THE VALUE OF PERFORMANCE.

NORTHROP GRUMMAN

Keck Study Airships; A New Horizon for Science”

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321-951-5930

Airship “Lighter than Air” Definition

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Airplanes are **heavier** than air and fly because of the *aerodynamic* force generated by the flow of air over the lifting surfaces.

Balloons and airships are lighter-than-air (LTA), and fly because they are buoyant, which is to say that the total weight of the aircraft is less than the weight of the air it displaces.[1]

The Greek philosopher Archimedes (287 BC – 212 B.C.) first established the basic principle of buoyancy. While the principles of aerodynamics do have some application to balloons and airships, LTA craft operate principally as a result of *aerostatic* principles relating to the pressure, temperature and volume of gases.

A balloon is an unpowered *aerostat*, or LTA craft. An airship is a powered LTA craft able to maneuver against the wind.

[1] NASA Web site U.S. Centennial of Flight Commission http://www.centennialofflight.gov/index2.cfm

Atmospheric Airship Terminology

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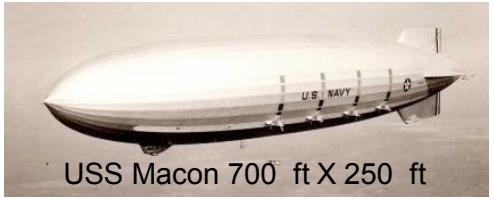
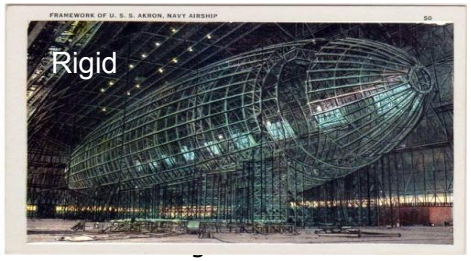
- Dirigible – Lighter-than-air, Engine Driven, Steerable Craft
- Airship –Typically any Type of Dirigible
  - Rigid –Hindenburg, USS Macon, USS Akron
  - Semi-Rigid – Has a Keel for Carriage and Engines
    - NT-07 Zeppelin
  - Non-Rigid – Undercarriage and Engines Support by the Hull
    - Cylindrical Class-C – “Blimp”
      - Goodyear, Navy AZ-3, Met Life Blimp, Blue Devil
    - Bi-Hull -LEMV
    - Tri-Hull- Lockheed P-791
- *Hybrid* Airship – Any Airship that Uses a Combination of Thrust Vector and Aero Lift
  - **All Modern Airships are Hybrid** - Combining aerostatic lift, from the conventional Lighter Than Air (LTA) concept, with various Aerodynamic lift capabilities



USS Macon 700 ft X 250 ft

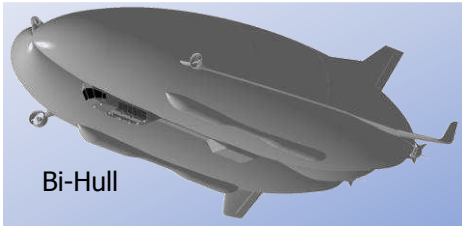


Zeppelin NT 07 246 ft x 57 ft


Size comparison Hindenburg and Boeing 707

Length: 803.8 feet
Diameter: 135.1 feet
Speed: 75 KTS
Range: 3500 miles 40 crew and 50 passengers


Blue Devil II 370ft x 100 ft



NGC LEMV AV-1 300 ft x 140 ft x 85 ft

LMC P-791 175 ft x 75 ft

Mass & Buoyancy Management- How Lighter Than Air - Airships Work

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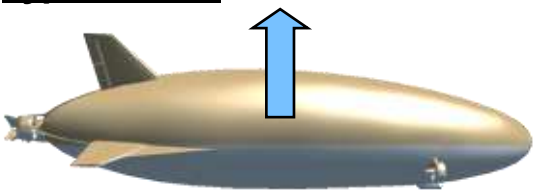
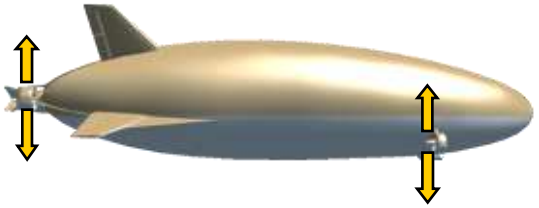
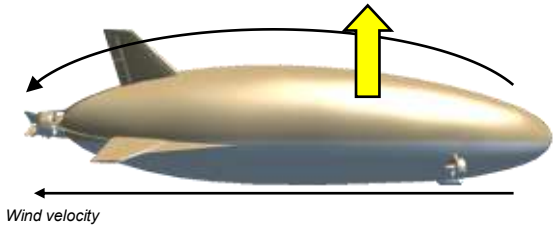
Types of Lift



