The Science of Airships

Anthony Francis

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- Computer Scientist

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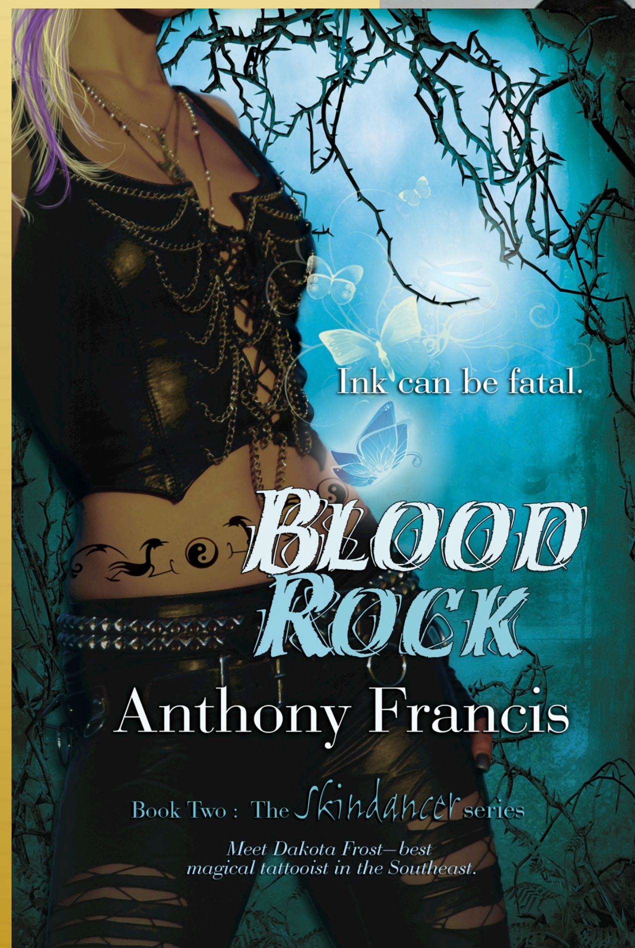

Who's Anthony Francis?

- Computer Scientist
- Urban Fantasy Author
- Steampunk Science Fiction

Why Study Airships?

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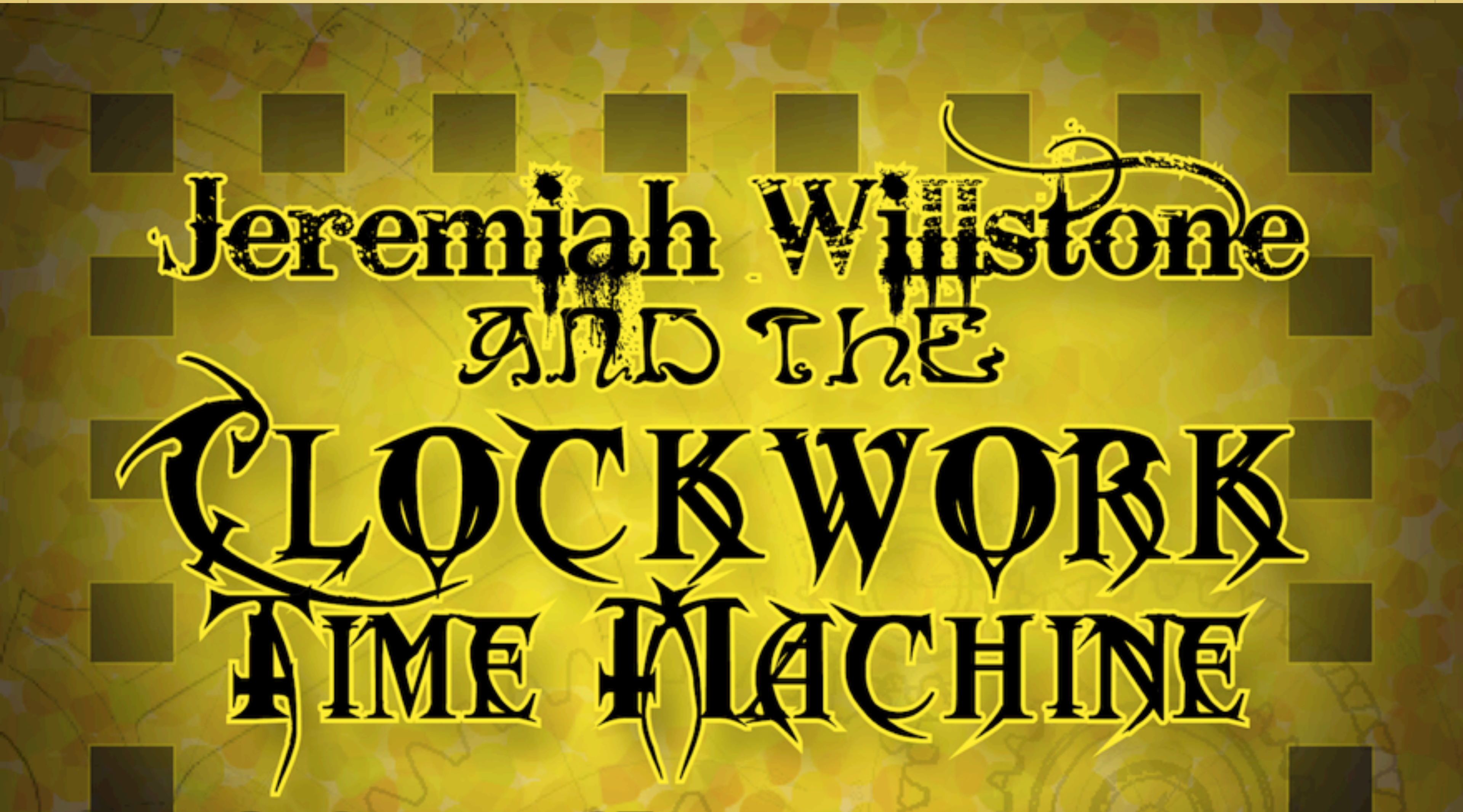
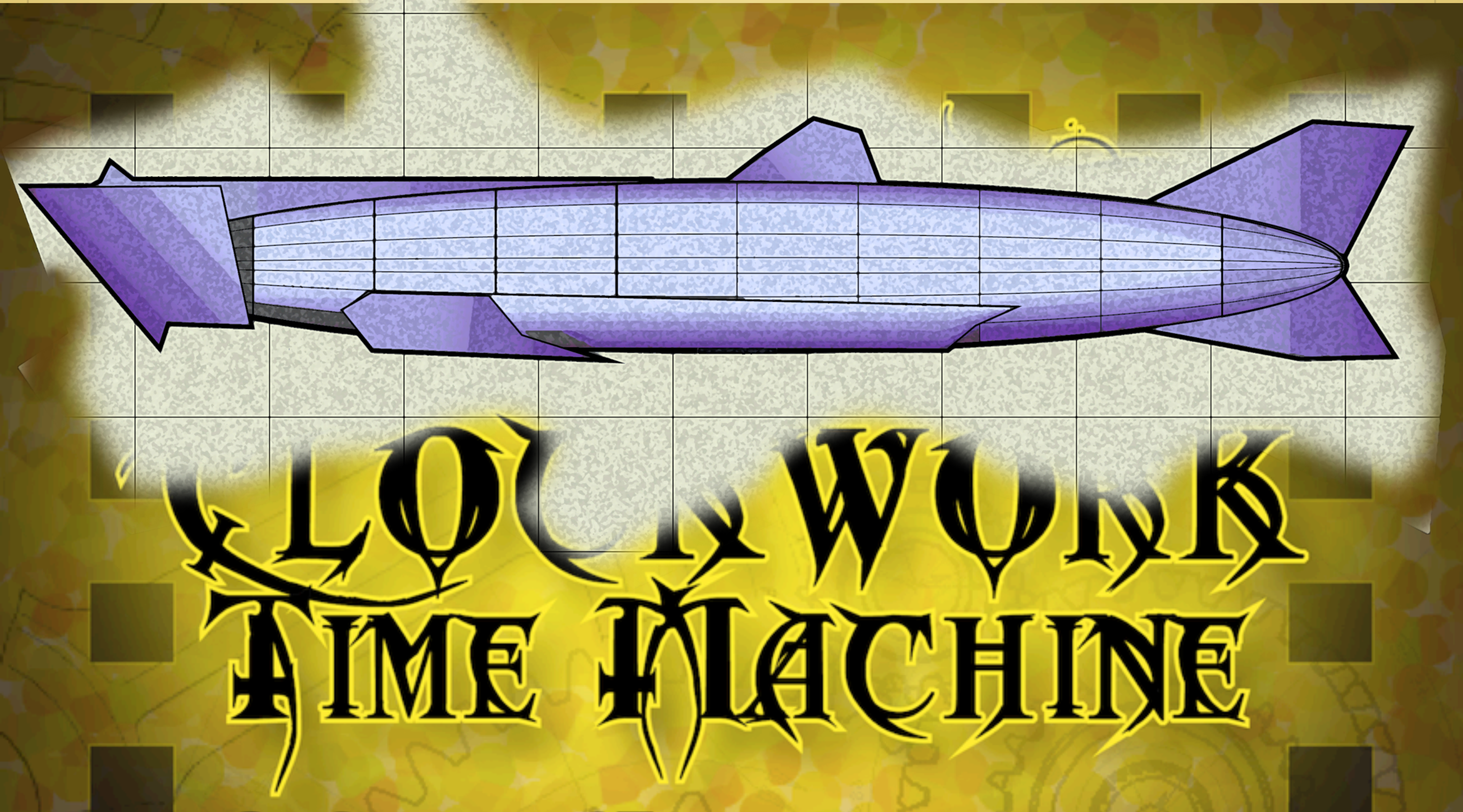


Why Study Airships?



The Forgotten Giants

Steampunk in the Air

What would steampunk be without airships?

- *Around the World in 80 Days**, Abney Park, *Leviathan*

But would our adventurers really want to fly them?

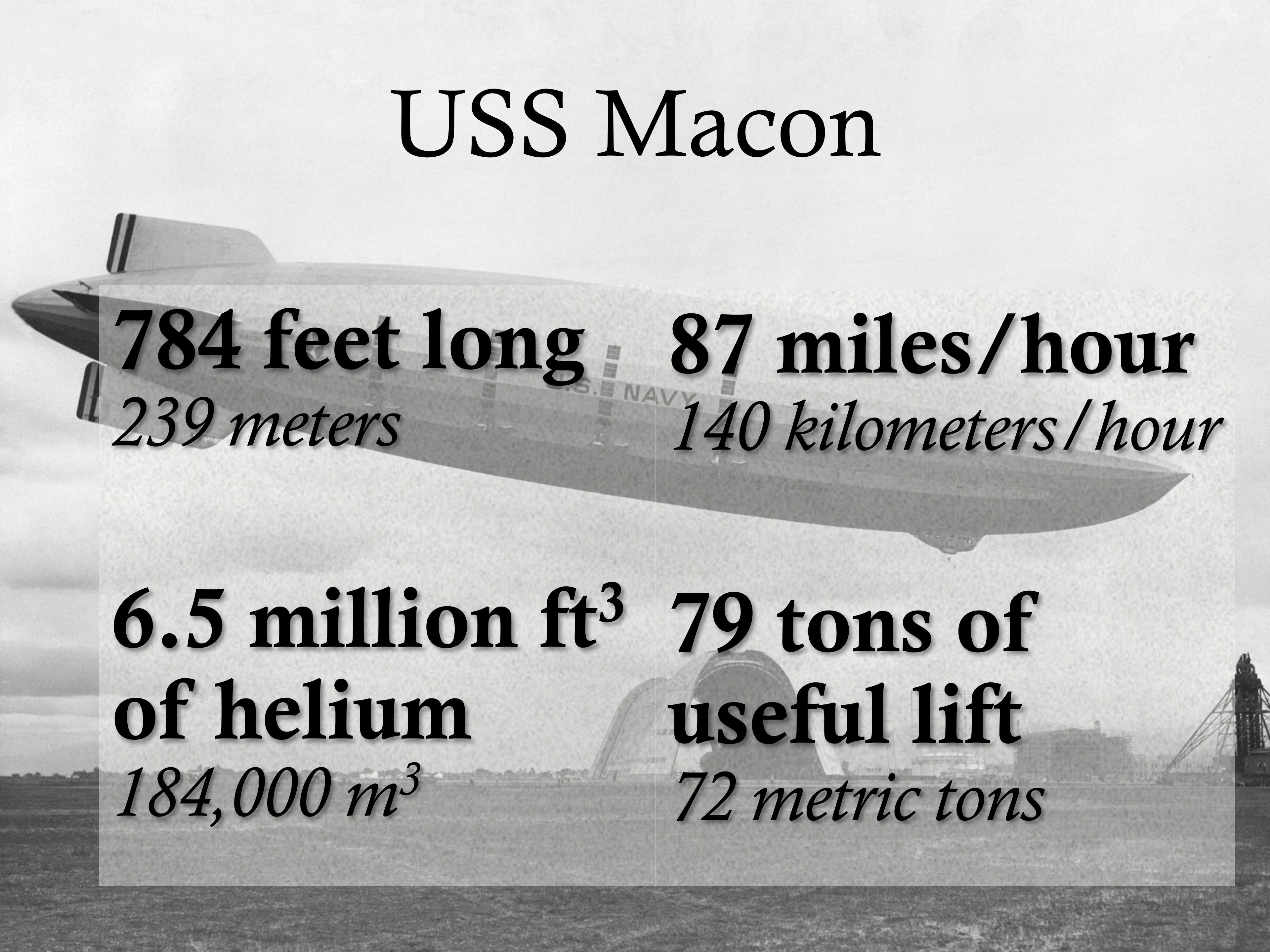
- The *R101*. The *Shenandoah*. The *Hindenburg*.

The reality of airships:

- Slow, fragile, vulnerable to fire … and idiots
- Large, stately, *enormous* lift capacity

*The movie

USS Macon



USS Macon

784 feet long
239 meters

87 miles/hour
140 kilometers/hour

6.5 million ft^3 of helium
184,000 m^3

79 tons of useful lift
72 metric tons

The Science of Airships

- How did airships fly?
- Why did they look like that?
- Why did we abandon them?
- Will we see them in the future?

Lift

The Science of Aerostatics

Peeling the Onion

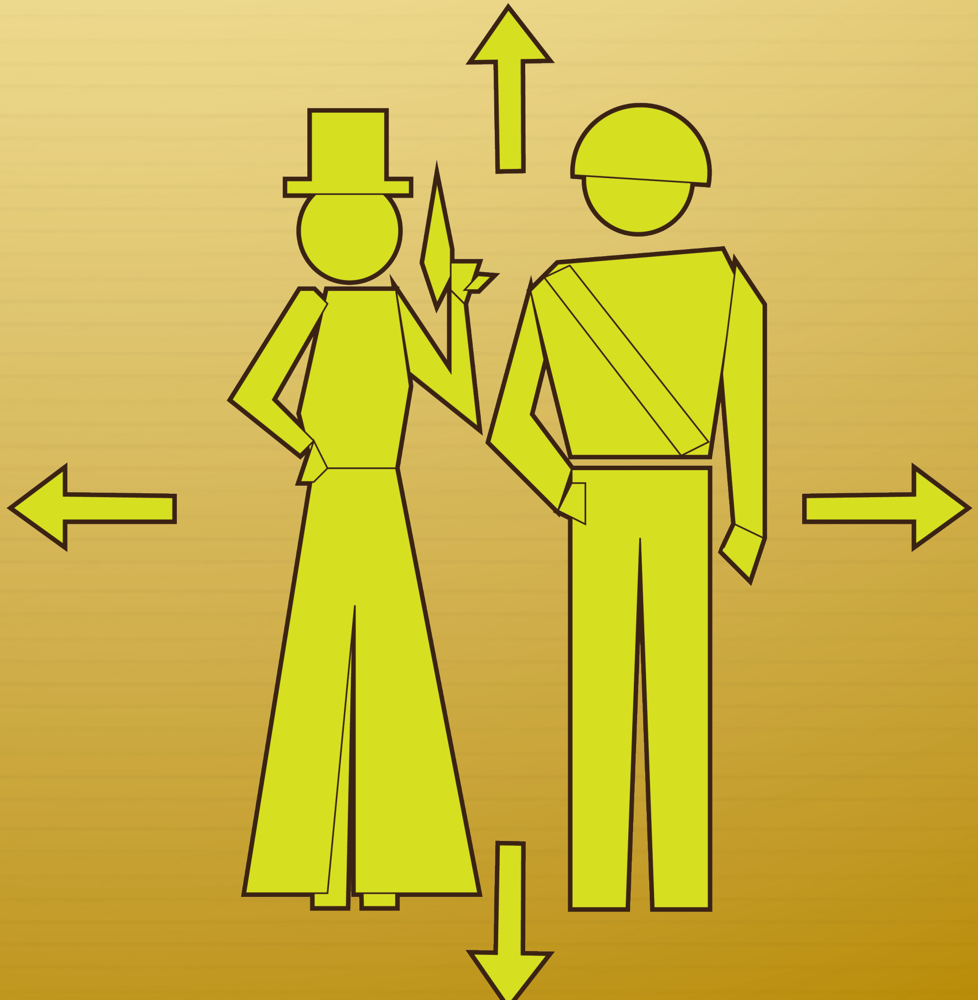
Airships are giant balloons:
large, hollow and fragile…

But Why?

Our Goal: *Adventure!*

As proper Steampunk adventurers, we want to go…

everywhere!

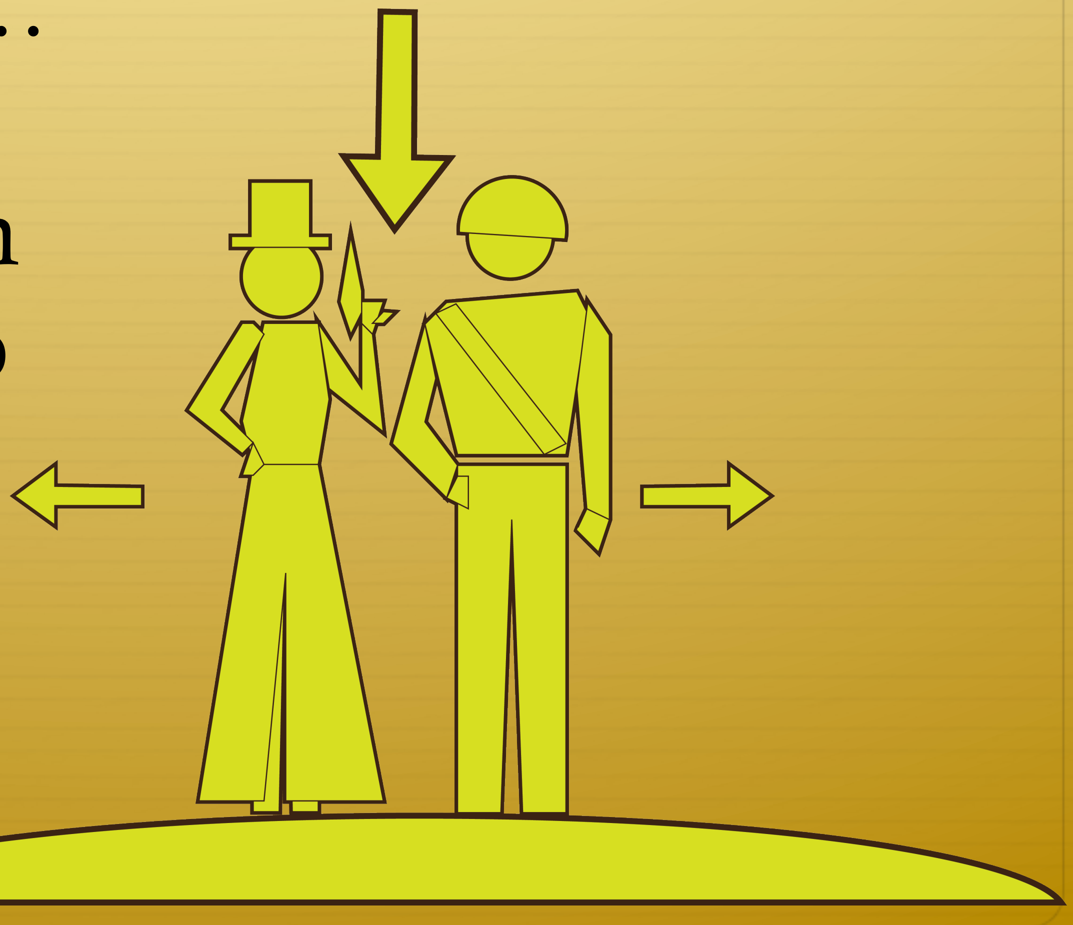


The Problem: *Gravity!*

The problem is …

Sir Isaac Newton has something to say about that.

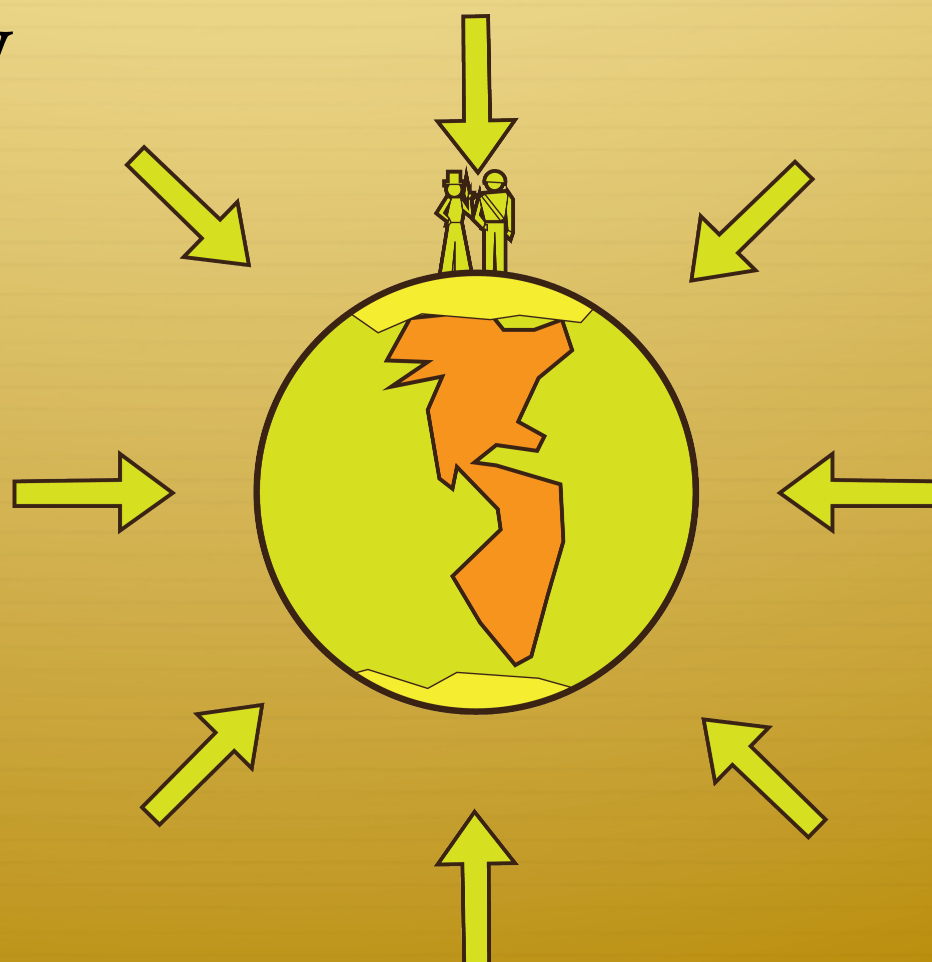
Gravity.



The Problem: *Gravity!*

Earth's gravity pins us to its surface…

but it also provides us a solution!



The Solution: *The Air!*

Earth's gravity also holds air to its surface…

…in a gradient that gets thinner the higher you go!

Air Pressure and Lift

We all know air exerts pressure…

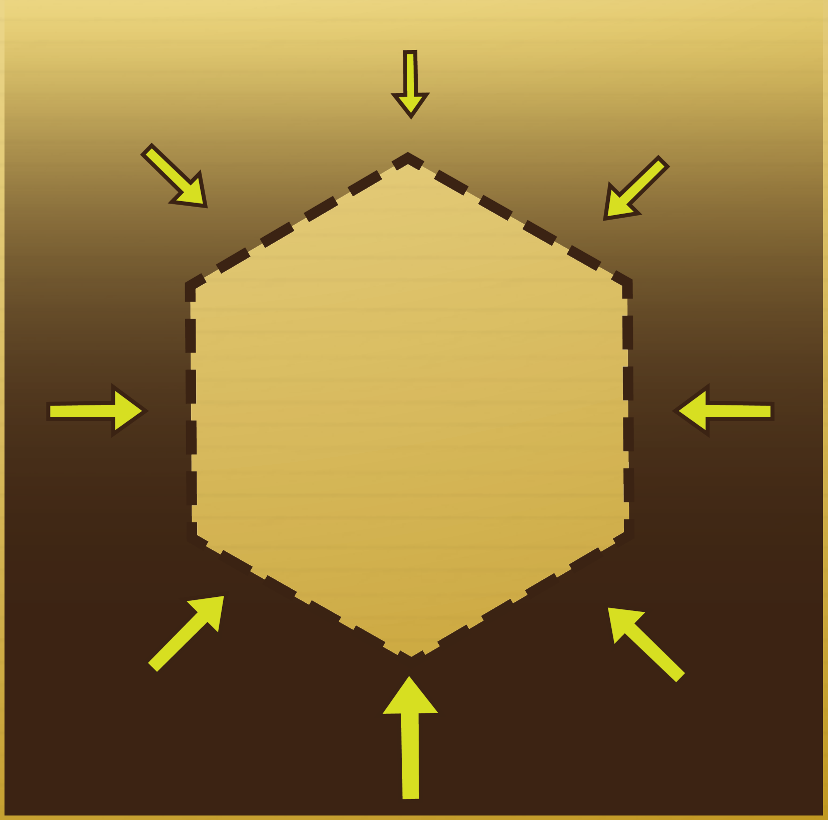
14.7 pounds

per square inch

101 kilopascals

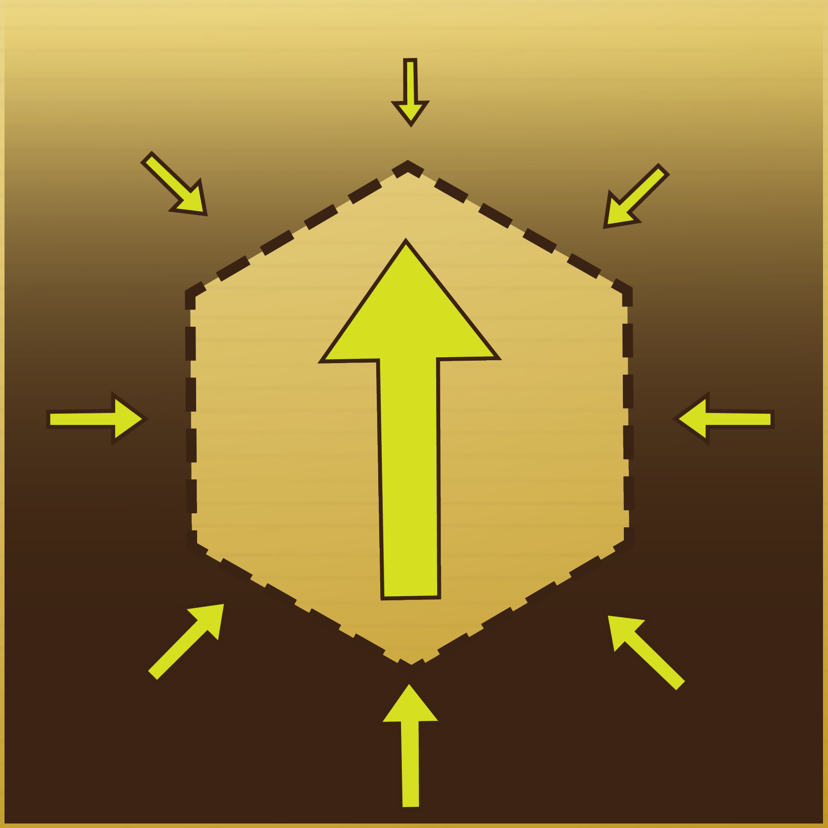
Air Pressure and Lift

But a real object has a non-zero height, and the air pressure gradient means there's less pressure on top …



Air Pressure and Lift

But a real object has a non-zero height, and the air pressure gradient means there's less pressure on top … *and net lift!*

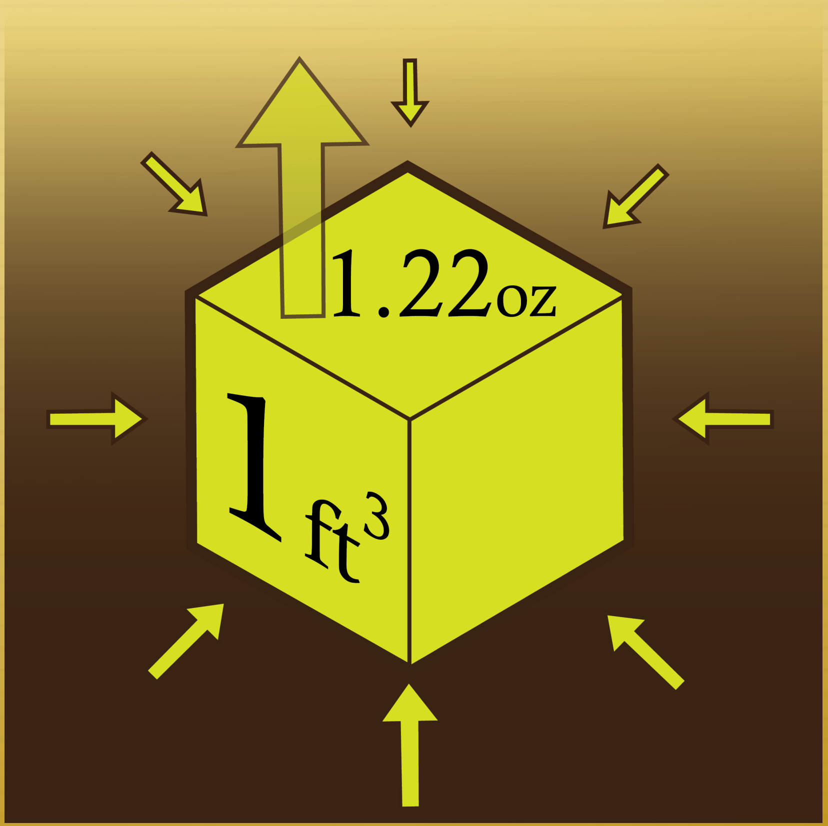


Air Pressure and Lift

Buoyancy is the weight of displaced air per volume…

1.22 ounces per cubic foot

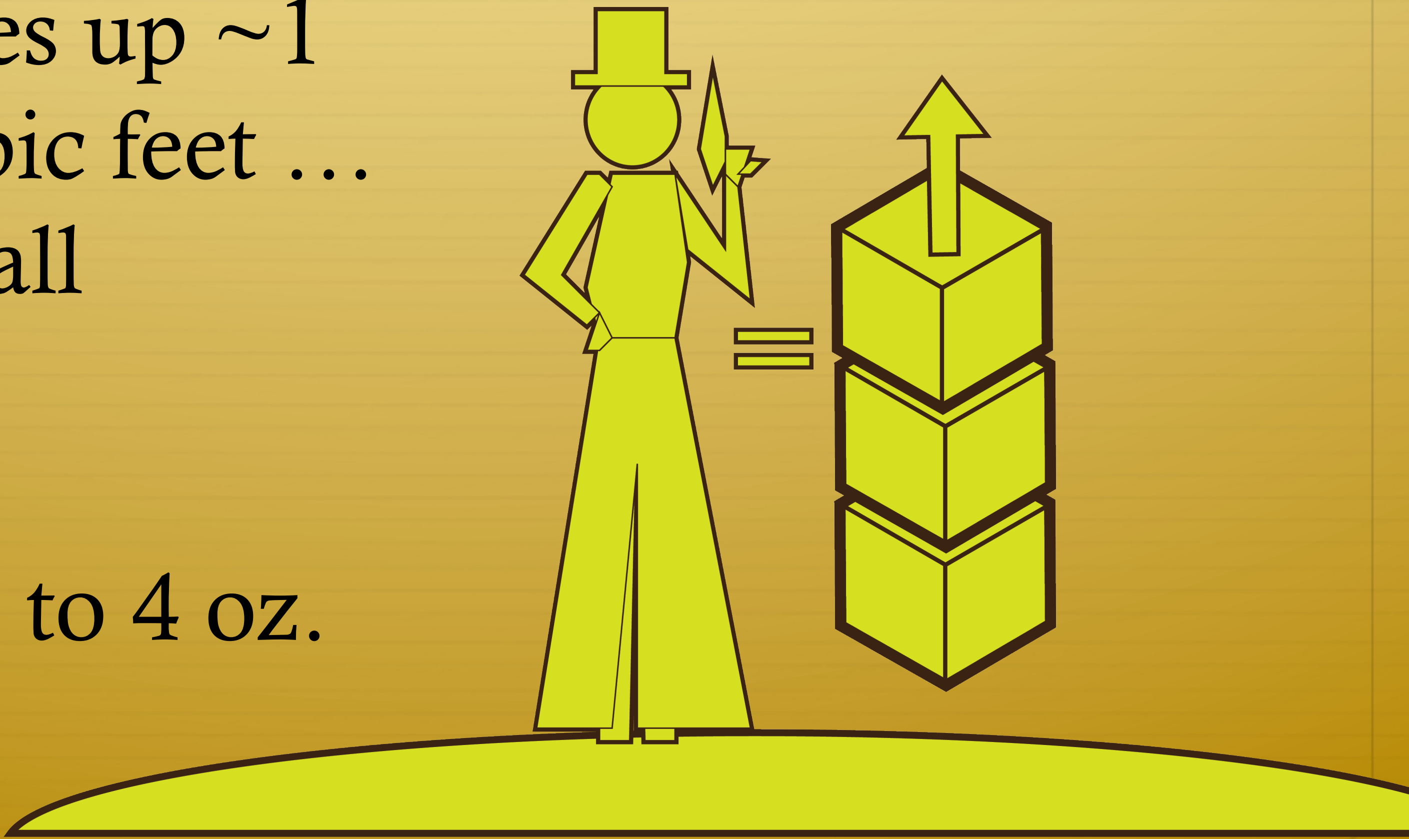
1.225 grams/liter



Good News, Everyone!

A typical human body takes up ~1 to ~3 cubic feet … so we're all buoyant!

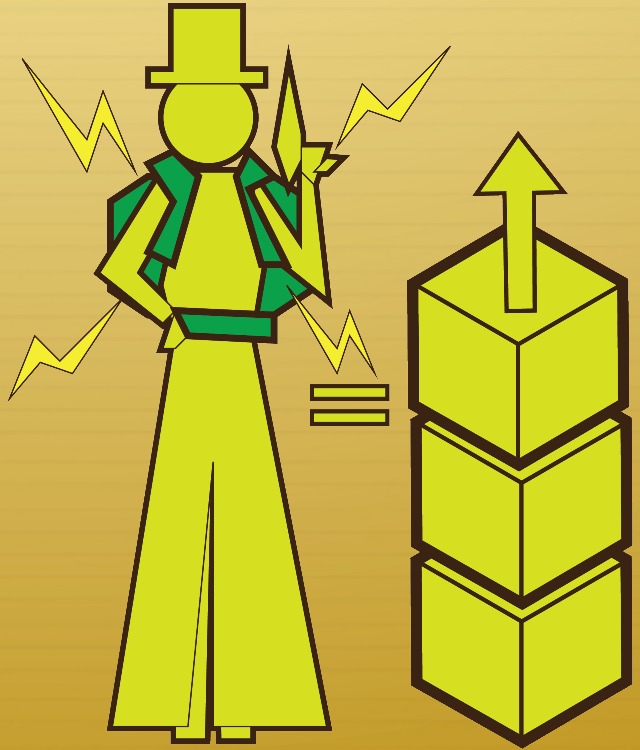
By ~1.25 to 4 oz.



Overcoming Gravity

If only we had a way to cancel out that weight!

Then our own buoyancy could lift us up!



The Science of Antigravity

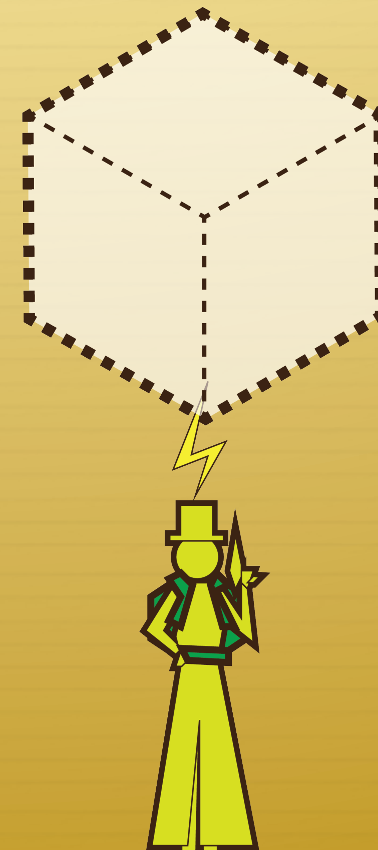
Anthony Francis

The Sci[illegible]ce of Ant[illegible]avity

[illegible]nthony Francis

Getting More Lift

The next idea:
displace enough air to lift a person!



