THE VALUE OF PERFORMANCE.

NORTHROP GRUMMAN

LEAF

Lifting Entry / Atmospheric Flight vehicle

Sky Rover for In Situ Exploration of Titan and Venus

June 1, 2016

New Frontiers Tech Workshop

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The Science Case for LEAF

- The scientific exploration of the atmospheres of solar system bodies other than the Earth has been mostly limited by the inability to do sustained, in situ measurements of atmospheric properties
- Our LEAF family of vehicles removes that limitation by providing a long lived, maneuverable science platform that opens new science domains to the Planetary Science community. A few examples:
  - Determining atmospheric chemistry as function of time of day, altitude, & geographical location
  - Characterizing spatial & temporal variations of photochemical & thermo-dynamical processes in the atmosphere
  - Constraining multiple atmospheric parameters that impact gaseous fractionation, planetary dynamics, & meteorology
  - Measuring atmospheric dynamics & circulation characteristics at all scales from local phenomenology to global circulation
  - Identifying and measuring stratification properties, local versus global phenomenology, the impact of topography on atmospheric properties
  - Understanding spatial & temporal variations of planetary weather phenomena & their drivers

LEAF Opens Up a New Era of Atmospheric Science

LEAF System Leverages High TRL Components for New Class of PSD Platform

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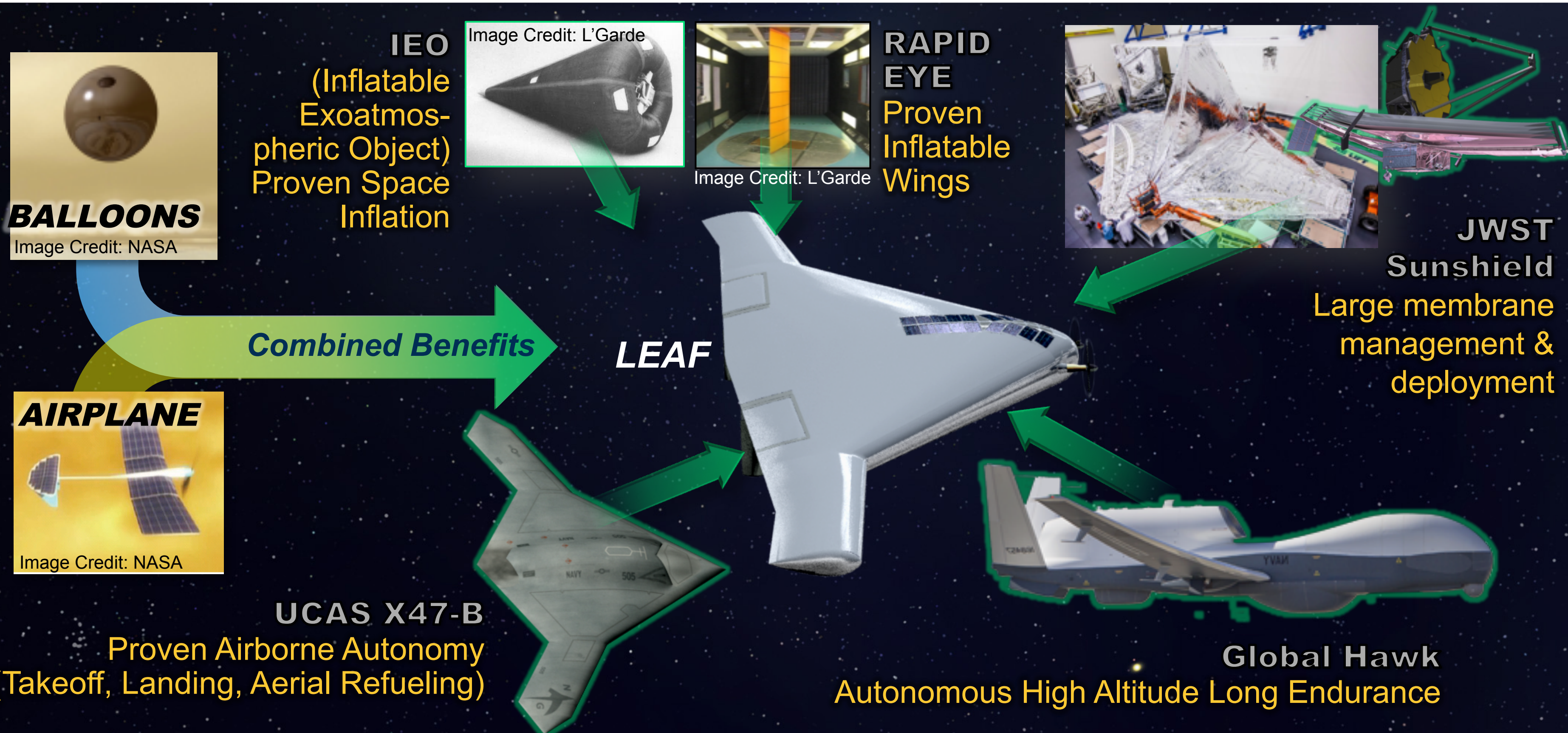