Aerostatic lift - generated by inert helium lift gas – at all times

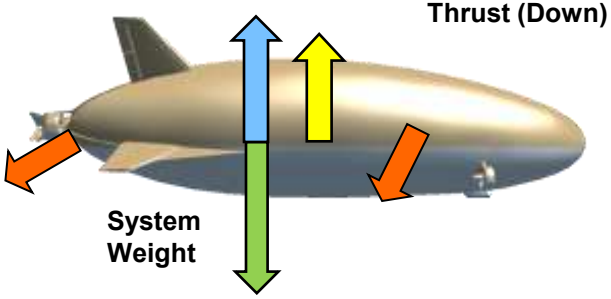


Vectored thrust lift - take off and landing and zero airspeed operation

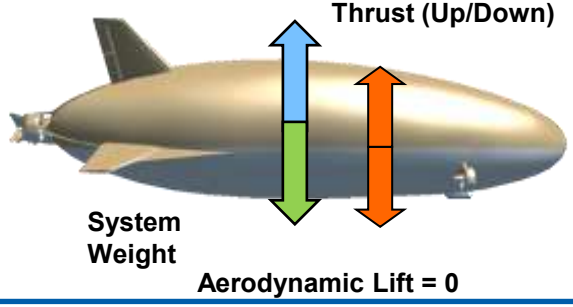


Aerodynamic lift – generated by lifting body hull – in cruise flight

Force Balance (Rolling Take-off)

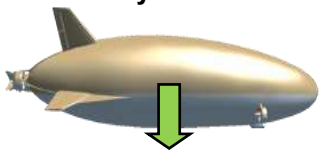


Force Balance (VTOL)

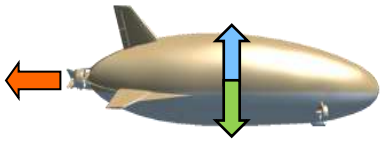


Typical Flight Profile

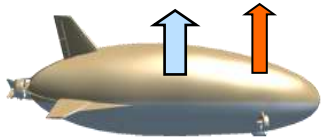
Take off: Heavy using Tilt rotors and aerodynamic lift



Transit : Controlled Balance of Dynamic / Aero Lift / Buoyancy & Weight Operate Light-Than-Air



Landing: Extremely Light using vectored thrust to keep from floating away

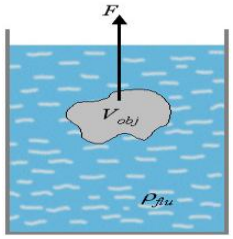


All Airships that use Tilt Rotors or Aerodynamic lift are "Hybrid Airships"

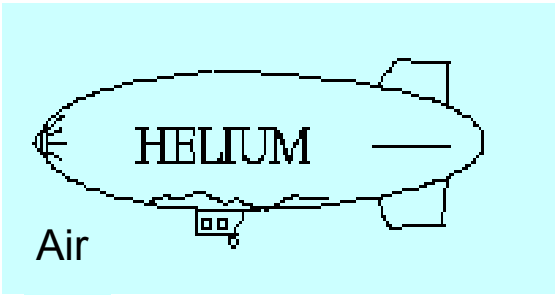
Principles of Lifting Gases

- Airships are called lighter-than-air (LTA) craft because to generate lift, they use gases that are lighter than air.
- The most common gas in use today is helium.
- Helium lifting capacity of 0.070 lb/ft^3.
- Hydrogen even lighter with a lifting capacity of 0.075 lb/ft^3 but more volatile

Density ρ of gases (at 20°C and 101.3 kPa)			(diff from Air)
gases	ρ in kg /m^{-3}	ρ in lb / ft^{-3}	ρ in lb / ft^{-3}
hydrogen	0.0899	0.0056	0.0750
helium	0.1780	0.0111	0.0695
methane	0.7170	0.0448	
ammonia	0.7710	0.0481	
steam100%	0.8800	0.0549	
carbon monoxide	1.2500	0.0780	
nitrogen	1.2510	0.0781	
air (dry), no CO_2	1.2920	0.0806	0.0000
oxygen	1.4290	0.0892	
carbon dioxide	1.9770	0.1234	
propane	2.0190	0.1260	
ozone	2.2200	0.1386	
chlorine	3.2140	0.2006	
xenon	5.8970	0.3681	



