Rapid Eye

Rapid Response, Long Range, Long Endurance Unmanned Aerial Systems (UAS)

Industry Day

July 25, 2007

Wade Pulliam
Tactical Technology Office
DARPA

Agenda

- DARPA's Charter & Commitment
- Rapid Eye Overview
  - Motivation / Vision
  - Program Objectives and Goals
- Technology Areas
- Acquisition Strategy
  - Program Plan (all phases)
  - Source Selection Schedule
- Program Solicitation Overview
  - BAA (& OTA) Requirements
  - Proposal Overview
  - Evaluation Process
- Summary
- Question and Answers

What is DARPA?

The Defense Advanced Research Projects Agency is the central R&D arm of the Department of Defense with the primary responsibility to conceive, explore, and demonstrate breakthrough system concepts and the most advanced technologies.

What is DARPA's Mission?

Maintain Superiority

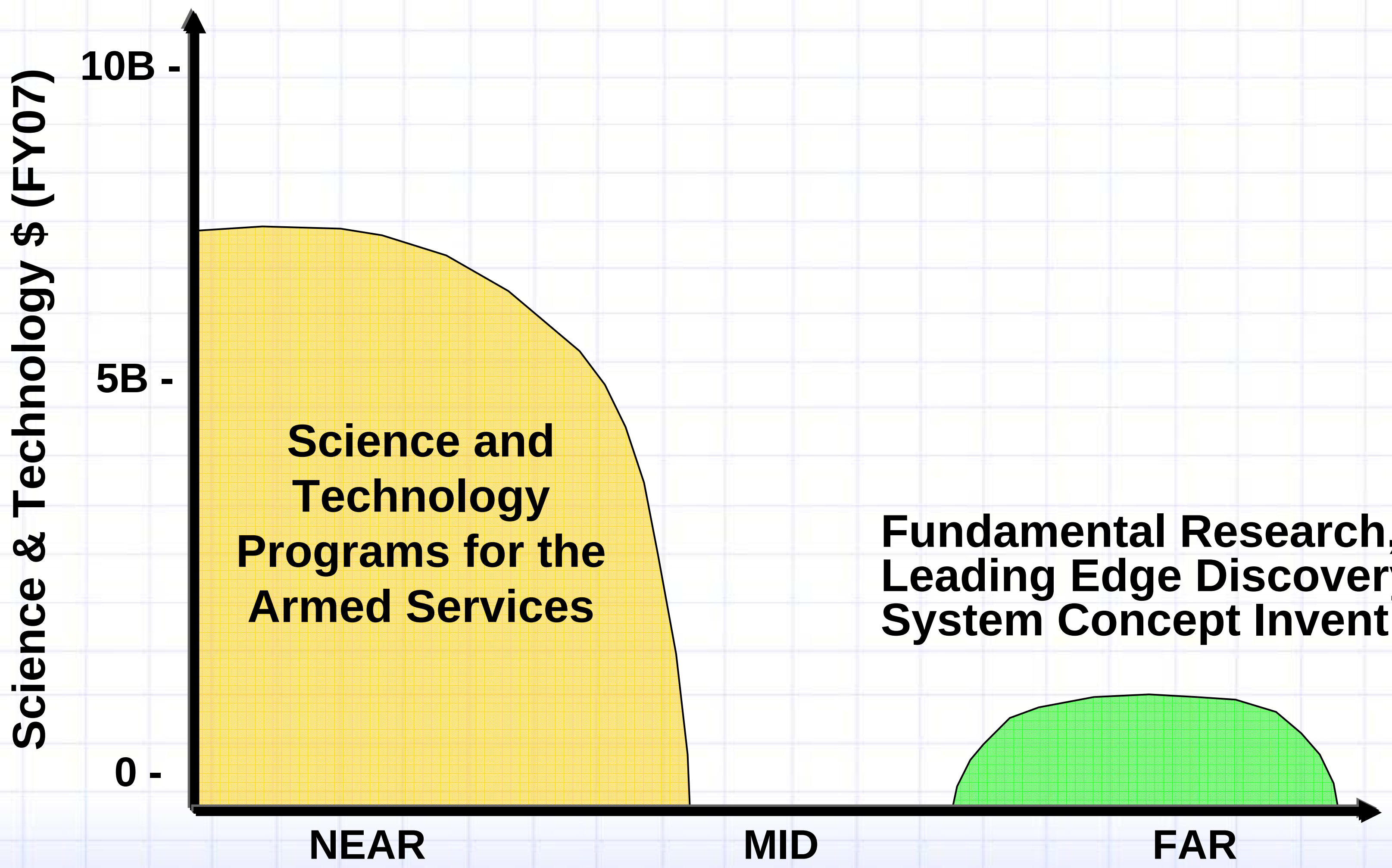
Prevent Surprise

DARPA's mission is to <u>maintain technological superiority</u> of the US military and <u>prevent technological surprise</u> from harming our national security by sponsoring revolutionary, high-payoff research that bridges the gap between fundamental discoveries and their military use.

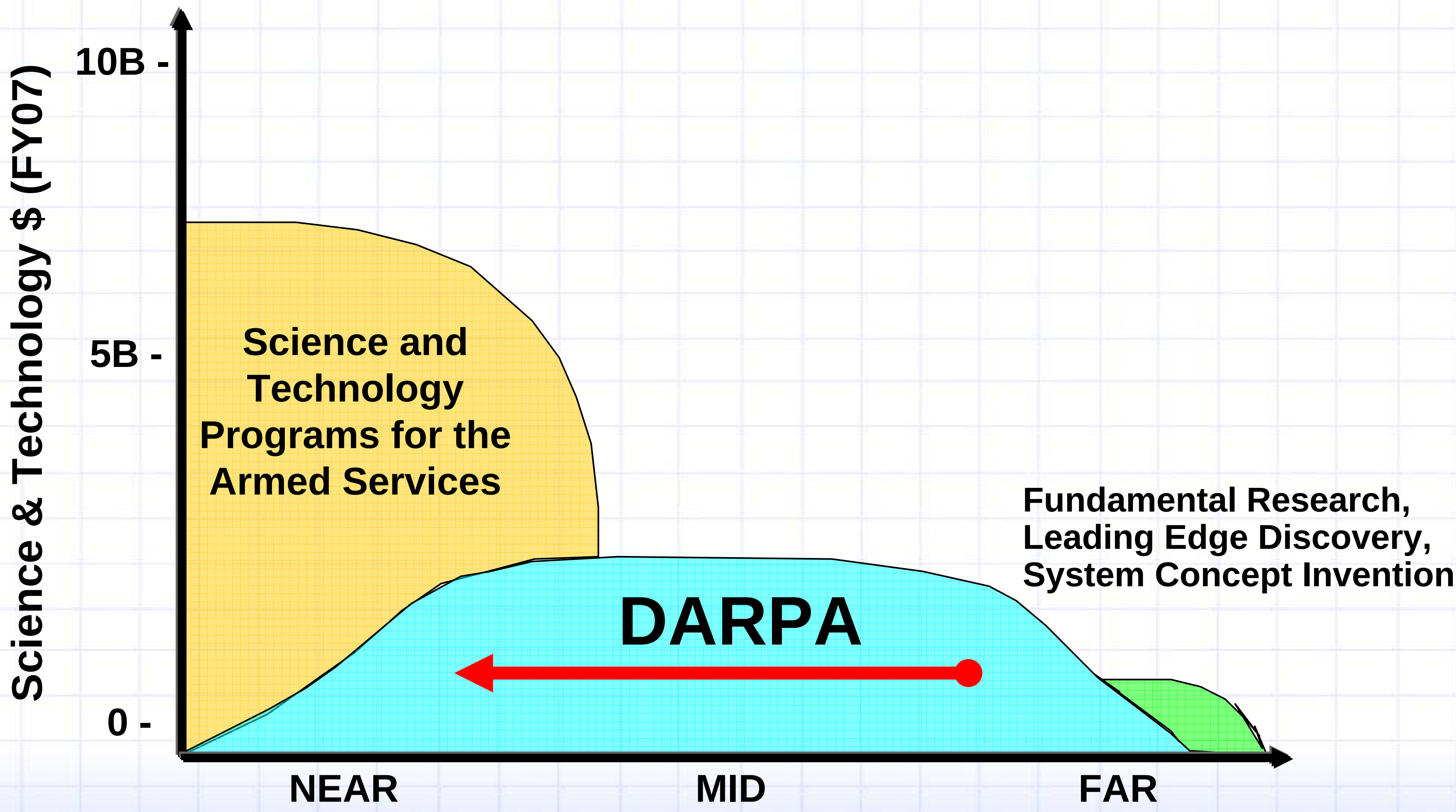
High Risk

High Payoff

DARPA Role in Science and Technology



DARPA Role in Science and Technology



DARPA Accomplishments

DARPA Organization

Director, Tony Tether
Deputy Director, Bob Leheny

Tactical Technology
Steve Welby
Steve Walker

- Air/Space/Land/Sea Platforms
- Unmanned Systems
- Space Operations
- Directed Energy Systems
- Precision Strike

Information Exploitation
Bob Tenney
Mark Davis

- Sensors
- Exploitation Systems
- Command & Control

Strategic Technology
Dave Honey
Larry Stotts/Brian Pierce

- Space Sensors/Structures
- Strategic & Tactical Networks
- Information Assurance
- Underground Facility Detection & Characterization
- Chem/Bio Defense
- Maritime Operations

Defense Sciences
Brett Giroir
Barbara McQuiston

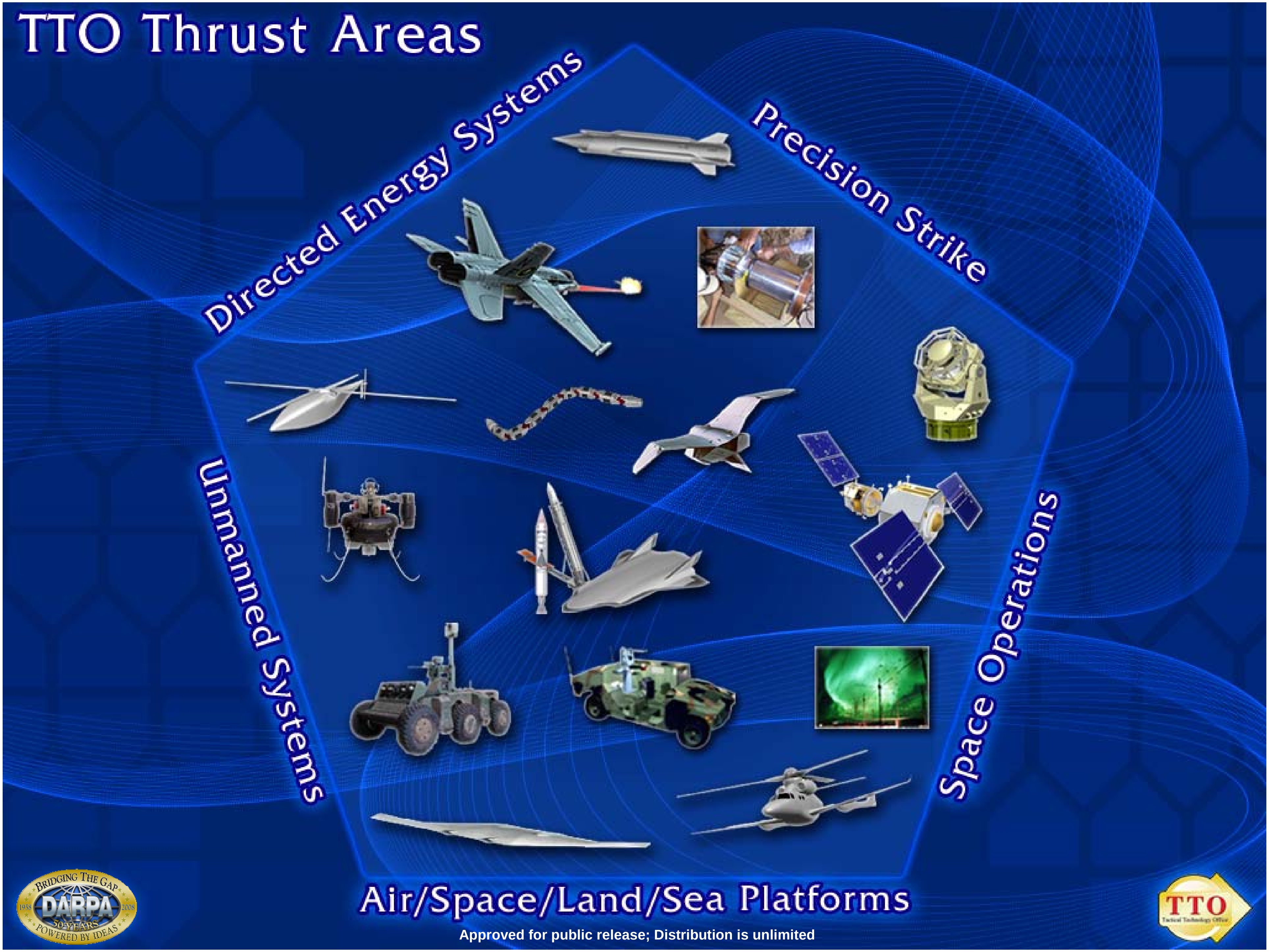
- Physical Sciences
- Materials
- Biology
- Mathematics
- Human Effectiveness
- Bio Warfare Defense

Information Processing Technology
Charlie Holland
Chuck Morefield

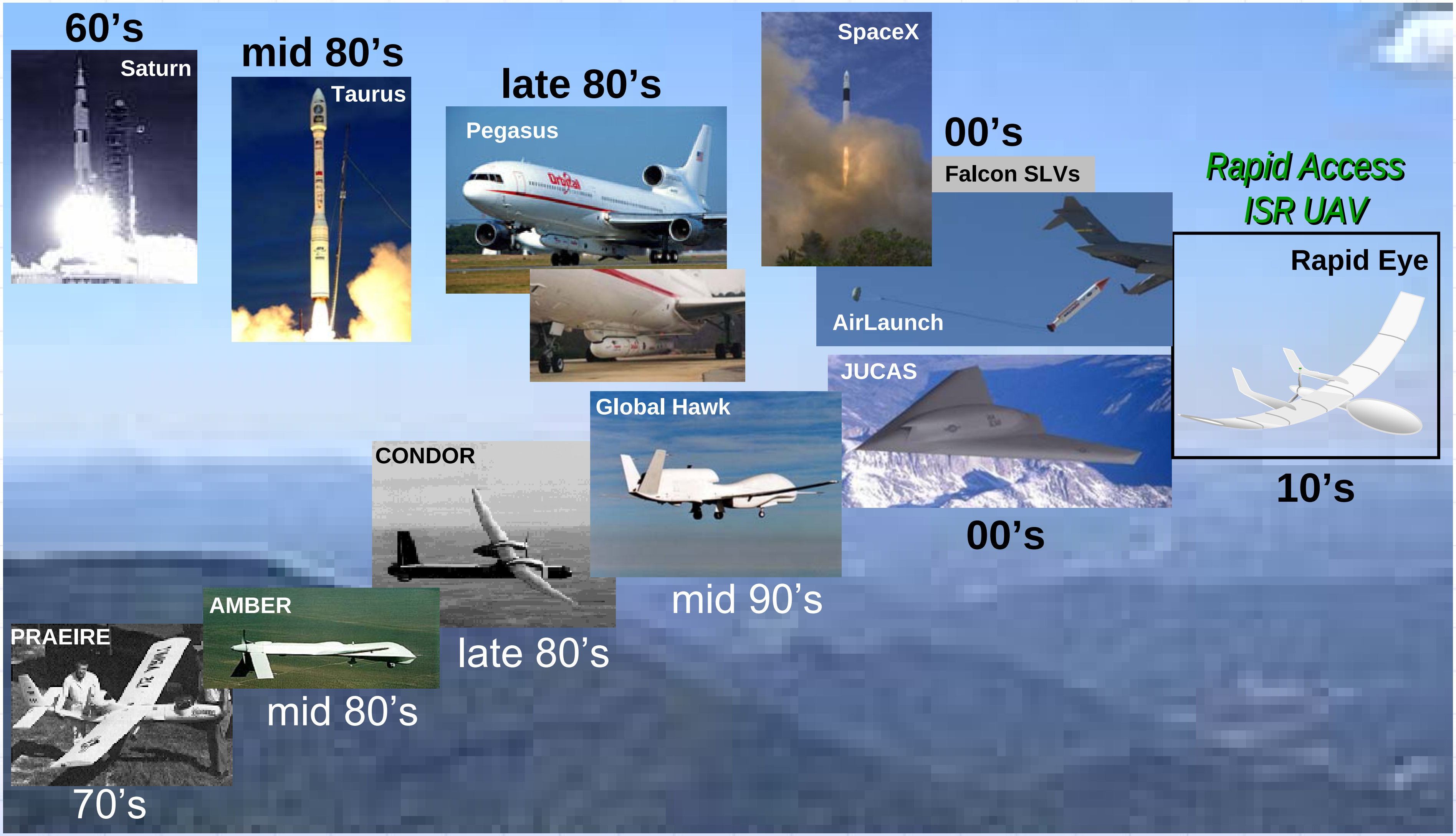
- Cognitive Systems
- High Productivity Computing Systems
- Language Translation

Microsystems Technology
John Zolper
Dean Collins

- Electronics
- Photonics
- MEMS
- Algorithms
- Integrated Microsystems


TTO Thrust Areas
Directed Energy Systems
Precision Strike
Unmanned Systems
Space Operations
Air/Space/Land/Sea Platforms
Approved for public release; Distribution is unlimited
Bridging The Gap
DARPA
1958
2008
50 Years
Powered by Ideas
TTO

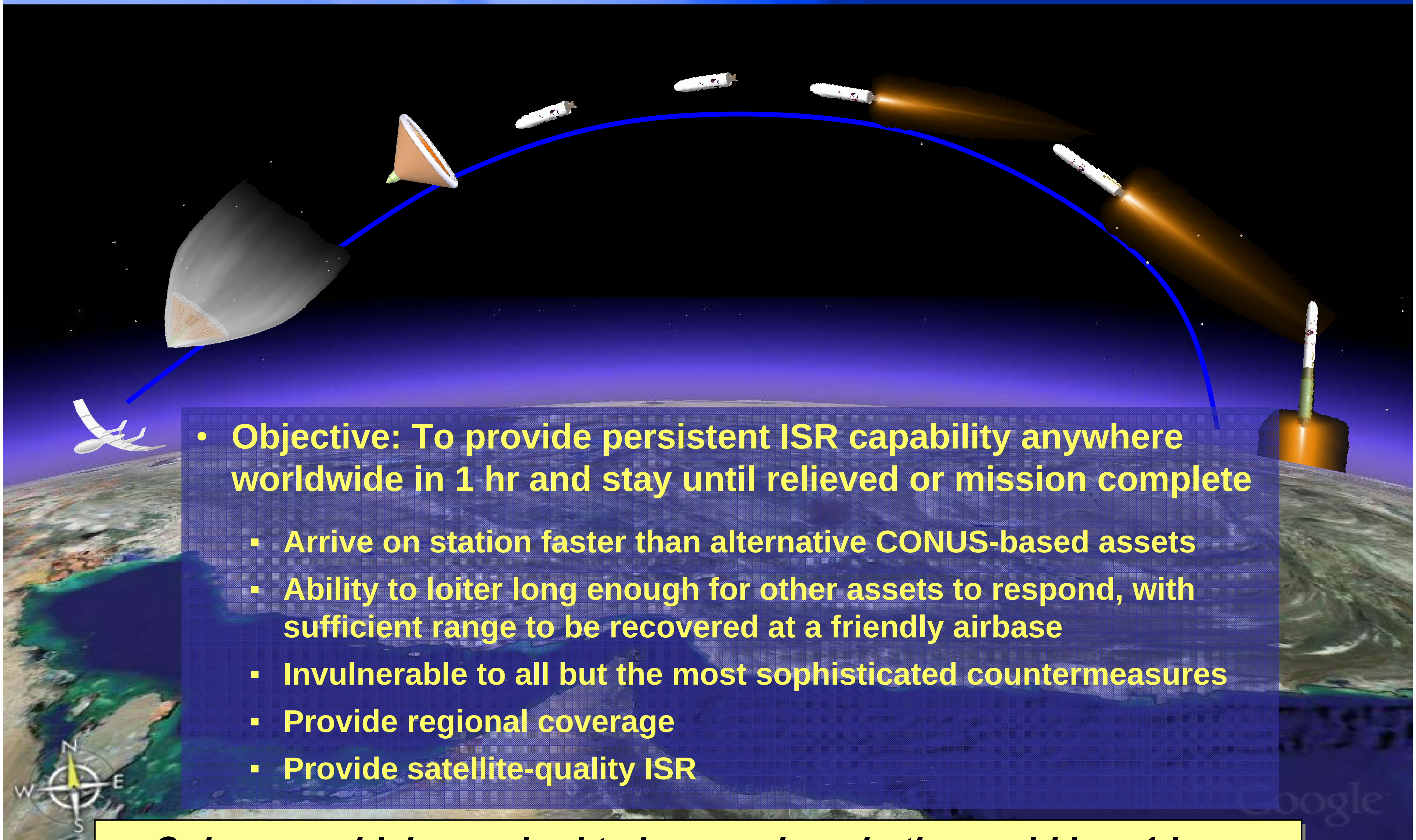
TTO Space and UAV Legacy



Rapid Eye: Concept

Get an ISR platform anywhere in the world in < 1 hour

Rapid Eye: Bridging the ISR Deployment Gap



- **Objective: To provide persistent ISR capability anywhere worldwide in 1 hr and stay until relieved or mission complete**
  - **Arrive on station faster than alternative CONUS-based assets**
  - **Ability to loiter long enough for other assets to respond, with sufficient range to be recovered at a friendly airbase**
  - **Invulnerable to all but the most sophisticated countermeasures**
  - **Provide regional coverage**
  - **Provide satellite-quality ISR**

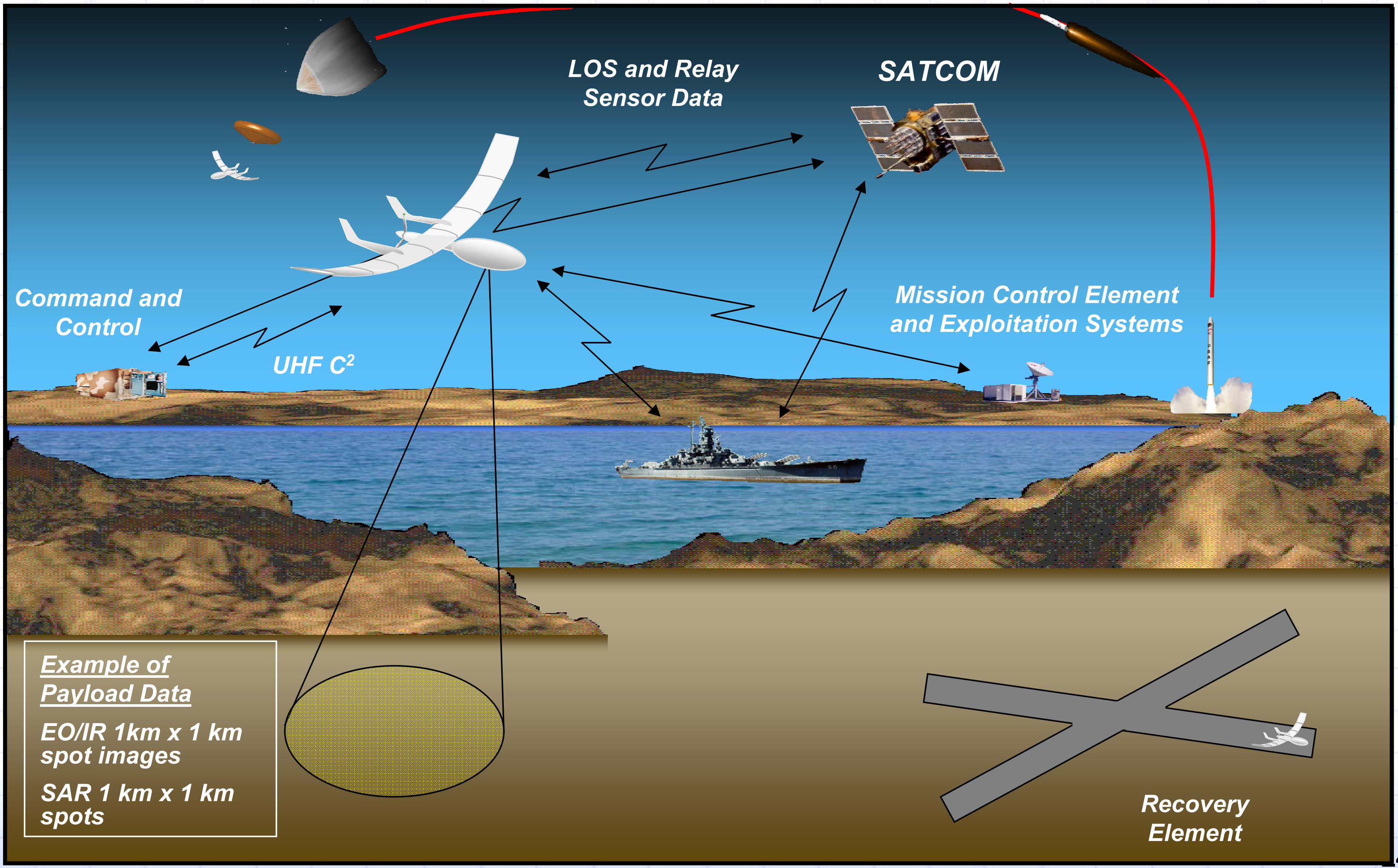
Only one vehicle required to be anywhere in the world in < 1 hour