- ☑ ***LARGE PAYLOAD / SCIENCE*** capability
- ☑ ***LONG LIFE,*** *sustained* exploration
- ☑ ***BUOYANCY for reduced operational risks***
- ☑ ***1st SKY ROVER*** for Planetary Exploration
- ☑ ***LIFTING ENTRY*** eliminates aeroshells & complex parachutes
- ☑ ***CONTROLLED DEPLOYMENT*** prior to entry
- ☑ ***3-DIRECTIONAL MANEUVERABILITY***

LEAF Sky Rover is Capable of Exploring Various Solar System Bodies with an Atmosphere

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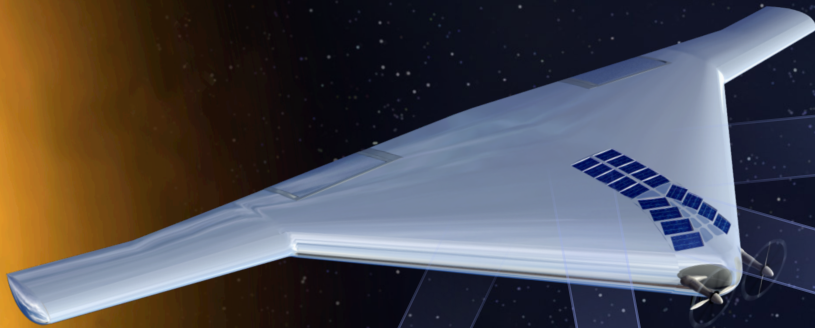

TITAN

- Long-lived flight at low altitudes with revisit capability
- High resolution surface imaging

MARS

- Controlled, targeted delivery of cargo/equipment to surface
- Low level imaging of specific targeted surface areas

EARTH

- ISS experiment or low-g life science experiment/ sample return
- High altitude atmospheric and surface interaction science
- Non-NASA applications

VENUS

- Long duration, sustained in situ aerial exploration
- Capability to vary altitudes and revisit areas of interest

LEAF core subsystems are adaptable

- Venus - H_2SO_4 protection (Teflon coating)
- Titan - radioactive power (TAPC instead of eMMRTG)

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VAMP Air Vehicle Key Features

