Ultra-HALE™ UAVs and Zero-Carbon Air Transports

A Presentation Prepared for

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by

S. Paul Dev

D-STAR Engineering Corp. / AurAayan Aerospace Divn.

4 Armstrong Road, Shelton, CT 06484

Ph : 203 925 7630 x 101; Mobile : 203 915 3166

Fx : 203 925 7631; em : SPaulDev@DStarEngineering.com / SPaulDev@gmail.com

Outline

1. **Ultra-HALE™ UAVs : Applications and Challenges**

2. **'Blimps' and 'Ribbon Wings', their Handicaps**

3. **Defining the Optimum Shape**
   Empirical Data Analysis for Airships
   Parameter Analysis for Generic Shapes : Finding the "Knee" of the Curve
   The Good, the Bad, and the Ugly : The Overall Goodness Score

4. **Ultra-HALE™ by D-STAR / AurAayan**
   A Shape for Each Application, Ultra-HALE™ for the HALE Missions
   Some Technical Features (Details not approved for Public Release)

5. **Directions for Future Transport Aircraft**
   From 'Tube-and-Wings' to Blended Wing-Body Aircraft
   Replacing Petroleum (Jet-A) by Hydrogen.

UAVs : Applications and Challenges

Shephard UV Handbook 2008 :

80 UAV Models in Production + 90 UAV Models Under Development.

UAV Applications :

Defense-related Surveillance / Force Protection (Bases, Shipyards, ...)

Interdiction of Drugs, Illegal Aliens, Terrorists

Emergency Response, Monitoring of Calamities and Natural Resources

Monitoring and Real-Time Vectoring of Road Traffic

Protection of Oil Fields, Refineries, Pipe Lines, Construction Sites
Airports, Shipyards, Railroad Tracks, Water & Electric Supplies
Tourist Resorts, Large Hotels, Upscale Residential Areas.

Communications : Wireless Broadband Networks

On-Demand / Versatile Cell Phone Networks (Hurricanes, Power Outages).

UAVs : Applications and Challenges

Limited Time on Station Increases UAV numbers, Initial Costs.

Limited Endurance Causes Logistics Headaches
(Launch and Recovery Facilities, Personnel to Fuel and Prep UAVs),
Increases UAV Life Cycle Costs.

Climb Out and Landing Gives Away Launch Sites,
Makes them Vulnerable to Hostile Action.

Climb Out and Landing Creates Traffic Conflicts
with Helicopters, Other Aircraft.

Low-Altitude Transition Makes UAVs Vulnerable to Weather.

The Unblinking Eye in the Sky is What Every Operator Wants.

The Solution : Ultra-HALE™ (High Altitude, Long Endurance) UAVs.

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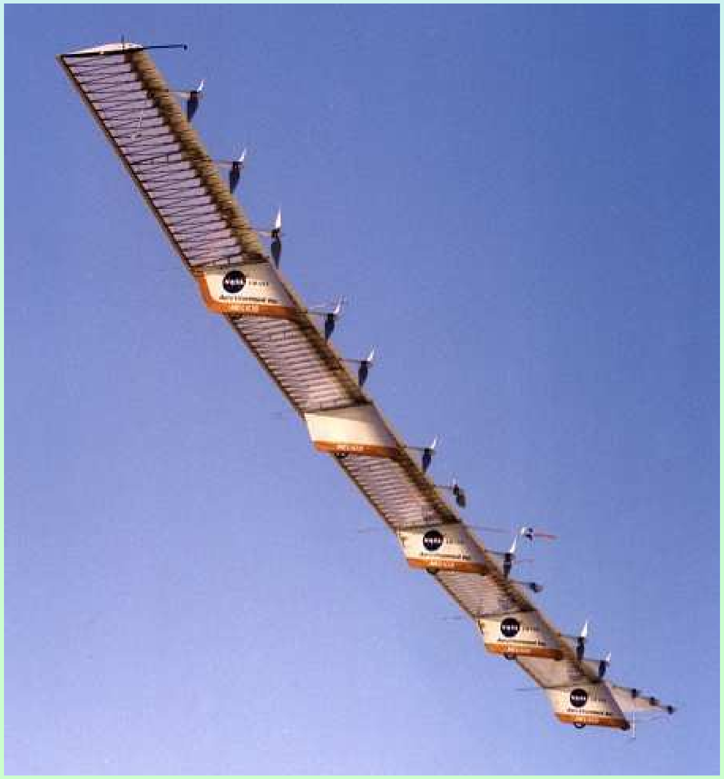
Traditional HALE UAVs : **‘Blimps’ and ‘Ribbon Wings’** (the two extremes)



Progress Made in Airships / Buoyancy Devices

Anglo-American DH-4, **1918**

Current Fighter : F-22

French-American Caquot 'R', **1918**

Now in WPAFB Museum

Current Blimp (Aerostat)

Now in Iraq

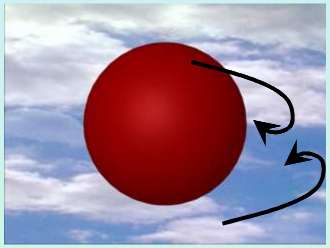
Blimps for HALE : e.g. the Lockheed Akron System

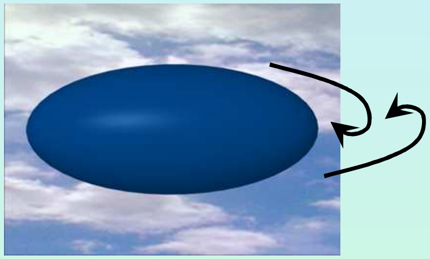
Basic Premise :

Flight Requires Power to Overcome Drag : Form Drag + Drag due to Lift.

Buoyancy Can Eliminate Drag Due to Lift (a.k.a. Induced Drag).

Hence Airships Will Need Less Energy to Fly.





Problem :

Airships have Zero or Small Induced Drag,

but have Much Larger Frontal Area, Much Larger Skin Friction Area,

Much Larger Form Drag, Equal or Larger Overall Drag.

Drag, and Power to Overcome Drag, are Not an Issue when the Airship is Still,

But, are a Major Concern when the Airship Needs to Resist Winds, or be Relocated.

Blimps are Not the Optimal Shape for Airships (**Lenses Are**!).

Pure Buoyancy Systems are Not the Optimal Solution for HALE (**Hybrids Are**!).

High Aspect Ratio 'Ribbon Wings'

Basic Premise :

Large Span Minimizes Induced Drag,
Small Wing Area Minimizes Skin Friction Drag.

But,
Large Span Creates Structural Difficulties.
Mitigated by Span Loading, by Use of Multiple Motors and Propellers.
However, Multiple Small Motors and Propellers are Less Efficient (low Re Numbers).

Small Wing Chord also has Low Reynolds Number, which Causes :
Larger Skin Friction Drag Coefficient,
Larger Pressure Drag Coefficient (Laminar Separation).

Small Wing Area Reduces Area for Solar Harvesting, and Reduces Available Power.

Smaller Wing Thickness Reduces Wing Bending Strength, Increases Weight.

Smaller Chord, Smaller Thickness Reduce Internal Volume
(a Handicap for Internal Fuel Storage).

High Aspect Ratio 'Ribbon Wings' vs. Blended Wing Body

Old Objective :

Minimize Power for Flight.

New Objective :

$$\textbf{Maximize Power Ratio} = \frac{\textbf{Power that Can be Harvested and Stored}}{\textbf{Average Power Consumption}}$$

Compared to a Ribbon Wing UAV, a BWB UAV with 2x longer Mean Chord,
Despite 50% increase in Gross Weight and Fixed Span, offers :
≈ 22% better Power Ratio, 100% Greater Gross Power, 300% better Volume for GH_2.

Propulsion Systems

Conventional Approach : High-Speed Motors and Geared Propellers

High-Speed (Light-Weight) Conventional Electric Motors

Geared Down to Large, Low-Speed Propellers (for low-speed flight),

Conventional Oil-Lubricated Bearings.

Gears Cost Weight and Efficiency Penalties.

Oil Lubrication has Reliability Concerns.

Oil Needs Replacement;

Oil Change Interval in Cars is ≈ 5,000 miles @ 50 miles/hour, or ≈ 100 hours.

5 year UAV mission needs maintenance interval = 44,000 Hours.