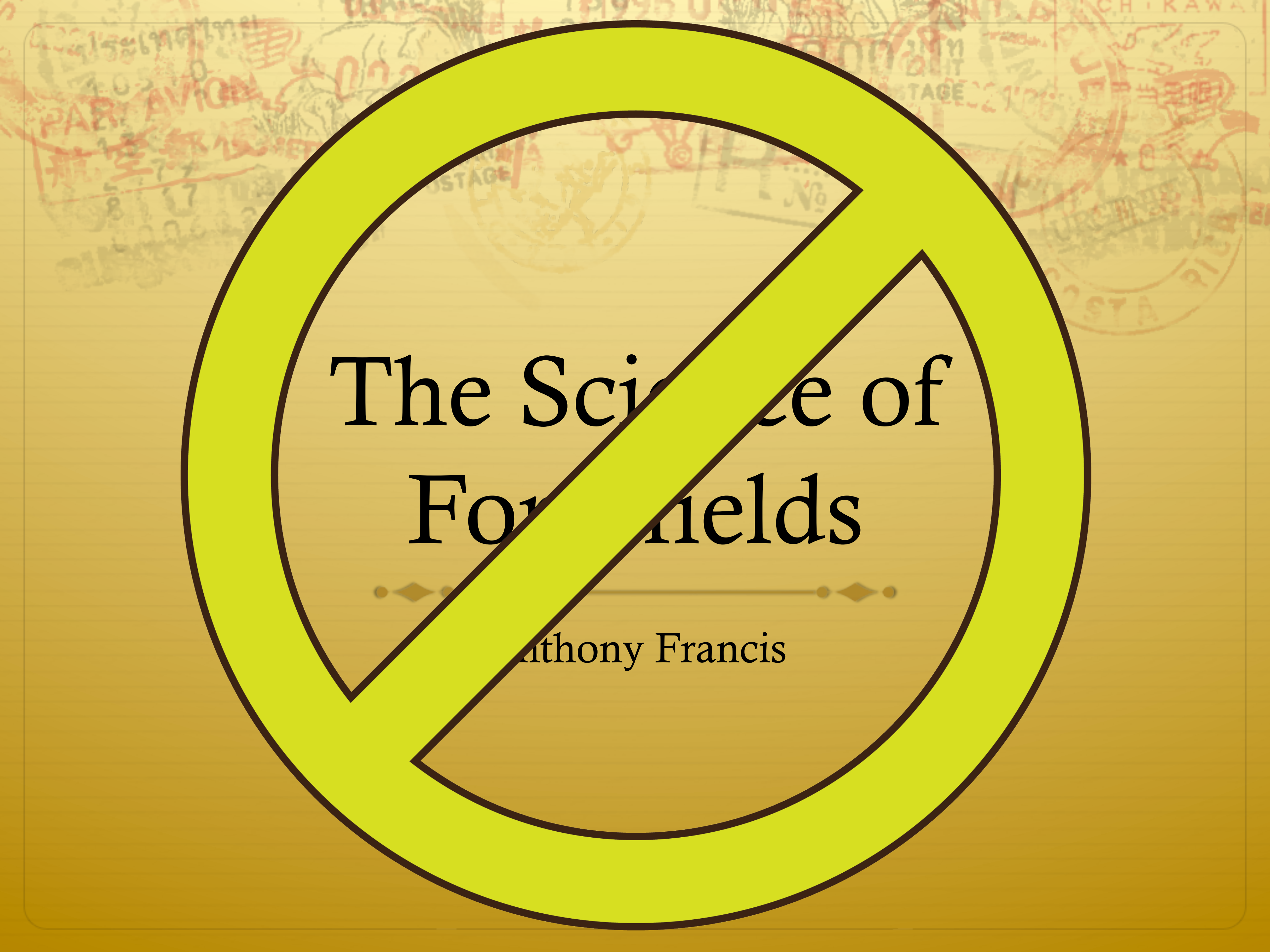
2889 cu.ft.

for a 220 pound person

81.81 meter^3 for 100 kilograms

The Science of Forcefields

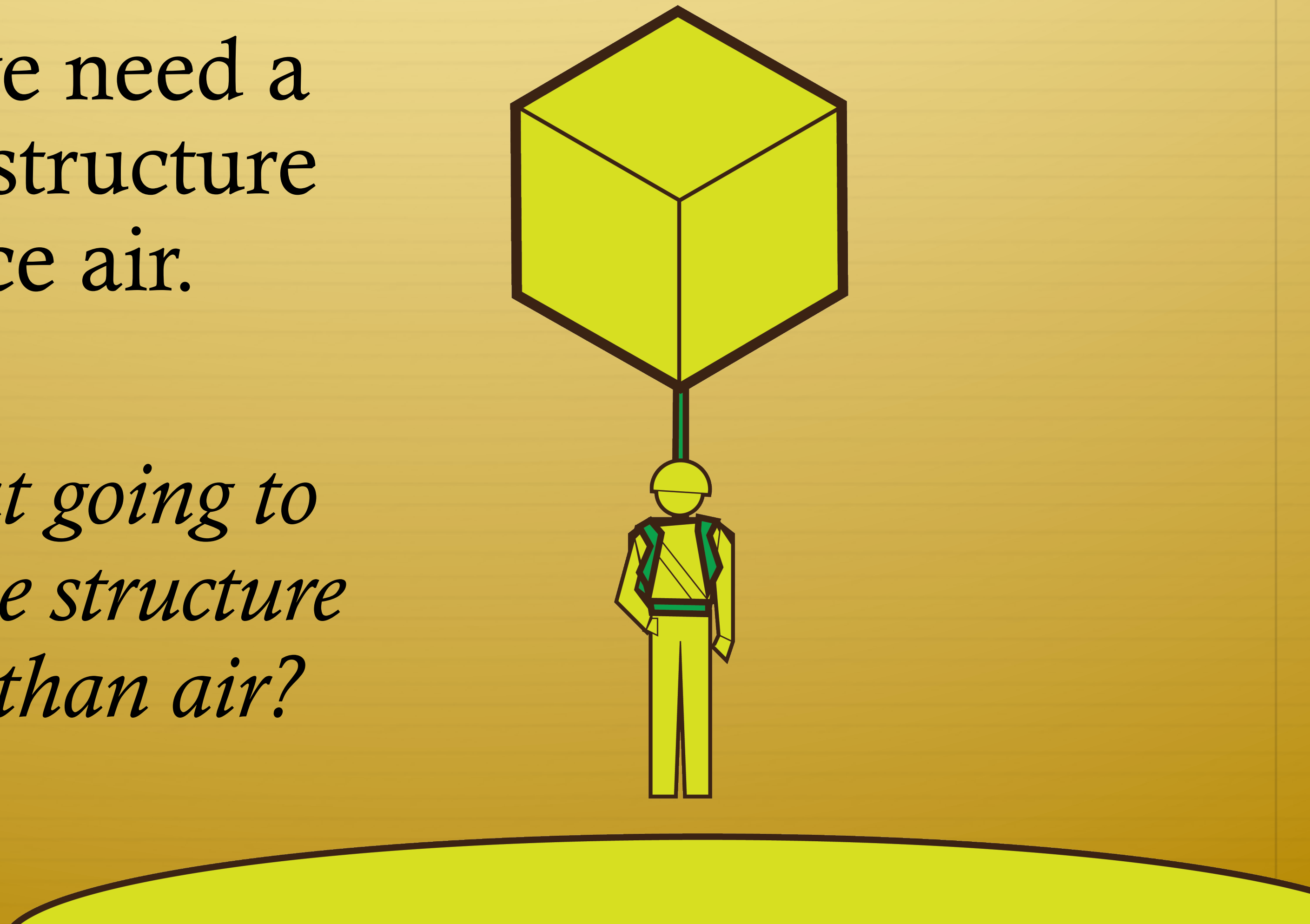
Anthony Francis


The Sci ce of
For hields
nthony Francis

Getting More Lift, Part 2

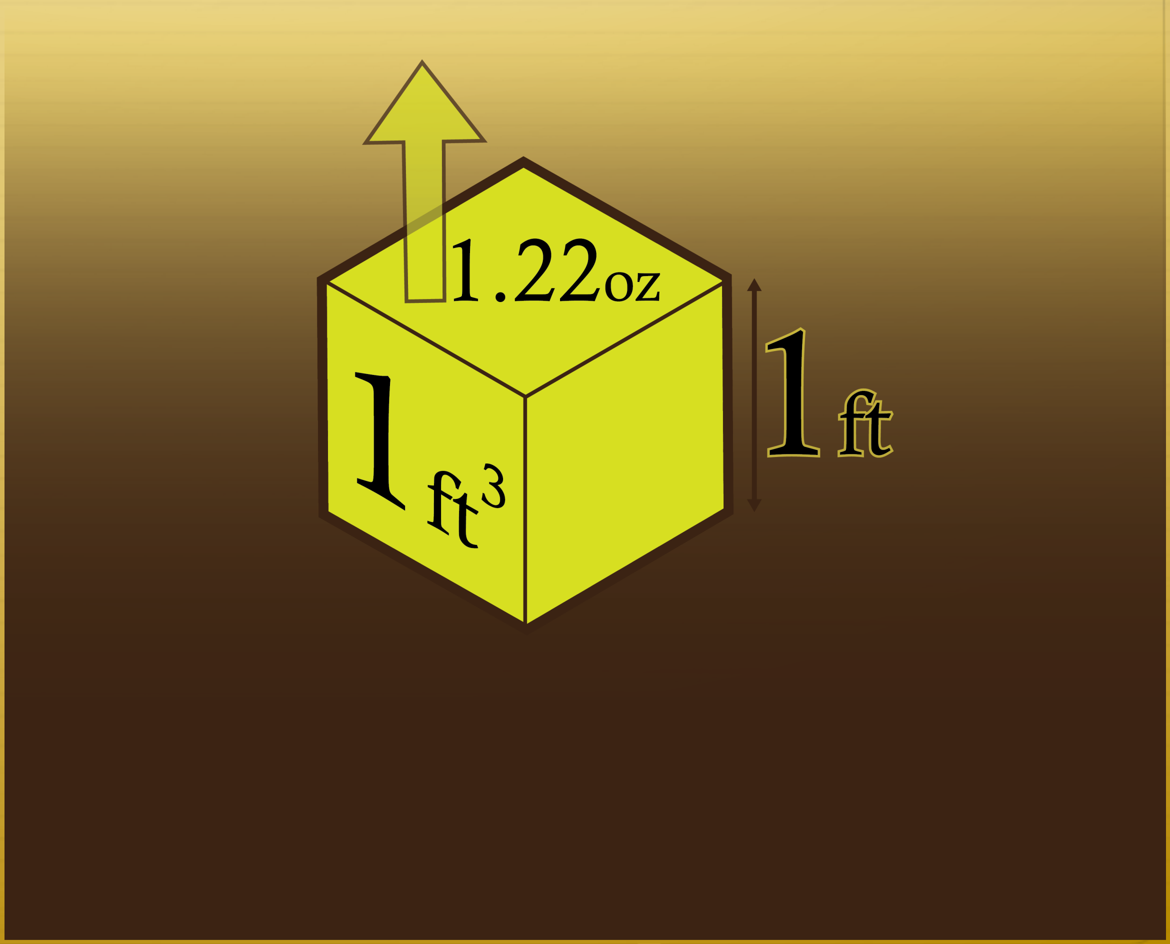
For lift we need a physical structure to displace air.

How's that going to work if the structure is heavier than air?



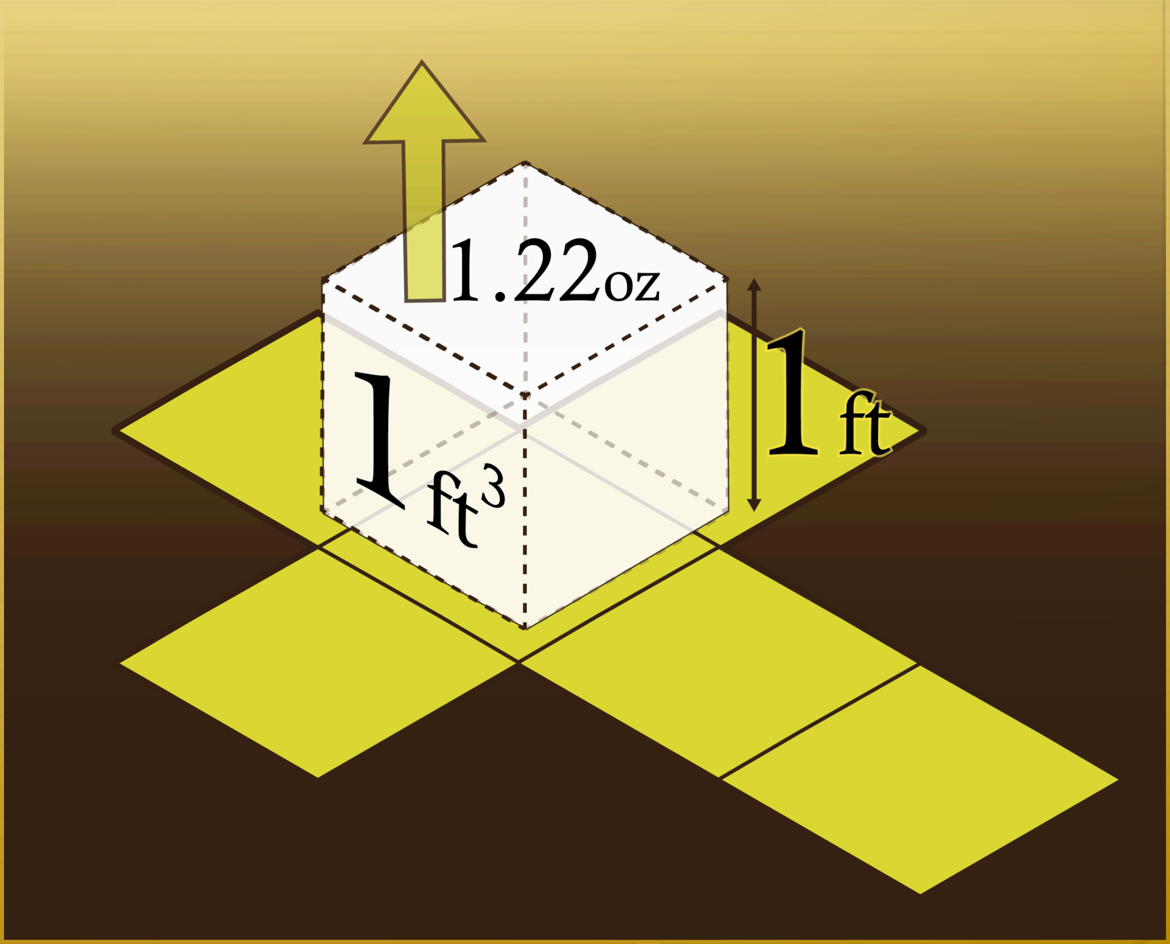
Carving Out Air

Return to our cubic foot.



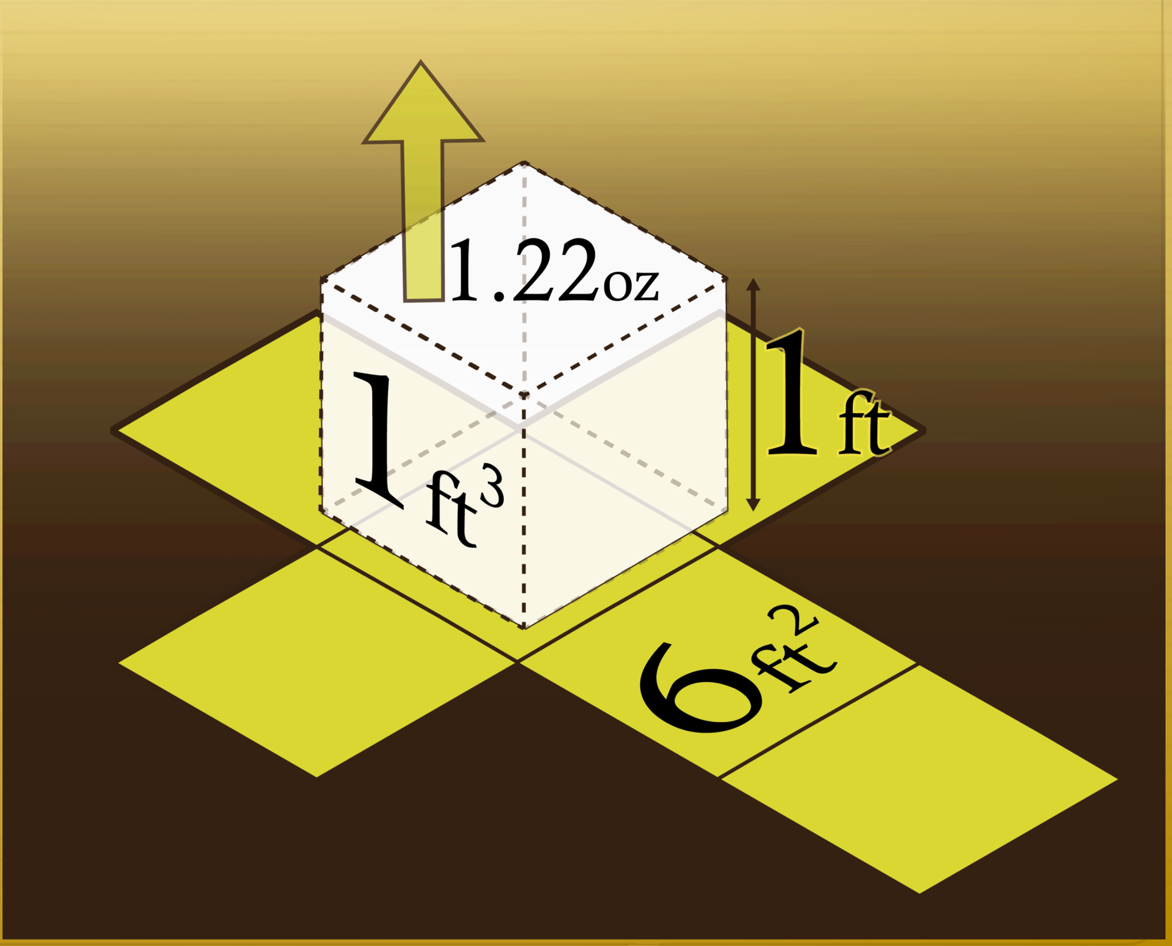
Carving out Air

Return to our cubic foot. Even if it was filled with nothing, the cube is still heavier than 1.22 ounces.



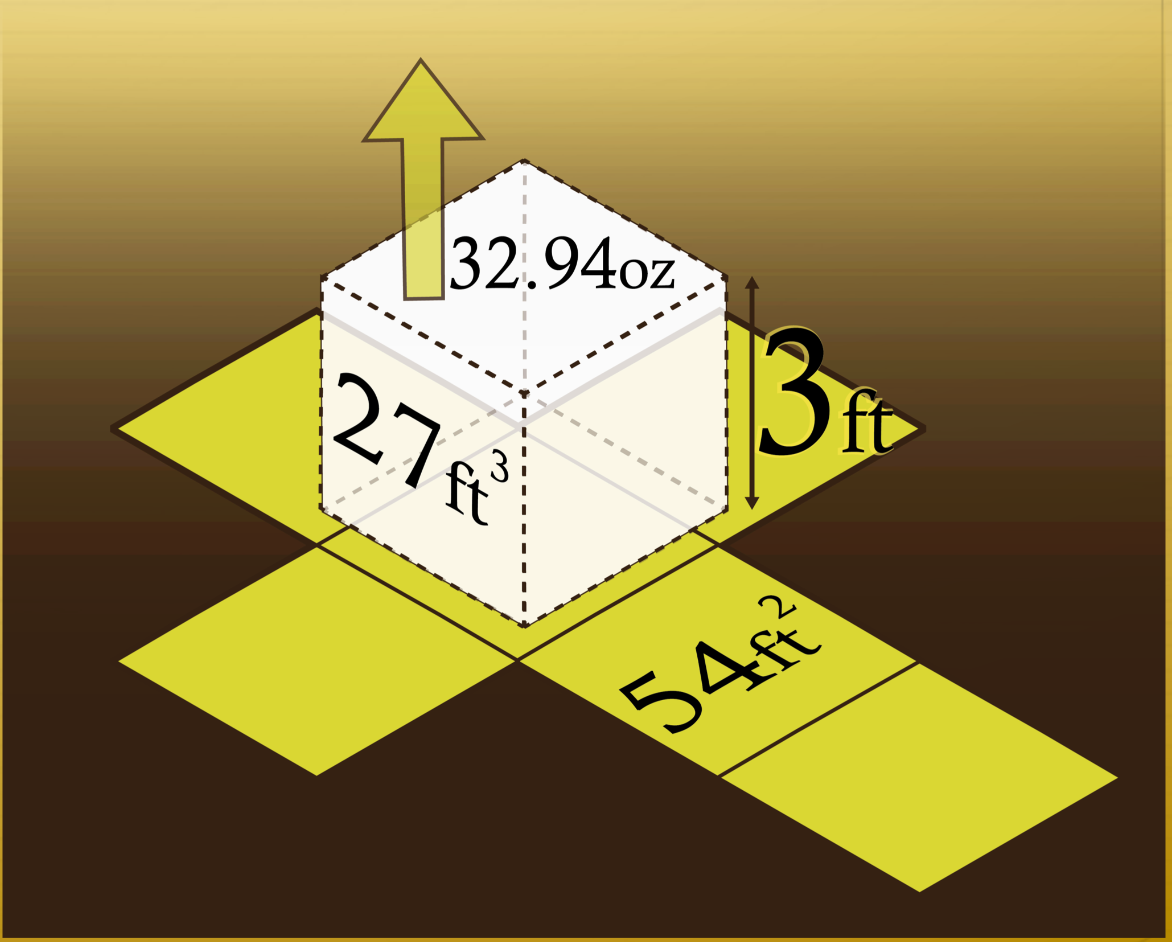
Vacuum with Packaging

The cube displaces one cubic foot of air with vacuum …
but has six square feet of packaging.



Scaling Up the Box

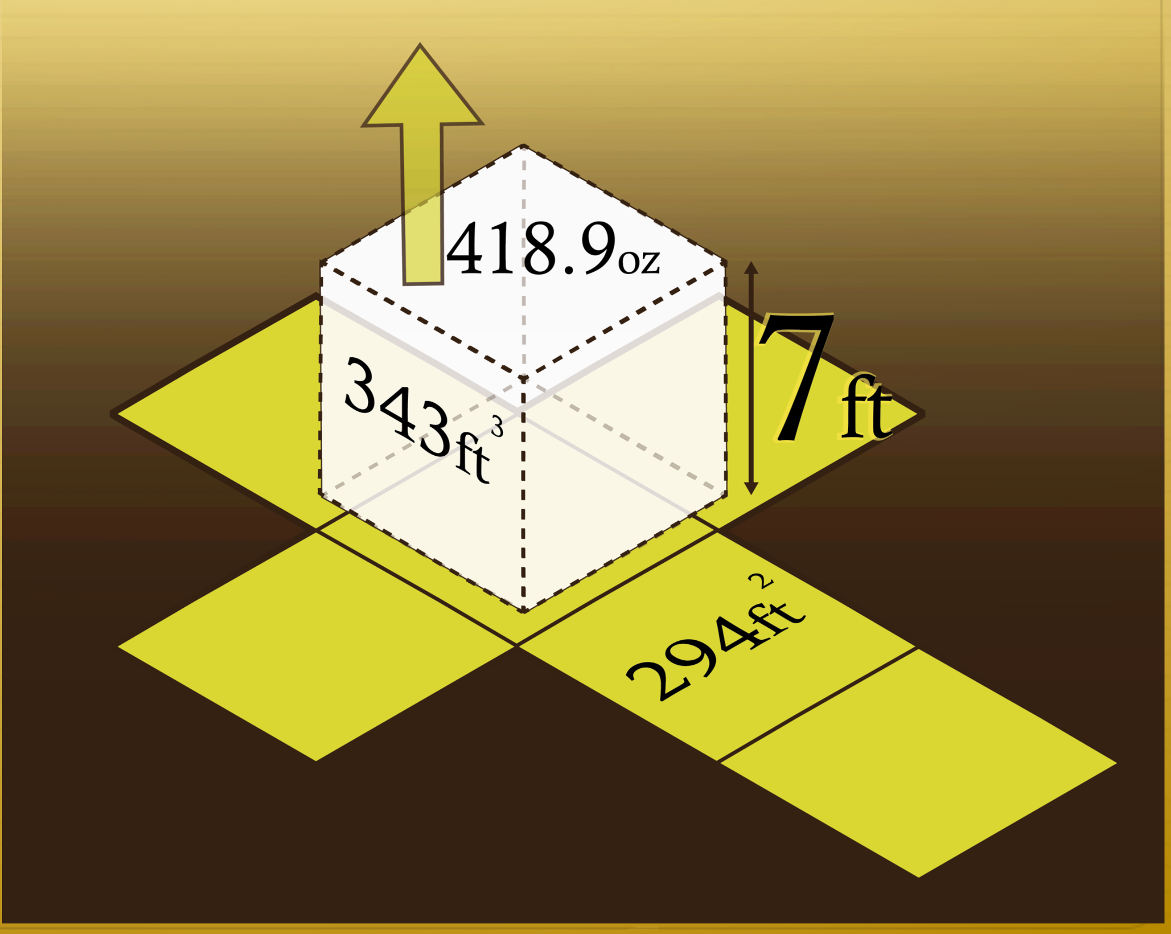
A cubic yard takes up 27 cubic feet of air and 54 square feet of packaging …
the volume grows faster!



More Vacuum than Package

By the time we hit a seven foot cube volume has outpaced surface area.

This is the *square cube law.*



The Square Cube Law

$$\text{Weight} \propto \text{Volume} \propto \text{Size}^3$$

Weight is proportional to volume

$$\text{Strength} \propto \text{Area} \propto \text{Size}^2$$

Strength is proportional to cross section

Square/Cube Hurts Solids

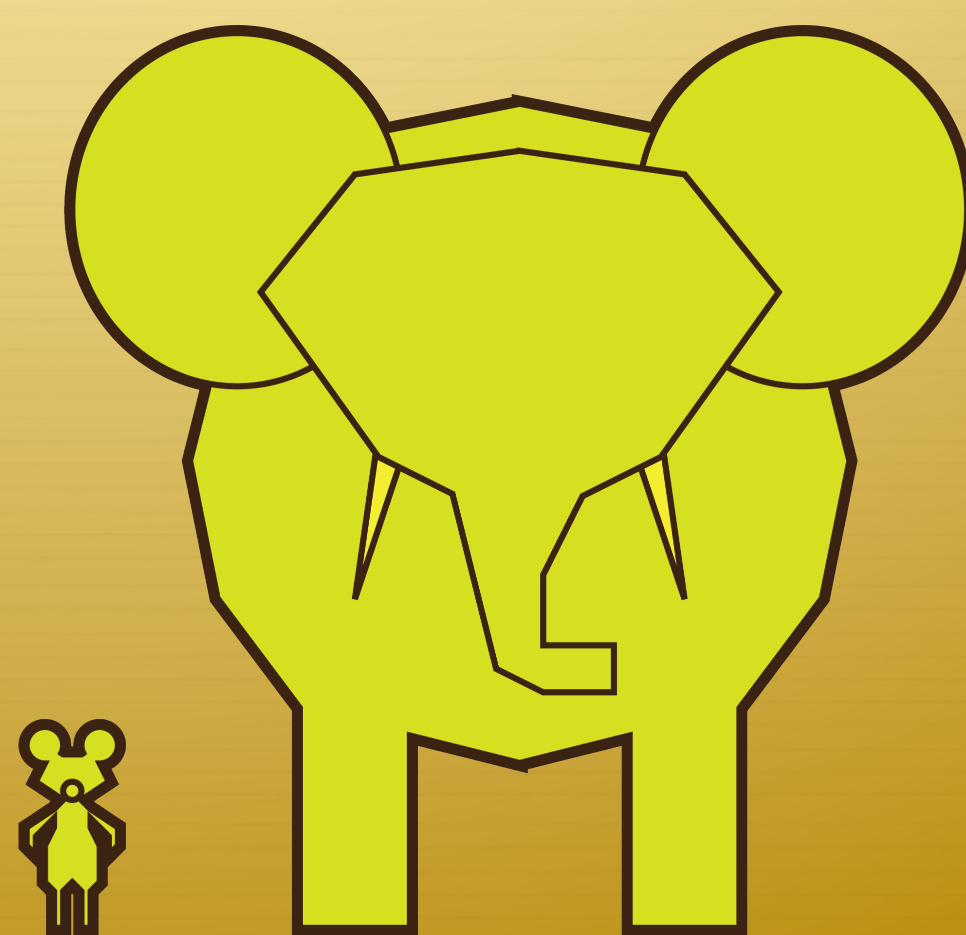
Weight $\propto$ Volume

$\propto$ Size^3

Strength $\propto$ Area

$\propto$ Size^2

This is why elephants have thicker legs than mice



Square/Cube Revisited

$$\textit{Lift} \propto \text{Volume} \propto \text{Size}^3$$

Lift is proportional to volume

$$\textit{Weight} \propto \text{Area} \propto \text{Size}^2$$

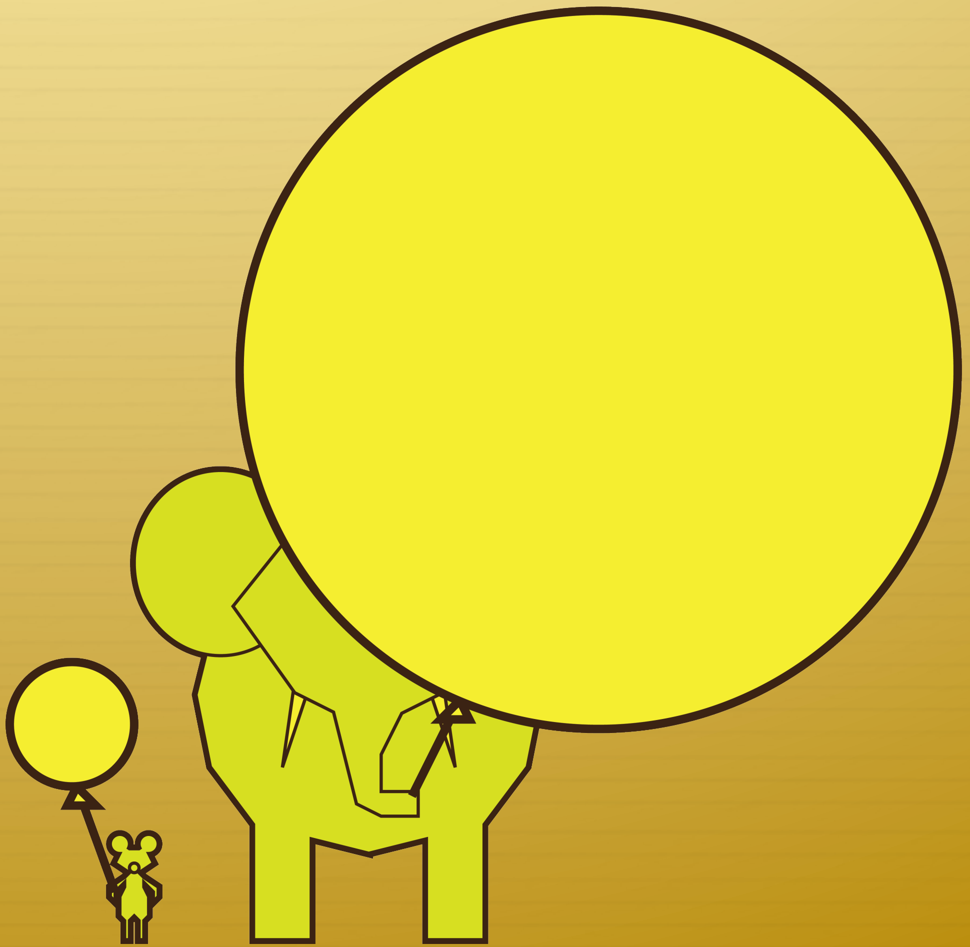
Weight is proportional to surface area

Square/Cube Helps Balloons

Lift ∝ Volume ∝ Size^3

Weight ∝ Area ∝ Size^2

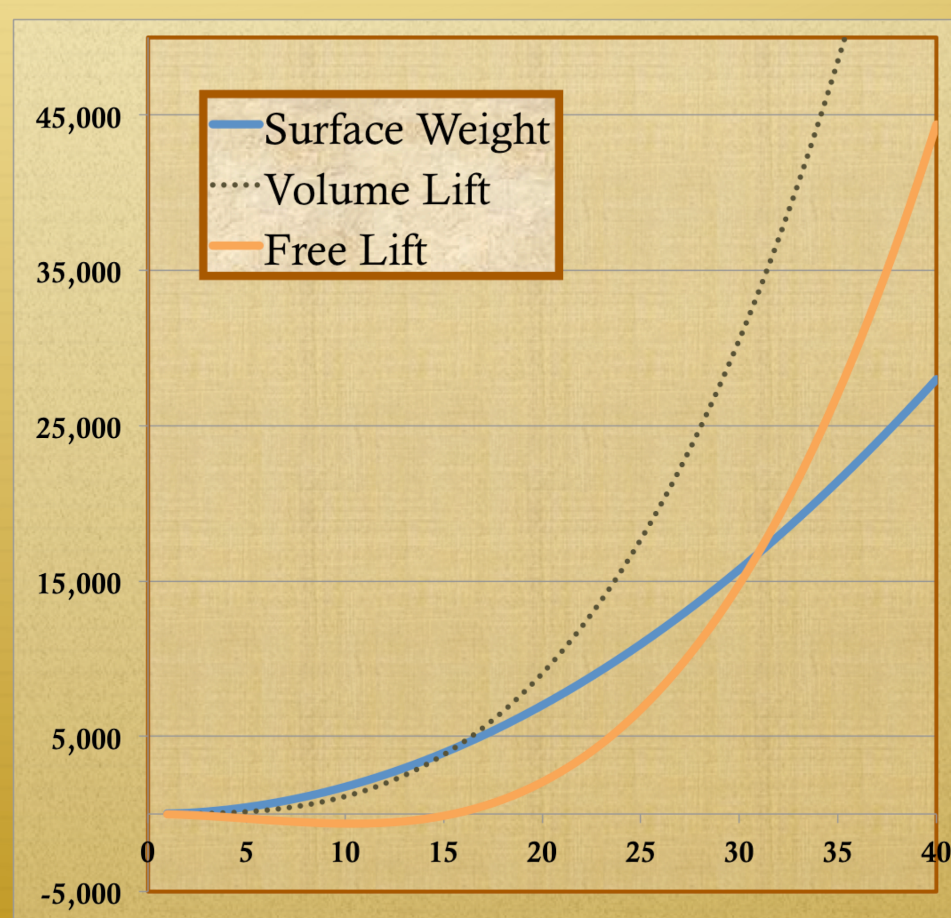
This is why balloons work!



How Big Must We Go?

Volume increases with size faster than surface area.

Envelope weight is overtaken by lift …*at larger sizes.*

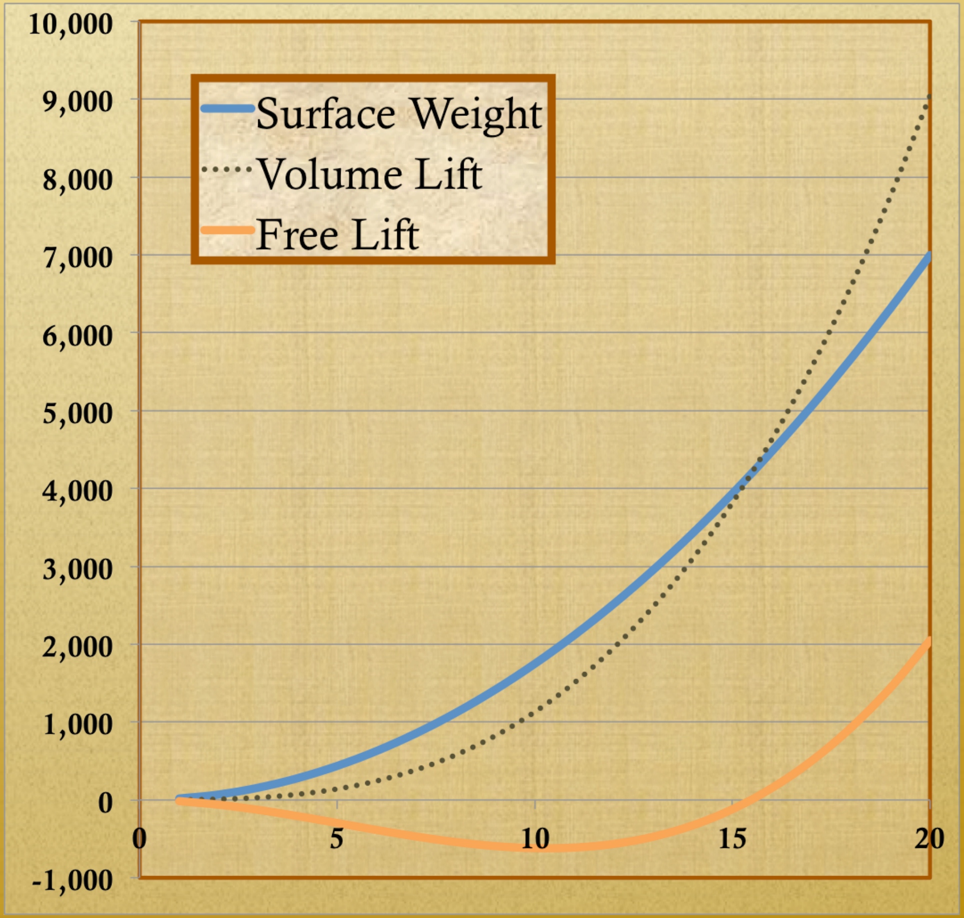


Lift in ounces versus box size in feet

Small Balloons Don't Help

Scale up the box. Under 15 feet, the weight of the walls beats the lift of displaced air.