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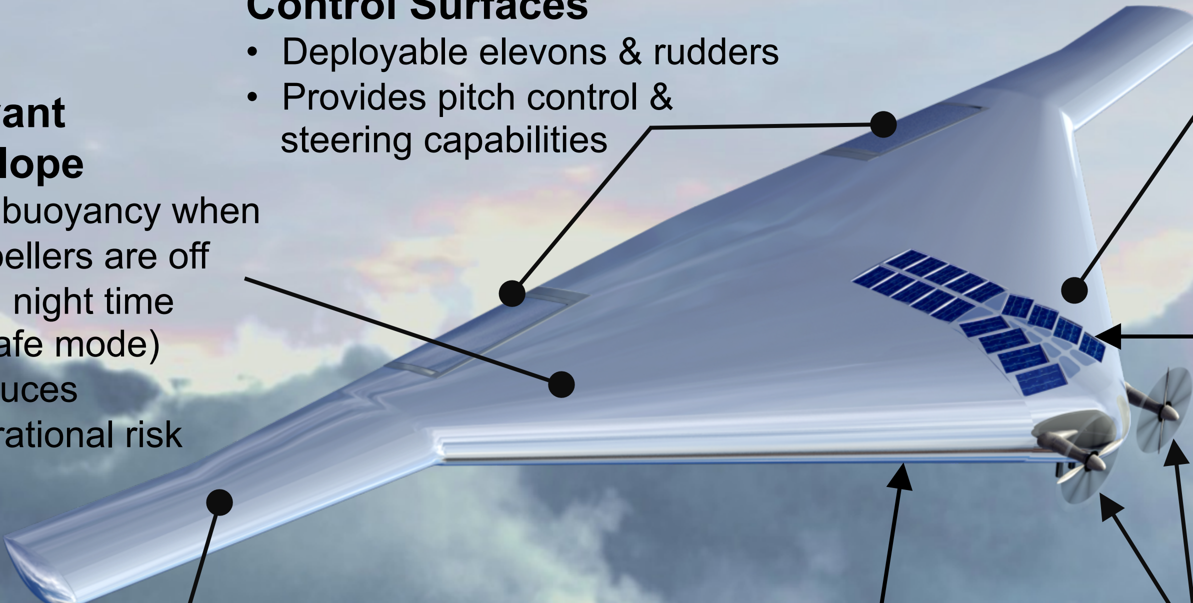


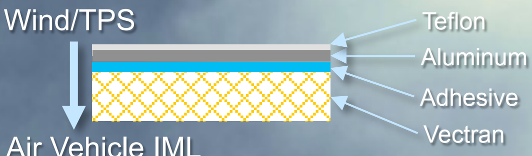
Control Surfaces
- Deployable elevons & rudders
- Provides pitch control & steering capabilities

Buoyant Envelope
- Full buoyancy when propellers are off (i.e., night time or safe mode)
- Reduces operational risk

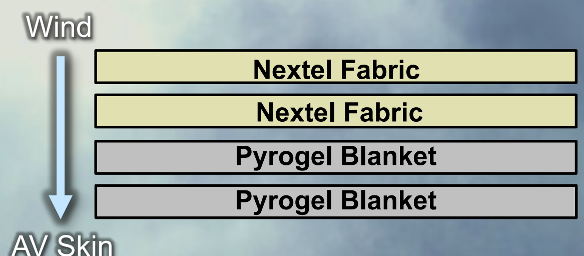
Equipment Bay
- ~30 m^3 of volume for instruments & avionics
- 50kg instrument capacity
- Houses avionics & instruments

Electrical Power Subsystem
- Solar array (> 8 kW capability)
- Powers propellers, avionics & instruments

AV Skin
- Teflon-Al-Vectran laminate
- Protects against sulfuric acid & solar heating
- Retains buoyancy gas inside the envelope



Thermal Protection System
- Protects air vehicle during entry
- Nextel fabric/Pyrogel laminate (max temperature 1,478K)



Propulsion Subsystem
- Provides altitude control & lift capability
- 2-blade, 2.5m diameter propellers
- Total of 400 – 450 N thrust
- Max speed ~30 m/s
- Max climb rate ~1.5 km/hr

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VAMP's Lifting Entry Enables New Science