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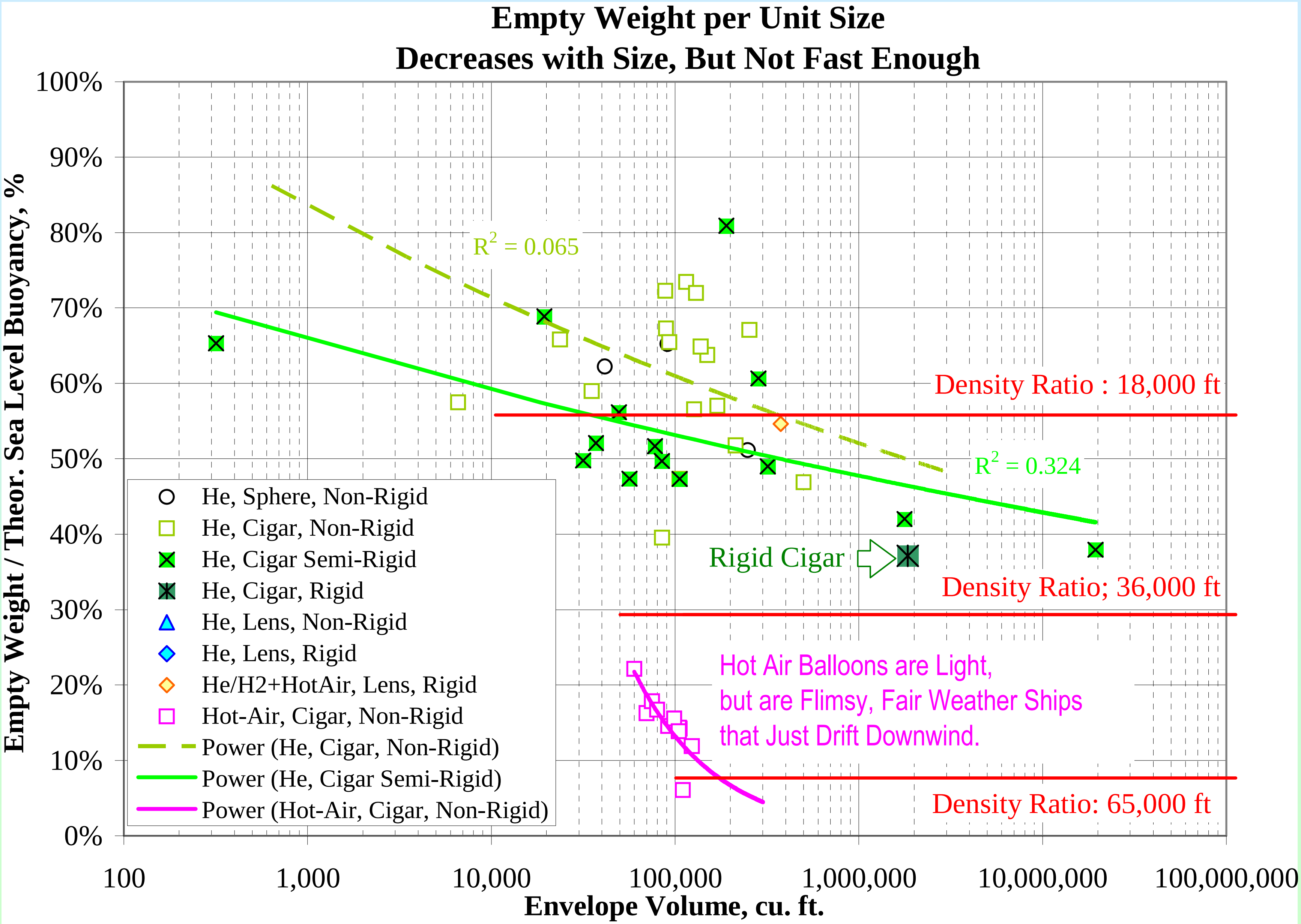
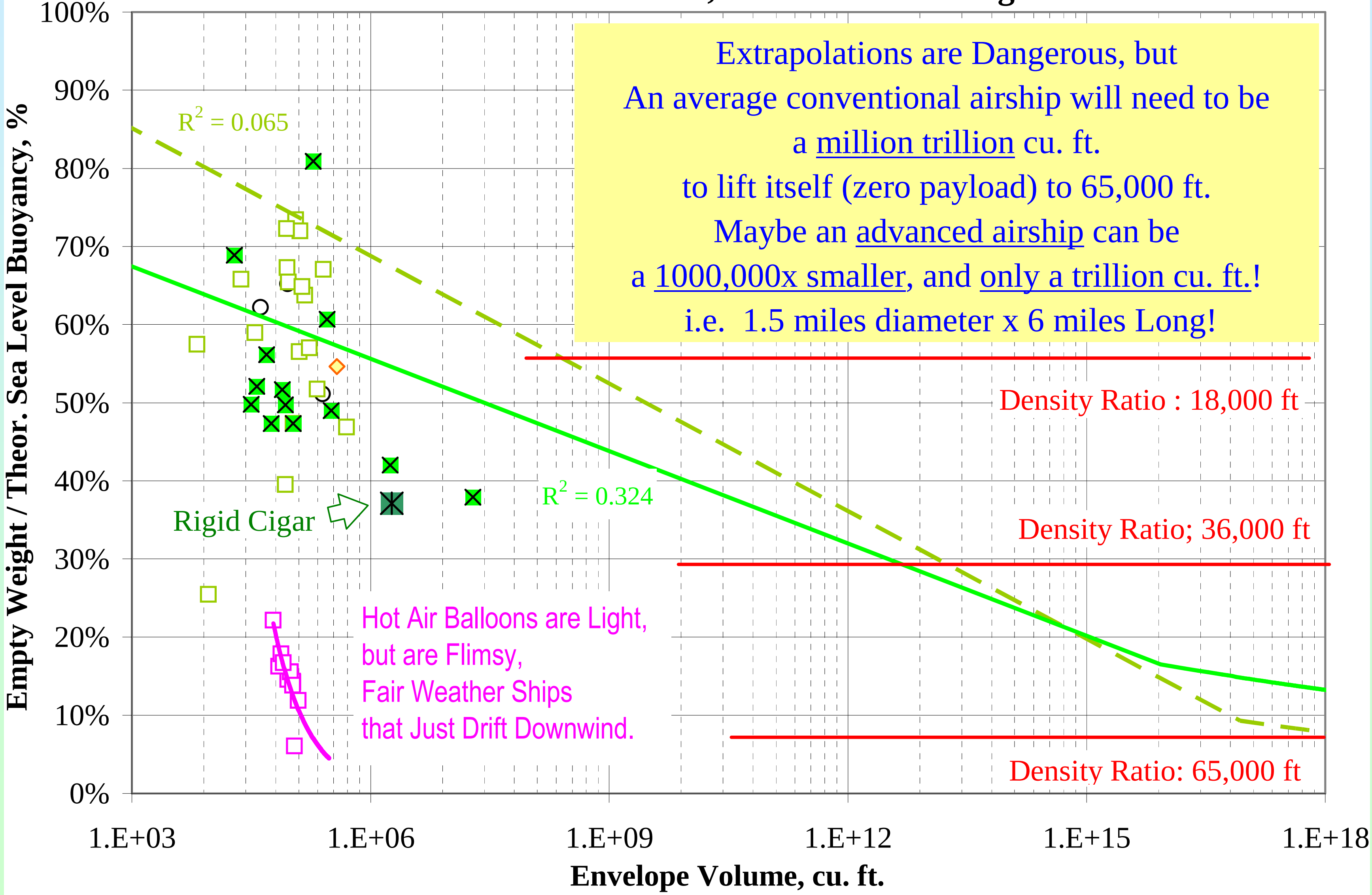
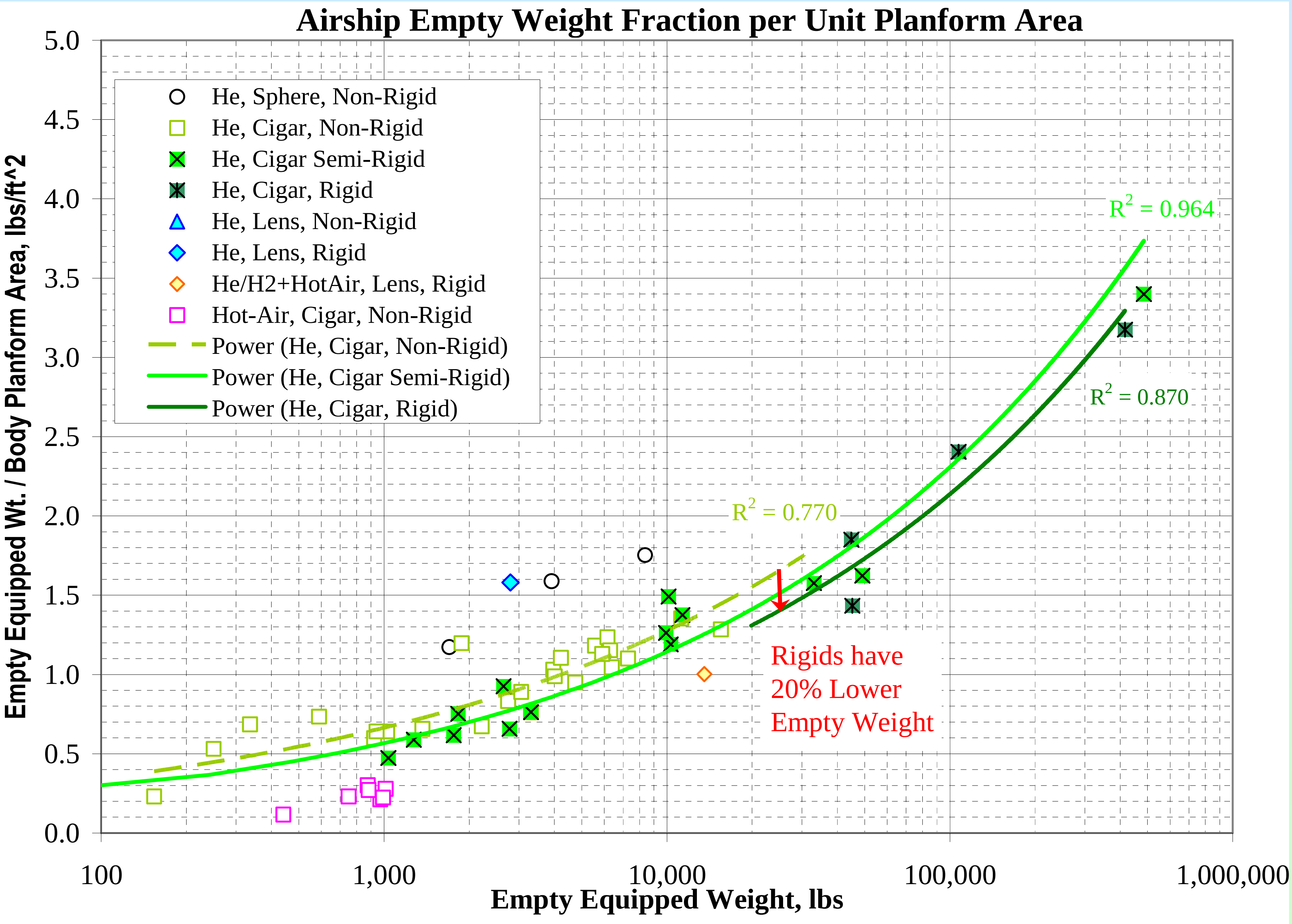