Over 15 feet … the box floats.

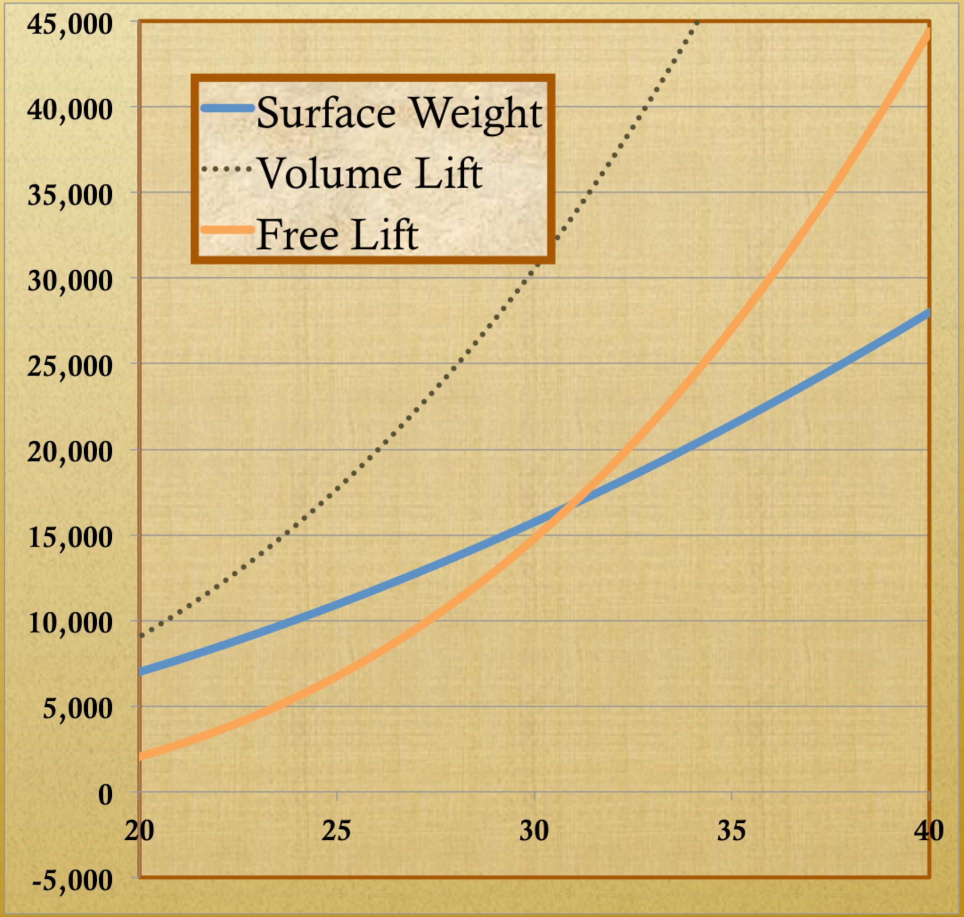


Lift in ounces versus box size in feet

Large Balloons Kick Ass

Volume lift keeps growing faster than surface area.

Over 30 feet, the free lift of a box filled with vacuum dominates its weight!



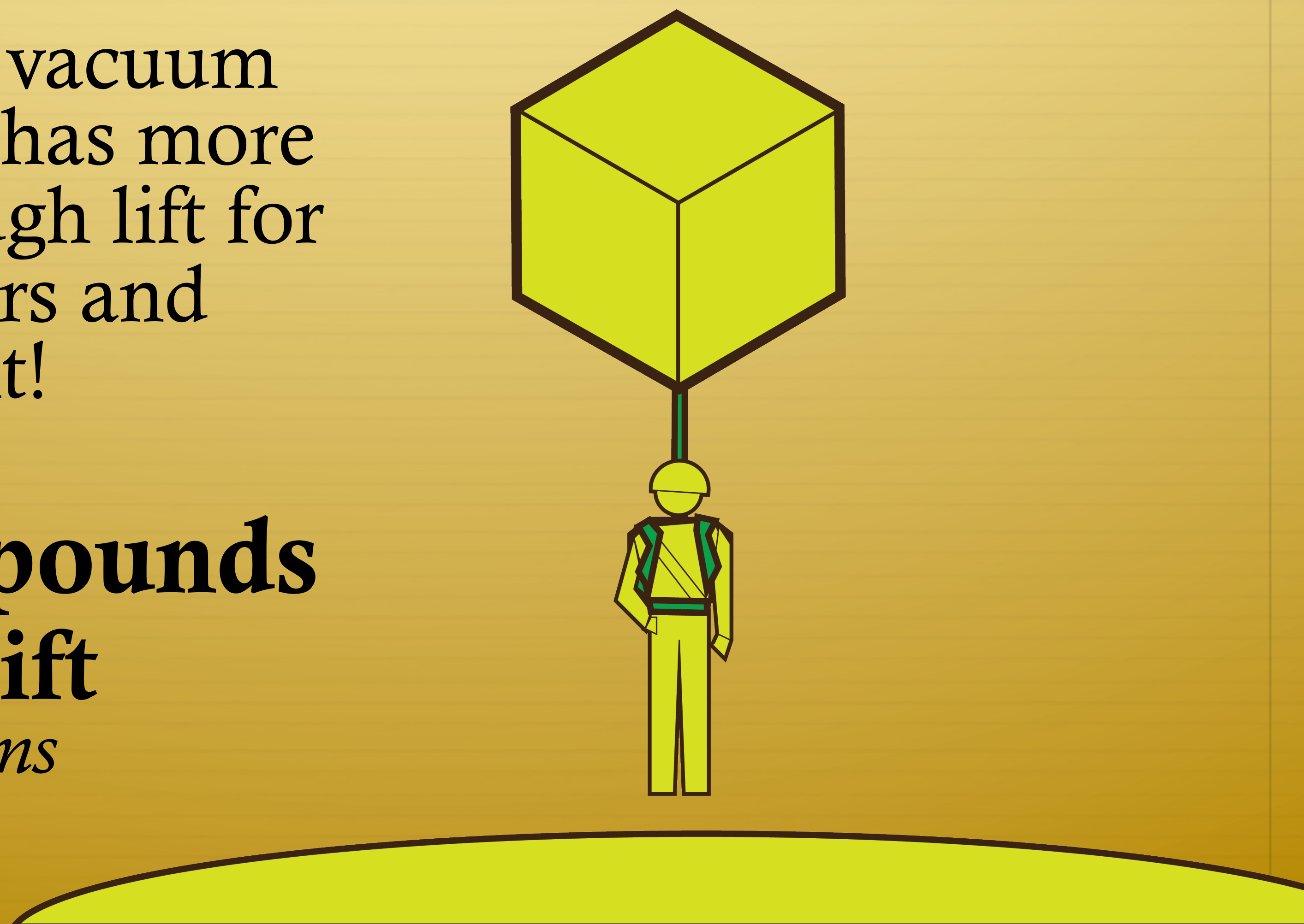
Lift in ounces versus box size in feet

Making Lift Practical

A 30 foot vacuum filled box has more than enough lift for adventurers and equipment!

925 pounds of free lift

419 kilograms

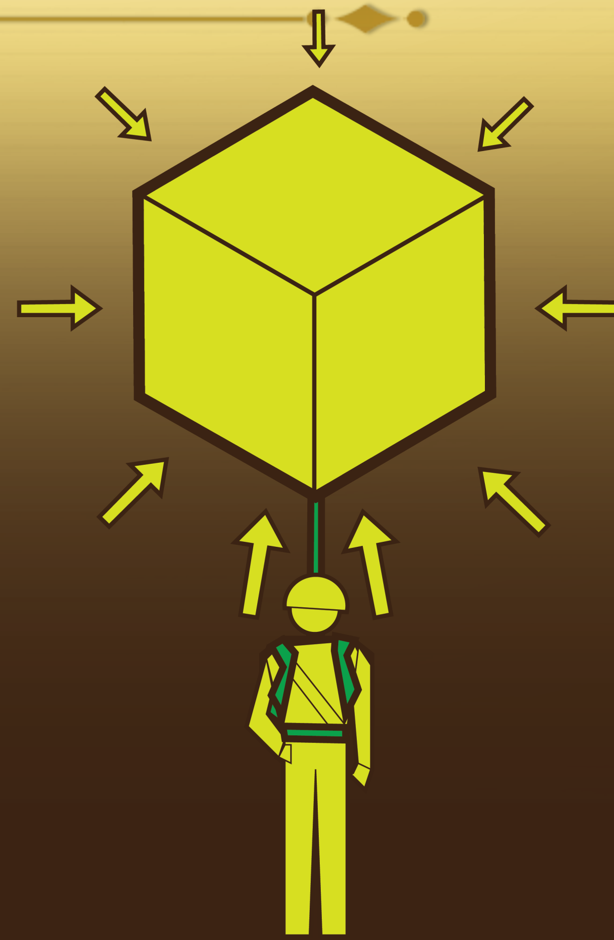


Making Lift Practical

Unfortunately, it's also under a lot of pressure…

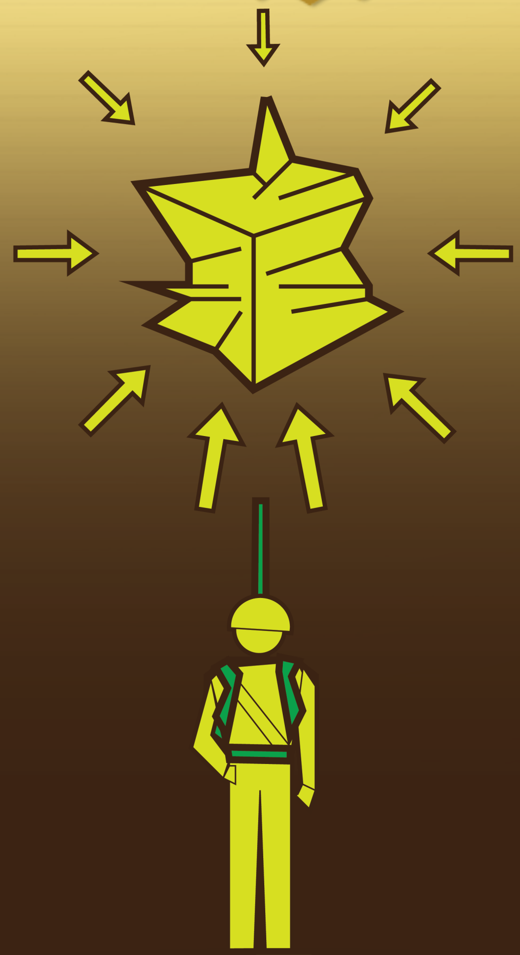
5543 tons of air pressure

4938 metric tons



Making Lift Practical

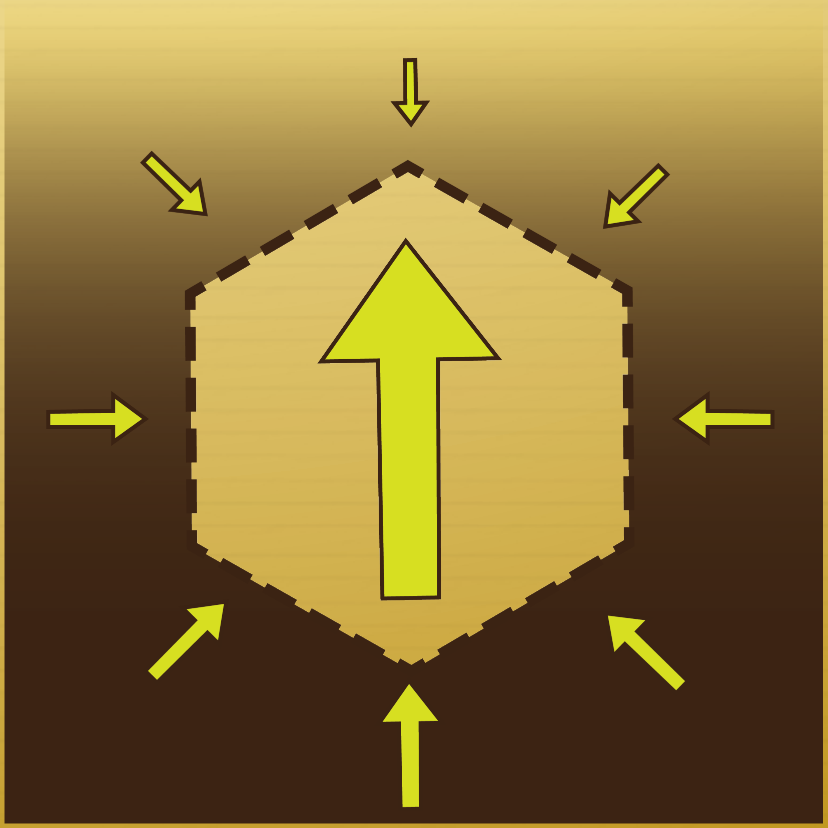
This would make any reasonably sized box collapse.



If you don't want a steel hull…

A vacuum is the best possible lift source …

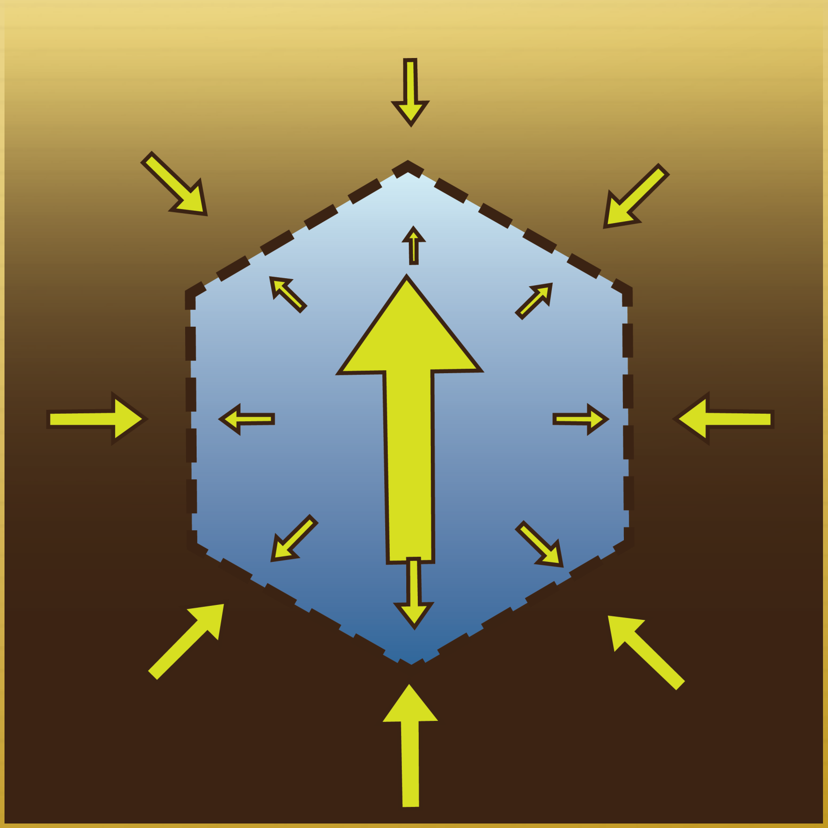
but it isn't the only thing lighter than air.



… try something not nothing.

Filling the volume with a light gas adds weight…

but counteracts pressure by equalizing it.



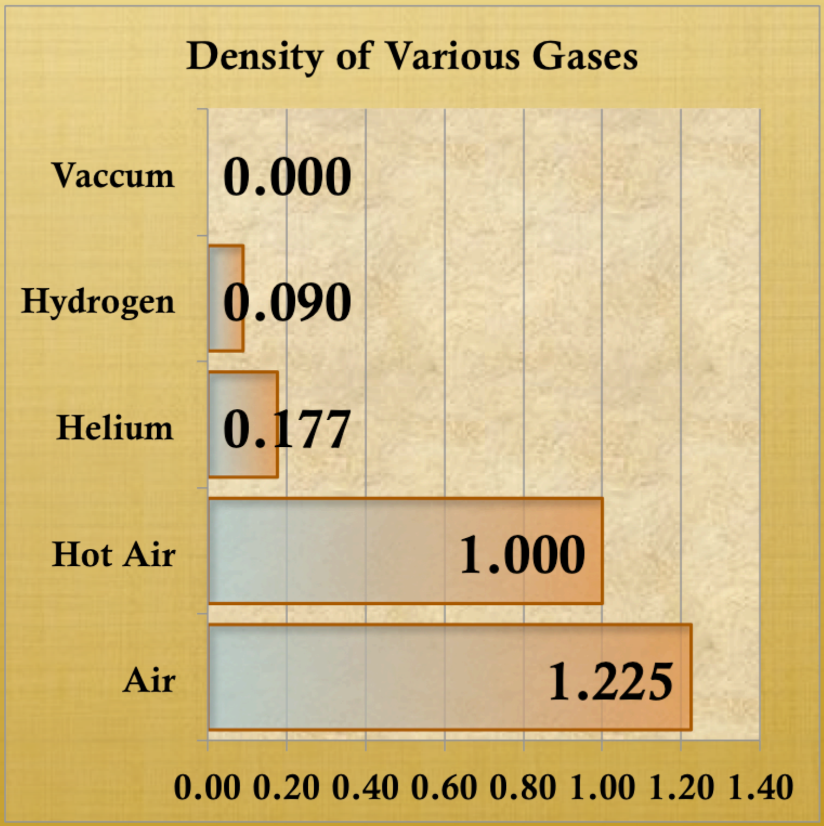
The Next Best Thing to Vacuum

Hydrogen is the next best thing to vacuum…

0.090oz

per cubic foot

0.090 grams per liter



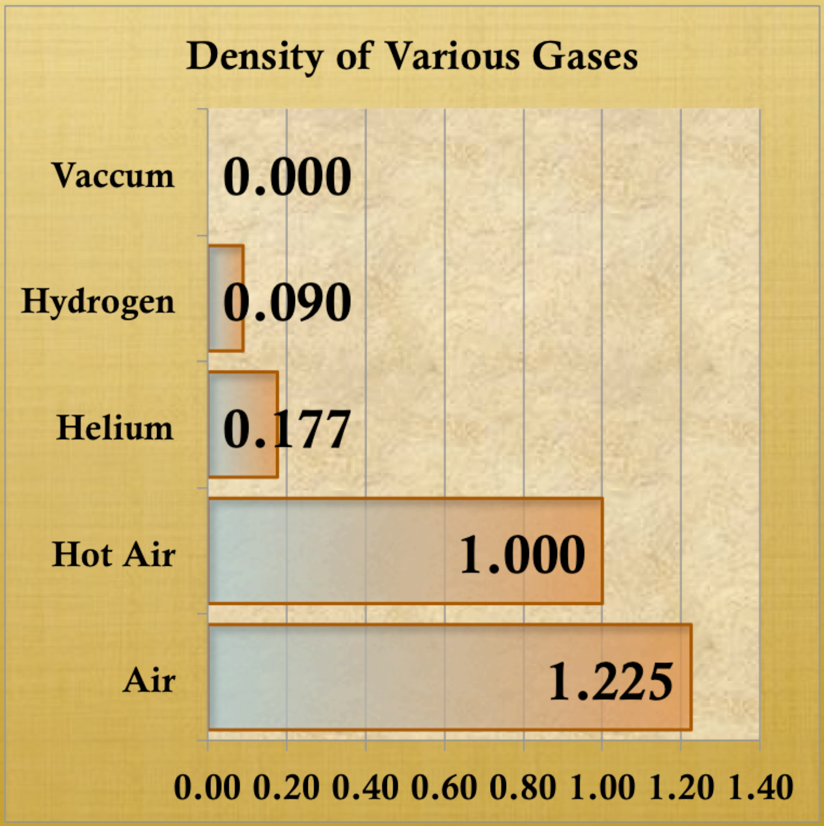
The Next Best Thing to Vacuum

… and provides nearly as much lift as nothing:

1.14oz

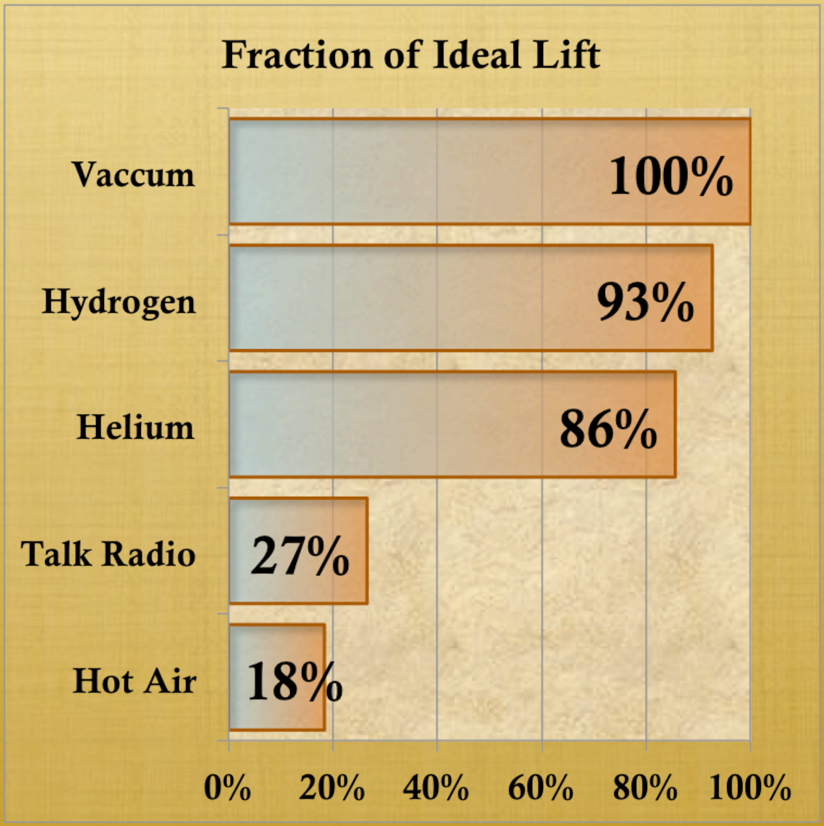
per cubic foot

1.13 grams per liter



The Next Best Thing to Vacuum

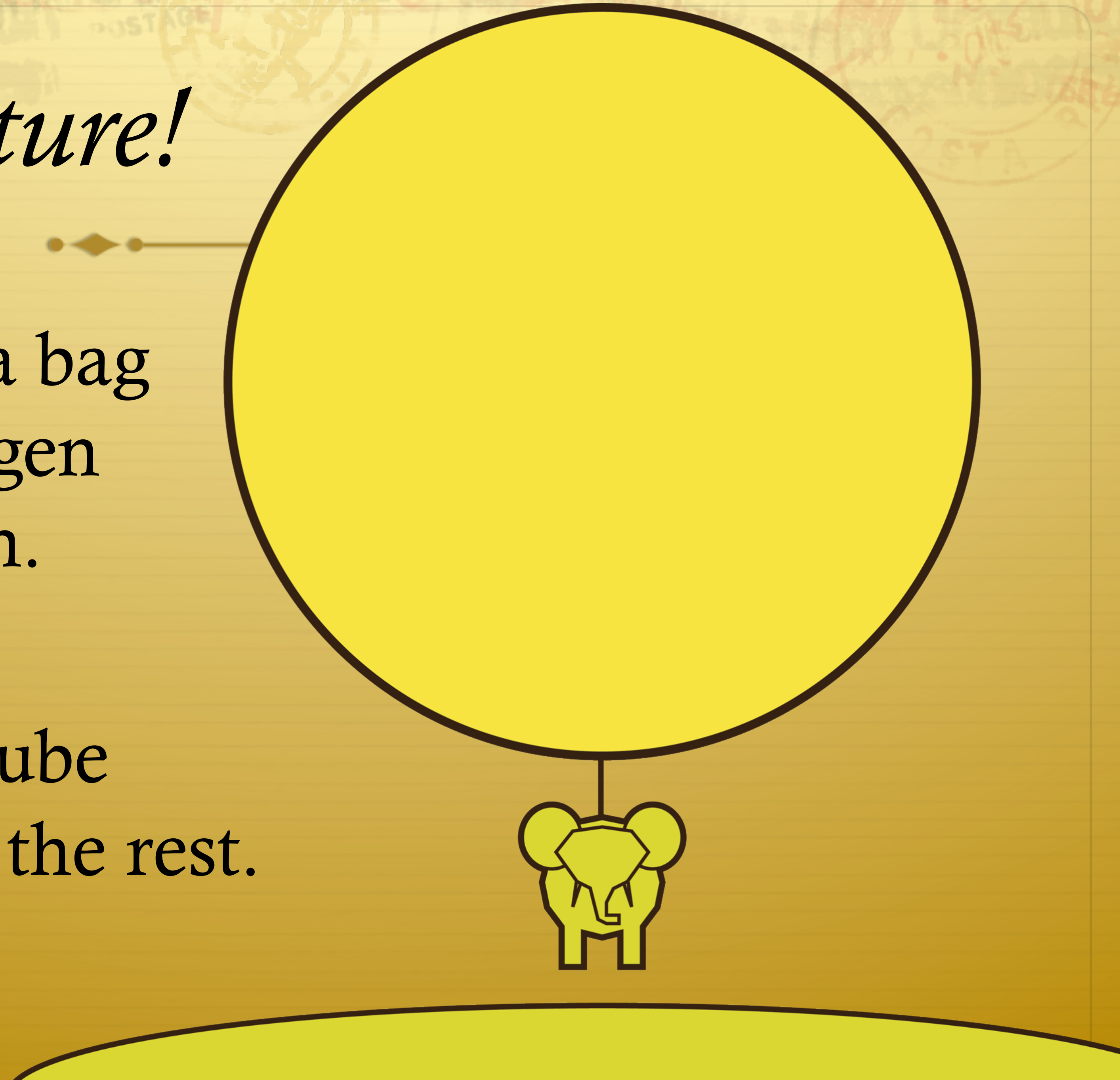
But hydrogen **and** helium are both so much lighter than air they're almost as good as vacuum.



Adventure!

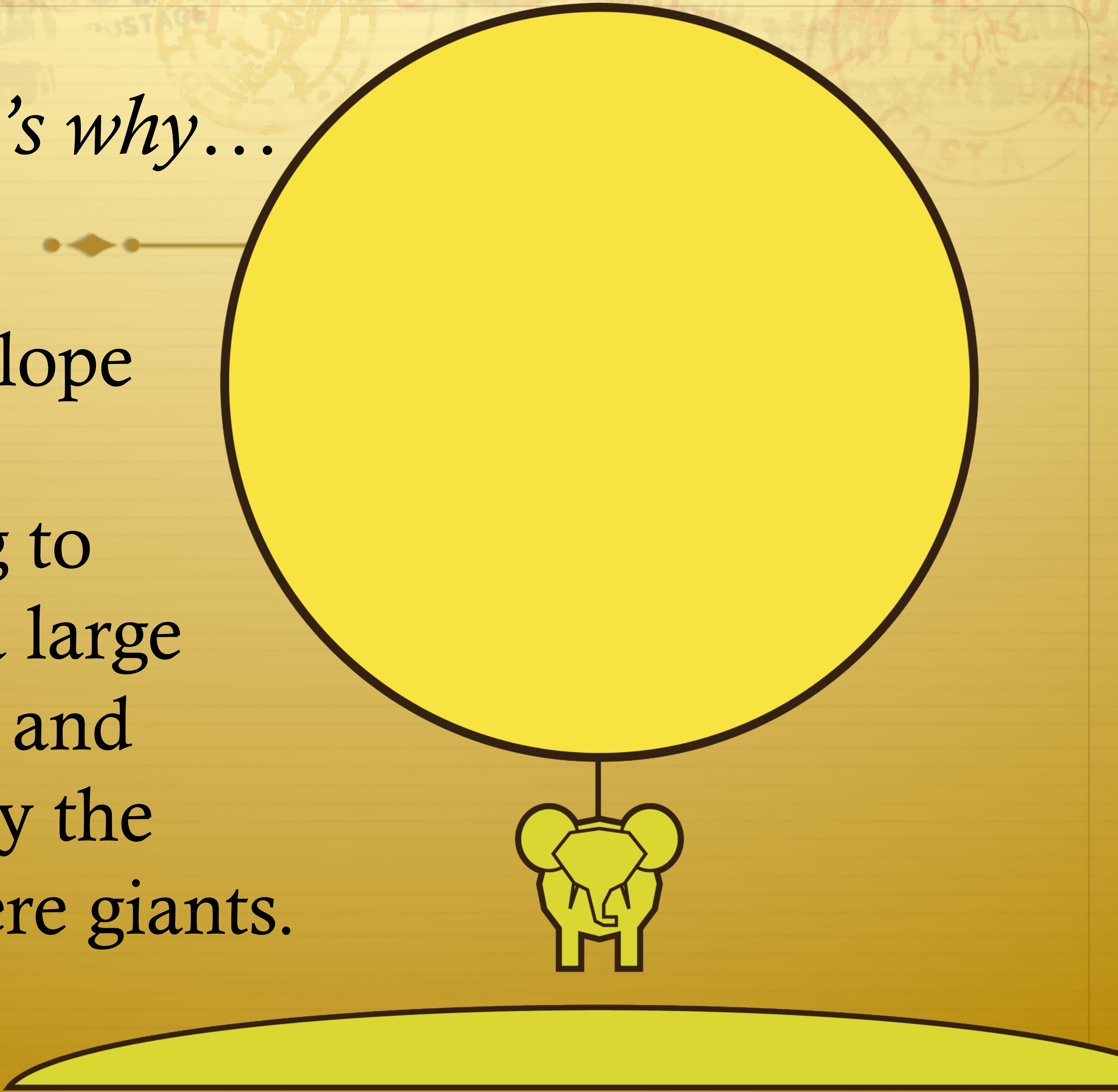
Just use a bag of hydrogen or helium.

The square/cube law does the rest.



And that's why…

The envelope has to be pretty big to support a large object … and that's why the giants were giants.



Ballooning

The Science of Vertical Flight

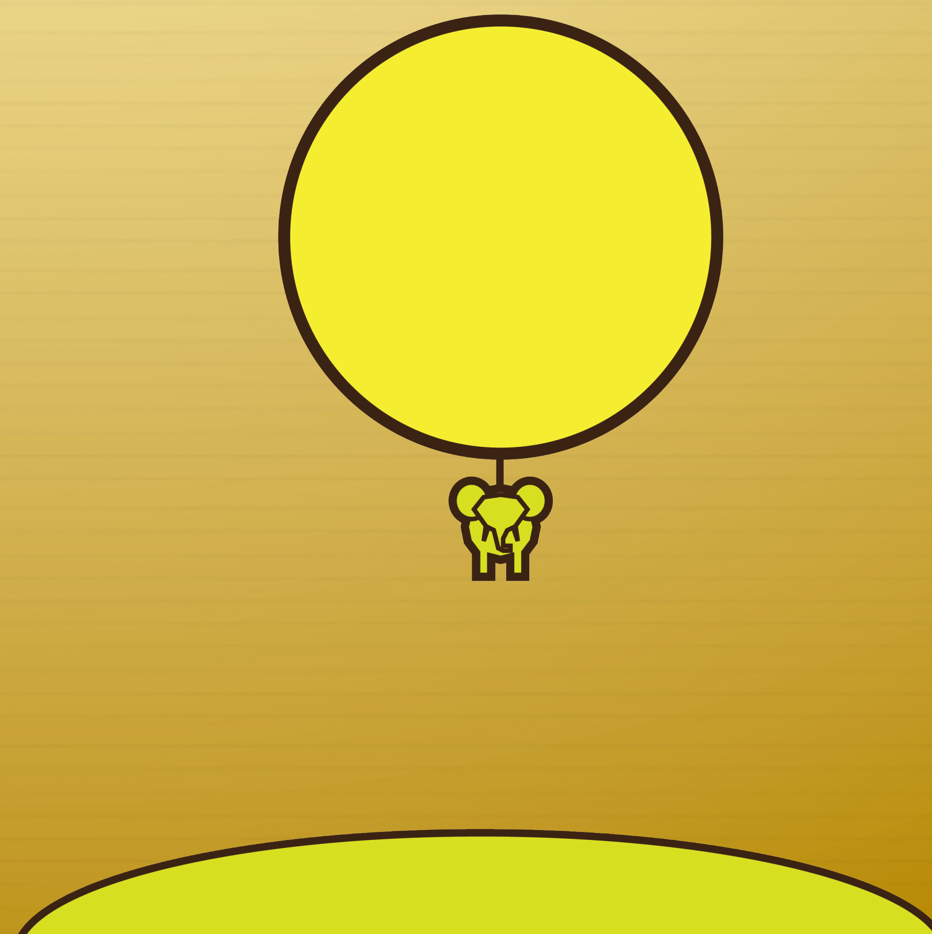
Peeling the Next Layer

Airships are low-flying…

But Why?