Motivation

- **Need for world-wide, on-demand, rapidly-deployable, persistent ISR capability**
  - **Prompt Global Reach – support delivery of ISR capability worldwide**
  - **Global War on Terrorism – tracking high-value, time-sensitive targets**
  - **CBRNE Incidents – collection of intelligence of hazardous material**
- **Increasing need to establish an "unblinking eye" over the battle-space through persistent surveillance *(QDR Report, 2006)***

Persistent ISR/Sensing In 1 Hour - Anywhere In the World

Launch-On-Demand CONOPS



Example of Payload Data

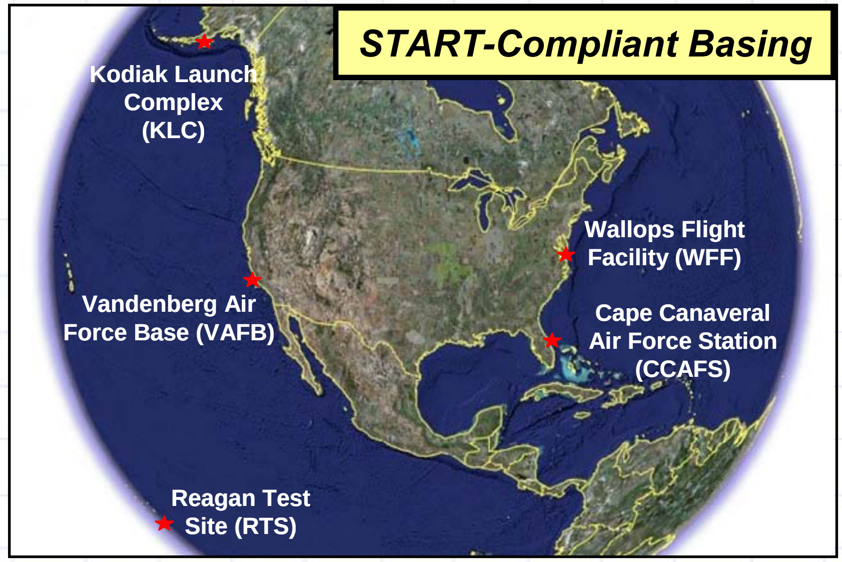
EO/IR 1km x 1 km spot images

SAR 1 km x 1 km spots

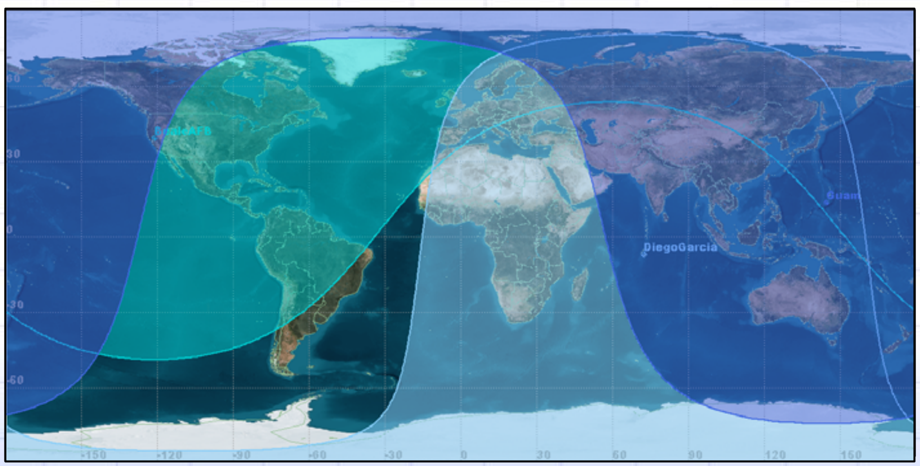
Rapid Eye Goals

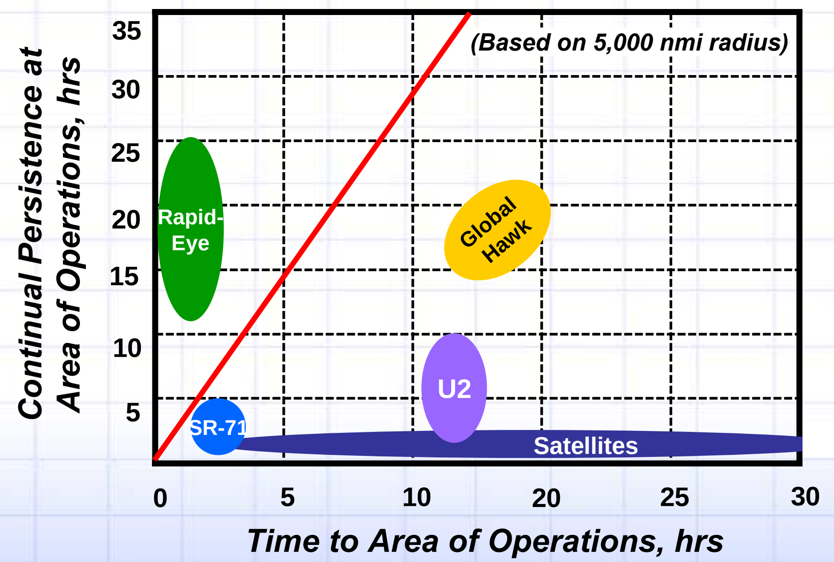
Program Goals

- ***Worldwide-delivery of ISR capability from alert pad < 2 orbits (~ 2 hours using an existing solid rocket)***
- ***Use only two START-compliant launch sites***
- ***Time on station > 7-15 hours***
- ***Loiter speed > 99% winds***
- ***Payload > 500 lbs, 5 kW***



Global Hawk Time to Station: 15 hours

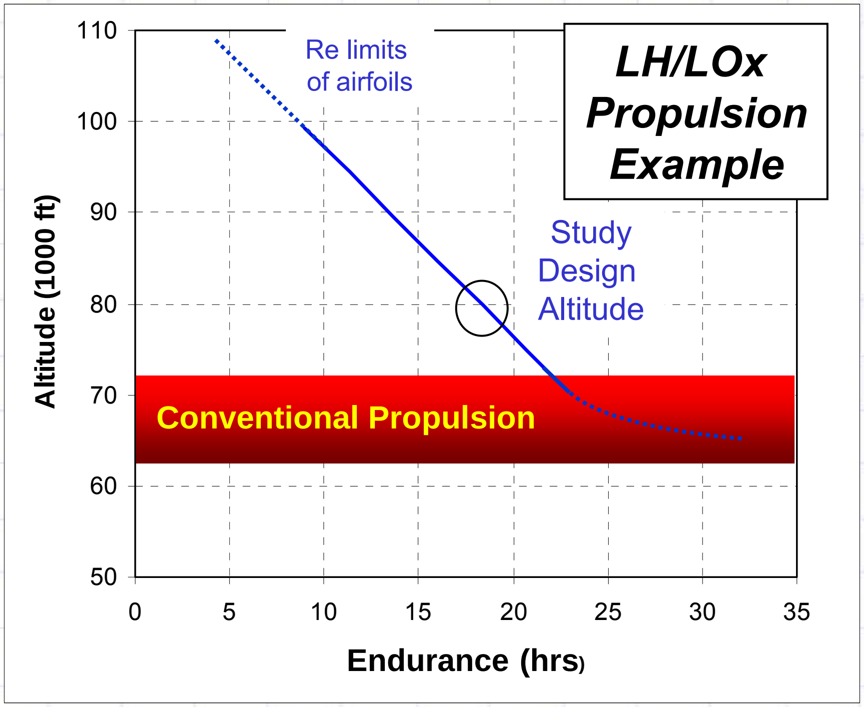




Study System Design Assumptions

Launch Vehicle and Basing

- Ground Launch System
  - Solid rocket to maximize responsiveness
- CONUS Basing (VAFB and CCAFS)
  - Matches current AF plans for conventional missiles
  - Coverage of all but S. America and north Central Asia
  - Aircraft mass is 1030 kg
  - Use of RTS increases aircraft mass to 1280 kg and allows complete coverage expect Northern Europe
- Safe Disposal of Launch Debris
  - 1st and 2nd stages must drop in ocean
  - Third stage and decelerator can be dropped at relatively safe velocity

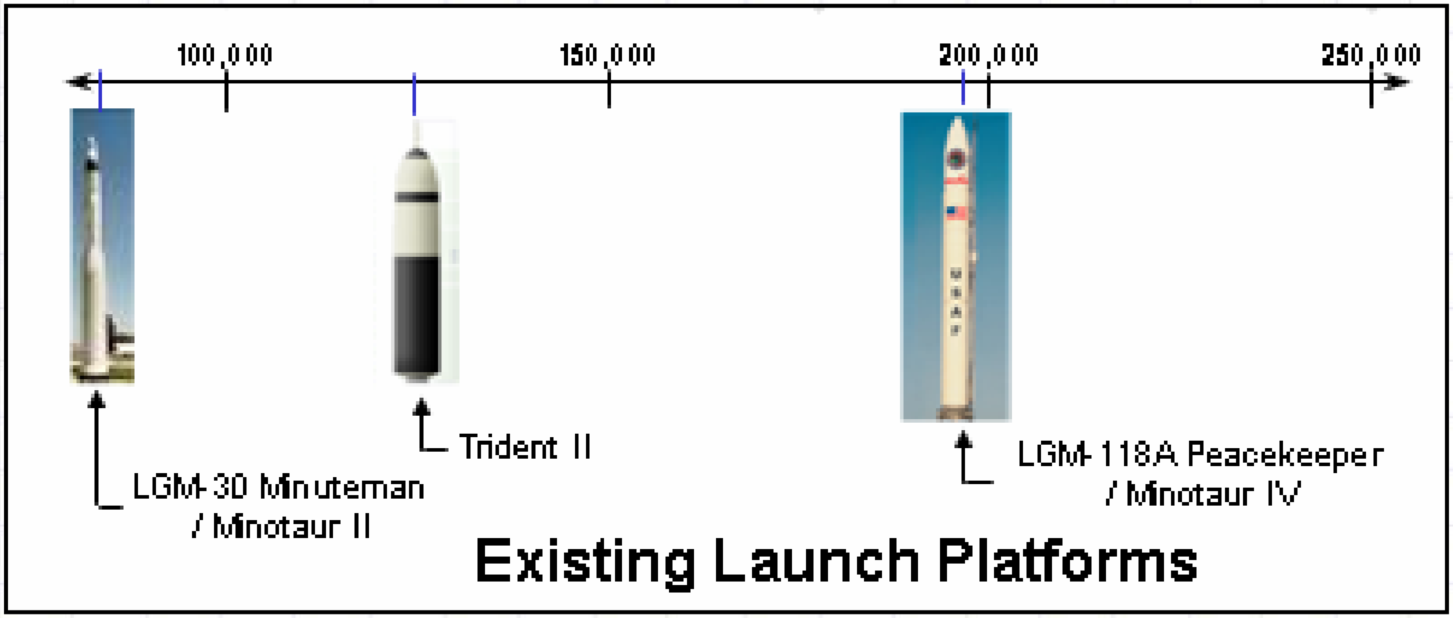


Aircraft Requirements

- Endure until relieved by Global Hawk
- Global Hawk basing at CONUS, Diego Garcia, and Guam
- Maintaining station design velocity driver
- High altitude for coverage and survivability
  - Requires working the hard problems

Existing Solid Launch Vehicles

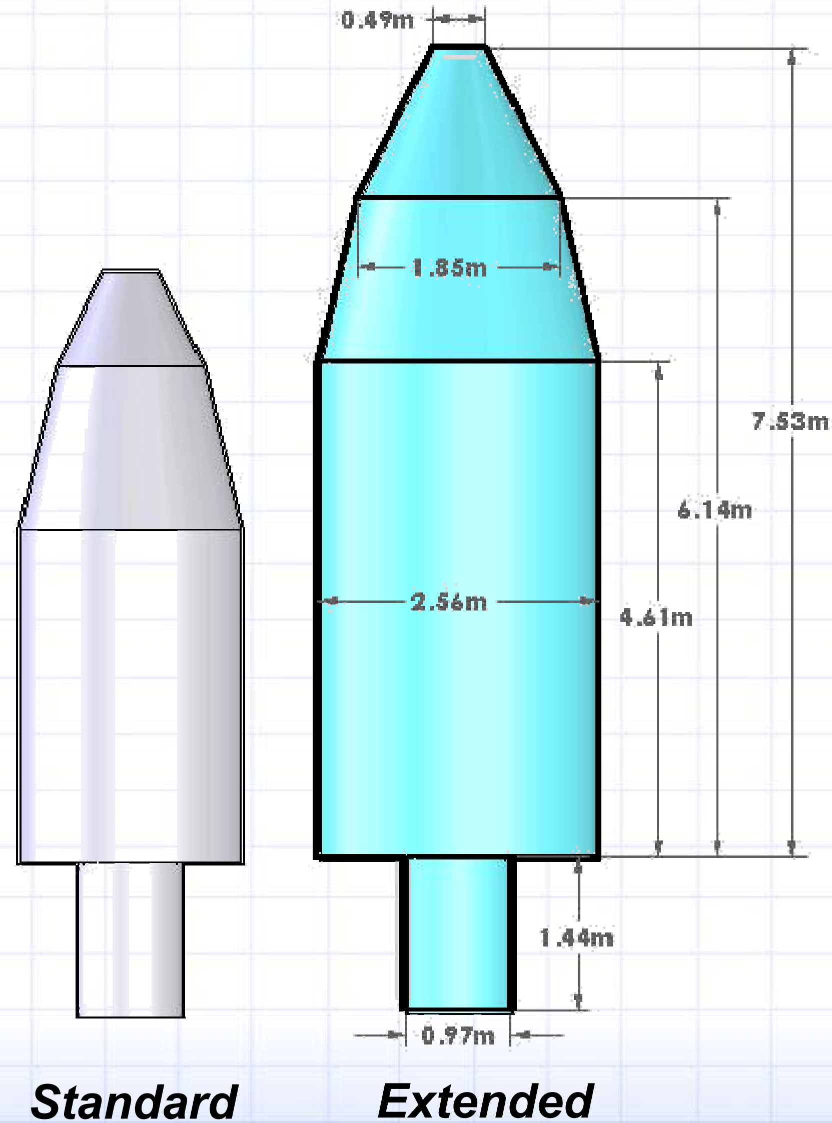
Launch Vehicle Gross Liftoff Weight (lbs)



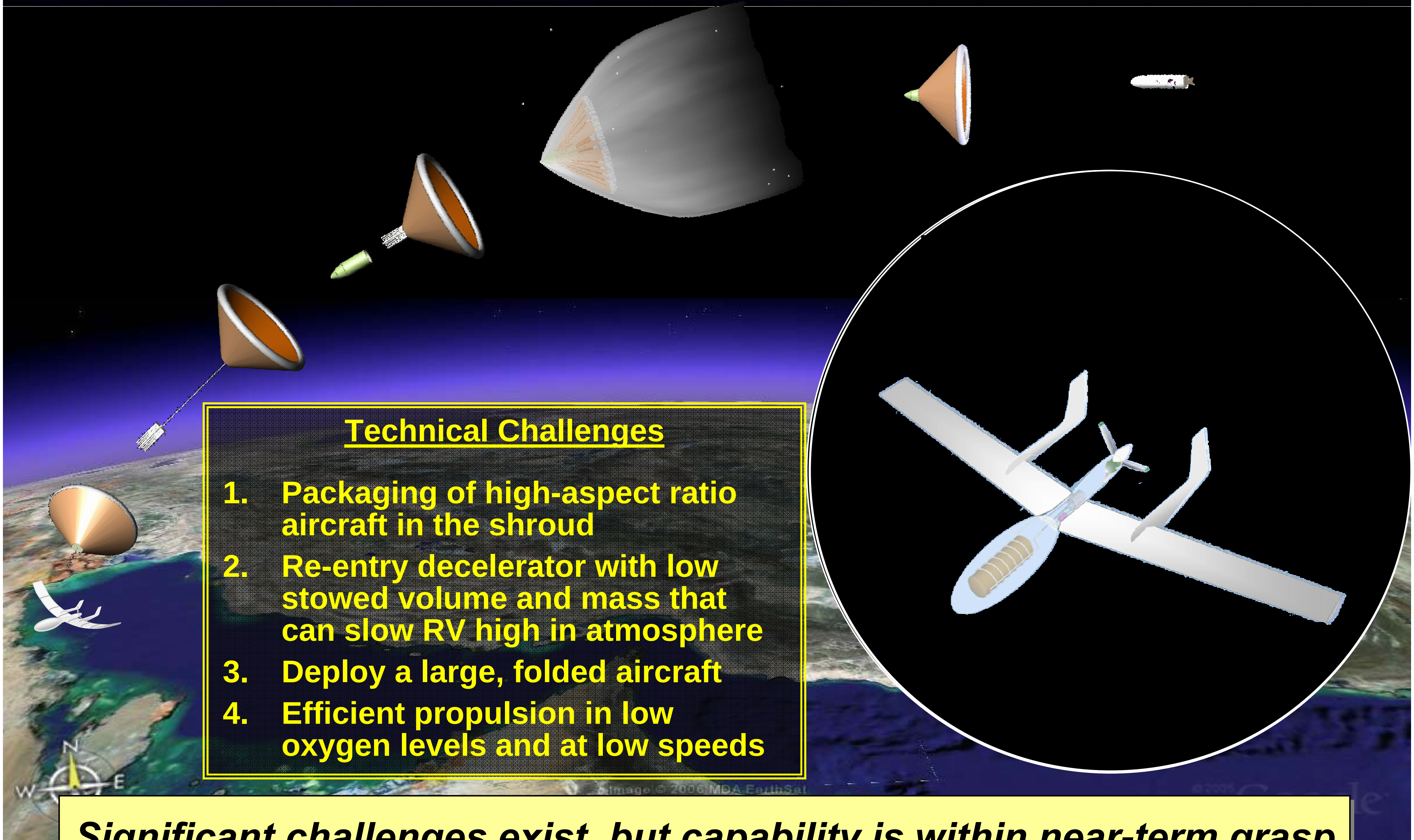
- **Solid rocket for launch-on-demand capability**
- **Existing rocket**
- **Problem is more volume constrained**

Minotaur IV Payload Envelope

- **Fairing Diameter**
  - **Standard: 2.05m**
  - **Extended: 2.56m**
- **Fairing Length**
  - **Standard: 5.49m**
  - **Extended: 7.53m**
- **Launch Mass**
  - **With 4th stage rocket motor: 2236 kg**
  - **Without 4th stage rocket motor: 3132 kg**
  - **Fourth stage motor not necessary for global reach – used by Minotaur only for orbital insertions**



Technical Challenges



Technical Challenges

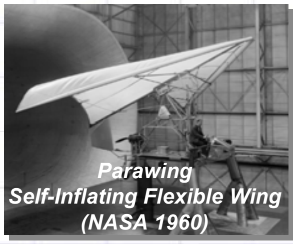
1. Packaging of high-aspect ratio aircraft in the shroud
2. Re-entry decelerator with low stowed volume and mass that can slow RV high in atmosphere
3. Deploy a large, folded aircraft
4. Efficient propulsion in low oxygen levels and at low speeds

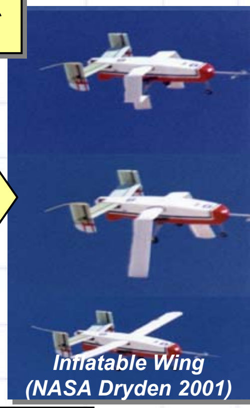
Significant challenges exist, but capability is within near-term grasp

Technology Evolution

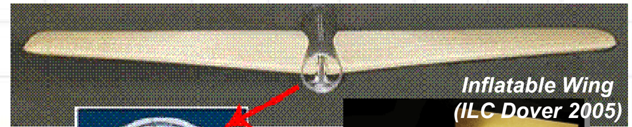
Recent Developments Increase Likelihood of Success

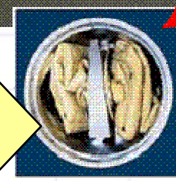
Deployable Wings

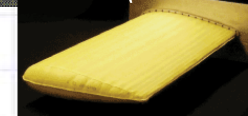

Parawing
Self-Inflating Flexible Wing
(NASA 1960)


Inflatable Wing
(NASA Dryden 2001)

Mars Flyer Demonstrator
(NASA LaRC 2002)



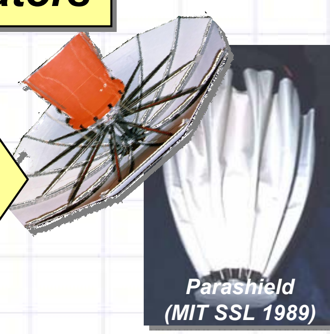



Inflatable Wing
(ILC Dover 2005)

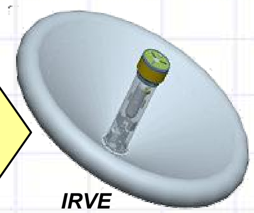

Big Blue III
at 96,000 ft
(UK, 2005)

Reentry Decelerators

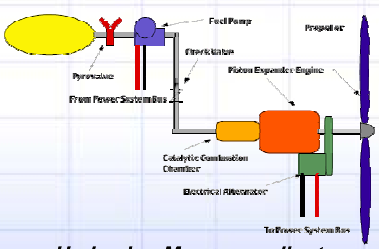

Apollo 7
(NASA 1968)


Parashield
(MIT SSL 1989)

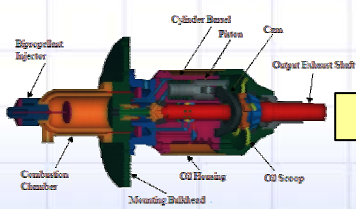

IRDT
(ESA, 2005)


IRVE
(NASA, 2007)

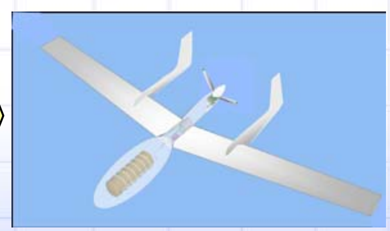
High Altitude Propulsion



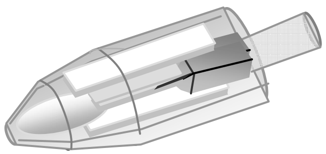
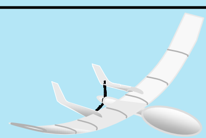
Hydrazine Monopropellant
(Mini-Sniffer, NASA 1977)



Bipropellant Piston Expander
(ERAST, NASA 1995)