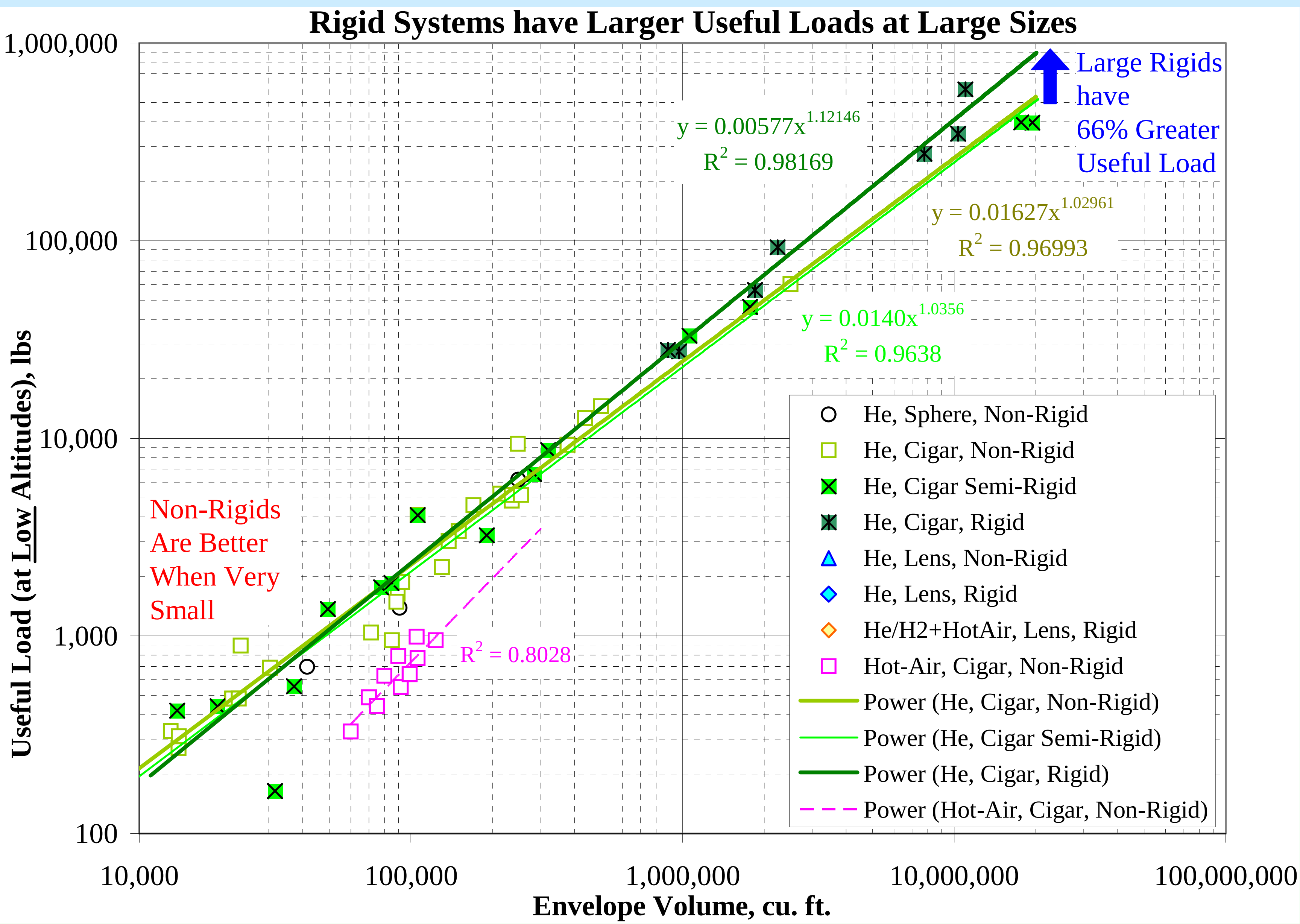
Empty Weight per Unit Size
Decreases with Size, But Not Fast Enough
Empty Weight / Theor. Sea Level Buoyancy, %
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
100
1,000
10,000
100,000
1,000,000
10,000,000
100,000,000
Envelope Volume, cu. ft.
R2 = 0.065
R2 = 0.324
Density Ratio : 18,000 ft
Density Ratio; 36,000 ft
Density Ratio: 65,000 ft
Rigid Cigar
Hot Air Balloons are Light,
but are Flimsy, Fair Weather Ships
that Just Drift Downwind.
He, Sphere, Non-Rigid
He, Cigar, Non-Rigid
He, Cigar Semi-Rigid
He, Cigar, Rigid
He, Lens, Non-Rigid
He, Lens, Rigid
He/H2+HotAir, Lens, Rigid
Hot-Air, Cigar, Non-Rigid
Power (He, Cigar, Non-Rigid)
Power (He, Cigar Semi-Rigid)
Power (Hot-Air, Cigar, Non-Rigid)

Empty Weight per Unit Size
Decreases with Size, But Not Fast Enough



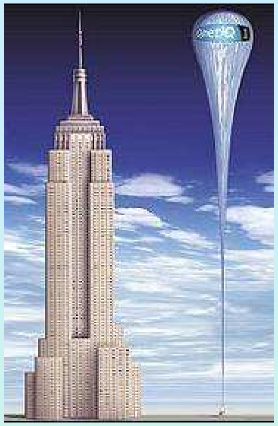


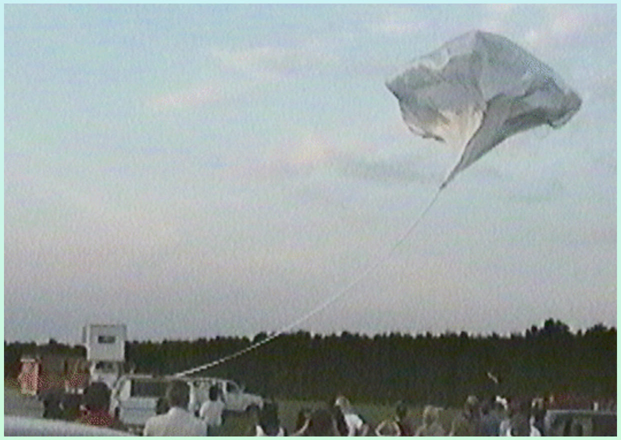
Airship Empty Weight Fraction per Unit Planform Area
Empty Equipped Wt. / Body Planform Area, lbs/ft^2
Empty Equipped Weight, lbs
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
100
1,000
10,000
100,000
1,000,000
He, Sphere, Non-Rigid
He, Cigar, Non-Rigid
He, Cigar Semi-Rigid
He, Cigar, Rigid
He, Lens, Non-Rigid
He, Lens, Rigid
He/H2+HotAir, Lens, Rigid
Hot-Air, Cigar, Non-Rigid
Power (He, Cigar, Non-Rigid)
Power (He, Cigar Semi-Rigid)
Power (He, Cigar, Rigid)
R^2 = 0.964
R^2 = 0.870
R^2 = 0.770
Rigids have
20% Lower
Empty Weight


Rigid Systems have Larger Useful Loads at Large Sizes
1,000,000
100,000
10,000
1,000
100
Useful Load (at Low Altitudes), lbs
10,000
100,000
1,000,000
10,000,000
100,000,000
Envelope Volume, cu. ft.
y = 0.00577x^1.12146
R^2 = 0.98169
y = 0.01627x^1.02961
R^2 = 0.96993
y = 0.0140x^1.0356
R^2 = 0.9638
R^2 = 0.8028
Large Rigids have 66% Greater Useful Load
Non-Rigids Are Better When Very Small
He, Sphere, Non-Rigid
He, Cigar, Non-Rigid
He, Cigar Semi-Rigid
He, Cigar, Rigid
He, Lens, Non-Rigid
He, Lens, Rigid
He/H2+HotAir, Lens, Rigid
Hot-Air, Cigar, Non-Rigid
Power (He, Cigar, Non-Rigid)
Power (He, Cigar Semi-Rigid)
Power (He, Cigar, Rigid)
Power (Hot-Air, Cigar, Non-Rigid)

Empirical Data Analysis : **Conclusions**

1. Take-Off Weight < 7.4% of Sea Level Buoyancy Can be Achieved Only by Large, Flimsy Balloons that Drift with the Winds, Cannot Hold Position.





2. A Successful Approach to High Altitudes is Likely to be A Combination of Buoyancy and Aerodynamic Lift.

3. The Hybrid Air Vehicle Can Achieve the Lowest Empty Weight with Greater Likelihood if it is has a Rigid, Not Blimp-Like Structure.

