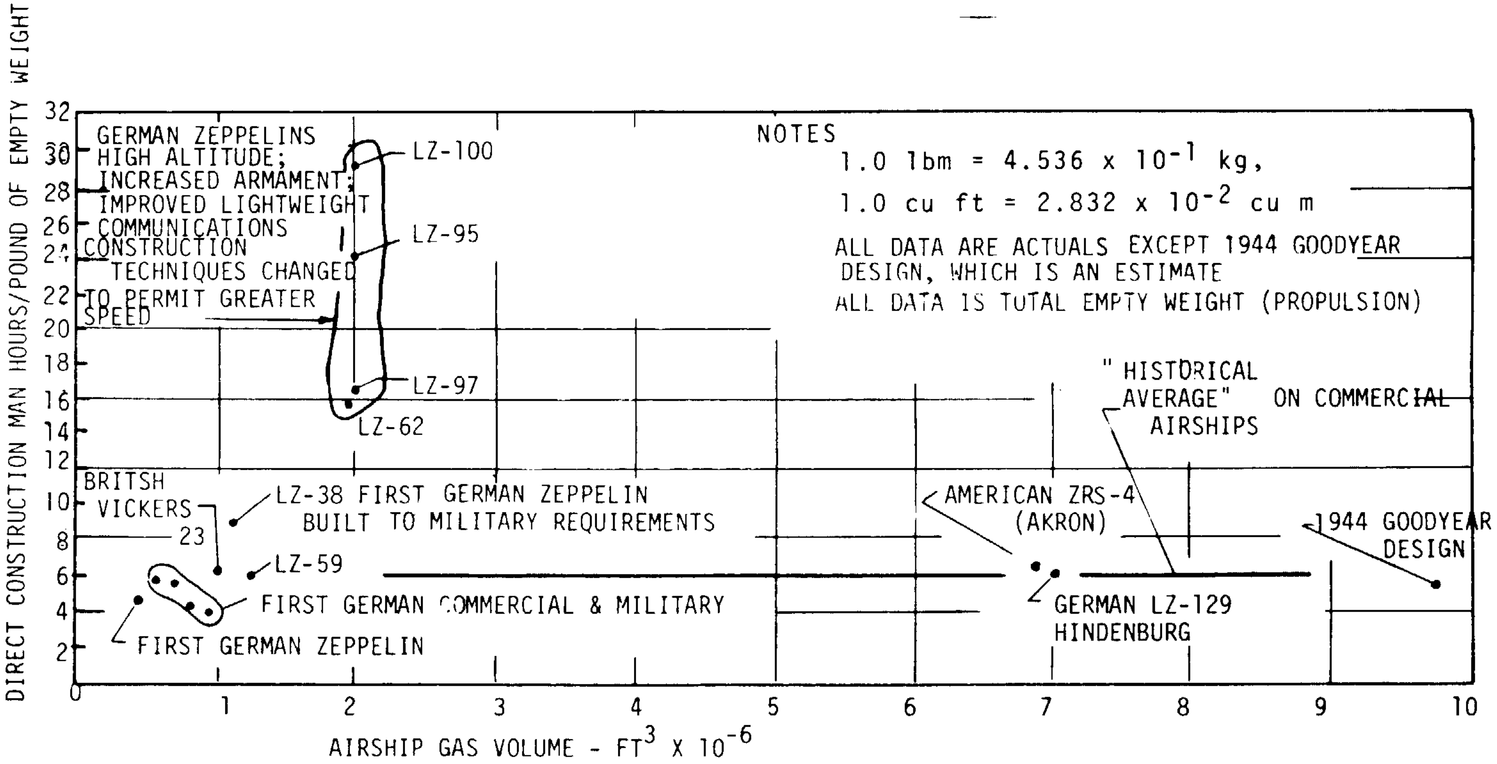
*Dollars are used for the non-rigid airships and hours are used for the rigid. Hours are used in the rigid to avoid the uncertainty of exchange rates, short term inflation effects, etc.



*INCLUDES PROPLUSION SYSTEM

Figure 17 - Direct Construction Man-Hours for Past Rigid Airships
(First Unit of New Design)

TABLE 22 - FABRICATION COSTS FOR NON-RIGID AIRSHIPS

I. PROTOTYPE					
A. Designation	XZSG-4	XZS2G-1	ZPG-1	ZPG-3W	
B. BUAER-GAC Contract No.	51-366	53-046	9861/229	56-383	
C. Quantity	1	1	1	4	
D. Delivery Date	8/27/54	4/22/55	6/16/52	9-24-59 4/4/60	
E. Envelope Volume (Ft^3)	527,000	650,000	875,000	1,500,000	
F. Empty Weight (lbs)	24,366	28,203	40,152	67,566	
G. Fabrication Dollars[2,4]	1,808,614	2,688,881	3,575,378	19,727,525	
H. Total Fabrication Dollars Per Pound	74.23	95.34	89.05	72.99	
II. PRODUCTION					
A. Designation	ZSG-4	ZS2G-1	ZPG-2	K Type Airships	
B. BUAER-GAC Contract No.	51-657	52-985 & 55-184	51-093, 52-984 & 55-169		
C. Quantity	14	17	15	42	85
D. Delivery Date	6/29/54 - 7/14/55	5/26/55 - 6/24/58	10/6/53 - 5/31/57	1942/1943	1943/1944
E. Envelope Volume (ft^3)	527,000	650,000	975,000	425,000	425,000
F. Empty Weight (lbs)	24,366	28,203	46,302	19,200	19,200
G. Fabrication Dollars[2,4]	13,641,063	21,177,451	42,096,551	-	-
H. Total Fabrication Dollars Per Pound (Avg)	39.99	44.17	60.61	17.28[3]	14.84[3]
I. Learning Curve Indicated	85%	83%	90%		

[1] All costs include materials; exclude engines and military electronics which were G.F.E.; excludes spares

[2] All inclusive cost as of date incurred

[3] Data from Reference 5 (other cost information from Goodyear Records)

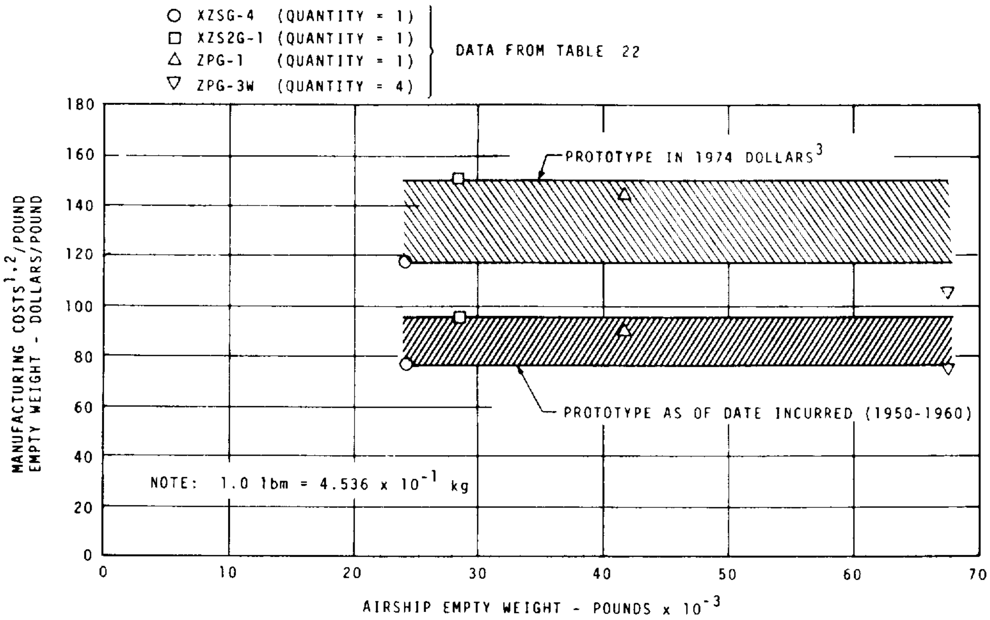
[4] Includes contract changes

Note: 1.0 cu ft = 2.832×10^{-2} cu m, 1.0 lbm = 4.536×10^{-1} kg

Figure 18 shows the prototype cost-per-pound data versus empty weight both at the incurred value as well as at the 1974 dollar level. Because four ZPG-3W's were built compared to one each of the other configurations, the ZPG-3W cost per pound is somewhat lower in terms of the 1974 common dollar basis. As a result, the cross-hatch in Figure 18 - which indicates a historical cost-per-pound range for a first-unit military prototype - excludes the ZPG-3W data point. Phase II must necessarily identify propulsion system, avionics, and electronics requirements based on specific mission requirements; costs for these items are additive. However, with that data and the data in Figure 19, acquisition of a military prototype should be reliably identifiable. A nonmilitary prototype would be considerably less than a military prototype, which is perhaps better indicated in Figure 19.

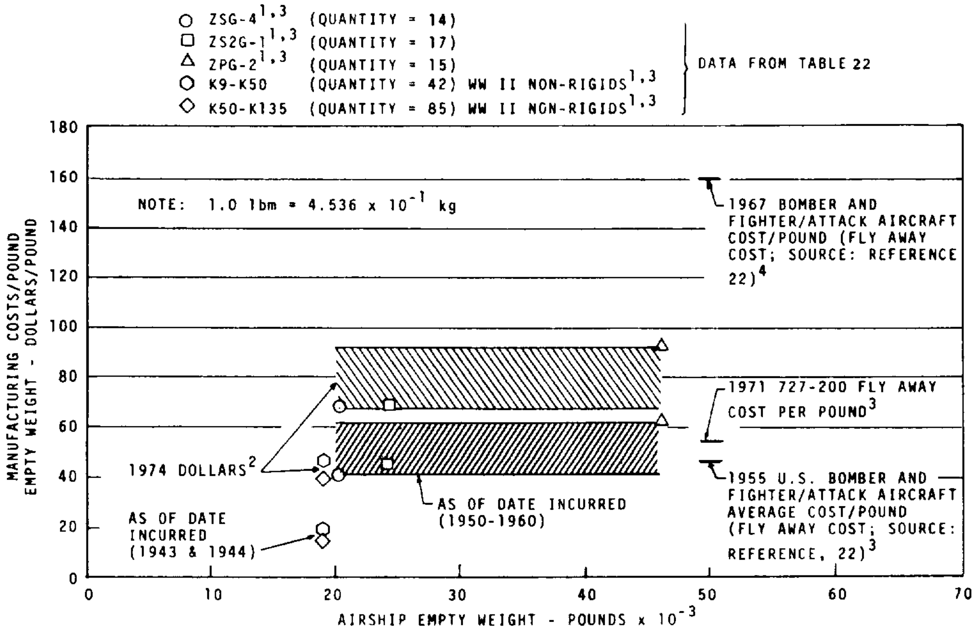
Figure 19 shows production costs for non-rigid military airships although there are differences in terms of the magnitude (and, as a result, in the techniques utilized) of airship production in comparison with HTA production. Figure 19 shows that:

1. There is a substantial difference between the World War II K-type configurations and the configurations following the war in terms of the common 1974 base due to increased military complexity as well as a quantity effect. This trend also is discernible in HTA military aircraft and is identifiable from the data presented for these vehicles. The military HTA cost-per-pound increase indicated from 1955 to 1967 is 350 percent, which converts to a real dollar-per-pound growth of 300 percent.
2. Mid-1950 military LTA and HTA costs per pound were on the same order as indicated in Figure 19, although the different comparison base suggests HTA vehicles exhibited a somewhat lower cost per pound.
3. Commercial HTA costs per pound are about one-third the cost per pound of the military HTA in terms of real dollars. This same trend will exist for LTA, with the extent of the factor a task to be performed in Phase II.



1. ENGINES AND MILITARY ELECTRONICS G.F.E.; MATERIALS INCLUDED
2. DOES NOT INCLUDE SPARES.
3. WHOLESALE PRICE INDEX USED TO ESCALATE. (SOURCE IS U.S. BUREAU OF LABOR STATISTICS.)

Figure 18 - Manufacturing Costs for Non-rigid Airships (Prototype)



1. ENGINES AND MILITARY ELECTRONICS G.F.E; MATERIALS INCLUDED
2. WHOLESALE PRICE INDEX USED TO ESCALATE. (SOURCE IS U.S. BUREAU OF LABOR STASTICS.)
3. DOES NOT INCLUDE SPARES.
4. DOES INCLUDE SPARES.

Figure 19 - Manufacturing Costs for Non-rigid Airships (Production)

The type of data presented in Figures 18 and 19 will be of significant assistance in establishing realistic acquisition costs in Phase II.

Table 23 summarizes engineering hour expenditures on the ZPG-1, ZSG-4, ZS2G-1, and ZPG-3W programs. This data is not analyzed in this report but should be a general guideline for Phase II.

Prior Goodyear Economic Studies (1944$)

Figure 5 shows that various rigid airship projects have continued at Goodyear Aerospace since the Akron and Macon era. In the mid-1940's, Goodyear Aerospace conducted an extensive design and economic study relative to six large airships 2.832×10^5 cu m (10,000,000 cu ft) in both a cargo and passenger transportation role. The following paragraphs describe the results of that study, which reflected use of the airship fleet in basically a sea-level capacity. The cost estimate was based on the actual cost of prior airships.

Commercial Passenger

Table 24 summarizes the total cost of the six airships. Thus the average total cost of one airship on the basis of six produced (over a 60 month period) is about $7.4 million (1944 dollars). In the analysis conducted at that time to determine the required passenger fares and cost per ton mile, the airships were conservatively assumed to cost $8 million. The following study was made to determine the passenger revenues required to support an airship passenger service:

Investment Required

One 2.832×10^5 cu m (10,000,000 cu ft) airship	$8,000,000
Helium inflation	120,000
Powerplants	75,000
Radio	100,000
Outbound terminal facilities	150,000
Total	$8,445,000

TABLE 23 - ENGINEERING HOURS BREAKDOWN

		ZPG-1		ZSG-4		ZS2G-1		ZPG-3W		Total	
		Hours	%	Hours	%	Hours	%	Hours	%	Hours	%
Design data and test											
Design	(D-2, D-5)	315,033		371,322		409,664		616,721			
Ground support	(F-7)							7,673			
Development	(D-8, F-5)	3,211				13,440		27,365			
Design services	(D-9, F-4)			1,657		3,603		28,249			
		318,244	37.7	372,979	50.4	426,707	44.0	680,008	43.6	1,797,938	43.7
Stress and weights	(D-6)	88,896	10.5	66,990	9.0	109,686	11.3	84,428	5.4	350,000	8.5
Aero and thermo	(D-7, F-3)	16,941	2.0	4,119	0.6	21,455	2.2	39,218	2.5	81,733	2.0
Static and mis test	(D-10, D-11, F-6)	78,999	9.4	16,542	2.2	55,223	5.7	141,695	9.1	292,459	7.1
Flight test	(D-12)	94,609	11.2	30,443	4.1	90,954	9.4	131,773	8.4	347,779	8.5
Final corr data	(D-13)	3,340	0.4			2,185	0.2	41,708	2.7	47,233	1.1
Detail spec and project eng	(D-1, D-4)	2,531	0.3	4,642	0.6	3,455	0.4	17,969	1.2	28,597	0.7
Mockup	(D-3)	31,315	3.7	43,461	5.9	31,798	3.3	29,642	1.9	136,216	3.3
Fabrication											
Design coordination	(F-1)	163,520	19.4	159,017	21.5	162,428	16.7	212,916	13.7	697,881	17.0
Stress and weights	(F-2)			9,044	1.2	22,893	2.4	60,025	3.8	91,962	2.2
Publications	(F-8)	45,343	5.4	32,140	4.3	43,993	4.4	118,473	7.6	239,949	5.8
Field service	(F-9)			1,054	0.2	10		2,000	0.1	3,064	0.1
Total engineering		843,738	100.0	740,431	100.0	970,787	100.0	559,855	100.0	4,114,811	100.0

TABLE 24 - COST OF SIX 10,000,000 - CU FT AIRSHIPS (1944$)

Item	Cost ($)
GAC engineering and design	5,561,058
GAC manufacturing	13,196,910
GAC tooling	3,528,142
GAC inspection	1,043,328
GAC overhead (labor only)	6,729,525
GAC overhead (building depreciation included)	10,213,229
Trial flights (labor only)	176,000
The Goodyear Tire & Rubber Company (including manufacture of outer cover and gas cells plus installations)	4,526,872
Administrative (1% of factory cost)	449,751
Total cost ($)	44,423,815
Average cost per unit ($)	7,403,969

Annual Fixed Cost

Depreciation, flight equipment (12-1/2%), and facilities	$1,055,630
Insurance on ship (5%)	422,250
Maintenance and repair	100,000
Interest on investment (2-1/2%)	211,130
Total	$1,789,010

Annual Operating Costs

	2500 mi*	3500 mi*
Salaries	$ 277,800	$ 277,800
Fuel and oil	239,618	189,600
All meals	91,728	67,392
Hangar ground crews, etc.	148,000	98,000
Helium purification	17,600	17,600
Compensation	4,139	4,139
Passenger and baggage liability insurance	53,543	18,207
Advertising, sales, administrative	200,000	200,000
Total	$1,042,426	$ 872,738

Recapitulation

	2500 mi*	3500 mi*
Total operating costs	$1,042,426	$ 872,738
Total fixed costs	1,789,010	1,789,010
8% profit on investment	675,600	675,600
Total cost	$3,507,036	$3,337,348

Thus, to produce sufficient revenue to permit meeting indicated costs and show an 8 percent profit (before taxes), the following fares can be charged on 192 one-way trips per year for a 4.023×10^6 m (2500 mi) flight and 92 one-way trips per year for a 5.632×10^6 m (3500 mi) flight:

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*1.0 statute mile = 1.609×10^3 m

Ship type	75% occupancy	Passengers per year (one way)	
		2500 mi*	3500 mi*
Deluxe	84	16,128	8,064
Pullman	174	33,408	16,704
Economy	216	41,472	20,736
Ship miles per year		480,000	336,000
Yearly utilization (hr)		6,000	4,2000
Direct operating cost per ship mile		$2.17	$2.60
Total all-inclusive operating cost per ship mile		$7.31	$9.93
Passenger miles per year			
Deluxe		40,320,000	28,224,000
Pullman		83,520,000	58,464,000
Economy		103,680,000	72,576,000

Direct operating cost per passenger mile is:

Ship type	2500 mi*	3500 mi*
Deluxe	0.0258	0.0309
Pullman	0.0125	0.0149
Economy	0.0101	0.0120

The total all-inclusive operating cost (including profit) brings the following one-way fares:

Ship type	2500 mi*	Per passenger mile	3500 mi*	Per passenger mile at 75% load factor
Deluxe	$217.45	$0.0879	$413.86	$0.1182
Pullman	104.98	0.0420	199.79	0.0571
Economy	84.56	0.0338	160.94	0.0460

The total all-inclusive operating costs appear to be in line with the Hindenburg costs presented earlier. Since the load factor was higher on the Hindenburg and Graf Zeppelin than in this analysis and since the

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*1.0 statute mile = 1.609×10^3 m for these two German airships were considerably higher, it appears that the economics of the passenger service were viable.

