

Airships 101: Rediscovering the Potential of Lighter-Than-Air (LTA)



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Agenda

- Intro to NASA Ames Aeronautics
- Airship classifications
- LTA Theory
- LTA Revival – Why Now?
- R&D Challenges
- LTA “Game-Changers”



Aeronautics at Ames Research Center

- Video available at:

http://www.nasa.gov/multimedia/videogallery/index.html?media_id=18992542

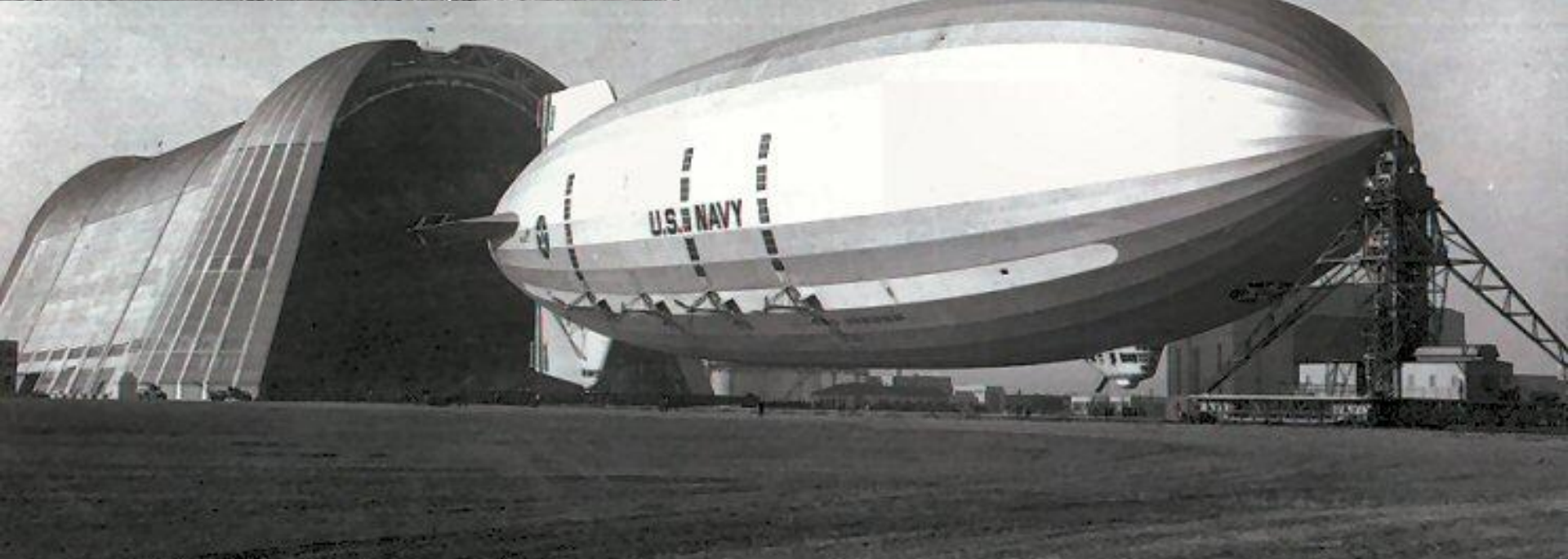
NASA Ames Airship Legacy



- Airships were focus of much early NACA work (Munk, Zahm)
- ARC home of the Macon (1933-35) and various USN blimp squadrons until 1947
- Approximately 50 research papers from the mid-1970s to mid-1980s were spawned by the energy crisis of 1973-1974
- 1970s research identified three potential LTA roles:
 - Heavy-lift airship
 - Short-haul commercial transport
 - Long-endurance naval patrol
- 1979 AIAA LTA conference in Palo Alto
- 1980s studies confirmed potential role for LTA in lifting heavy and oversized cargo
- 1980s research focused on quad-rotor + LTA concepts for heavy lift
- Minor involvement with Piasecki quad-rotor and Cyclocrane
- 1994 operations research with Westinghouse used Vertical Motion Simulator



USS Macon on Mooring Mast near Hangar 1 Moffett Field 1935



NASA Ames Federal Airfield





70+ Years of Innovation



Tektites



Apollo Re-Entry Shape



Pioneer



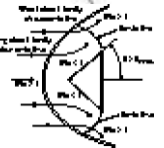
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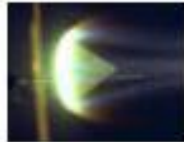
Lunar Prospector



NASA Research Park



Blunt body Concept (H. Allen)