LiH Propulsion

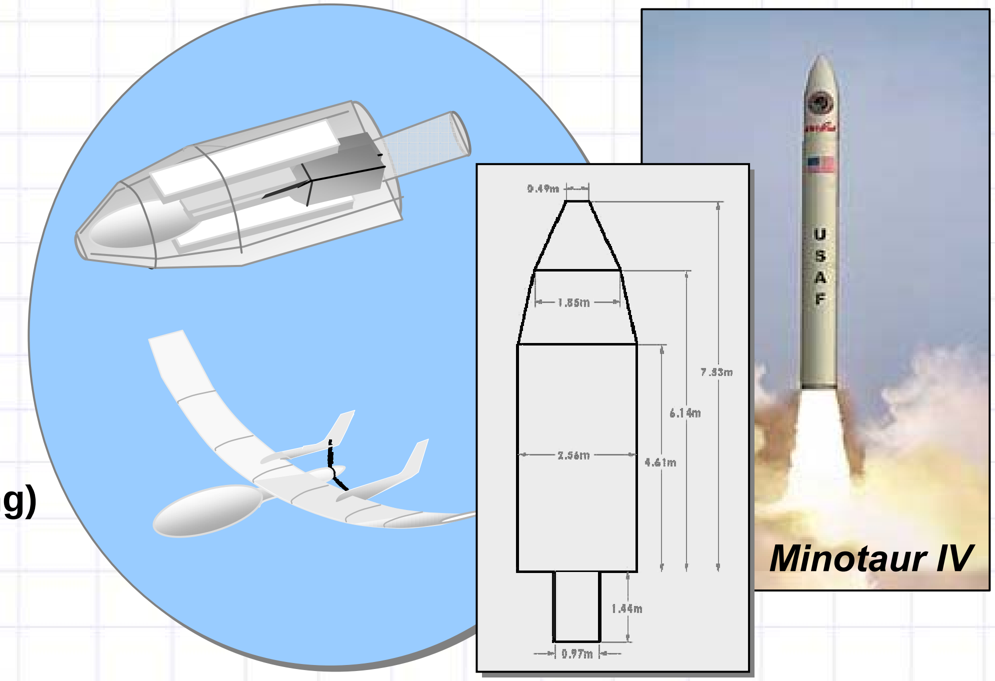
Launch Vehicle Weight Breakdown from DARPA System Study

	Minotaur IV Throw Weight (With Fairing)	
	2050 kg (Using VAFB & CCAFS)	2550 kg (Using RTS & CCAFS)
Shroud (Extended)	306 kg	306 kg
Package Connection Hardware	250 kg	250 kg
RV Subtotal	1500 kg	2000 kg
Decelerator (~20% of RV) 	285 kg (15% margin)	400 kg (20% margin)
Air Vehicle 	1030 kg (15% margin)	1280 kg (20% margin)

Vehicle Packaging and Deployment
Technical Challenge No. 1 and 3

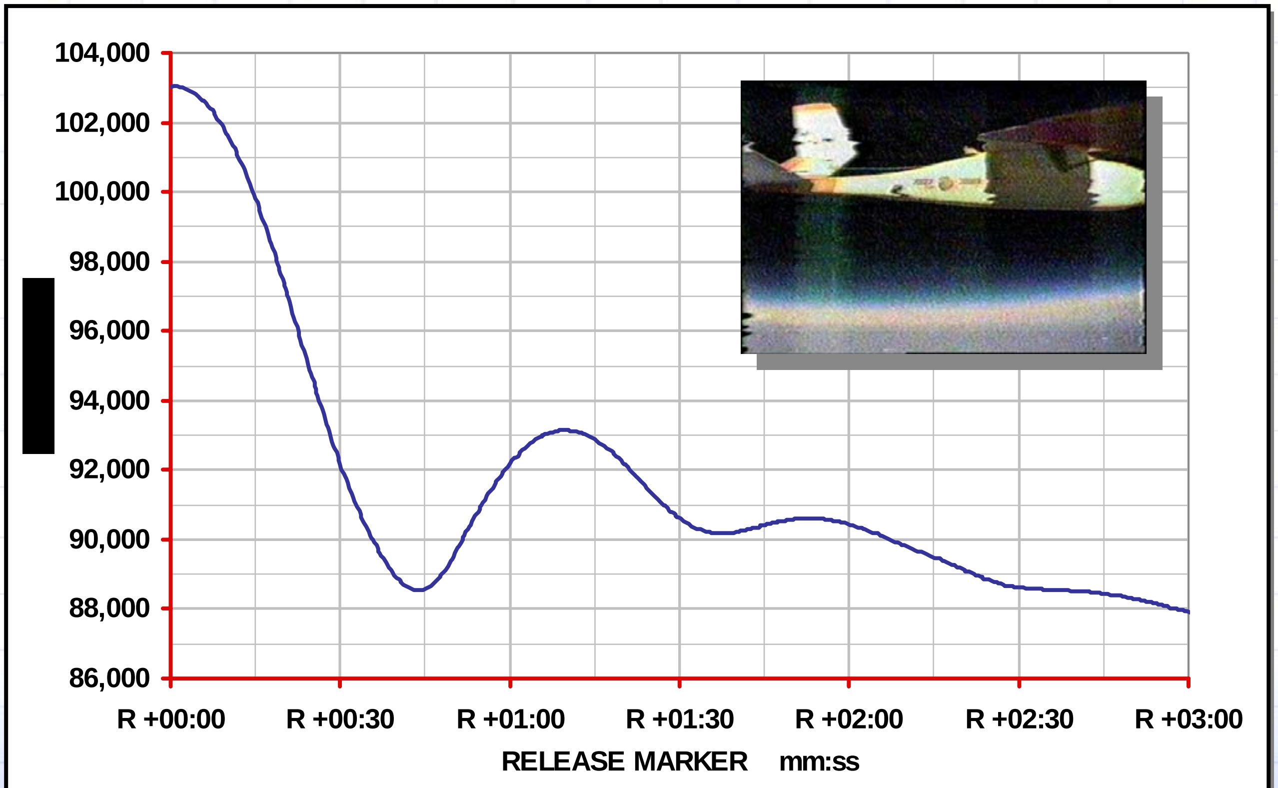
Design Drivers for DARPA Study

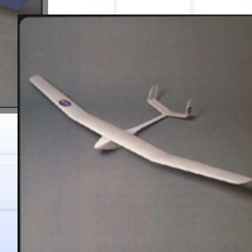
- **Limited volume**
  - **Extended fairing of Minotaur IV rocket**
  - **37.35 m³ payload volume**
- **Limited mass**
  - **Throw weight (with fairing) – 2050 kg**
    (for world coverage from CONUS,
    Could increase using OCONUS basing)
  - **Air vehicle – 1030 kg (maximum)**
- **Operational loads**
  - **Deployment (45–55 g deceleration)**
  - **Flight (+2/-0 g)**
- **Minimum cruise speed**
  - **Account for 99% winds at 80 kft altitude - > 80 knots**
- **Long endurance**
  - **Enough time on station for a conventional asset to arrive**
  - **15 hours minimum**



NASA Ames
Mars Airplane Prototype

- **Demonstrated feasible and predictable recovery from being dropped with a high aspect ratio wing at 100,000 ft.**
- **Balloon-launched from 103 kft**
- **Concept also explored the ability to fold body and wings for spacecraft deployment**

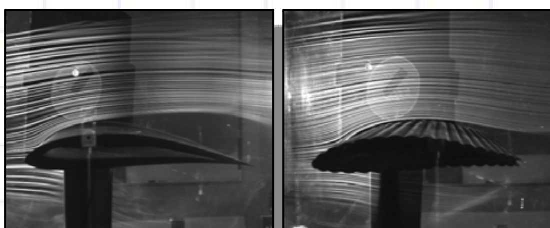


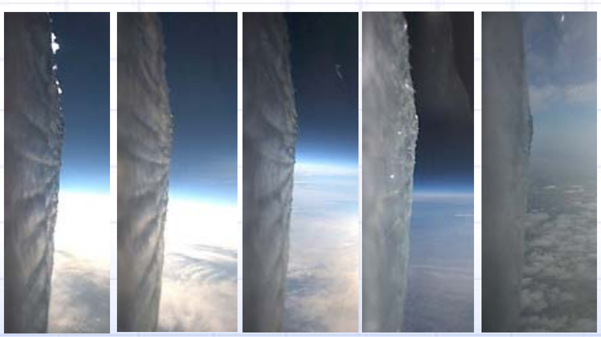


UK/OSU

BIG BLUE Mars Airplane and Inflatable-Wing

- BIG BLUE (Baseline Inflatable-Wing Glider Balloon-Launched Unmanned Experiment) is a NASA Workforce Development project
- BIG BLUE objective is to verify and demonstrate feasibility of inflatable wings for use in the Martian environment
  - First to demonstrate inflatable/rigidizable wing technology with high-altitude deployment and cure
  - Multiple high-altitude tests conducted since 2003



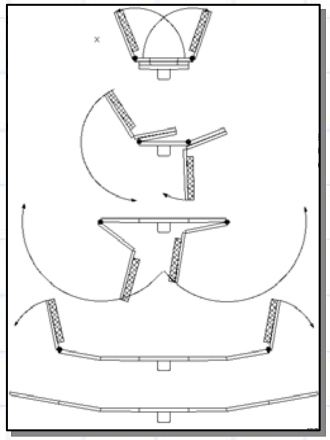


58,000 ft 63,000 ft 86,000 ft 89,000 ft 17,000 ft

Vehicle Packaging and Deployment
Technical Challenge No. 1 and 3

Carbon Composite

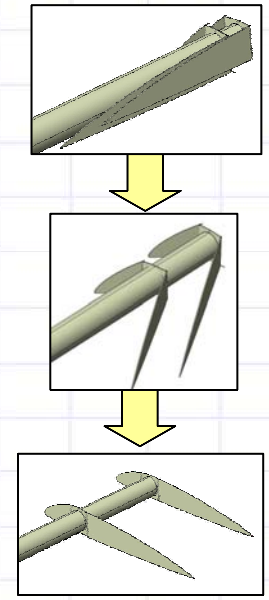
- Conventional, predictable aerodynamics
- Rigid, smooth structure
- Limited wing area possible
- Complex deployment
- Lower endurance



Aero Risk
Structure Risk
Deployment Risk

Telescoping Spar

- Mylar skins with rigid ribs allows for dense packing
- Reasonable aerodynamics with high performance structure
- Large number of hinges and joints
- Concept never demonstrated in aerodynamic application



Aero Risk
Structure Risk
Deployment Risk

Inflatable Spar

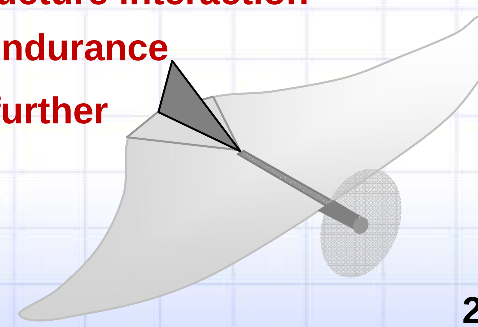
- High packaging flexibility
- No limit on ribs for accurate airfoil shape control
- Simple, reliable deployment
- Needs thick spar and airfoil
- Collapsible ribs not proven

Aero Risk
Structure Risk
Deployment Risk

low
moderate
high

Membrane Structure

- High packaging flexibility
- Good aerodynamic characteristics
- Strong aero and structure interaction
- Lower L/D – lower endurance
- Technology needs further development



Aero Risk
Structure Risk
Deployment Risk

Vehicle Packaging and Deployment
Structural Design Study

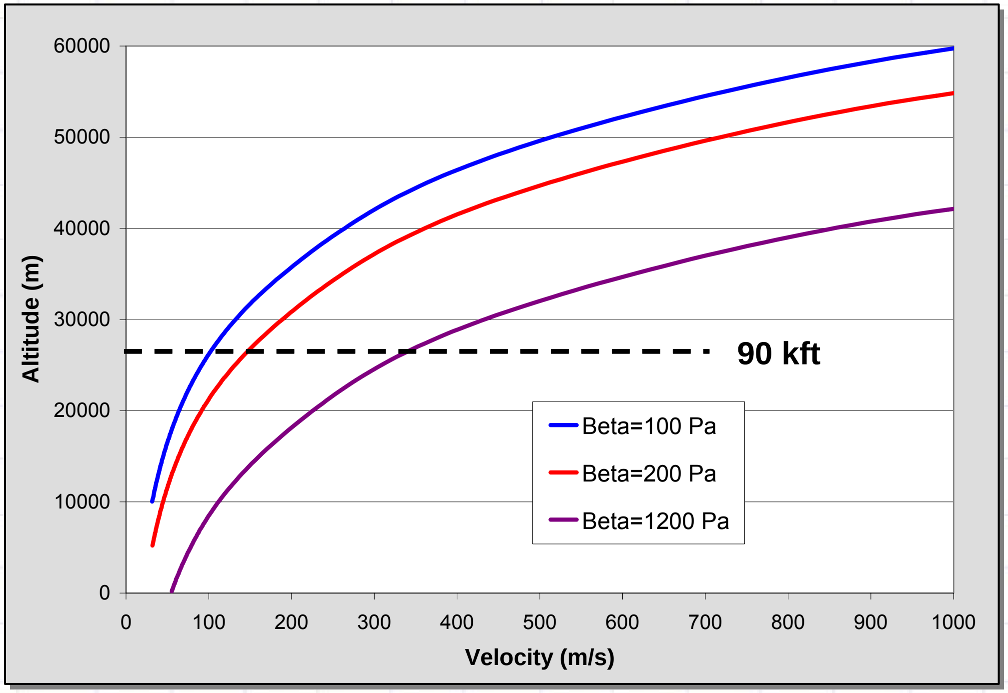
	Span (m)	Structural Mass (%)	L/D	Cruise Speed (KTAS)	Endurance (hr) Hydrazine	Aero Risk	Structure Risk	Deployment Risk
Carbon Composite	28	24	29	150	7.6	low	moderate	moderate
Telescoping Spar	60	26	28	82	11.4	moderate	moderate	high
Inflatable Spar	55	30	25	78	9.7	moderate	moderate	moderate
Membrane	55	34	23	82	7.7	high	moderate	high

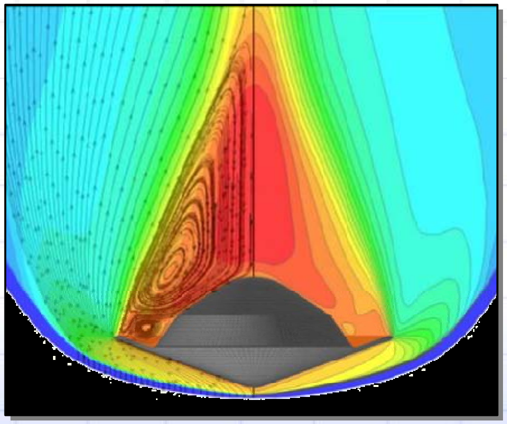
- **Study assumptions:**
  - **Packed volume < 32.35 m^3**
  - **Vehicle gross weight = 1030 kg**
  - **Hydrazine: SFC = 2.65 gm/hr-W**
  - **Operational altitude = 80 kft**
- **Technical risk defined as the difficulty of both predicting performance and achieving that performance in operational use**

Reentry Decelerator
Technical Challenge No. 2

Design Drivers for DARPA Study

- **Low ballistic coefficient, β**
  - **Decelerating from M = 25+ to 100 m/s high in the atmosphere**
  - **Apollo: β ~ 4800 Pa**
    Gemini: β ~ 3000 Pa
  - **Goal: β < 300 Pa**
- **Low stowed volume and mass**
  - **Volume < 37.35 m^3 (Minotaur IV example)**
    (air vehicle + decelerator)
  - **~20% of RV payload**
- **Possible energy capture**
- **Very low ground impact speed (< 1 m/s)**





Reentry Decelerator
Configuration Options

Rigid Decelerator

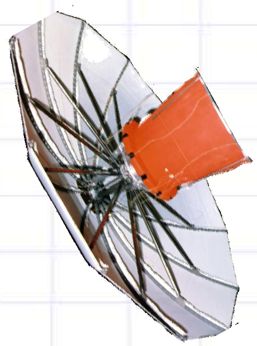
- High maturity
- Low volume
- Limited packaging options
- High weight fraction
- Low altitude for subsonic deployment (high β)

Rigid Aeroshell

Low Risk

Deployable Decelerator

- Lower β
- Reduced heating conditions
- Packaging advantages limited by structural frame
- Medium weight fraction
- Low maturity
- Payload not enclosed

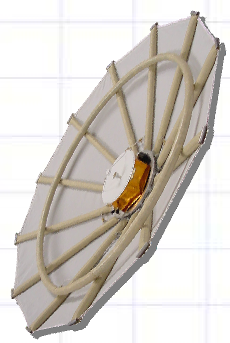


Parashield

Moderate Risk

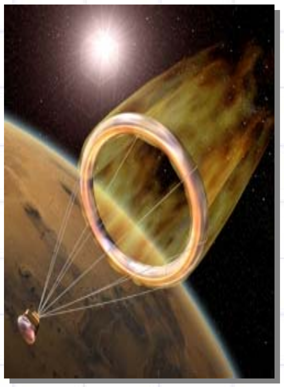
Inflatable Decelerators

- Packaging efficiencies
- Reduced heating conditions
- Applicable to payloads of all sizes and shapes
- Low maturity
- Payload not enclosed



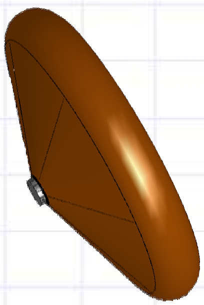
Inflatable Aeroshell

Moderate Risk



Trailing Ballute

High Risk



Clamped Ballute

High Risk

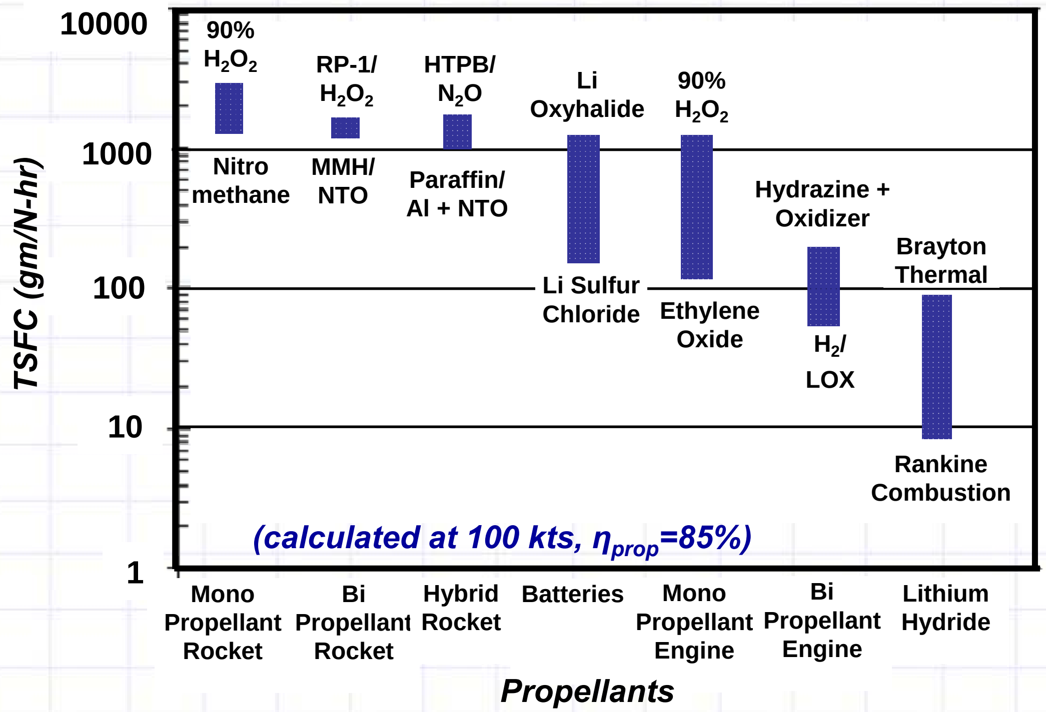
Reentry Decelerator
Technical Challenge No. 2

Advanced Decelerator Concept	% Weight Total Payload (prior art)	Beta (Pa)	Deployment Altitude (kft)	Transition to Flight	Safe Disposal	Development Risk
Rigid Aeroshell	40	650	33	Paraglide or small rocket	Moderate	Low TRL 9
Parashield	20	300	39	Paraglide or small rocket	Moderate	Moderate Studied in detail
Inflatable Aeroshell	15	75	90	Paraglide or small rocket	Simple	Moderate Currently in development
Trailing Ballute	9	10	+100	Direct Transition	Simple	High Currently only paper studies
Clamped Ballute	9	10	+100	Direct Transition	Simple	High Currently only paper studies

High Altitude Propulsion
Technical Challenge No. 4

Design Drivers for DARPA Study

- **Efficient propulsion**
  - **15 hour endurance**
- **Storable for months**
- **Operation at low oxygen levels**
  - **3.6% of atmosphere at 80 kft**
- **High specific energy**

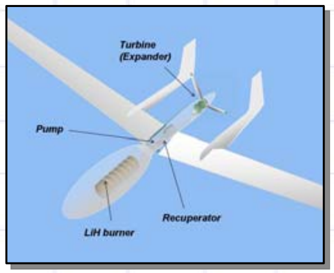


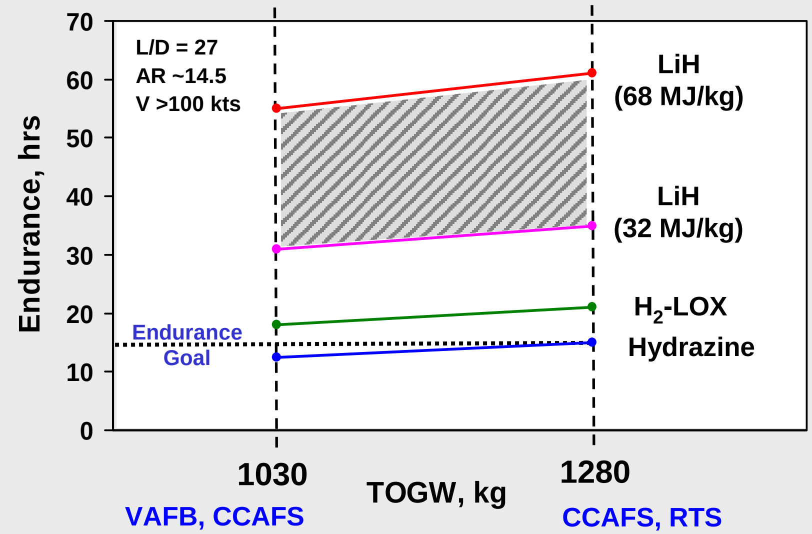
Propellants	*Effective Energy (MJ/kg)*	*Development Risk*
Li Sulfur Chloride Battery	1.6	moderate
Hydrazine	1.4	low
Hydrazine & Ni Tetroxide	2.0	low
Hydrogen & LOX	13.3	low
LiH (Brayton Combustion)	~30-65	high

High Altitude Propulsion
Technical Challenge No. 4

High Risk Solution: LiH Propulsion

- Reentry heat and LiH combustion powers a thermal engine
- TSFC = 93 gm/N-hr at 100 kts
- Solid - Indefinite storage at any temperature
- Gains mass with time
- Never demonstrated





Low Risk : Hydrazine Propulsion

- Proven design for high altitude aircraft (*NASA Mini-Sniffer, 1975*)
- Higher TSFC; 160 gm/N-hr at 100 kts
- High freezing point (1.5°C)
- Poor engine efficiency

NASA Dryden Mini-Sniffer

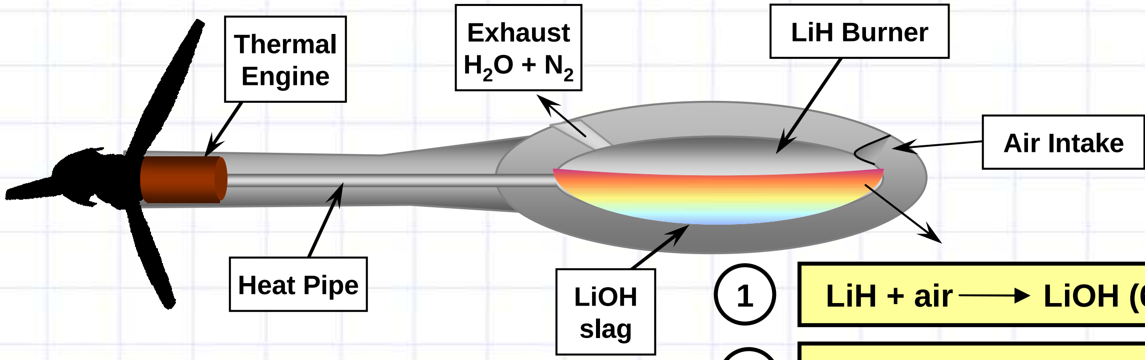
Medium Risk Solution: Hydrogen/LOX Propulsion