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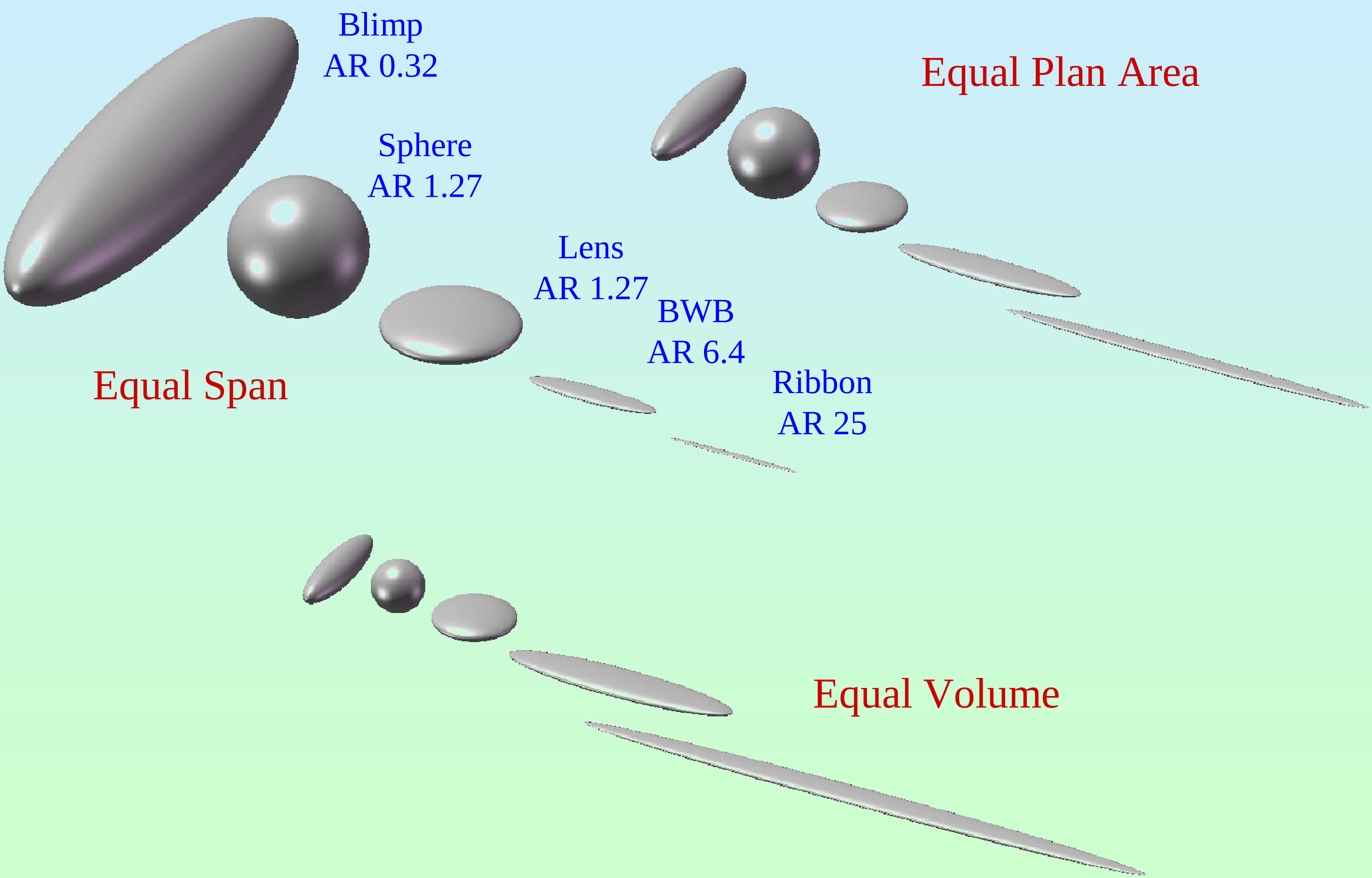
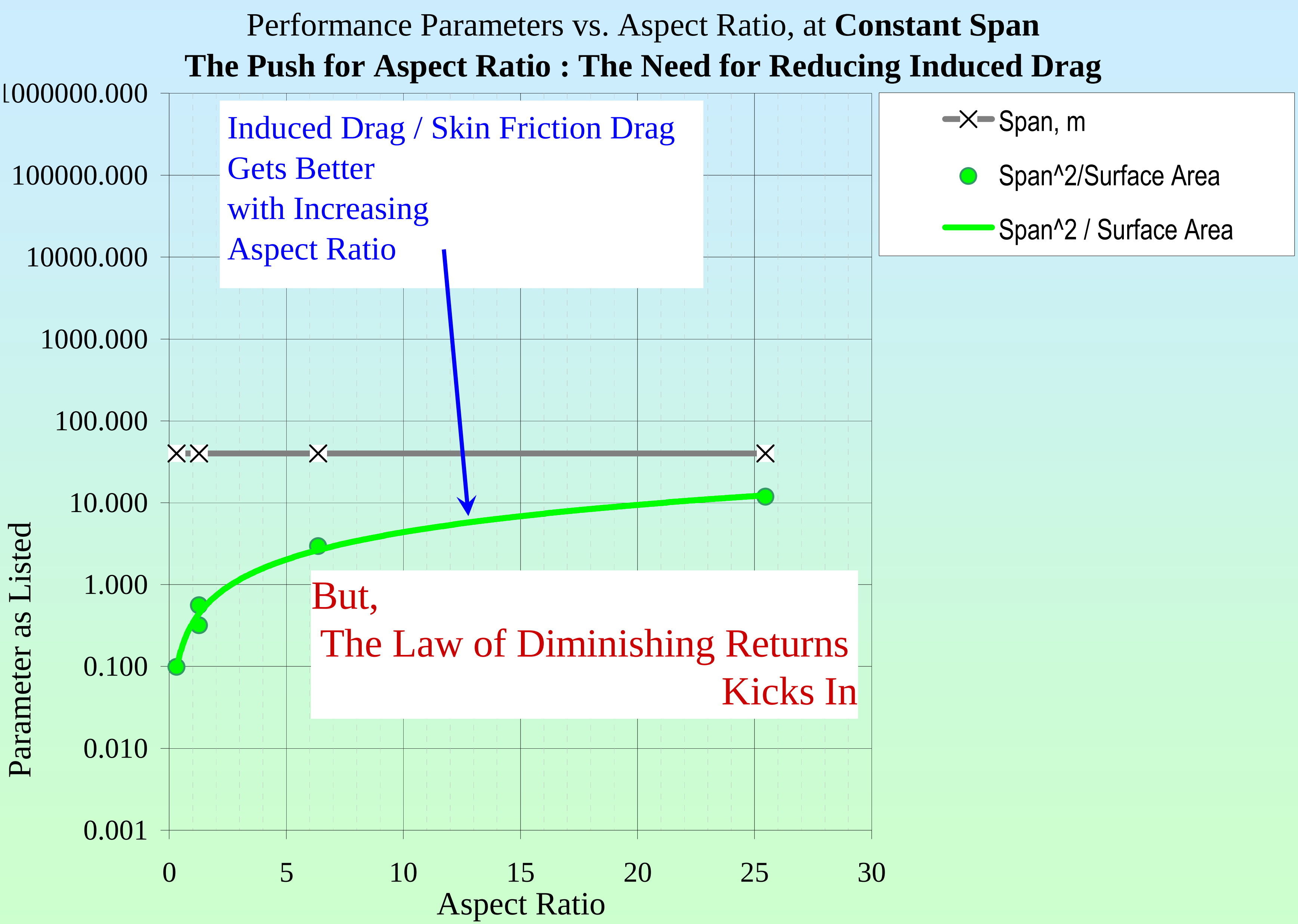
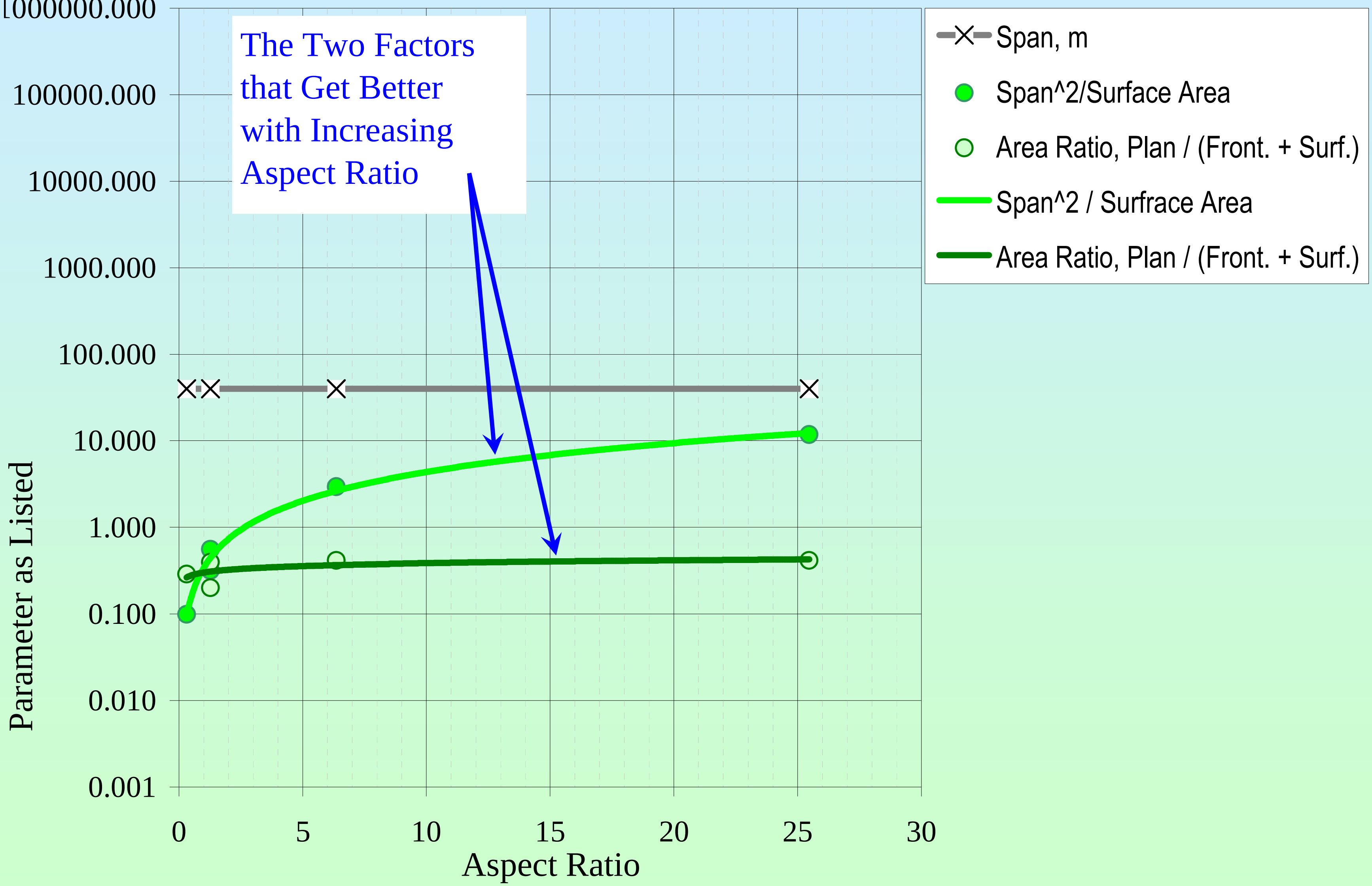
Different Air Vehicle Shapes, a Visual Comparison




Performance Parameters vs. Aspect Ratio, at **Constant Span**
The Push for Aspect Ratio : The Need for Reducing Induced Drag
1000000.000
100000.000
10000.000
1000.000
100.000
10.000
1.000
0.100
0.010
0.001
Parameter as Listed
0
5
10
15
20
25
30
Aspect Ratio
Induced Drag / Skin Friction Drag Gets Better with Increasing Aspect Ratio
But, The Law of Diminishing Returns Kicks In
Span, m
Span^2/Surface Area
Span^2 / Surface Area