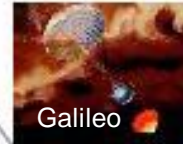
Apollo Heat Shield Tests



Air Transportation System



Tiltrotor



Galileo



Nanotechnology



World's fastest operational supercomputer

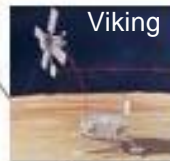
2000



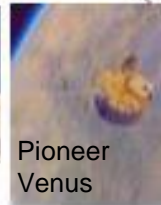
Transonic Flow



Apollo Guidance System



Viking



Pioneer Venus



Astrobiology



Human Centered Computing



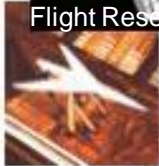
Flight Research



Flight Simulation



Hypervelocity Free Flight



Swept-Back/wing



Lifting body



Computational Fluid Dynamics



Kuiper Observatory



X-36

1990



Conical camber

Arcjet Research



Life Sciences Research



80x120 Wind Tunnel

1950

1960

1970

1980

Ames Spacecraft and Aeronautics Expertise

- Inflatable (Fabric) and Lightweight Structures
 - Advanced FEA tools: LS-DYNA, Abaqus, NASTRAN
- Piloted Simulation requiring Vertical Motion Sims
 - Helicopters, Moon landers
 - Controls development for VTOL aircraft
- Aerodynamics Design, Analysis, and Test
 - CFD tools: OVERFLOW, STAR-CCM+
 - Large wind tunnels, Supercomputers



LTA vehicles face many of the same engineering challenges that confront current NASA Ames aircraft AND spacecraft programs

Airships 101a

LTA Taxonomy and Theory

Aircraft Taxonomy

Aircraft

Heavier-Than-Air
(HTA)

Lighter-Than-Air
(LTA)

Fixed Wing
(Airplanes)



Rotary Wing
*(Helicopters /
Autogyros)*



Hybrid
(V-22)



Powered Lift
(JSF)



Unpowered

Untethered
(Balloons)



Tethered
(Aerostats)



Powered and Steerable
(Airships = Dirigibles)

Conventional
(Fully buoyant)

Rigid

Semi-rigid

Non-rigid



Hybrid
(Semi-buoyant)

Rigid

Semi-rigid

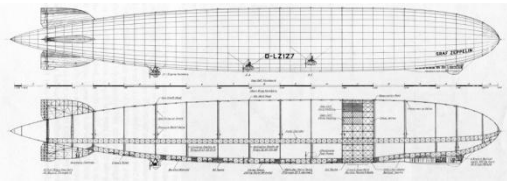
Non-rigid



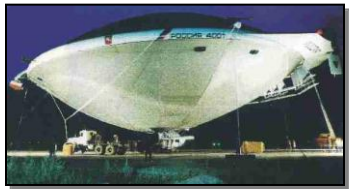
Airship Examples



AMS Skyship 600 Airship



Graf Zeppelin LZ-127



Russian Lenticular Airship



21st Century Airships
Spherical Airship



hybrid-winged concept



Lockheed ADP P-791

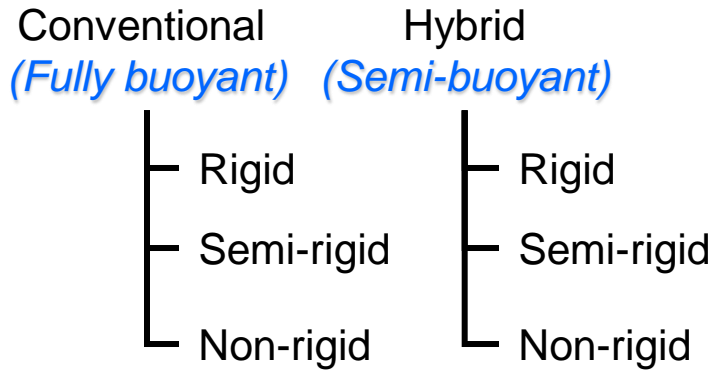


Piasecki PA-97 Helistat



BOEING SkyHook

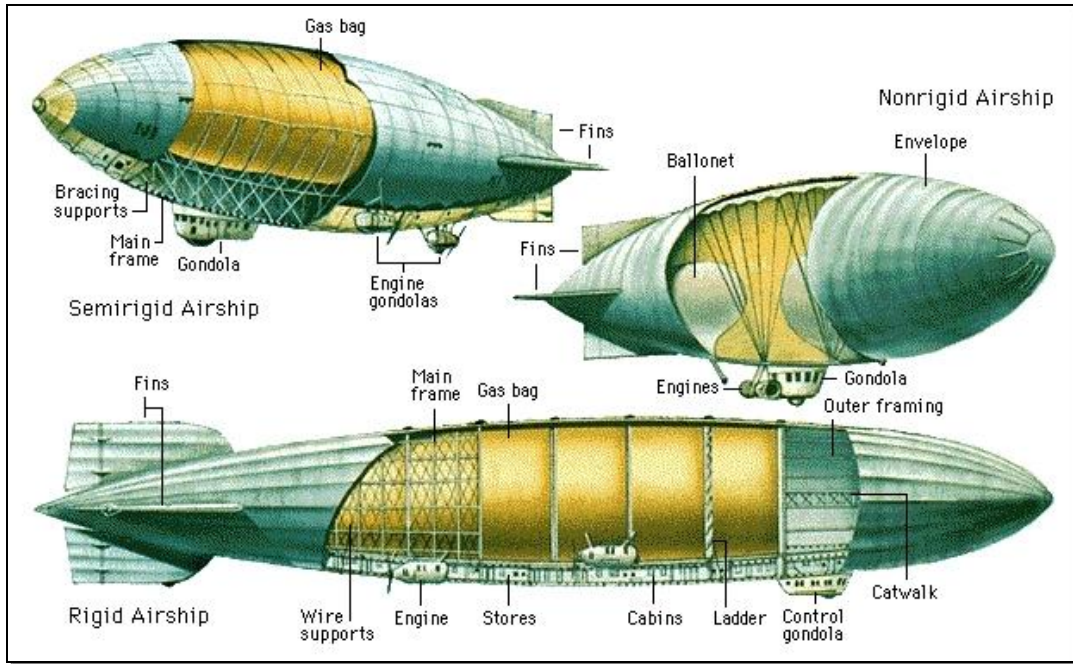
Powered and Steerable
(Airships = Dirigibles)