Archimedes



The buoyant force is given by: $F = g\rho_{flu}V_{obj}$

Airship 300 ft long ~ Volume 1 Million ft^3

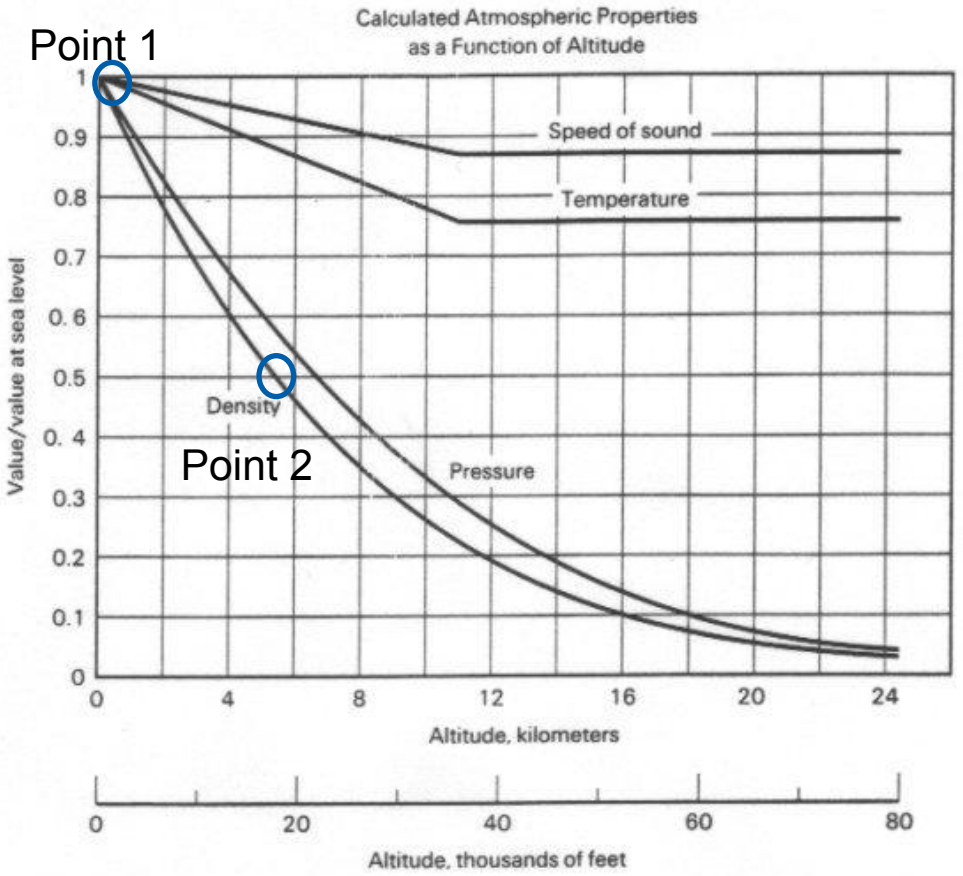
Force = 1 x10^6 ft^3 x 0.0695 lb / ft^3

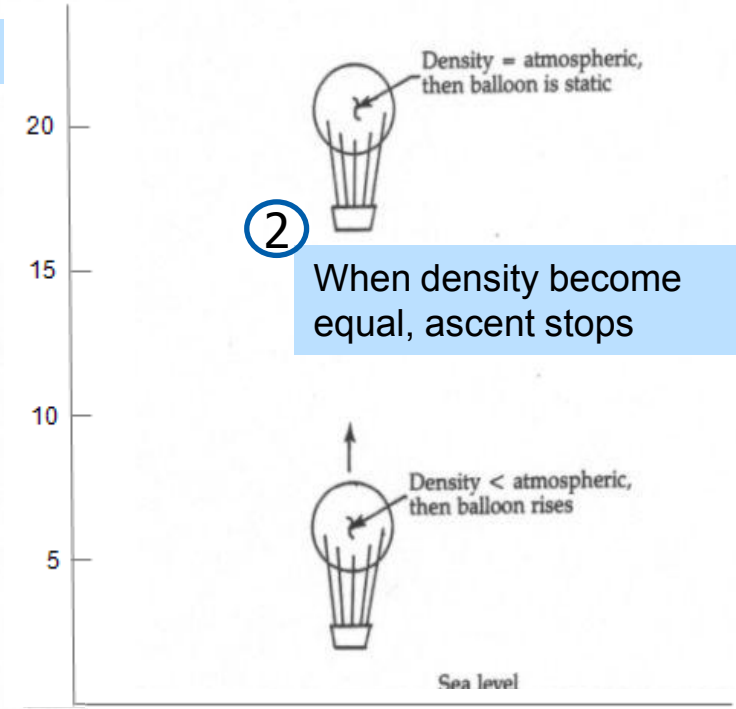
He Lifting Force = 69,538 lbs

H^2 Lifting force = 75,000 lbs (7% better)