- Proven fuel and engine concept
- High energy content
- Difficult storage on the launch pad
- Tank weight

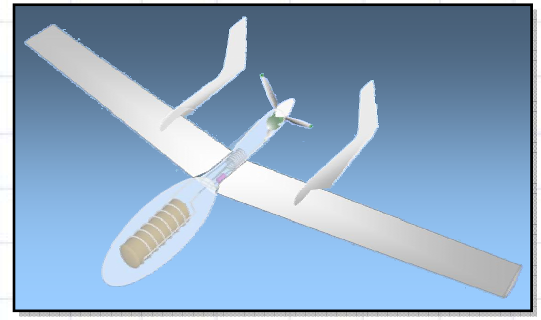
High efficiency Quantum tank

Proven high altitude LH2 ICE (AeroVironment)

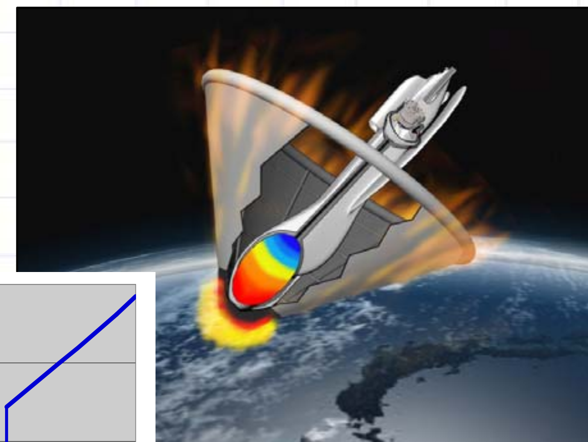
LiH Propulsion

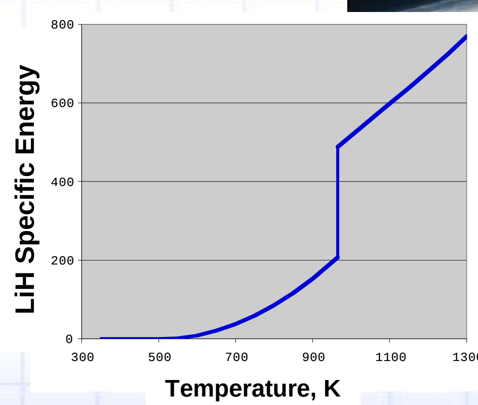


1. LiH + air ⟶ LiOH (68 MJ/kg)
2. LiH + air ⟶ $H_2O + Li_3N$ (32 MJ/kg)



- Reentry heat and LiH combustion powers a thermal engine
- Simple burner design – melted LiH is hypergolic
- Combustion provides between 32 and 68 MJ/kg – similar to gasoline
- Potential for reentry energy capture
  - 400 MJ is achievable from initial study
  - Heat transfer via Heat Pipe provides heat for melting stored LiH
- Requires further development
  - Kinematics chemistry experiments
  - Burner design and test
  - Optimum design of re-entry system nose

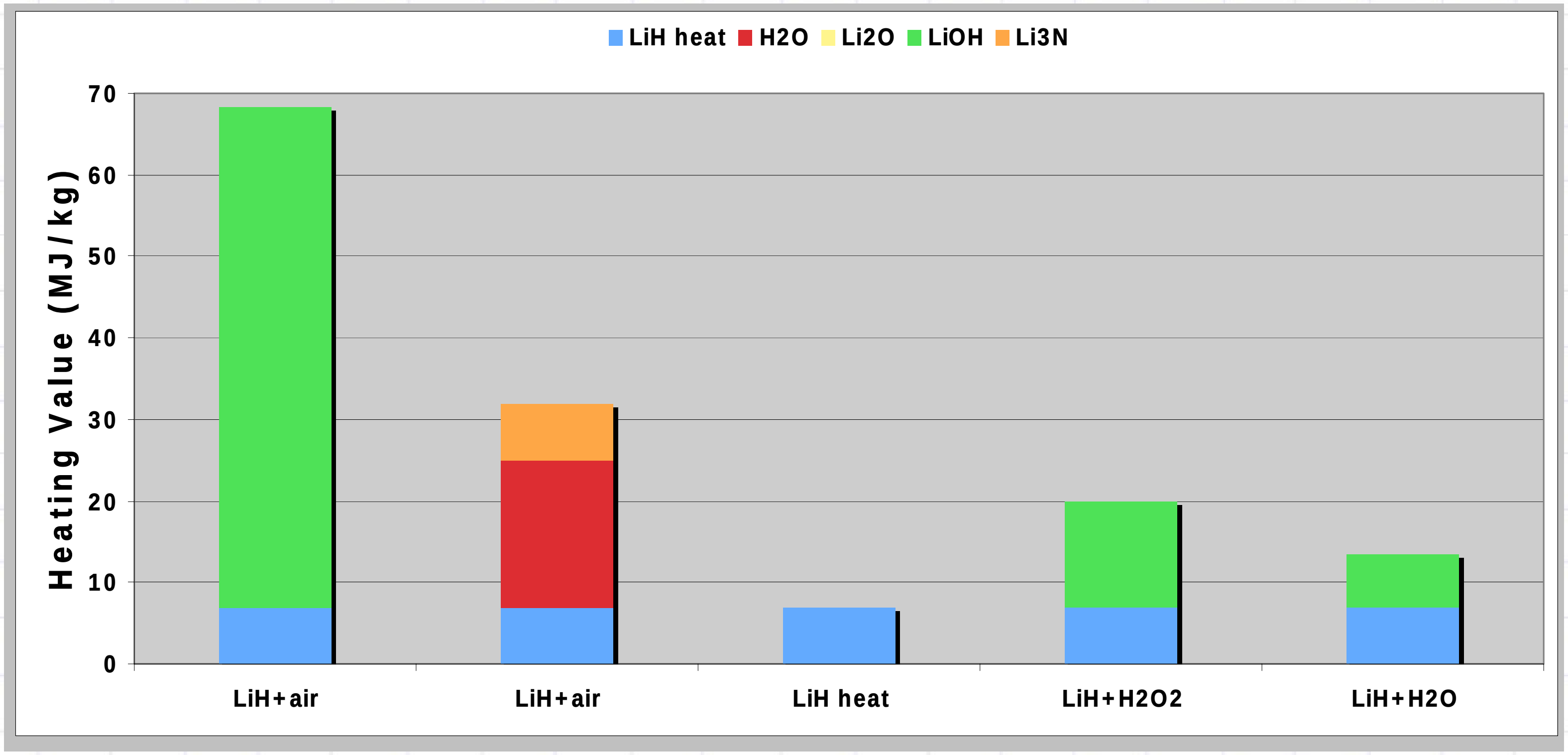




33 GJ available – only 1-2 GJ required

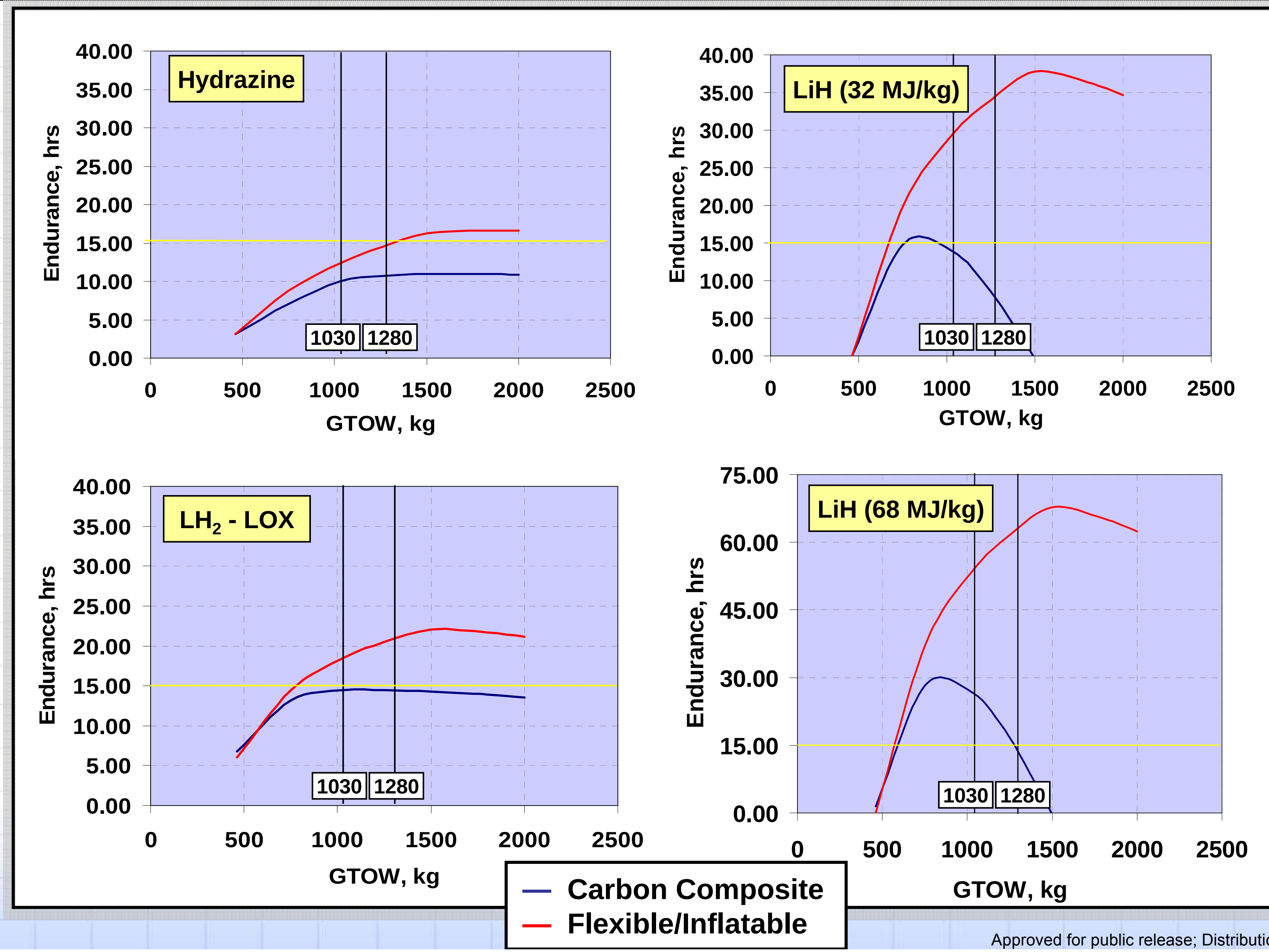
Approved for public release; Distribution is unlimited

High Altitude Propulsion
LiH Burning Paths



- The combination of liquid LiH and air provides the highest heating values
  - Best case – LiH + air $\longrightarrow$ LiOH
  - Worst case – LiH + air $\longrightarrow$ $H_2O + Li_3N$
- Heating LiH during reentry provides 7 MJ/kg
- Alternative is to carry an oxidizer onboard – hydrogen peroxide or water
  - Propulsion independent of air
  - Heating values not as high

Propulsion Performance

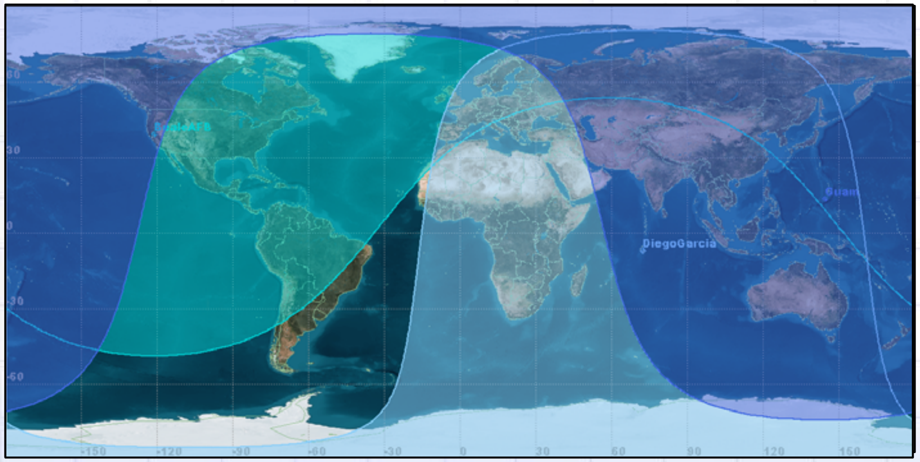


Rapid Eye BAA Requirements

Tentative BAA Requirements

- *Worldwide-delivery of ISR capability from alert pad < 2 orbits (~ 2 hours using an existing solid rocket)*
- *Use only two START-compliant launch sites*
- *Time on station > 7+ hours*
- *Loiter speed > 99% winds*
- *Payload > 500 lbs, 5 kW*

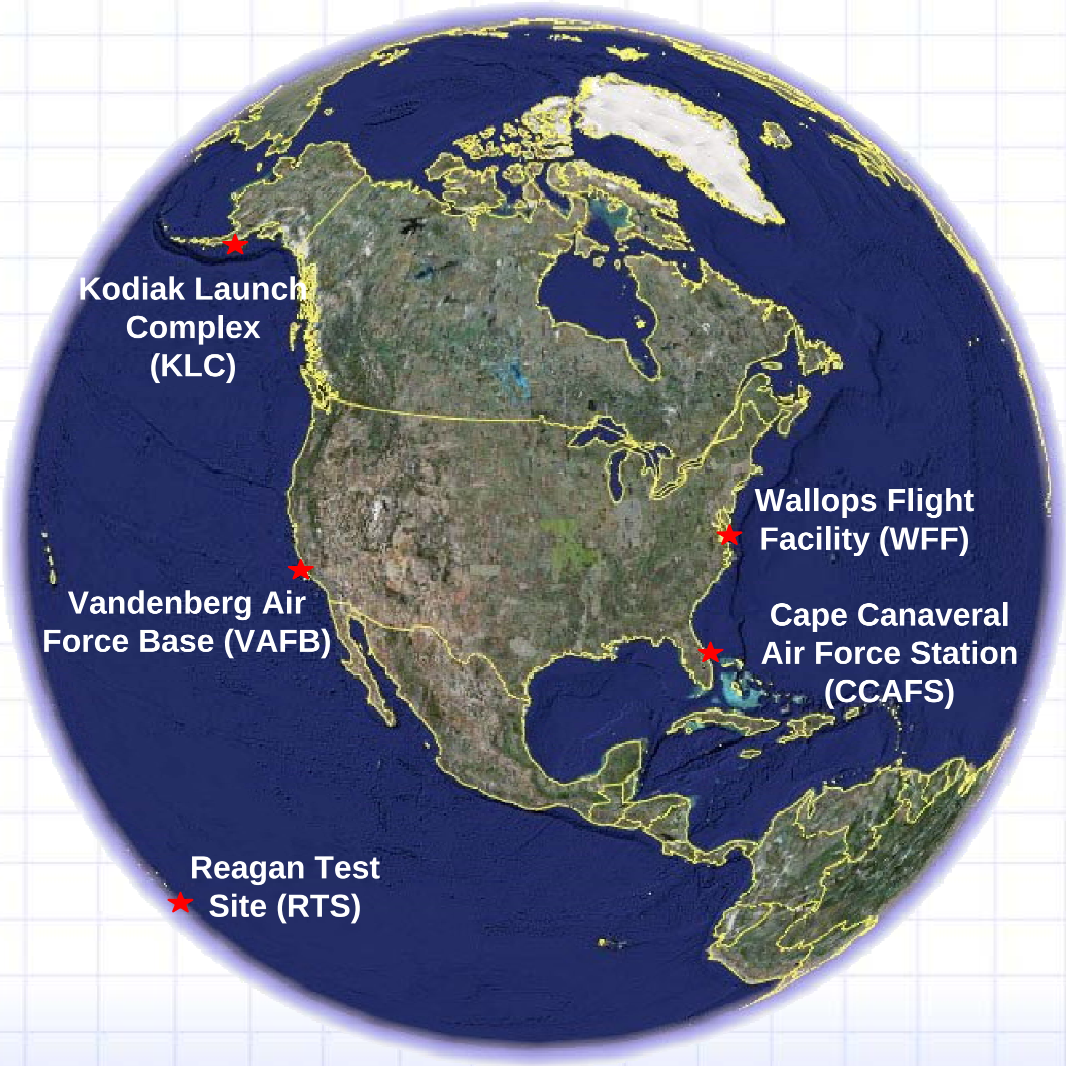
Global Hawk Time to Station: 15 hours



Additional Possible Objectives

- *Altitude equated with survivability*
- *Substantial recovery distance*
- *Safe disposal of third stage*

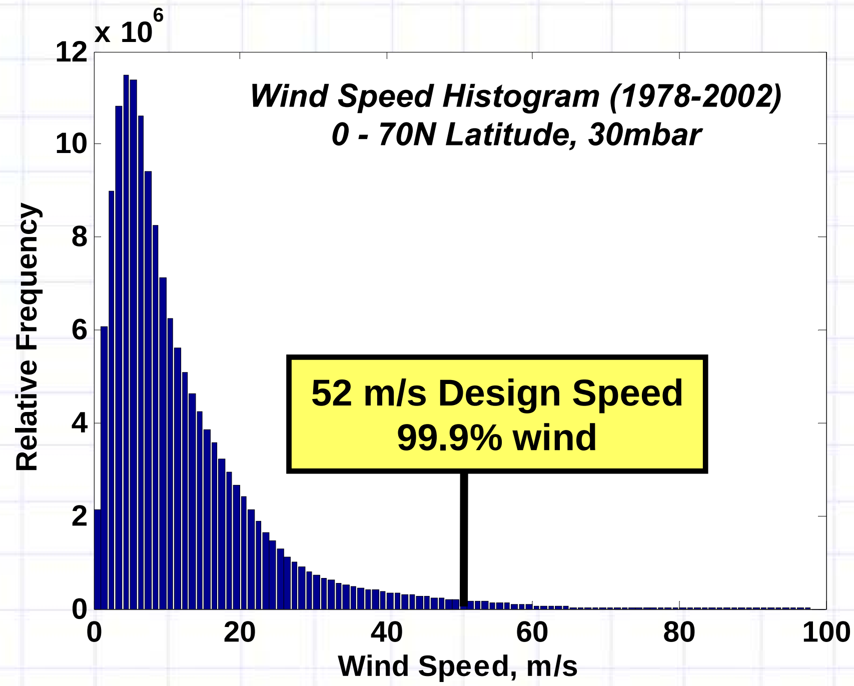
START - Compliant Launch Sites

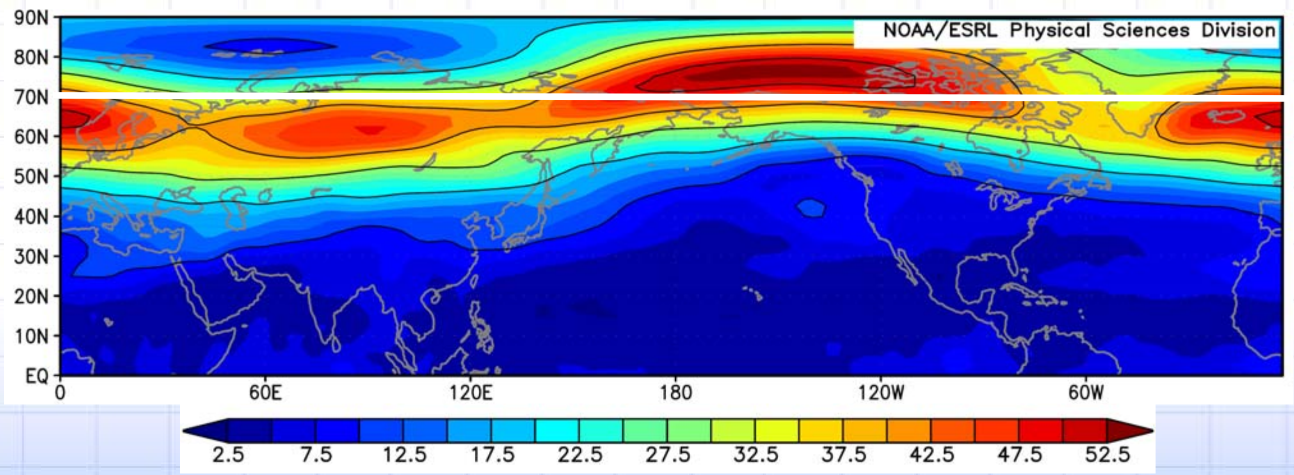


Winds at 80 kft
(1978-2002)

- **Air vehicle design speed equivalent to 99-percentile winds at 50N latitude**

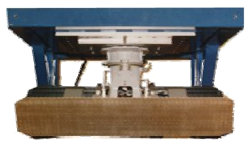
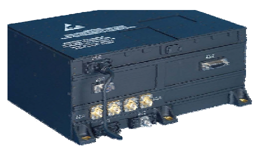
Latitude	0 N	10N	20N	30N	40N	50N	60N	70N
Wind Speed (m/s)	30	32	26	24	35	52	59	62





January 2007
Mean Wind Speed (m/s)
30mbar

Possible Rapid Eye Payload Complement

Payload		Weight* (lbs)	Power* (W)
Hi-Res Dual-Band EO/IR		150	1200
Dual Mode GMTI SAR		300	3600
High BW Comms (900 Mbps)		50	225
Total (est.)		**~500 lbs**	**~5000 W**

***Estimated – Weight / Power reduced versions**

Technology Discussions

- **Overview of the ARES Mars Airplane**
  Henry Wright, NASA LaRC

- **Deployable Reentry Decelerators**
  Charles Player, NASA LaRC

- **Deployable Aircraft Structures**
  Richard Foch, Naval Research Laboratory

- **Inflatable Wing Deployment & Testing**
  Suzanne Smith, University of Kentucky

- **Low-Oxygen Propulsion Options**
  Christopher Kuhl, NASA LaRC

ARES-2011

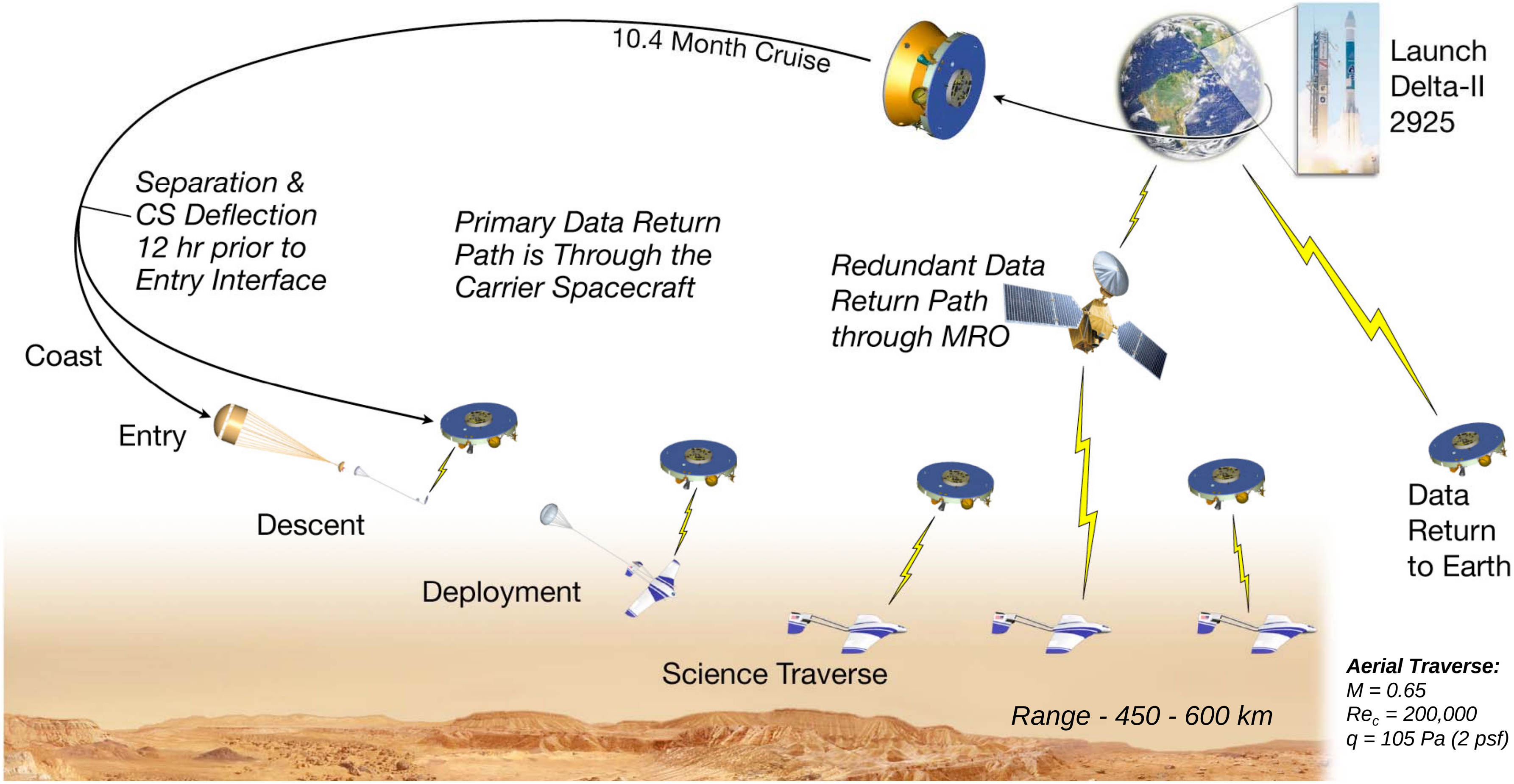
From Earth to Mars - An Overview of the ARES Mars Airplane