Vertical Flight

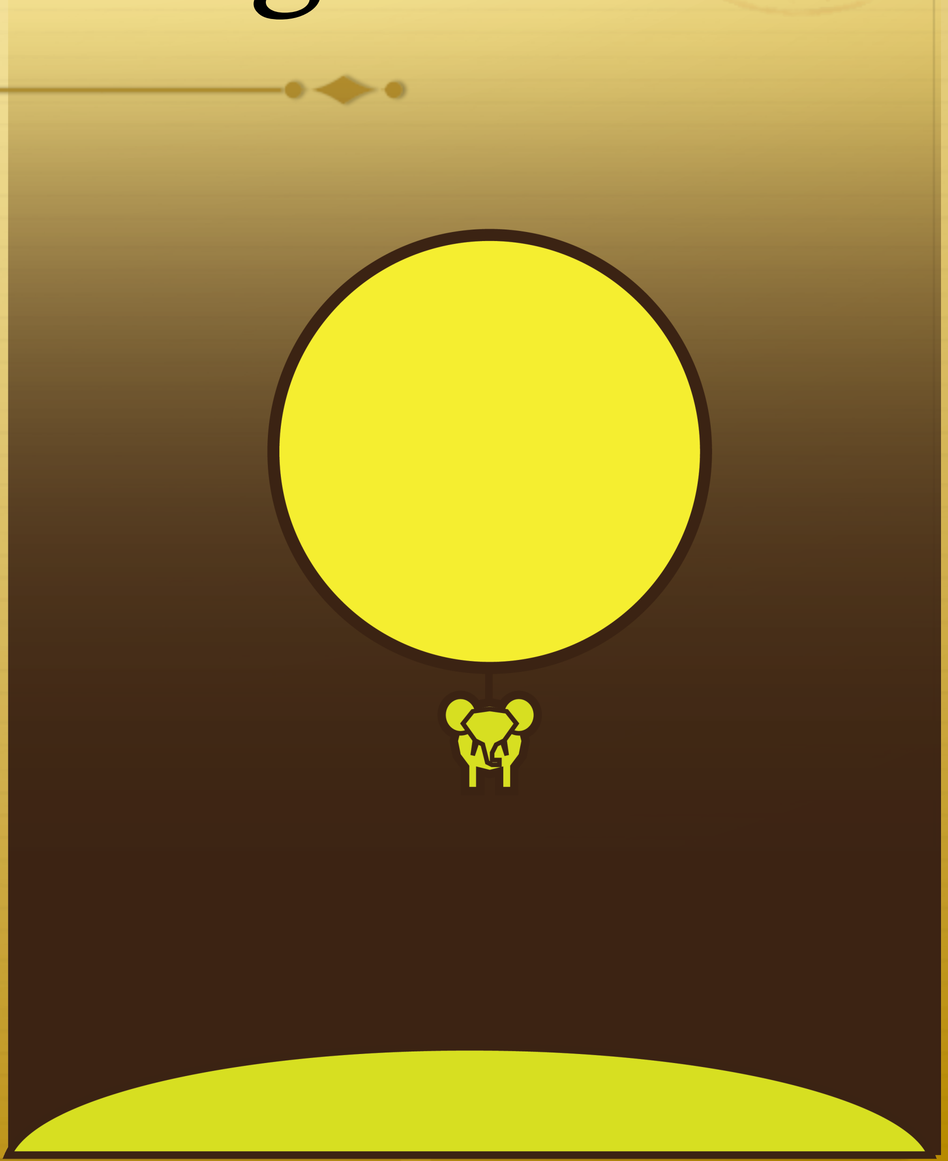
Once we begin to fly, we encounter another problem:



Vertical Flight

Once we begin to fly, we encounter another problem:

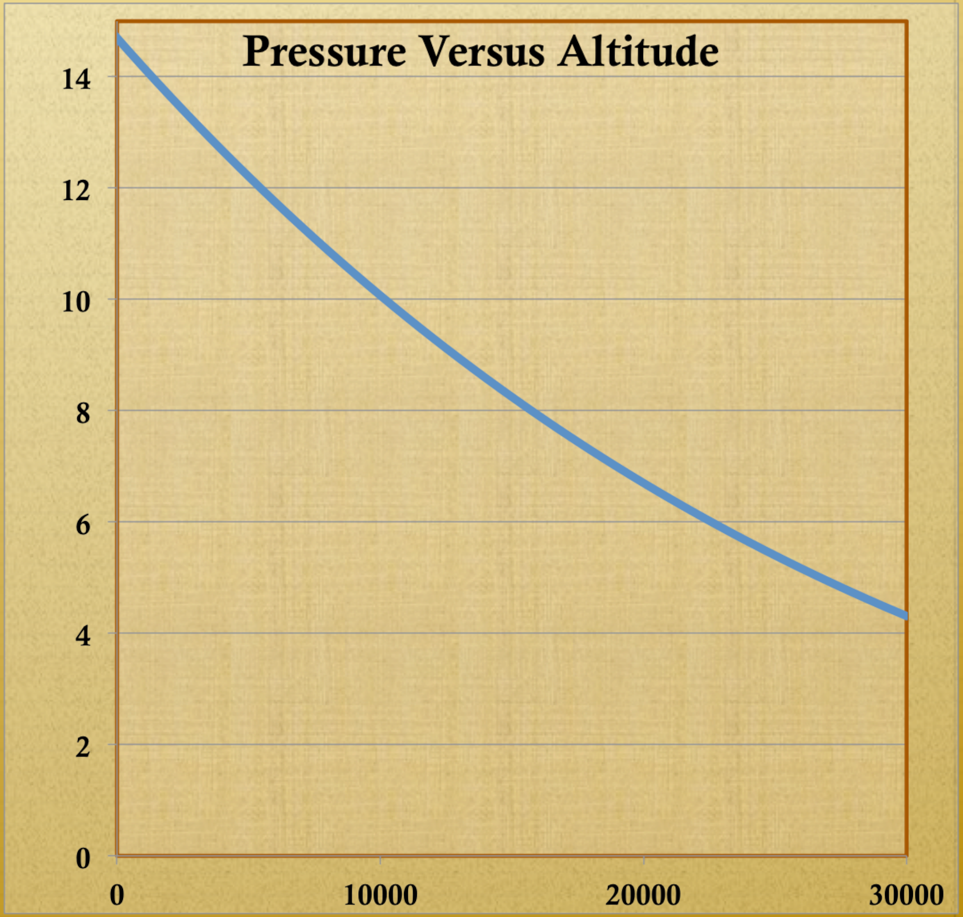
The air thins out with a gradient.



Thinning Air

Pressure drops exponentially with altitude…

$$\textbf{\textit{pressure}} \approx 14.7 \times (2.25 \times 10^{4} - 1.53 \times \textit{height})^{5.25}$$

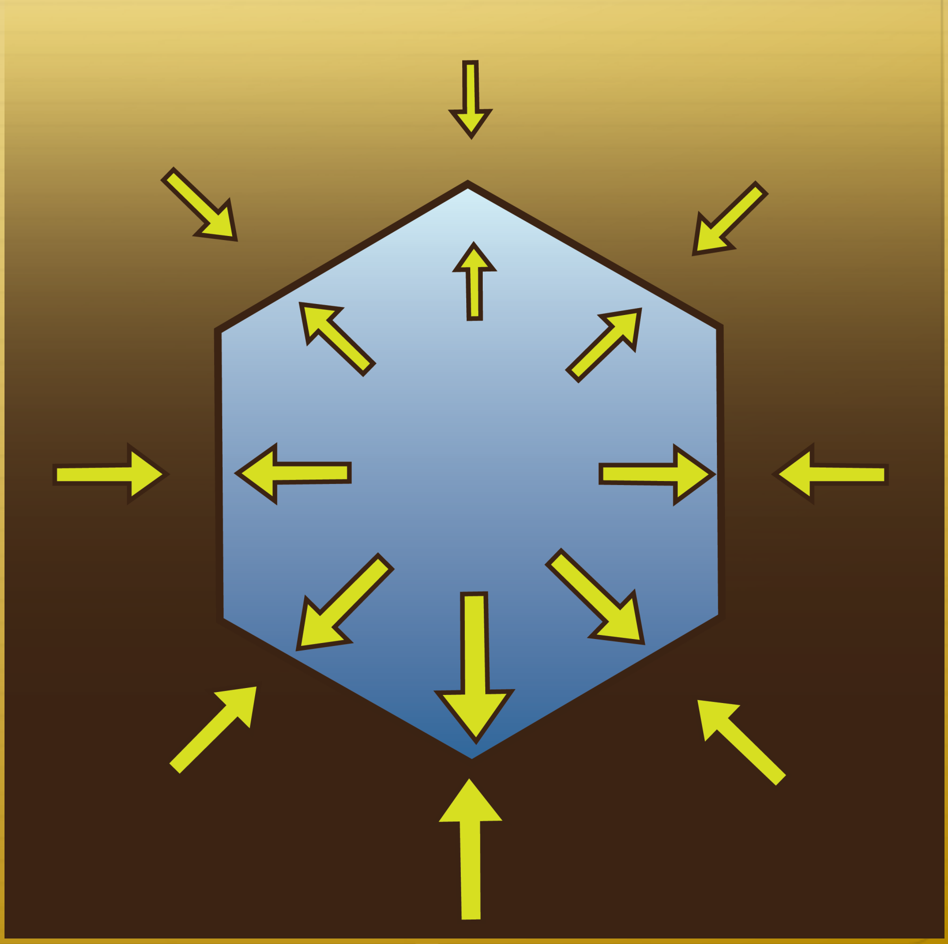


Pressure in psi versus altitude in feet

Lift Your Own Lift Gas

Unlike a hot air balloon, airships can't make gas.

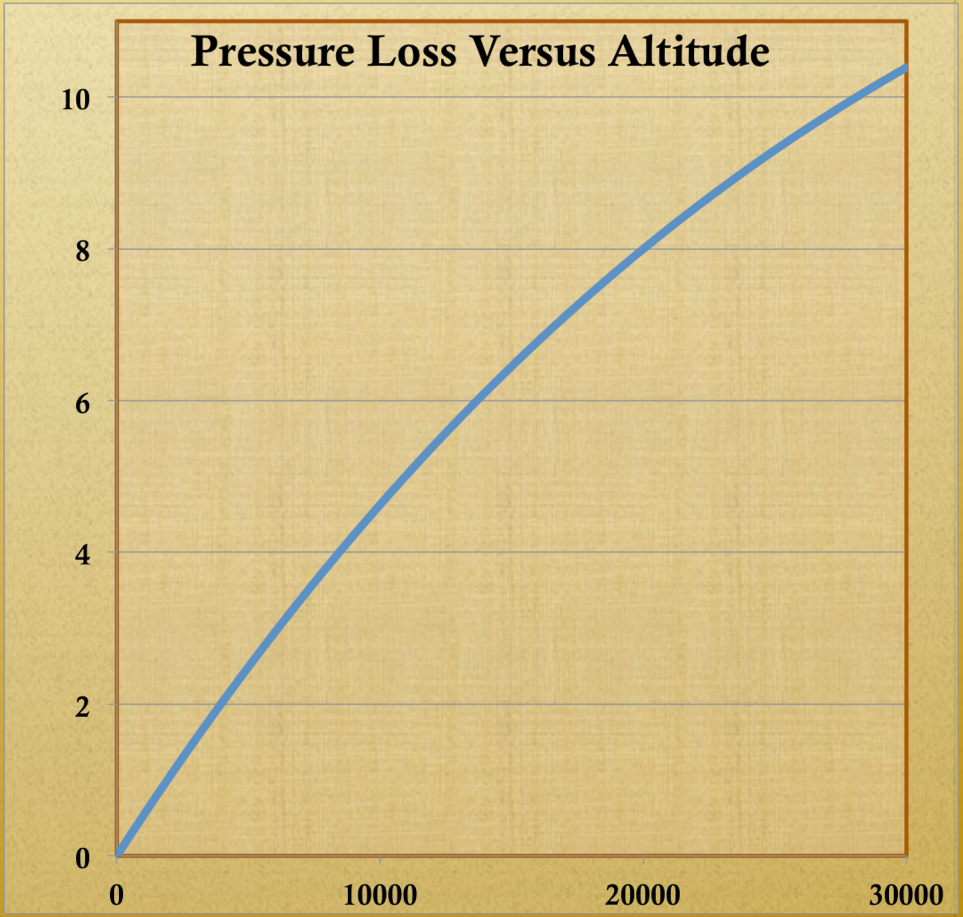
Sealed envelopes trap lift gas … *at sea level pressure*.



Pressure Lost at Altitude

Even as low as 1,000 feet, pressure drops almost 4%, to 14.2 psi, *half a pound per square inch* less than sea level:

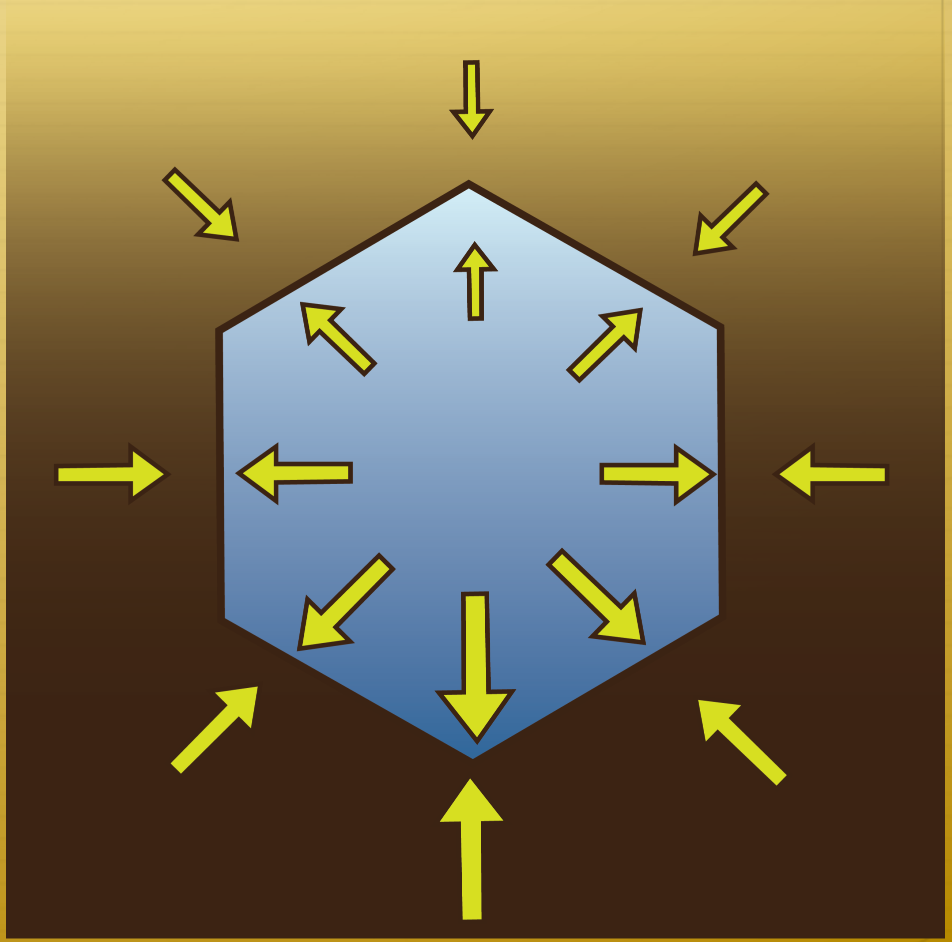
0.528 pounds
per square inch
3.64 kilopascals



Pressure loss in psi versus altitude in feet

Overpressure at Altitude

A 30 foot box at 1,000 feet would have ridiculous overpressure:

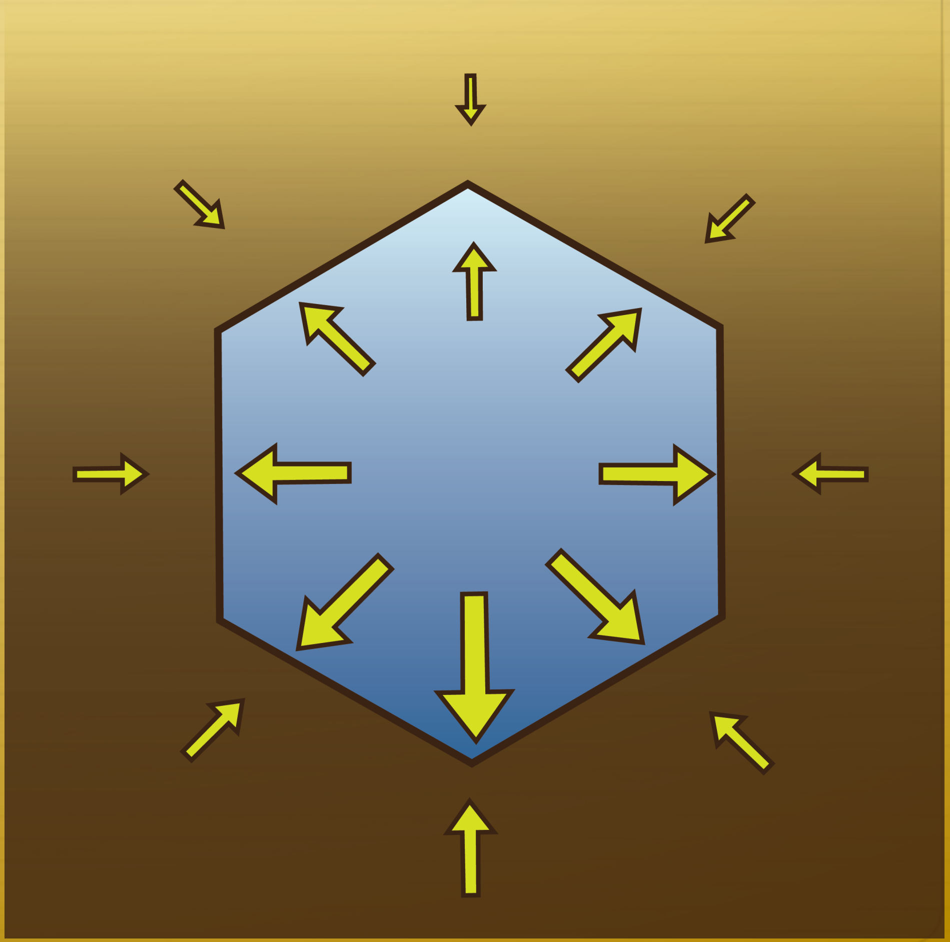


Overpressure at Altitude

A 30 foot box at 1,000 feet would have ridiculous overpressure:

205 tons of pressure

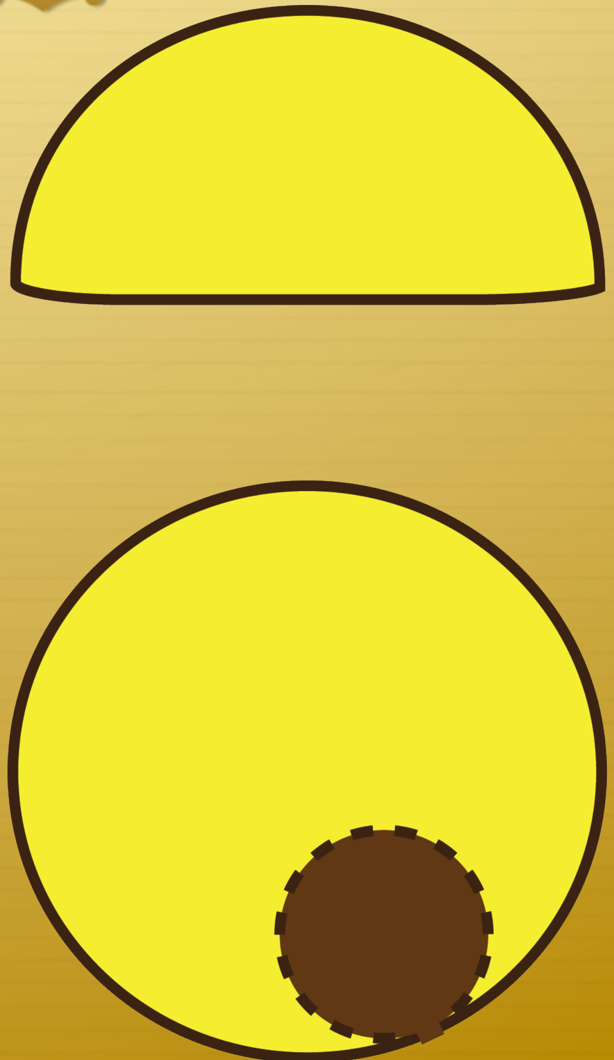
186 metric tons



Dealing with Overpressure

There are two typical strategies for dealing with overpressure:

- Partial Inflation
- Ballonets



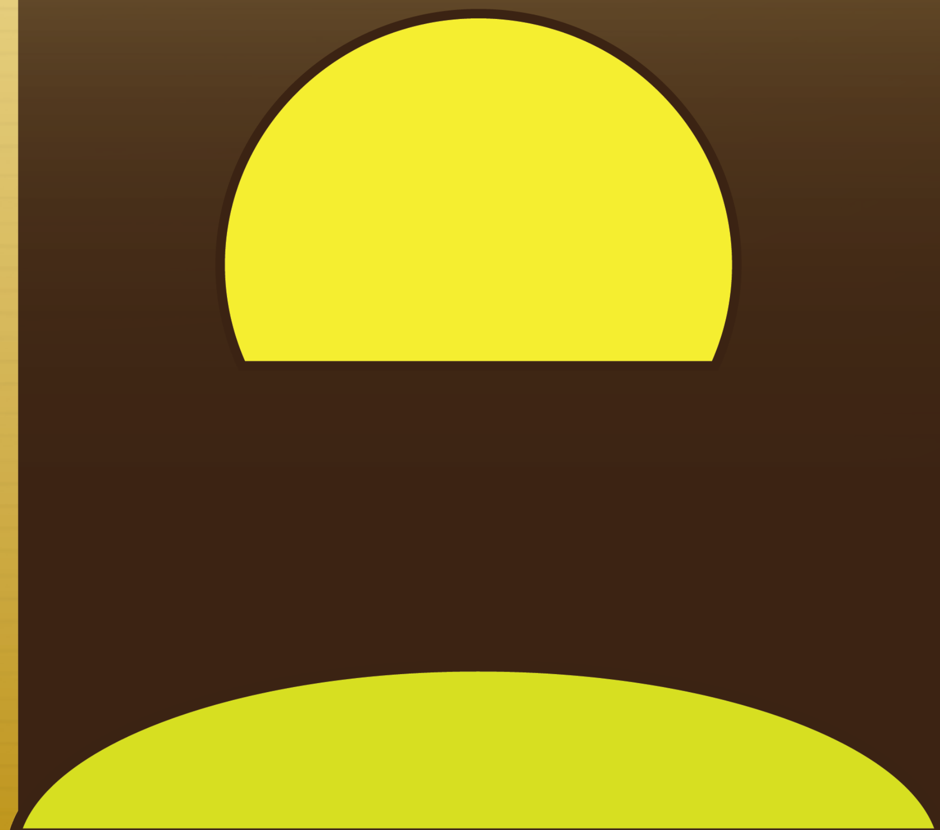
Launching when Deflated

Typical powered airships use fixed-size envelopes.

Partial inflation enables them to rise to height.

Launching when Deflated

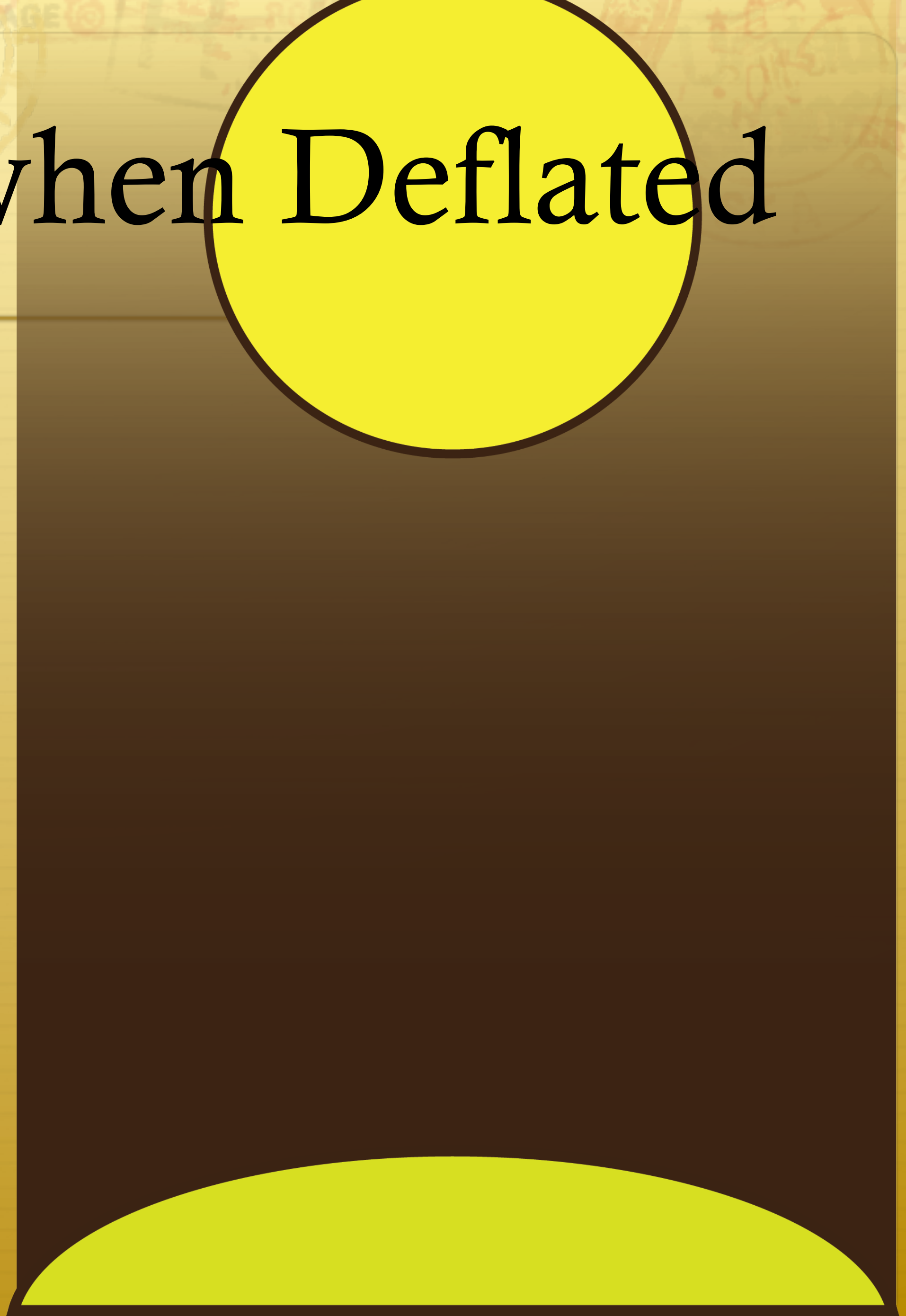
As the balloon rises, the lift gas slowly expands, reducing pressure inside to match the outside.



Launching when Deflated

Eventually the lift gas completely inflates the balloon.

Rising further will cause overpressure.



Blimps and Ballonets

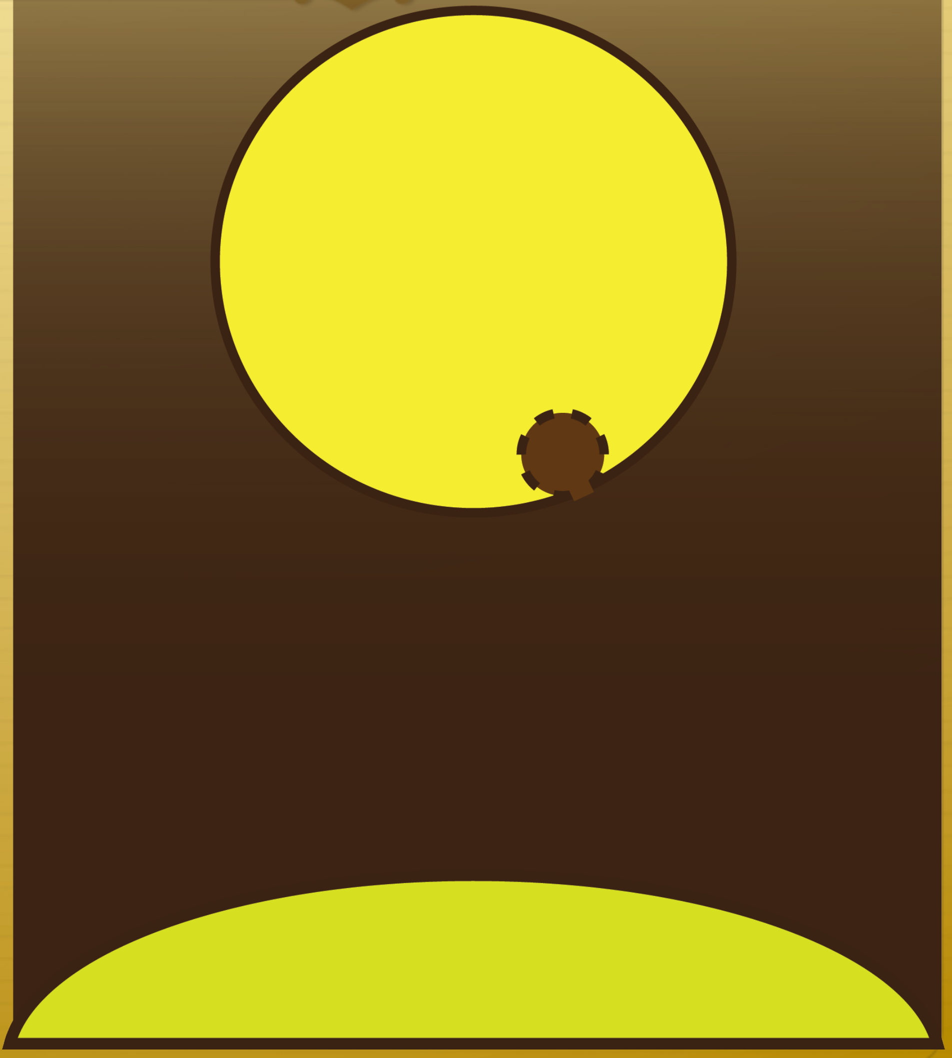
Ballonets let blimps maintain fixed pressure.

They launch with it filled with air, then pump it out.

Blimps and Ballonets

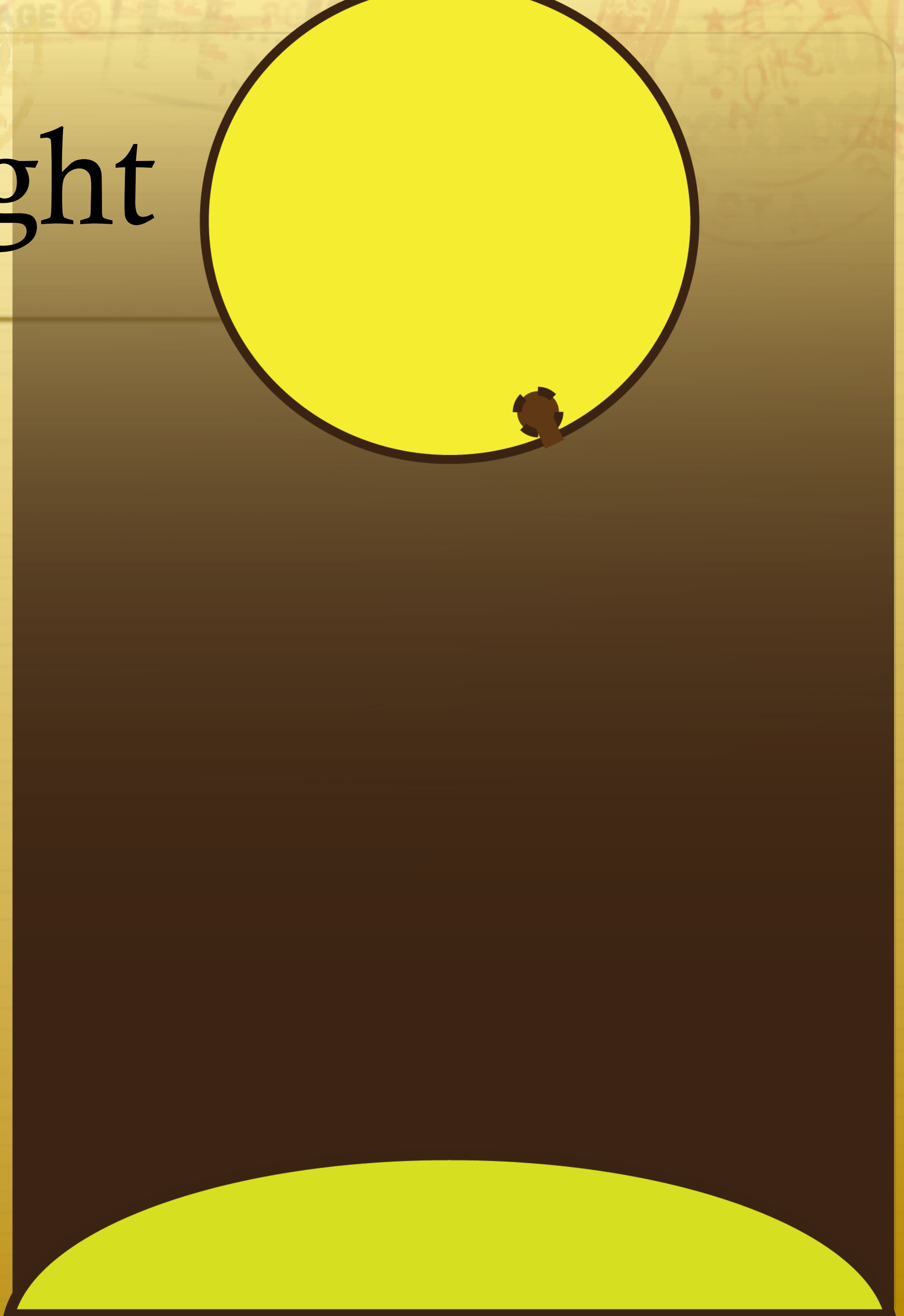
As the blimp rises, the ballonet collapses.

The expansion of the lift gas pushes air out of the ballonet bladder.

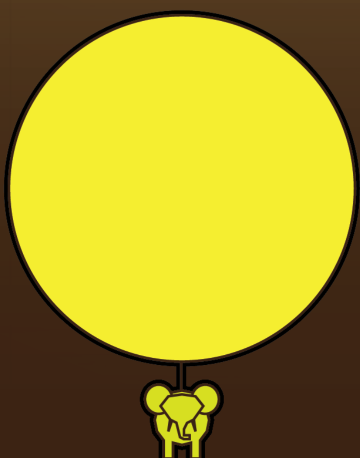


Pressure Height

The height at which a ballonet is pumped empty, or a deflated envelope reaches capacity, is the *pressure height.*

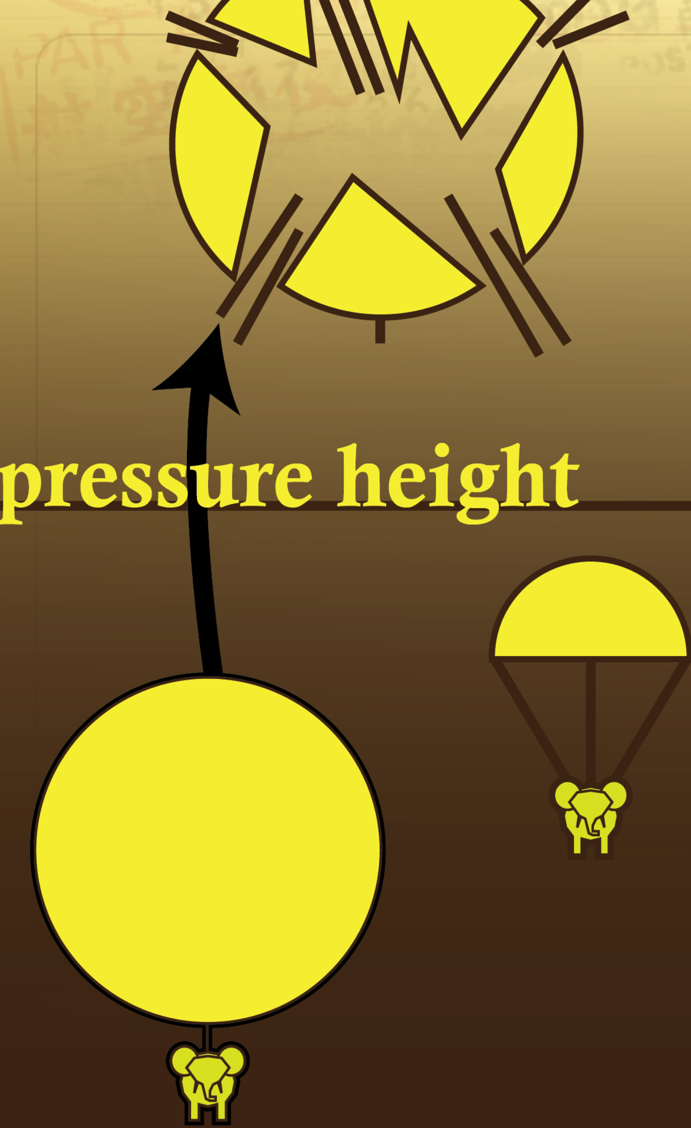


pressure height

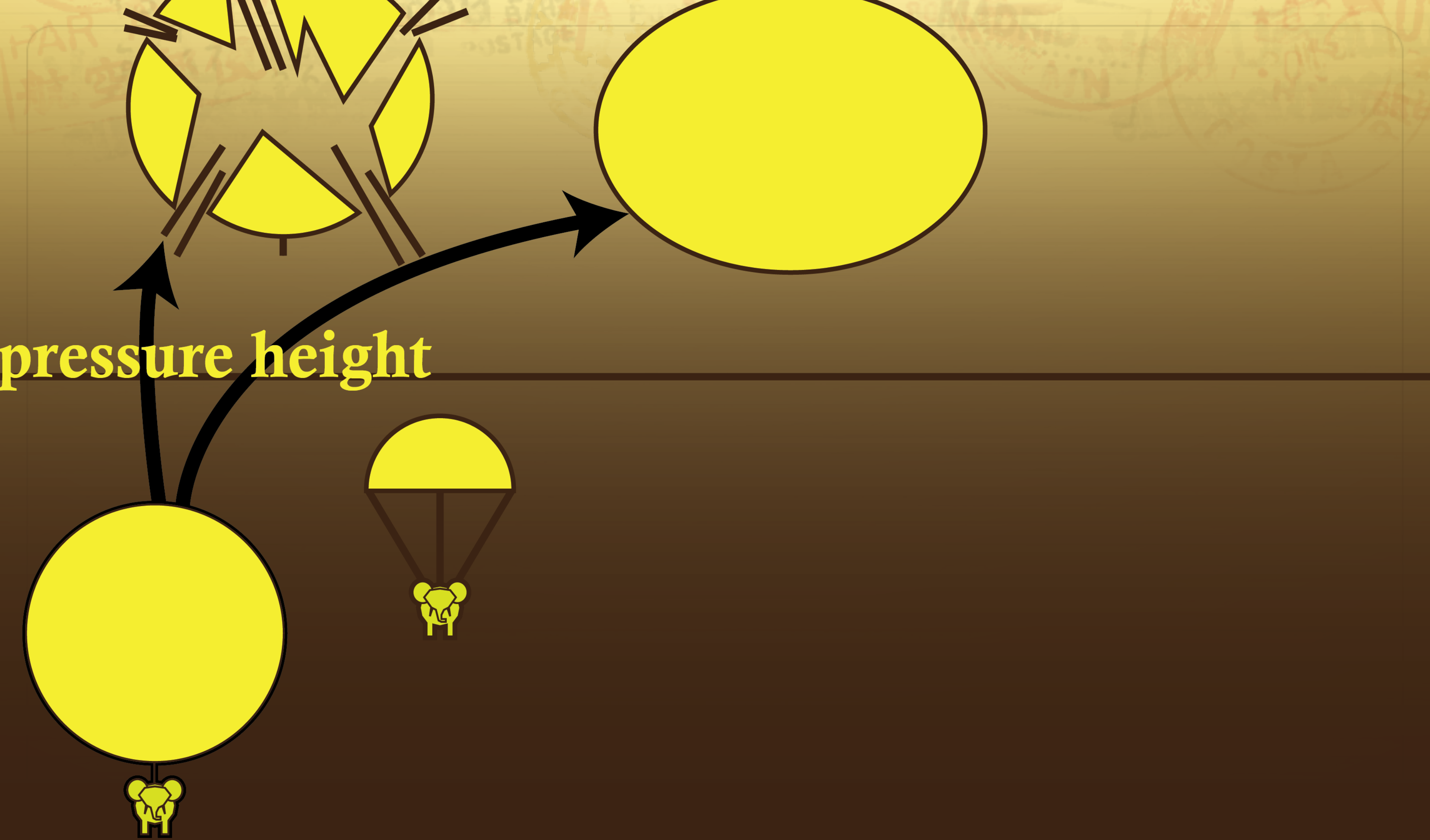


An airship with a fixed size envelope must vent gas at pressure height … or court destruction.