Shape Control - Other Physics Involved

Both pressure and density decrease as altitude increases



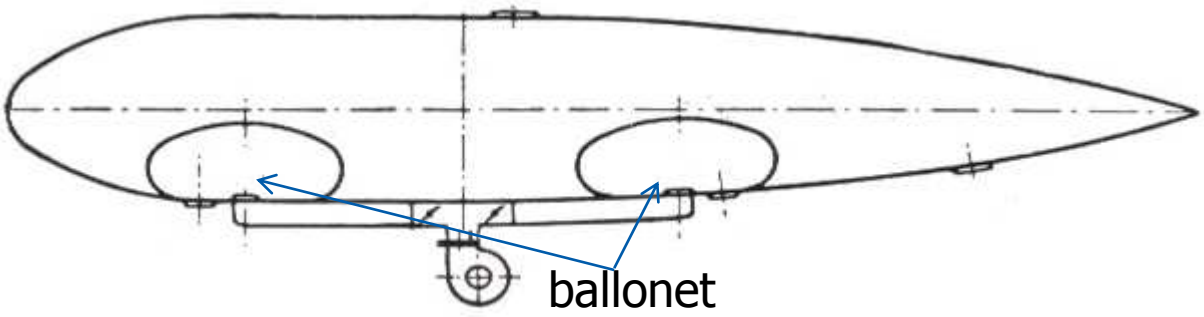


2 When density become equal, ascent stops

1 Gas inside the balloon is lighter than the surrounding air causes it to rise

As the Vehicle Rises the lifting Gas Expands Within the Hull, Which if not Controlled Would Burst the Hull

Airship Ballonets – Maintains Shape

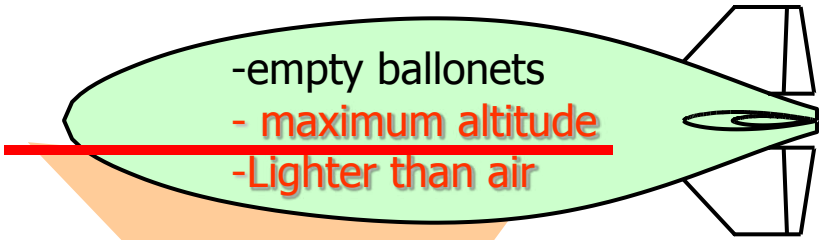


A Ballonet is a air-filled flexible chamber (or airbag) inside the envelope of a non-rigid airship.

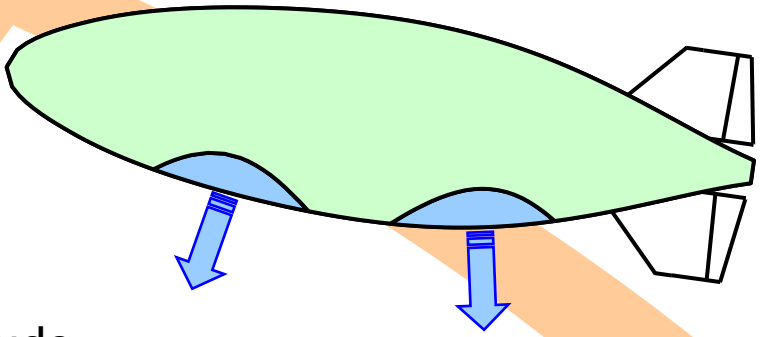
Such an airship can have one or more ballonets, commonly one fore and one aft.

Because air is heavier than the lifting gas the ballonets are deflated or inflated with air to maintain the external shape of the airship during ascent or descent. They are also used to control the pitch of the airship; since air weighs considerably more than helium.

Ascending Flight Operation

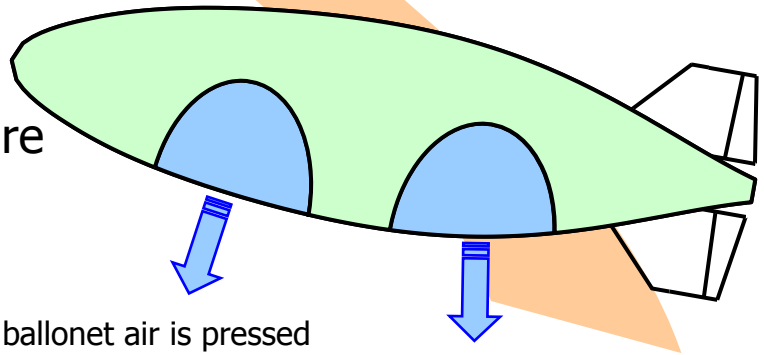


Descending ambient pressure causes expanding helium and decreasing ballonet volume