Atmospheric sampling opportunities 1080 seconds after entry

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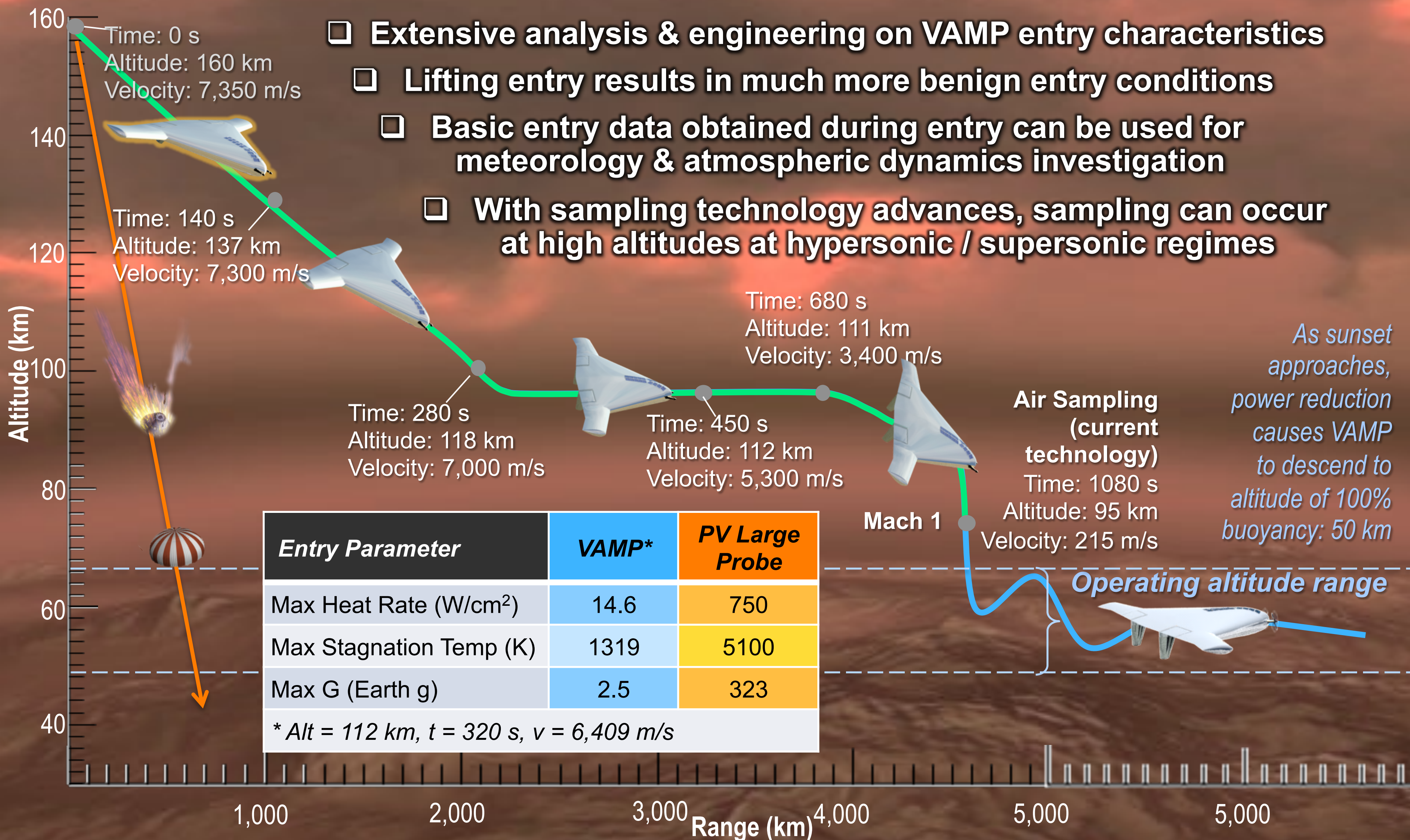
- ❑ **Extensive analysis & engineering on VAMP entry characteristics**
- ❑ **Lifting entry results in much more benign entry conditions**
- ❑ **Basic entry data obtained during entry can be used for meteorology & atmospheric dynamics investigation**
- ❑ **With sampling technology advances, sampling can occur at high altitudes at hypersonic / supersonic regimes**



Entry Parameter	*VAMP**	*PV Large Probe*
Max Heat Rate (W/cm^2)	14.6	750
Max Stagnation Temp (K)	1319	5100
Max G (Earth g)	2.5	323
** Alt = 112 km, t = 320 s, v = 6,409 m/s*		