Commercial Cargo

A similar analysis was made in 1944 for the use of six airships as commercial cargo transporters:

Summary from Passenger Revenue Analysis

Total investment	$8,455,000
Annual fixed costs	$1,789,010

Annual Operating Costs

	2500 mi	3500 mi
Salaries	$180,000	$180,000
Fuel and oil	239,616	189,600
Crew meals	28,800	21,200
Hangar, ground crews, etc.	136,400	83,900
Helium purification	17,600	17,600
Compensation	4,139	4,139
Cargo, crew, insurance	61,030	61,030
Administration, sales, advertising	200,000	200,000
	$867,585	$739,969

Recapitulation

	2500 mi	3500 mi
Total operating cost	867,584	739,969
Total fixed costs	1,789,010	1,789,010
8% profit on investment	675,600	675,600
Total cost	$3,332,195	$3,228,579

Trips per year (one way)	192	96
Cargo (lb) per trip	180,000	155,000
Ship miles per year	480,000	336,000
Ton miles per year	43,200,000	26,040,000

	2500 mi	3500 mi
Direct operating cost/ship mile	$1.81	$2.27
Direct operating cost/ton mile	0.020	0.029
Total operating cost/ship mile	6.94	9.61
Total operating cost/ton mile	0.077	0.124

The analysis was then expanded and refined to cover various options then of interest. Ton-mile cost comparisons were made with other means of air cargo transport of the day (see Figure 20). This figure shows that the airship compared very favorably with other forms of air transport.

The types of comparisons in Figure 20 will be of interest in Phase II.

American Military Experience (1916 to 1961)

During World War I, America operated three airship bases in Britain and one in France. It is reported, however, that no American blimps were used. A limited number of submarines were reported off the U.S. Atlantic Coast and bombs were dropped. The primary purpose of the U.S.-built blimps during World War I was to train crews, with patrol a secondary role. Following World War I, the U.S. Navy's interest turned to the rigid airship, of which the Navy ultimately operated five*.

The operations assigned to rigid airships with the fleet did not develop the airship's most promising roles, that of strategic scouting or information seeking and airplane carrying. The Akron and Macon operated for about 1700 hours each and the Los Angeles for 2800 hours. The operational assignments of the

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*The Shenandoah, the British R-38, the Los Angeles, the Akron, and the Macon. Reference 17A gives a comprehensive history of rigid airship developments within the U.S. Navy.

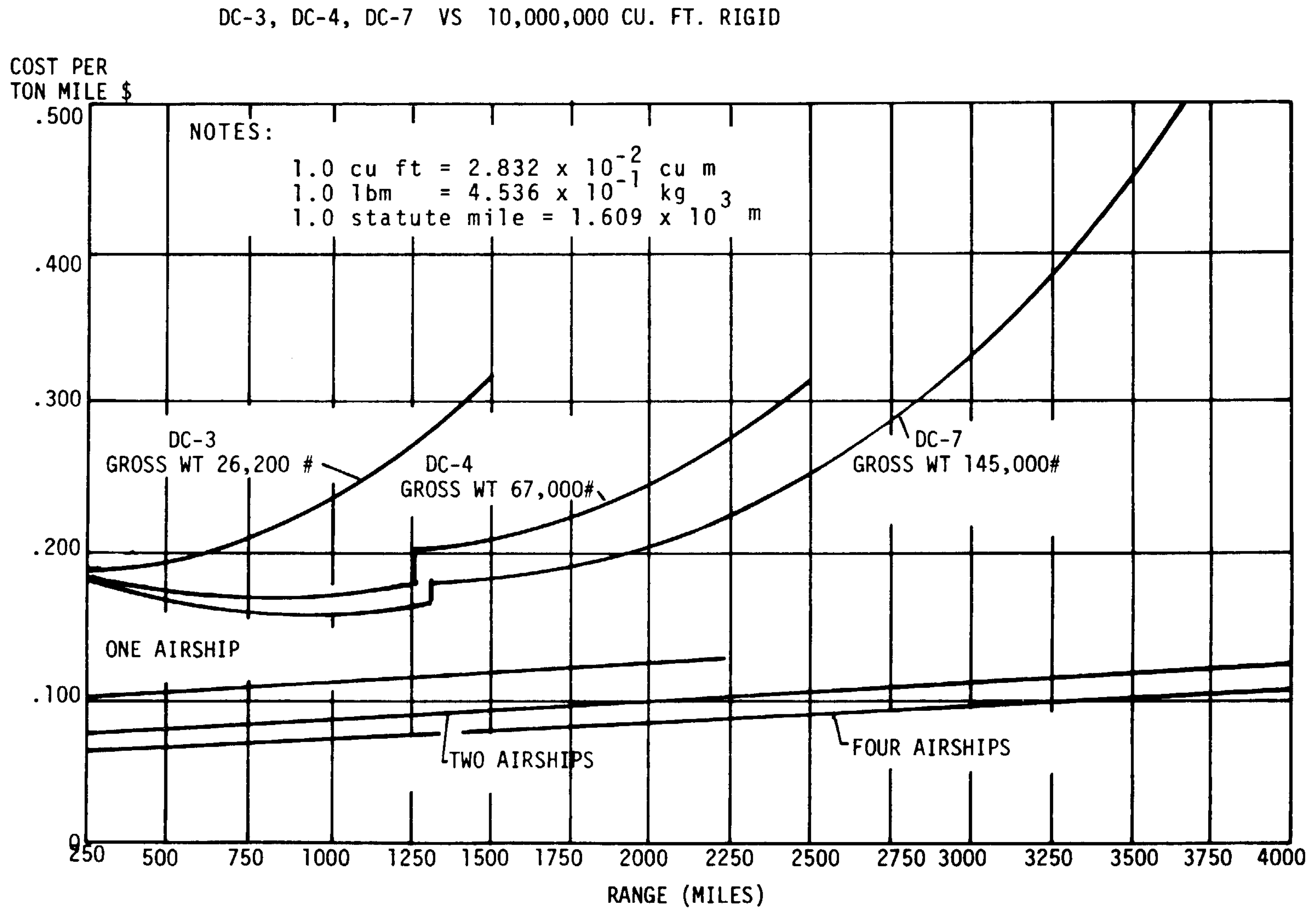


Figure 20 - 1944 Operating Cost Comparison for Various Forms of Air Transport

airships mainly were tactical, with the airships supporting surface vessels in simulated proximity to combatant areas.

The uses of rigid airships to carry airplanes in varying numbers were set down in a memorandum from Rear Adm. E. J. King, then Head of the Bureau of Aeronautics, to the Secretary of the Navy on 12 February 1940:

1. Scouting
    a. Search operations at long ranges
    b. Contact scouting (strategic)
    c. Observation
    d. Reconnaissance
2. General
    a. Neutral patrols
    b. Locating enemy commerce raiders
    c. Convoying merchant vessels
    d. Locating mines and submarines
    e. Bombing (by planes) under certain conditions
3. Miscellaneous
    a. Radio station calibration, as radio relay, direction finding, etc.
    b. As special communication station
    c. Transport of special personnel or supplies
    d. As "assisted takeoff" means for overloaded airplanes
    e. Flight research laboratory

At the time of Pearl Harbor, the U.S. Navy had 10 non-rigid airships, six of which were suited for service at sea. A Japanese submarine sank the S.S. Medio off the coast of California on 20 December 1941 and attacked oil derricks at Santa Barbara, Calif., on 23 February 1942. Ships ultimately were being sunk faster than they could be replaced. Based upon the success of World War I blimps, the Navy's blimp force was rapidly increased.

In the Atlantic and Gulf coastal waters of the United States and in the coastal waters of the Caribbean, eastern Central America, and Brazil, 532 vessels were sunk but none were sunk under escort of an airship.

In addition to an increase in airships from 10 at the time of Pearl Harbor to more than 165 at the close of the war, huge increases in personnel also occurred (from 130 in 1941 to more than 10,000 in 1944). Airship squadrons were stationed at Lakehurst, N.J.; Richmond, Fla.; Trinidad, B.W.I.; Recife, Brazil; Key West, Fla.; Moffett Field, Calif.; and Port Lyantey, French Morocco.

At the peak of operations, U.S.Navy airships patrolled about 2.787×10^5 sq m(3,000,000 sq mi) of the Atlantic, Pacific, and Mediterranean coasts. In all, airships escorted 89,000 ships while making 55,900 flights totaling 550,000 flight hours.

Only one airship was lost due to enemy action and only after its bombs failed to release while the airship was directly over the submarine. The blimp was hit by machine gun fire, with a resulting slow loss of helium causing the airship to float to the surface. All of the crew was rescued the next day except one.

The wartime uses of blimps, in addition to their major use in escort and antisubmarine patrol operations, are listed below.

1. Search operations

    Friendly submarines in reported areas

    Overdue or lost surface craft

    Crashed planes and survivors

    Survivors of torpedoed or wrecked vessels

    Crew of destroyed U-boat; located by blimp after 48-hour unsuccessful search by planes and surface craft

    Convicts escaping by boat from South American penal colony

    Fisherman at sea located and draft summons delivered him by blimp

    Escaped prisoners of war

Several boat loads of survivors from sunken German blockade runner that were rounded up and guarded until arrival of surface craft.

Uncharted sunken vessels

2. Observation

Oil and air leaks from new or overhauled U.S. submarines

Harbor antisubmarine nets and other items

Speed and other trials of naval vessels

Maneuvers of PTs, landing craft, minesweepers, and other types

Amphibious training operations for Army and Navy personnel

Rocket firing and shell bursts for BuOrd

Underwater explosion tests

Effectiveness of coastal and city blackouts

Inspection of damaged surface craft to determine salvage possibilities

Inspection of Brazilian jungles and military installations by Brazilian officials

Inspection of hurricane damage

Army tank maneuvers

Results of Army long-range gun firing tests

Operational training of fleet units

Inspection of naval stations and activities

3. Photography

Merchant vessels, for identification purposes

Men-of-war, for identification purposes

Submarine operations, for instruction purposes

Classified special projects for BuOrd and other departmental units

Airplane maneuvers

Speed and turning trials of surface craft

Surface craft maneuvers

Amphibious exercises, for training films

Flight maneuvers of new Army fighter plane

Prospective real estate acquisitions

Results of Army gunfire with new fire control equipment

Army gunnery exercises

Hurricane damage

Landfalls, for aviators' training

Inlets and channels, for Coast Guard

Landslides, for highway authorities

Disabled destroyer, for BuShips

Fall of shot in gunnery exercises

Enemy mine adrift off coast, for identification purposes

4. Mine operations

Spotting mines and mine fields, and plotting locations

Direction of and assistance to surface craft in mine sweeping activities

Destruction of surfaced mines by gunfire

Warning and diversion of surface sweepers standing into mine danger

Warning and diversion of unescorted surface craft from floating mine

5. Rescue operations

Rescue of plane-crash survivors from isolated island beach

Rescue of plane-crash survivors from the sea

Rescue of plane-crash survivors from Brazilian jungle

Rescue from isolated beach of survivors of torpedoed vessel

Rescue from desert of stranded rescue party plus removal of body of plane-crash victim

Coverage of carrier flight training exercises and location of and assistance to ditched aviators therefrom

Location and marking men overboard

Rescue patrol during joint Army-Navy Frontier defense exercises

Rescue patrol in areas of dense air activities

Search for and location of sunken merchantmen survivors known to be adrift

6. Assistance to vessels and persons

Location of disabled surface vessels and direction of salvage craft to them

Location of convoy stragglers or late-comers, and their direction to junction with convoy

Emergency diversion of surface craft from shoals

Guidance of surface craft through fog-bound harbor entrances

Guidance of buoy-tenders to uncharted wrecks

After survey of abandoned torpedoed merchantmen, blimp called for tow, directed crew to return aboard; merchantmen consequently saved

Coverage of cable ship while making cable repairs

Shipping control, convoy formation and dispersal, by carrying shipping controller and delivering oral or written orders at sea or off port

Prevention of inevitable collision of two convoys, still visually separated

Location of barges broken adrift and effecting their recovery by towing vessel

Delivery of written or oral orders to men-of-war and merchantmen at sea, during radio silence

Delivery to shore of messages received visually from merchantmen at sea

Delivery ashore of urgent message received visually from damaged merchantmen at sea requesting immediate docking upon arrival

Relay of message to have ambulance awaiting upon arrival of surface vessel in port

Landing on carrier at sea, picking up confidential matter and delivering it ashore

Location of favorable firing area for vessels conducting A.A. exercises

Effecting rendezvous between escort vessels and friendly submarines

Effecting junction of surface escorts and convoys in bad weather

Furnishing position to bewildered surface craft

Lowering of medical officer from airship to surface vessel to treat seriously ill crewman

Delivering confidential matter on deck of carrier at sea, for use by General Doolittle's air-raid on Tokyo

Towing disabled Army launch out of danger of going aground in neutral territory

Delivering gasoline to Army crash boat on a rescue mission

Delivering 50-gallon drums of gasoline to PBY stranded on beach

Delivery of food, water, medical supplies, etc. to survivors at sea

Emergency transportation of injured personnel to hospital

Location of crashed planes in isolated areas

Guidance of rescue parties to isolated survivors and crash scenes

Delivery of messages, food and water to salvage party on barren island

Scheduled delivery and pick-up of mail at isolated Coast Guard station in Caribbean

Delivery of medical supplies to remote Coast Guard station for treatment of badly burned personnel

Scheduled delivery of food and water to engineers working on emergency landing strip in Brazilian jungle

Delivery of urgently needed material and transport of personnel between stations in South America by BATS (Blimp Air Transport Service)

Coordinated communications for removal of sick seaman from a merchant tanker by Coast Guard plane

Delivered Army aerologist and equipment to isolated post

Coordinated salvage operations by surface craft in case of grounded transport

Escorted vessel that reported damaged, compass to Columbia River lightship

Sighted Army tug aground, lowered survival kit and stood by until rescue surface craft arrived

Sighting and reporting of surface craft in distress, standing by until arrival of surface aid and homing latter

Sighting and reporting of unmanned surface craft at sea, standing by until arrival of surface aid

Sighting of burning vessel at sea, summoning and homing surface aid

Guided rescue party to scene of plane crash and illuminated with blimp's landing light

Came upon tanker with disabled engines, summoned and directed salvage vessel to it

Hurricane damage to islands and coastline

Coastline for sites for amphibious training

Migratory birds for Department of the Interior

Fire damage in isolated areas

Radar and RDF calibration assistance, for both ships and shore stations

Weather observation and reporting in Caribbean (and other) areas

Reporting of fires in isolated areas

Location and reporting of schools of fish

Tracking and marking torpedoes for recovery, for submarines and shore units

Tracking and marking for recovery, torpedoes fired from torpedo planes

Located and directed salvage operations of floating bales of rubber from sunken German blockade runners

Sighting and reporting of floating obstacles dangerous to shipping

Salvage of $37,000 worth of equipment from crashed B-25s in Brazilian jungle, by repeated airship landings

Dropping of parachute troops and parachute riggers for live-jump training

Trailing banners for Red Cross drives

Training of HTA personnel in sonobuoy operations

Sighted floating boiler at sea - a menace to navigation - and sank it by gunfire

Reported malfunctioning of Block Island Sound marker light and illuminated it with blimp's spotlight for repair party

Subsequent to World War II, the Navy used the blimp primarily in an antisubmarine warfare and an aircraft early warning capacity. The Navy concluded its airship activities in 1961. Appendix B of Volume IV summarizes the Navy airships procured after World War II.

C 2

Airship Safety

Airships are safe for the following reasons:

1. They have a low landing speed (compared with HTA) which is particularly true of conventional LTA.
2. Multiple engines permit an essentially normal landing in the event of engine(s) failure(s). Neutrally buoyant airships were capable of landing without power under a variety of conditions.
3. Essentially all airships are provided with an emergency deballast capability (fuel and water recovered from products of combustion) in the event that loss of lift begins to occur. The ZPG-3W, which was capable of heavy takeoffs, could release sufficient ballast on an almost instantaneous basis (fuel in slip tanks, etc.) to bring the airship into a neutrally buoyant condition if the ability to sustain heavy flight was lost.
4. Rigid airships use gas compartmentalization (individual gas cells), which results in two safety related features:
   - a. Loss of lift, in all but the gravest of emergencies, is limited to the loss associated with one cell being deflated. A deballasting capability is provided to retain a neutral buoyancy condition during such an occurrence.
   - b. The airship structure is designed to accommodate the increase in the maximum static bending moment resulting in one gas cell being deflated, thus increasing the basic vehicle safety.

Non-rigid airships have typically used envelopes designed with large factors of safety since the gas historically has not been compartmentalized. Additionally, these envelopes are tested periodically to verify their continued integrity.

Non-rigid airships are typically designed with only a small positive pressure within the envelope in order, among other considerations, to minimize fabric stresses, thereby better ensuring structural integrity. The shape of the forward portion of the envelope is maintained during flight by radial stiffening members (battens) emanating from the nose of the ship (see Figure 2).

Although never accounted for in the design process, the ability of the non-rigid airship to momentarily deflect and relieve the load causing the deflection is an added safety feature inherent in the non-rigid design.

Another aspect of airship safety is it's ability to remain airborne without using large quantities of fuel during severe weather that may momentarily prevent landing. Weather avoidance both enroute and in terms of preflight planning has progressed enormously since the days of the last commercial airship service and would make airship operation much safer from the weather standpoint. While severe thunderstorms were purposely avoided in prior airship operations, airships flew through storm fronts by flying the breaks in the passing front. Weather as it affects airship operation is discussed subsequently.

Although never a problem with past airships due to the number flying and location of flights, collision avoidance now requires attention where airships are used at and around existing airports and conjested airways. Today's avionics and the continual advances being realized in this area are directly applicable to the design process for a modern airship vehicle (MAV). This fact alone minimizes the potential problem of collision avoidance with a MAV. Another factor favoring the MAV in this respect is its size, which would lead to early identification by nearby aircraft. In addition, the closing speed of an airship and nearby aircraft would be minimal by comparison with that of two commercial jetliners.