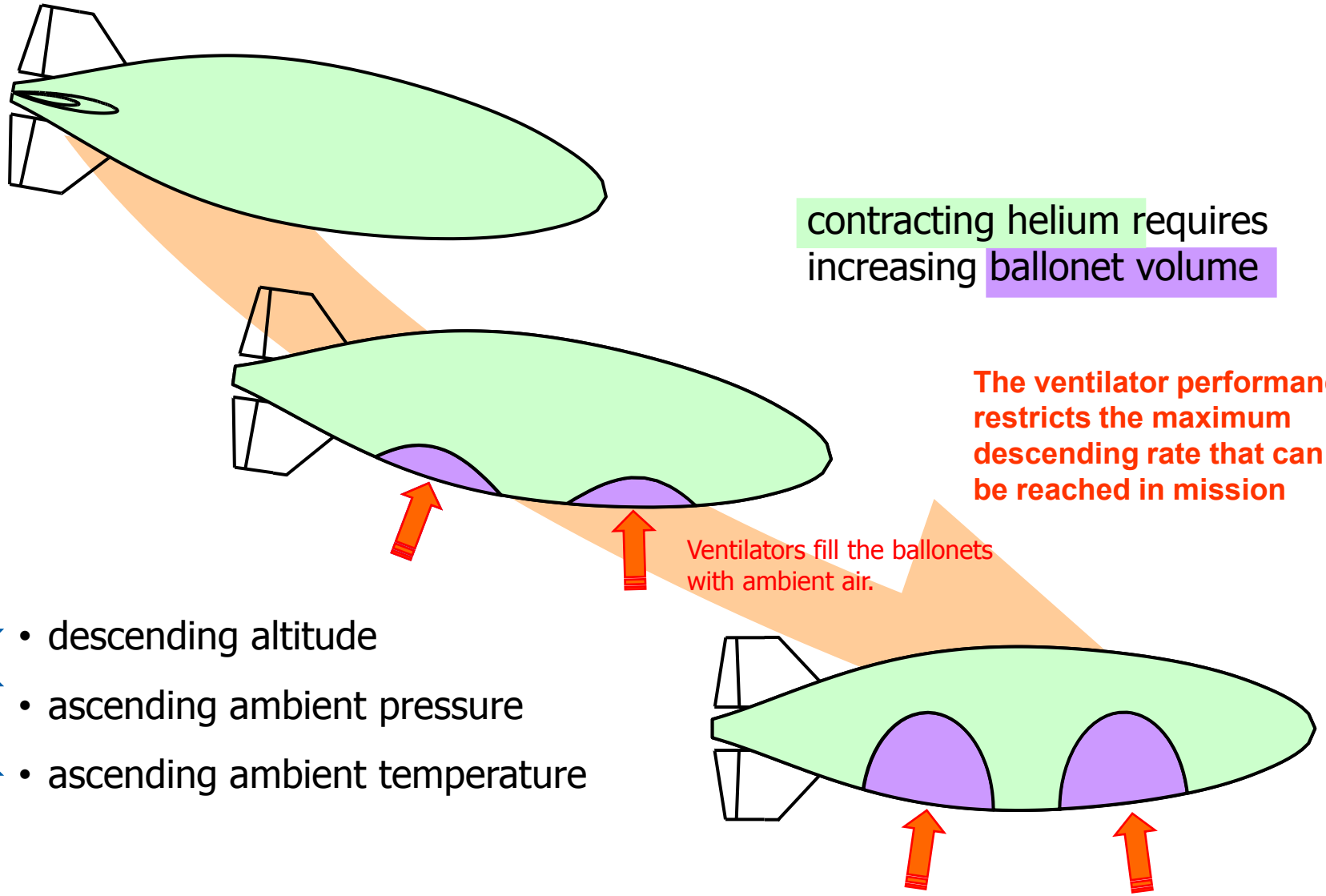
The percentage of ballonet volume restricts the maximum altitude that can be reached in mission

- ascending altitude
- descending ambient pressure
- descending ambient temperature



The ballonet air is pressed out through valves by the increasing helium pressure

Descending Flight Operations



contracting helium requires increasing ballonet volume

The ventilator performance restricts the maximum descending rate that can be reached in mission

Ventilators fill the ballonets with ambient air.

- descending altitude
- ascending ambient pressure
- ascending ambient temperature

What Happens When a Non-Rigid Blimp Fails to Maintain Proper Pressure

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Med-Altitude Airship Similarities/ Differences

Ellipsoid Class –C Characteristics

Lifting Body “Hybrid” Configuration Characteristics

Features

- Efficient Hull Shape
- Economical Operation
- Stable even at High Speeds
- Low Risk Manufacturing
- Less Fabric and Internal Structure
- Much Lower Helium Leakage
- Cheaper to Operate and Maintain
- Short takeoff / Landing Distances
- Recognized FAA Certification
- Stable Ground Handling

Considerations

- Requires Back-Haul Cargo or ballast if the cargo is off loaded
- Endurance days manned

Common Airship Elements

- Fabric Design
- Fabric Seaming
- Helium/Air Valves
- Control Systems
- Control Surfaces
- Cargo Handling
- Propulsion Engines
- VTOL Propulsor
- Equipment Load
- Control Station
- Mooring Equipment

Features

- Cargo Delivery without Backhaul or ballast
- Shorter Aircraft Length – but wider
- Better Weight Distribution
- Longer Endurance at Slow Speeds

Considerations

- Higher Manufacturing Cost / Complexity
- Higher Hull Weights
- Need FAA New Certification Criteria (2 years or more required to establish certification criteria)
- Needs long takeoff and landing area
- More difficult ground handling

US Navy Airship History

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US Navy Operations 1915 - 1962

Convoy escort

AEW

SAR

Patrol Recon (ISR)

ASW

WW II Flight Statistics

Airships: 16 in 1942, 148 in 1945

Flight hours: 545,527

Sorties: 57,710

Ships escorted: 80,038 with no losses

Over 20 airship squadrons in service at peak.