Design space for LTA is at least as large as HTA, but has only been “randomly sampled” with flight vehicles spaced over decades

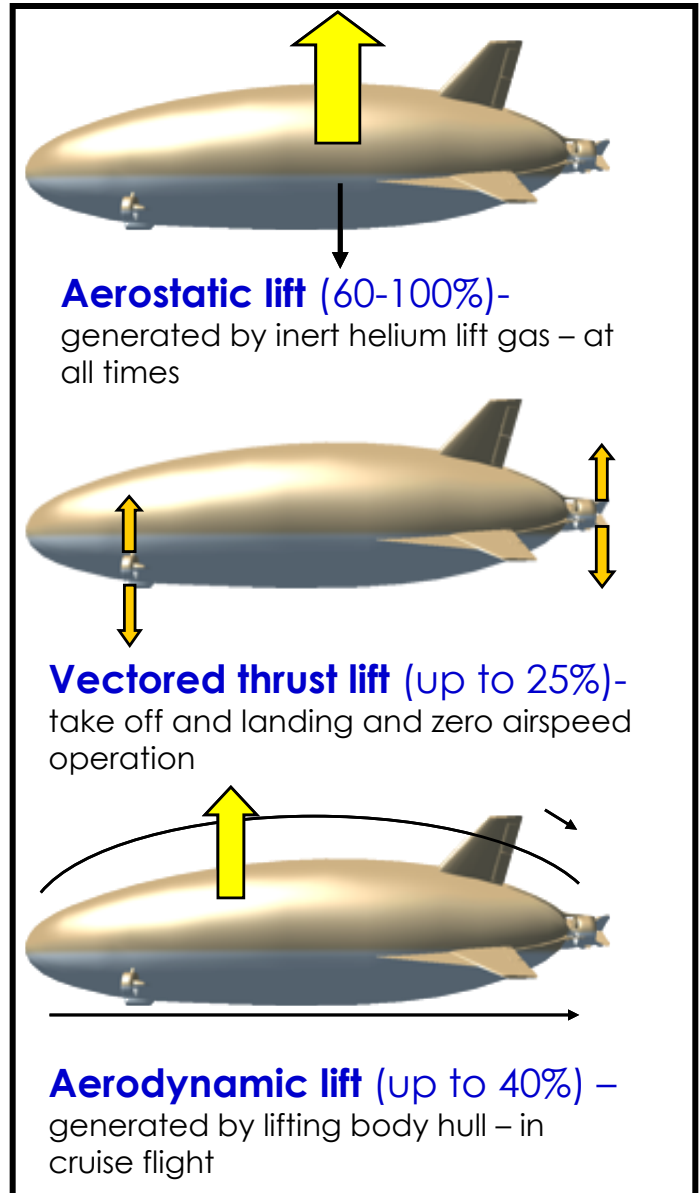
LTA engineering is MUCH broader than the Hindenburg (LZ-129) and Goodyear Blimp

Conventional and Hybrid Airships



Conventional airships control heaviness by changing aerostatic (buoyant) lift and ballast

Hybrid airships combines aerostatic (buoyant) lift with aerodynamic lift (wing-borne) and direct (propulsive) lift



LTA Theory

- Lifting force from displacement (Archimedes, 287-212 BC)

- Useable Lift = $\underbrace{\text{Vol} * (\rho_{\text{He}} - \rho_{\text{air}}) * g}_{\text{Displacement Lift}} - W_{\text{dead}}$

- Hydrogen (H₂): 70 lbf per 1000 ft³ (1.14 kg/m³)

- Helium (He): 65 lbf per 1000 ft³ (1.06 kg/m³ or 93% of H₂)

- Dead weight historically > 50% of displacement lift

- Hindenburg (H₂): 54%, 260K lbs Dead, 220K lbs Useable

- Fuel, ballast, crew, consumables further reduce useable lift available for cargo

- Lift, Drag, Weight, and Thrust still apply – but apparent mass, buoyancy control, and ballast complicate design

Airships 101b

LTA Revival and Missions

Reviving the LTA Dream – Why Now?