The suggestion of dedicated airspace that has been made relative to MAV use is perhaps a pessimistic generalization. If MAV's were used at the busy international airports in this country, the standard practices at these airports would have to be interrupted. However, the airship's potential is best realized when it is used at much less sophisticated facilities, thereby reducing door-to-door times. In this respect, the dedicated airspace is somewhat academic. In order to be most effective from a transportation standpoint, conventional airships would fly at low altitudes (nominally below 1524 m (5000 ft) above sea level).

Fire hazards in airships from the inflation gas would be non-existent today due to the use of helium.

Another feature available today is thrust vectoring, which can be accomplished by any of several means. Thrust vectoring enhances low speed control of the airship in terms of simplifying the approach, landing, and takeoff operations and also enhances the safety with which airship operations can be undertaken.

Realizing that many design-related safety features are available and would be incorporated into the design of a MAV, it is still essential to review the safety record of past airships in order to generate some part of a data base to support the contention that a MAV would be a safe vehicle by today's standards.

German Zeppelin Experience. - During the 1910 to 1914, the 1919, and the 1928 to 1937 commercial service, not one passenger was injured or killed except for the 13 passengers killed in the Hindenburg crash. Twenty-two crew members also were lost with the Hindenburg.

From 1910 to 1914, service was restricted primarily to fair weather as the rigid airship at that time had had a very short history. During that period, 37,000 passengers were carried on 1600 trips, or a total of 5.23×10^8 m (325,000 statute mi), without fatal accident to passengers or crew. The 1919 service flew nearly every day within Germany (flights to Stockholm were also made), thereby successfully encountering a variety of weather conditions as the war had resulted in a huge expansion of severe weather experience. The 1928 to 1937 period of service included intercontinental and transoceanic flights of both the Hindenburg and Graf Zeppelin under a variety of weather and climatic conditions. The only injury or death occurred aboard the Hindenburg, which would have been avoided had helium been available to the Zeppelin Company.

During World War I, not one zeppelin-type rigid airship was lost due to a structural failure in flight (Reference 15). Included in this statistic were 115 German Army and Navy airships flying approximately 26,000 hours, a distance of nearly 2×10^9 m (1,250,000 mi) during nearly 5000 flights (Reference 15). Such statistics, for flights necessarily undertaken under risky conditions, were a monumental testimony to the Zeppelin design and operational expertise.

Of the 115 zeppelin-type rigid airships utilized in World War I, the following summarizes their disposition:

Disposition	Number
Dismantled after successful career	21
Surrendered to Allied governments	10
Destroyed deliberately by own crews after Armistice	7
Shot down by enemy	36
Landed in neutral or enemy territory	7
Destroyed by enemy action in hangars	8
Destroyed by fire in hangar	5
Destroyed by handling while on ground	6
Destroyed while landing	12
Destroyed by fire in air	1
Destroyed due to defective gas cells	1
Destroyed due to defective ventilation	1

In summary, about 33 percent of the 115 ships were retired intact after successful careers; 44 percent were lost due to war and war-related incidents; 21 percent of the airships were lost due to inexperience; less than 2 percent were lost due to engineering inexperience (Reference 15).

This summary suggests that the zeppelin airship design was indeed structurally reliable. A significant number of airships were lost due to operating inexperience. These losses reportedly were due to the war effort, which reduced the time necessary to properly train pilots, flight crews, and ground crews. This statement appears to be amply verified by the very successful commercial service established by the German Zeppelin Company following the war (1919 and 1928 to 1937). During both periods, no losses occurred due to operational experience.

In summary, with respect to the zeppelin airship and airship operations, there is nothing inherent in the zeppelin design that would suggest airships are inherently unsafe or impossible to operate safely. On the contrary, the zeppelin ships and operations are the premier example of the safety record attainable with well-designed airships and properly trained personnel.

British losses included the loss of their first rigid, the Mayfly, due to a ground handling mistake (Reference 15). The R-33 and R-34 experienced good success, but the R-38 was lost on its fourth flight. Structural weakness developed on the first three flights, after which the ship was repaired and presumably strengthened. On the fourth flight, maneuvers with the rudders terminated in structural failure. The loss was ultimately concluded to have resulted from structural weakness brought about by the attempt to design the airship for a 25,000-ft ceiling (Reference 15).

Neither the British 100 or 101 were successful airships, with more than one source reporting mismanagement at various levels of these programs. The Durand Report (Reference 3) details certain aspects of the design that indicate technical problems seemingly not typical of well-disciplined programs. The Durand Report (Reference 3) details the loss of the R-101, which used stainless steel as the principal structural member, as being due to an attempt to further increase lift (after the ship had been lengthened to provide added lift following its first trial flights). The second attempt entailed a loosening of the gas cell wiring in order to attain an increase in gas volume, which permitted chafing and subsequent damage of the gas cells, with loss of the ship resulting. The R-101 was lost on the first flight after the wires were loosened.

It would appear that portions of the British experience alone would not lend credence to the theme that airships were safe vehicles. It further appears that the British losses, which were readily explainable, would have been avoided had proper expertise been available to them or perhaps had the expertise been better utilized that was available to them.

American losses relative to the rigid airship include the Shenandoah, which was lost in a severe thunderstorm over Ohio. During this storm, the airship literally broke in half, thereby indicating a weakness in the hull structure in the longitudinal directions. Substantial efforts were subsequently undertaken to determine a more appropriate longitudinal strength criteria for subsequent designs. Later airships, including the Graf Zeppelin, Akron, Macon, the British R-100 and 101,and the Hindenburg, incorporated much stronger hulls as a result of the investigative efforts following the loss of the Shenandoah. Extensive investigations were conducted following the loss of the Akron and Macon, which indicate further increases in hull strength of the Akron, Macon, and Hindenburg were desirable.

The Akron had a very successful 19-month career. It flew about 1700 hours prior to its loss in April 1933 in a thunderstorm over the Atlantic. The airship flew too close to the water for conditions that existed. When a violent down gust forced the airship toward the ocean, there was insufficient altitude to permit maneuvering. Appropriate instrumentation was aboard the airship to permit its altitude to be determined, but was not used. The Naval Court of Inquiry and a Congressional Committee of Inquiry made exhaustive investigations of the loss and came to the conclusion that the loss was due to faulty judgment. The airship was found to have been well-built and equipped. After its own investigation, the Joint Committee of Congress recommended "continuity in experience, training and transmission of knowledge", and stated that the experience of Dr. Eckener and other German navigators seems to show that airships can be developed to a point where the airship either may avoid or survive storms. It was concluded that there is no substitute for knowledge and experience.

The Macon was lost after a successful 22-month career. It flew about 1800 hours prior to its loss in February 1935. The Macon was lost due to a known structural weakness in the fin support structure. Recommendations to repair and materials, etc., necessary to effect the repair had been provided. At the time of the failure, three of the four fin supports had been strengthened; however, time did not permit the fourth fin support to be repaired and the airship was sent out to participate in fleet exercises. It was the unstrengthened fourth fin that failed while the airship passed through a gusty Pacific front.

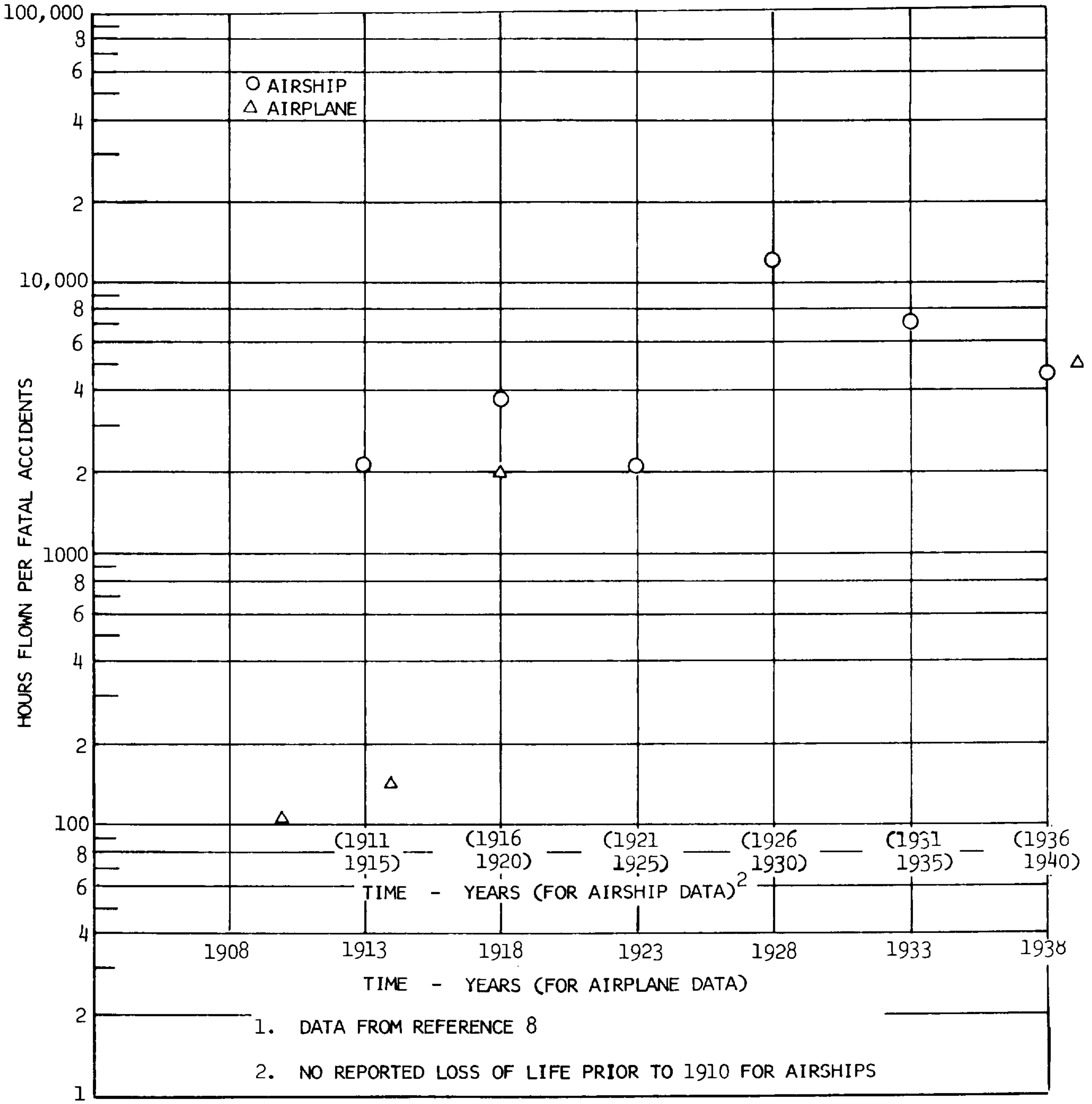
In 1936, the Durand Committee, which was appointed by Executive Order No. 6238 and contained such noted scientists as Theodor Von Karman and Stephen Timoshenko, concluded with respect to the general question of airship safety and future of the airship as an agency of transport.

1. All development of a new form of transport and more broadly all new developments are subject to possible hazards. This has been true in marked degree with the airplane, the heavier-than-air form of air transport. These hazards and casualties are a part of the price that must be paid for all such steps forward.
2. Study of the record of these casualties leads to the belief that, with the lessons that have been drawn from them, and with the general advance in our understanding of the technical problems of airship design, construction, and operation, the probability of a repetition of such casualties under like conditions should, for future construction, be reduced to a point which, if not vanishing entirely, may be considered as acceptable in comparison with the promise of useful service.

This committee also recommended that continuing investigations be made related to a large airship design.

With regard to comparative safety statistics with airplanes of a comparable era, Figure 21 has been prepared exemplifying the first of the Durand Committee findings. As is indicated in the figure, the airship operations were as favorable as, if not better than, airplanes in terms of hours between fatal accidents for a corresponding period in time. Airplanes have improved tremendously since 1939 so that major jet airline typical safety statistics indicate more than 1,000,000 hours between fatal accidents.

Given the tremendous improvement that nearly 40 years of technology has brought in airplane safety, realizing the outstanding safety record that the only real commercial airship operation actually had (even with the exclusive use of hydrogen), and considering the findings of the Durand Committee, it seems illogical to come to any conclusion other than the safety of an MAV can be assured.



1. DATA FROM REFERENCE 8

2. NO REPORTED LOSS OF LIFE PRIOR TO 1910 FOR AIRSHIPS

Figure 21 - Safety Statistics for Airships and Airplanes

In terms of non-rigid airship safety, the U.S. Navy's experience during World War II during which 55,900 operational flights were made and 550,000 flight hours recorded with only one airship lost due to enemy action and loss of one crewman essentially speaks for itself. The loss of one of the Navy's four ZPG-3W blimps in 1960, during which 18 lives were lost, was ultimately determined to have been the result of operational error.

During the entire period of Goodyear commercial (advertising) airship operations dating back to the middle 1920's, not a single passenger injury has occurred. During this nearly 50 years of operation, 750,000 passengers have been carried and a distance of nearly 1.13×10^{10} m (7,000,000 mi) flown.

CRITICAL DESIGN AND OPERATIONAL CHARACTERISTICS

General

Rigid airship design had progressed to a rather advanced level in the German Zeppelin Company by 1924. At that point, about 120 rigid airships had been systematically designed, built, and operated over a variety of atmospheric conditions without a single airship lost due to a storm. At that time Dr. Karl Arnstein, who as chief engineer of Luftschiffbau Zeppelin was fully responsible for the structure of Zeppelin airships LZ-38 through LZ-126 (the Los Angeles), left Germany and came to the Goodyear with 12 of his technical experts. Dr. Arnstein continued to serve as a consultant to both the German Government and the German Zeppelin Company on the Graf Zeppelin (LZ-127), the Hindenburg (LZ-129), and the Graf Zeppelin II (LZ-130).

This team, along with the invaluable help of Dr. Hugo Eckener of L-Z, regarded as the most knowledgeable expert relative to airship operations in the world, provided the Navy with the rigid airships Akron and Macon. Although the Akron was lost due to an operational error and the Macon due to a known structural weakness (for which hardware to remedy the weakness had been provided and partly installed), it was determined following these losses that additional research was advisable. These efforts* lead to greatly enhanced methods for determining the static and dynamic loads acting on the airship and how these loads collectively lead to the various stresses present within the airship. Improved designs of various structural members within the airship naturally followed. Since these developments are not generally known, it may be of interest to review them.

An engineering analysis of any structure requires first a breakdown of all the loads acting on the structure. Figure 22 shows the breakdown into the general classifications of static, aerodynamic, and other dynamic loads acting on the airship. The static load group consists of all dead weights, useful loads, and the lift of gas. The aerodynamic and dynamic loads either are caused by maneuvers involving changes in pressure distribution on the hull and empennage or by a gust. An airship often encounters gusts when a maneuver is being executed; accordingly, this condition must be assumed in the design.

The top illustration in Figure 22 indicates the combined aerodynamic loadings in straight flight, pitched flight, and passage through a gust. Points on Curves A, B, and C represent transverse forces resulting from pressures on the transverse sections integrated over the airships length. Lightly shaded areas represent negative pressures or suction, while the darker areas indicate positive pressures. Curve A results from straight flight; B results from the dynamic lift effect in pitched, heavy, or light flights; and C results from gusts. The second group of illustrations shows typical transverse sections with distributions of the aerodynamic loads at various stations. The curves are of a qualitative nature only.

In the third illustration, Curve A shows the total normal force distribution in pitched flight and gives the resultant of the components of all aerodynamic loads at stations along the ship's axis. Curve B shows the shear force load integrated from the normal forces, and C is the bending moment integrated from the shear curve. Curve D represents the maxima aerodynamic and dynamic bending moments due to maneuvers and gusts for which airship hulls would be stressed today. The dots are test values determined by an ingenious

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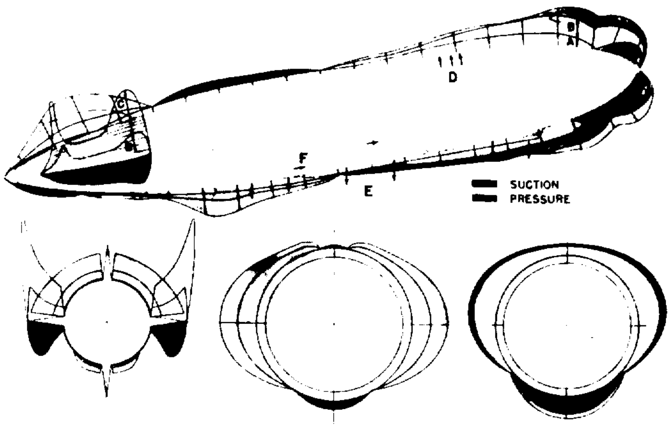
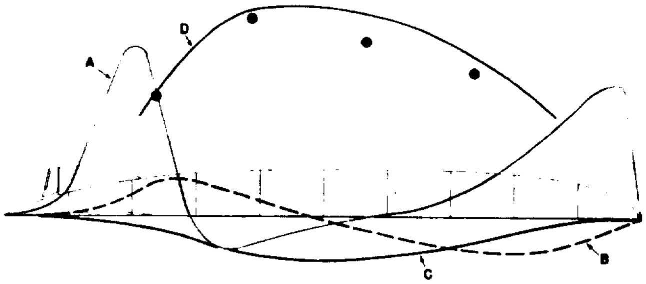
*Performed after Hindenburg was built.