Henry Wright
NASA Langley Research Center
Henry.s.wright@nasa.gov
757-864-6928

25 July 2007

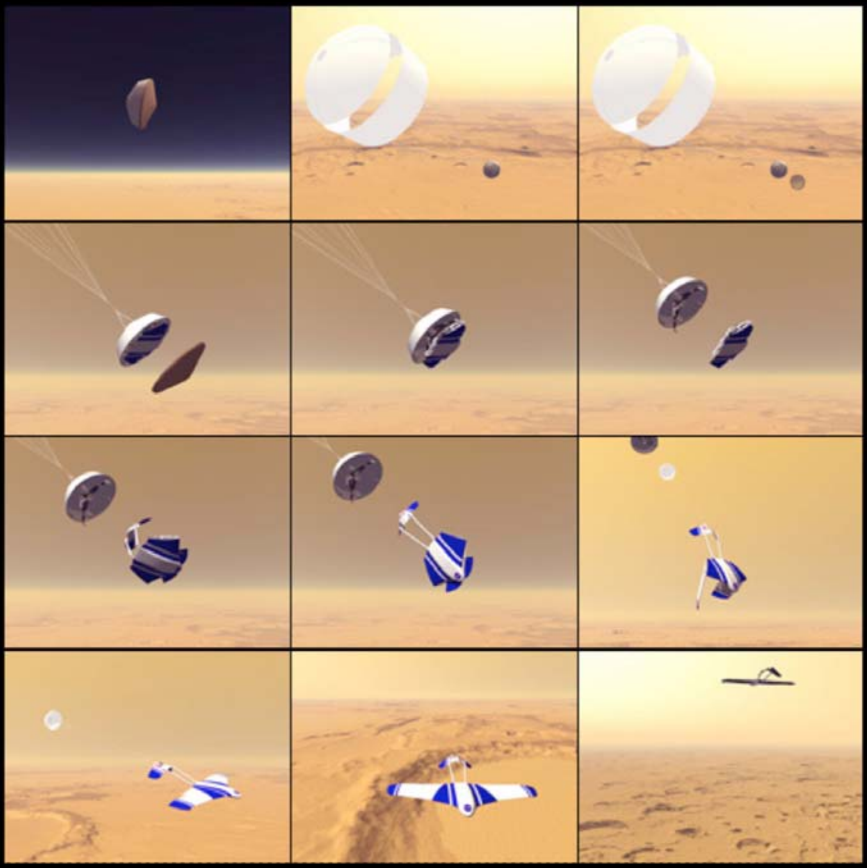
WHAT IS ARES?

- ***ARES*** - Aerial Regional-scale Environmental Survey of Mars
- ARES - a science-focused Mars mission to perform a survey of remnant crustal magnetic regions and sub-surface water, while characterizing the surface and atmosphere chemical interactions and dynamics



Aerial Traverse:
M = 0.65
Re_c = *200,000*
q = 105 Pa (2 psf)

THE ARES MISSION



MISSION IMPLEMENTATION CONTEXT

Key Constraints:

- **Cost** - Total Mission Cost $\leq$ \$537 M (RY)
- **Schedule** - 4 year implementation schedule (from mission selection to Launch)
- **Launch Vehicle** - Delta II-2925(H) or Atlas V
- **Other** - Biologically sterile (Planetary Protection guidelines)

Reduce Mission Risk:

- Mission emphasis is return of science data
- Ensure systems function
- Ensure "on-time" delivery for launch opportunity (*45 days every 26 months*)

Key System Level Trades

Science Measurements ↔ Platform Selection

Platform = Powered Airplane

Data Return Strategy ↔ Platform Performance ↔ Delivery Strategy ↔ Data Return Strategy

Testing Strategy ↔ Delivery Schedule ↔ Environments ↔ Testing Strategy

Subsystem/Component Selection

Cost & Schedule

ARES implementation strategy balances science needs with mission constraints

WHY ARES?

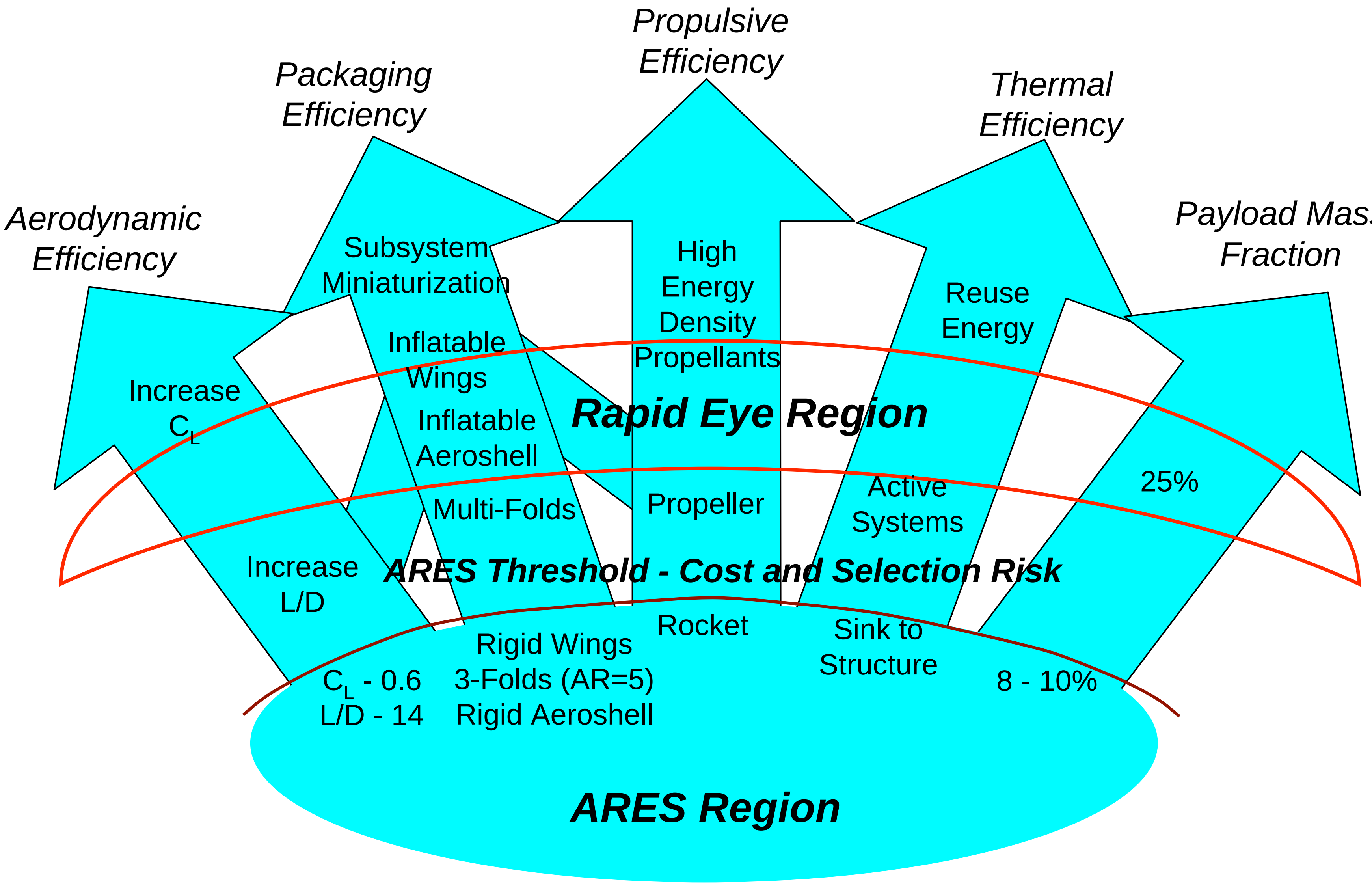
- ARES Mars Airplane shares many similarities with Rapid Eye
- ARES Mars Airplane was developed from 2001 through 2006
  - Enabling technologies emphasized in risk reduction program
  - ARES Mars Airplane has completed extensive ground and flight testing campaigns to provide demonstrated performance

Attribute	ARES Relevance to Rapid Eye
Deployable Airplane	ARES Mars Airplane is folded to fit within an entry aeroshell and performs a mid-air extraction and unfolding.
Operating Environment	ARES Mars Airplane is designed to fly at near surface conditions on Mars - similar to atmospheric environment at 100,000 feet on Earth. (Aerodynamic, flight dynamics, propulsion, and thermal)
Longevity	Operation required after extended time in storage ARES Mars Airplane is designed for a life time limited by its on-board consumables, less than 10 hours of flight time
Payload	ARES Mars Airplane has a blended, multi-sensor capability which provides bounding performance criteria

ARES MARS AIRPLANE TECHNICAL CHALLENGES

ARES Technical Challenge	Relevance to Rapid Eye	Comments
Packaging in Aeroshell	High	Airplane is folded to fit within entry system
Entry, Descent, & Deployment	High	Simulations for entry, multi-body dynamics (unfolding), and Pullout. Extraction method.
Aerodynamic regime	High	Low Reynolds No., subsonic Mach No.
Flight Dynamics	High	Autonomous operation; Robust software; Low damping environment; High Alpha initial operation
Aeroelasticity	Medium High	Analysis and testing to characterize.
Data Return	Medium High	Return in-flight in lieu of ground recovery.
Propulsion	Medium	Bi-propellant rocket sufficient. Extensive studies identified potential for improved endurance with alternative propulsion
Operating Environment	Medium	Similar environment
Navigation	Low	Navigation without GPS or compass
Thermal	Low	A key issue for Rapid Eye
Interplanetary Trajectory	Low	N/A

TECHNOLOGY PATHWAYS

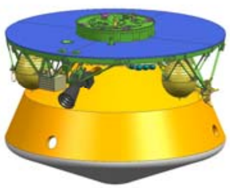


PRE-DECISIONAL DRAFT - For Planning and Discussion Purposes Only

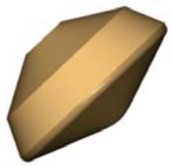
ARES ENTRY, DESCENT, DEPLOYMENT PHASES

ARES-2011

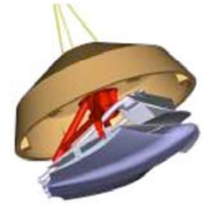
Pre-Entry Operations	Hypersonic Operations	Parachute Operations	Pullout Operations
• TCM-5 Ops • Pre-Entry Operations • Navigation Update • Separation: E-12 hours • Coast to EI • Spin stabilized 2 RPM	• Ballistic Entry • -12° FPA • Wait for Parachute • All devices energized	• Deploy Parachute • Release Heat Shield • Extract Airplane	• Deploy Drogue Chute • Release Drogue Chute • Complete Pullout • Initiate Powered Flight



Interface-EI:
Sensed g=0.03

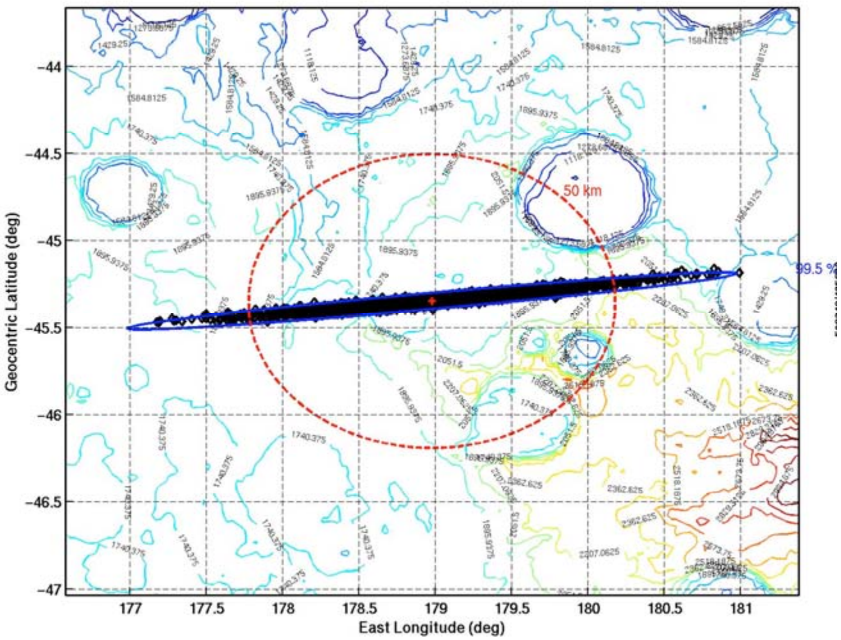


Interface-PD:
Navigated M=1.9
(V = 400 m/sec)

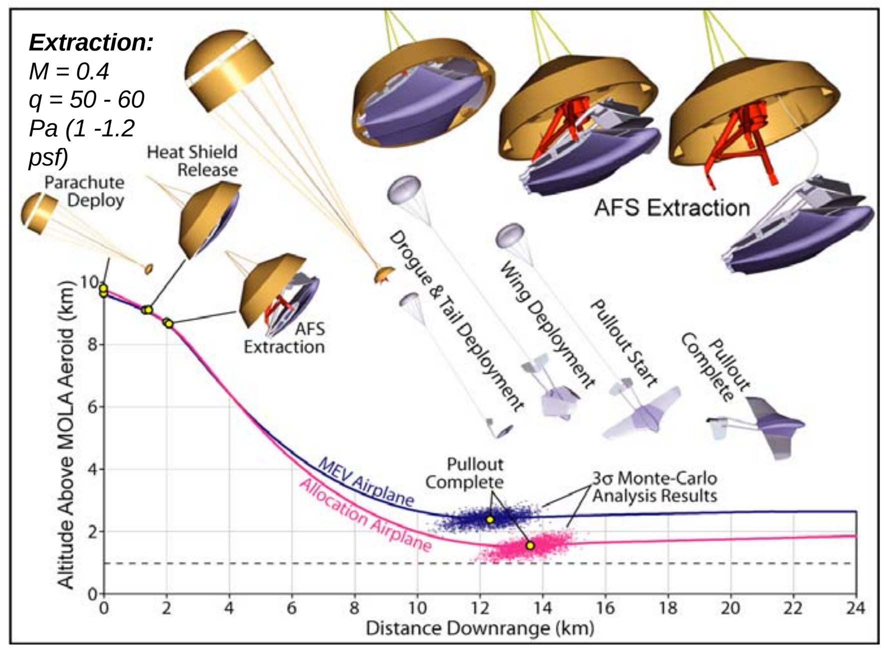


HSR Release:
Navigated M=0.8

Interface-Deploy.:
Timer 7 s
after HSR

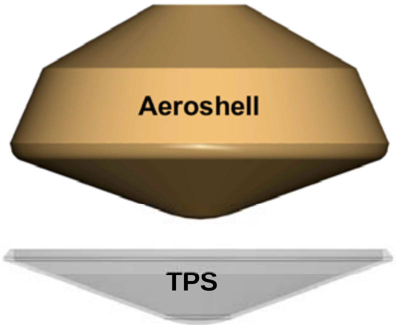


Delivery Footprint at Start of Extraction



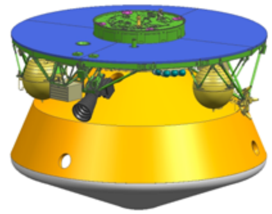
Extraction, Unfolding, and Pullout Sequence

ARES OVERVIEW-SYSTEM IMPLEMENTATION

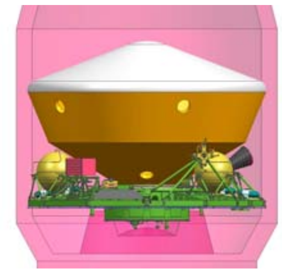


Supersonic Parachute
Disk-Gap Band

Entry Flight System
JPL/LaRC



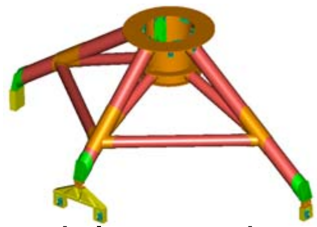
Interplanetary Cruise



Launch

ARES Spacecraft - *JPL/LaRC*

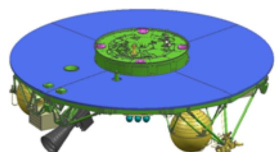
Launch Vehicle
JPL/KSC

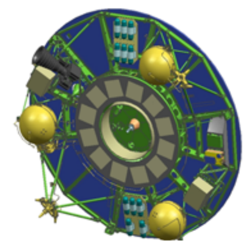


Airplane Extraction Subsystem

Drogue Chute

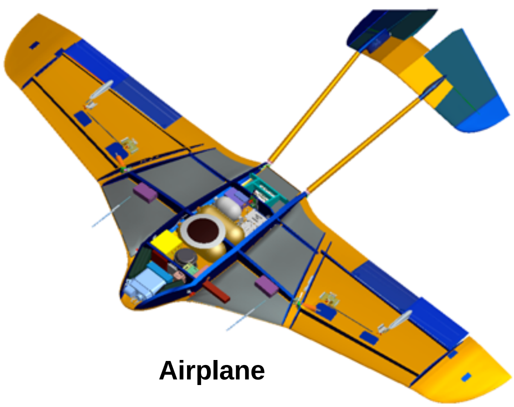
Deployment System - *LaRC*





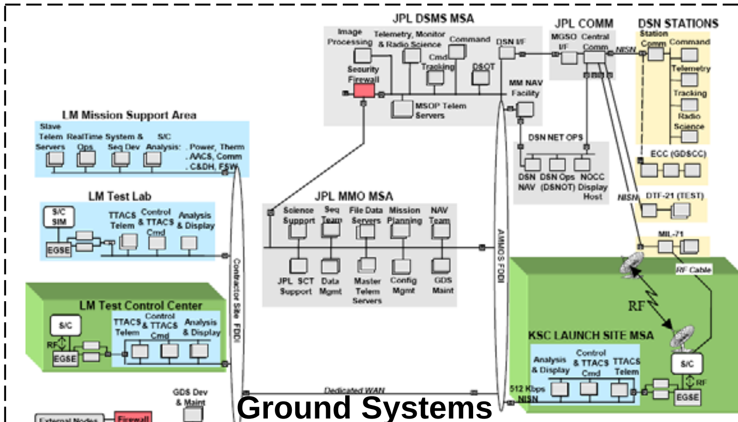
Carrier Spacecraft Flight System - *JPL*

Science Payload



Airplane

Atmospheric Flight System - *LaRC*

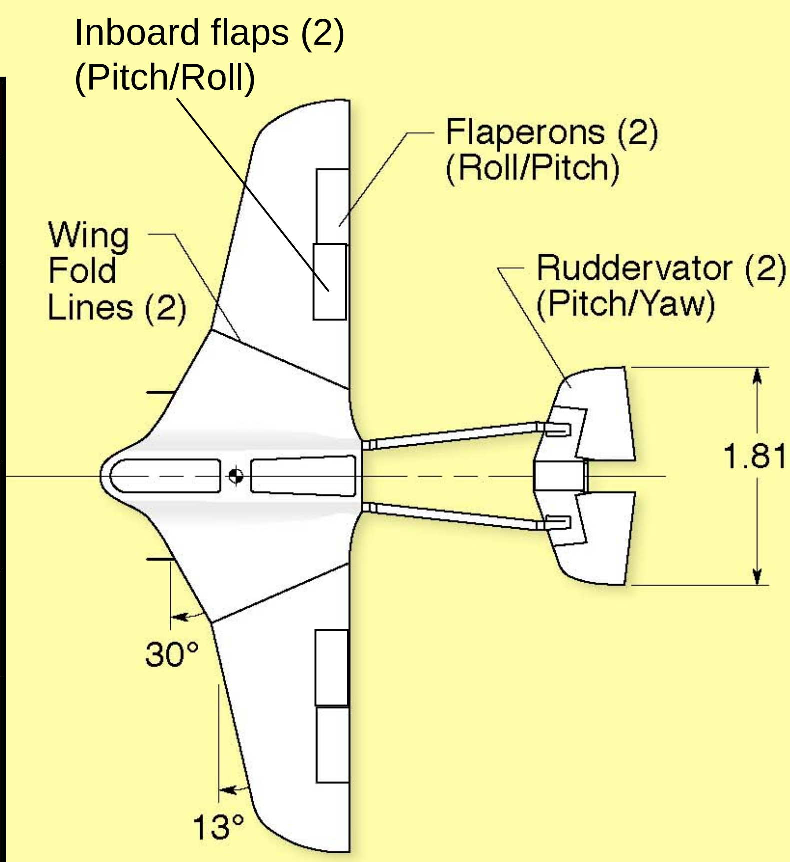


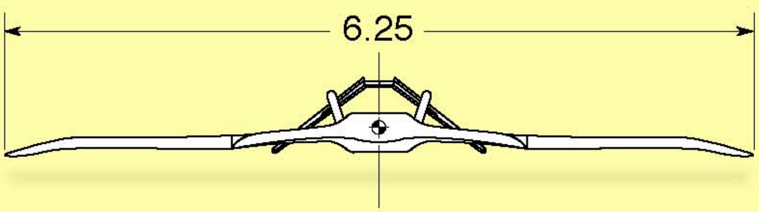
Ground Systems
JPL

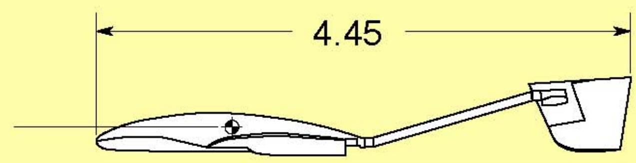
ARES AIRPLANE CONFIGURATION

ARES-2011

Parameter	Value	Benefit
Reference Area	**7 m^2**	**Enable STA access through pullout margin**
Mean Aerodynamic Chord	**1.25 m**	**Allows credible aerodynamic determination because Reynolds number is in a validated, predictable regime**
Propulsion	**Pulsed Rocket**	**Low risk, proven propulsion for low density applications**
Number of Folds	**3**	**Few folds increases deployment reliability**
Stability	**Naturally Stable**	**Static stability allows use of traditional flight control system and simplifies flight software**