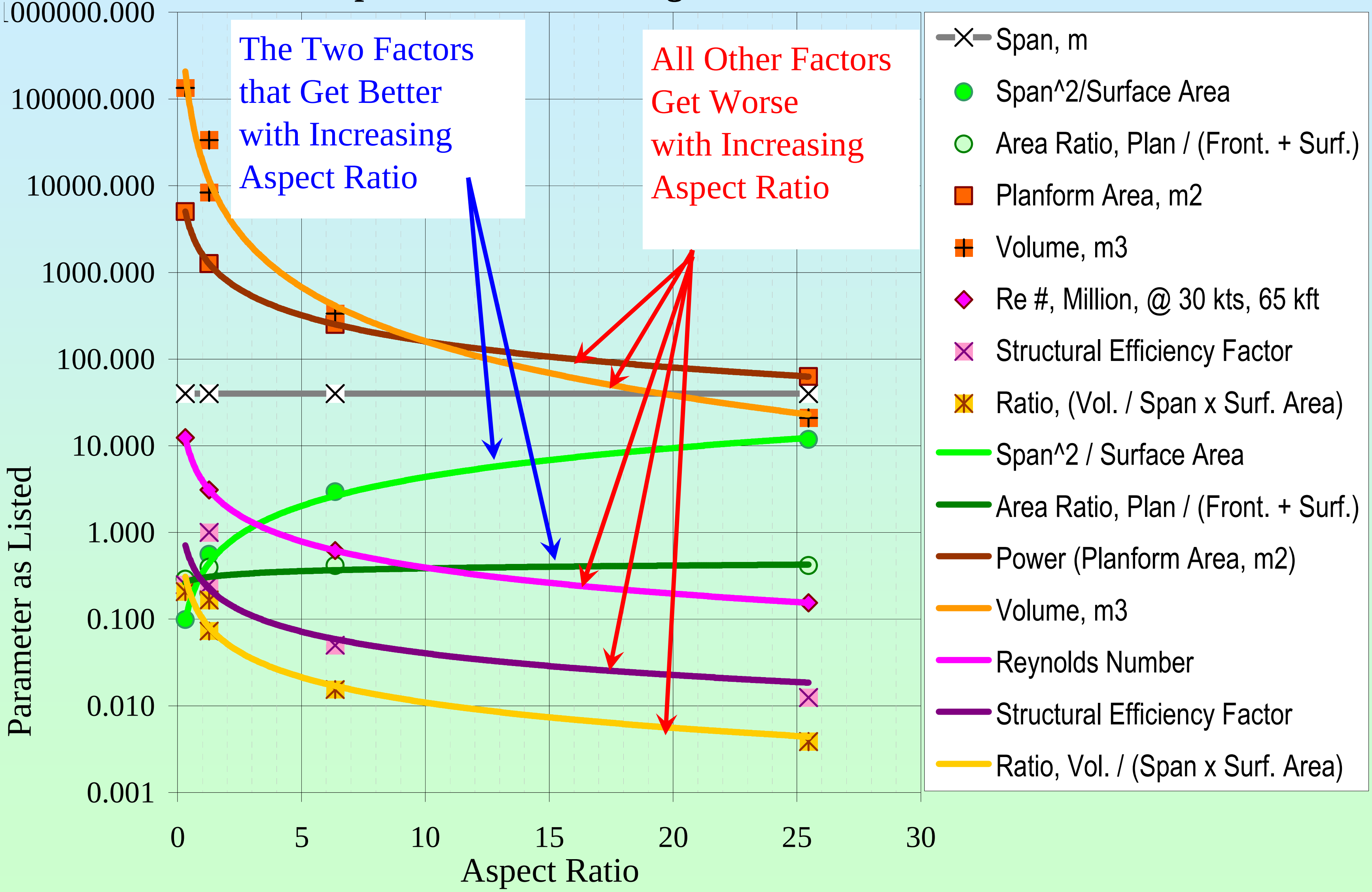
Performance Parameters vs. Aspect Ratio, at **Constant Span**

The Push for Aspect Ratio : Two Benefits



Performance Parameters vs. Aspect Ratio, at **Constant Span**

The Complete Picture : Seeking the 'Knee' of the MDO Curves



Multi-Parameter Analysis : **Conclusions**

1. Chasing Aspect Ratio is Good Only for Reducing Induced Drag.
   But, Even in this Case, the Law of Diminishing Returns kicks in.

2. Increasing Aspect Ratio Improves Two Parameters
   But Makes Five Parameters Worse.

3. The ‘Knees’ of the MDO Curves
   Appear to Lie at an Aspect Ratio Less Than 5,
   At Least when Plan Area and Volume are Important,
   Which is the Case for HALE UAVs.

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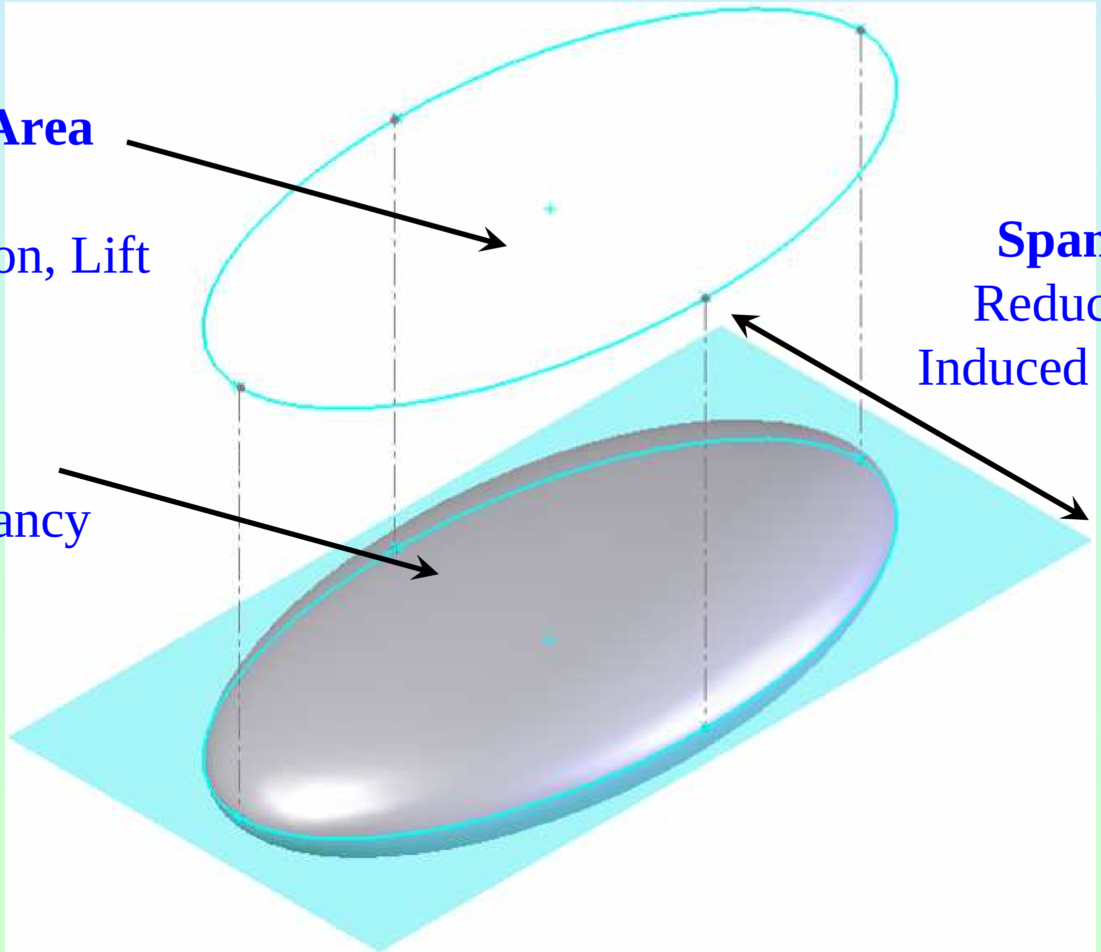
Airship Design Parameters : The Good, the Bad and the Ugly!