- Commercial – the “E’s”
 - Environment, Emissions, Energy, and Economics
 - New market opportunities
 - New aerospace exports
 - Endurance for scientific and commercial missions
- National Security
 - DoD transport and surveillance needs
 - Homeland security
 - Humanitarian airlift



There are numerous LTA missions besides tourism and advertising!

Environment, Emissions, and Energy

- Low noise
- Pavement “optional” – concrete not required
- Reduces port, freeway and railway congestion
- Reduces cargo aircraft at airports, reducing ramp/taxi delays and emissions
- Utilization of secondary airports and shallow ports
- Operations at lower altitudes reduce air traffic conflicts
- Large size and low speeds promote autonomous operations



Airships have minimal infrastructure requirements and their low-altitude operations are inherently green

Environment, Emissions, and Energy

- Safe, convenient, airborne platform for the development and demonstration of green propulsion technologies: biodiesel, electric, solar technologies
- Emissions restrictions:
 - will continue to tighten
 - provide barriers to trade
 - may supercede fuel costs
 - are aviation's biggest environmental challenge
- Low altitude operations eliminate high-altitude aviation emission concerns



Unlike 1973-74, emissions will become increasingly important regardless of short-term oil price trends. Airships can stimulate the development of low-power green aviation prototype propulsion systems

Environment, Emissions, and Energy

- Dramatically reduced power requirements

$$\text{Power} = D V = \frac{1}{2} \rho_{\text{air}} S C_D V^3 = \text{Fuel Flow/SFC}$$

- Uncertain future of oil prices and supply
- Energy independence is a national goal
- Speed will likely become MUCH more expensive due to rising energy costs and emissions
- Strong arguments for LTA in 70s and 80s...
 - NASA CR-2636, 1976 “Cargo Transportation by Airships: A Systems Study”
 - NASA TM 86672, 1984 “Missions and Vehicle Concepts for Modern, Propelled, Lighter-Than-Air Vehicles”

Modern airships can be a component of GREEN aviation

C-130, C-17, B747-400 and Hindenburg

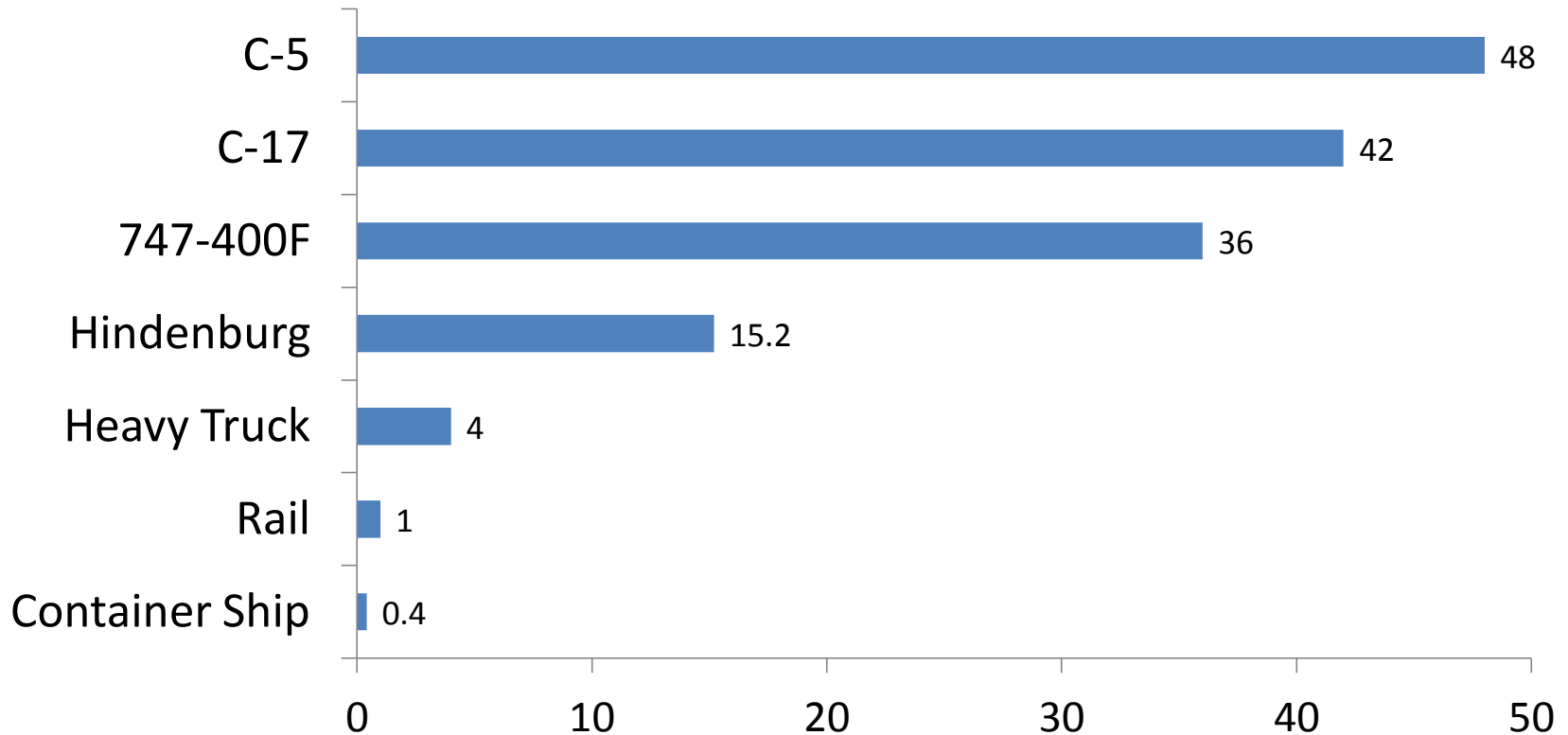
	C-130	C-17	B747-400F	Hindenburg
Fuel + ballast (tons)	32	119	200	53+16
Cargo (tons)	22	85	124	43
Useful Lift (tons)	54	204	324	112
Range (miles)	2360	2785	5120	6840
Fuel/cargo-kmile	0.62	0.50	0.31	0.18
Power (hp)	4x4300		4x22000	4x1200
Speed (mph)	460	518	560	90