ZPG-2A With Radar Installed

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Weather Limitations

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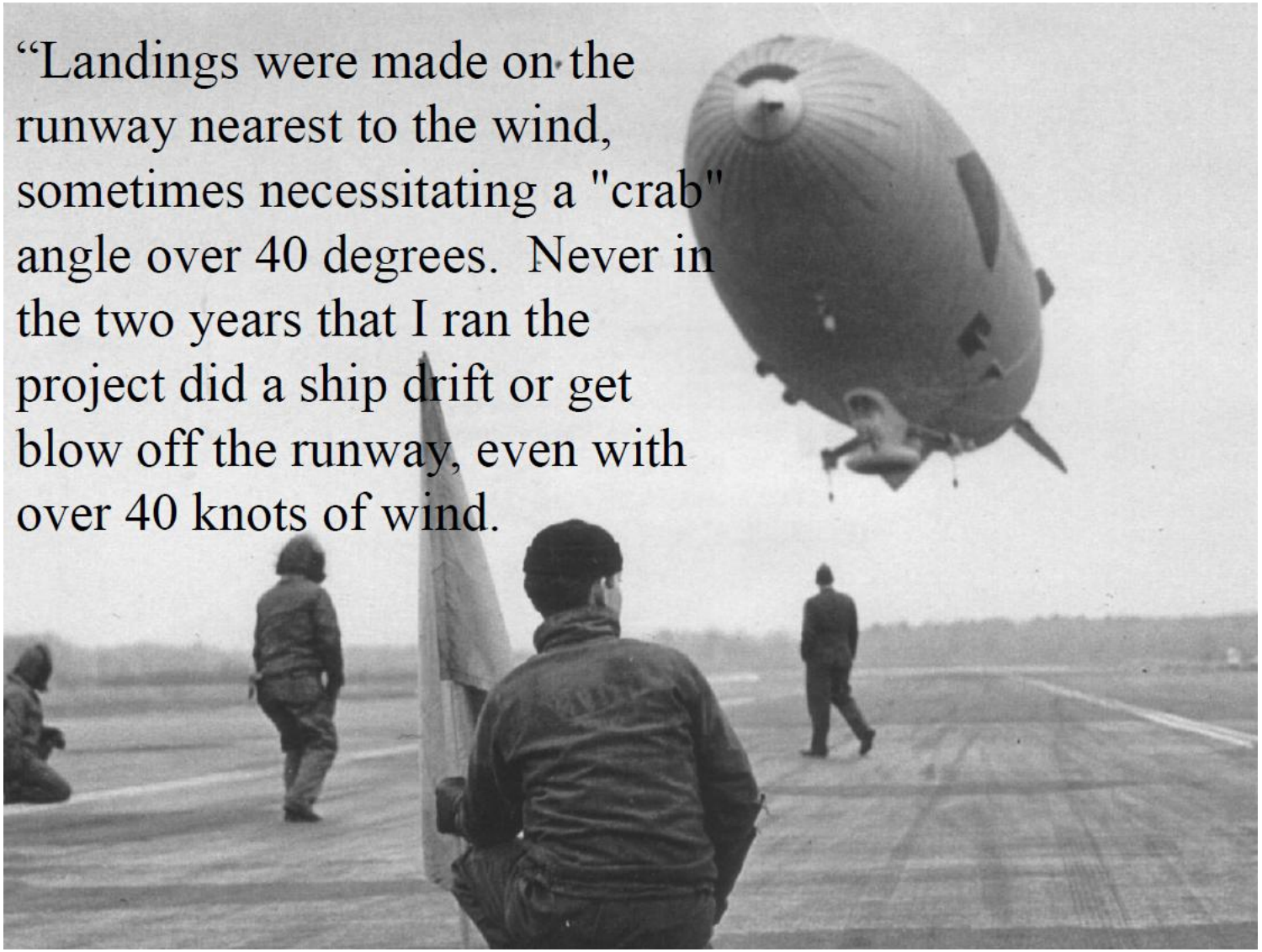
Operation "Whole Gale"

- Objective: Maintain at least one airship on station in a specified patrol area off the New Jersey coast 24/7 for a period of two months in the worst weather months of the year (winter storms)
- Achieved: Feb – 882 flt hrs; March – 765 flt hrs; aircraft availability – 87%