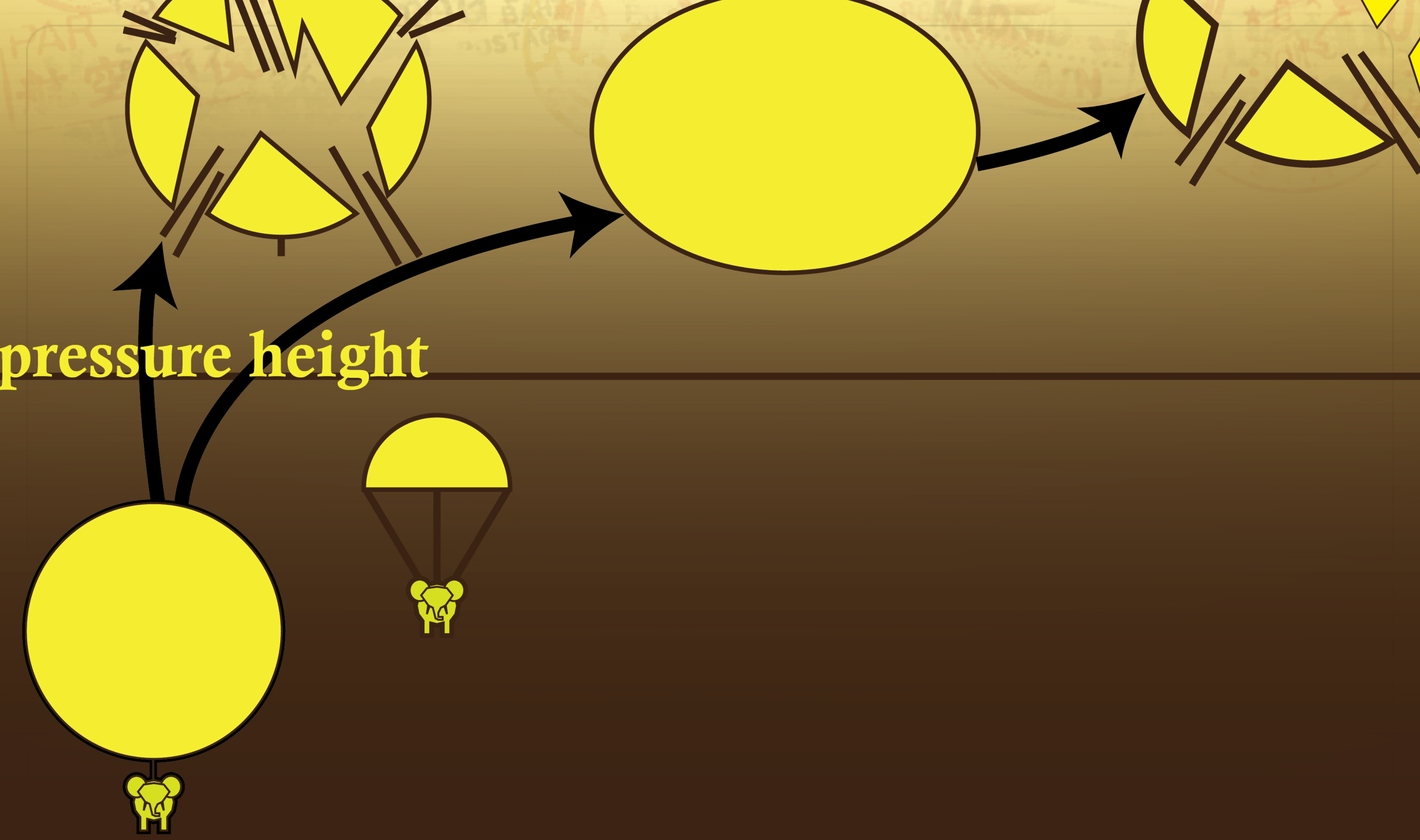
Coping with Pressure Height



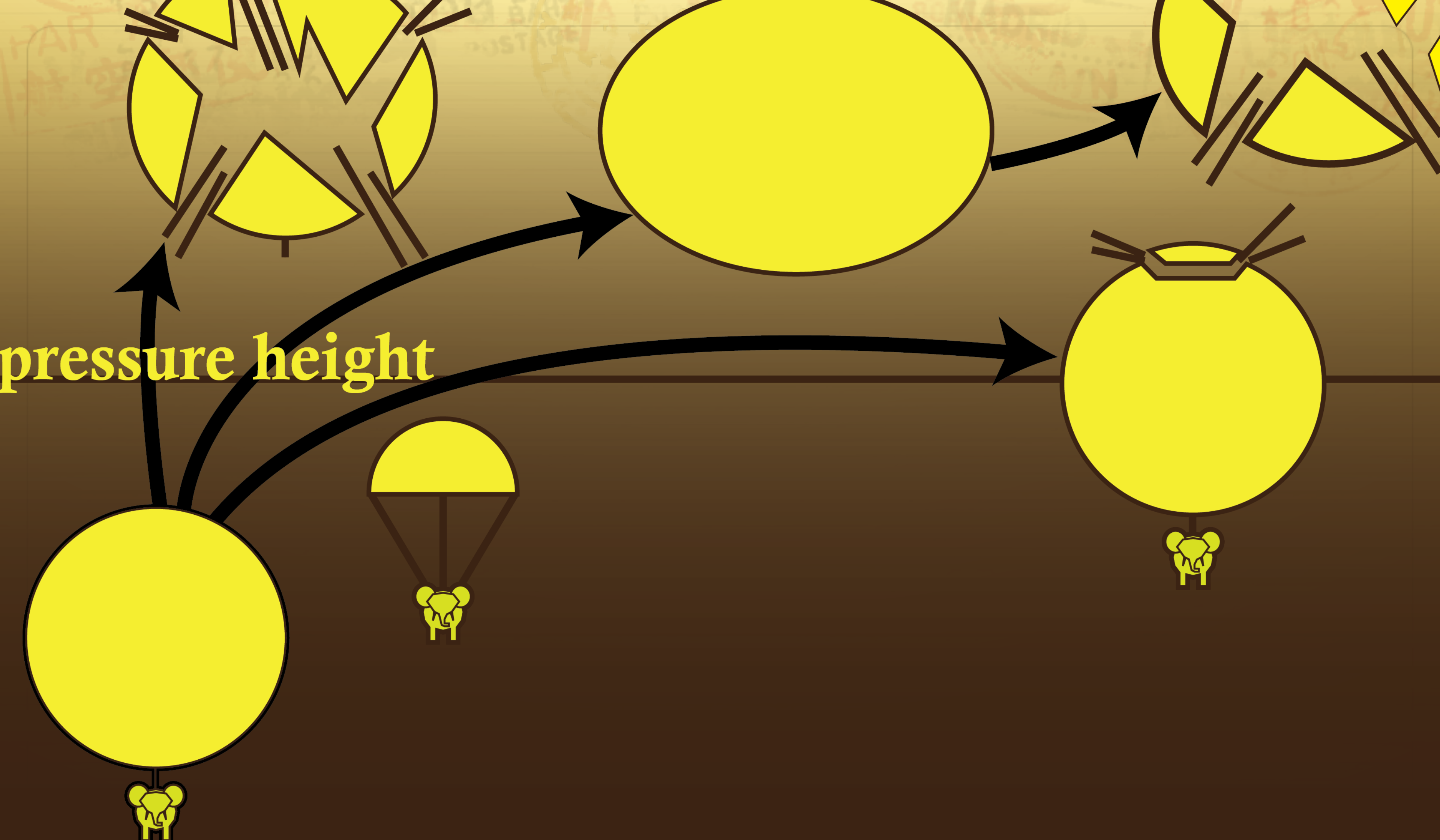
1. Let your balloon explode



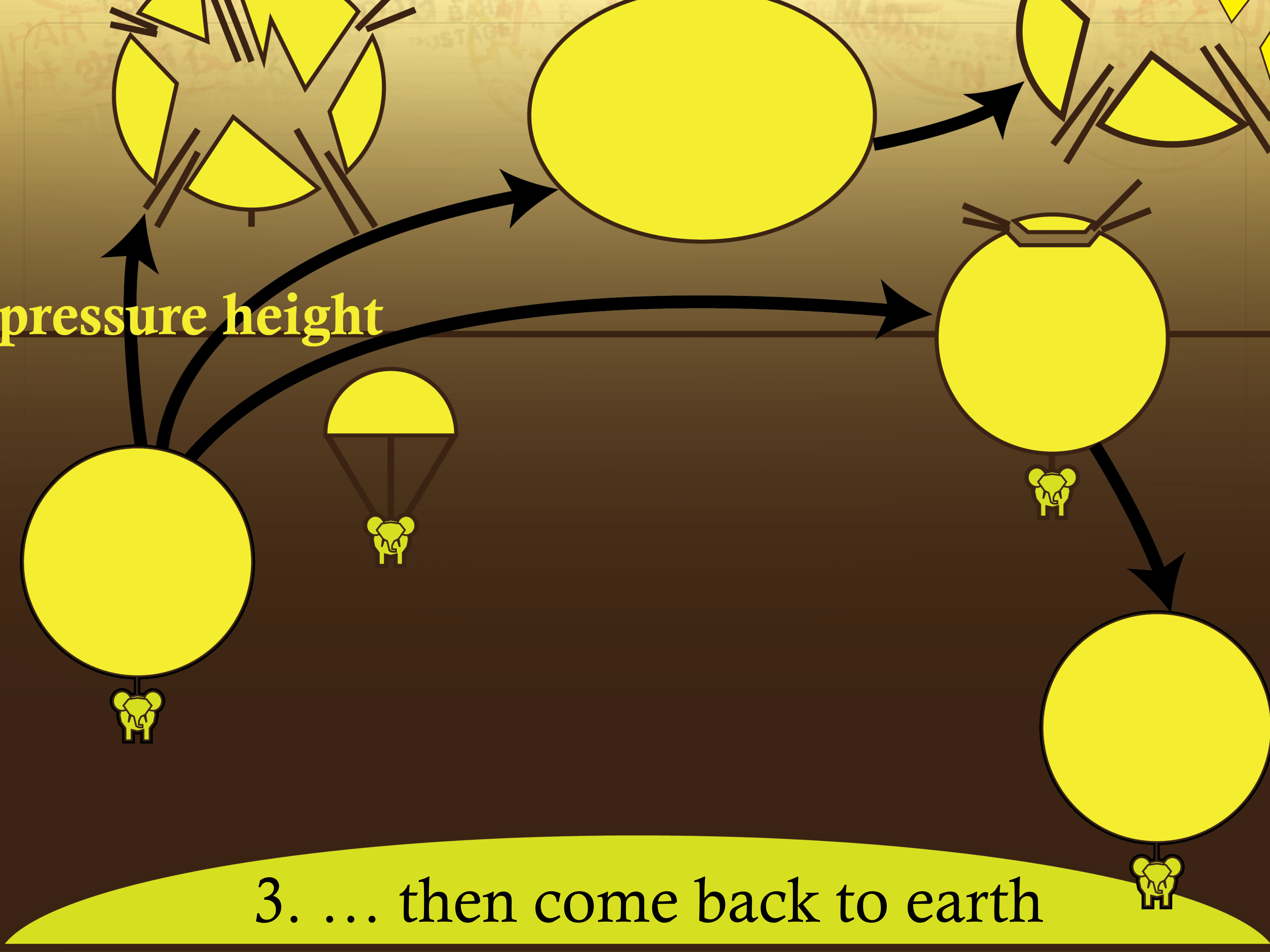
2. Let your balloon expand…

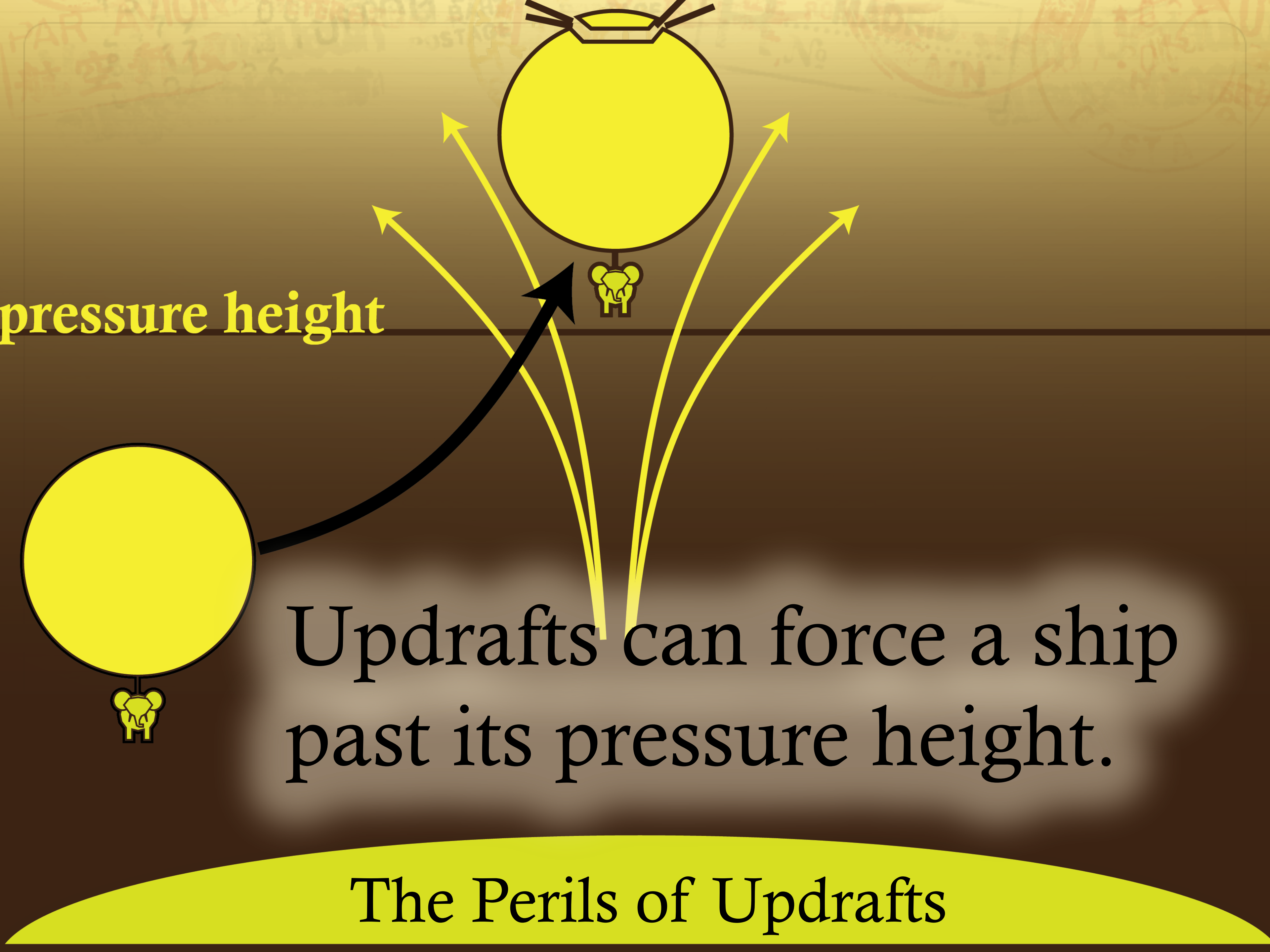


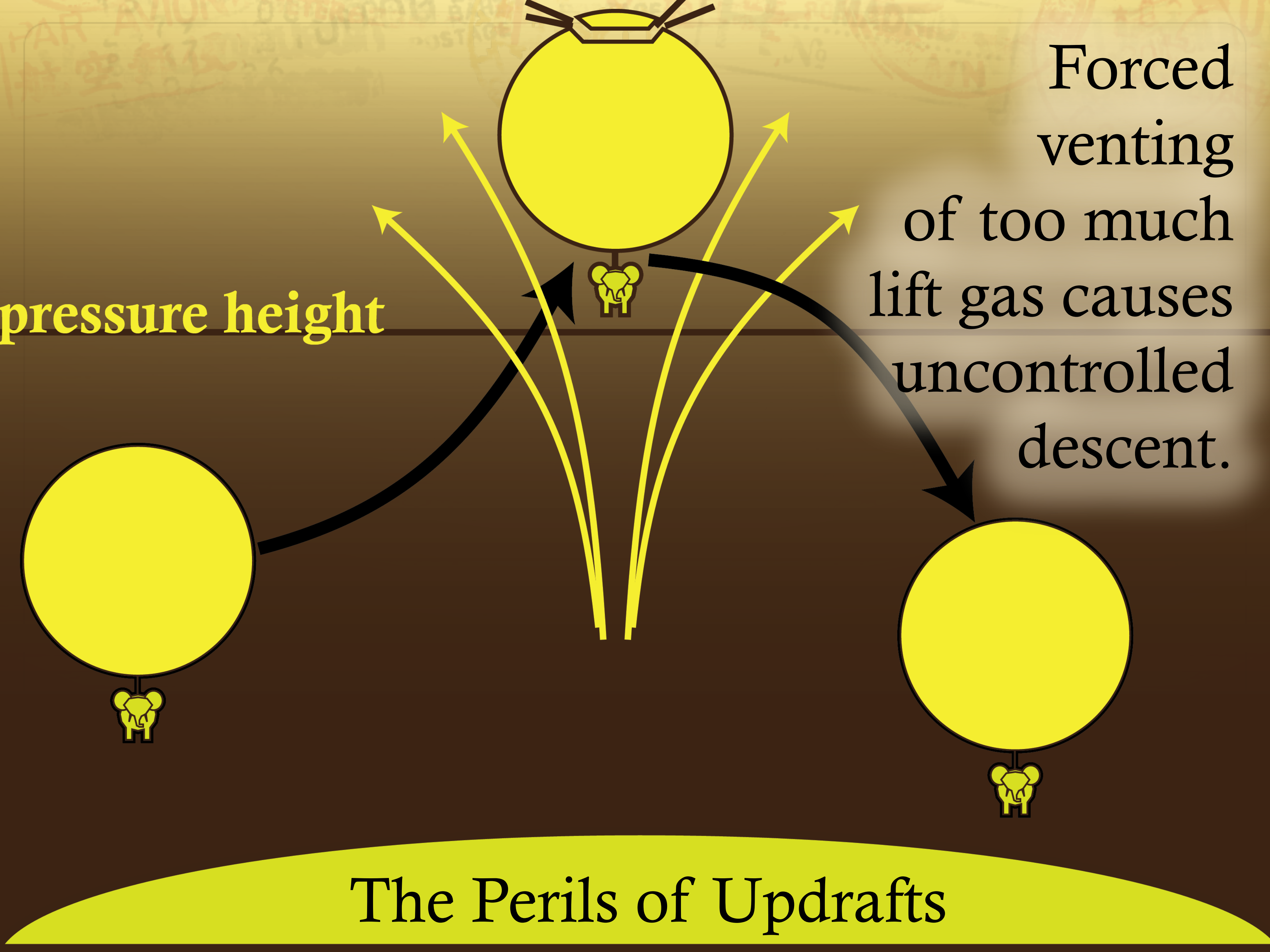
2. …then explode



3. Add valves to let off gas…


pressure height
3. … then come back to earth


pressure height
Updrafts can force a ship
past its pressure height.
The Perils of Updrafts

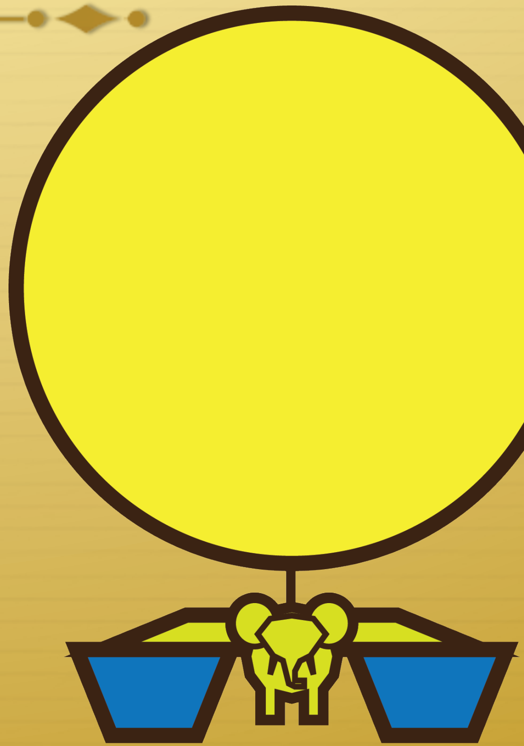

pressure height
Forced venting of too much lift gas causes uncontrolled descent.
The Perils of Updrafts

Dealing with Lost Lift

Sources of Lift Loss

- Gas Venting
- Rain Water

Ballast is anything material that can be dropped to gain lift



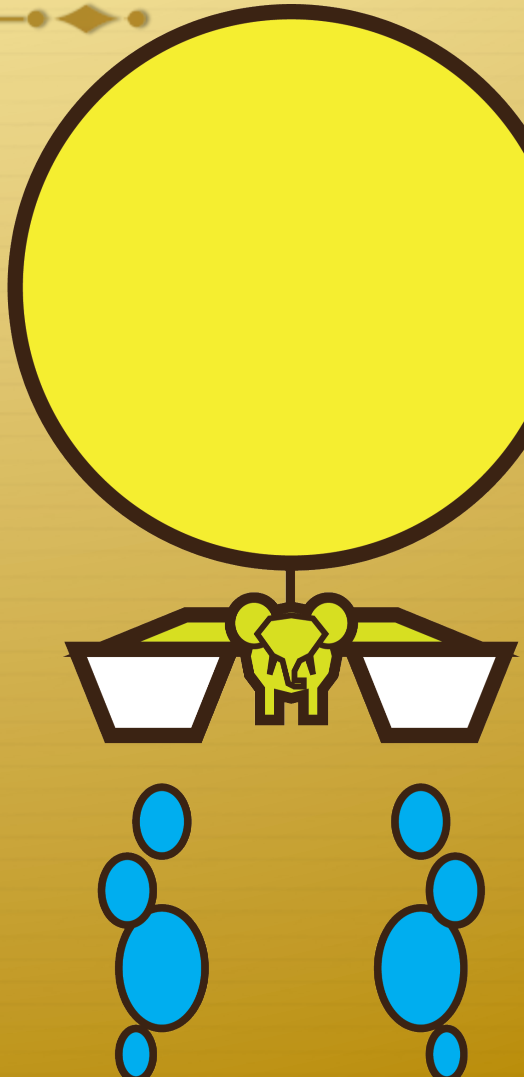
Ballast Types

Typical Ballast:

- Water
- Sand
- Shot

Emergency Ballast:

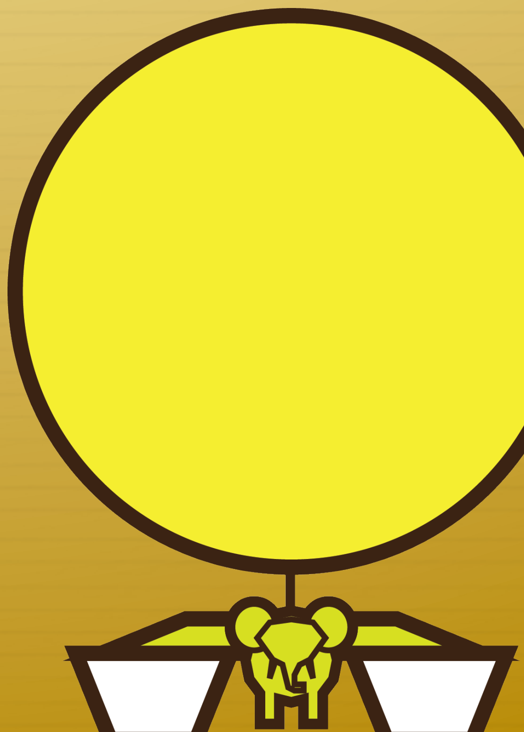
- Fuel



What if you're still falling?

Ballast is usually at most 15% of the free lift weight.

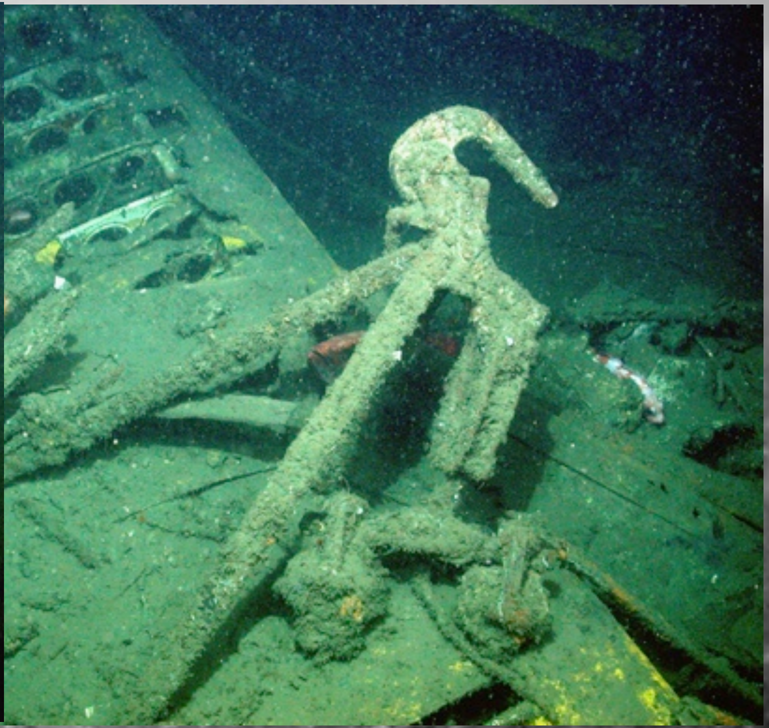
Beyond that…



The Death of the *Macon*

The *USS Macon* was destroyed when operator error took it past pressure height over the ocean, forcing a sea landing.

The Death of the *Macon*



The *USS Macon* was destroyed when operator error took it past pressure height over the ocean, forcing a sea landing.

Aerodynamics

The Science of Horizontal Flight

Peeling the Cucumber

Airships are slow, tapered and have small fins…

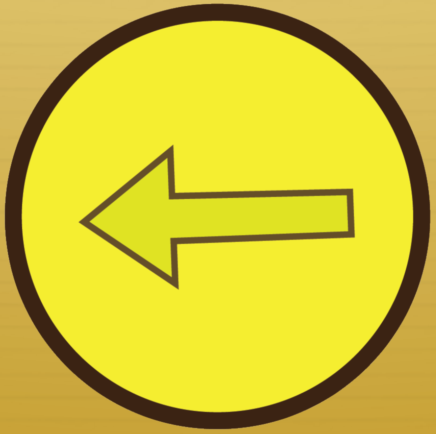
But Why?

Objects in the Air

Balloons can’t be directed in flight.

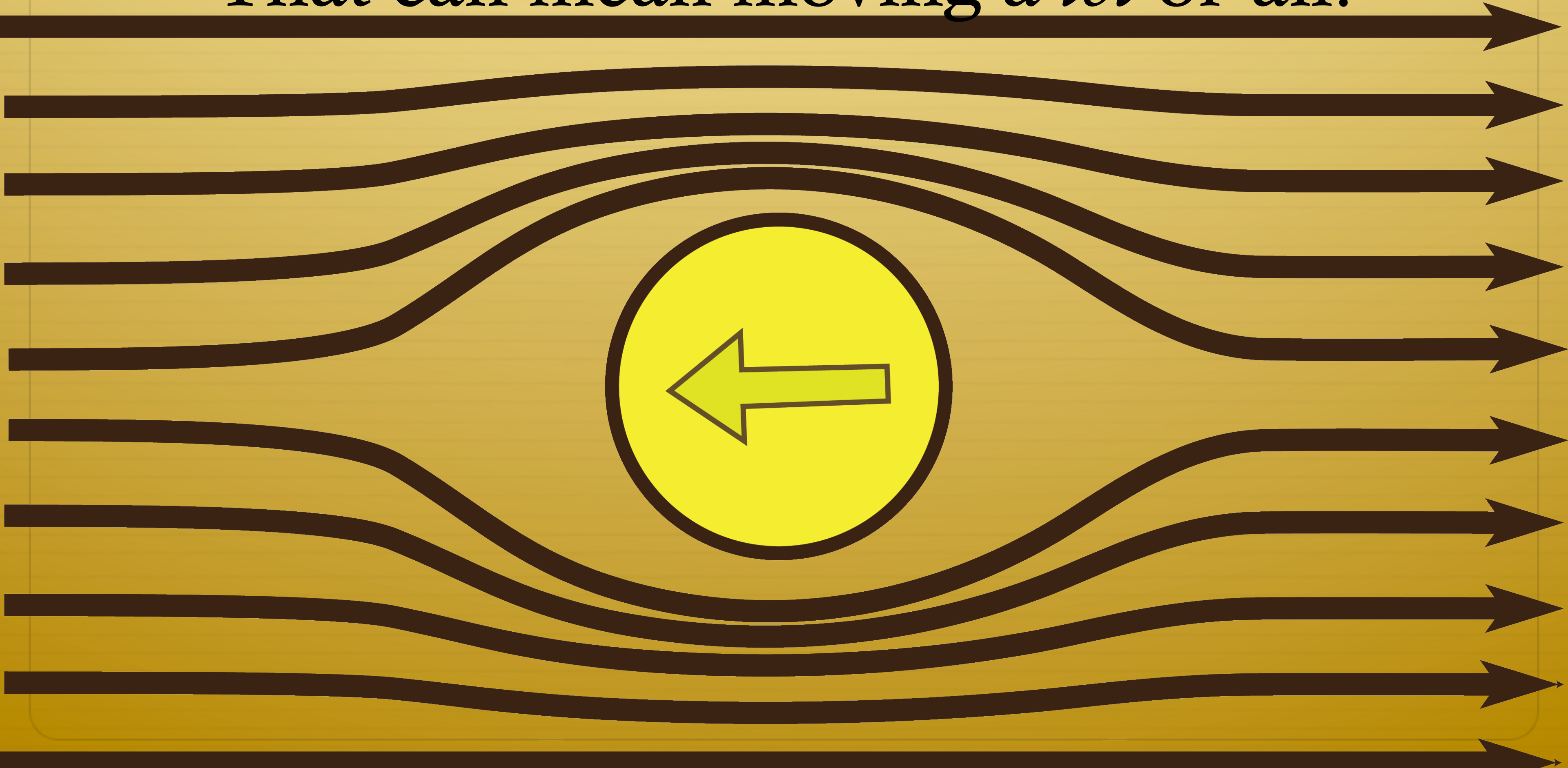
Objects in Motion

Dirigibles move under their own power.



Moving Against the Air

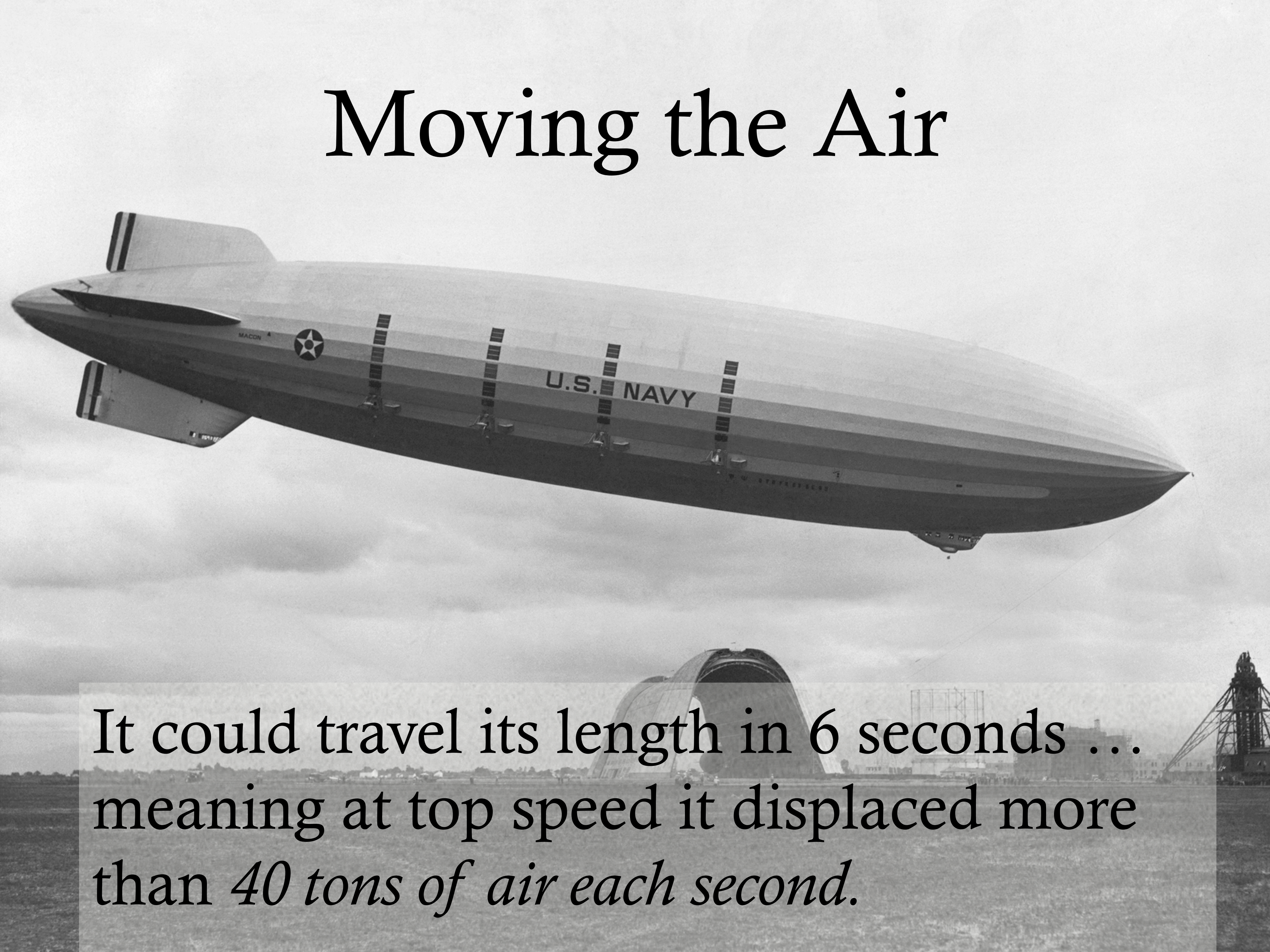
That can mean moving a *lot* of air.



Moving the Air

The *Macon* was the largest helium airship ever: 784 feet long, top speed 87 mph… and 6.5 *million* cubic feet of helium.