Data is VERY approximate and from multiple sources

- LTA can be VERY competitive on fuel use
- If Hindenburg ballast is considered cargo, F/c-km = 0.13
- Productivity comparisons *must* include speed differential

Relative Cargo Transport Fuel Efficiency

Energy per Cargo ton-mile
(Relative to Rail)



Advanced cargo airships will be the only aircraft capable of approaching trucks in freight fuel efficiency

Economics

- LTAs open trade and supply routes to regions lacking surface transportation infrastructures
 - Logging
 - Mining
 - Oil exploration
 - Arctic/Africa/Asia and others
- Satellite surrogate, WiFi/Broadband relays
- Short haul passenger transport/feeder
- New class of aerospace vehicles for export (aka, *jobs!*)

Airships can promote new markets for US exports and service environmentally sensitive and remote regions

Transport Airship Markets

- Short distance movement of cargo, equipment, and supplies
 - Direct delivery of materials, equipment, prefab structures, etc...for roadway, rail, port, bridge, and building construction projects
 - Reduces ground footprint and disruption to areas surrounding construction sites compared to conventional approach
 - Permits “just-in-time” movement of materials and supplies;. reduces on-site storage, shortens project schedules, and reduces project costs
 - Moving cargo where deep water port facilities aren't available
- Long distance freight transport
 - Transport between multi-modal shipping centers (trucking terminals, etc.)
 - Transport within transportation poor developing countries
 - Transport into and out of remote or otherwise inaccessible regions



Ship Handling Facilities



Heavy Lift Helicopter



Drilling Rig Assembly



Canadian Ice Road

DoD Mobility Needs

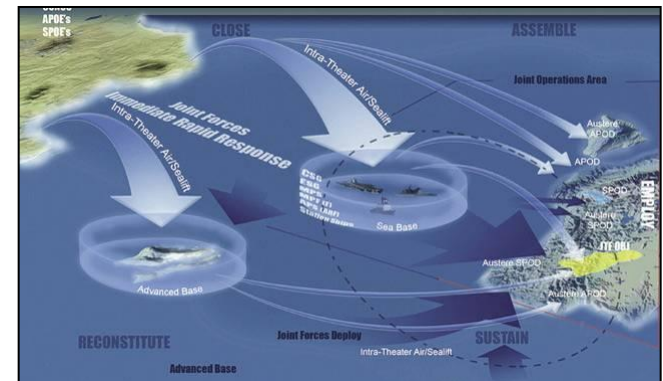
- Insert materials into critical points that can't easily be reached
- Provide additional deployment lift for current force
- Service Operational Concepts + Network-Centric Operations (NCO)
 - Reduce number of moves required in the Area of Operations
- Move new things in new ways (support to Seabasing concepts)
- US forces need advantage of adaptive power projection
 - Bypass choke points
 - Deliver intact capabilities at multiple entry points
 - Maintain uninterrupted deployment momentum
 - Move select air cargo forward from last secure area
 - Minimize surface convoys
 - Avoid IEDs and ambushes