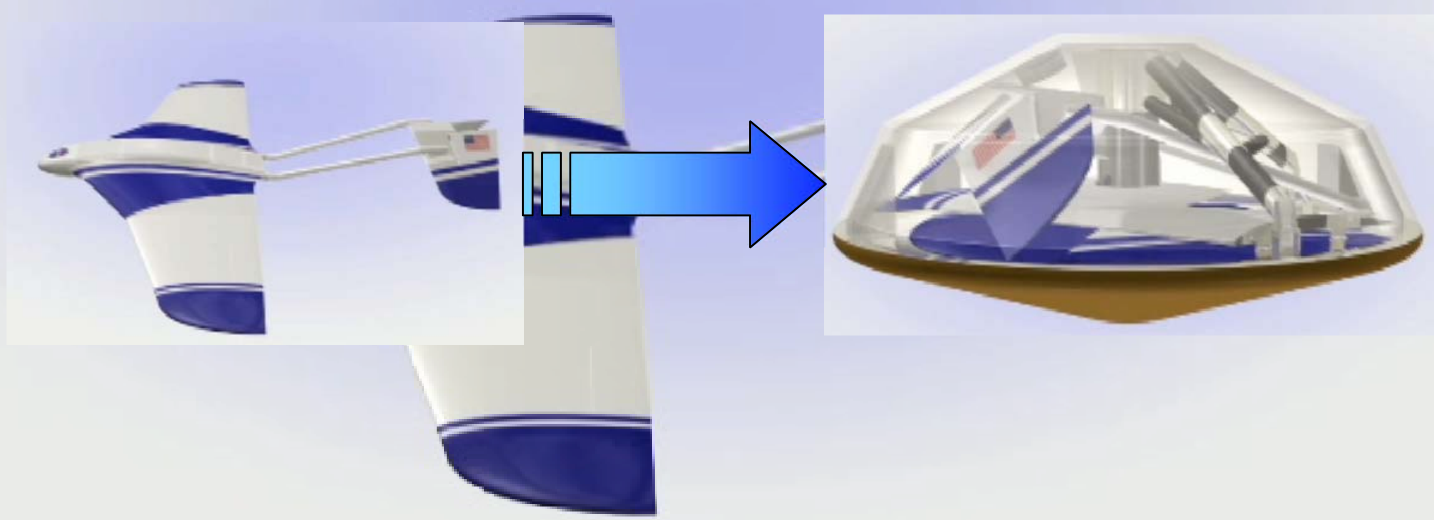




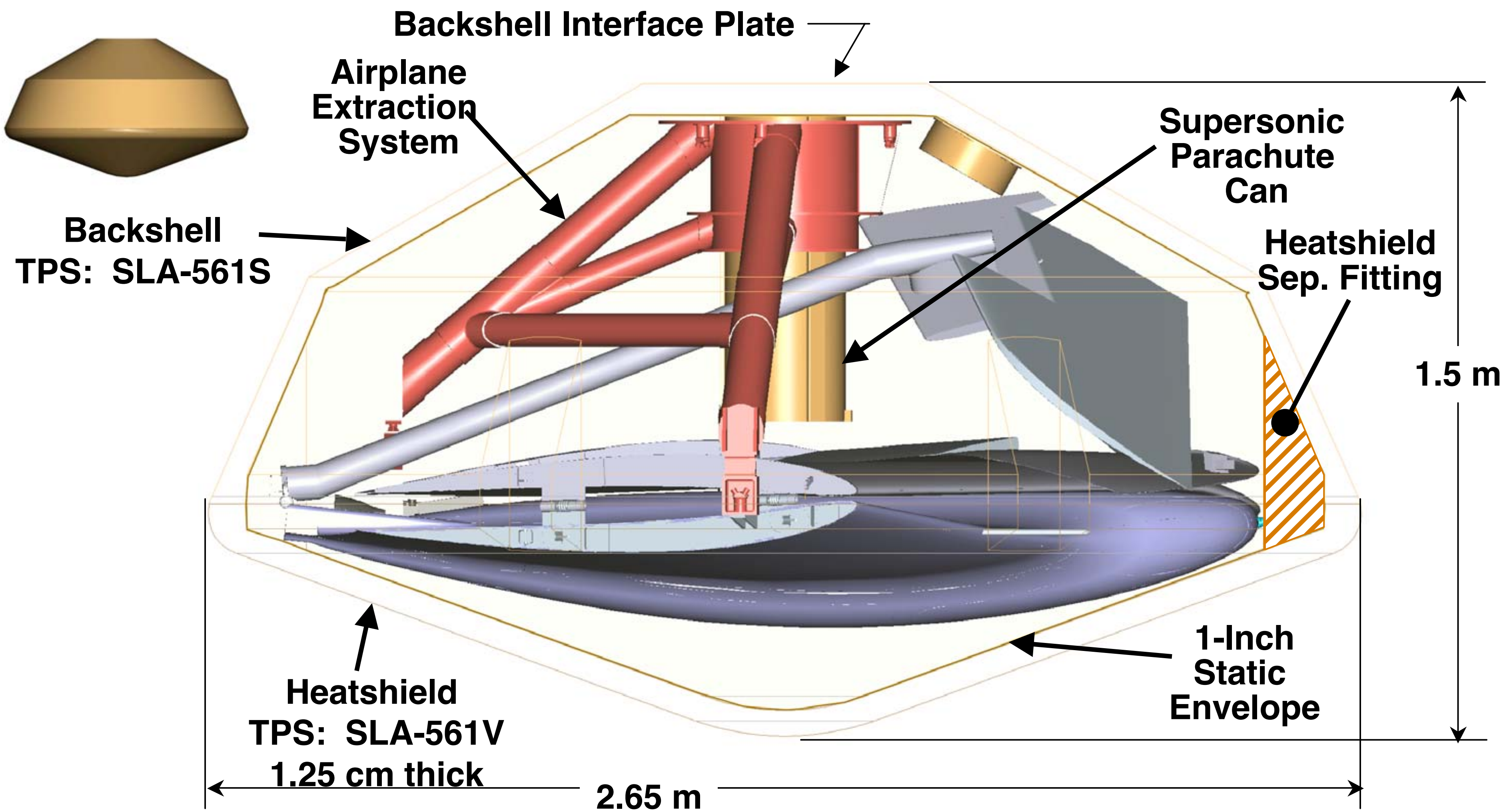
Dimensions in meters

ARES AEROSHELL PACKAGING DRIVES AIRPLANE CONFIGURATION

- Airplane configuration balances packaging within entry vehicle and launch vehicle with mission needs
- Packaging can drive configuration by:
  - Relating span to folding strategy within entry vehicle
  - Accommodating entry vehicle systems/structure
  - Strategy for extraction or separation of airplane from entry vehicle
  - Load path for launch and (re)entry loads



ARES ENTRY SYSTEM CONFIGURATION

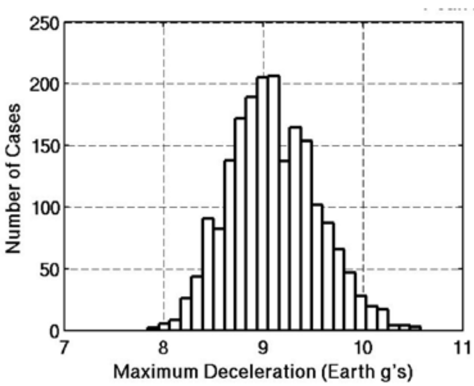


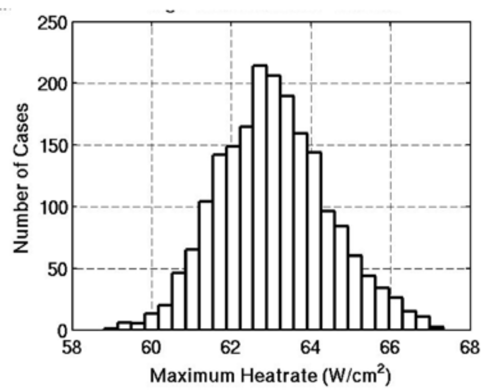
Forebody - 70 deg. Sphere Cone

ENTRY, DESCENT, DEPLOYMENT SIMULATIONS

Entry, Descent: POST2 - Program for Optimizing Simulated Trajectories

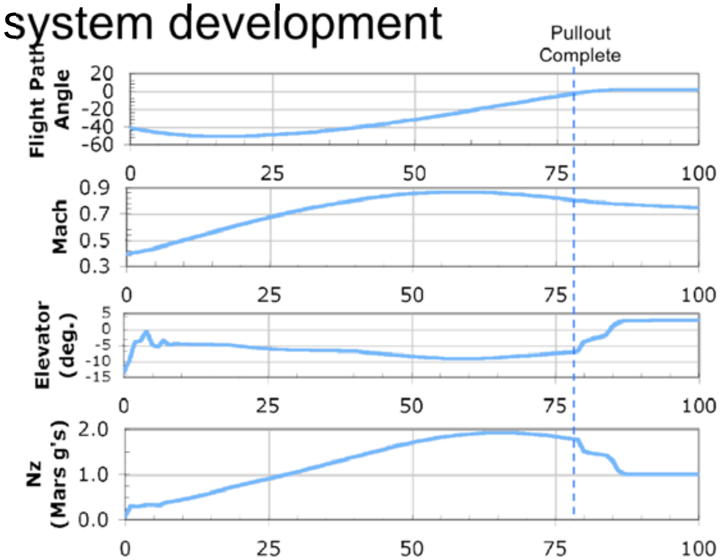
- High fidelity 3-DoF and 6 DoF simulations for entry and descent
- Loads definition (structural, dynamic, and thermal)
- Defining mission time line





Deployment (Pullout): LaSRS - Langley Standard Real-time Simulation

- High fidelity 6 DoF simulation for airplane flight
- Overall performance
- Primary tool for airplane flight control system development



Existing simulation tools are sufficient to address design issues. Configuration specific assessments will take time to develop and validate.

EXTRACTION AND UNFOLDING - GROUND TESTING

Unfolding Wind Tunnel Test March 2002

Release Test June 2006

Extraction Dynamics Wind Tunnel Test Jan 2006

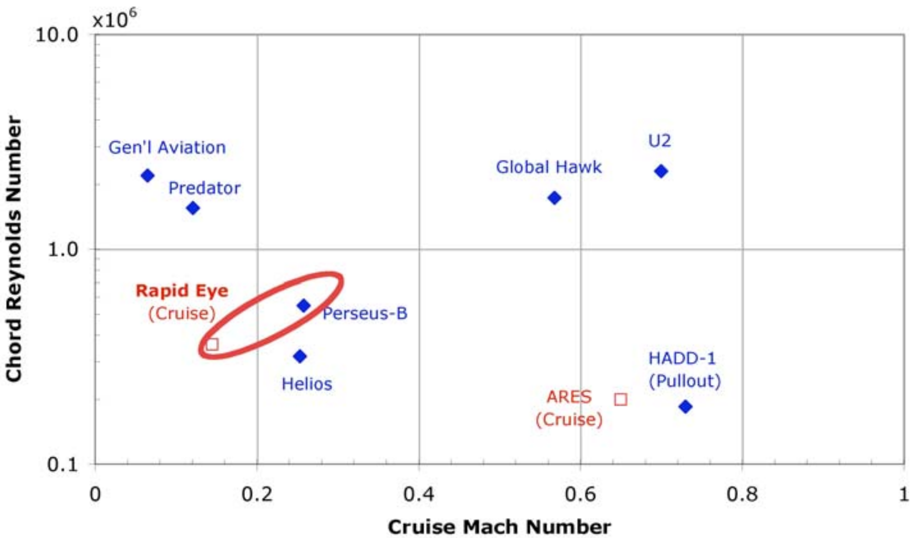
Extraction Test-Oct. 2003

Extraction Drag Wind Tunnel Test Jun 2006

Extraction and transition requires extensive simulation, ground testing, and flight testing to bound performance - one of the key design features.

AERODYNAMIC PERFORMANCE

- ARES cruise regime (Low Reynolds No. with high subsonic Mach No.) requires extensive testing and analysis to validate performance
- Rapid Eye cruise regime appears to be reasonably bounded by existing vehicles and existing methods (test techniques and analytical tools). If a high speed pullout is needed as part of transition phase, then aerodynamic regime may be similar to ARES.

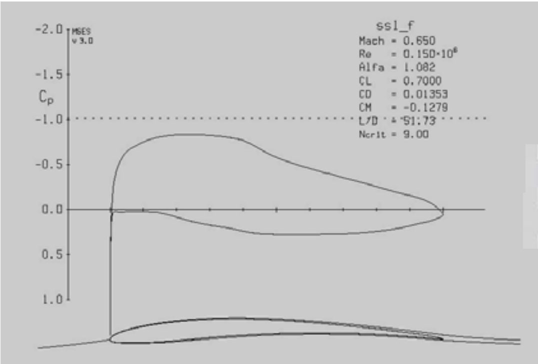


Comparison of Cruise Mach No. and Chord Reynolds No. for vehicles with similar aerodynamic conditions

Airplane	Cruise Alt.	Propulsion	Other
General Aviation	10 kft	Propeller - Engine	Crewed
Predator	25 kft	Turbo-Prop	Uncrewed-RPV
Perseus-B	60 kft	Propeller-Turbo Charged Piston	Uncrewed-RPV
Helios	96 kft	Propeller - Solar	Uncrewed-RPV
Global Hawk	60 kft	Turbo-Fan	Uncrewed-Auto.
U2	65 kft	Turbo-Jet	Crewed
HADD1	100 kft	Glider	Uncrewed-Auto. GHe balloon
ARES	105 kft (equiv)	Rocket	Uncrewed-Auto. L/V
Rapid Eye	80 kft	TBD	Uncrewed-Auto. L/V

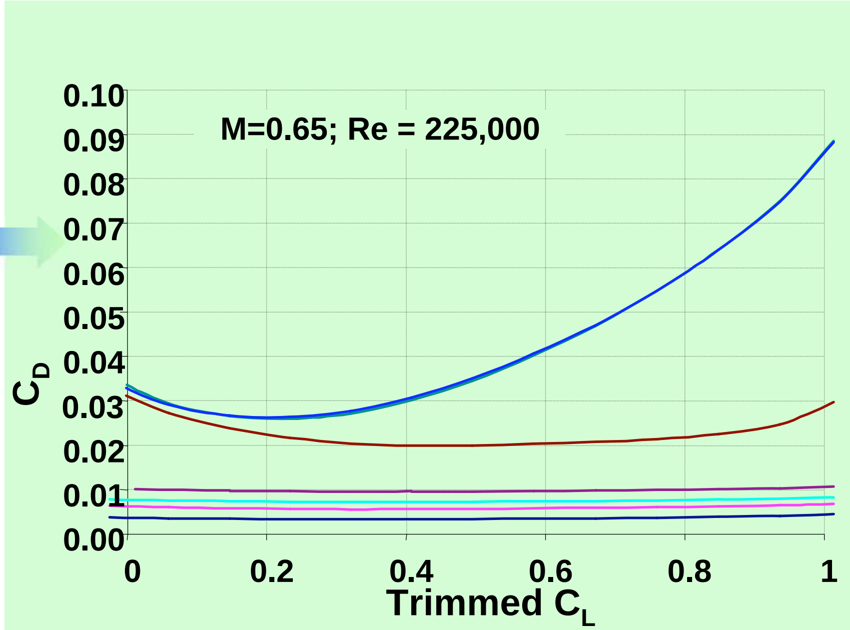
PREDICTIVE CAPABILITY EXISTS

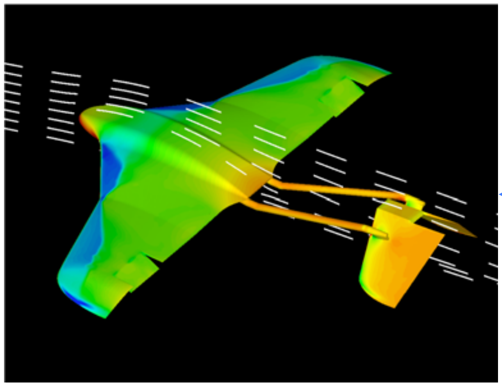
ARES-2011



Tailored Airfoil for Mars Environment

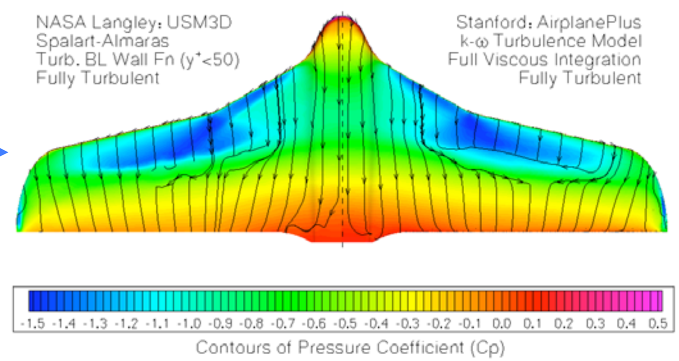
Analytical Tools
Vorview
VORLAX
AVL
PANAIR
MSES
Nonlinear Weissinger
Airplane Plus
Tetruss
FUN3D
PAB3D
USM3D





Flaperon Droop At Pullout

Comparison of N-S Solutions
ARES 2.2OML at Pullout: M=0.72 / α=5.5° / Re_C=150K



Independent Corroboration

EMPIRICAL BASIS FOR PERFORMANCE PREDICTIONS


13%-Scale


8%-Scale
(2D)

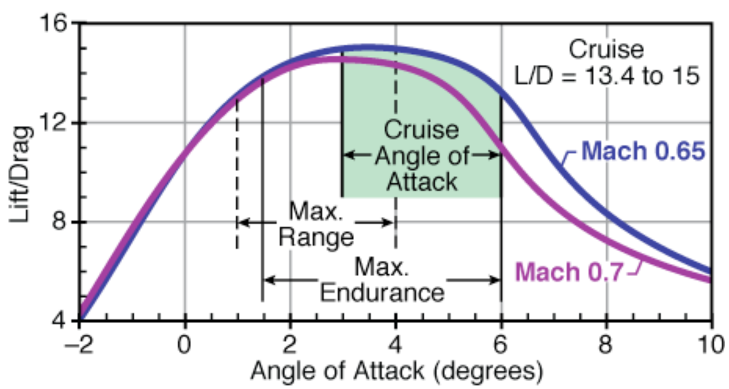
Transition Effects


Delta Effects


Damping

25%-Scale - Subsonic Testing


25% Scale - Transonic Testing




25%-Scale - Unfolding
(Static Aero)


25%-Scale - Drogue
(Proximity Aero)


14%-Scale - Dynamic
(Rotary Balance)

VALIDATION VIA HIGH ALTITUDE FLIGHT TESTING

High Altitude Deployment Test, Sept. 19, 2002 103,000 feet

Tail Deploy

Left Wing Deploy

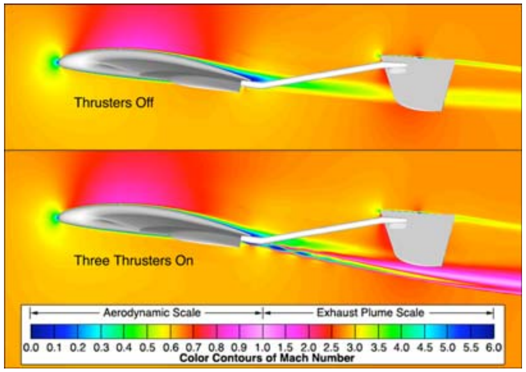
Right Wing Deploy

Autonomous Operation

AEROPERFORMANCE CONCLUSIONS

1. ARES' configuration balances extraction and deployment risk (low number of folds) with needed aerodynamic efficiency (Cruise L/D) to meet science requirements along with development cost (configuration that lends itself to testing and analysis).
2. Extensive simulation and ground testing has shown that current tool set is capable of providing reasonable aerodynamic performance predictions even for Reynolds number as low as 75,000 at a 0.6 to 0.8 Mach No.
3. Aerodynamic efficiency can be enhanced with:
   - Increased span (reduce induced drag) - but at the price of needed additional folds (additional mechanisms) or use of telescoping or inflatable wings
   - Other drag reduction techniques (suction/blowing), etc.

ARES TRADE - PROPULSION



ARES Propulsion Trade Study
Bi-Propellant Rocket Propulsion

Propeller Driven:

Pros
- Most efficient for long range or endurance

Cons
- Packaging and unfolding increase complexity
- Efficiency will suffer at higher Mach no. (Supersonic tips?)
- Propeller wash over wing will reduce aero efficiency (Tractor)
- Pusher will shift CG aft
- Motor and gearbox heat rejection will be challenging
- Extensive development needed

Battery:

Pros
- Existing technology

Cons
- Constant mass
- System mass grows as mission endurance increases
- Battery heat rejection
- Limited options for high current withdrawal

Fuel Cell:

Pros
- High fuel efficiency
- Benefits increase as mission endurance increases

Cons
- Heat rejection
- High current withdrawal

Engine:

Pros
- Wide range of propellants
- Potential to use air as an oxidizer
- Lower system mass

Cons
- Heat rejection

KEY ISSUE - FLIGHT CONTROLS

Flight Controls Robustness:
Single String vs Block Redundant
Functional Redundancy
Fault Tolerance

Flight Software:
New vs Reuse
Real-Time Operating System
Development Environment
Software updates/uploads
Data collection and return
Redundancy Management

Flight Controls Strategy:
Autonomous vs Remote
Deployment flight initialization
High Speed Pullout
Cruise strategy
Recovery strategy

Navigation Strategy:
Rapid Deployment - Initialization
I-Loads Updates
Terrain recognition for position knowledge augmentation
Retasking during operations

Sensors:

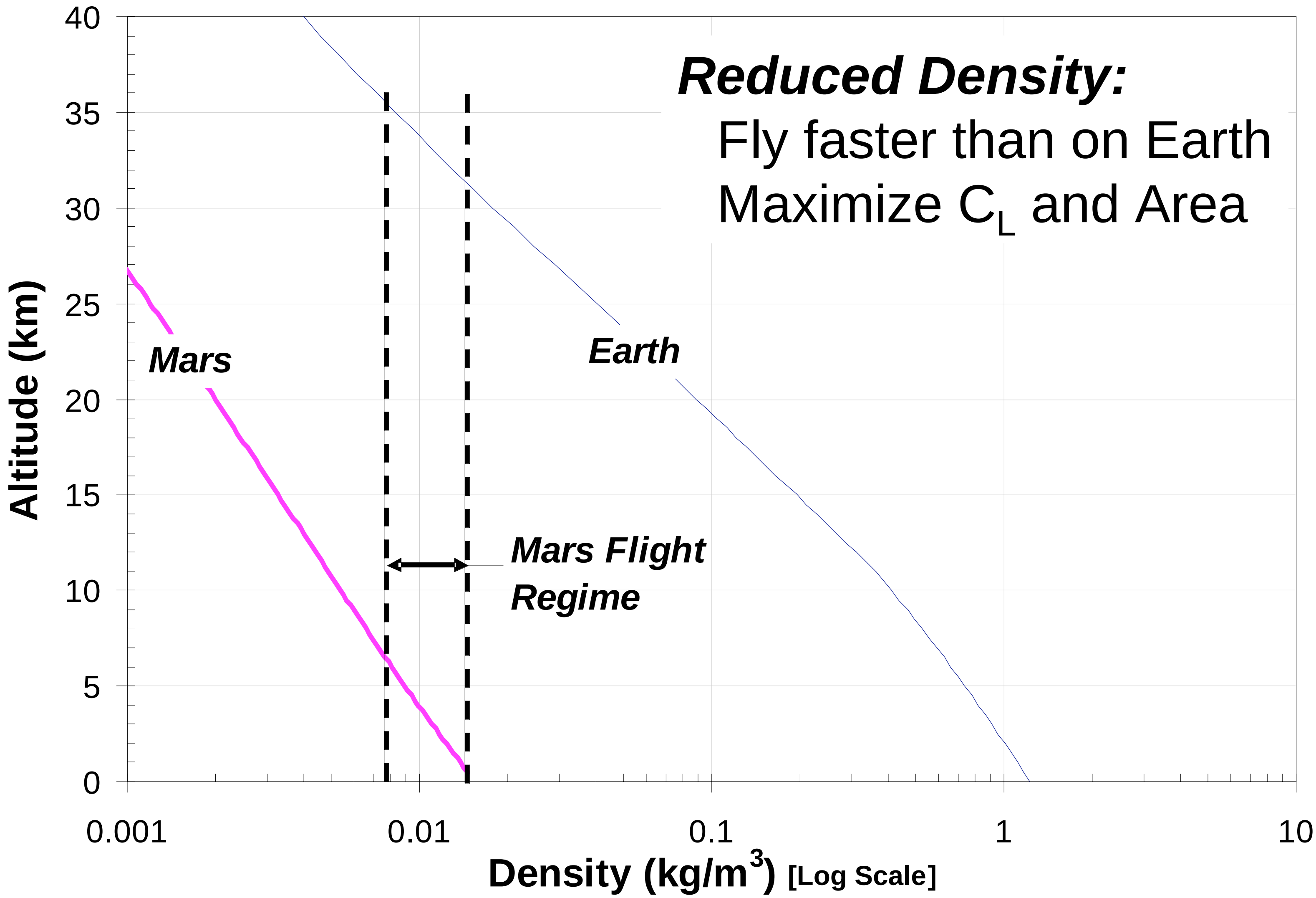
Environments
Self-calibration
Reliability after long-term storage
Air Data in low pressure
Low drift IMU
Redundancy

LAUNCH ENVIRONMENT COMPARISON

Parameter	Delta II-2925H (ARES)	Minotaur IV (reference)
Payload Mass Considered	1050 kg (to Mars)	2050 kg (suborbital)
Fairing Static Envelope ID	2.54 m (2.65 m with exceptions)	2.06 m
Fairing Length	4 m	4.62 m
CG Height Above Attachment Plane	1.15 m (based on 1050 kg)	?
First Axial Mode	35 Hz	35 Hz - no isolation 12 Hz - with isolation?
First Lateral Mode	15 Hz	12 Hz
Peak g's - Liftoff	11.3 g's - Axial 4.5 g's - Lateral	3.9 g's - Axial 0.46 g's - Lateral
Peak g's - MECO	16.7 g's - Axial 0.2 g's - Lateral	3.96 g's - Axial 2.89 g's - Lateral (2nd Stage Ignition)
Peak g's - TECO	8.8 g's - Axial 0.1 g's - Lateral 80 RPM Spin - Z-axis	6.45 g's - Axial 0.59 g's - Lateral

Primary structure sizing dominated by launch loads and frequencies leading to large structural mass fraction. Fairing diameter and vertical CG limits drive configuration as well. Strategies for increasing the overall structural capability are essential.