A– AERODYNAMIC FORCES DUE TO STRAIGHT FLIGHT
B– AERODYNAMIC FORCES DUE TO PITCHED FLIGHT
C– AERODYNAMIC FORCES DUE TO GUST
D– AEROSTATIC LIFT
E– DEAD WEIGHT, USEFUL LOAD, AND INERTIA FORCES
F– POWERPLANT FORCES



AERODYNAMIC SHEAR FORCES AND BENDING MOMENTS

A– TYPICAL NORMAL FORCE DISTRIBUTION IN PITCHED FLIGHT
B– TYPICAL AERODYNAMIC SHEAR FORCES IN PITCHED FLIGHT
C– TYPICAL AERODYNAMIC BENDING MOMENTS IN PITCHED FLIGHT
D– BENDING MOMENTS FOR GUST AND MANEUVERS
● WATER MODEL TEST POINTS FOR GUST AND MANEUVERS



STATIC SHEAR FORCES AND BENDING MOMENTS

SHIP IN STATIC EQUILIBRIUM FULLY INFLATED AND FULLY LOADED

A– TYPICAL SHEAR FORCES
B– TYPICAL BENDING MOMENTS
C– TYPICAL BENDING MOMENTS DUE TO GAS PRESSURE GRADIENT

SHIP WITH A DEFLATED CELL

D– TYPICAL SHEAR FORCES
E– TYPICAL BENDING MOMENTS

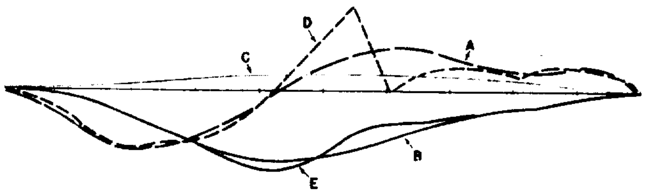


Figure 22 - General Distribution of Forces on Airship

investigation, financed by a special research grant that the Bureau of Aeronautics made to the Guggenheim Airship Institute. These tests are discussed subsequently.

The bottom illustration of Figure 22 shows shear and bending moment resulting from the analysis of the various static loads. In one condition, all gas cells of the ship are fully inflated; this is covered by Curves A, B, and C. A is the shear force curve, B is the bending moment curve, and C is an additional moment caused by the gas pressure gradient.

Another condition is the case of a deflated cell, indicated by Curves D and E, where the shear force curve instead of being smooth now has a sudden discontinuity. The loss of gas in a cell causes this disturbance in the shear force distribution and a slight increase in the maximum static bending moment, which must be accounted for.

The years of regular rigid airship flight operation furnished a fair estimate as to the magnitude of loads that must form a basis for design criteria. More coordinated information came from well-executed flight tests with proper instrumentation. For example, valuable flight load data were obtained by NACA from the Los Angeles. This method is limited in that aerodynamic disturbances cannot be controlled and a considerable number of tests under all conditions are necessary to reasonably extrapolate for the worst design conditions.

For this reason, wind tunnel tests under hypothetical or arbitrarily severe conditions (Fuhrman, Goettingen) that measured forces and moments were conducted, which formed an early (prior to the Akron and Macon) basis for the design criteria.

Gusts produce the most critical of all aerodynamic loads acting on an airship. It is unfortunate that the Shenandoah had to be lost to give birth to the basic theory for gust loads on the hull of airships. A gust theory was worked out by engineers of the Bureau of Aeronautics and of Goodyear. Also, an elaborate study of atmospheric gust structure was undertaken; these resulted in a vast increase in the knowledge of this all-important point.

At the time the Macon was designed, conditions upon which the fin loading was based were assumed to satisfactorily cover the gust conditions. However, during a flight over Texas, extremely turbulent air was encountered and damage occurred on some structural elements of the main frame supporting the forward part of the horizontal fins; this was the first actual flight indication that assumed loads on the forward part of the fins resulting from a combination of maneuvering and gust loads were not sufficiently high. All wind tunnel tests made in various laboratories in Germany and at CIT, MIT, and NACA in this country before the design specifications for the Akron and Macon were established did not indicate loadings sufficiently high to support the actual flight experience cited.

However, tests conducted subsequently on the large scale model of the Akron at NACA (1932 and 1937) gave a definite indication that larger loads might be concentrated in the region of the forward part of the fin.

It is also necessary to know what effective local angles of attack exist at the fins. Some information was obtained from measurements made during flights on various airships which indicated angles that were used when the specification for the Akron and Macon was written (10 to 12 degrees). It was not, however, until the first water channel test was made in 1940 that actual effective angles of attack from bow to stern were accurately determined.

These results indicate the maxima for an assumed ratio of ship speed to gust speed. The 10 to 12 degrees assumed as being satisfactory were confirmed for the forward half of the ship only. The angles at the stern were found to be as high as 15 degrees.

Certain test data from older flights and the 1932 NACA tests, appraised in the light of the Macon experience during the Texas flight, gave indications of the possibility of higher loading requirements. These indications had caused Goodyear to recommend reinforcements on the Macon, then still in service, and furnish material for installation in this particular region to meet a higher load based on this new information. It was very unfortunate for airships that this reinforcement was not completed before the Macon was maneuvered through a gusty front when it returned from a mission over the Pacific. Reinforcements had been carried out on all fin supports except that of the upper fin, where failure occurred.

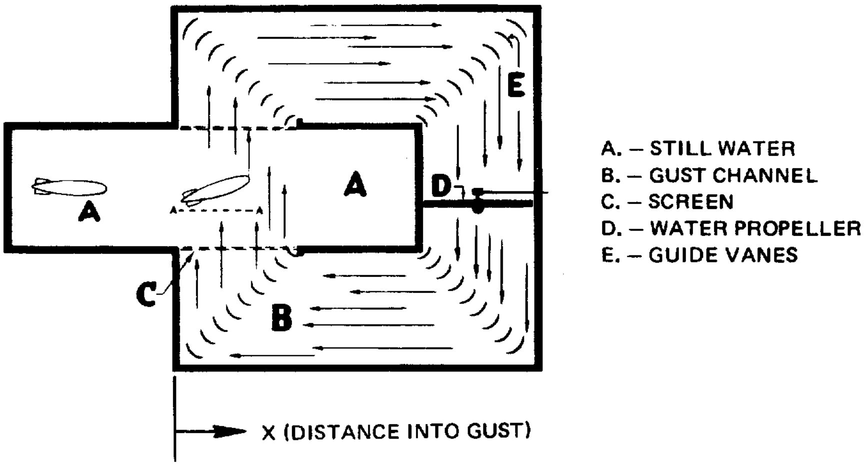
After the loss of the Macon, considerable energy was directed along the lines of fundamental research for reappraising all aerodynamic loading requirements. This work was conducted by the Guggenheim Airship Institute under a grant by the Bureau of Aeronautics and resulted in new types of model tests involving a whirling arm tunnel, with and without gusts, and a free-flight, self-propelled model in a water channel. These studies eventually resulted in a comprehensive understanding of the general aerodynamic loads acting on all parts of the airship. During the strenuous wartime activity of a large fleet of nonrigid airships, no fin structure failure occurred.

Figure 23 shows a schematic diagram of the Guggenheim water channel. The model, consisting of four articulated sections, was constructed of a magnesium alloy casting and weighted until it just floated under the water. It was started at the left end of channel "A" with a certain forward speed. Entering the cross channel, it was struck by the cross-flow representing the gust. The structure of this gust could be arbitrarily controlled so that it closely approximated any generally accepted type gust. The forces producing the bending moments measured by this apparatus were undeniably the closest representation of natural conditions that had been developed.

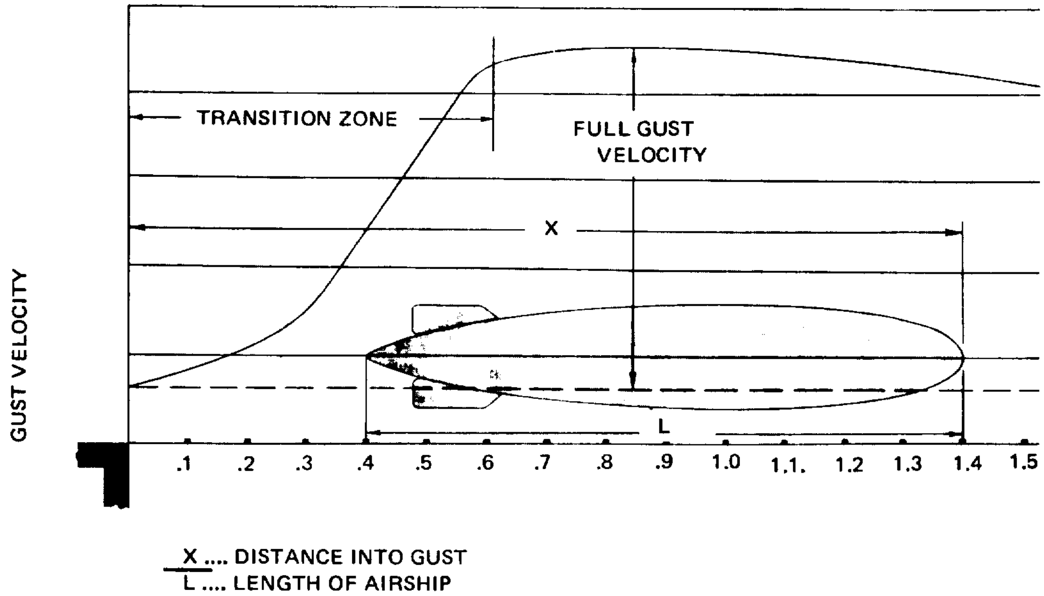
Once the loads on any structure are established, there remains the problem of determining their effect in terms of stresses and to design each member to efficiently carry these loads. In early rigid airships, methods for calculating stresses in the hull framework were taken from other fields of engineering, mostly civil, and applied with as much judgment as experience permitted, but many new and novel treatments were devised as the art grew.

At the time the Akron was designed, methods for treating generally applied forces were well established. The effect of local loads, however, still required simplifying assumptions, and these assumptions were checked by building and testing full-scale joints, segments, or sections of the actual structure. In 1933 and 1934, before the loss of the Macon, the need of a more precise treatment for determining the stresses in all basic parts of the airship framework was expressed at Goodyear and work was started along slightly different lines from that previously followed. Methods permitting a high degree of accuracy in the calculation of stresses in an airship hull were developed.

(A) A SUBMERGED FREE–FLOATING, SELF–PROPELLED MODEL IS STARTED IN STILL WATER AND TRAVELS THROUGH A REGION OF DISTURBANCE REPRESENTING A GUST. BENDING MOMENTS EXPERIENCED BY THE MODEL AND ITS ENTIRE MOTION IN SPACE ARE RECORDED.



(B) TYPE OF GUST IN CHANNEL RELATIVE TO SHIP'S SIZE.



REGION A–A

Figure 23 - Investigation of Gust Forces by Water Model Tests

The accuracy of theoretical methods for such calculations were proved by a novel method of stress model testing. Under the added stimulation of the Bureau of Aeronautics, Goodyear concentrated on stress model work and devised a new type of structural element.

After this girder type was developed, a complete airship model 3 ft in diameter and 18 ft long and correctly scaled in its principal characteristics was built. The model is shown in Figure 24 and is surrounded by a cage of steel rings. Loads representing a great variety of conditions that an airship experiences were applied to the model by means of tension or compression springs between the joints and the steel rings.

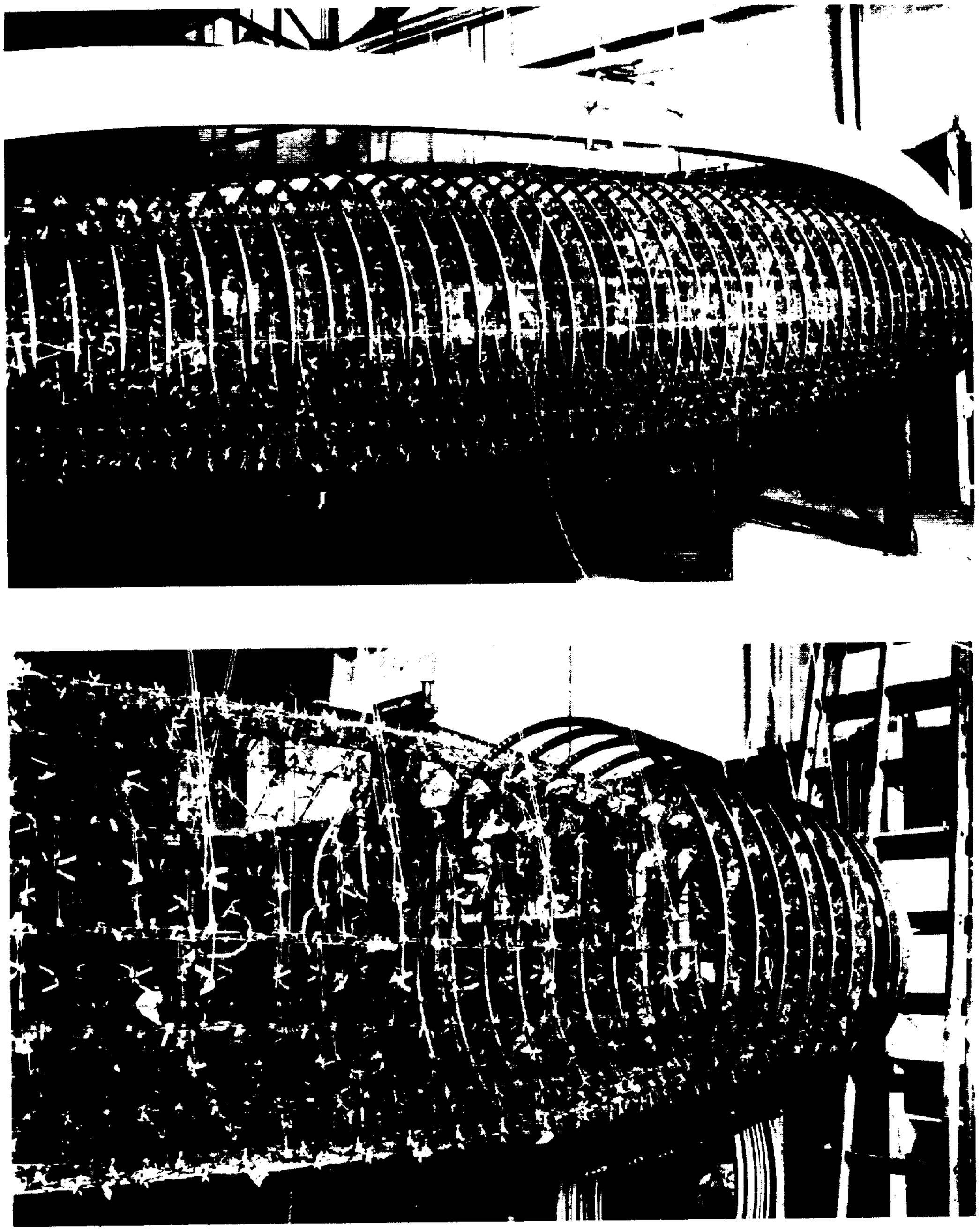
Close agreement was obtained between the new theory developed and test results from this model. This ended a long-drawn controversy between many international scientists on the question of whether an airship hull should be stressed following the bending or shear theory.

After this complete model was finished, the work was continued by building a stress model of a large bay in greater detail. This model was 10 ft in diameter. The effect of gas pressure loads was explored by inserting gas cells and applying internal pressure, and the effect of change in initial tension in the brace wires was studied.

Another fundamental problem that was answered by a bay model test was the question of stability or buckling strength of one bay. The test proved close agreement with a new theory which was developed for this particular problem. Figure 25 shows the close agreement between theory and stress model measurements in this case.

Extensive testing efforts were undertaken relative to structural member and structural joint fatigue problems with better design techniques resulting.

It is certainly essential, if realistic weight estimates for a modern airship are to be attained, that the impact of the results of these efforts be factored into the parametric weight equations along with more obvious considerations of today's material and propulsion capabilities.



THIS FIGURE SHOWS THE GENERAL STRUCTURAL MODEL OF A COMPLETE RIGID AIRSHIP HULL. THE STEEL RINGS FURNISH THE BASES FROM WHICH LOADS ARE APPLIED TO THE MODEL. THE MODEL WAS SUBJECTED TO NUMEROUS STATIC AND AERODYNAMIC LOADING CONDITIONS. EXTENSIVE READINGS OF STRESSES IN GIRDERS AND WIRES AND OF DEFORMATIONS WERE MADE.

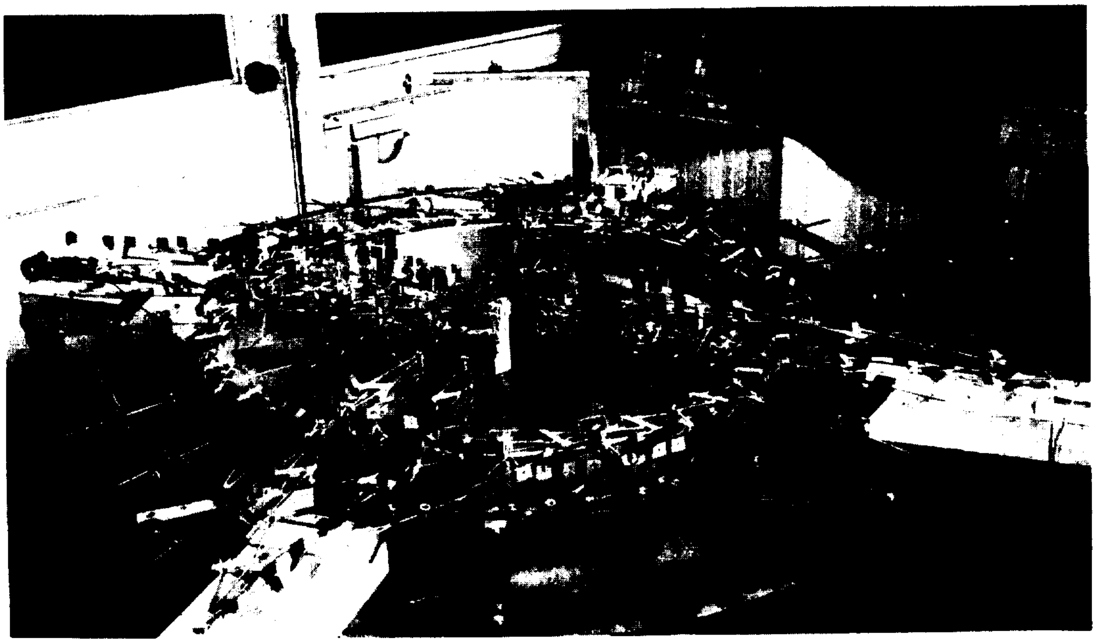
Figure 24 - Structural Model Tests

$$P_{CRITICAL} = -\frac{K_1}{K_2}\frac{1}{r}F_{mn} + M_x m^2 x^2 + M_s \frac{n^4 S^4}{m^2 X^2} + \left(N_x + N_s + 2M_{xs}\right) n^2 S^2 + pr\frac{1}{2} + \frac{n^2 S^2}{m^2 X^2} - \frac{1}{m^2 x^2 r^2}$$

TEST NUMBER	MODEL	INTERNAL PRESSURE	P_c TEST (#/IN CIRC)	P_c CALCULATED (#/IN CIRC)	% DIFFERENCE	N TEST ($m=1$)	N CALCULATED ($m=1$)
1	I	25 mm. H_2O	207	210	−1½	4	3.9
2	I	0	173	175	−1	4	3.7
3	II	25 mm. H_2O	204	206	−1	4	3.9
4	II	0	171	170	+½	4	3.6
5	III	25 mm. H_2O	196	188.6	+4	3.5	3.8
6	III	0	151	148.7	+1½	3.5	3.6

$\frac{K_1}{K_2}$ = UNITY FOR THIS PARTICULAR TYPE OF LOADING AND THIS GENERAL TYPE OF STRUCTURE.