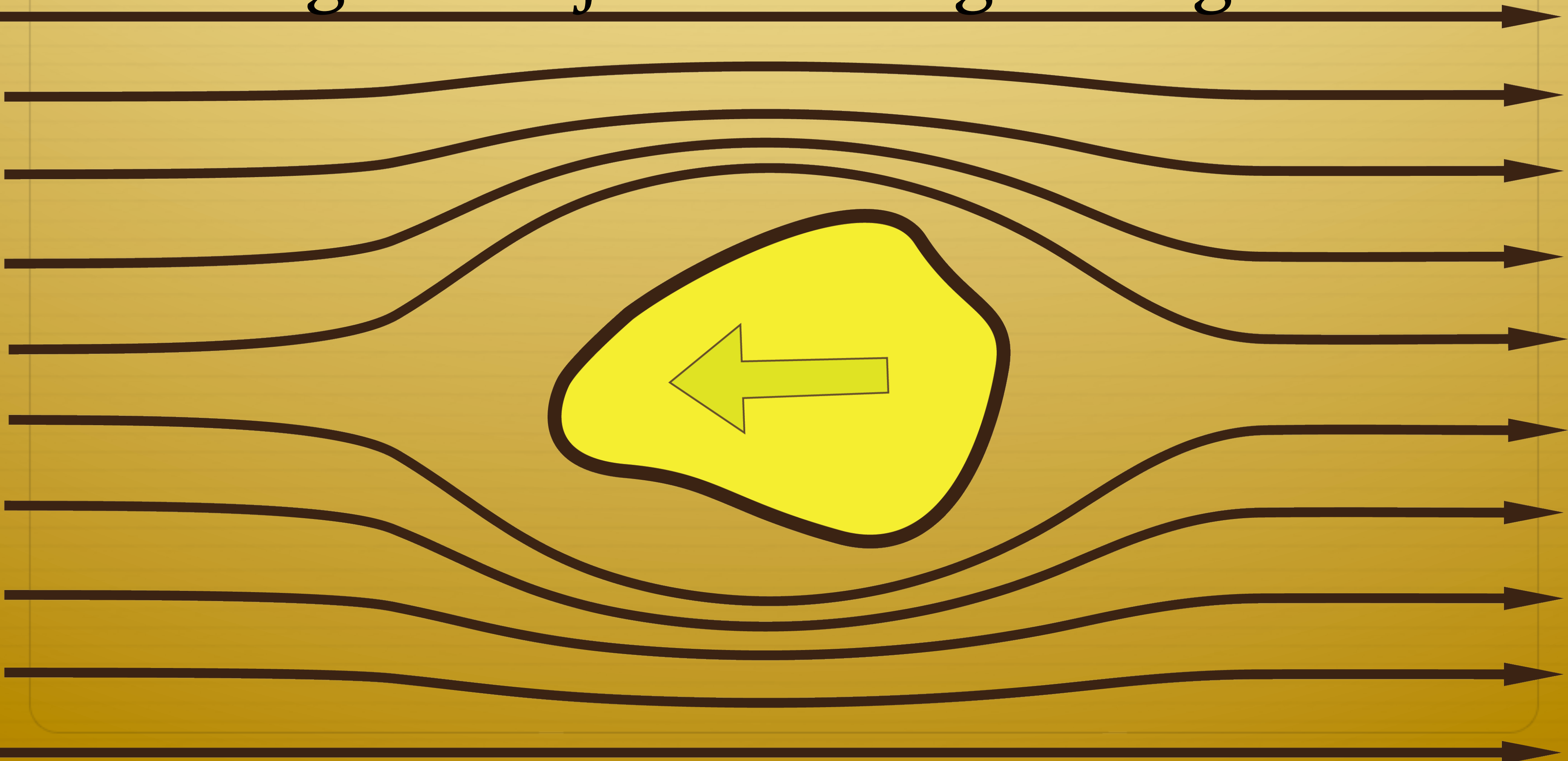
Moving the Air



It could travel its length in 6 seconds … meaning at top speed it displaced more than *40 tons of air each second.*

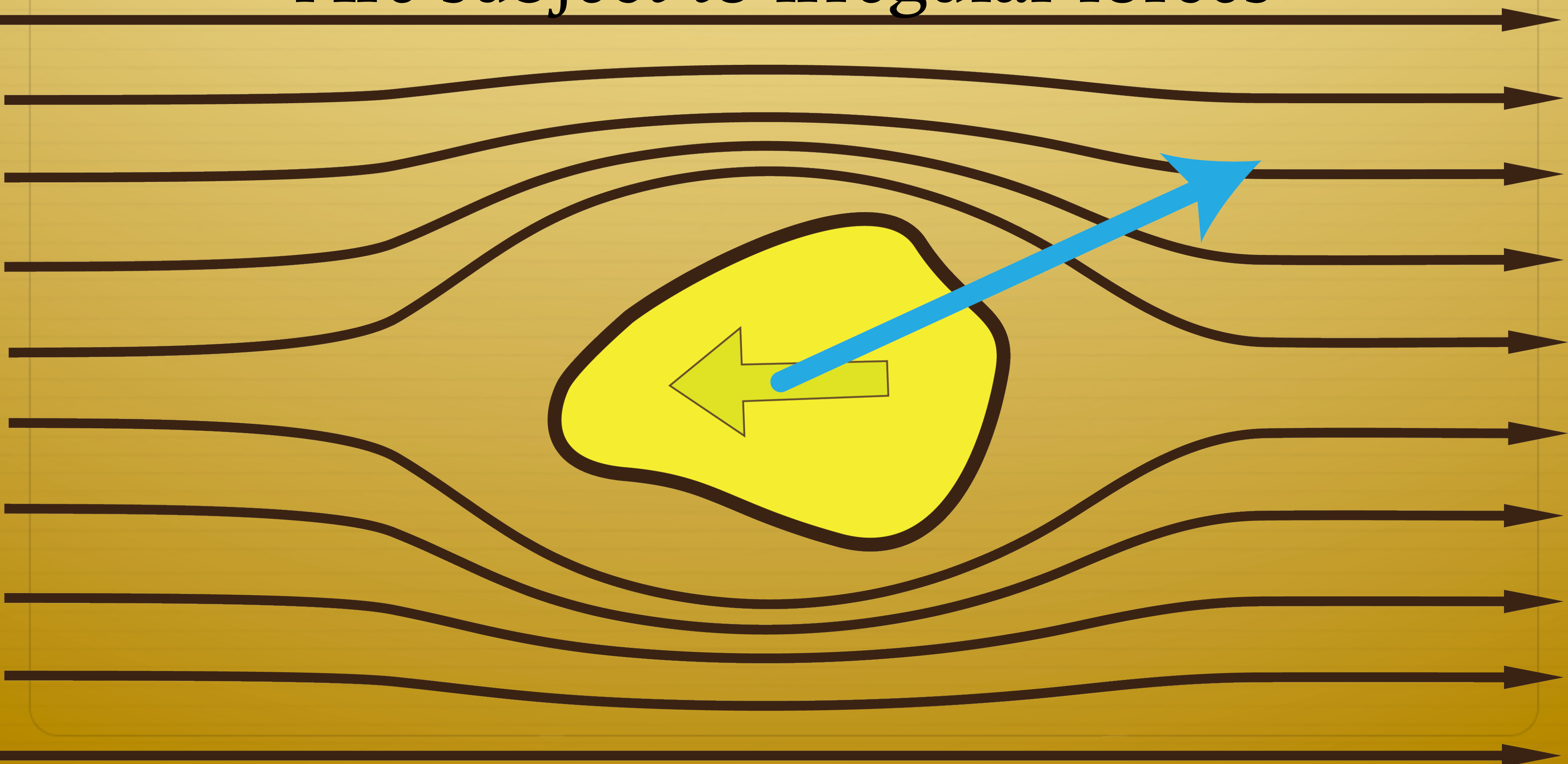
Complicated Objects

Irregular objects moving through air



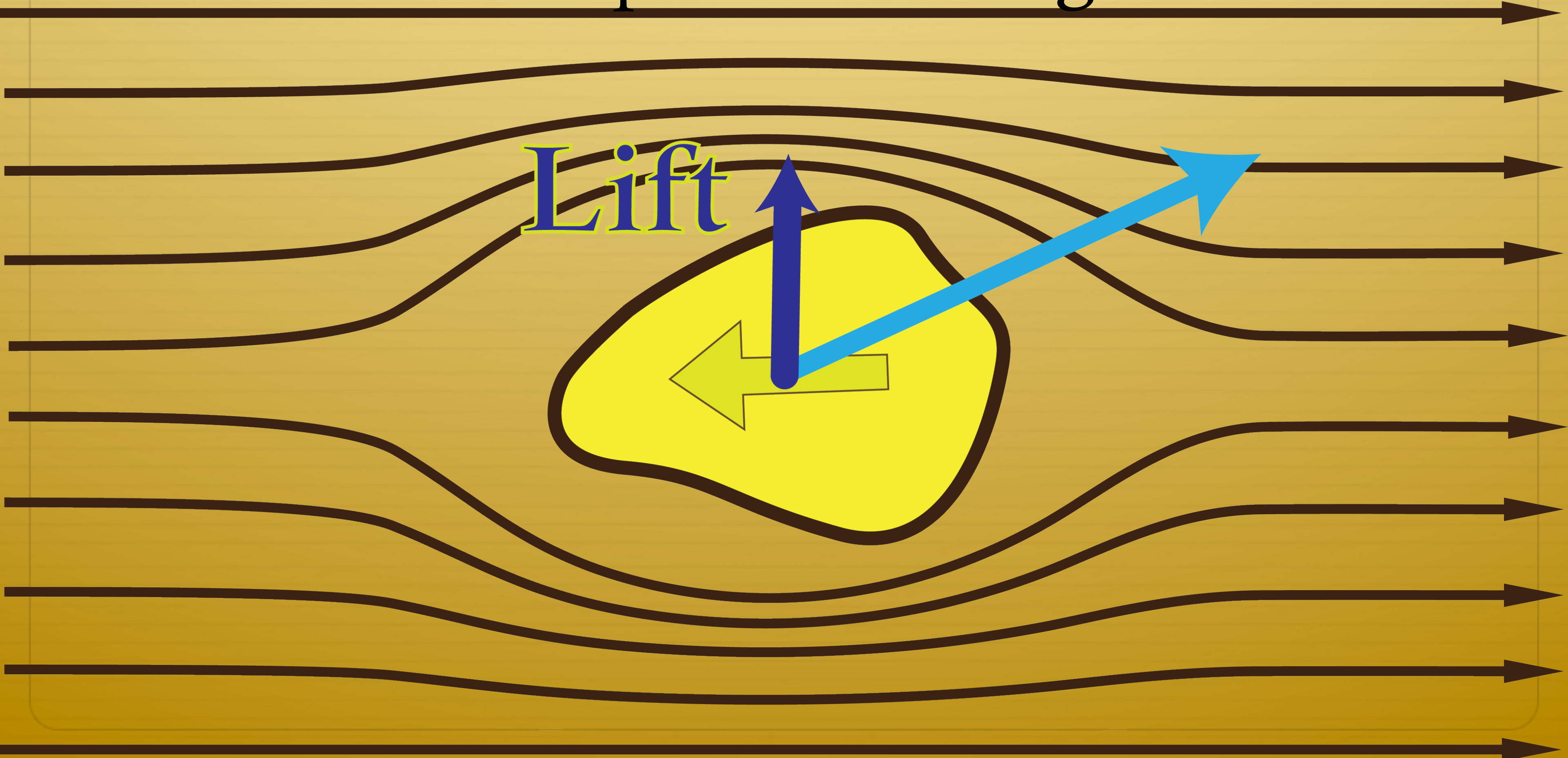
Complicated Forces

Are subject to irregular forces



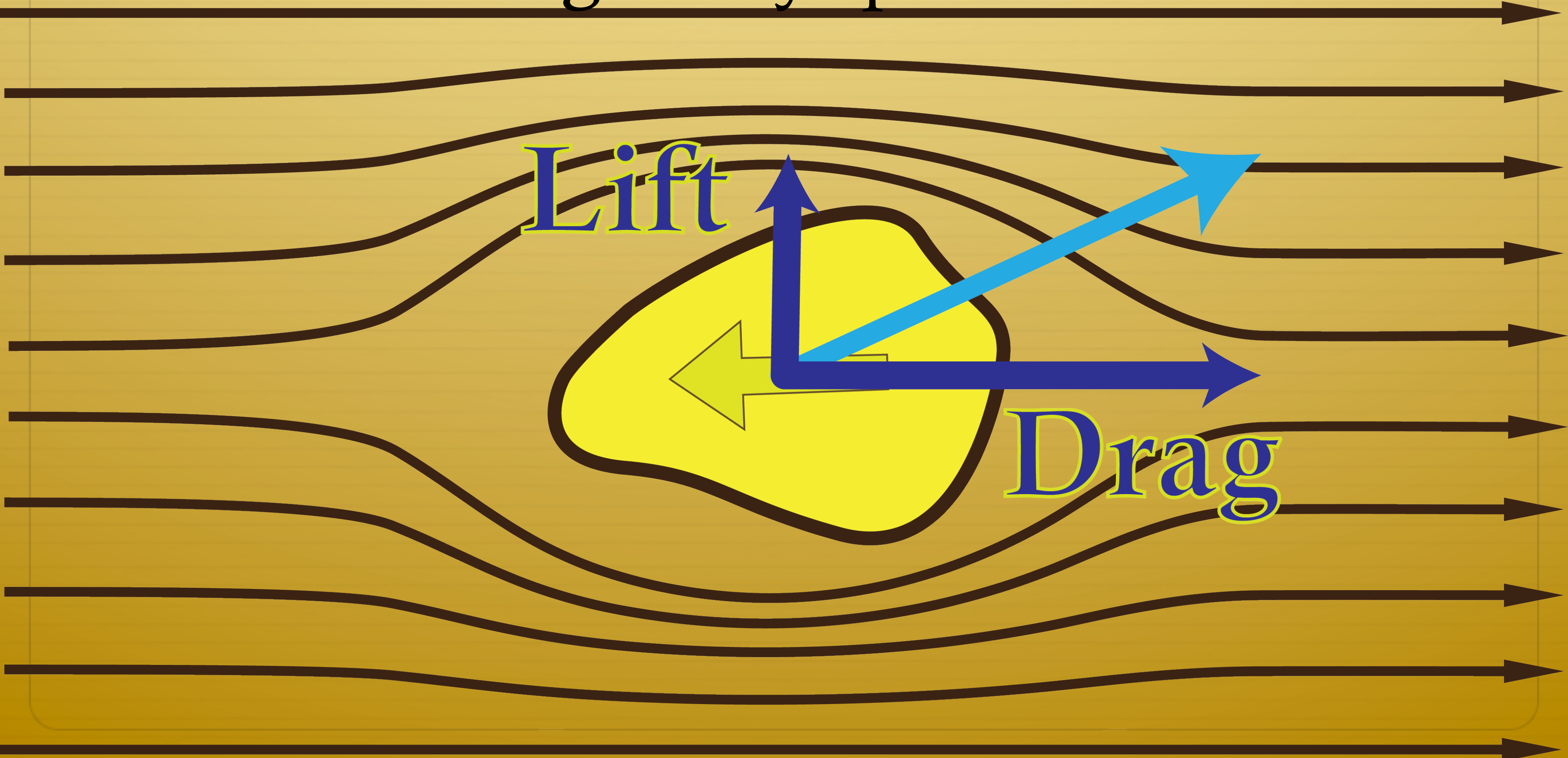
Component Analysis

Lift can be positive or negative…



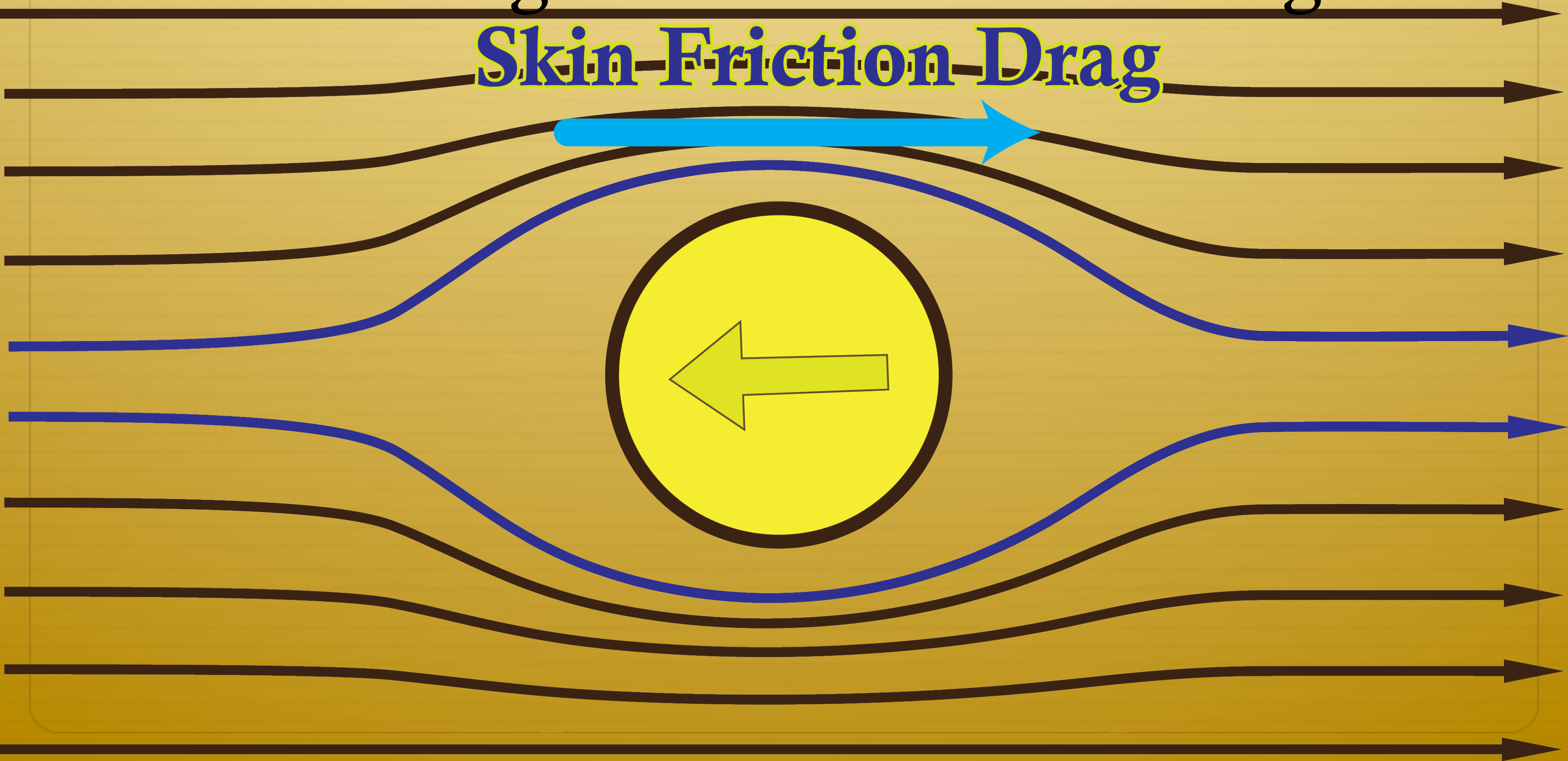
Lift and Drag

But the drag always pushes us back.



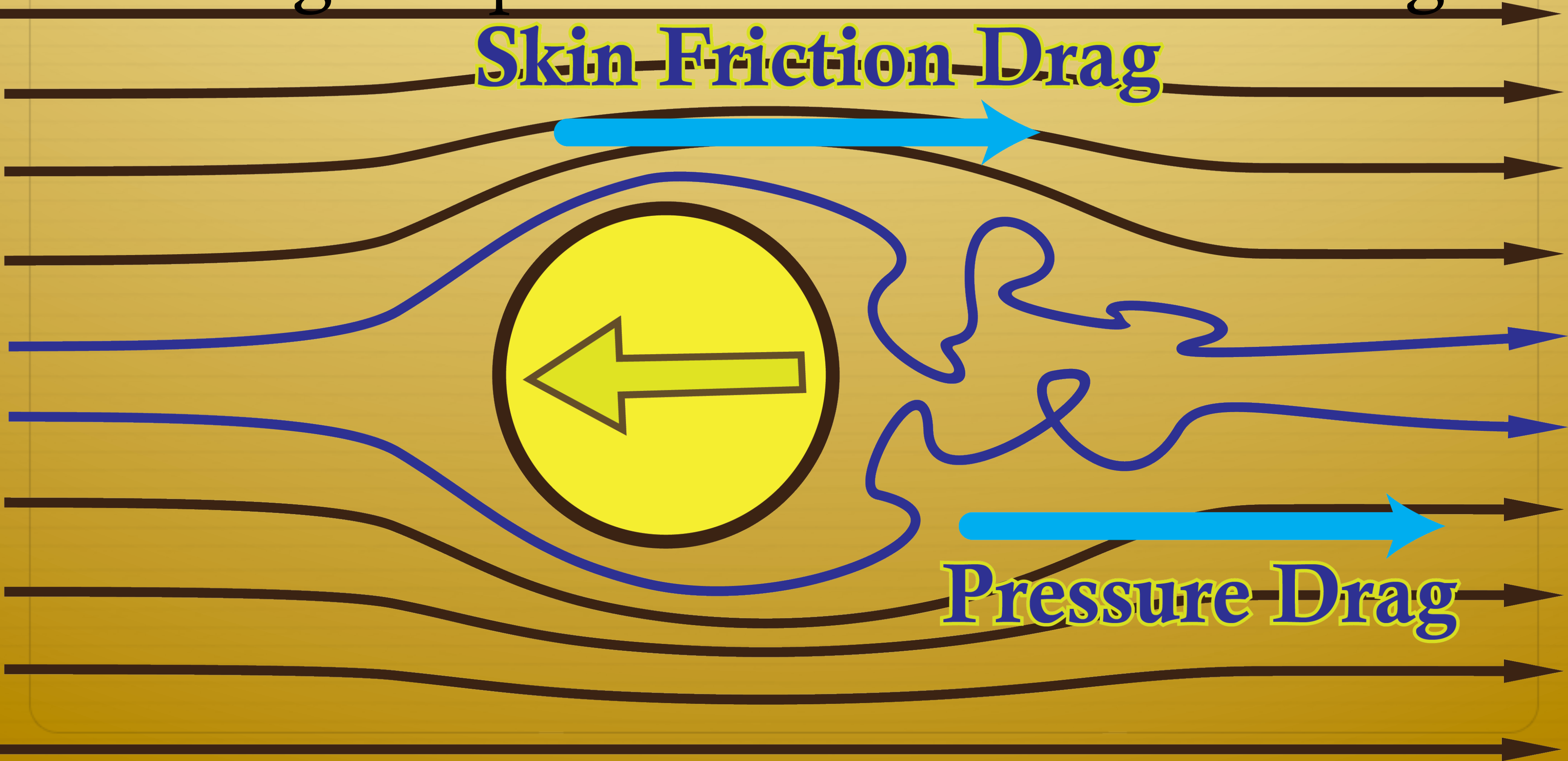
Types of Drag

Air moving over a surface has drag…



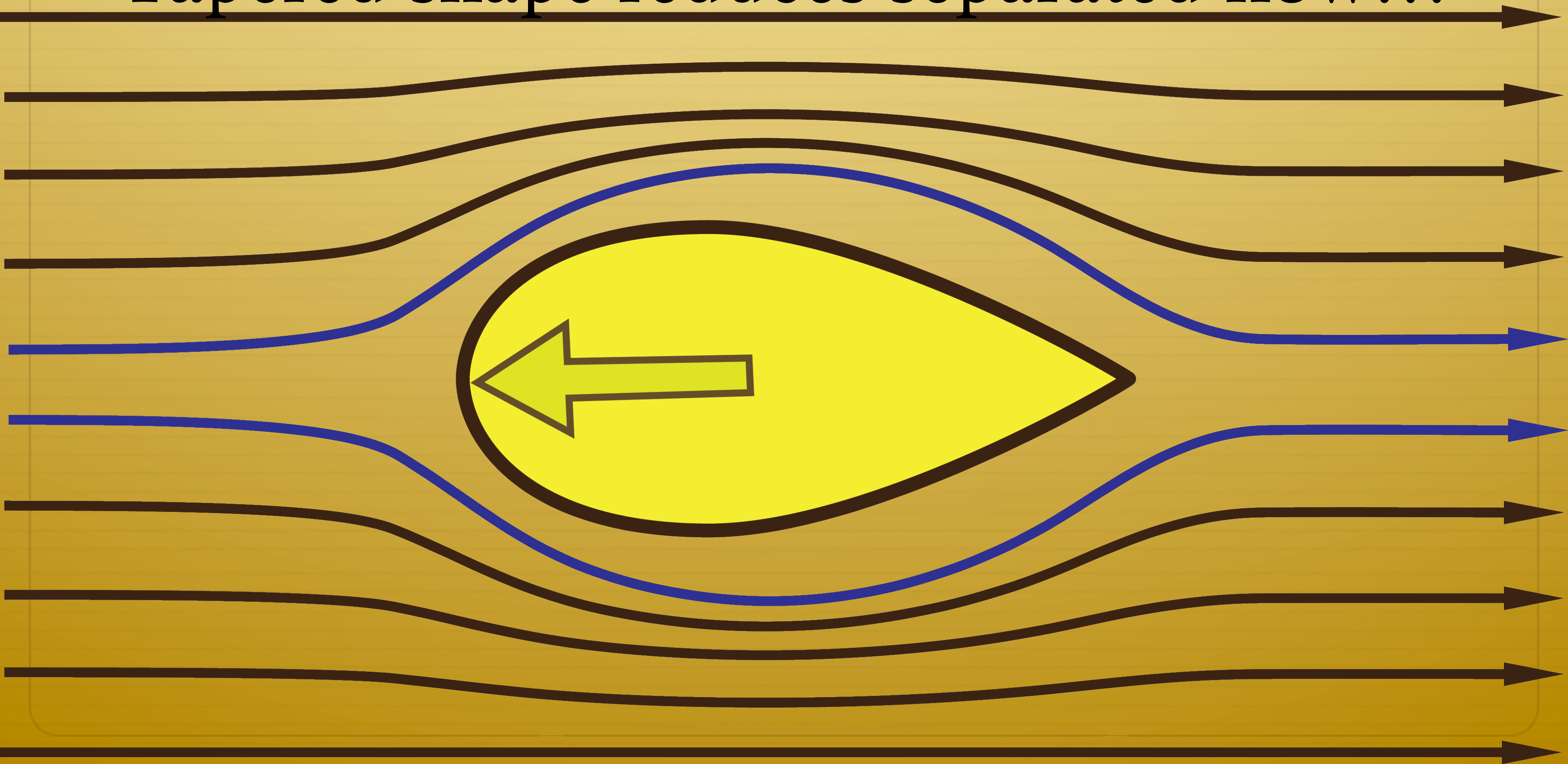
The Separation Point

At higher speeds turbulence causes drag



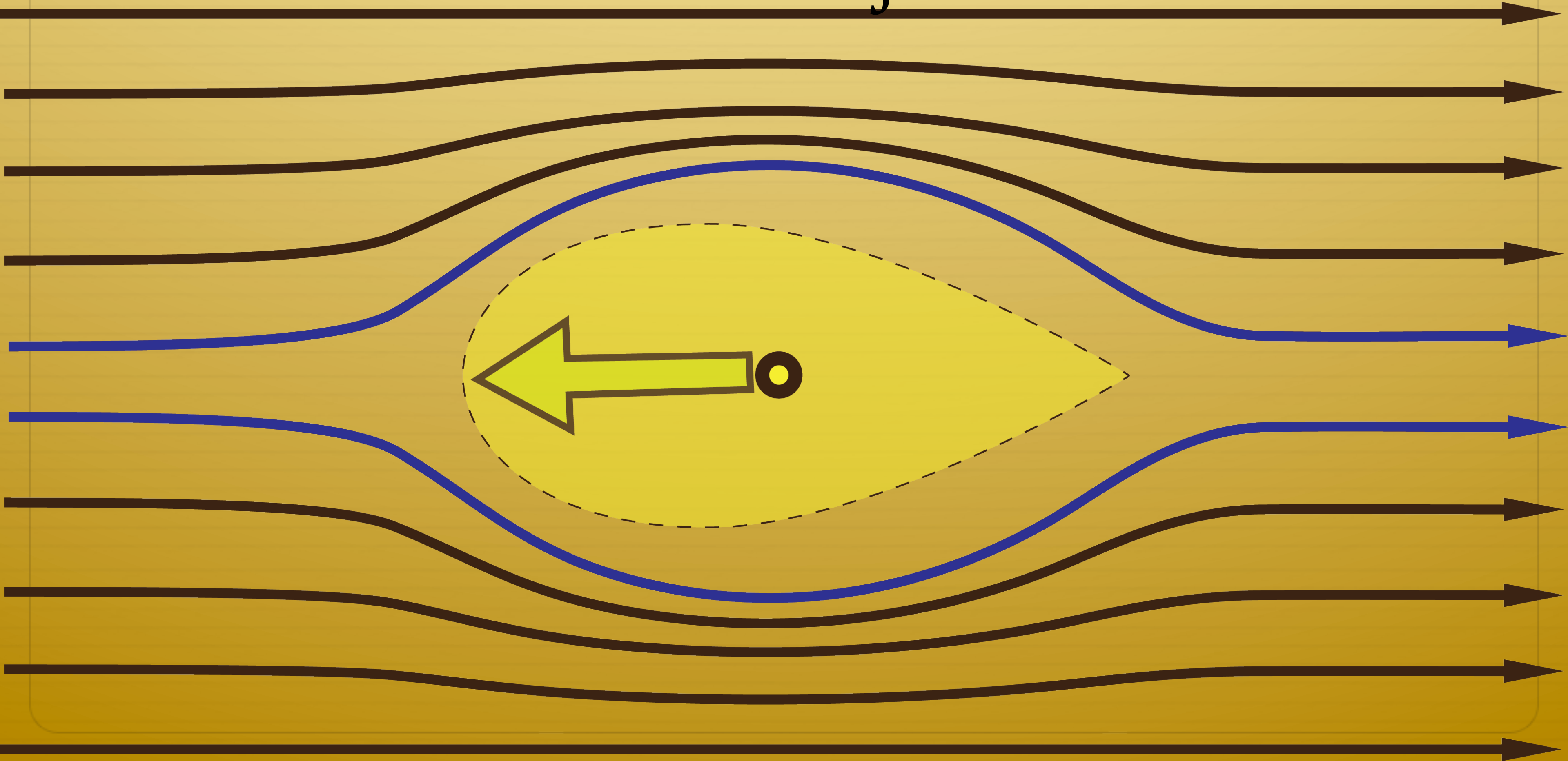
Streamlining

Tapered shape reduces separated flow…



Streamlining

…to that of a blunt object *1/10th its size!*

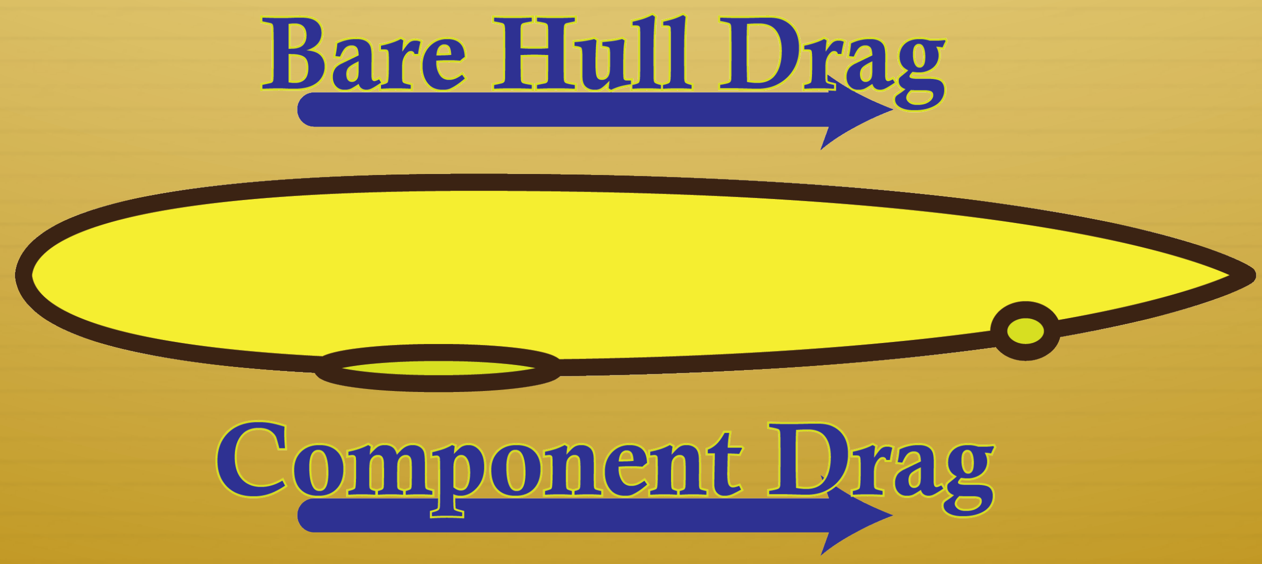


Mathematically Slender

An ideal airship hull has very low drag

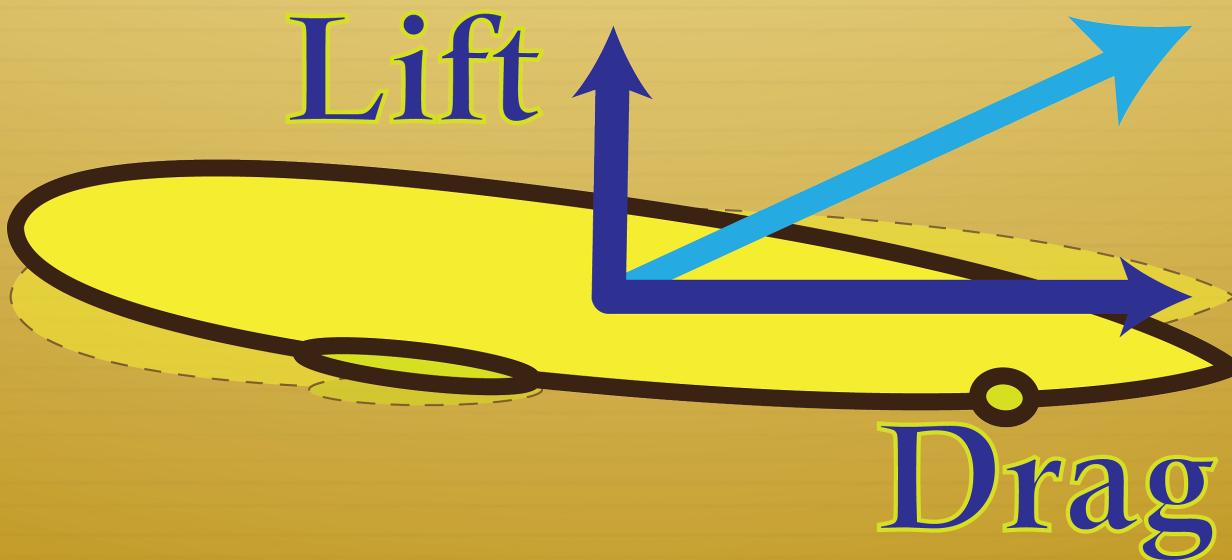
Practical Drag

A gondala and engines can *double* it!



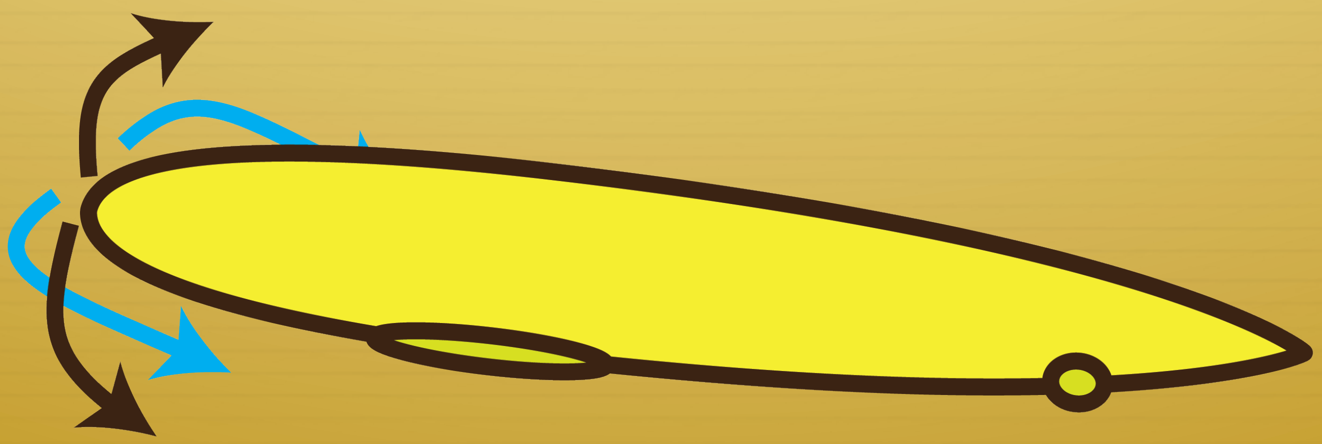
Lift at Incidence

Tilting the ship in flight can add lift…



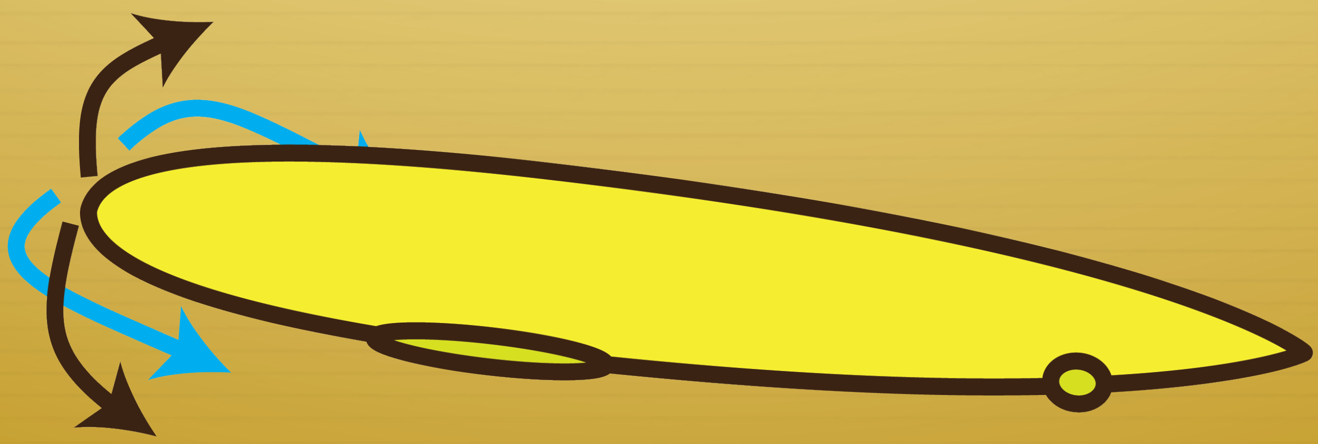
Instability in Flight

An airship *always* tries to tilt in flight.