Army Surface Convoy



Vertical Ship Replenishment



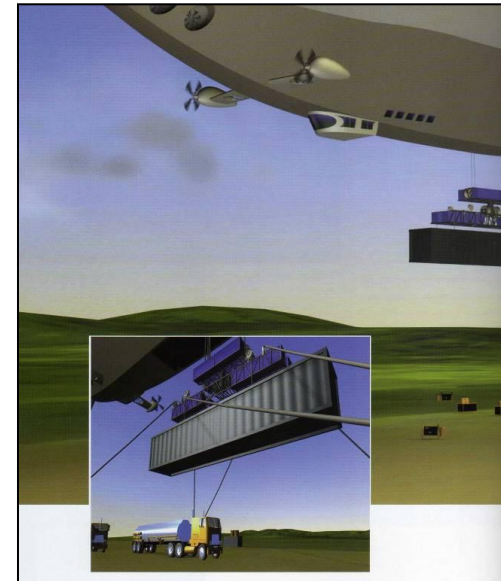
Seabasing Overarching Concept

2005 CAA Transport Airship Study

- Heavy lift airships are feasible with current technologies up to around 90 tons
- Follow on development to larger sizes require timed S&T investments
 - 5 years and 8 years for two distinct development phases
- 12 years development to achieve conventional airship with 360 tons lift
- 18 years development to achieve hybrid airship with 450 tons lift
- Commercial market demand is strongest for project freight
 - Ranges for commercial demand are 25 to 250, and 400 to 800 miles
 - Ranges for military demand are 400 to 800 miles, and (1,000 to 3,000 miles)
- Recommended airships be commercially developed, for lease to DoD



ATG SkyCat-1000 Hybrid Airship Concept



CargoLifter CL-160 Aerial Crane Airship Concept

Major Project Freight Applications

Oil and Gas Pipeline Construction

- In-land logistics (from main entry port) is 25% of construction costs
- 90% of cost is just moving heavy equipment, materials, and consumables up and down the project right of way
- For typical 52" pipeline, this is \$100 -150 million per 1000 km of pipeline
- \$100 to 120 billion in pipeline projects scheduled over next 10 – 15 yr



Pipeline Right of Way

Logistics Support to Canada

- University of Manitoba study shows interest in airships for shipping fuel
- Forecast for transport airships in Canada alone could range between 185 to 635 airships, of 50 metric tons lift



Canadian Diamond Mine



Canadian Ice Road Truck

Vertical Lift for Precision Positioning



MAGLEV Pylons and Rail Segments

- Installing pre-fab windmills and geothermal generation equipment in optimized locations
 - Electrical grid installations
 - Towers, transmission lines, switches, transformers, etc.
 - High speed rail components
-
- Supports regional movement of equipment which otherwise must be moved by conventional means
 - Airship transport reduces handling steps, point-to-point distances, overall transport time, and overall expense
 - Vertical lift airships can deliver and install temporary capital equipment to meet cyclical industrial production demands
 - Production equipment and facilities can be leased on as needed basis
 - Reduces investment commitment and financial risks
 - Encourages industrial expansion, and economic growth



Generator Moving Through a Village



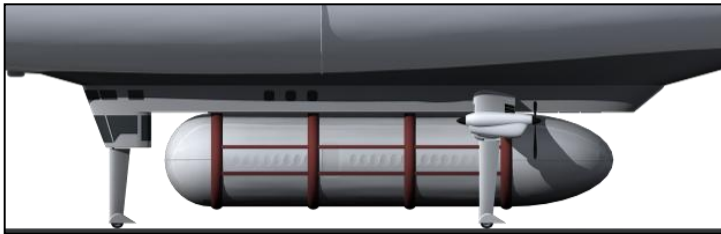
Crane Hoisting Propeller onto Windmill

Outsized Freight and Load Exchange Handling

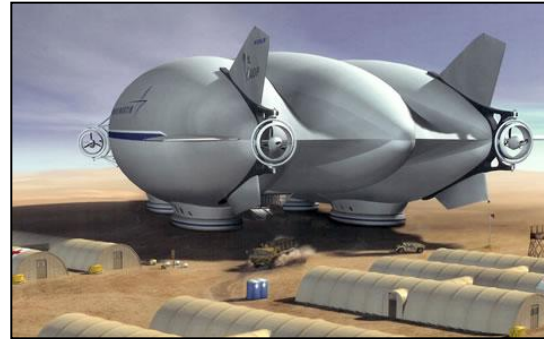
- Internal winch in gondola can accommodate high point loads
 - Supports sling loads and palletized freight
- Wide landing gear stance can handle outsized payloads
 - Extended fixed landing gear provides ground clearance for large outsized items
- Internal payload bays can be equipped for roll-on-roll-off load handling