(A) TEST DATA OBTAINED ON MASTER BAY MODEL WITH ANALYSIS



(B) STRUCTURAL MODEL OF AN EMPENNAGE MAIN FRAME. LOADS WERE APPLIED FROM THE HEAVY STEEL RING

Figure 25 - Comparison of Theoretical Calculations with Test Results

Maximum Bending Moment Criterion

Perhaps the most important and most elusive criterion to parametrically establish is the maximum aerodynamic bending moment resulting from gust loads. Historical criteria are extremely limited in terms of a representative fineness ratio range while promising analytical approaches are characteristically complex and time consuming. The following paragraphs briefly describe the historical criteria and discuss the rationale leading to the development of the maximum aerodynamic bending moment to be used in the current parametric study.

Prior to the mid-1940's, the maximum aerodynamic bending moments used in the analysis of nonrigid airship envelopes have been estimated from the expression

$$M = 0.018qV^{2/3} L$$

This criterion is uniquely related to similarities in mass distribution and geometry as well as to a specific gust velocity ratio. Since all nonrigids designed to this criterion closely satisfied the implied similarities and flew at approximately the same speeds, the limits of applicability were not violated. Furthermore, considering the corresponding long records of successful flight operation, the magnitude of the coefficient is not debated here. However, the indiscriminant application of this historical expression to new geometries and speeds that depart from its empirical base may well lead to erroneous conclusions.

In 1944, C. O. Burgess (Reference 18) evolved a criterion for the maximum bending moment experienced by a rigid airship encountering a discrete gust disturbance having an amplitude of 10.67 m/s (35 ft/sec):

$$M = 0.96 \rho v V L^{0.27}$$

This expression stemmed from interpretations of a series of related studies conducted by the Daniel Guggenheim Airship Institute. These studies included water channel, wind tunnel, and whirling arm tests on airship models and an atmospheric gust investigation. Results up to 1940 are summarized in Reference 18 with further detail provided in References 19 to 21.

The principal water channel test article was a small (1/150 scale) free-floating model of the Akron, which satisfied the dynamic similarity requirement about all three axes. The water gust channel is as described previously and is further detailed in Reference 23. Tests were conducted with five different types of fins at various rudder settings and movements, the latter while the bow of the ship was entering the gust. The gust profile was characterized by a gradient distance of one-half the ship's length (121.92 m, or 400 ft full scale) followed by an essentially steady region at the peak transverse velocity, u_o (this gradient distance of one-half the airship's length was selected as that which would produce the critical loading).

The commendable analysis of Reference 24, which introduced a full-cycle 1-cosine gust profile, tends to support the water channel results illustrated in Reference 24. Bending moments were measured at four stations along the airship's longitudinal axis during model runs made at velocity ratios (v/u_o) of 2.4, 2.6, 3.5, and 5.25.

The resulting envelope of maximum bending moment coefficients showed the peak occurring at approximately 0.40 L from the stern and a velocity ratio of approximately 3.5, with little change resulting from further increases in the incremental angle of attack, u/v. The lower (u/v) data point(s), however, indicated a substantially linear variation in maximum bending moment over the velocity ratio range of principal interest.

In deriving the maximum bending criterion, Burgess:

1. Accepts the maximum bending moment coefficient given by the water tunnel test for the Akron
   ($C_m = \frac{\text{moment}}{qV} = 0.095$ at $u/v = 1/3.5$)
2. Reasonably assumes a linear variation of C_m with u/v
3. Simulates the gust profile (indicated by the gust investigation) with an expression in which the gust velocity varies as the width of the transition zone (one-half ship's length) to the 0.27th power; $u = u_o = (L/L_o)^{0.27}$.

At this point, Burgess departs from nondimensional form and introduces a "standard" ship's length, L_o, of 243.84 m (800 ft) and a related "standard" gust velocity, u_o, of 10.67 m/s (35 ft/sec). In effect, he writes:

$$u = 0.198\ u_o\ (L/2)^{0.27}$$

Thus, the maximum effective gust velocity is made a function of the ship's length and is not fully developed for lengths under 243.84 m (800 ft).

Expressing the maximum bending moment coefficient as

$$M = C_m\ q\ V$$

where

$$C_m = \left(\frac{C_m}{u/v}\right)\left(\frac{u}{v}\right)$$

$$q = \frac{\rho v^2}{2}$$

$$V = \text{displacement volume}$$

Then

$$M = \left(\frac{C_m}{u/v}\right)(u)\ (\tfrac{\rho}{2})\ (v)\ (V)$$

in which

$$\frac{C_m}{u/v} = (0.095)\ (3.5)$$

$$u = 0.198\ u_o\ (L/2)^{0.27}$$

$$u_o = 10.67\ \text{m/s}\ (35\ \text{ft/sec})$$

Making the indicated substitutions,

$$M = 0.96\ \rho v\ V\ L^{0.27}$$

As evolved, this expression was considered generally confined to hull configurations dimensionally similar to the Akron and Macon.

Having deemed the applicability of historical bending moment criteria too limited for parametric usage and confronted with the problem of finding an early viable solution, the following assumptions were made:

1. Differences in maximum bending moment attributable to variances in configuration-to-configuration weight distributions will not alter the results to any significant degree.
2. Aerodynamic bending moments resulting from penetration of a discrete gust disturbance similar to that simulated in the water tank tests are reasonably indicative of critical loadings.
3. The peak bending moment coefficient obtained in the water tank tests is a firm anchor point about which to hinge the parametric estimates.

With the introduction of the foregoing assumptions, estimates of the relative change in bending moment coefficient due to changes in fineness ratio, f, from the reference point (f = 5.91) were considerably simplified. First, hull geometries were described at a fixed volume and varying fineness ratio by reasonably assuming similar nondimensional x-y coordinates at a constant prismatic coefficient. The related changes in transverse aerodynamic force distributions were then estimated using modified (viscous correction) slender body theory including an empirical adjustment based on limited experimental data for a fineness ratio forebody. The proportional change in the maximum bending moment coefficient thus resulting was then applied about the reference point to yield the variance shown in Figure 26. Several interesting but probably fortuitous aspects of Figure 26 were subsequently noted and are described below.

As fineness ratio is varied at constant volume and prismatic coefficient (as in the present study), it can be readily shown that

$$\frac{\left(V^{2/3}L\right)_2}{\left(V^{2/3}L\right)_1} = \left(\frac{f_2}{f_1}\right)^{2/3}$$

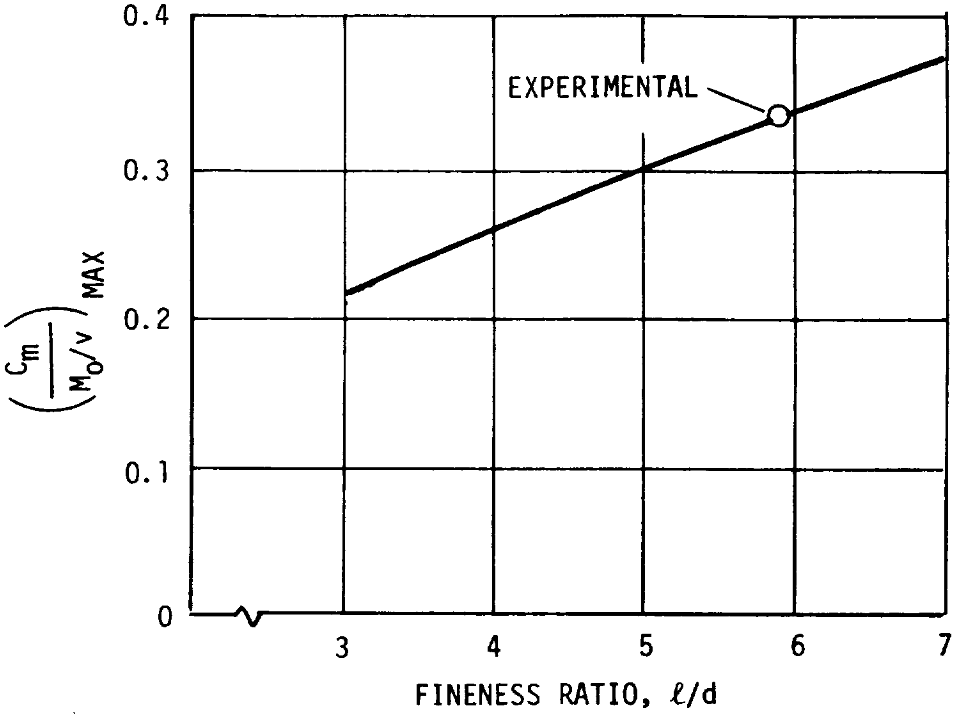


Figure 26 - Estimated Variation of Peak Bending Moment Coefficient with Fineness Ratio,

$C_m = M/q\ V$

which also closely approximates the actual rigid/non-rigid relationship as might be expected. Using this to convert the bending moment coefficients of Figure 26 from a volume to a $V^{2/3}$ L basis indicates that $\left(\frac{fm}{u/v}\right)_{max}$ so referenced is nearly a constant and equal to 0.0822 per radian. The latter compares closely to 0.0805 for a 4.5 to 1 fineness ratio for the semi-rigid airship.

Another relevant comparison is provided by translating the historical non-rigid criterion of $C_m = 0.018$ (based on $V^{2/3}$ L) to an equivalent gust velocity using the present preliminary result:

$$\frac{u}{v} = \frac{0.018}{0.0822} = 0.219$$

which for the 36 m/s (70-knot) class non-rigids equates to a design gust velocity of about 7.92 m/s (26 ft/sec) and indicates a comparative degree of optimism.

The relative longitudinal bending strengths of prior rigid airships are shown in Figure 27. where the recommended moment from the water channel results have been used to nondimensionalize the ordinate. Of these ships, only the Shenandoah was lost due to a longitudinal structural failure and this failure occurred in what was reported to be a very severe thunderstorm.

As can be seen from the figure, the Shenandoah is by far the most inadequate from the standpoint of the findings of the late 1930's and early 1940's. Realizing this and that the design represented by the parametric formulations for the structural weight of the conventional rigid is about 25 percent stronger in longitudinal bending than the strongest airship ever built (Akron and Macon), it is believed that the parametric design is structurally very adequate.

Prior to actually building a rigid MAV, extensive testing and analyses will be required to precisely define the aerodynamic loads associated with the particular vehicle shape and aerodynamic environment of interest. Recommendations relative to this and other technology needs as well as suggested approaches for meeting these needs are important aspects of Phase II.

Operational Aspects of Airships

Mooring and Ground Handling

From the early 1900's to the mid-1930's, much progress was realized in mooring and ground handling large rigid airships. The following paragraphs provide a very quick historical picture with respect to the evolution of mooring and ground handling techniques and equipment during these periods of time.

From 1900 to 1909, the rigid airships of the German Zeppelin Company were operated from Lake Constance (Bodensee). The airships were docked in floating hangars while they rested on floats themselves.* The airships were removed from the hanger while still on the floats under the motive power of small tug boats. The early airships ascended from and landed on the floats. After landing, the airship was replaced in the hangar again under the motive force of the tugs. Water landings and ascension were discontinued

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*Early German Zeppelins also were constructed in floating sheds.

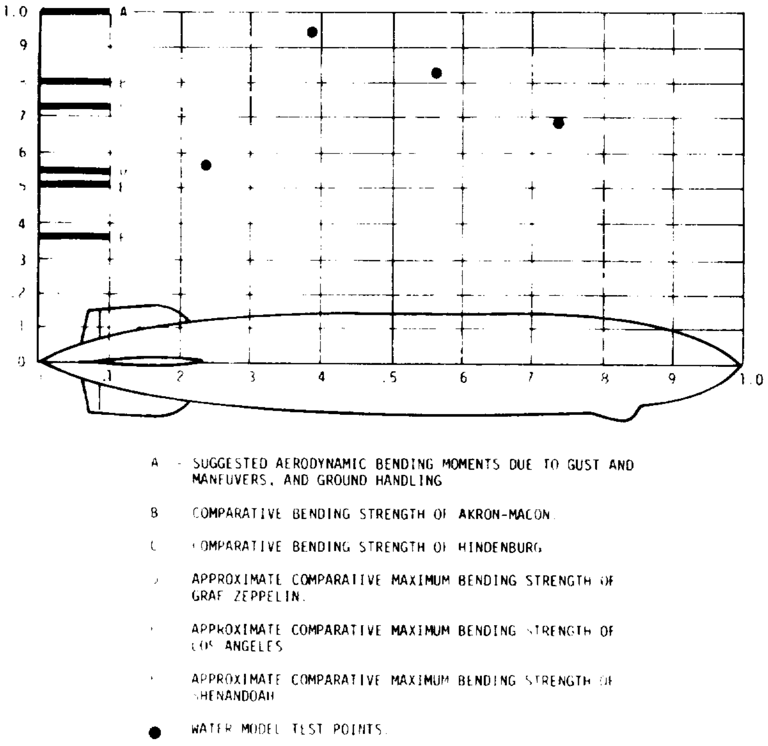

Figure 27 - Comparative Aerodynamic Bending Strength of Different Airships

on a regular basis in 1909; however, they have been accomplished periodically throughout the history of airship operations. This also includes some rather extensive and successful efforts with non-rigids.

From the end of water operations until early 1911, the airships were docked and undocked by manpower alone. In May 1911, however, one of the Delag commercial service ships (LZ-8) was carried away by a strong wind (cross hangar) from a ground crew of approximately 300 during an undocking maneuver. Following this incident, which was a severe blow to the newly founded service, Dr. Eckener developed a successful system of docking rails and trolleys. In general, the rail system (similar to a train) extended the length of the hangar and several hundred feet beyond so that the airship was well clear of the hangar when it ascended. After the airship cleared the hangar, the lines securing the airship to the trolley were loosened and manned by the ground crew; the airship then ascended. A similar procedure was followed when docking.

Very large ground crews were used by the Germans to handle the large zeppelin warships(600 to 700 men were not uncommon during severe weather). The zeppelin warships were never moored during the war (i. e, they were always placed in the hangar after a flight); one reason for this was a noticeable savings in weight when the mooring equipment was eliminated, as well as a general reduction in hull strength. Designing the hull to withstand mooring loads would have induced added weight, which would not have been conducive to attaining sufficient bombing altitude to avoid improving defenses.

Great Britain contributed significantly to developing a suitable technique for mooring large rigid airships during nonflight periods so the hangaring (docking) requirement after each flight could be avoided. The British developed and successfully used the high-mast mooring system. Later in 1919 when the British perfected the technique of actually flying to the mooring mast, they were able to moor their ships with a ground crew of approximately six men. Takeoffs from the high-mast were performed with even fewer ground crew members.

The U.S. Navy later used the high-mast mooring technique on its early rigid airships but later developed a preferrable low-mast technique. The principal disadvantages of the high mast were excessive cost, permanent installation, and a substantial portion of the crew had to remain aboard at all times since the airship had to be essentially flown while on the high mast.

In 1927, the Los Angeles was the first rigid to use a low mast for mooring. In addition to being much less expensive, the low mast permitted the airship to be unattended while moored when the airship was ballasted heavy. Initial low masts used by the Los Angeles were fixed, and a taxi wheel carriage was secured to the aft car; thus, the airship was able to weathervane, with ballasting preventing the airship from kiting in the wind. Less than a year later, a "ride-out" car was introduced that consisted basically of a railroad flatcar (free to move on a circular railroad track with a radius of about 134.11 m (440 ft) to which the aft car was secured. The rideout car incorporated rail clamps as well as ballasting provisions; thus, the airship was positively secured. Yaw cars were used on each side of the rideout car and on the same track as the rideout car. Lines from the airship to the yaw cars controlled the lateral motion of the airship during mooring. The airship nose was controlled by the main mooring line. All line lengths during mooring were controlled from winches at the mast, with the airship ultimately pulled to the mast under the action of these lines. Once at the mast and with the nose of the airship secured into the mast cup, the aft power car was secured to the rideout car.

The Navy made further improvements by developing a mobile low mast in 1929, which as a result of its telescoping nature could accommodate the Los Angeles as well as the larger Akron and Macon soon to be available. The Los Angeles made both flying moors and takeoffs from the mobile mast. In addition, the Los Angeles also was docked in the Lakehurst hangar by a mobile mast towed by a tractor-type vehicle. This operation required about 60 men, whereas 400 to 500 men were required in moderate winds on each side of the airship just a few years earlier.

Further advances in ground handling equipment were associated with the Akron and Macon projects. Mobile railroad masts were used, the rideout and yaw cars (as in the Los Angeles) were used on a necessarily larger circle, and a stern beam was added (which operated on the same railroad track as the mobile mast) to control the tails during docking and undocking. In general, the handling of these large ships was quite mechanized with the dangers to the airship and ground crew that had existed a few years earlier greatly minimized if not essentially eliminated.

Very significant improvements were realized by the Navy in handling airships subsequent to the mid-1930's. These improvements related to the nonrigid airship. However, the equipment and experience gained by the Navy that culminated in its handling and mooring techniques for the ZPG-3W airships, which were over 134.11 m (400 ft) in length, are very applicable to much larger rigids. The most significant Navy development in this respect were ground handling mules and mobile masts. The gound handling mules were highly maneuverable tractors with a constant-tension winch capable of accepting handling line loads from any direction. Landing and mooring of the ZPG-3W required about 18 to 20 in the ground crew, whereas the early German rigids of a similar size often used crews in excess of 400. Docking and undocking were performed with 11 to 12 men; takeoff required approximately the same number.

What mooring and ground handling techniques might be used in conjunction with an MAV are discussed in the last subsection of this overview. References 25 and 26 give comprehensive details relative to ground handling and mooring of rigid airships and Reference 27 relative to non-rigid airships.

Weather

General - No vehicle is truly an all-weather vehicle in that it can effectively perform its assigned mission in any weather condition except possibly a submarine, which can operate below weather effects. However, many vehicles can survive severe weather conditions and resume operations after the weather has passed. In terms of the severity of weather in which the airship can actually operate, the mid-1950 demonstrations by the Navy and their conclusions are certainly of interest.