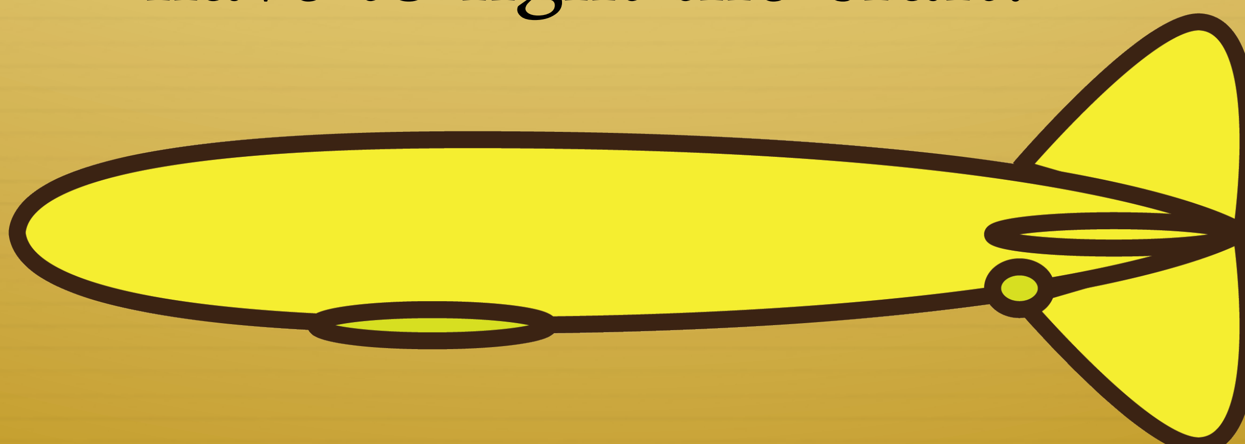
Instability in Flight

Putting the gondola, engines and keel low help keep the airship level, but…



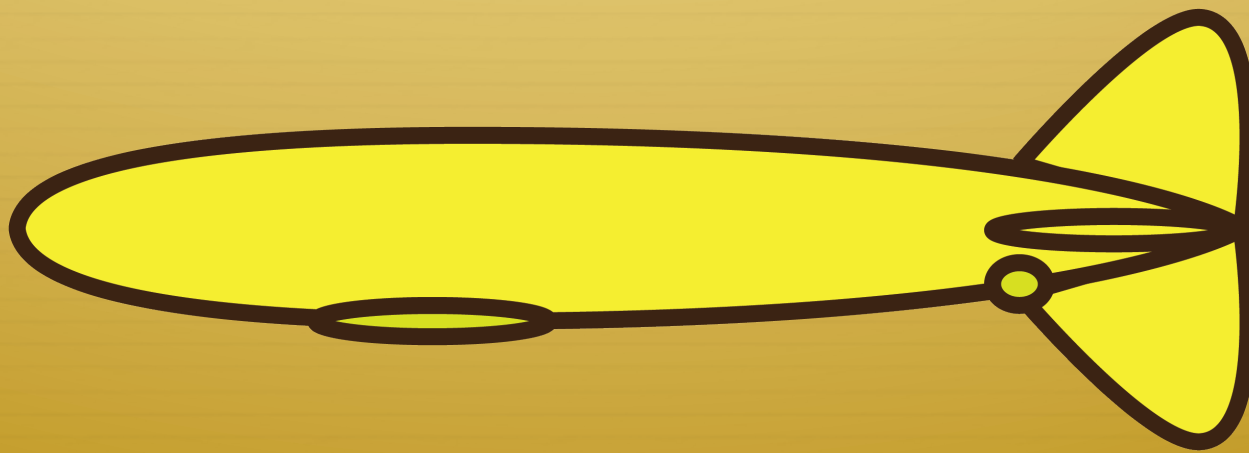
Elevators and Rudders

…fins are needed to keep flying straight. Otherwise the pilot would constantly have to fight the craft.



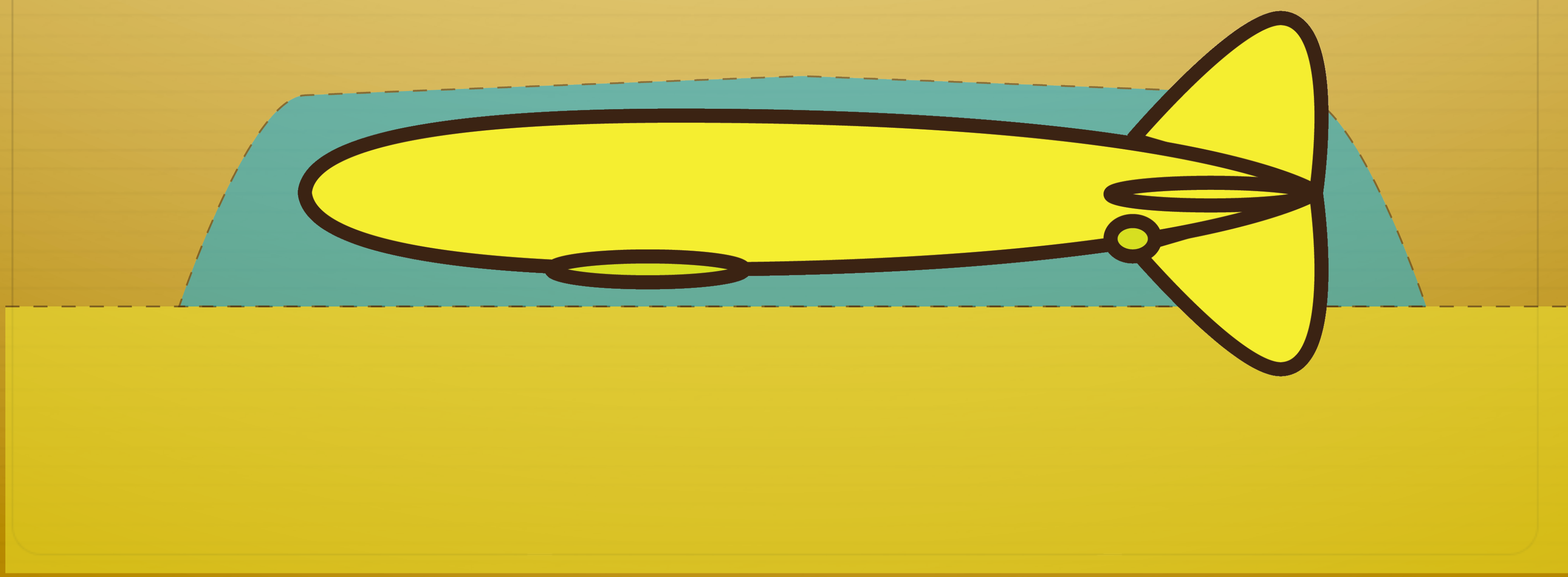
The Fin Size Dilemma

Fins add weight because of the square cube law … they're essentially surface.



The Fin Size Dilemma

Fins that are too large can also cause ground handling problems



The Fin Size Dilemma

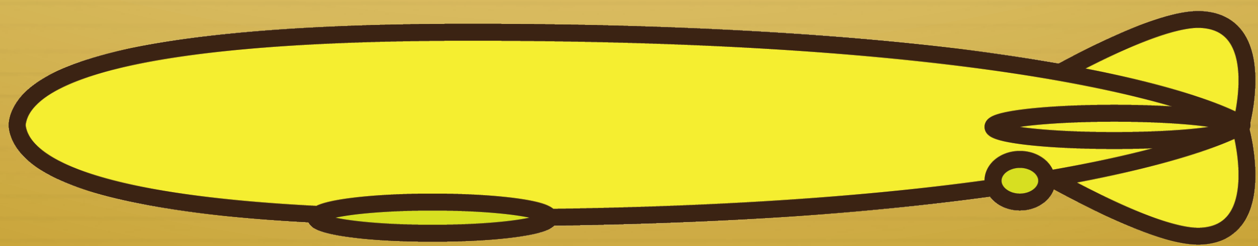
Small fins allow adequate control, but it can take up to a minute for a large airship to respond to a change.

Fin Arrangement Options

Using X or Y fins gives better ground clearance than a cross … but makes the airship much harder to control.

A Classic Shape

So that's why airships are long, slender, with small fins and the gondola and engines on the bottom.



Structure

The Construction of Airships

What Did the Count Know?

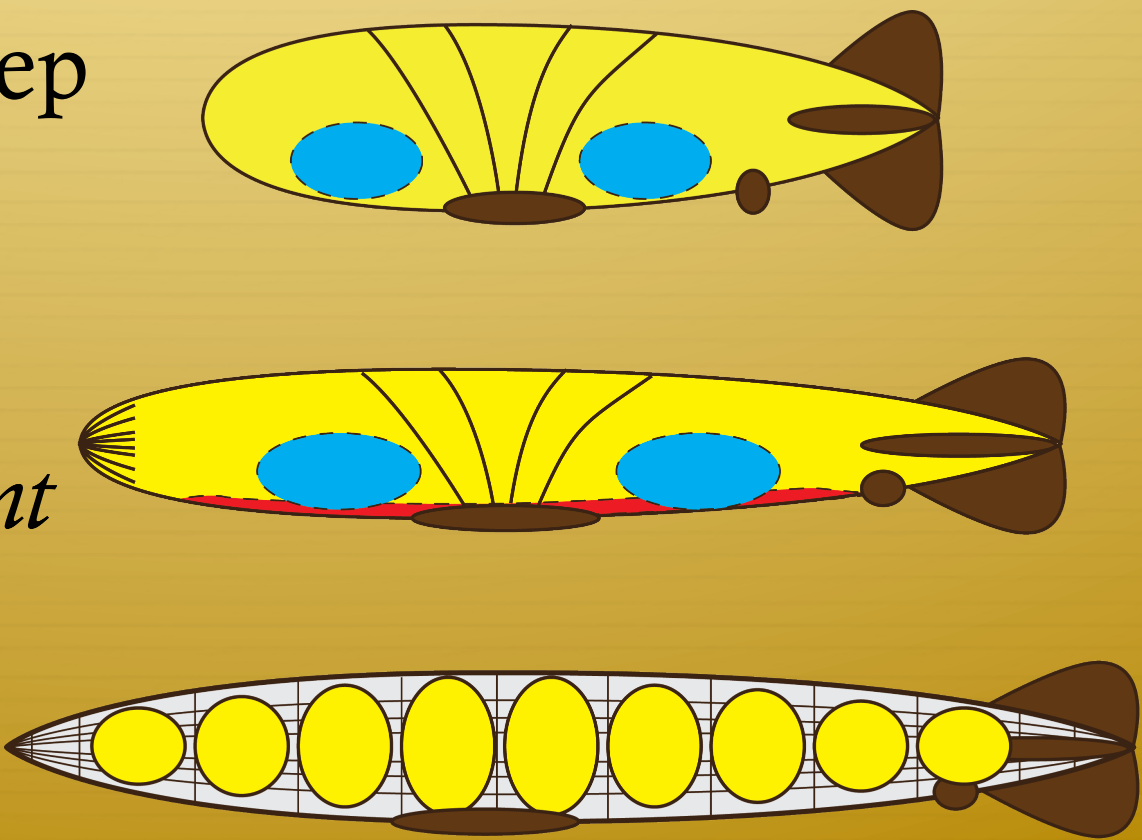
The biggest (classic) airships were always zeppelins.

Why?

Types of Airships

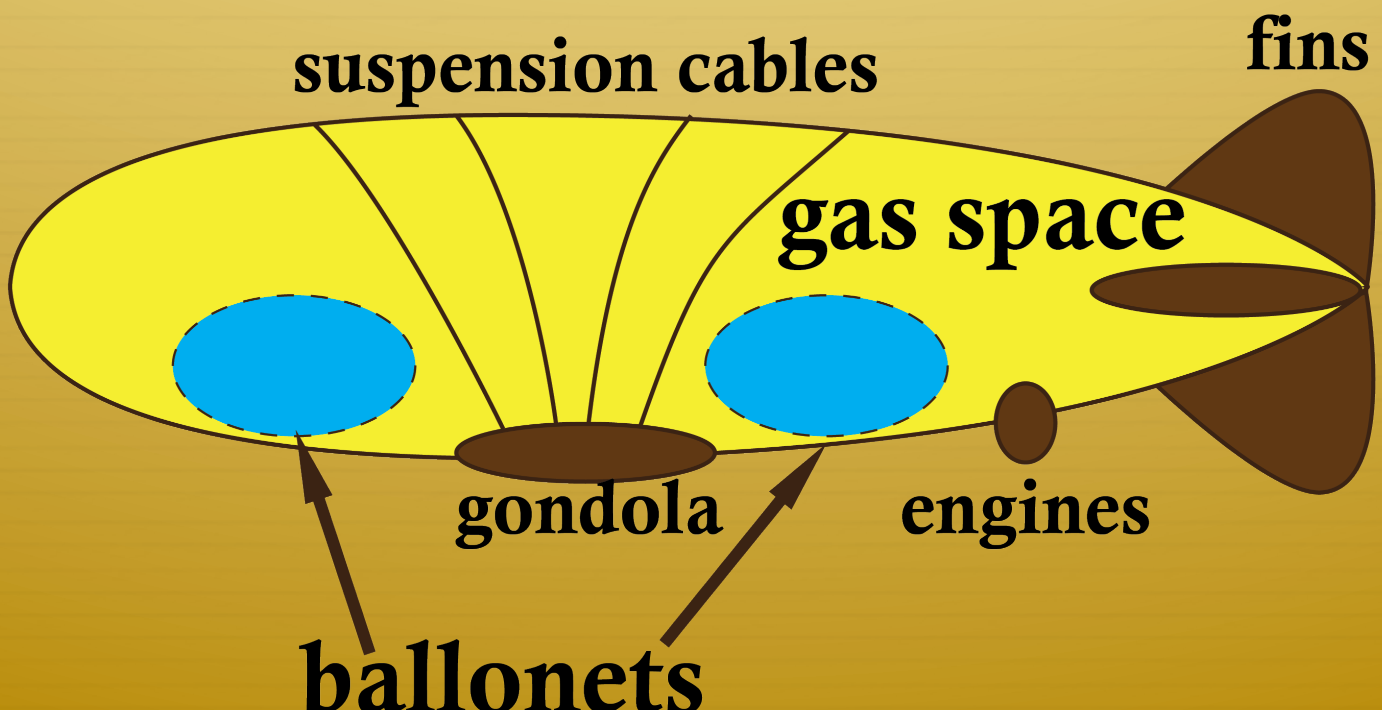
Airships use three schemes to keep their shape:

- *Pressure*
- *Reinforcement*
- *Structure*



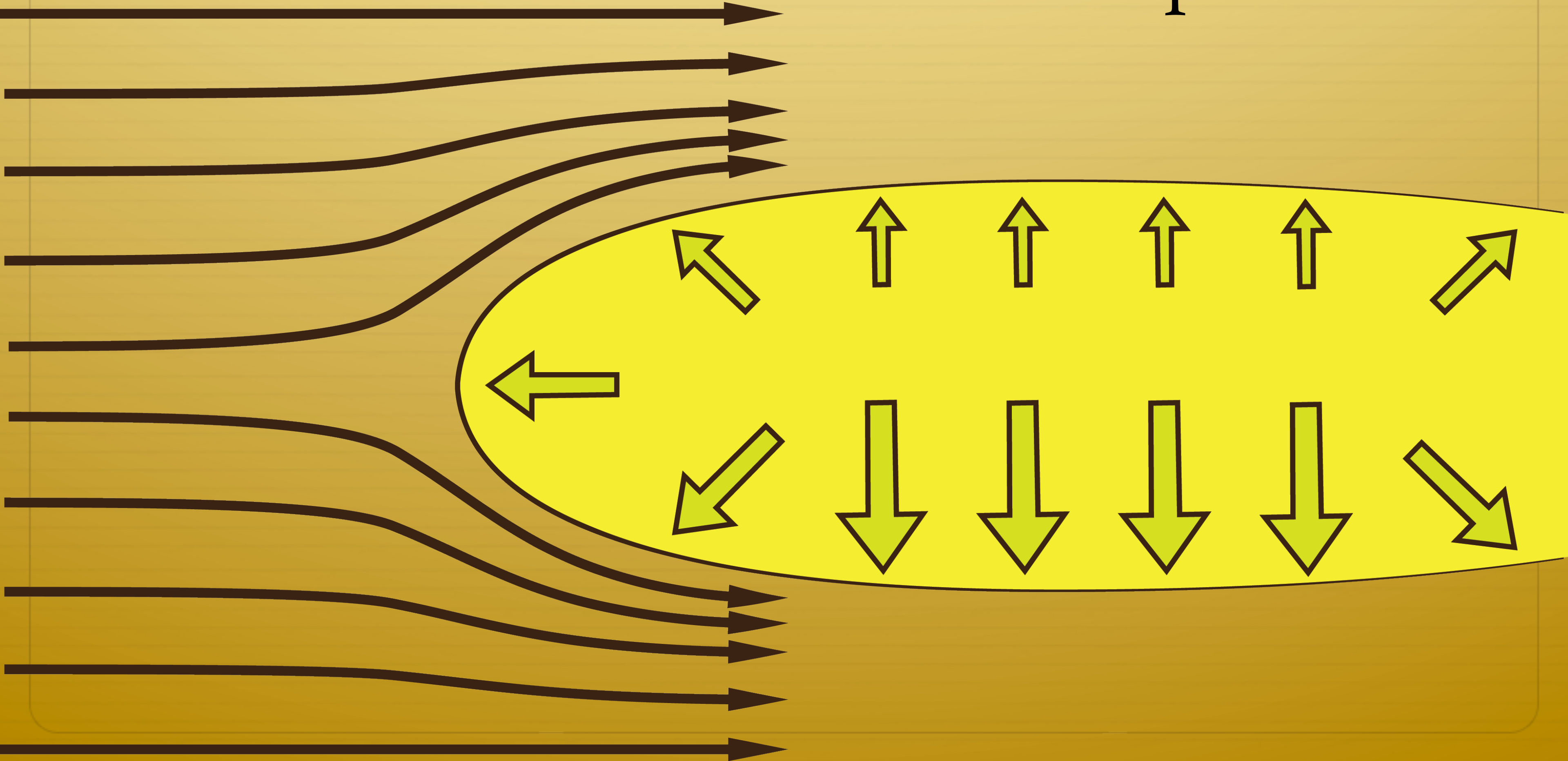
Pressure Airships

"Non-rigids" use pressure to maintain shape



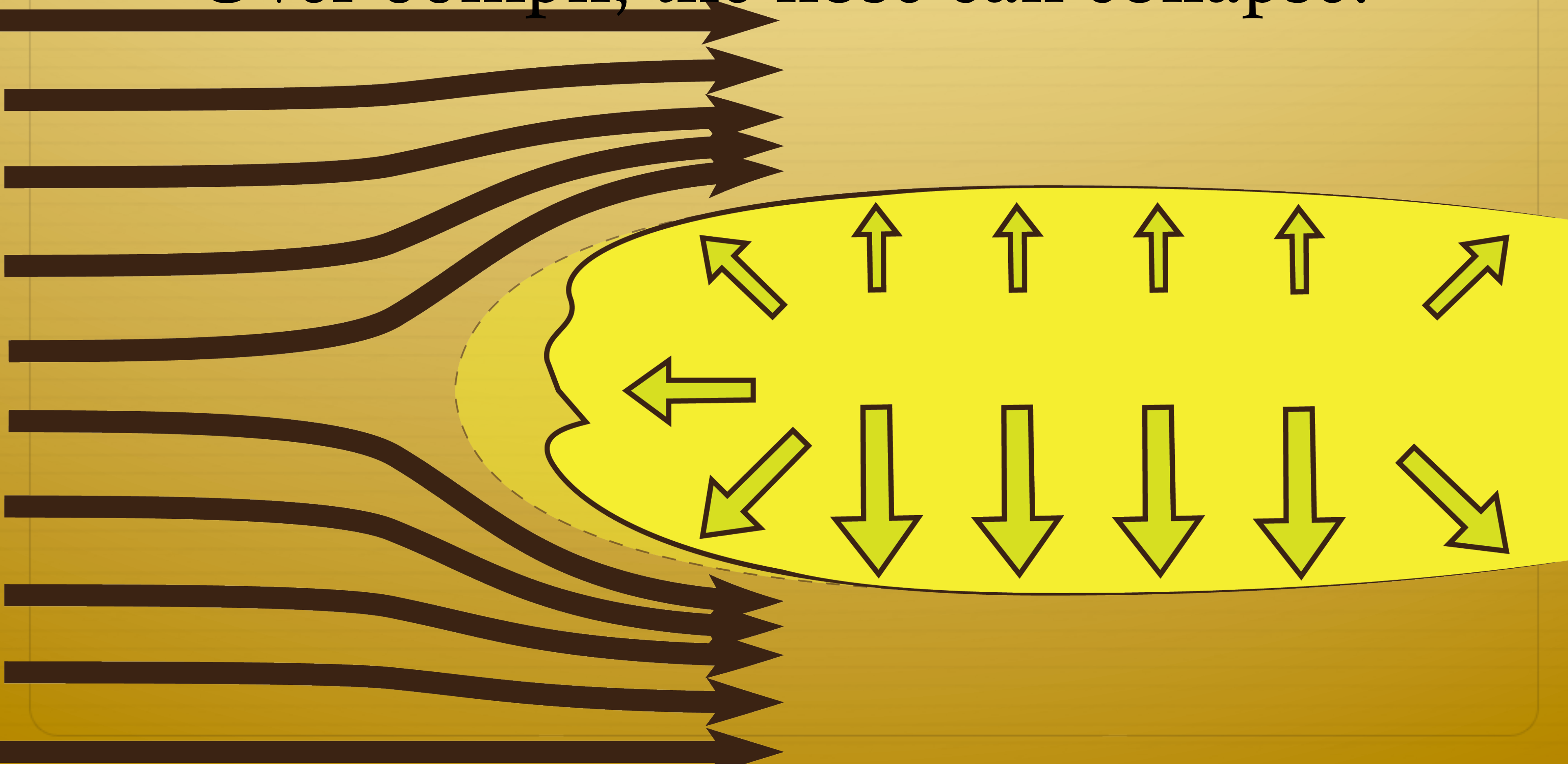
Limits of Pressure Airships

But movement creates forward pressure



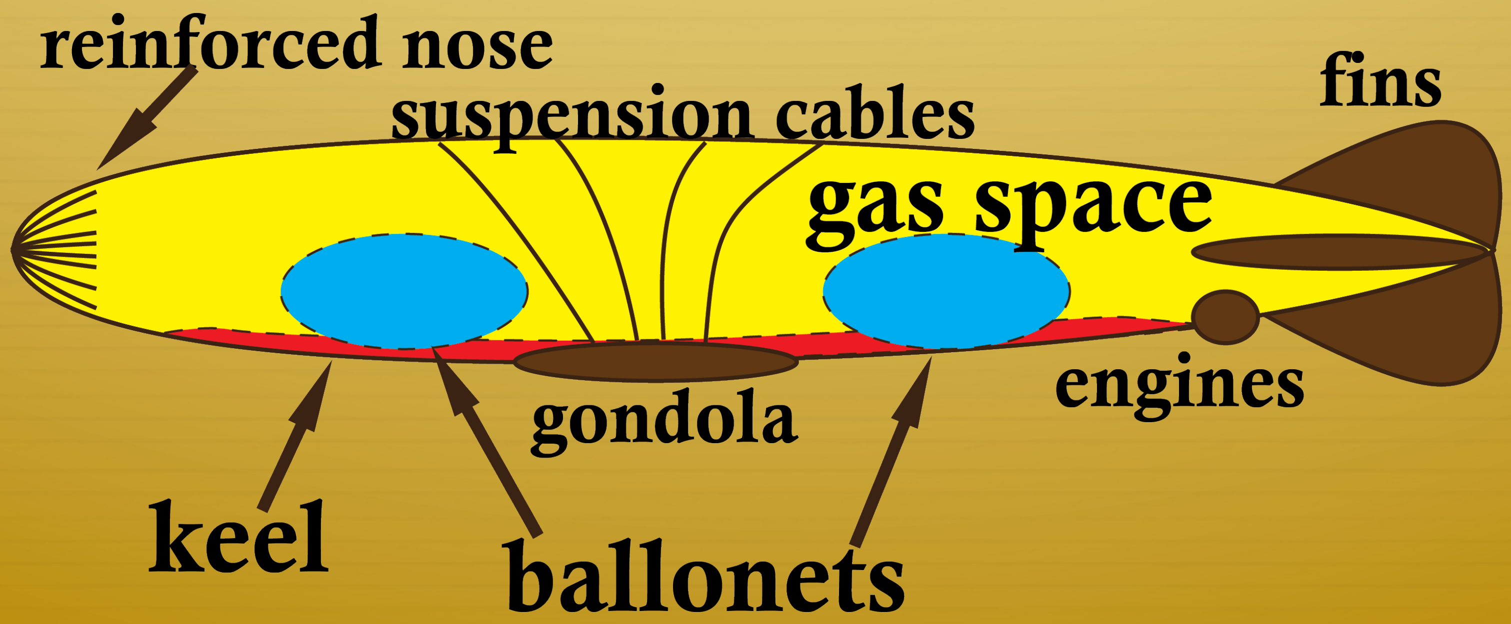
Limits of Pressure Airships

Over 60mph, the nose can collapse!



Reinforced Airships

"Semi-rigids" add a keel for strength

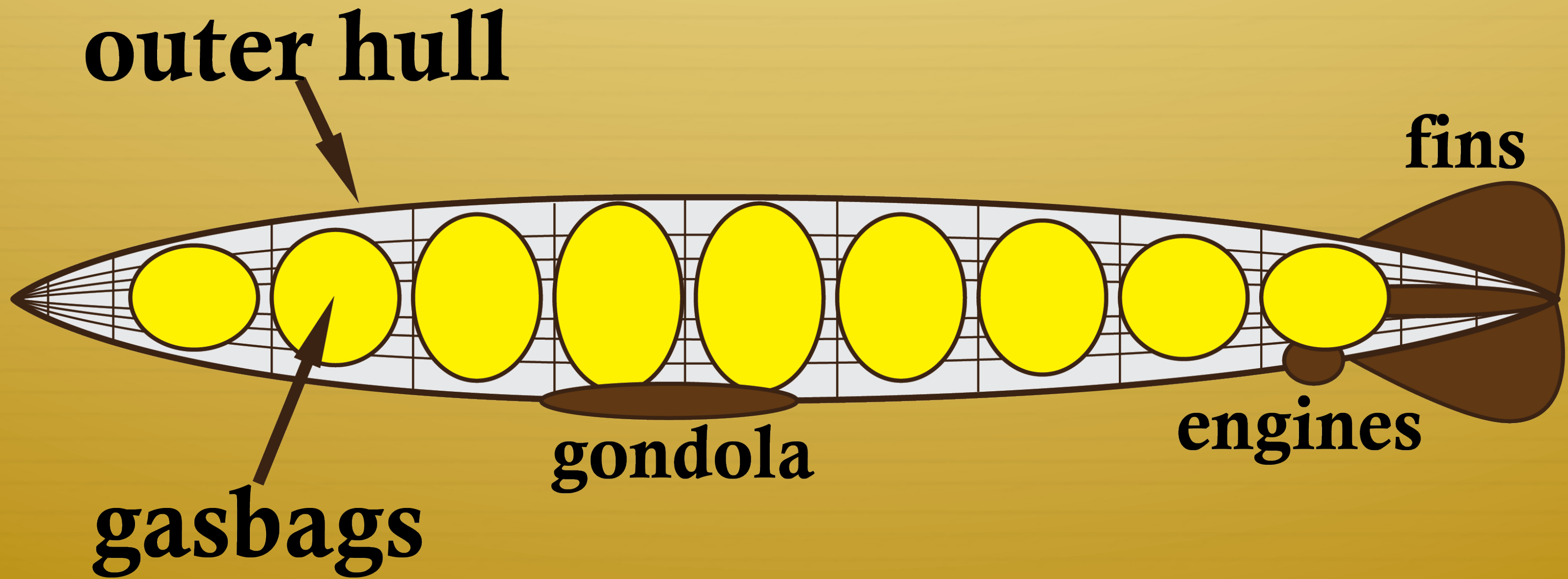


Tearing in Turbulence

Side gusts could destroy
even reinforced gasbags.
This limited semirigid size.

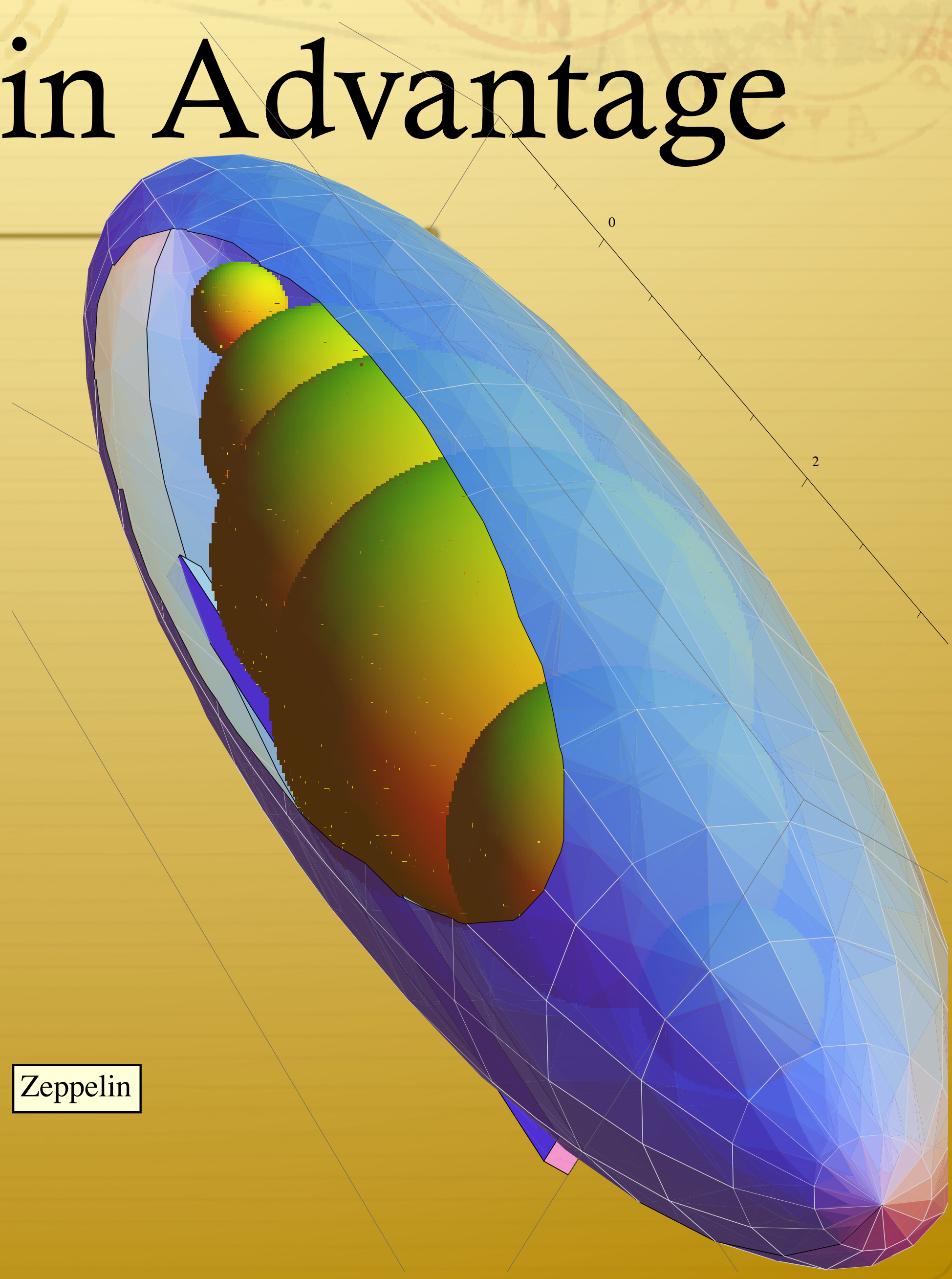
Structure Airships

Rigid airships have a hard outer shell



The Zeppelin Advantage

- Better storm resistance
- Lower gas pressure
- Lighter gas bags covers



Building a Giant

The *USS Shenandoah* under construction.

Propulsion

Making Airships Fly

Why Were They So Slow?

Airships are slow vehicles.

Why?

The Power Laws of Flight

$$\textit{Distance, Stress} \propto \text{Speed}^2$$

Stress and *Distance*
are proportional to air speed squared

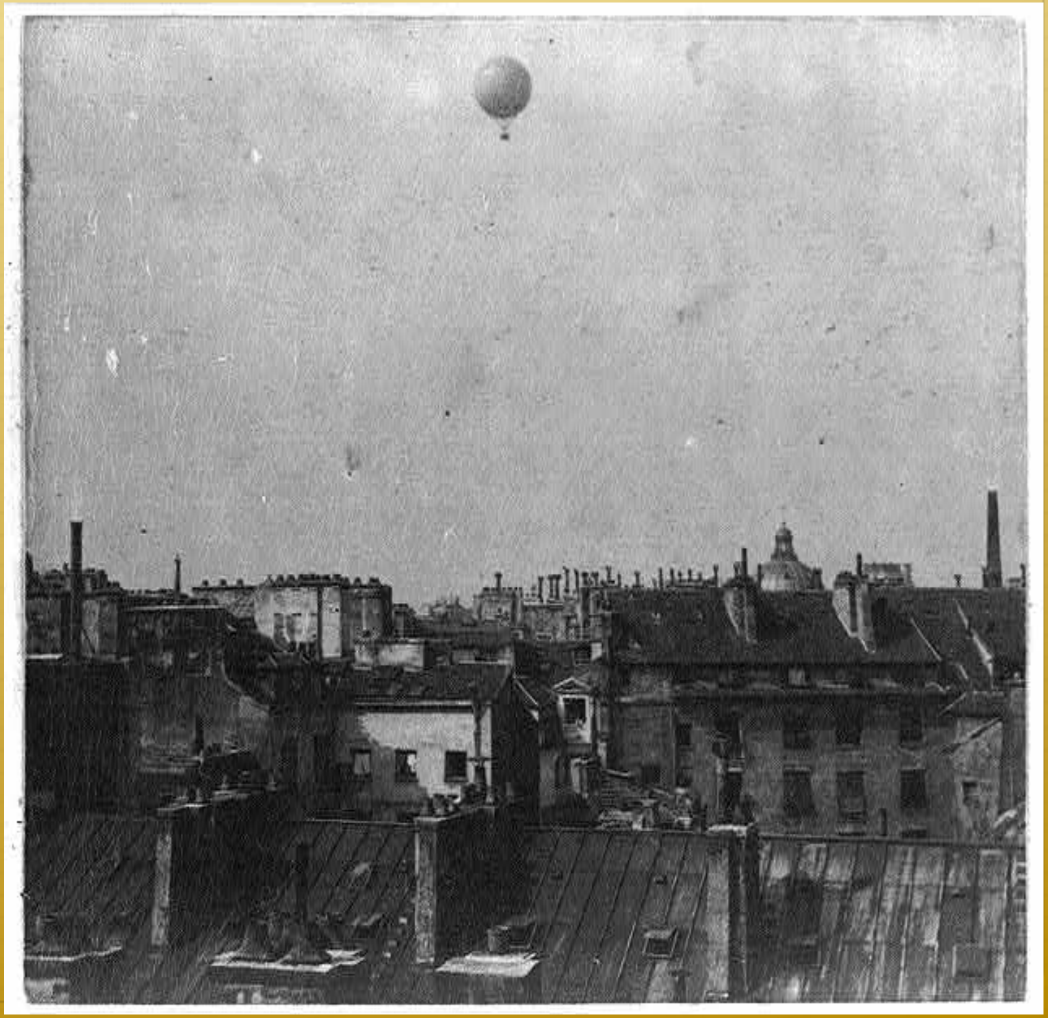
$$\textit{Power} \propto \text{Size}^3$$

Power is proportional to air speed cubed

Impractical Power

Henri Giffard:
Steam, 1852

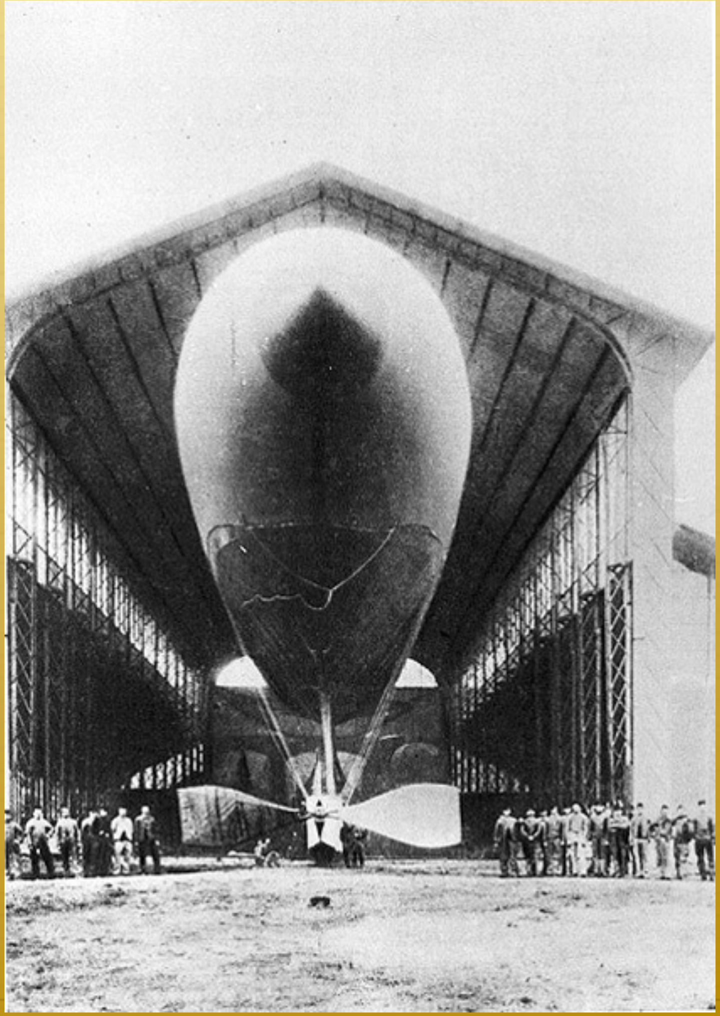
- 250 Pounds (not counting fuel + boiler)
- 3 Horsepower
- Still Air Only



Impractical Power

La France:
Electric, 1884

- 1000 Pounds (each battery)
- 14 Miles Per Hour
- Controllable!