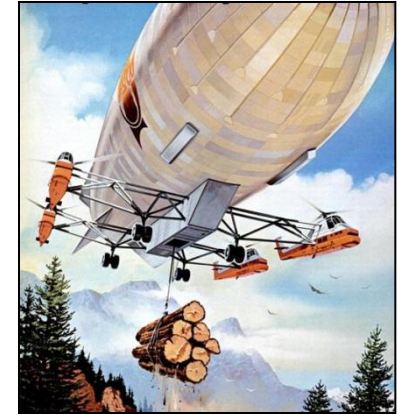
Airship with CONEX boxes



Airship with 20 ft. diameter aircraft center body



Roll-on-roll-off loading systems



Rotary airship with sling load

- Payloads can attach to flat underside of gondola
 - Handle standard CONEX boxes
 - Accommodate specialized cargo
 - Lightweight composite boxes allow more payload weight
 - Roll on, roll off boxes can facilitate quick movement of wheeled loads
- Initial operations can utilize ballast exchange
 - Pre-loaded ballast bags can be winched or loaded into gondola structure
 - Facilitates quick payload/ballast load exchange in austere areas
 - Ballast environmental issues minimized in short distance operations within region
- NASA Ames R&D needed to facilitate development of optimal buoyancy control system

Why aren't there more Cargo Airships?

- Many cargo airships have been proposed but have failed to succeed or have yet to come to fruition for various reasons
 - Inadequate program funding and resources
 - Poor management practices
 - Shortage of designers and engineers with unique airship skills
 - Insufficient customer input on airship design and operation
 - Unmanageable gap between airship capabilities and customer expectations
 - Excessively short or unachievable development schedules
 - Investor or customer impatience with airship development time and costs
 - Reluctance by investors and customers toward staged development approach
 - Schedule delay or increased costs due to unanticipated technical obstacles
 - Investors and customers impatience with airship technology R&D efforts to reduce future program risks
 - Unfamiliarity by aviation authorities with factors governing airship design, operation, and promulgation of appropriate regulations

What is the Right Size for a Cargo Airship?

- The technology and engineering expertise to design and develop large cargo airships is available today
- But what airship size and performance capabilities are required?
 - Choose too large and it's too costly in time and money to develop
 - Choose too small and it's economic utilization is too limited for markets
- What is the performance “sweet spot” for a successful cargo airship?

Cargo airship requirement considerations:

- Cargo airships need the right mix of mature technologies and advanced technologies
- Payloads need to meet the freight shipment sizes preferred by customers
- Utilization rates must be high to maintain operational profitability
 - The shorter the distances, or greater the speed, the greater the utilization
- Freight transport costs must be attractive compared to current alternatives
- Should accommodate current cargo shipping systems preferred by customers
- Have the capability of operating at well developed sites (airports) and austere sites
- Facilitate ease of operation and maintenance in remote areas
- **MUST MAKE MONEY FOR ALL PARTICIPANTS!**

Customer and User Inputs Needed

Alaska and Canada are the best initial markets for cargo airships

- **Designers need user inputs to develop the right airship and operation**
 - Cargo types, sizes, and weights
 - Priorities for freight type, delivery locations, and schedule
 - Critical cost points for freight and delivery locations
 - Specific cost factors that govern airship operations
 - Local cost and availability of airship fuel
 - Manpower costs for experienced aviation crews (flight and ground)
 - Local weather and site info on proposed airship cargo delivery areas



Airships 101c

Research, Challenges, and
Technology “Game-Changers”

LTA Research Opportunities

- Incorporation into future airspace
 - Utilization of secondary airports
 - Impacts of low-altitude operations
- Lightweight structures (design, analysis, fabrication)
- Materials (engineered fabrics, composites)
- Controls and Dynamics, especially near ground
- Ground operations
- Drag reduction, BLC, and synergistic propulsion
- Thrust vector control
- Showplace for green power sources (solar, biodiesel, hydrogen, fuel cells, etc.)
- Localized weather prediction

LTA Research Challenges

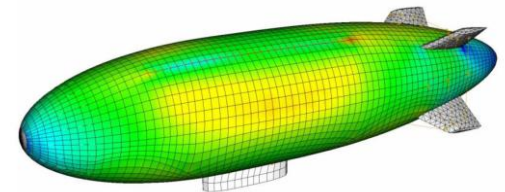
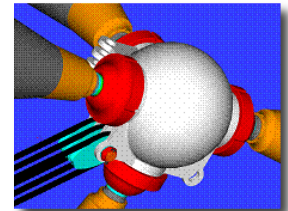
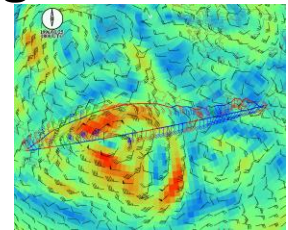
- Few modern examples, difficult to predict ultimate economic success
- Large lightweight structures are historically risky to build and fly
- Competition with HTA and surface transport industry
- Hindenburg imagery, public confusion of He and H₂
- Speed and Size do matter - must successfully match vehicles, cargo, and missions for economic success
- Weather and ground handling
- Conveying seriousness of emissions and environmental challenges
- Small number of LTA engineers
- LTA not included in aerospace engineering curriculum
- No existing national LTA “culture” (as compared to HTA)
- Existing LTA infrastructure (hangars) in disrepair...