In 1954, the Office of Naval Research assigned to the Naval Air Development Unit at South Weymouth, Mass., a project to demonstrate the all-weather capability of the airship. Technical guidance and instrumentation were furnished by the National Advisory Committee for Aeronautics. During the first two years, nine flights were made in weather conducive to icing, snow, and other winter weather conditions.

On the last two flights, ice accumulation was recorded. One flight ascended and descended through a freezing rain and accumulated an estimated 1361 kg (3000 lb) of clear ice. At no time was the control or flight characteristics of the airship changed, other than the static heaviness, and the crew became psychologically adapted to flying in icing conditions. The airship was a Model ZPG-2, with an envelope volume of 27,612 cu m (975,000 cu ft), a length of 104.55 m (343 ft), and a maximum diameter of 22.68 m (75.4 ft).

As a result of this project, several minor modifications were made in the airship used for the experiment, such as adding heading tapes to various valves and drains, heat for the pitot head, protective coating for the upper surfaces of the lower fins (an X arrangement), flush antennas, electrically heated propellers, and ruddevator horn pulley covers.

The third year's operations consisted of three phases, as follows:

Phase I - a weekly flight of approximately 30 hours when the worst weather was predicted

Phase II - a joint operation with a squadron from Lakehurst, N. J., to man a specific station for 10 days during January when the worst winter weather might be expected

Phase III - a long simulated barrier flight from South Weymouth over the North Atlantic to another base along the eastern seaboard

During Phase I, seven flights were made, during which icing conditions were encounted on two occasions.

Phase II was scheduled from January 14 to 25, and the worst East Coast weather in many years was experienced; icing, fog, sleet, snow, rain, and gale winds were encountered. The station was manned continuously for 240 hours using five airships. Eleven flights were made. The "icing" ship accounted for five of the flights and on one flight spent 30 hours in icing conditions. Even though field conditions at South Weymouth were rigorous, the operations were conducted off a mobile mast; the airship was hangared only once for a regular maintenance check.

Phase III began on schedule on March 15. After successfully completing the assigned mission of a 60-hour patrol across the North Atlantic, the airship continued to circumnavigate the Atlantic without refueling. It landed at Key West, Fla., after 11 days in the air and covered almost 1.34×10^7 m (8300 mi).

The conclusions of the official report on Phase II were:

> "Airship ground handling evolutions can be accomplished in virtually all weather conditions.
>
> "Routine ground maintenance can be accomplished under extremely adverse weather conditions.
>
> "Rime ice accretion at normal airship operating altitudes is not considered a deterrent to proper stationkeeping for protracted periods of time.
>
> "Maintaining a continuous barrier station over the Atlantic Ocean appears to be feasible under all weather conditions."

Wind - Wind is the most important weather element in airship operations. However, while high winds in themselves are no threat to the structural safety of an airship in flight, historically its limited speed necessitated that high head winds be avoided by flying the pressure patterns. This technique has been demonstrated in countless instances dating back to the World War I German operations.

Gound operations can be delayed, particularly where the winds are turbulent. The airship's ability to remain aloft with minimal fuel consumption and thereby delay a landing until the unfavorable period passes was a demonstrated operational technique. Where the fuel supply was low, the Navy relied on in-flight pickup of fuel in containers while the airship was hovering or flying at low ground speed.

Airships can be masted out in winds up to 46.25 m/s, or 90 knots, (Reference 28) and can be docked and undocked in down hangar winds up to 21.03 m/s (41 knots). As the wind direction approaches 90 deg to the axis of the hangar, the maximum velocity for docking operations approaches 10.28 m/s (20 knots).

Thunderstorms are typically avoided; however, experienced pilots have shown during hundreds of flights in thunderstorms that properly designed airships can safely fly in this environment. Modern weather forecasting, communications, and constant weather updates along with onboard radar would ensure an airship's being able to avoid a thunderstorm. Goodyear advertising airships use onboard radar for such purposes.

Snow - Perhaps the most troublesome situation for a moored airship is when a heavy, wet snow of several inches accumulates on the hull and fin topsides. In several instances, the Navy has flushed the snow off with a fire hose. Some promising experiments have been conducted in which the envelope helium was heated to melt the topside snow, but the Navy did not think it necessary to make this operational. Wet snow usually occurs near the ground and can be avoided in flight by a moderate increase in altitude.

Lightning - Lightning has never caused concern with a helium-inflated airship. Although all aircraft attempt to avoid lightning areas because of the turbulence that usually exists, there has been evidence of strikes on airship cars, fins, and topside radomes but none that caused detectable damage to an envelope of a non-rigid. There have been reports of small holes in the outer coverings of rigid airships where charges hit the metal structure beneath, but the structure was not damaged.

World War II Record - The most convincing demonstration of the all-weather capability of airships took place during U.S. Navy operations in World War II when airships patrolled nearly 7.77×10^{12} sq m (3,000,000 sq mi) over the Atlantic, Pacific, and Mediterranean. Only two bases outside the United States had hangar facilities. A significant factor in this performance was the high availability factor. Of the airships assigned to fleet units, 87 percent were on the line at all times; that is, they were in operation or in readiness for operation, which was a high factor for military aircraft during the war.

STATE OF THE ART

Rigid Airships (Materials)

General

Table 25 presents the state of the art of past rigids with respect to materials and material strengths as characterized by the airship Macon. The table also includes suggested replacement materials and their properties for

TABLE 25 - MATERIALS AND MATERIAL STRENGTHS (RIGIDS)

	Material Used in Macon ^{2}					Material for Modernized Macon					
	Description	Yield Strength (PSI)^9	Ultimate Strength (PSI)^9	Strength/Weight (gm/denier)	Strength/Weight (lbs/in/oz/yd^2)^{10}	Description	Yield Strength (PSI)^9	Tensile Strength (PSI)^9	Strength/Weight (gm/denier)	Strength/Weight (lbs/in/oz/yd^2)^{10}	Empty Weight of Modernized Macon^1 (lbs)^{11}
1. Hull Structure											70,423
A. Main Frames, Intermediate Frames, Longitudinals	Aluminum (17SRT)	42,000	55,000	-	-	Aluminum (7050-T76)	75,000	78,000	-	-	
B. Wire Bracing	Steel	-	250,000	2.54	-	Kevlar	-	400,000	19	-	
2. Empennage	Aluminum (17SRT)	42,000	55,000	-	-	Aluminum	75,000	78,000	-	-	10,587
3. Gas Cells		-	-	-	Approx. 7.7	Mylar/Scrim	-	-	-	25	6,731
4. Outer Cover											6,923
Cloth	Cotton	-	-	2.4	17.1	Dacron	-	-	9.0	40.6	
Coating	Acetate Dope^5	-	-	-	-	Tedlar Film	-	-	-	See Footnote 4	
Total											
5. Gas Valves, Hood, Ventilation	-	-	-	-	-	-	-	-	-	-	2,792
6. Nettings	Cotton	-	-	2.4	-	Kevlar	-	-	19	-	72
7. Fuel and Oil System	-		-	-	-	-	-	-	-	-	5,000
8. Ballast and Water System	-	-	-	-	-	-	-	-	-	-	3,430
9. Control Car	-	-	-	-	-	-	-	-	-	-	1,286
10. Controls	-	-	-	-	-	-	-	-	-	-	1,505
11. Electrical Systems	-	-	-	-	-	-	-	-	-	-	3,840^6
12. Heating and Ventilating	-	-	-	-	-	-	-	-	-	-	1,500^7
13. Crew Quarters	-	-	-	-	-	-	-	-	-	-	4,826
14. Instruments	-	-	-	-	-	-	-	-	-	-	
15. Radio and Communication	-	-	-	-	-	-	-	-	-	-	3,020^8
16. Mooring and Handling	-	-	-	-	-	-	-	-	-	-	3,083
17. Power Plant	-	-	-	-	-	-	-	-	-	-	4,480
18. Water Recovery	-	-	-	-	-	-	-	-	-	-	12,922
19. Miscellaneous	-	-	-	-	-	-	-	-	-	-	754
20. Total											143,174

Notes:
(1) On a material and component substitution basic only
(2) Macon Weight breakdown given in Table 4
(3) Compression
(4) Assumed to be zero in analysis
(5) Aluminum power in last two coats
(6) Approximate weight for Boeing 747 electrical system
(7) Estimates from similar components for Boeing 747
(8) Approximate weight of Boeing 747 Avionics
(9) 1.0 psi = 6.894 × 10^3 newton/sq m
(10) 1.0 lb/in /oz/sq yd = 526.86 m
(11) 1.0 lbm = 4.536 × 10^{-1} kg

attaining a modernized conventional airship.

The analysis in this subsection is very much a first-order approximation and is for illustrative purposes only. A modern airship would not be designed on strictly a materials substitution basis. The bending moment and fin loading criteria have changed since the last rigid was built and probably would change again based on added research and analysis that unquestionably would be performed prior to constructing another rigid airship. Goodyear developed improved girder designs after the Macon that, if no additional development in this area took place prior to developing another rigid, would be used in a modern airship. Even in view of these qualifications, however, the materials substitution approach is a reasonable approach for understanding the impact of today's technology.

Associated with any approach of this nature must be a decision as to what development risks and costs are reasonable. The parametric analysis (Volume II) shows that the "far reaches of today's technology" do not have to be explored to arrive at a conventional rigid configuration far superior to the last rigids. In fact, substantially more conservatism has been adopted in the parametrics than in the following analysis. The general philosophy used in Volume II was "what would be used if one were to start fabrication tomorrow". Thus, the criticism that sometimes surrounds a parametric analysis hopefully will be avoided.

The following paragraphs relative to a modern Macon should prove informative.

Hull Structure

For the main structural members of the rigid airship, composites are an interesting and promising replacement for conventional aluminum.* Similar NASA studies for an HTA vehicle have indicated structural weight savings in excess of 25 percent. Costs at first might seem a problem; however, such materials, when they are actually applied in an airship would be apt to be

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*Called duraluminum

more competitive than today. Naturally, the difference in composite cost per pound versus aluminum tends to be minimized since less pounds of the composite are required and since fabrication costs potentially can be reduced. At this time, however, the application of these materials either on a wide scale or as reinforcement members has not been adequately analyzed.

Stainless steel has been considered in the airship girder application; in fact, girder tests have been performed by Goodyear using stainless steel.* However, the structural elements resulting are thin by comparison to aluminum and lead to buckling problems. Other metals could be considered but offer only modest weight savings at added cost.

The most practical approach at this juncture is to apply a modern fatigue-resistant aluminum alloy such as 7075-T6. 7075-T6 is commonly used with aircraft structures and has a yield approaching twice that used on the Macon. However, the Aluminum Company of America has indicated that its X-7050 T76 alloy is a better fatigue-resistant material and possesses a slightly improved compressive yield strength. Appendix C of Volume IV provides a copy of a letter (along with additional detail on this alloy) from the Aerospace Industries Association of America, Inc. (AIA) in which AIA states that NAVAIR proposes to substitute the 7050 alloy for all new weapon system airframe components and spare parts currently manufactured from 7075, 7079, 7178, and 2014 alloys. NAVAIR states that substitution is expected to result in improved reliability and lower life cycle costs.

On the basis of this material substitution, the weight of a compression member will be (42,000/75,000),$^{1/2}$or 0.75 percent of the Macon weight; this results in a savings of 3616.10 kg (7972 lb) in the main frame, 507.78 kg (1119 lb) in the intermediate frames, and 2212.66 kg (4878 lb) in the longitudinals.

The steel bracing wires used in the Macon could be reduced in weight by approximately 10 to 12 percent using wire per QQ-W-470b. However, a substantially improved weight savings would result from the use of

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*The British actually used stainless steel girders in the R-101. While this airship generally was regarded as overweight, their is no specific reference to the stainless steel contributing to excessive weight.

Kevlar.* Kevlar is being applied in an ever-increasing number of industrial and aerospace applications, with Kevlar 49 having been applied widely in the cable and rope area. Antenna and tower guy wires of Kevlar (protected from ultraviolet by plastic shielding) also are being successfully used. Protection of Kevlar airship bracing would not be required since it is internal to the hull covering. End fittings and splices were somewhat of a problem with early applications of Kevlar in the rope and cable area due to high modulus, which did not permit the various yarns in the cross section to assume equal loading. Proper construction of the rope or cable and proper end fittings, however, has eliminated these earlier problems. The strengths required for the bracing "wires" range from approximately 108.86 kg (240 lb) minimum to 5216.40 kg (11,500 lb) maximum. This corresponds to approximately four plies of 1500 denier and 166 plies of 1500 denier, respectively. Thus, there are no minimum gage constraints, and efficient constructions are viable in both cases. GAC has extensively used Kevlar in a number of aerospace applications in recent years, and its parent company (GT&R) is currently using it as a belt material for tires.

The tenacity of the steel used in the wire bracing of the Macon averaged approximately 2.54 grams per denier. Kevlar, with a near optimum twist, is 21 grams per denier. Assuming a more conservative value of 19 grams per denier, Kevlar will result in an 85 percent weight reduction. Thus, on the basis of this substitution, the resulting weight savings is 3441.92 kg (7588 lb).

There are areas requiring some effort prior to applying Kevlar for defining cyclic and static fatigue characteristics. Some work has been performed in this area, and other efforts are underway. Specific recommendations will be made in Phase II.

The outer cover wires constitute 714.42 kg (1575 lb) of the miscellaneous hull reinforcement. Kevlar will result in a weight savings of 607.37 kg (1339 lb). It is conservatively assumed that a 10 percent savings in the rest of the

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*Basic difference between Kevlar 29 and 49 is one of modulus. Kevlar 29 and Kevlar 49 are two high-strength, high-modulus, low-density organic fibers introduced in recent years by DuPont.

miscellaneous reinforcement structure could be realized, or a savings of 445.89 kg (983 lb).

The total hull structure weight savings is then 10,831 kg (23,879 lb).

Empennage (Structure)

As in the hull structure, 7050-T76 aluminum alloy will permit a 25 percent savings in the weight of the original Macon empennage structure. Thus, a weight savings of 1600.75 kg (3529 lb) would be realized.

Gas Cells

Appendix C of Volume IV summarizes the Macon gas cell data. Two different fabrics actually were used. However, to simplify the calculations, it is assumed that the material to be used in the modern Macon must have a strength equal to or greater than the strongest Macon fabric, which was about 892.91 kg/m (50 lb/in.) tensile strength (warp and fill). Lightweight, scrim reinforced films used in recent years in many aerostatic balloon applications appear well suited for this requirement. Such a film would have a weight per unit area of about 6.78×10^{-2} kg/sq m (2.0 oz/sq yd) for a strength of 892.91 kg/m (50 lb/in.).

Goodyear Aerospace's use of a scrim reinforced film in a hot air balloon application in recent years attested to the ability to develop adequate seam strengths at elevated temperatures that would encompass the range of strengths and temperatures of interest in the gas cell requirement. Other companies and government agencies have used scrim reinforced films in a wide variety of applications over many years. With scrim reinforcement, the film tear strength is greatly increased and damage due to handling during manufacturing and installation is definitely minimized.

Although not expected to be a problem, one area that would require added evaluation is the cyclic environment that the gas cell would experience once in use within the airship. This would be a rather straightforward program and could be performed in a laboratory environment using a scaled gas cell and hull structure section. The laboratory pressure and temperature environment would be controlled through a predetermined cyclic exposure representative of actual flight conditions. The laboratory environment would be cycled, in a few weeks maximum, the same number (or greater number if desired) of cycles that the cell would see during its total life in an airship. Permeability and tensile strength tests would be performed before and after to verify lack of degradation. Various film materials could be evaluated and screened in this manner.

The total gas cell area for the Macon was 4.50 x 10^4 sq m (53,848 sq yd) (see Appendix C of Volume IV). For the 6.78 x 10^{-2} kg/sq m (2.0 oz/sq yd) reinforced film, this results in a total gas cell weight of 3053.18 kg (6731 lb), or a savings for the Macon of 6821.24 kg (15,038 lb).

Outer Cover (Doped) Including Empennage

The outer cover of the Macon was cotton cloth (approximately 1160.79 kg/m (65 lb/in.) predoped prior to installation, with the final coats of dope applied after installation. The weight of the finished fabric was about 0.456 kg/sq m (6.1 oz/sq yd).

The use of a film laminate for the outer cover of the modernized Macon appears to be a very practical consideration. While Kevlar seems to be a logical choice, minimum gage* is a problem even with the 200 denier yarn.** Therefore, for the current discussion the use of dacron will be considered. A dacron cloth with sufficient strength would be about 0.120 kg/sq m (1.6 oz/sq yd). A Tedlar*** film would be used to protect the dacron from ultraviolet radiation and conservatively would have a weight-to-area ratio of 0.075 kg/sq m (1.0 oz/sq yd). In addition, the film would prevent moisture from penetrating into

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*For larger higher-speed conventional airships, minimum gage may not be a problem and its use in such a case should be reconsidered.

**200 denier is currently the smallest denier Kevlar yard available. DuPont has stated that, at this time, it does not intend to manufacture smaller deniers.

***Trademark of J. T. Scheldahl Company.

the interstices of the dacron cloth. While adhesive layers as small as 0.037 kg/sq m (0.5 oz/sq yd) are possible, 0.0561 kg/sq m (0.75 oz/sq yd) is more practical as an average production consideration. Thus, the total film laminate weight-to-area ratio would be about 0.250 kg/sq m (3.35 oz/sq yd) compared with the 0.456 kg/sq m (6.1 oz/sq yd) for the Macon outer cover; this represents a weight savings of 2579.17 kg (5683 lb).

Film laminates have found widespread application in balloon applications and easily can be adapted. Once the grommets are installed, the film laminates would be laced to the hull structure just as the predoped cotton outer covering actually used on the Macon. Handling during manufacturing and installation should not be a problem. As with any new material, a film laminate would require an individual or component qualification program prior to its acceptance into a modern airship design.

Gas Valves, Hood, Ventilation; Fuel and Oil System; Ballast and Water System; Controls; Mooring and Grounding Handling; Miscellaneous

It is conservatively assumed that each of these weight groups can be reduced by 10 percent of the original Macon weight.

Netting

If the original netting is replaced with Kevlar, a total netting weight of 61.69 kg (136 lb) will result.

Control Car and Crew Quarters

The revised weight for these weight groups based on the X-7050 T76 alloy is $(42,000/75,000)^{1/2}$ (1718 + 6450), or 2772.40 kg (6112 lb).