Weather Limitations



Weather Limitations

CDR Mills wrote, “On one flight, intentionally ascending and descending through freezing rain, about 3000 lbs of clear ice were accumulated. At no time were control or flight characteristic changed, except for the static heaviness, and the crew become adapted to flying in icing conditions.“

Comparison to Navy Airship ZPG-3
Elliptical Hull Right Answer For JPL Problem

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Navy ZPG-3 In Service 1957 to 1962

- U.S. Navy operated airships from 1915 to 1962
- 292 airships, 25 different types
- Primary Missions:
  - Coastal Patrol, Convoy Escort, Air/Sea Rescue, ASW, Mine Clearing and Airborne Early Warning
- Largest: ZPG-3W

Volume:	1,500,000 cubic feet
Length:	403 feet
Static Lift:	22,360 lbs
Crew:	25 (varied)
Max Speed:	82 kts
Normal Cruise:	45 kts

- Set world record for nonstop un-refueled flight:
  - 264 hrs. / 9,448 miles (ZPG-2 "Snowbird")

The first flight of the ZPG-3W was in July 1958. The envelope of the blimp was used as a radome for the 42 ft (12.8 m) radar antenna, thus providing the airship with a clean aerodynamic shape. Ship landed and took off with landing gear extended.

NGC M1400

Volume: 1,400,000 cu ft
Length: 370 Ft
Static Lift: >30,000 lbs
Crew: 2-3 Manned
Max Speed 80+ kts
Cruise Speed: 45 kts

Northrop Grumman's M1400 has Lighter Hull, and Stronger Structures, and a Better Pressurization Systems Yielding More Lift than ZPG-2/3

What's Different now?

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New Technologies

- Stronger Fabric – Able to hang more weight from the airship without deformation of the hull and hoop stress failure
- More Durable Fabrics – Hull fabrics leak much less and last years longer than in the past – almost maintenance free
  - Better seaming technology
  - Higher operating pressures
- Modern Control Systems that reduce the pilot load allowing the vehicles to potentially be optionally manned and flown with a single pilot
- Data Links- Reduce Crew Size
- Northrop Grumman Proven Tilt Rotor Designs

What's Missing – Very Large Efficient Flight Certified Diesel Engines

What's Not New

- Laws of Physics
- FAA Type Certification for Airships

FAA Certification Background

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Prior to 1987, there were no US Federal airworthiness criteria for type certification of airships

– Airships were built to U.S. Navy specifications, with civil approval for type certificates based on the Navy's detailed Design criteria.
– Approvals were predicated on the extensive experience of the U.S. Navy with airship design, construction, and operation
* The U.S. Navy decommissioned its last airship in the early 1960‘s, and did not resume operation of airships until 2009

US Navy ZPG-3W

Airship Certification Regulations in flux

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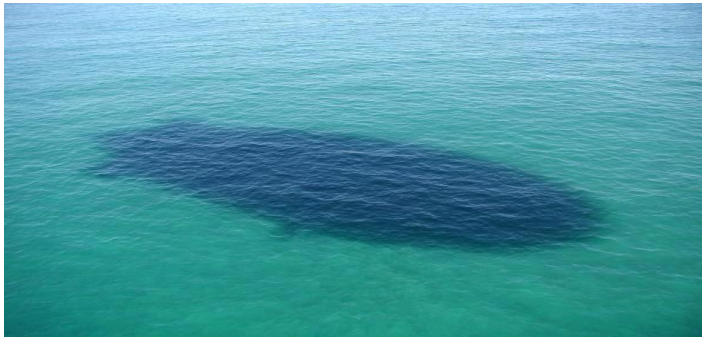
- **FAA still does not have airship Certification Regulations**
  - **"Small Aircraft Directorate" in Kansas City, MO, has overall responsibility for FAA certification of LTA vehicles**
  - **The Kansas City FAA office provides oversight of the activities carried out by the local FAA airship certification authorities**

- **The Local FAA office nearest to the airship's manufacturer's location assumes the responsibility for day-to-day interaction with airship manufacture and establishing the DER/DAR requirements for Type Certification**
  - The KC Office provides guidance and coordination with other DER/DAR and Local Activities



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Airships

http://www.faa.gov/aircraft/air_cert/design_approvals/airships/airships_regs

Regulations & Policies

Updated: June 27, 2011

Title 14 Code of Federal Regulations

14 CFR part 21, Certification Procedures for Products and Parts

14 CFR part 43, Maintenance, Preventive Maintenance, Rebuilding, and Alteration

14 CFR part 91, General Operating and Flight Rules

Advisory Circulars (AC)

21.17-1, Type Certification-Airships

Related Guidance

Transport Airship Requirements (PDF)

(Under the provisions of 14 CFR Part 21.17, it is planned that these requirements will be accepted as "airworthiness requirements")

FAA-P-8110-2, Airship Design Criteria (PDF)

LFLS - Airworthiness Requirements for the type certificate of airships in the categories Normal and Commuter

(Under the provisions of 14 CFR Part 21.17, it is planned that these requirements will be accepted as "airworthiness requirements")

Small Airplane Directorate Additional Policy for Airship Type Certification Projects (PDF), December 1, 1997

FAA Certification

FAA - ADC (Airship Design Criteria) or the German LFLS (Lufttüchtigkeitsforderungen für Luftschiffe) are very similar and provide the minimum requirements for non-rigid/semi-rigid airships.