LTA Engineering

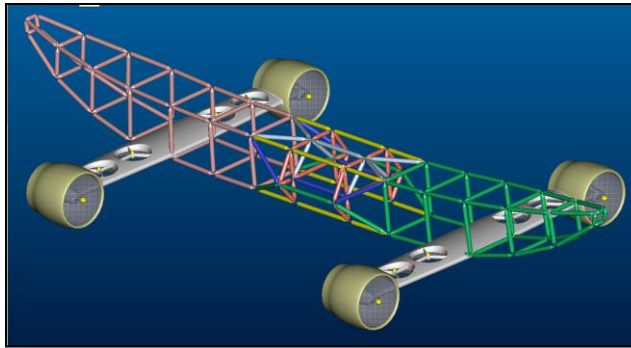
- Modern LTA can capitalize on advances in:
 - Materials and instrumentation
 - Digital/optical electronics and computers
 - Structural design, analysis, and testing
 - Aerodynamic design, analysis and testing
 - Digital control
 - Fabrication and advanced manufacturing
 - Weather prediction and avoidance
 - Propulsion system efficiencies
 - Systems engineering processes

LTA “Game Changers”

- Eliminating Ballast: Buoyancy control via compression/cooling
 - Regulations governing brown/foreign water disposal
 - Heaviness avoids the cargo/ballast matching required during offloading
 - Availability of ballast materials in remote areas
- Ground handling: Control systems, thrusters, micro-climate
- Emissions: Solar cells, biodiesel, fuel cells, ocean sailing
- En route weather information and path optimization
- Autonomous capabilities
- Electrochromic paints
- Distributed, synergistic propulsion reduce P_{req} by additional 30%
- Materials: Engineered fabrics, composite structures
- Advanced structures and engineered materials
- Lifting gases: H_2 , H_2 encased in He, Hot Air, Steam
- Analysis and Design Tools: CFD, FEA, Controls

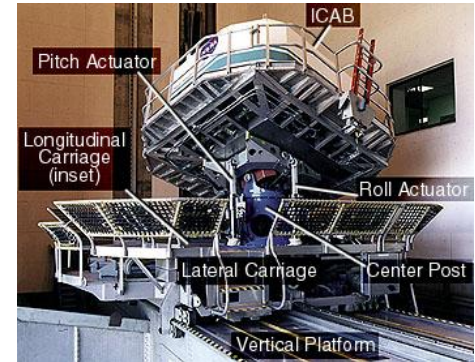


NASA Ames Airship Analysis



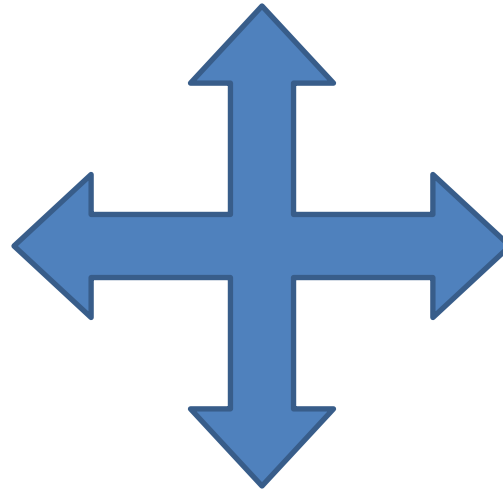
Structures

- Design and Analysis
- Testing and Instrumentation
- Materials



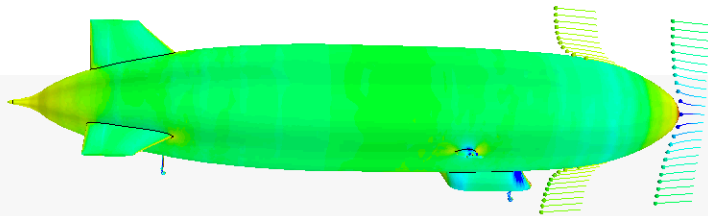
Aerodynamics

- Steady Loads Estimation
- Performance
- Gust and Fin loads



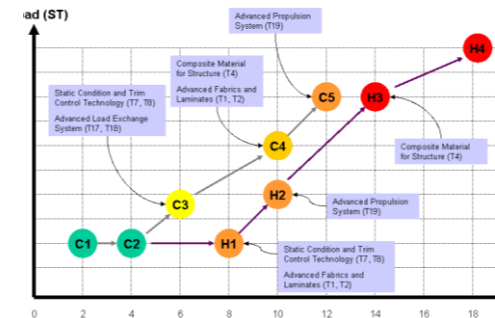
Flight Simulation

- Handling Qualities
- Controls Development
- Mooring
- Buoyancy Management
- Vectored thrust



Mission Analysis

- Airspace Operations
- Cargo Handling
- Risk Analysis



Conclusions

- LTA remains one of the last unexploited aviation frontiers
- LTA is the most environmentally responsible aviation transport technology
- LTA vehicles face numerous challenges, but today's technologies can provide the solutions
- LTA vehicles offer significant, game-changing capabilities for major economic and social advances