Electrical System; Heating and Ventilating; Instruments; Radio and Communication

The weight of these groups has been increased to the approximate weight of these systems in the Boeing 747.

Powerplant

Modern turboprop engines with gear box result in approximately 0.4 pound per horsepower uninstalled. Installed weight per horsepower generally is considered to require one pound per horsepower. Thus, for the original Macon power rating of 4480 horsepower, the powerplant weight was 2032.13 kg (4480 lb).

Water Recovery

Although water recovery cannot be effectively used with the turboprop, the weight of this category has been retained under the assumption that an alternative technique can be provided today at approximately the same weight. Appendix H of Volume IV discusses the possibilities of alternative techniques.

Summary

In summary, the empty weight-to-gross weight ratio has been reduced from 0.59 to 0.34 by using materials and propulsion characteristics of today's technology.

Material Life Characteristics

In general, the fabric materials used in the Macon would have remained in a serviceable condition from five to seven years. The duraluminum was expected to have a life of at least from 10 to 15 years.

By way of comparison, an envelope* of one of the Goodyear advertising airships has been in service for more than seven years. Currently, it appears that 10 years is a reasonable life time.

Twenty-year service lives for film and film laminates are considered reasonable specifications today and are undoubtedly attainable. Life characteristics of materials common to HTA craft and their maintenance requirements are not given since they are well known.

In terms of the Goodyear advertising airships, the only maintenance perhaps not somewhat typical of HTA vehicles is when the top of the envelope is recoated to ensure continued ultraviolet protection. This requirement would probably continue for non-rigids using coated fabrics. It would not be a requirement for film laminates such as those suggested for a modern rigid.

Non-rigid Airships (Materials)

In general, many of these rigid airship considerations are applicable to the non-rigid and thus are not restated. The gains in most cases, however, would not be as dramatic since the last non-rigids were designed in the mid-1950's. The use of Kevlar in the envelope is one area of significant benefit requiring specific comment.

The use of Kevlar in the envelope for non-rigids of the ZPG-3W size and larger offers substantial increase in useful lift at a given gross weight. Kevlar has a strength-to-weight ratio about twice that of dacron. Prior estimates have indicated that the useful lift of the ZPG-3W, which used a neoprene coated dacron cloth envelope, could be increased 25 percent by a neoprene coated Kevlar cloth. Further substantial improvement is attainable via film laminates. In the non-rigid, the film renders the envelope impermeable and protects the load-carrying member from weathering. Whether film laminates can be incorporated into an LTA application where a man rating is required requires considerable additional testing and evaluation. Accordingly, the subject is not dealt with further in this phase. The parametric analysis (Volume II),

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*Neoprene coated dacron.

however, illustrates the benefit derived from neoprene coated Kevlar. While some unknowns remain, for instance, in the area of static and flexural fatigue, through proper choice of the many variables at the designer's disposal coated Kevlar is a very promising consideration for non-rigid envelopes. Studies are underway by a variety of agencies and companies; the results or interim results would permit a comprehensive plan to be developed in Phase II that would scope the magnitude of a program leading to the demonstration of a Kevlar envelope.

A recent innovation, known as Doweave, may be of interest in terms of detailed consideration during Phase II. This material is a three-thread set weave in a single ply, and its use would eliminate the conventional "bias" ply used in past non-rigids. Both cloth and coating weight would be reduced for the same capability. Envelope fabrication costs also would be reduced. Further analysis would possibly reveal whether the reduced fabrication costs would offset increased cloth cost that would undoubtedly occur compared with a standard weave.

Rigids (Economically)

Past conventional rigids were constructed in a labor intensive manner. Hulls were assembled in a single large dock in a continuous fashion frame by frame. Frames were individually constructed in an adjacent area and moved to the hull assembly area when needed. The wire bracing was terminated by hand wrapping and soldering. The time required to terminate one wire brace was about 40 minutes, and there were several thousand such terminations in a large airship. Today, this operation would be performed by a bench - mounted mechanism in about 75 percent of the terminations and by a hand-held mechanism in 25 percent of the terminations. Such an approach would reduce the 40-minute time period to something nearer three minutes. Use of Kevlar, instead of steel wire, as a bracing material could foreseeably further reduce the time to effect bracing terminations.

The hull itself would be errected in an entirely different manner than previously. Firstly, today's tooling techniques would permit the components comprising the longitudinals, main frames, and intermediate frames to be final cut prior to assembly as opposed to a cut-to-fit at assembly technique that was used to a certain extent previously. Additionally, the time required in joining the longitudinals to the main and intermediate frames would be greatly reduced. Short sections of the longitudinals would be joined to the main and intermediate frames at the time the individual frames are assembled. The longitudinals would then be attached during the errection of hull sections to the extensions emanating from the frame proper. Thus, the interface would be a straightforward simple contour connection as opposed to prior techniques where, at erection of the entire hull assembly, the longitudinals were attached directly into the frame which required the fitting of complex cuts on the interfacing members.

The time-consuming attachment of the outer cover would also be minimized both by improved technique and the use of a covering not requiring doping after installation.

Perhaps most significant in reducing manufacturing costs would be the revision in hull errection. The hulls of rigids of conventional construction would be built up in sections with scaffolding used to facilitate access to the hull section as construction proceeded vertically upward. At the longitudinal center of the hull section would be the main frame with intermediate frames (one-half the number per cell) on either side of the main frame. The hull sections would then be joined at erection by overhead equipment that would attach, by means of cables to the main frame, to each hull section and rotate and translate the sections to the desired location. The hull sections could be moved more easily than individual frames were moved previously because of their greater rigidity.

While assessing the impact of such modifications on acquisition cost is far beyond the scope of this phase of the study, it is believed the results in Figure 28 are of some interest. Figure 28 presents a very preliminary estimate, using the historical data presented previously for today's acquisition cost of rigid airships of conventional construction over a range of weights of interest to this study. Salient features of the estimate are:

1. The historical average of 13.23 direct construction man-hours per kilogram (6.00 direct construction man-hours per pound) of empty weight has been used (thus, prior construction techniques are implicit)
2. A lot size of 400 units has been assumed, and conservatively an 85 percent learning curve has been applied
3. 1974 material costs have been used as well as 1974 cost for propulsion and avionics

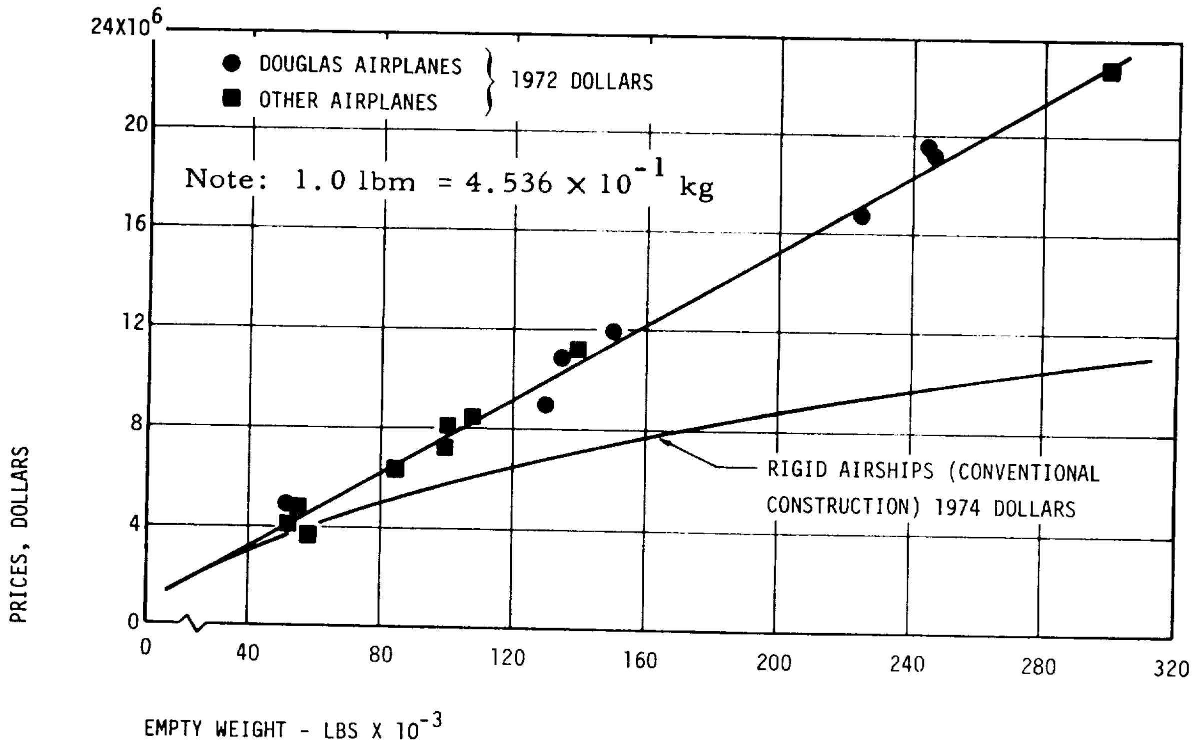

Figure 28 - Preliminary Estimate of Price versus Empty Weight for Conventional Rigid Airships

4. Hourly rates (labor and overhead) correspond to 1974, those of major domestic airframe manufacturers
5. Erection facility and maintenance facility costs have been amortized.
6. Tooling costs were assumed to be 4 percent of the average factory cost of 400 units
7. RTD&E costs were considered to be a factor of 10 greater than the cost of the first unit
8. Indirect support was considered at 5 percent of total direct support
9. Spares were considered at 2 percent of total direct plus indirect
10. Profit was considered at 10 percent of total cost including spares

From the results of this preliminary analysis, it is apparent that rigid airship acquisition costs can be expected to be below that of today's major domestic aircraft on a price-per-pound basis. It is plausible to suggest that when considering the impact of the prior discussion relative to new construction techniques that the price per pound may approach that of light airplanes.

Non-rigids (Economically)

A similar analysis could be performed for the historical data provided earlier for non-rigids with similar trends resulting. It is not clear, however, at this point that another such analysis would add significantly to our understanding. Accordingly, further economic analyses are better reserved for Phase II.

Operational Aspects of Conventional MAV's

Mooring and Ground Handling

Based on the brief historical summary presented earlier, it was apparent that much progress had been made in mooring and handling large airships. In view of the projected in-frequent requirement to hangar (or dock) of an MAV, prior techniques may well be substantially adequate. In any event, quantum advances are not essential in this respect to render an MAV a viable consideration.*

It is generally acknowledged that the manner in which prior airships were moored requires considerable improvement although the Navy work of the 1950's was approaching what might be regarded as commercially practicable operation for the size airship being used. Larger ships, however, would result in large crews and added equipment given the same approach.

In general, an automatic flight control system consisting perhaps of much of the equipment in Figure 29 would be on-board a large MAV. This equipment would lead to a greatly improved opportunity to minimize ground crews and ground handling equipment. With such a control system, under all but the most severe of conditions, an MAV probably could be flown to and restrained to (without external assistance from a ground crew) a turntable that would permit the ship to weathervane subsequent to landing.

After suitable computer simulations are developed to model the behavior of an MAV with the control system under a variety of landing environments, the ability to provide "pinpoint" controllability is not limited, as suggested above, to only the most severe conditions. Given this possibility, such a control system may require some augmentation in terms of ground crew and equipment similar to that used by the Navy in the late 1950's. Although not used in past airship operations, it seems reasonable to suggest television as an aid to ground handling and perhaps more importantly to mooring.

Other approaches such as those described in Reference 29 have been suggested that do not require the actual landing of the airship while cargo is off/on loaded. Such a system would have its greatest merit for operation in areas where fixed bases do not exist. However, in view of the results of this study it is doubtful that the vehicle suggested in Reference 29 is best suited to the delivery of cargo to areas other than where fixed bases do not exist.

Relative to fixed base operations, the suggestion made relative to landing and mooring appears more realistic in that it is a much smaller departure

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*Extremely large MAV's would not be docked for maintenance nor would they be built in an enclosed hangar (Reference 29).

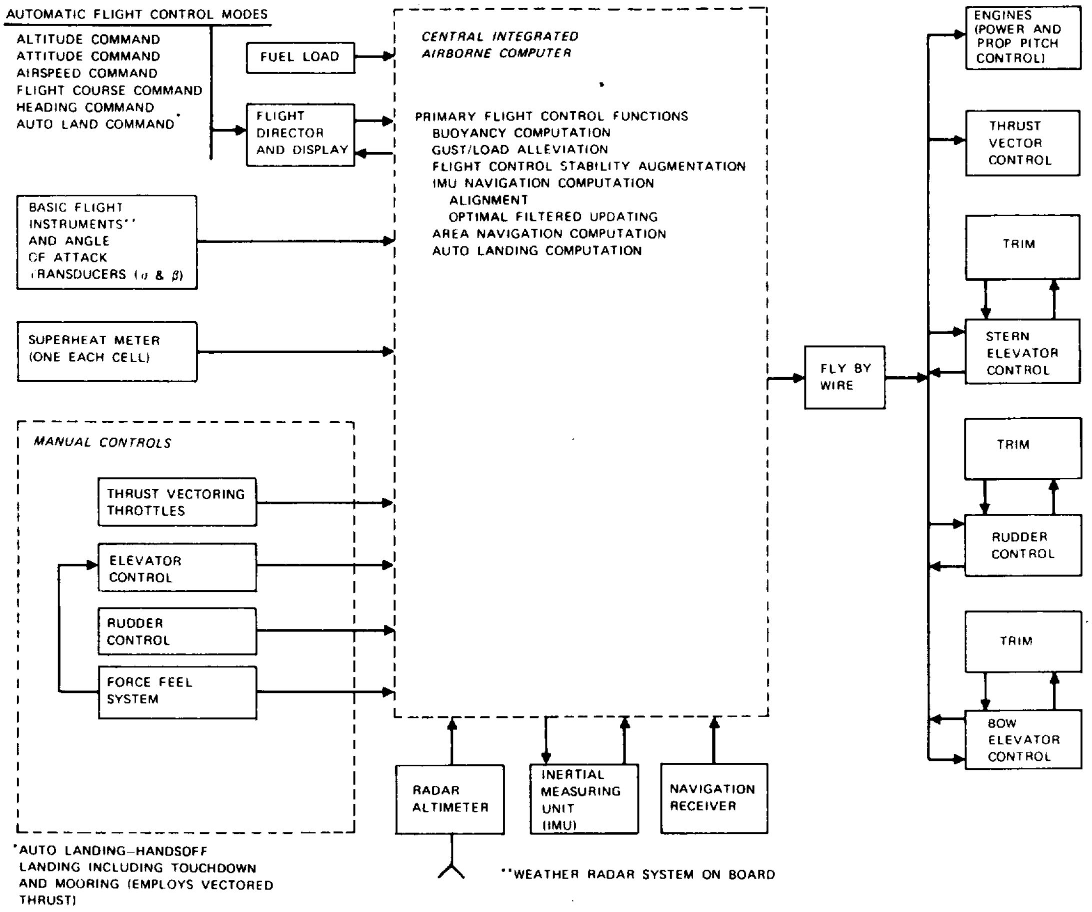

Figure 29 - Automatic Flight Control System Schematic

from past practices and would appear to result in less weight penalty to the airship itself.

Depending upon the response of the turntable/airship system to changes in the incident winds, it may be desirable to have a network of wind sensors surrounding (at a suitable distance from) the turntable. Information from the sensor would provide inputs to a turntable drive mechanism, which in turn would orient the MAV into the wind. A similar scheme is suggested in Reference 29.

Weather

General - Very significant progress in forecasting general and local meteorological conditions has been realized since the last rigid airships were flown, a factor that has contributed much to the continuing improvement in HTA safety. The use of the avionics onboard today's modern aircraft will be essential in an MAV. This capability will provide the ability to avoid severe weather, something that the German pilots were able to do very successfully even without such equipment.

Onboard radar in the Goodyear advertising ships is used to avoid severe weather when the airship is penetrating passing fronts.

Not only will the advent of weather satellites, onboard radar, improved navigation, and improved communications result in safety benefits but the economics of prior operations also will be improved. These capabilities will permit an optimal (least unfavorable) headwind route to be flown. The adverse effects of headwinds themselves will be minimized by higher design velocities that, with today's extensive advances in propulsion and noticeable improvements in materials, can be obtained with minimal weight penalty. Nevertheless, avoidance of excessive headwinds will remain an operational consideration.

In past operations, it was often common to fly close to the ground (where turbulence is less) during very severe weather. Controllability of past configurations in this environment probably was not adequate since, to obtain a nose-up attitude, the tail of the ship necessarily was forced toward the ground. Vectored thrust can remedy this problem, but a more suitable approach in some cases may be to use bow elevators. These devices were successfully incorporated and used on a non-rigid airship; thus, their feasibility is not questionable.

Wind - The subject of minimizing the adverse effects of headwinds as well as the use of radar to avoid severe weather has been discussed. The technique that would be used in a conventional MAV relative to landing in extremely adverse wind conditions is the same as previously used; this consisted of delaying the landing until the turbulent ground winds passed.

Snow - The techniques devised by the Navy relative to this problem and discussed earlier should prove adaptable to future operational needs both during flight and while moored.

Tropical Storms - There are recorded instances where airships (such as the Macon) have survived aspects of tropical storms. It would be essential that an MAV (as in HTA vehicles) be removed from areas of expected tropical disturbances.

Institutional Constraints

Institutional constraints are described in Volume I. Their impact relative to the parametrics is addressed in Volume II.

Current Goodyear airship operations have no reason to operate other than in a static equilibrium, or light condition, or in conditions not suited to visual landings. As a result, exemption No. 1552 dated 27 March 1972 has been obtained that permits Goodyear's airships to operate over populated areas within the same minimum altitude and VFR weather minimums as helicopters. The effect upon flying configurations in a heavy condition will have to be reviewed during Phase II to assess the constraints that may be placed on such operations.

Buoyancy Management

This subject involves a variety of considerations and is included in Figure 28. This subject, as related to the increase in buoyancy accompanying the consumption of fuel of a density greater than that of air, is discussed in Volume II. There are schemes such as those used in the Graf Zeppelin that eliminate this problem. The multitude of possibilities available over the range of parameters involved in this phase relative to the approaches for buoyancy management eliminates a serious discussion of refinements or revision to past techniques until specific vehicle/mission combinations are considered in Phase II.