- **§ 601 General**
- The suitability of each questionable design detail and part having an important bearing on safety must be established by tests.
- **§ 603 Materials and workmanship**
- (a) The suitability and durability of materials used for parts, the failure of which could adversely affect safety must.…
- **§ 605 Fabrication methods**
- (a) The methods of fabrication used must produce a consistently sound structure. If a fabrication process requires close control to reach this
- objective, the process must be performed in accordance with an approved process specification. b) Each new aircraft fabrication method must be substantiated by a test program
- **§ 609 Protection of structure**
- Each part of the airship must
- (a) Be suitably protected against deterioration or loss of strength in service due to weathering, corrosion, abrasion, or other causes;
- **§ 613 Material strength properties and design values**
- (a) Material strength properties must be based on enough tests of material meeting specifications to establish design values on a statistical basis.
- **§ 627 Fatigue strength**
- The structure must be designed, as far as practicable, to avoid points of stress concentration where variable stresses above the fatigue limit are
- likely to occur in normal service.
- **§ 881 Envelope design**
- (a) The envelope must be designed to be pressurized ..... while supporting the limit design loads for all flight conditions and ground
- conditions..... The effects of all local aerodynamic pressures ..... must be included in the determination of stresses at the limit-strength requirements for the envelope fabric.
- (b) The envelope fabric must have an ultimate strength not less than four times the limit load determined by the maximum design internal pressure combined with the maximum load
- (d) It must be demonstrated by test in accordance with the section Tearing Strength of the appendix that the envelope fabric
- (h) Internal and/or external suspension systems for supporting components such as the car must be designed to transmit and distribute the loads to the envelop

"The airship must be capable of rapidly restoring itself to a state of equilibrium following failure of one or more engines during any flight condition. Only designated ballast may be used!"

FAA Certification So What?

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- If an airship does not meet the FAA definition of an airship, then the certification basis becomes Title 14, Code of Federal Regulations (14 CFR) part 25 or worse.
  - Airship Cert Basis must meet aircraft standards
    - Most light weight structure will not meet material allocations resulting in significant increase in structural elements
    - Engines must be beefed up to meet stricter requirements
    - Flight Controls have added redundancy requirements and become flight critical
  - Negotiating a New Class of Transport Aircraft is a multi-year proposition

Bottom Line if the Airship does not Meet FAA requirements for Airships . . . . You'll Never Get it Off the Ground

Requirement Drivers

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- Altitude:
  - Operating Altitude Determines Ballonet Size , Increased Ballonet Decreases Helium

Sample calculation for a 1.5 M cu ft Airship

Altitude	Effective Lift
5000 ft	84651 lb
10000 ft	72975 lb
15000 ft	61299 lb
20000 ft	49623 lb
25000 ft	37947 lb
30000 ft	26271 lb
35000 ft	14595 lb

Typical Empty Weight of a 1.5 M ft^3 airship is around 20,000-24,000 lb
– Clearly a 1.5 M ft^3 can't lift itself to 35,000 ft

Above 35,000 ft Airship are Significantly Different

Speed Over Ground

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- Clearly an Airship is not very Aerodynamic, above 50 kts the horsepower requirements increase with the cube of the velocity.
  - Diesel propeller thrust typically used .39 lb or fuel per hp/hr
  - Turbo-prop typically uses .65 lb of fuel per hp/hr
  - Fuel usage depending on Altitude and speed
- Above 100 kts the issues with nose structure become more significant
- Cross wind results in large crab angles thereby reducing forward motion

Airships Have Demonstrated Arctic Operations, Station Keeping and Long Distance Patrolling with Long Endurance

Carrying Capacity

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- Airships are extremely conducive to carrying loads, the useful load of an airship is the weight of the payload, crew and fuel
  - Fuel can be traded for payload
  - Sensor can be carried on top, hung from the sides, strapped or hung from the bottom or placed inside
- An airship hull is non-conductive[1], and is RF transmissive at many radar frequencies
  - Many Airships have “housed” radar inside the envelope
    - Provision for maintenance must be design into the hull
  - Many Modern Aerostats have RADARs operating inside the hull

Best quality of an Airship is that Adding Cargo (Sensors) to the Top, Sides or Bottom Rarely Impact the Airships Flight Certification Unless the Airship Doesn’t Meet the FAA’s Definition of an Airship

[1]except in the lightning protection areas and control surfaces


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