Airship Design Parameters : **The Good**

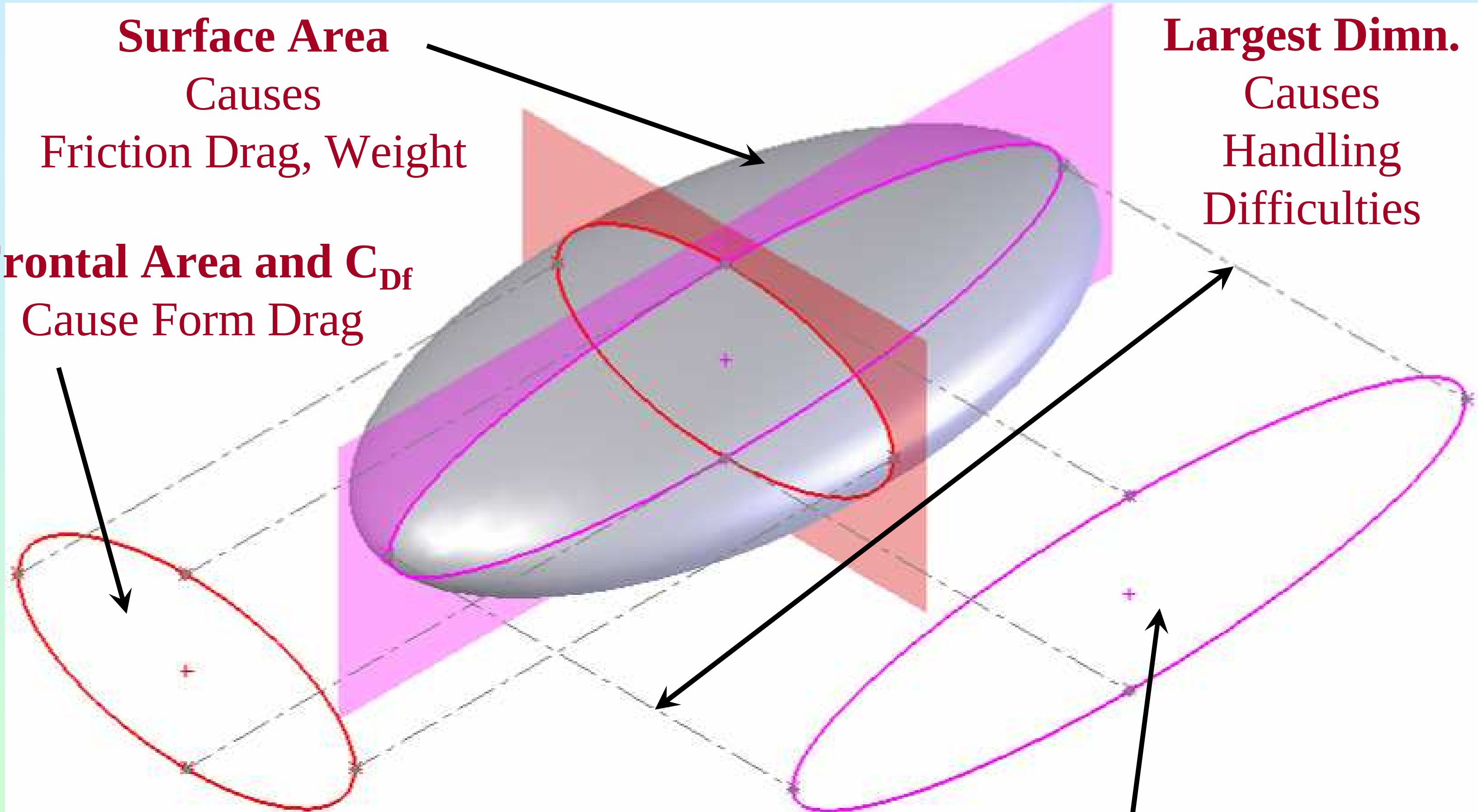


Planform Area
Offers
Solar Collection, Lift

Span²
Reduces
Induced Drag

Volume
Offers Buoyancy

Airship Design Parameters : **The Bad**

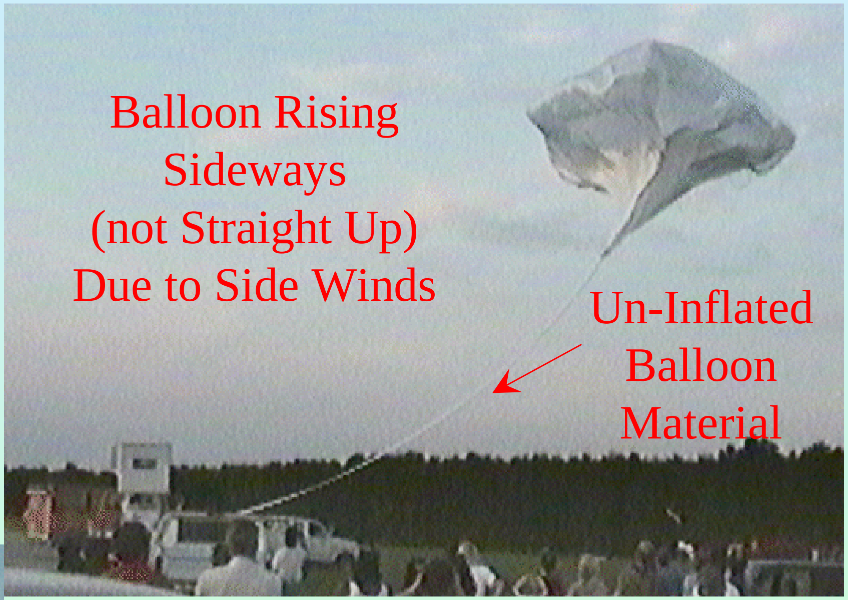


Max. Length / Min. Length Ratio
Causes Structural Difficulties

Profile Area and C_{Dp}
Cause Wind Drift

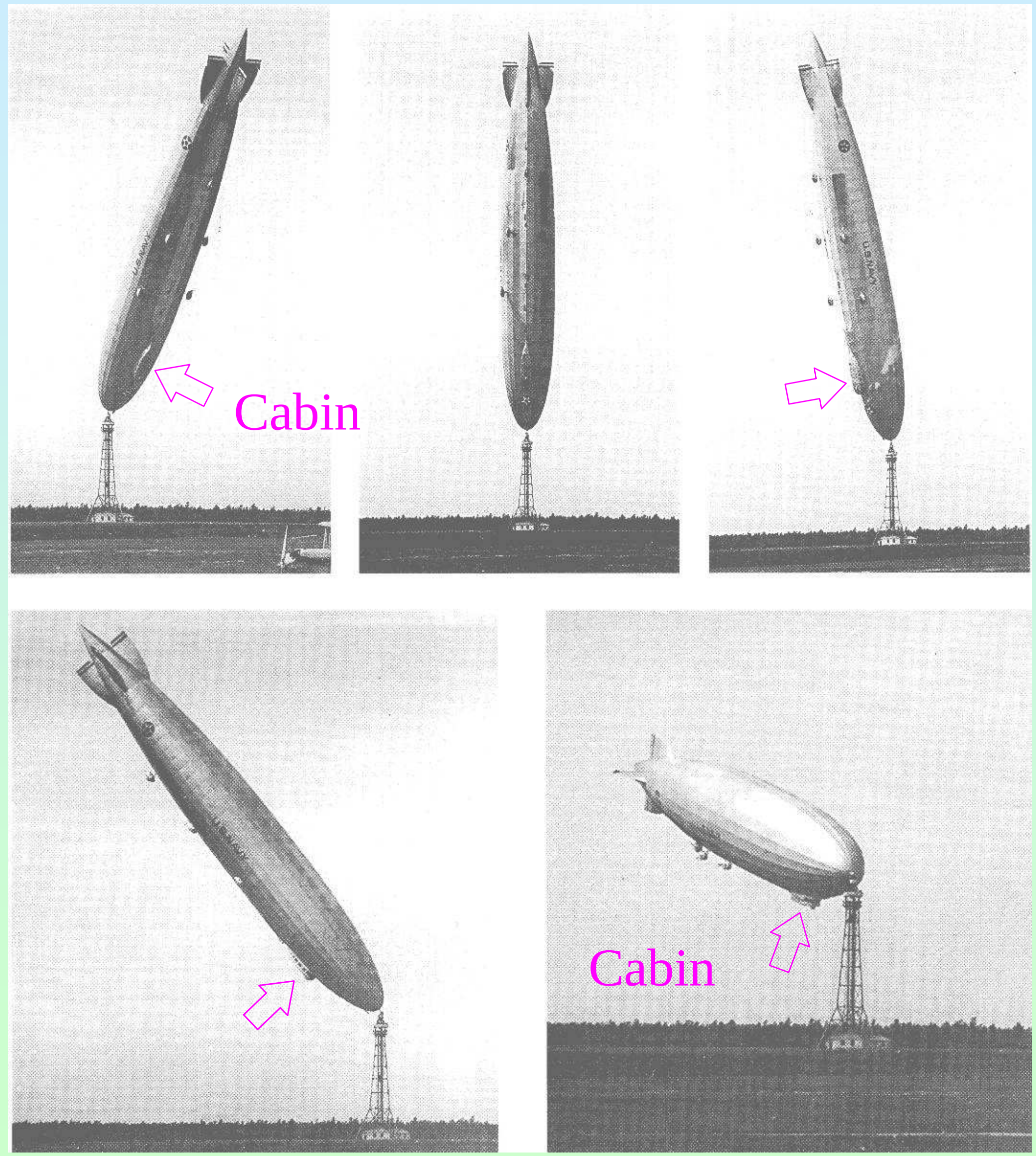
Airship Design Parameters : **The Ugly!**

Flimsy Construction, Difficulties of Ground Handling



Airship Design Parameters : The Ugly!

Sensitivity to Wind Gusts



U.S. Navy
LZ-3 Los Angeles
Somersaulting
on its Mooring Tower,
with People On Board!

Source :
USS Los Angeles
by William Althoff, 2004
Published by Brassey's Inc.

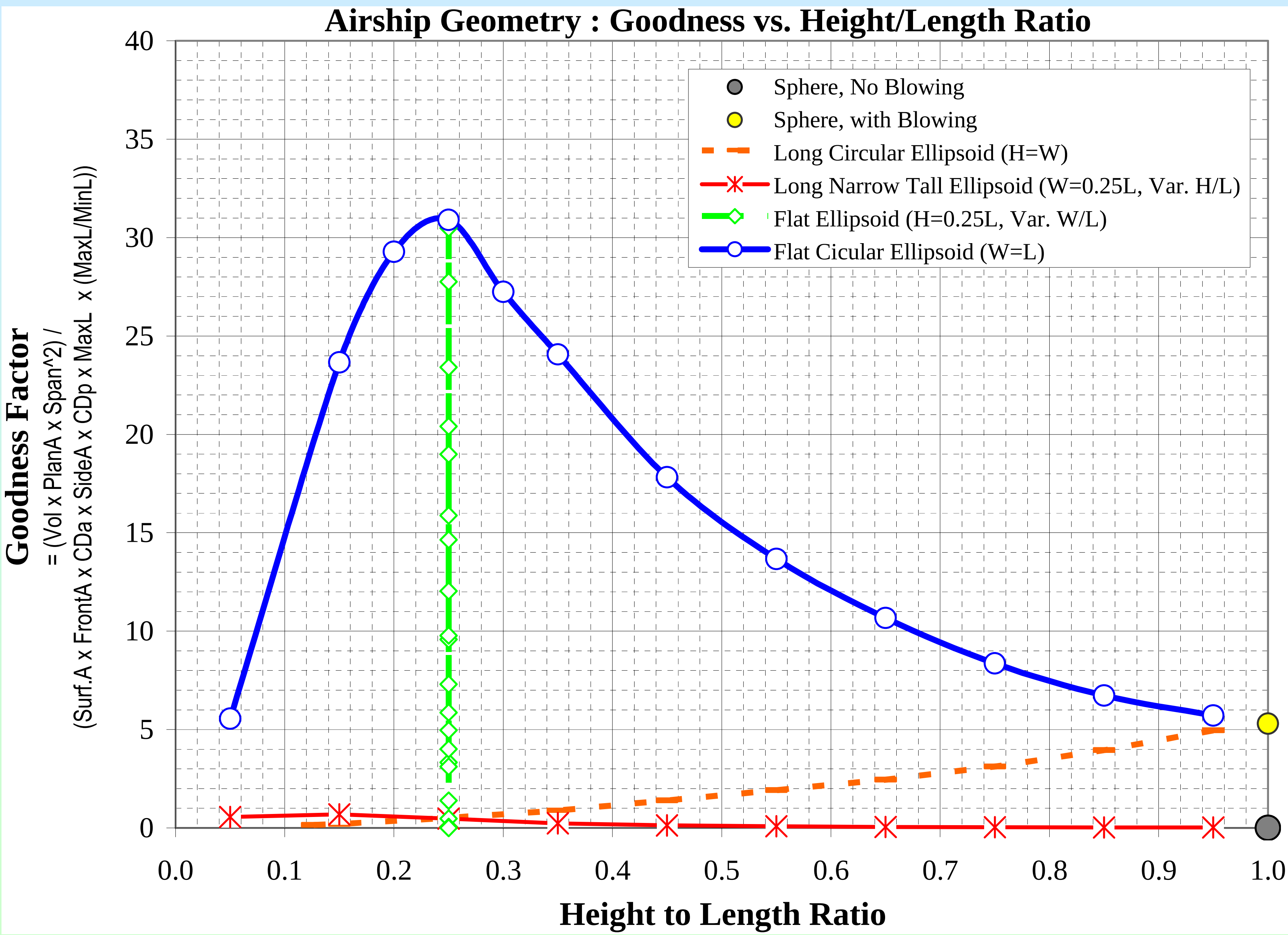
Airship Geometry Features and their Effect on Airship Goodness