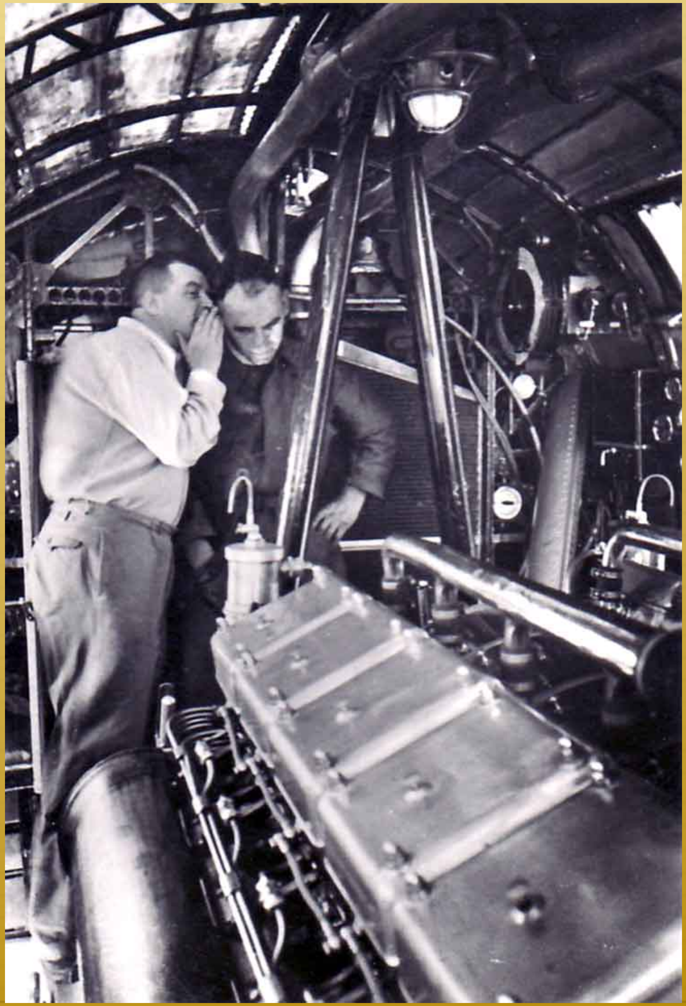


Practical Power

Daimler 1886:
Internal Combustion

- Gasoline
- Diesel

Power to weight ratio is crucial!



The Fuel Weight Problem

Burning fuel causes loss of its weight! Gasoline's density:

6.073lb per gallon

719.7 grams per liter

Combating the Problem

Finding New Sources of Weight

- Rain Capture
- Sea Water
- Fuel Condensation

Blau Gas

The Graf Zeppelin used *blaugas*, a fuel gas with the same density as air.

Burning blaugas doesn't change an airship's buoyancy.

Landing

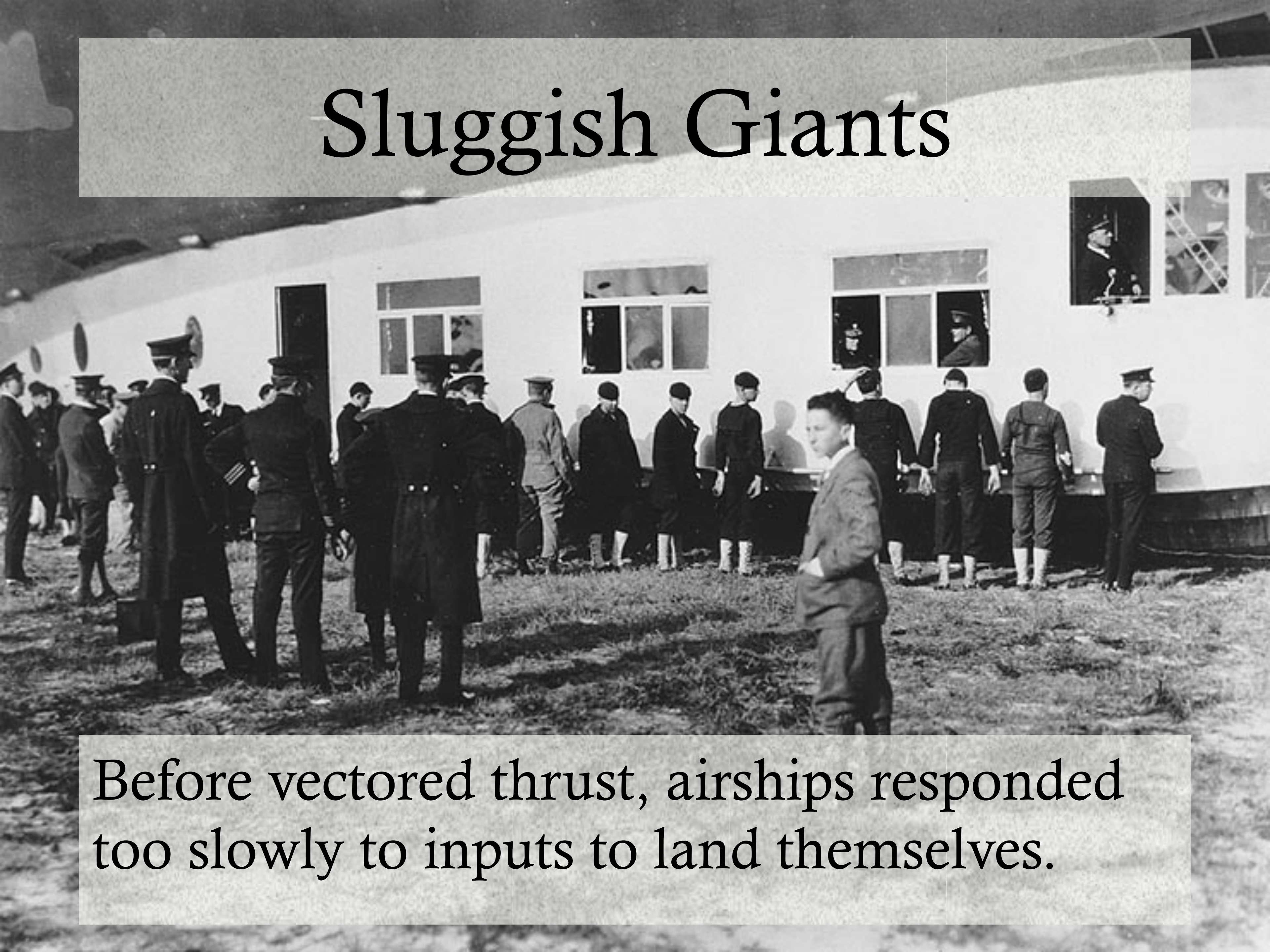
Coming Back to the Ground

How Did Airships Land?

Airships used giant hangars.

Why?

Sluggish Giants



Before vectored thrust, airships responded too slowly to inputs to land themselves.

Ground Crews and Mooring

Ground crews were required to maneuver airships into place

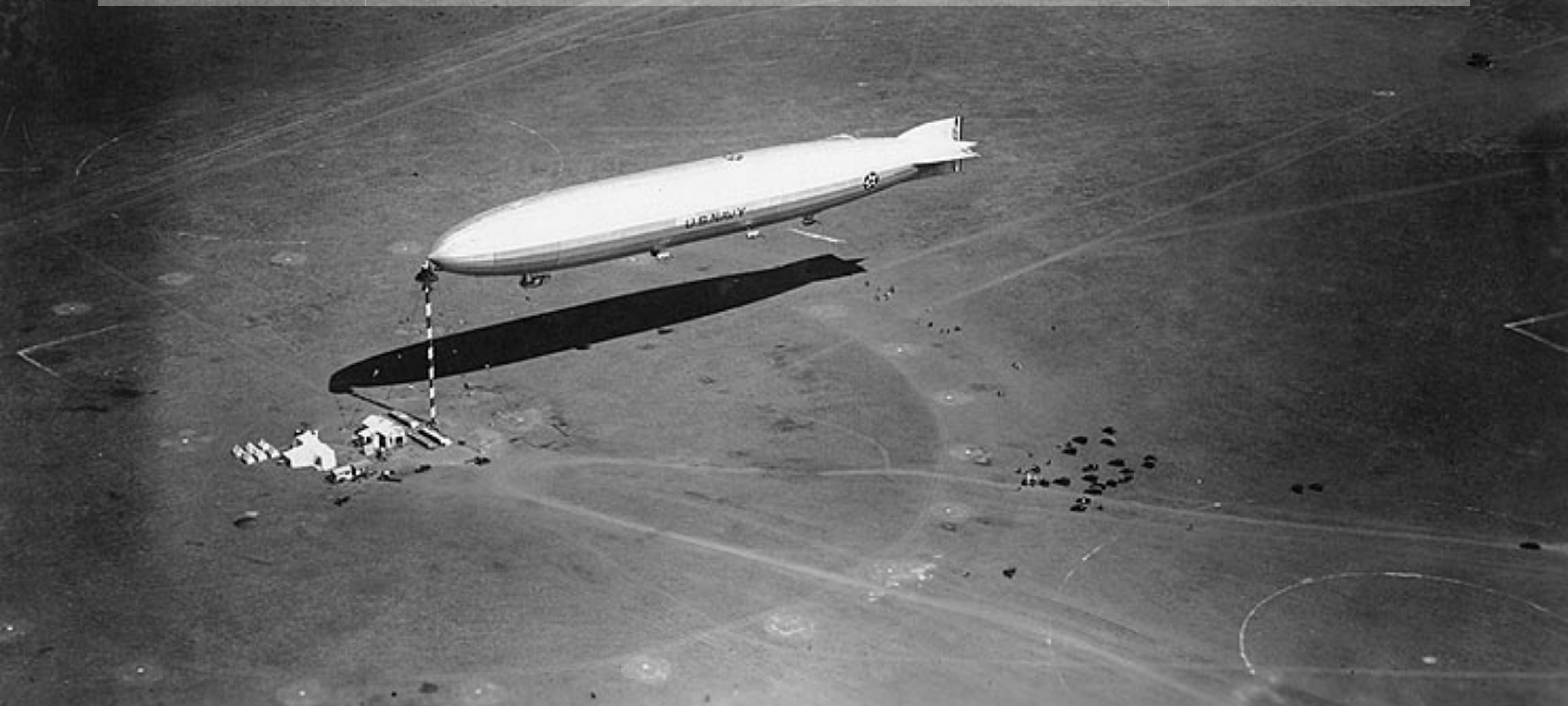
- Spider Lines
- Mooring

There are two main ways to moor airships:

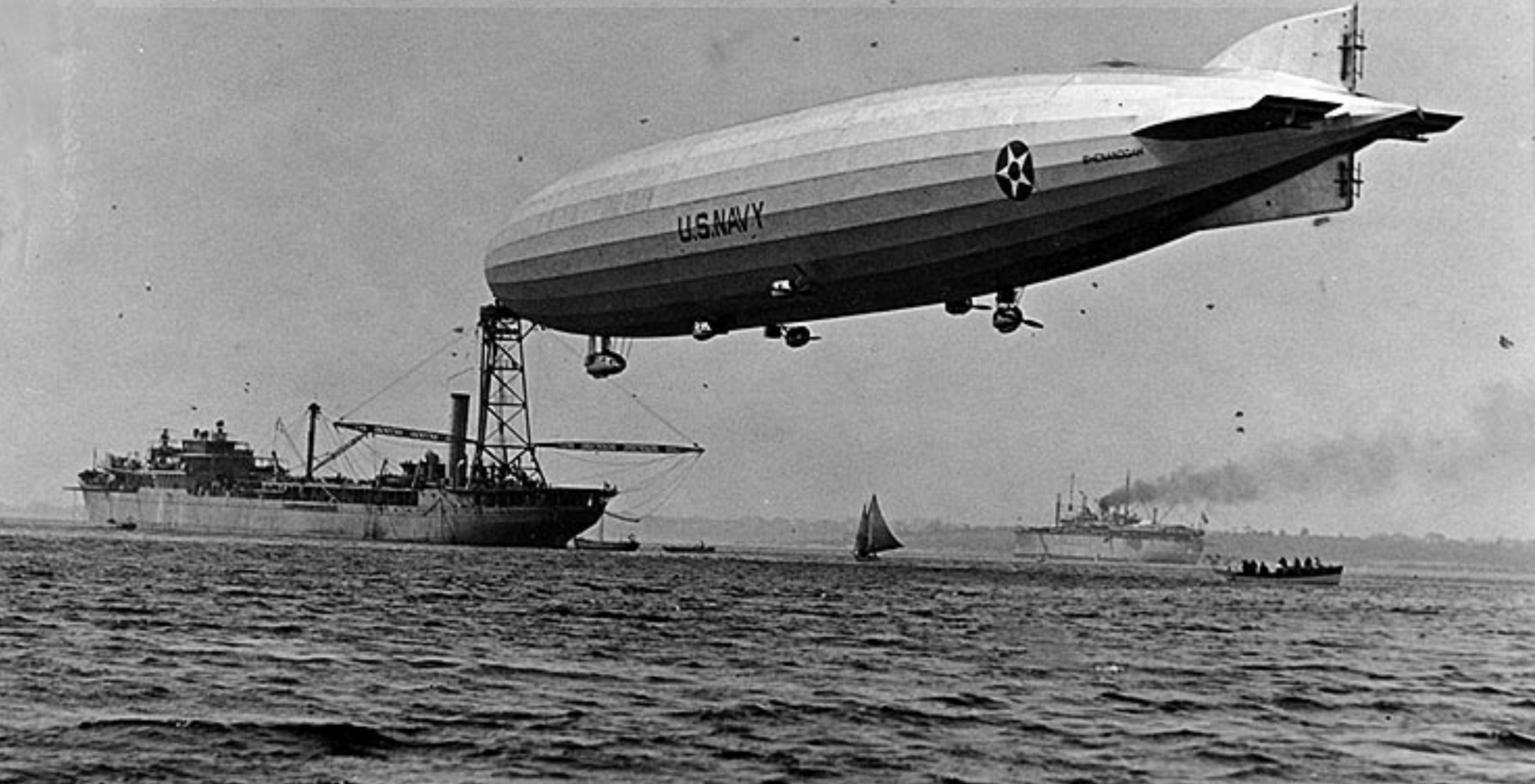
- Mooring Masts
- Hangars and Sheds

Mooring Masts

Mooring masts are cheap, enabling the airship to weathercock in the wind.



Mooring at Sea



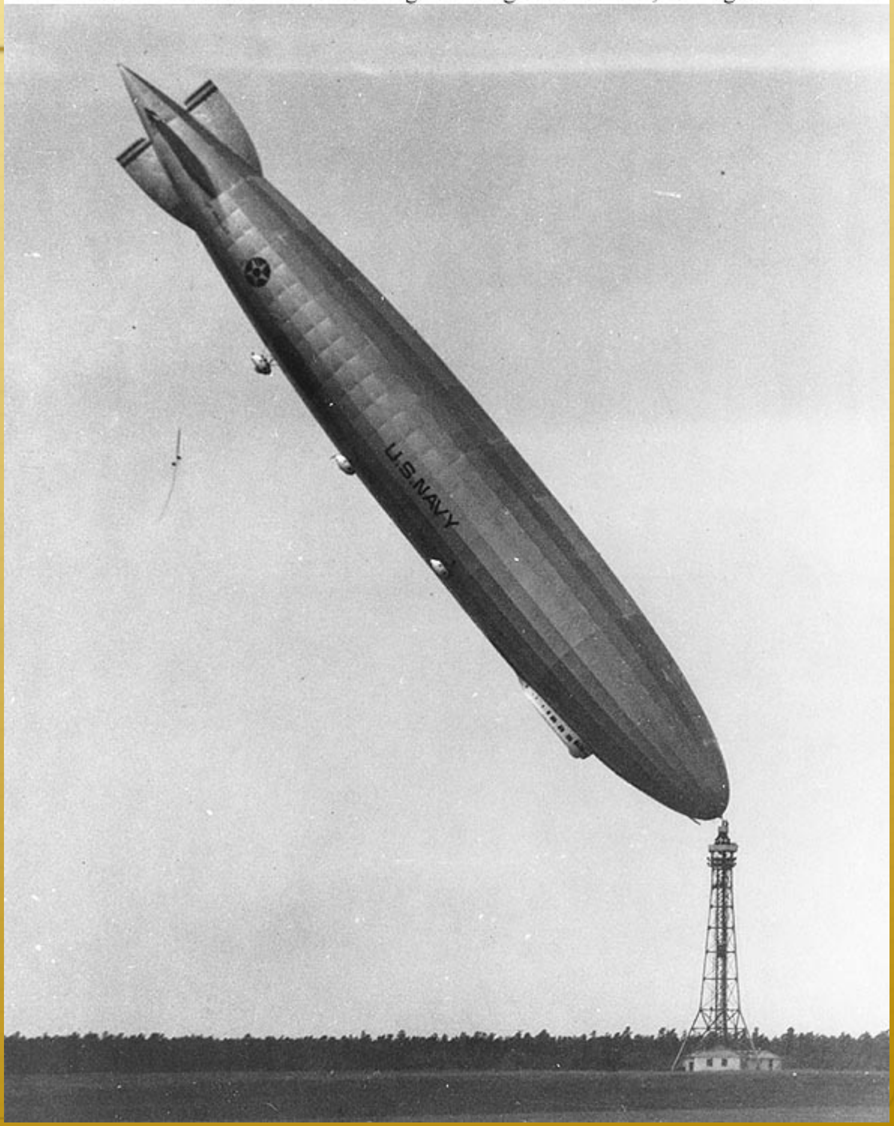
Masts work for waterborne operations.

Problems with Masts

But mooring masts can't protect airships against weather.

A gust tilted the *USS Los Angeles* to *85 degrees.*

Photo # NH 84567 USS Los Angeles rising out of control, 25 August 1927



Hangars

To truly protect an airship from the weather, you need a hangar.

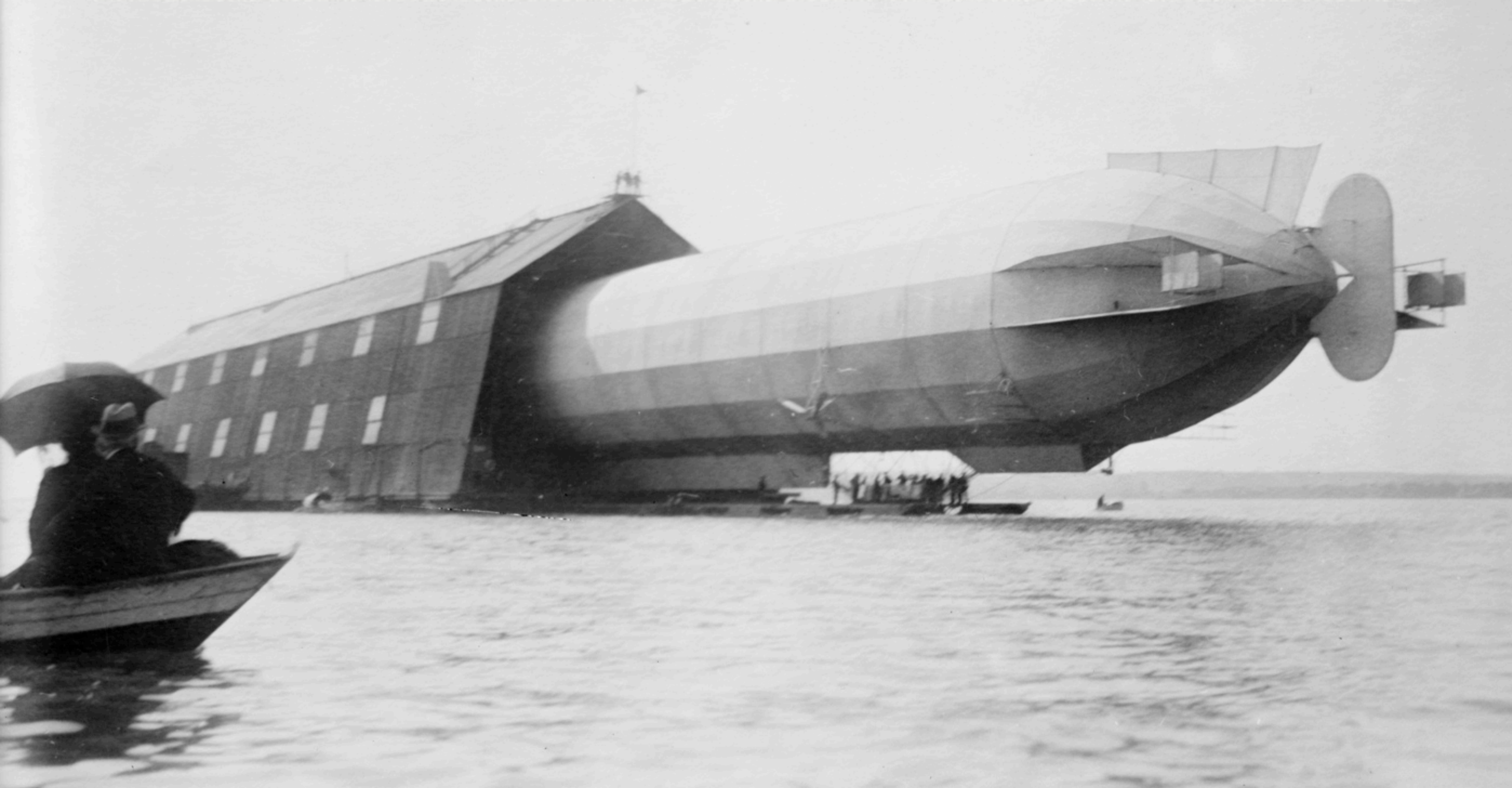
Hangars

The problem: hangars are *frigging huge*.

Hangar One

The top of Moffat Field's Hangar One is painted black to prevent condensation forming underneath the roof.

Mooring at Sea



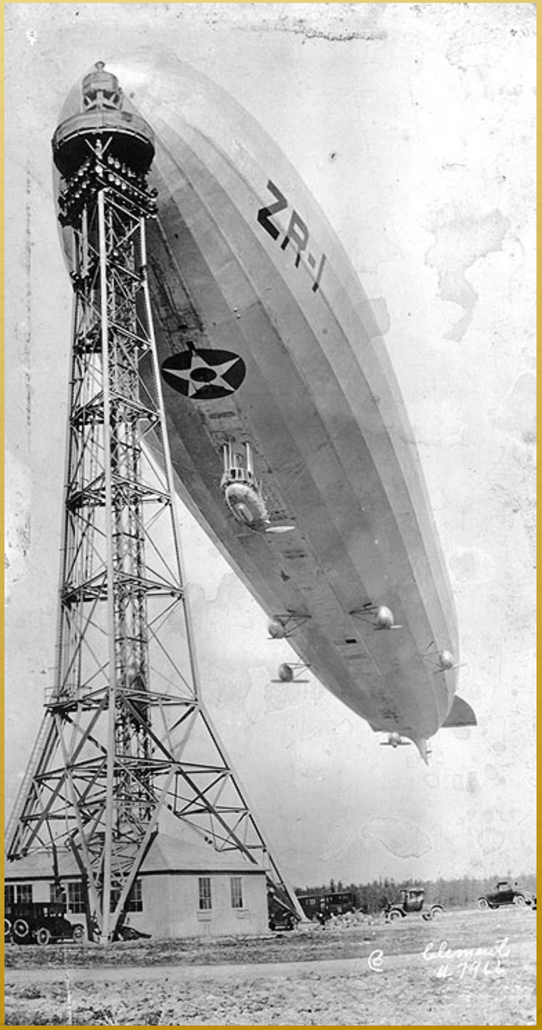
The first airship hangars were waterborne!

Hazards

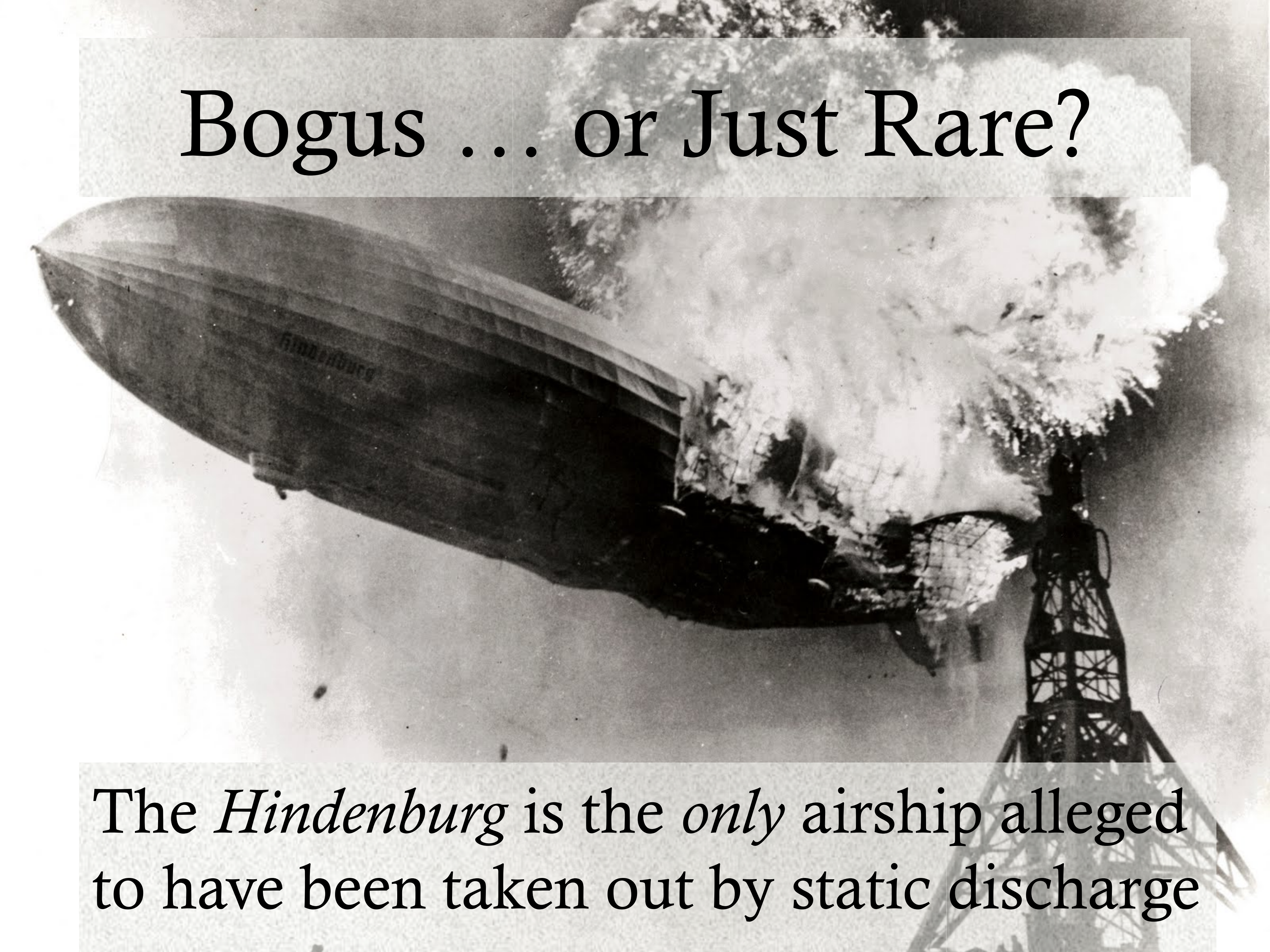
What Knocks Airships Down

Airships *Aren't* Vulnerable To…

- Bullets
  (they go through)
- Lightning
  (even the *Hindenburg*)
- Static Discharge
  (*only* the *Hindenburg*)



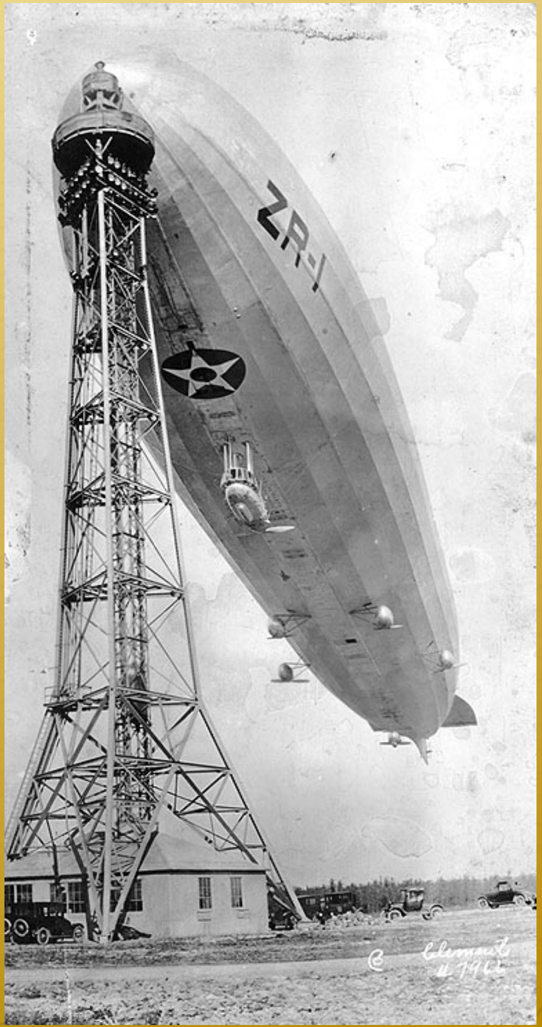
Bogus … or Just Rare?



The *Hindenburg* is the *only* airship alleged to have been taken out by static discharge

Airships *Are* Vulnerable To…

- Fire (from engines, or lightning when venting)
- Storms
  (can tear an airship apart)
- Human Stupidity
  (flying when / how they shouldn't)



Damage from Storms

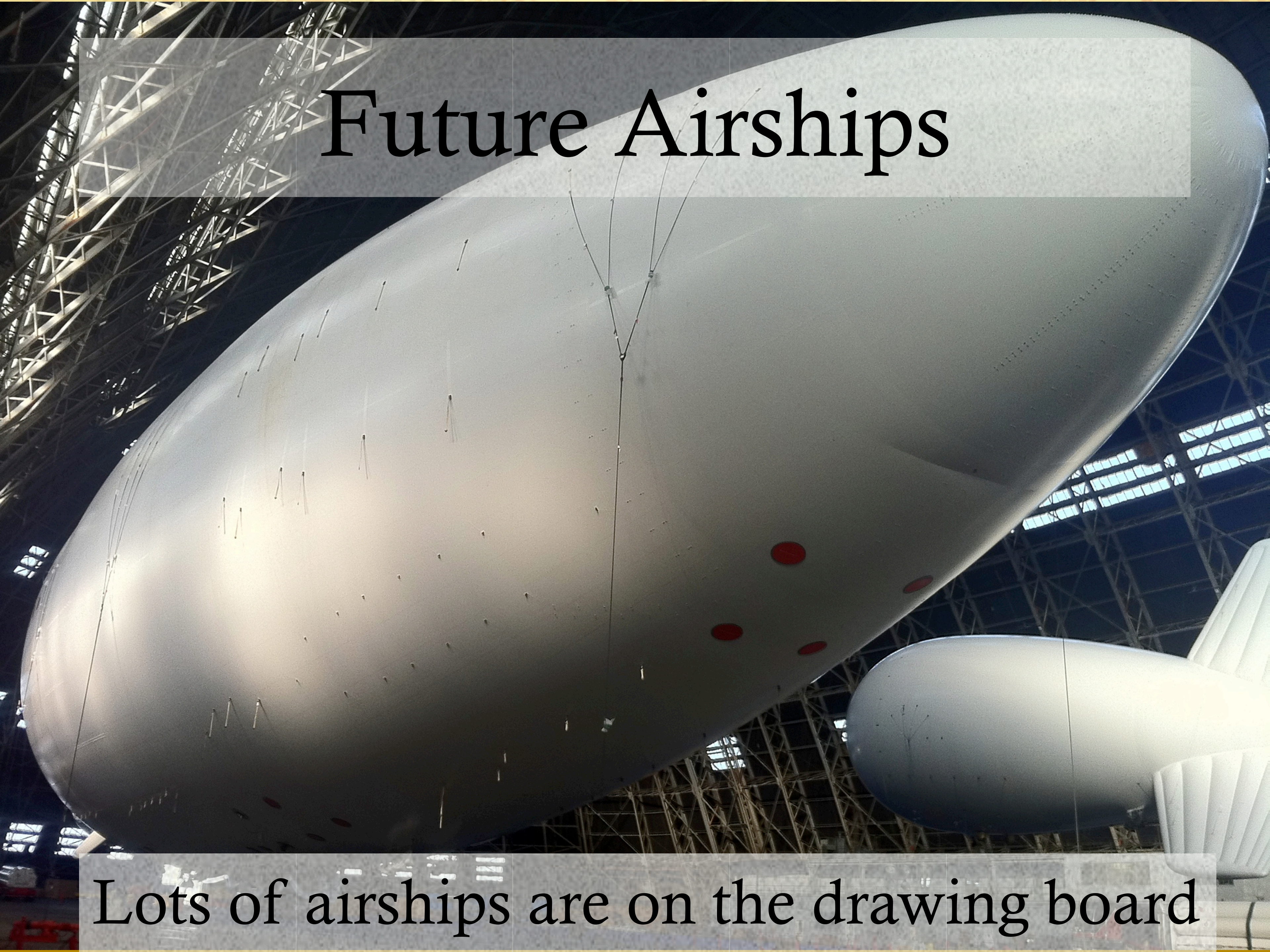
The *USS Shenandoah* suffered significant damage in a storm…

Death of the *Shenandoah*

… and a year later was destroyed in another storm which tore it apart.

The Future

Airships on the Drawing Board


Future Airships
Lots of airships are on the drawing board

The Semi-Rigid Future

New materials take us back to semi-rigids

Heavy Lift Ships

Combine large static and dynamic lift

The Limits of Possibility

Designs on the drawing board can lift 1000 tons … or fly 200 miles per hour!

Further Reading

Books

Airship Technology, 2e – Gabriel Alexander Khoury

Hindenburg – Rick Archbold / Ken Marschall

Anthony Francis

http://www.dresan.com/

http://www.dresan.com/science/airships/

http://www.dakotafrost.com/

http://facebook.com/dakotafrost