Many considerations are involved including type of propulsion system, type of fuel, type of vehicle, use of heavy takeoff, whether vehicle is power extensive, and altitude requirements. Accordingly, many specific decisions, often interrelated, must be made unless one is to present a shopping list. While no specific design innovations have been included in the "parametric design," the weight equations include allowances for buoyancy management techniques updated to include today's materials.

Recent LTA/HTA Vehicles and Concepts

Recent interest in LTA combined with HTA as a hybrid vehicle featuring the best of these two has received considerable attention in recent years. There are several reasons for this:

1. A growing awareness of the ecological and energy problems associated with current transportation systems
2. The realization that the operational characteristics and capabilities of airships either are not available or are available only to a limited extent in other transportation systems
3. The conviction that the quantum advancements in aerospace and aviation systems technology can place modern airships on the same level of safety, economy, and performance capability as alternate transportation system
4. The identification of many conventional and unique missions that modern airship vehicles could potentially perform cost effectively

As a result of these reasons, conventional and unconventional LTA as well as LTA/HTA vehicles have been proposed and analyzed to varying degrees. The more notable configurational concepts and designs to emerge in recent years are discussed in the following paragraphs. It is beyond the scope of this report to critique, evaluate, or rate the concepts/designs. Such a task would undoubtedly and understandably be complicated by the varying extent of design analyses performed and the extent to which results of analyses that have been performed might be considered proprietary and therefore unavailable. It is certainly fair to say, however, that Goodyear maintains an interest and knowledge of continuing LTA and LTA/HTA vehicle concepts and designs and has applied this awareness and knowledge throught the present study.

The Airfloat heavy lift transporter by Airfloat Transport Ltd. and a cargo transporter by Cargo Airships Ltd. are two of the most notable efforts undertaken in recent years by British concerns. The Cargo Airship Ltd. project involves a 1, 132, 800 cu m (40, 000, 000 cu ft) conventional rigid long-haul airship while the Airfloat project considers a 849, 600 cu m (30, 000, 000 cu ft) conventional rigid designed for short-range carriage of large indivisible loads.

Certain points of interest made in the Airfloat study, some of which have been commented on previously, are summarized below:

1. Possible elimination of water recovery apparatus by
    a. Heavy takeoff with decreasing fuel load accounted for by modulating dynamic lift
    b. Heated helium at takeoff, which is permitted to cool as fuel is consumed
    c. Intermediate ballast pickup
2. Loading and unloading cargo while the airship is hovering, which necessitates a somewhat elaborate but plausible ballast exchange system, the rudiments of which Airfloat has outlined. Airfloat also has realized the requirement for a means of sensing and correcting misalignment from wind directional changes, etc., during the hovering (loading and unloading) process. Plausible concepts for accomplishing this are also suggested.
3. Use of a turntable permitting the capability of mooring the airship over its entire length while still permitting it to weathervane.

With regard to hull construction, the "conventional rigid" as well as the semi-monocoque metalclad and an aluminum faced honeycomb skin were considered by Airfloat. The "conventional rigid" using update materials was the approach ultimately retained.

Powerplants considered included nuclear, gas turbine, reciprocating diesel, and reciprocating petroleum. Airfloat concluded that nuclear power, although attractive for long hauls, was expensive for producing a limited number of airships and was not readily available. Gas turbines were ultimately favored due to their superior power-to-weight ratio, which more than offset their somewhat higher specific fuel consumption.

Another British effort, the Skyship Project, is apparently continuing with a 13.61 m (30 ft) "prototype" having recently flown in Cardington, England. The operational Skyship configuration is a 1,047,840 cu m (37,000,000 cu ft) volume flying saucer-shaped vehicle some 317.52 m (700 ft) in diameter. Fuel and payload capability is on the order of 4×10^5 kg (400 tons); maximum speed is 51.44 m/s (100 knots).

The Heli-Stat (Reference 30) heavy lift vehicle by the Piasecki Aircraft Corporation is currently undergoing detailed study and definition by that firm under contract to the Navy. Goodyear is assisting Piasecki with such items as defining the LTA hull and helicopter support structure, preparing manufacturing cost information, and providing guidance from the overall LTA aspects of such a vehicle.

This 68, 032 kg (75 ton) payload Heli-Stat uses an essentially conventional helium-filled rigid airship hull (minus tail surfaces) of approximately 82, 128 cu m (2, 900, 000 cu ft) to which four CH-54B helicopters are attached. The LTA hull and helicopters are joined by a lightweight truss work that ties the fuselage structure of the helicopter to the main frame structure of the LTA hull. Thus, the 68, 032 kg (75 ton) payload design employs demonstrated technology in the LTA hull and existing components in the helicopters to arrive at a vehicle that can lift payloads 10 times those of one of the helicopters alone and more than twice as much as an LTA vehicle of comparable size. The static lift of the LTA structure supports approximately the full weight of the entire vehicle; the rotor thrust is available for useful load and maneuvering control forces.

The helicopter's control systems are interconnected so that they respond to one set of controls in the master control helicopter. A qualified pilot is stationed in each helicopter and serves as a manual instrument-monitoring system with override capability if a component fails.

The helicopters are free to use their cyclic pitch in all directions (approximately 11 deg). In addition, they can be made to rotate about a transverse axle in longitudinal pitch 60 deg forward and 30 deg aft but normally are locked in a trim position. In the lateral direction, in addition to the rotor's lateral cyclic control of approximately 11 deg, the helicopter can be made to tilt outboard approximately 11 deg.

In the yaw direction, the helicopters are rigidly fixed to the aerostat structural keel. For yaw moments, the port and starboard helicopters can differentially incline their longitudinal cyclic. For lateral roll control, differential rotor collective pitch on one side, versus the opposite side is used. Pitching attitude is via differential collective pitch of the forward rotors versus the aft.

Propulsion is achieved from the forward cyclic pitch of all rotors. The helicopters can be included as the dynamic lift of the aerostat develops with forward speed. The aerostat angle of attack, and hence its lift, can be independently adjusted by its longitudinal trim elevators. Retardation is achieved by tilting the rotors aft.

Plausible approaches for emergency (i.e., complete power loss in one helicopter) landing have been advanced in terms of complying with existing FAA regulations. Plausible mooring provisions have been proposed and are currently being reviewed for possible improvement.

The Aerocrane is a heavy lift vehicle proposed by the All American Engineering Company. Parametrics have been performed by All American for payloads up to 226,200 kg (250 tons), with resulting sphere diameters of 76.3 m (250 ft) and forward velocities up to approximately 24.7 m/s (48 knots).

A small 6.8 m (15 ft) in diameter HTA model of the Aerocrane concept has been made by All American. While the model does not use a lifting gas, it illustrates the fundamental vehicular principles involved in the concept.

Under contract to the Navy (see Reference 31), Goodyear performed a comparative parametric and design study of conventional rigid and nonrigid airships as well as dynamic lift aerostats (Dynastat) as applied to future naval missions. The Dynastat vehicle is one class of vehicle being considered in the current study.* The study considered gross weights ranging from 45,360 to 680,400 kg (100,000 to 1,500,000 lb), design velocities ranging from 46.1 m/s to 107.9 m/s (90 to 210 knots), static lift-to-gross weight ratios ranging from 0.6 to 1.0 for the Dynastat-type vehicles and 0.8 to 1.0 for the conventional airships, and operational altitudes ranging from 457.20 to 6096 m (1500 to 20,000 ft).

The Helium Horse also is a configuration involving aerodynamic and aerostatic lift similar in some respects to the configuration of that description analyzed in this study.

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*Reference 32 discusses a semibuoyant, lifting-body airship that is described in Volume II.

Another area of study by Goodyear that is of some historical interest relative to modern airships is to control the boundary layer. Reference 33 summarizes the Goodyear boundary layer control (BLC) study, which in this case is applied to a non-rigid airship.

The findings of the BLC airship showed sufficient increase in the airship performance to warrant further study. The following specific conclusions were offered:

1. The wind tunnel tests confirm the ability of the theoretical methods to predict the boundary layer control of a body of revolution at zero angle of attack.
2. The theory confirmed by the wind tunnel tests together with allowance for inlet and duct losses predicts that the bare hull power requirements for a full-scale BLC airship hull of fineness ratio 3.0 at zero angle of attack can be expected to be 10 to 20 percent less than the power requirements of a conventional airship hull of equal volume.
3. The difference in the components, other than the hull associated with the two configurations, offer an additional 5 to 10 percent reduction in power requirements for the BLC non-rigid airship.
4. A BLC configuration with a fineness ratio 3.0 can be expected to reduce the total propulsive power requirements 15 to 25 percent of a conventional non-rigid airship of equal volume.
5. If both configurations have equal fuel quantities available, BLC can be expected to increase the endurance 20 to 40 percent.
6. Indications exist that the fineness ratio of 3.0 may not be optimum for a BLC airship.

Several recommendations resulting from the BLC study will be integrated into an overall LTA technology plan to be developed as a part of Phase II.

A third area of investigation by Goodyear in recent years applicable to the concept of modern airships is that of gimbaled stern propulsion. Under contract to ARPA (Reference 34), Goodyear modified one of its advertising airships to incorporate a gimbaled stern propulsion system (see Figure 30) and subsequently demonstrated the feasibility of this approach for low-speed control of the conventional airship configuration. Stern propulsion is often considered and logically so for the BLC airship because the stern propeller to an extent affects BLC. In the Phase II technology plan development, recommendations are contemplated regarding the combination of stern propulsion and BLC investigations as an area leading to possible worthwhile improvements in future airship performance.

Aereon Corporation has built vehicles and conducted design studies of vehicles combining aerostatic and aerodynamic lift as reported in Reference 35. Aereon III was a three-hulled rigid airship 25.91 m (85 ft) long. This configuration was dismantled in 1967, and a vehicle combining aerodynamics and aerostatic lift (called Dynairship) was subsequently built and successfully flown. This configuration could be considered for the aerodynamic/aerostatic vehicle analyzed during this study.

Interest in the Soviet Union relative to LTA and LTA/HTA vehicles in recent years reportedly has been significant. In 1965, the first all-Soviet Union Conference on Dirigible Construction was held, at which time new techniques and design criteria were explained. Substantial public controversy relative to the desirability of extensive development of dirigibles by the USSR following this conference also has been reported. While there is no reported authorization of major national proportions, the Soviet Ministry of Aviation is said to have authorized full exploration of several schemes.

One known project that reached a hardware stage is described below. An airship design group in Kiev in 1969 built and tested a cigar-shaped airship known as the D-1, which is 84 m (275.6 ft) long and 25 m (82 ft) in diameter. The D-1 is a double-skinned semi-monocoque construction; the hull liner is fiberglass and the space between the inner and outer walls is filled with foam. The airship is fully rigid, with four transverse frames and four stringers installed inside the lining. One of the stringers has been reinforced to function as a corridor between the cabins, which are located in the bow, tail, and center of the ship below the hull. Helium gas bags of a thin synthetic material were reportedly used.

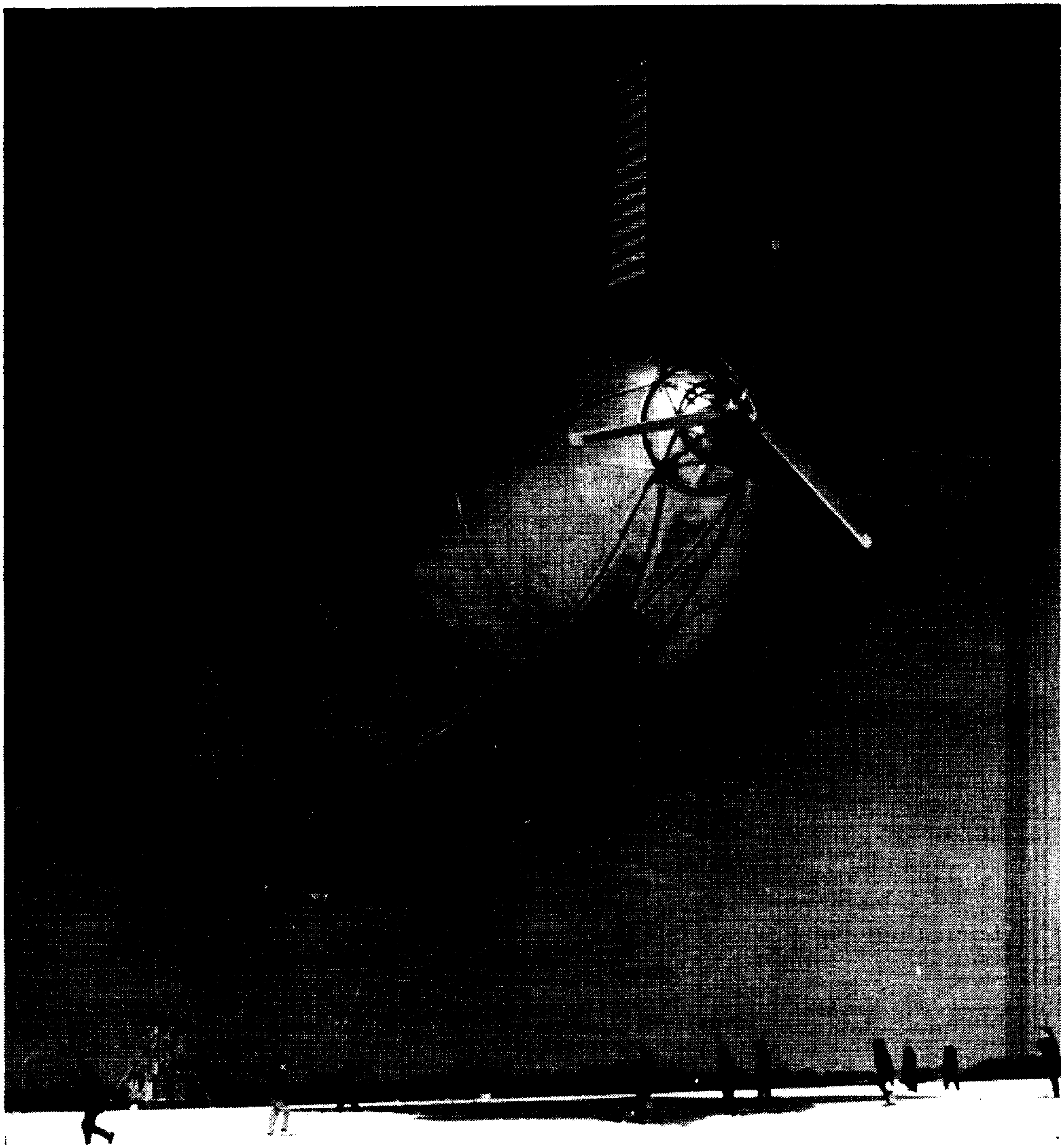

Figure 30 - Goodyear Mayflower Stern Propulsion Demonstration

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The D-1 reportedly operates at altitudes up to 7000 m (22,920 ft) and can travel 3000 km (1620 naut mi) nonstop. A turbofan tail-mounted engine is reportedly used, with speeds ranging up to 200 km (108 naut mi) per hour. Also, a mooring mast with a revolving platform is planned.

Airship designers in Leningrad reportedly are working on plans for a double-hulled rigid airship under the supervision of an aero-nautical commission sponsored by the Soviet Geological Society. Uses for which airships have recently and are apparently still being considered are:

1. Transporting heavy loads over long distances in Siberia
2. Transporting and installing heavy structures at building sites
3. Radio communications
4. Medium-range airbuses and tourist cruisers

Various reports that non-rigid airships are being used in the Soviet Union (apparently since the early 1960's) exist. Designers (W. Schmidt and Ulrich Queck) in East Germany are reportedly involved with an advanced airship design called the Dolphin. The concept is reported to have originated from a study of the mechanism of motion employed by the Dolphin as it propels itself through the water. Claims, which perhaps can be substantiated although no detailed analysis is known to be available, are that such an airship would be able to fly at over 500 km (270 naut mi) per hour, take off and land vertically, rotate about one point, and fly backward. It also is claimed that this type of airship will displace conventional airship and sea-going vessels for mass passenger travel in less than 100 years.

Recent interest in West Germany has centered around the efforts of Theodor Wüllenkemper, who in 1972 built a 6000 cu m (212,000 cu ft) non-rigid airship at a reported cost of $625,000. Reportedly, a second and possibly a third airship of similar description has flown, with one airship about to fly with the third sold to a Japanese firm. The initial Wüllenkemper airship was very similar to the Goodyear advertising airships.

Projected details regarding Wüllenkemper airship configurations are given in Table 26. Reportedly, the airships will see a wide variety of commercial

TABLE 26 - TECHNICAL DETAILS OF PROPOSED (AND EXISTING) WÜLLENKAMPER NON-RIGID AIRSHIPS*

Detail	WDL 1 experimental	WDL 2 experimental	WDL 3 experimental	WDL 4 commercial design
Expected completion	1971	1972	1973	?
Volume (m^3 helium)	6,000	13,000	20,000	64,000 +
Length (m)	55	70	80	120
Max diameter (m)	14.5	18	20	28
Gross weight (kg)	6,300	13,650	21,000	21,000 (65,000?)
Useful load (payload kg)	1,500	5,000	10,000	30,000
Useful load (payload tons)	(1.5)	(4.5)	(9)	(30)
Envelope weight (kg)	1,600	3,200	4,500	11,000
Power Plant (hp)	2 x 180	2 x 350	2 x 400	2 x 700
Max speed (kmh)	100	120	140	140
Range (operating radius)(km)	400	1,000	1,800	2,600+

*1.0 cu ft = 2.832×10^{-2} cu m, 1.0 ft = 3.048×10^{-1} m, 1.0 lbm = 4.536×10^{-1} kg, 1 HP = 7.457×10^{2} watts, 1 mi = 1.609 km

uses including passenger transport, heavy load transport, and rescue operations and will use a stable platform for scientific observation and military surveillance. Reportedly, Wüllenkemper has recently applied for a permit to erect a permanent hangar for building additional larger airships.

Two French configurations are of some interest and are briefly described below. The Obelix Flying Crane consept uses existing equipment and specifically is a heavy-lift, reasonably short-haul vehicle. It uses four balloons, each with nearly 743,200 cu m (8,000,000 cu ft), to which eight helicopter rotors are attached by means of a support structure. The responsible French design team believes such a vehicle could be flying by 1980 if started in 1975. The team has determined that three such vehicles could be used in France and 10 additional units in the remainder of Europe.

The second French configuration of some interest is again a flying saucer-shaped vehicle 234.70 m (770 ft) in diameter, with a volume of about 9.29×10^{6} cu m (100,000,000 cu ft).

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