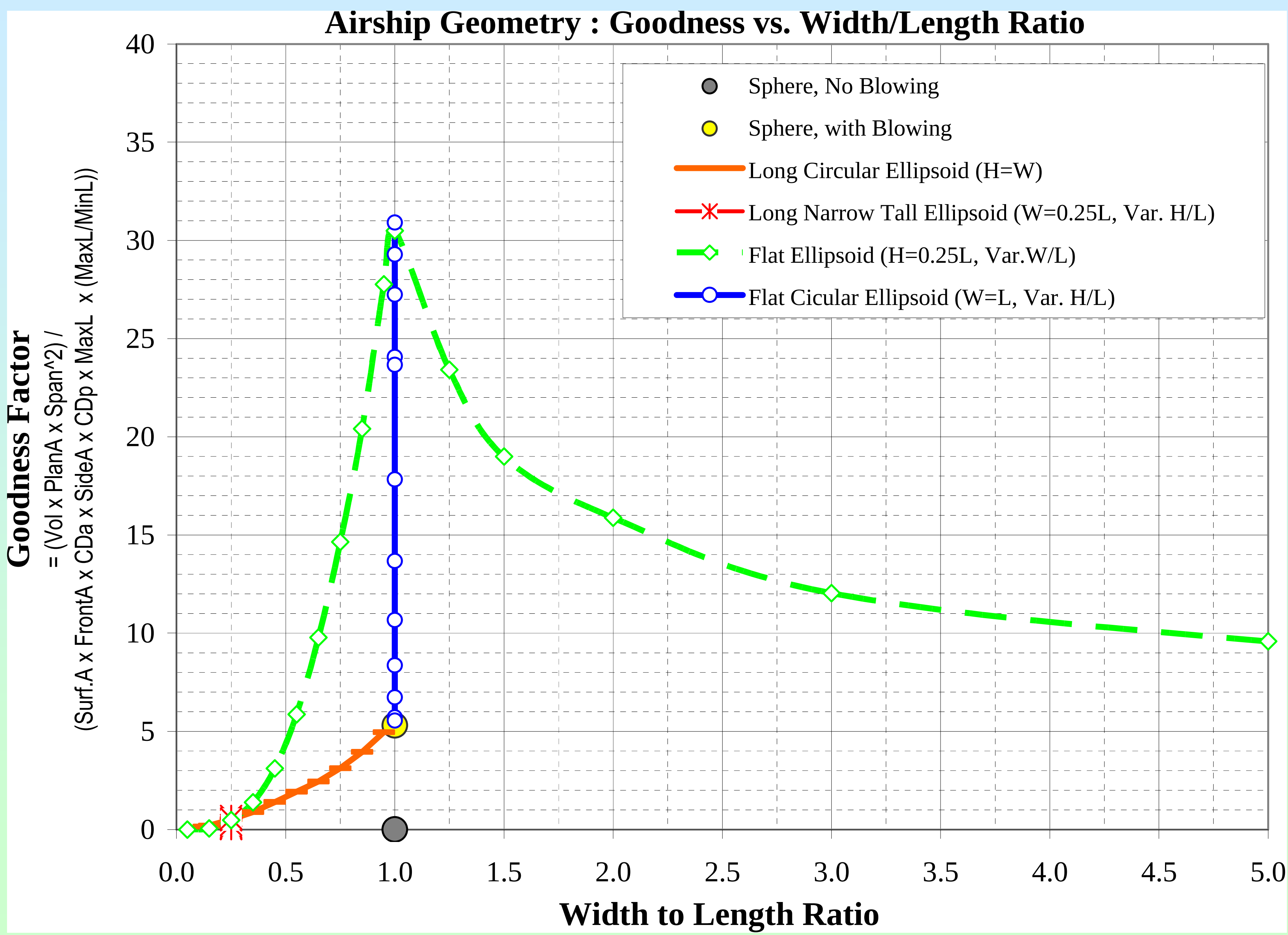
Feature	Units	Positive Effect	Negative Effect	Exponent on Length	Proposed Power	Net Exponent
Volume	**m3**	**Buoyancy**		3	1	3
Frontal Area	m2		Cruise Drag	2	-1	-2
Front. Drag Coeff.			Cruise Drag		1	
Profile Area	m2		Side Force	2	-1	-2
Side Drag Coeff.			Side Force		1	
Plan Area	**m2**	**Solar Collection**		2	1	2
Surface Area	m2		Skin Weight	2	-1	-2
Span	**m**	**Less Induced Drag**		1	2	2
Max. (L, W)	m		Maneuvering	1	-1	-1
Max. L / Min. L			Struct. Ineff.			
Overall Balance of Units (for Non-Dimensional Comparison)						**0**

Airship Design : A Combined Non-Dimensional Parameter

Overall Goodness Score =

$$\frac{\textbf{Volume} \times \textbf{Planform Area} \times \textbf{Span}^2}{Af \times CDf \times Ap \times CDp \times As \times Max(L,W) \times (Max.\ L / Min.\ L)}$$


Airship Geometry : Goodness vs. Height/Length Ratio
Goodness Factor
= (Vol x PlanA x Span^2) /
(Surf.A x FrontA x CDa x SideA x CDp x MaxL x (MaxL/MinL))
Height to Length Ratio
Sphere, No Blowing
Sphere, with Blowing
Long Circular Ellipsoid (H=W)
Long Narrow Tall Ellipsoid (W=0.25L, Var. H/L)
Flat Ellipsoid (H=0.25L, Var. W/L)
Flat Cicular Ellipsoid (W=L)



Airship Geometry : Goodness vs. Width/Length Ratio
Goodness Factor
= (Vol x PlanA x Span^2) /
(Surf.A x FrontA x CDa x SideA x CDp x MaxL x (MaxL/MinL))
Width to Length Ratio
0
5
10
15
20
25
30
35
40
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Sphere, No Blowing
Sphere, with Blowing
Long Circular Ellipsoid (H=W)
Long Narrow Tall Ellipsoid (W=0.25L, Var. H/L)
Flat Ellipsoid (H=0.25L, Var.W/L)
Flat Cicular Ellipsoid (W=L, Var. H/L)

Airship Design : A Combined Non-Dimensional Parameter

Overall Goodness Score =

$$\frac{\textbf{Volume} \times \textbf{Planform Area} \times \textbf{Span}^2}{Af \times CDf \times Ap \times CDp \times As \times Max(L,W) \times (Max.\ L / Min.\ L)}$$

Airship Shape Analysis : **Conclusions**

1. **Lens-Shaped Airships Offer the Highest Goodness Score** (Best Combination of the Good and the Bad).

2. **The Optimum Airship** for the High-Altitude, Solar-Assisted Mission would be a **LensCraft with Rigid Structure**.

3. **Further Enhancement of Performance** Can be Achieved by Modified Lens-Shaped Geometries with Special Features (e.g. **Lifting Body, Wings, Winglets**).

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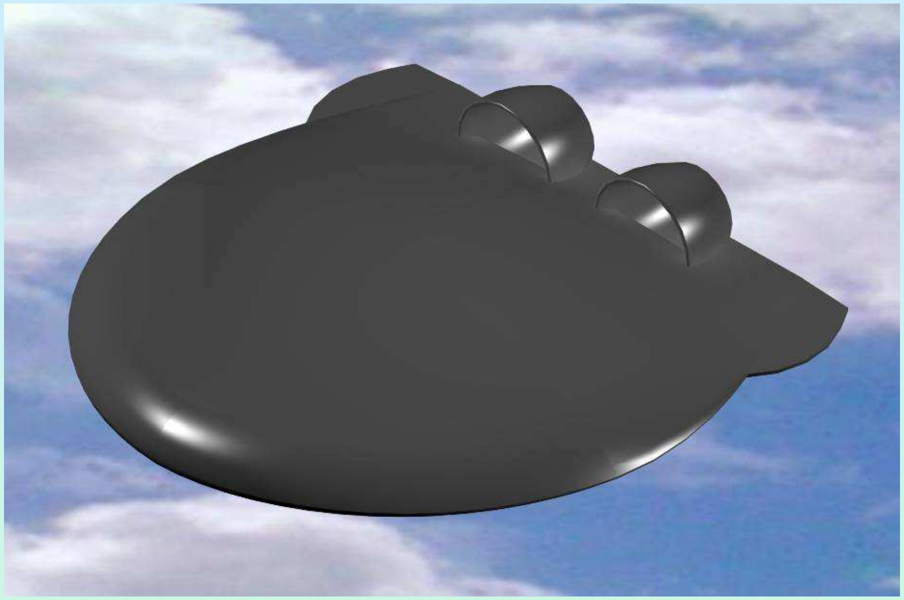
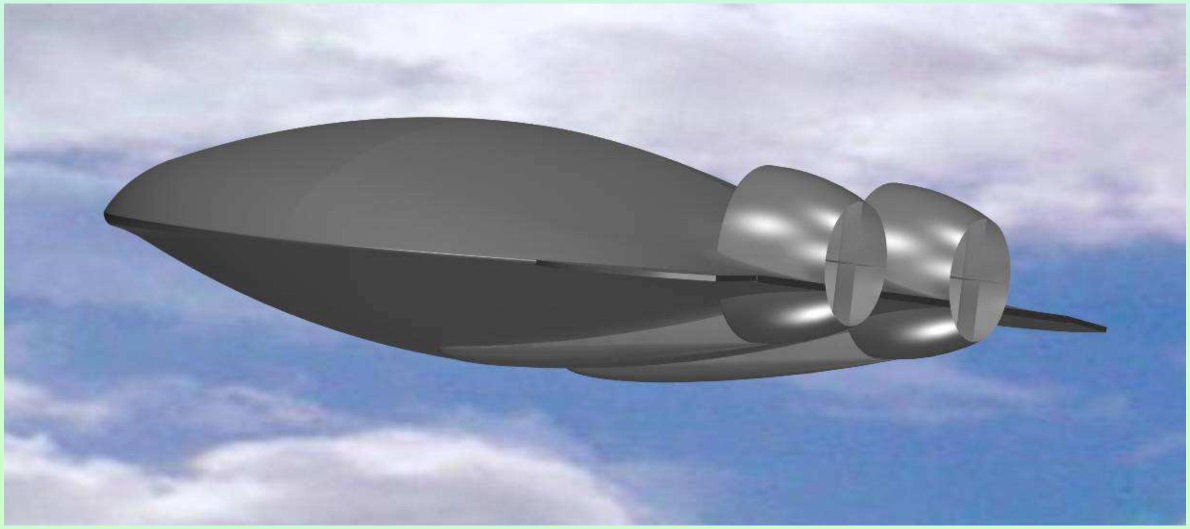
Conclusions, Recommendations : A Shape for Each Application

Shape	Advantages	Disadvantages	Optimum Application
Sphere	Very Large Volume for GH_2 Storage, Lightest Structure	Greatest Drag	**Ascent Balloons**
Blimp	Fairly Light Structure	Reduced Drag	**Tethered Balloons (Aerostats)**
Lens	Very Large Planform Area for Solar Harvesting, Very Large Volume for GH_2 Storage, Large Span for Lift, Low Drag for Cruising	Greater Structural Weight	**HALE UAVs** with Hydrogen as Energy Storage
BWB	Large Planform Area for Solar Harvesting, Large Volume for GH_2 Storage, Very Large Span for Lift, Low Drag for Cruising	Much Greater Structural Weight	**HALE UAVs** with Batteries for Energy Storage
Ribbon Wing	Lowest Induced Drag	Largest Structural Weight, Low Planform Area	**Battery Powered UAVs** (High Density Batteries Used as Wing Surfaces)

Ultra-HALE™ by D-STAR / AurAayan





Ultra-HALE™ by D-STAR / AurAayan

Some Technical Features (Details not approved for Public Release)

- ✓ Hybrid Air Vehicle (Lifting Body with Buoyancy Assistance)
- ✓ Hydrogen Stored at Low Pressure for Energy Storage (buoyancy is a bonus)
- ✓ Hybrid Solar Reversible Fuel Cells for Energy Harvesting, Recycling
- ✓ Hybrid Aero-Electric APEX Fans (a derivative of patented AVX Fan)
- ✓ Enhanced Aerodynamics Management, Drag Reduction
- ✓ Fast-Response Gust Load Management
- ✓ New Light-Weight Structure Concept
- ✓ Scalable System
  Initial Prototypes : 40 m x 40 m (Same hangar as C-130)
  Scaled-Up Systems : 80 m x 80 m (Same size as largest transport aircraft).