Different VAMP Configurations

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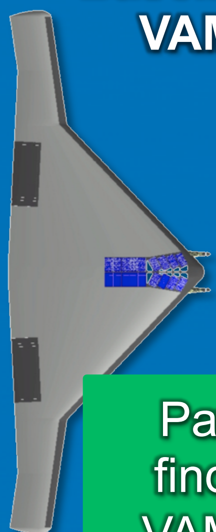
	Baseline VAMP	Pathfinder VAMP	Tech Demo VAMP
Objectives	Powered flight Full climb ability to 68 km altitude Greatly expanded science	Powered flight Limited climbing ability Nighttime science operations Expanded science	Lifting entry Operation in H_2SO_4 environment Basic science (temperature, pressure, wind speed, etc.)
Nominal Science Ops Duration	Up to 1 year	1 – 3 Months	1 – 4 Weeks
Nominal Altitude Range	50 – 65 km	Low to mid 50 km	Fixed (~50 km)
Science Instruments & Capabilities	See slide 15	See slide 15	See slide 15
Minimum Power	8,000 w (day); 100 w (night)	300 w (day); 100 w (night)	100 w (day); 20 w (night)
Notional Wing Span	59 m	30 m	8.5 m
Vehicle Mass	880 kg including instruments	450 kg including instruments	100 kg including instruments
Launch Vehicle	Atlas V 551 or Equivalent	Atlas V 401 or Equivalent	Piggy-back on Venus flyby spacecraft

Different VAMP Configurations
Science Instruments



Configuration	Instruments	Science Objectives
Baseline VAMP	**Radiometer**	☑ *Radiative balance in & above clouds* ☑ *Integrated solar flux* ☑ *Search for & characterize lightning*
	Micro-barometer	☑ *Seismology; Gravity waves; Infrasonic*
	HD camera	☑ *Cloud imagery; Atmospheric thunder; Outreach*
	Radar altimeter	☑ *VAMP state vector determination*
	Microscopic imager	☑ *Determination of shape and size of aerosol particles*
	Drop/Rise Sondes	☑ *Tropospheric structure & composition* ☑ *Surface sounding; Residual magnetism*
Path-finder VAMP	**Gas Chromatograph Mass Spectrometer**	☑ *Trace gases; Isotopic abundance*
	Mass Spectrometer	☑ *Atmospheric noble gases; Isotopic abundance*
	Nephelometer	☑ *Cloud particle microphysics (particle size, #, density, refractive index)*
	IR Spectrometer	☑ *Surface thermal emission* ☑ *Geophysics*
	Meteorological	☑ *Atmospheric structure, dynamics and turbulence*
	Electrical / Magnetic	☑ *Electrical & magnetic properties & atmosphere & surface* ☑ *Search for & characterize lightning*
Tech Demo VAMP	**Accelerometers**	☑ *Wind turbulence and buffeting*
	Pitot tubes (pressure sensors)	☑ *Atmospheric pressures & pressure gradients*
	Thermocouples	☑ *Atmospheric temperatures & temperature gradients*
	Wind velocity anemometers	☑ *Wind speed / air speed*

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In Situ Platform Comparison

Attribute	VAMP	Probe	Balloon	Airplane
Mission duration	Months to 1+ year	Hours – limited by extreme T & P	Days – limited by drifting winds leading to polar vortices	Weeks – limited by power & propulsion
3D Directional Control	Travels w/ winds; flight velocity control latitude	None	None	Travels w/ winds; flight velocity control latitude
Geographical Coverage	Tens of km in altitude, latitude control during day, repeatable	Single vertical profile, no latitude or longitude range, not repeatable	Some altitude control, limited latitude control, limited repeatability	Tens of km in altitude, latitude control during day, repeatable
Science Payload Mass & Power	Large ~ 50 kg, > 1 kW pwr daytime	Minimal < 10 kg, ~ 50 W	Minimal ~10 kg, ~50 W	Minimal ~10 kg, ~50 W
Deployment Risk	Low: Slow deployment in orbit	Moderate: Traditional entry behind aeroshell	High: Deploys rapidly during descent	High: Deploys rapidly during descent
Operational Risk	MODERATE: somewhat complex; safe mode buoyant, balloon-like	LOW: Simple to operate	LOW: Flight is maintained by inherent buoyancy	HIGH: somewhat complex; limited recovery time from safe mode

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