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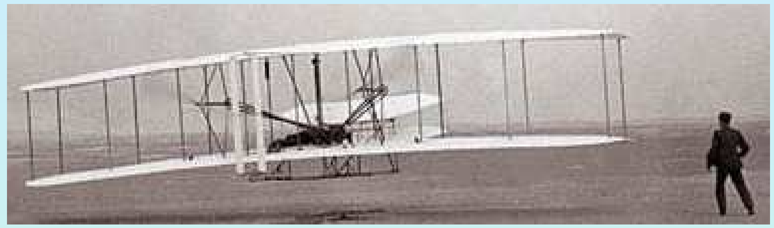
From ‘Tube-and-Wings’ to Blended Wing-Body Aircraft

Aircraft have Evolved

from
Wings with Wire Braces



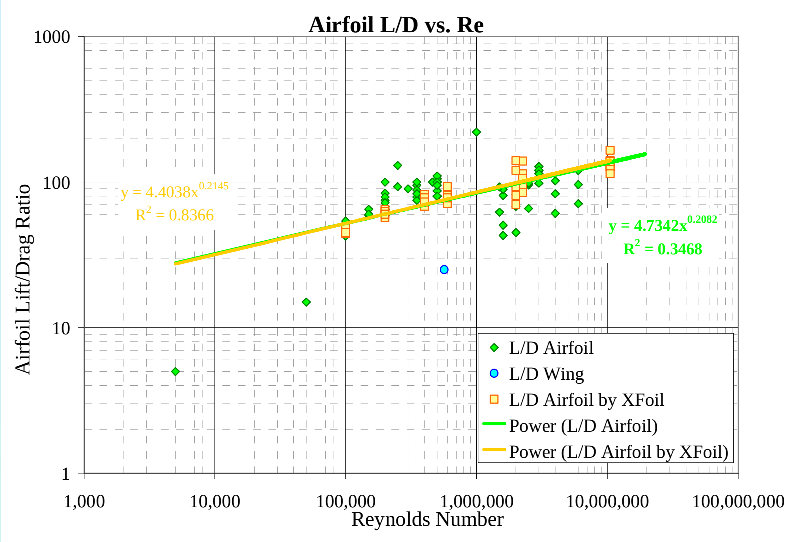
to
Wings with Struts

to
Tube-Fuselages and Cantilevered Wings

to
Wings Faired into Bodies

to
Blended Wing Body Aircraft.

Advantages of BWB Aircraft



Longer Chord, Greater Internal Volume

2x chord, same t/c $\Rightarrow$ 4x Internal Volume.

Larger Reynolds Number :
Greater Lift/Drag Ratio

Fuselage Skin Area Eliminated, Interference Drag Reduced.

But, Greater Wing Thickness, Improved Distribution of Lift $\Rightarrow$
Reduced Structural Weight, Reduced System Weight, **Reduced Overall Drag.**

Greater Plan Area to Capture Solar Energy,
Much Greater Internal Volume for Accommodations.

Business Class Seats for the Price of Coach Class.

Large Internal Volume Can be Used to Carry Gaseous Fuel.

Replacing Petroleum (Jet-A) by Hydrogen

For Same Energy, Hydrogen has 3x Lower Weight.

Long-Range Aircraft : Fuel Weighs 45%, Payload 15%.
Replacing Jet-A by Hydrogen offers 3x Greater Payload,
or **3x Lighter Aircraft for Same Payload-Range,**
also offers **3x Lower Energy Usage.**

Hydrogen has **Zero Carbon Footprint**, Zero CO, CO2 and Smoke Emissions.

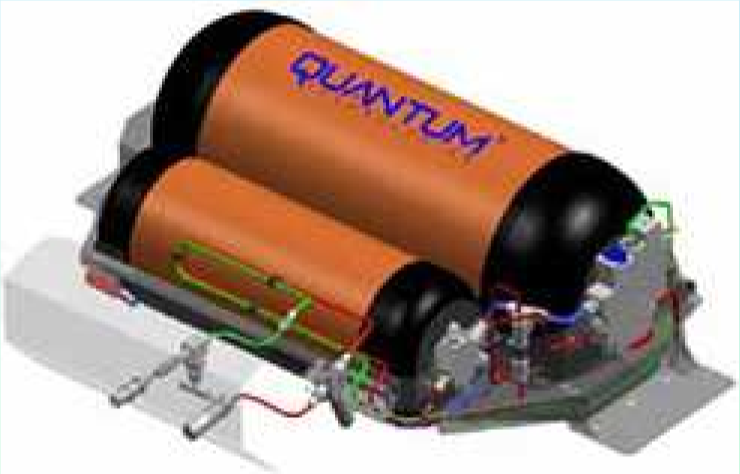
Hydrogen is an extremely safe fuel.
One Hindenburg vs. Many, Many Aircraft Fireballs on Crashes.

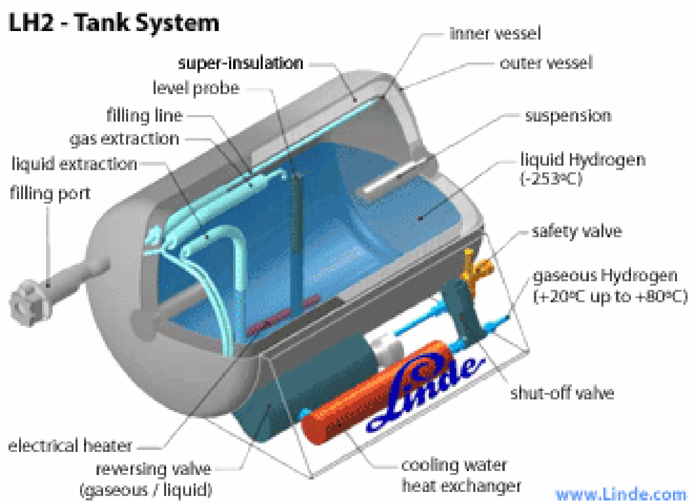
Aircraft Can be Designed for Complete Safety in Case of a Hydrogen Leak.

Tube-and-Wing Aircraft have Trouble Storing Hydrogen.

Not Enough Volume ⇒

High Pressure Storage or Cryogenic Storage.





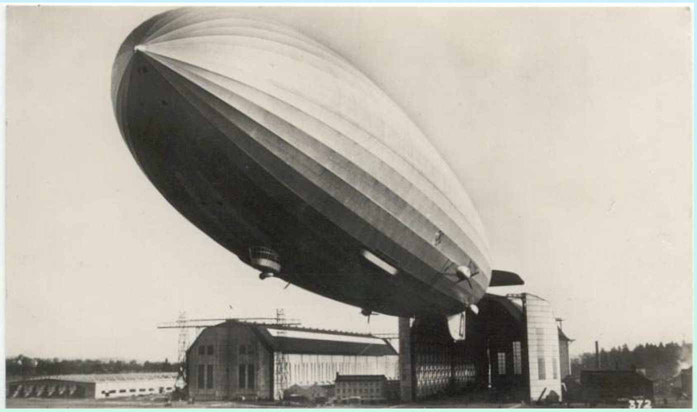
Both Impose Severe Weight and Logistics Penalties.

Blended Wing-Body Aircraft Have Large Internal Volume,
Can Store Hydrogen as Gas at Low / Moderate Pressure,
for Greatly Reduced Tank Weight Penalty,
Maybe Even Get Some Buoyancy for Free.

Maybe Future Aircraft Will have a Gene from Airships, after all :

Low / Pressure Storage of Hydrogen as a Clean, Energetic Fuel

with Some Buoyancy as a Bonus!



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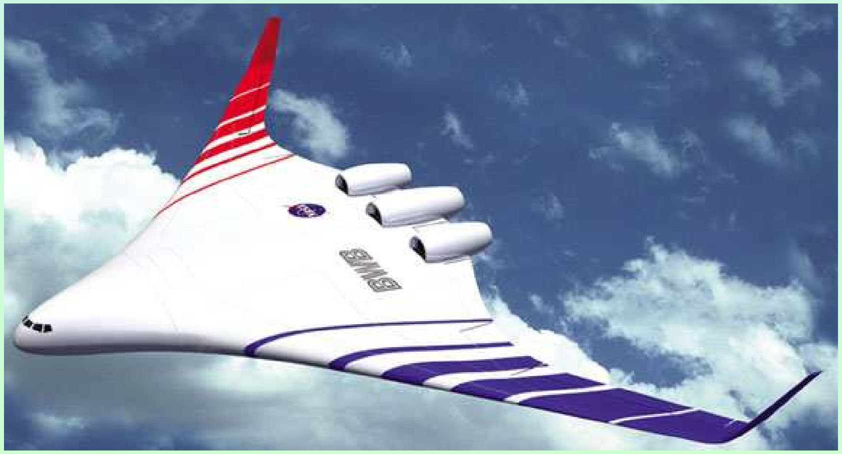

Blimps + Tube-and-Wing Aircraft = Blended Wing Body Aircraft.