OPERATIONAL ENVIRONMENT COMPARISON



OTHER ISSUES

- Thermal - Heat Rejection
  - ARES mission duration allowed systems to reach upper limits while sinking heat into the structure
  - Rapid Eye mission duration will most likely require dedicated subsystems to absorb and/or reject heat - convective heat transfer is strongly coupled to Reynolds number so that the low Reynolds number cruise at high altitude will be a significant issue
- Electrical Power - source
- Structures and Mechanisms
  - Reliable mechanisms/systems needed for deployment
  - High launch and deployment loads will drive structural arrangement
- Aeroelasticity - low damping available; high aspect ratio wings will be susceptible to aeroelastic effects
- Data Return
  - ARES strategy of in-flight data return is analogous to Rapid Eye
  - Band is important
  - Antenna size and placement are essential - broadcast up and down?

SUMMARY

- Enabling Technologies:

Packaging/Delivery:
Within Entry System & Launch Vehicle
Extraction & Unfolding
Energy Management

Propulsion:
Efficiency
Energy Storage & Conversion
Accommodation of Prime Mover
Heat Rejection

Flight Controls:
Sensors
Navigation Strategy
Robustness
Autonomy

- Driving Issues:

Environments:
Launch & Entry
High Altitude Ops.
Thermal, Low Pressure, Aero

Payload/Requirements:
Mass/Power
Pointing/Stability
Heat Rejection
Endurance/Loiter
Data return

Aero/Flight Dynamics:
Re/Mach No.
Stability (Natural, Augmented)
Performance (Lift, Drag, Trim)

Deployable airplanes from a launch vehicle and/or entry system are within the state of the art.

ARES POINTS OF CONTACT

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ARES Website:
http://marsairplane.larc.nasa.gov

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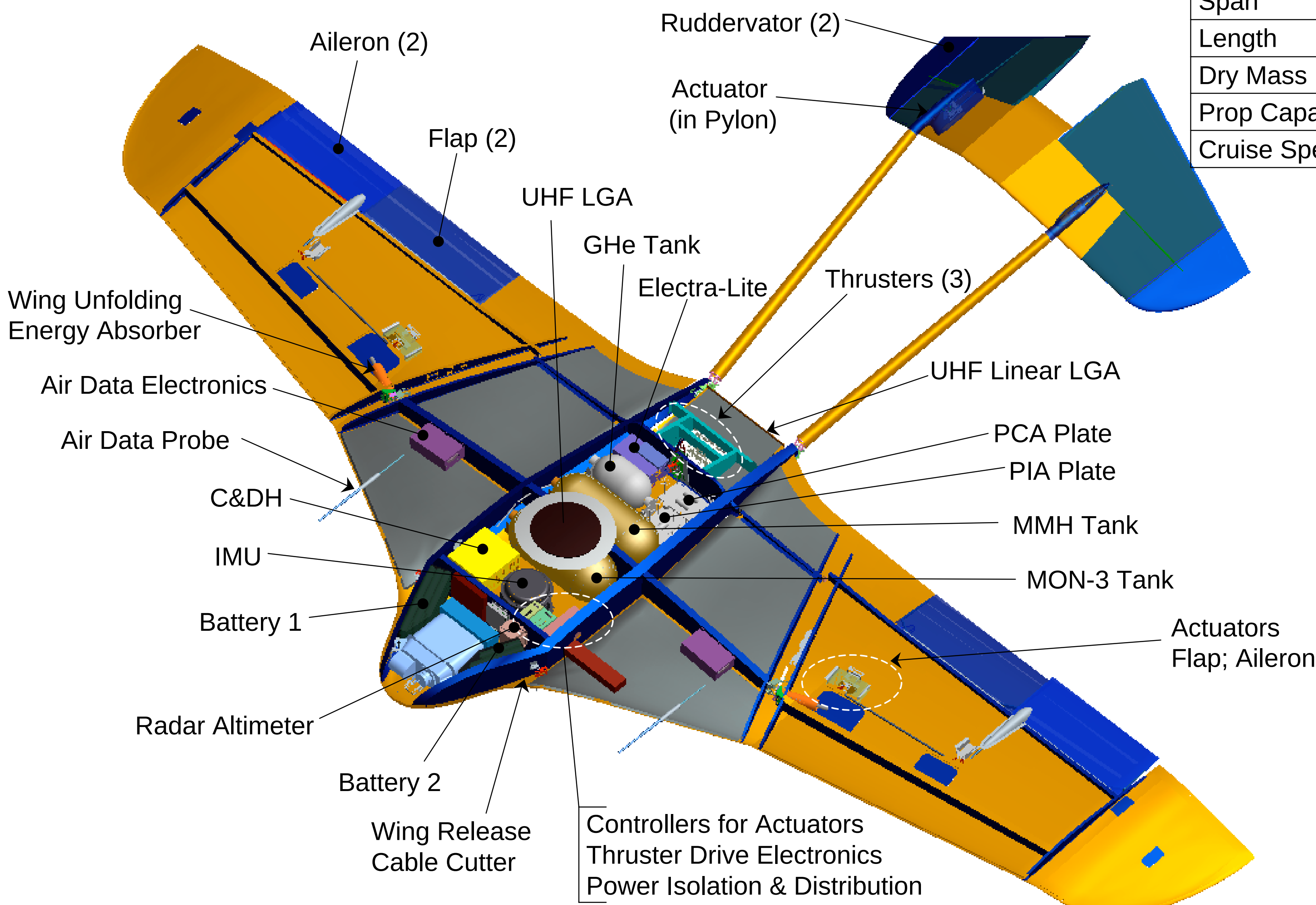
- "Design of the ARES Mars Airplane and Mission Architecture," Journal of Spacecraft and Rockets, vol. 43, No. 5, Sept-Oct 2006
- "Liquid Rocket Propulsion for Atmospheric Flight in the Proposed ARES Mars Scout Mission," AIAA 2004-3696
- "Planetary Flight Vehicles (PFV): Technology Development Plans for New Robotic Explorers," AIAA 2005-7132
- "Science from a Mars Airplane: The Aerial Regional-scale Environmental Survey (ARES) of Mars," AIAA 2003-6576
- "Mars Airplane Airfoil Design with Application to ARES," AIAA 2003-6607

BACKUP INFORMATION
ARES Mars Airplane

ARES AIRPLANE CONFIGURATION

Span	6.25 m
Length	4.45 m
Dry Mass	113 kg
Prop Capacity	45 kg
Cruise Speed	145 m/s

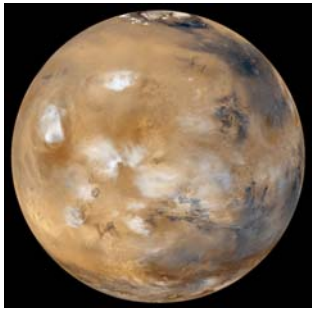


AIRPLANE SUBSYSTEM OVERVIEW

Subsystem	Description
Airframe	Composite structure; Titanium hinges and deployment energy absorbers
Propulsion	Liquid rocket (bi-propellant - MMH & MON-3); Titanium tanks with PMD's; Helium pressurant; Pressure Control in tanks; 3 Thrusters (22 N ea);
C&DH	Rad750 based processor, 3u form factor in a cPCI format. Vx Works OS
ACS (G&N)	IMU, Radar Altimeter, Air Data Subsystem, Actuators
FSW	Flight Software - from Separation through End of Flight
Electrical Power	Primary batteries ($Li\text{-}SO_2$), dual bus, 28 VDC
Telecom	UHF Uplink/Downlink, Omni Patch antenna on airplane for downlink
Thermal	MLI, Thermostatic Heaters, Heat Sinks

EARTH-MARS COMPARISON

ARES-2011

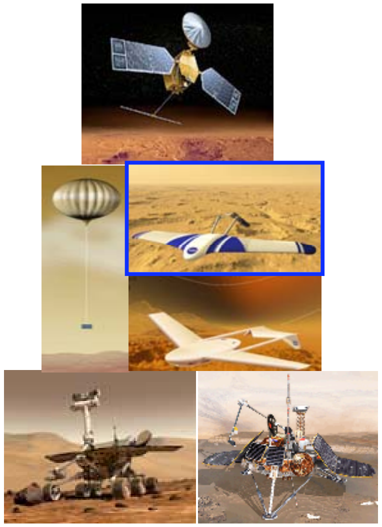


Distance from Sun = 93 Million miles
Diameter = 7917 miles
Atmos. = 79% N_2; 21% O_2
Speed of Sound = 760 mph
Gravity = 32.2 ft/sec^2
Surface Pressure = 1000 mbars
Surface Temperature = 70° F

Distance from Sun = 142 Million miles
Diameter = 4213 miles
Atmos. = 95.3% CO_2; 2.7% N_2;1.6% Ar
Speed of Sound = 500 mph
Gravity = 12.1 ft/sec^2
Surface Pressure = 6.4 mbars
Surface Temperature = -80° F

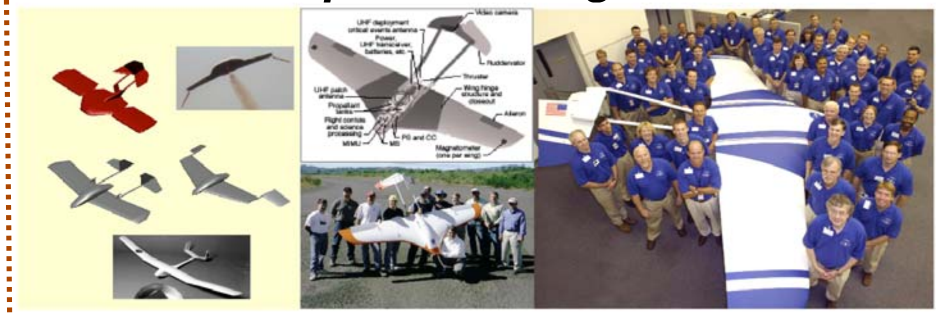
KEY ARCHITECTURE TRADES

Platform Selection



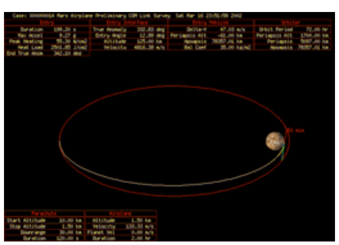
Orbiter - unable to meet science resolution requirements
Aerial-Balloon - unable to provided needed control
Aerial-Powered Airplane - meets all science requirements
Aerial-Glider - unable to meet science range within cost
Surface-Rover - unable to meet science measurement needs
Surface-Lander - no mobility

Airplane Configuration

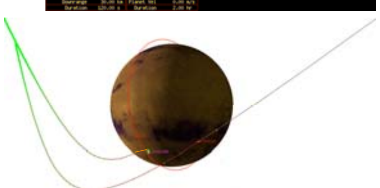


Driving constraints included aeroshell packaging and mission requirements. Final airplane configuration was evolved from cursory studies (weeks) through detailed design and testing (months). Current configuration has complete aerodynamic data base.

Entry Strategy



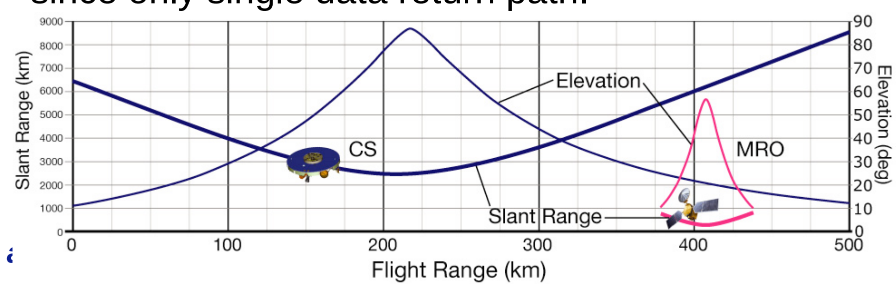
Deorbit - unable to remain within cost cap; not needed to meet science requirements.



Direct Entry with Flyby S/C - meets all science requirements and remains within cost cap
Direct Entry without S/C - Data return limited to 7 minute window; risk of lost data is too high

Data Return Strategy

Post-flight - Requires survivable landing - increases complexity (ability to meet launch date)
In-Flight - Dual path through Carrier S/C and existing orbiter (MRO) - meets all requirements
In-Flight - single path through Carrier S/C - potential descope - increases risk of lost data since only single data return path.



Inflatable Aerodynamic Decelerator Technology Development

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Atmospheric Flight & Entry Systems Branch
NASA Langley Research Center

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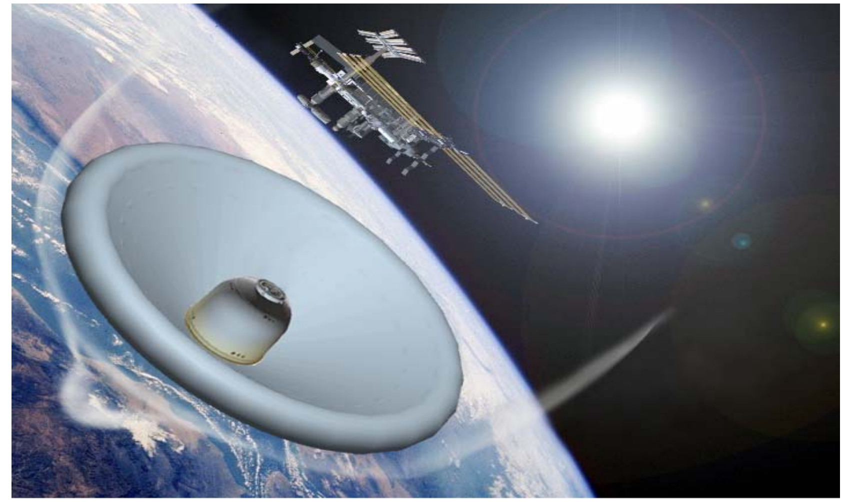
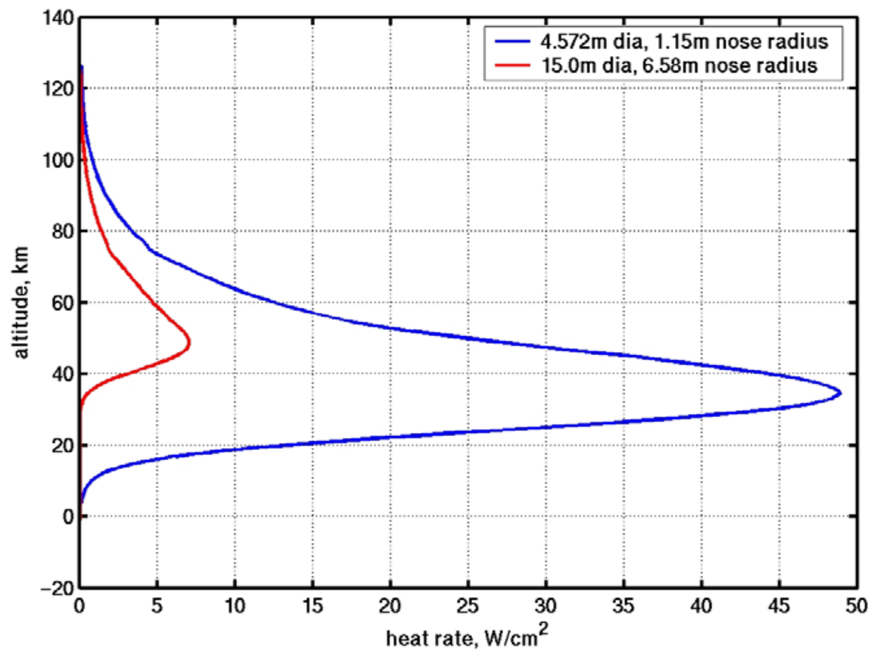
Inflatable Aerodynamic Decelerators

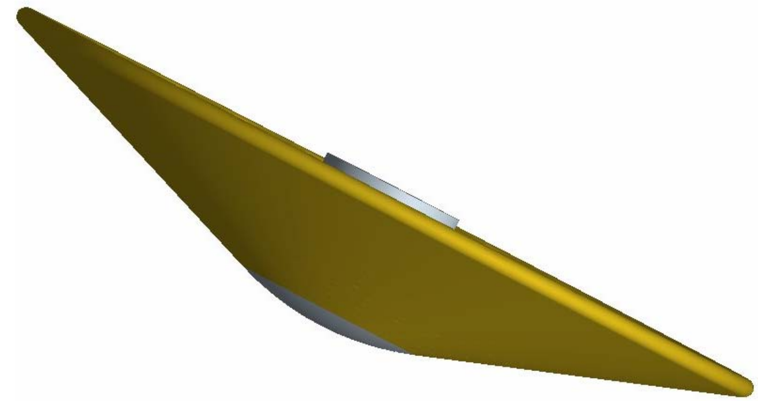
- **Inflatable Aerodynamic Decelerators support NASA's Missions through:**
  - For Mars…
    - Increasing landed mass, payload mass fraction, and payload volume fraction for missions Increasing the altitude to which payloads can be delivered
  - For Earth…
    - Providing a low-mass, low-volume method for returning payloads to Earth (International Space Station payloads in the post-Space Shuttle era, planetary sample-return missions, etc.)



Motivation – Mars Entry, Descent, & Landing

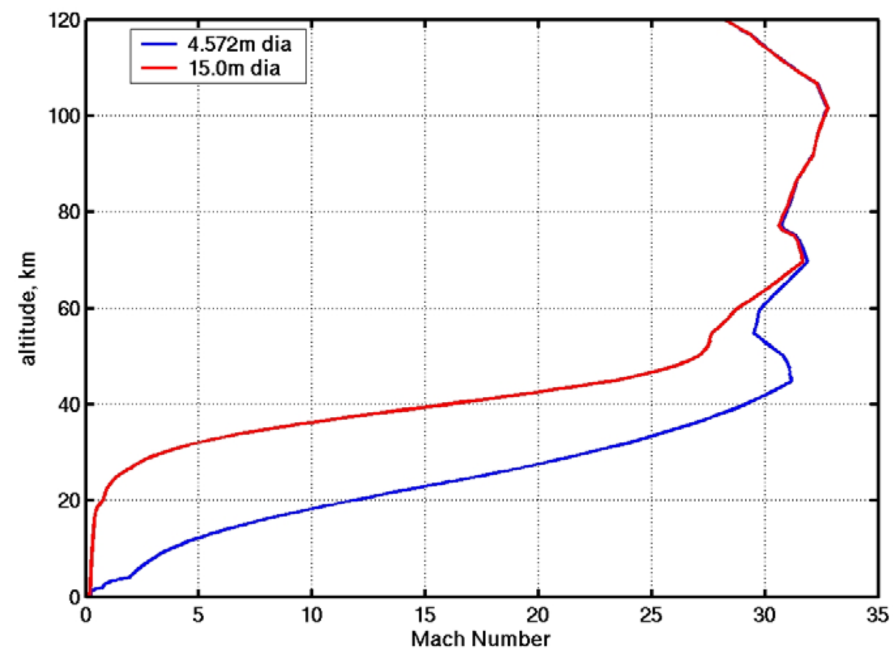
Direct Ballistic Entry, 6km/s, 2200kg Entry Mass,
1.3N, 27.0 longitude landing site



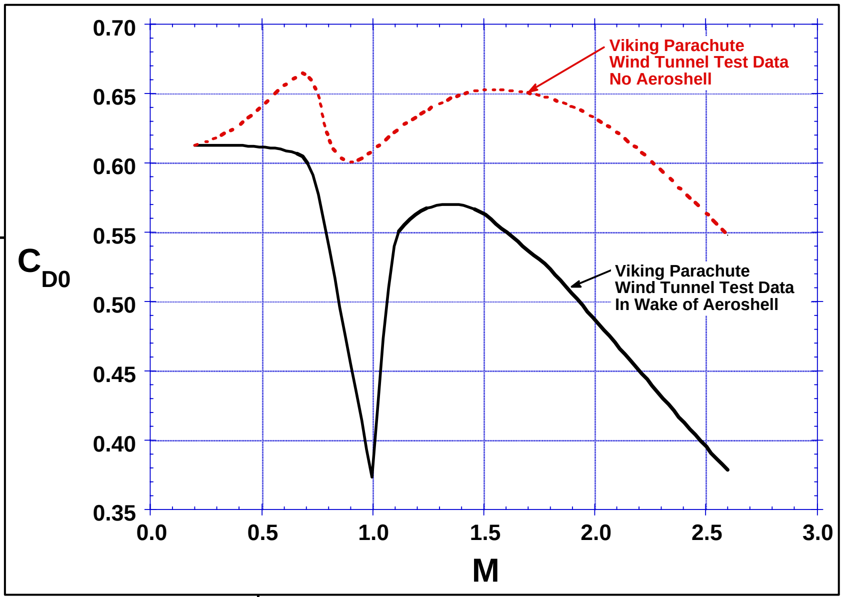


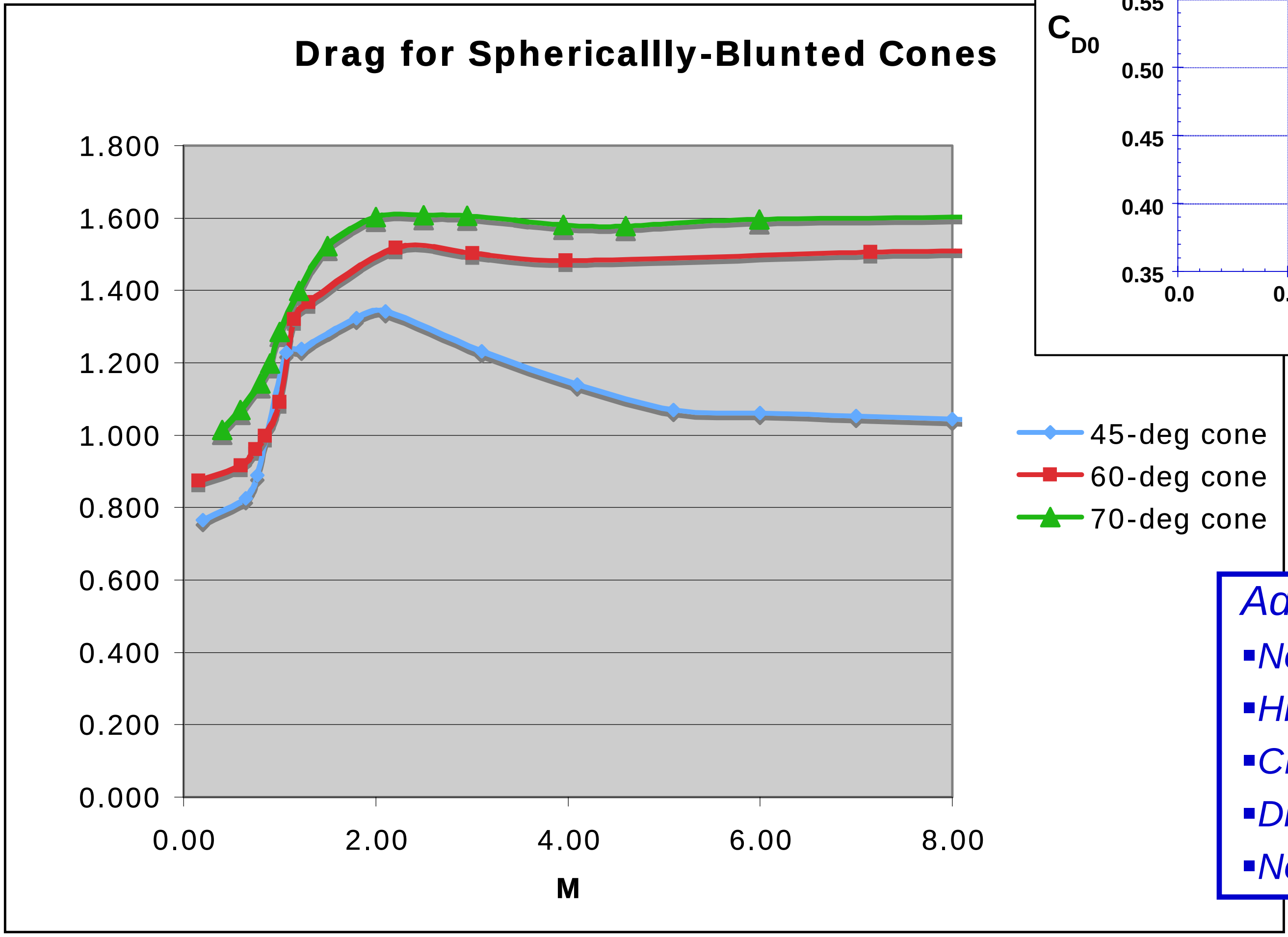
15m Inflatable 70deg Sphere-Cone

4.572m Rigid 70deg Sphere-Cone



Motivation – Supersonic Decelerator





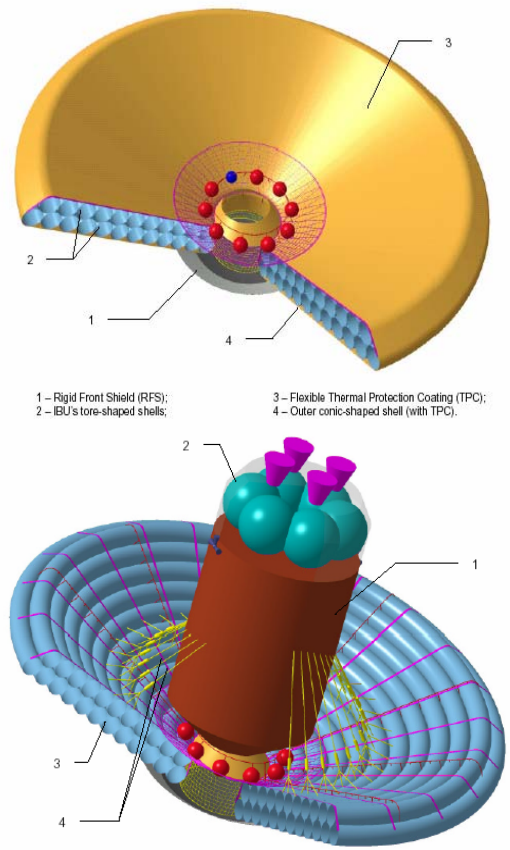
Advantages over parachute:

- *No transonic drag bucket*
- *Higher CD*
- *CD maintained with increasing M*
- *Directionally stable*
- *No 3-body motion*

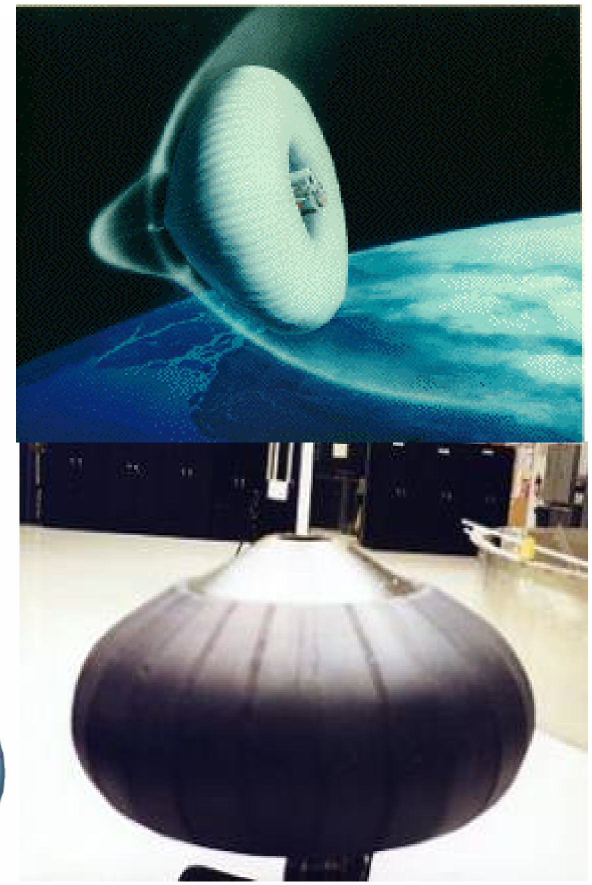
Inflatable Aerodynamic Decelerator Concepts

Inflatable Reentry & Descent Technology (IRDT)

Mars Inflatable Aeroshell System (MIAS)

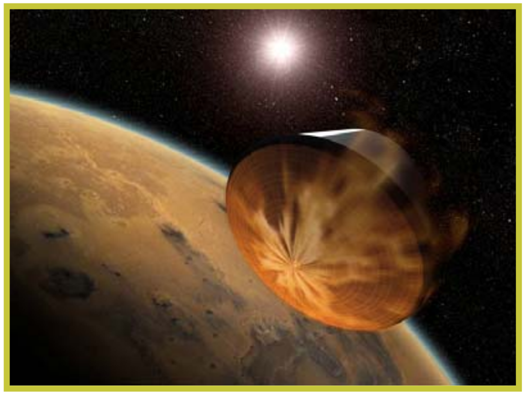


Balloon + Parachute Ballute



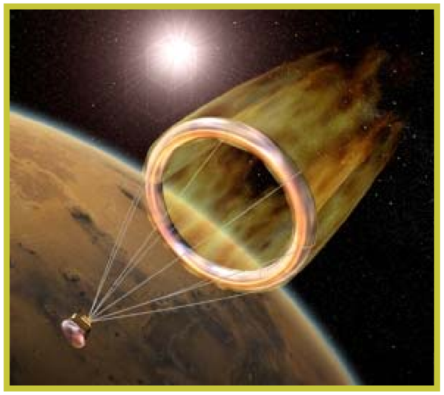
Low Ballistic Coefficient Entry System Alternatives

Higher TRL
Rigid Aeroshells

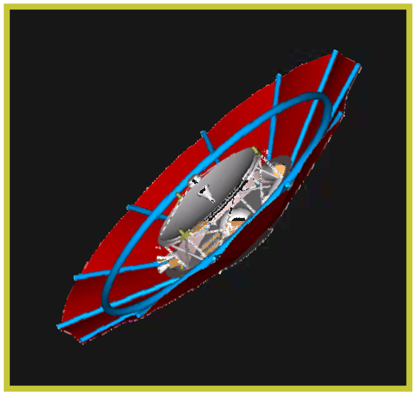


- Moderate to high maturity
- Rigid aeroshells widely used in direct entry systems: Mars Rovers, Genesis, Stardust…
- Provides modest tolerance for nav and atmospheric uncertainties

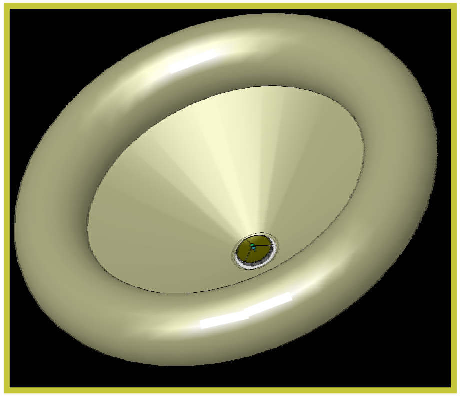
Lower TRL
Inflatable Deceleration Systems/Ballutes ("Balloon Parachutes")



Trailing Ballute



Inflatable Aeroshell



Clamped Ballute

- Lower maturity
- Applicable to all size and shape payloads
- Payload not enclosed during interplanetary cruise as with rigid aeroshell system
- Reduced heating conditions
- Packaging efficiencies

Technology Development Areas

- **Ten Technology Development Areas**

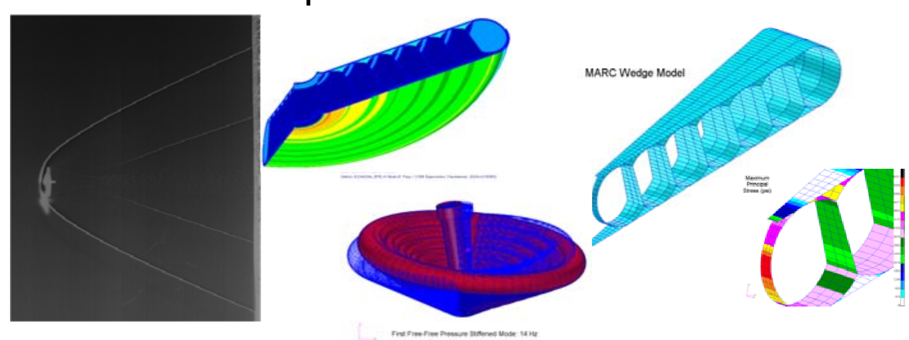
1. Heatshield Materials
2. Bladder Materials
3. Atmospheric Deployment
4. Aerodynamic Performance Requirements
5. Structural Configurations
6. Aero-thermo-elasticity Analysis
7. Inflation Systems
8. Health Monitoring Systems
9. GNC – Implications of the Inflatable
10. Payload Separation System

- Inflatable Aeroshell Only
- High-Mach Supersonic Decelerator Only
- Both

Areas under investigation in IRVE and/or PAIDAE

- **IRVE**
  - First-time build & flight of non-ablative Inflatable Aeroshell Concept

- **PAIDAE**
  - Initial research, testing, and systems analysis to mature each technology development area.



Inflatable Re-entry Vehicle Experiment (IRVE)

Inflatable Re-entry Vehicle Experiment

- **Inflatable Re-entry Vehicle Experiment (IRVE)**
  - Began: December 2003
  - Sounding Rocket Flight Test: August 28, 2007
  - Post Flight Conference: November 2007

IRVE Mission Concept

Separate RV from TM, 80s

Separate T/M, RV assembly from Payload Shroud, 70s

Inflation begins at 200s

RV completes inflation prior to Reentry Phase (T=315s)

RV begins broadcast of data after separation of Payload Shroud

Separate Payload from Booster, 60s

T=335s **80 kilometers**

Reentry Phase

Coast to 72 km, (60s),

RV passes through peak pressure ~47.6 kilometers. T=364s

2nd stage burnout, 40 seconds
2nd stage ignition, 15 seconds

Flight Experiment concluded after vehicle has passed 40km

T=373s or Alt < 40 km

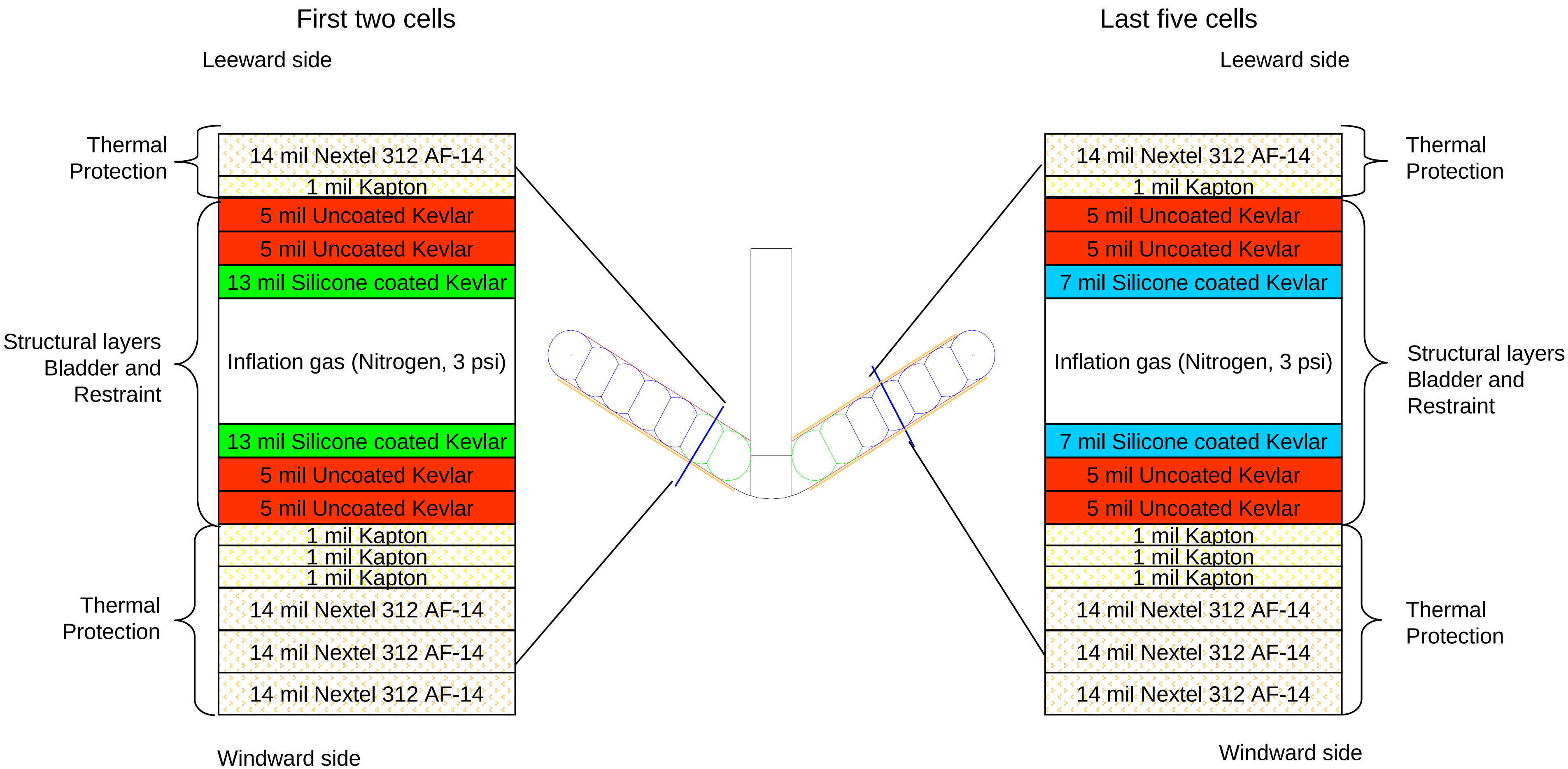
Launch on Terrier-Orion From Wallops Island

T=0s

WFF provides launch operations, telemetry acquisition, and radar track of flight

Ballistic Coefficient = 11
Max Dyn. Pressure = 628 Pa
Max Deceleration = 6.5 g
Max Heat Rate = 1 W/cm^2
Total Heat Load = 32.7 J/cm^2

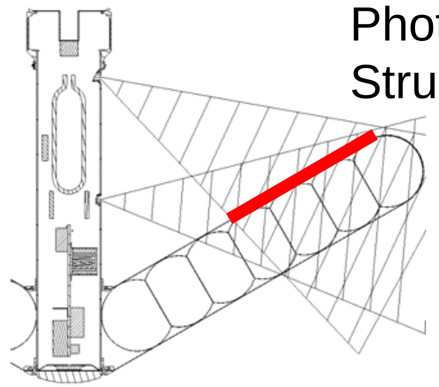
Inflatable Aeroshell Ply Lay-Up



- **Off-the-shelf aerospace fabrics**
- **Non-optimal structure (with respect to mass)**
- **Aeroshell “overkill” for IRVE flight environment**

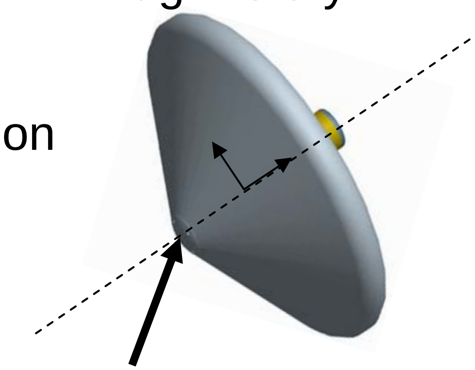
Data Products

- **Aeroshell Structural Dynamics (Photogrammetry Results)**
- **Flight Path Data Products**
  - Trajectory Reconstruction
  - Angle-of-Attack History
  - C_A History
- **In-depth & radial Aeroshell Temperature Distribution**
- **Housekeeping Data Products**
  - Inflation System Tank Temperature & Pressure
  - Aeroshell Bladder Pressures
  - Ambient Pressure
  - Transmitter Temperatures
  - Voltages

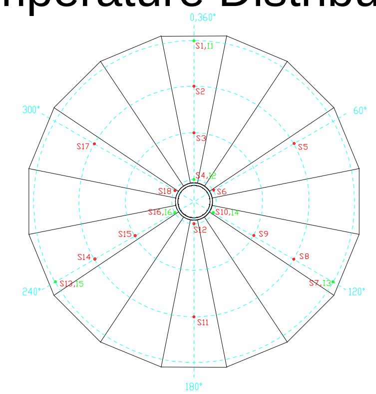


Photogrammetric Structural Analysis

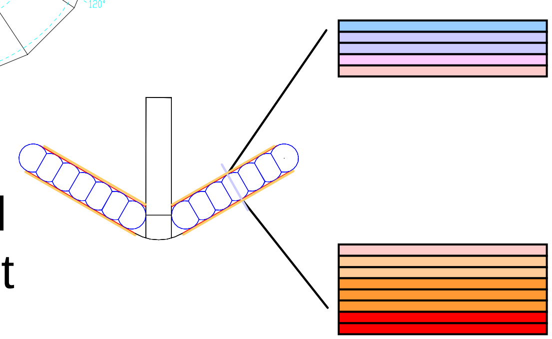
Attitude, Trajectory, Drag History



Temperature Distribution

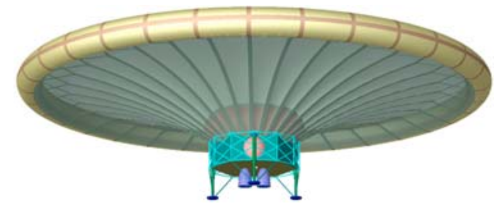


Thermal Gradient



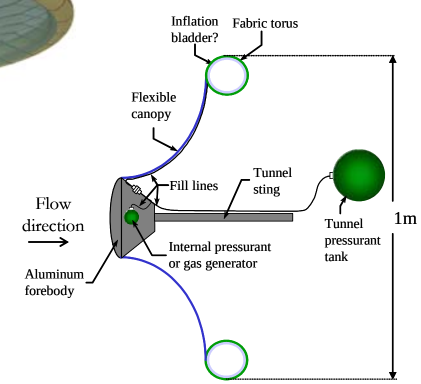
Program to Advance Inflatable Decelerators for Atmospheric Entry (PAIDAE)

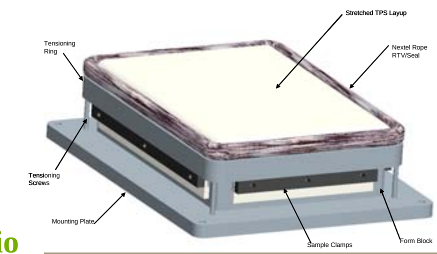
- **Program to Advance Inflatable Decelerators for Atmospheric Entry (PAIDAE)**
  - Began: November 2006
  - Ground Testing & Analyses ongoing through September 2007
  - Data Reduction & Documentation through Spring 2008



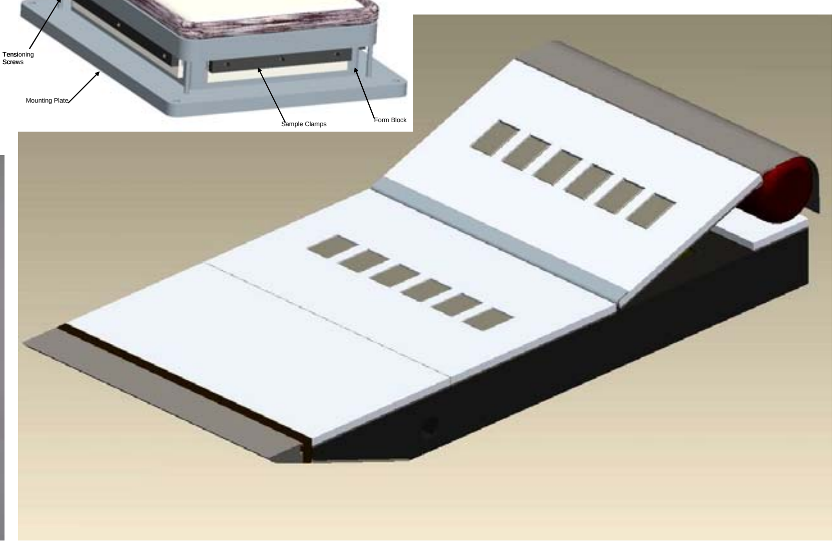
Graphics source: AIAA 2003-2167

Atmospheric Deployment Testing
GRC 10x10 Facility
LaRC Unitary Facility
Model Concept: Tension Cone

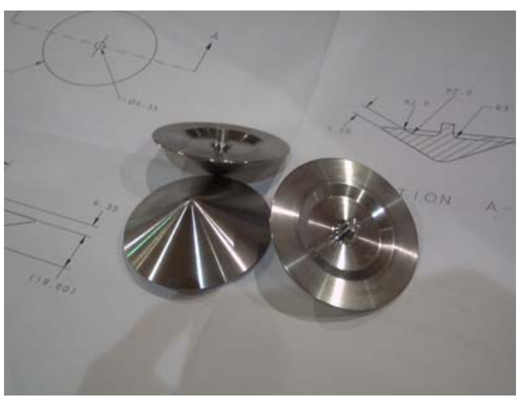




8' HTT TPS Coupon Test

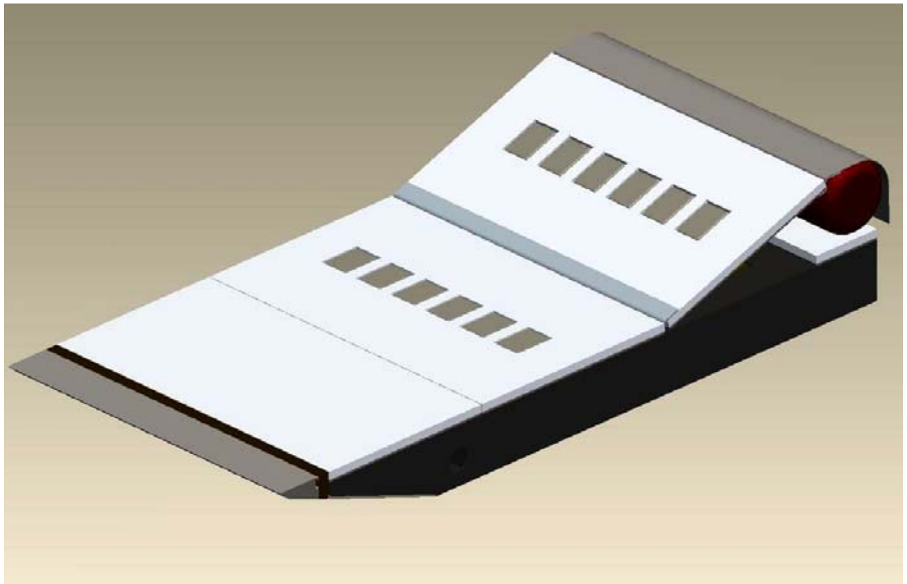


Ballistic Range Test Matrix:
-Tests w/ variations in half-angle, shoulder radius, & aftbody aspect ratio



8' High Temperature Tunnel Test

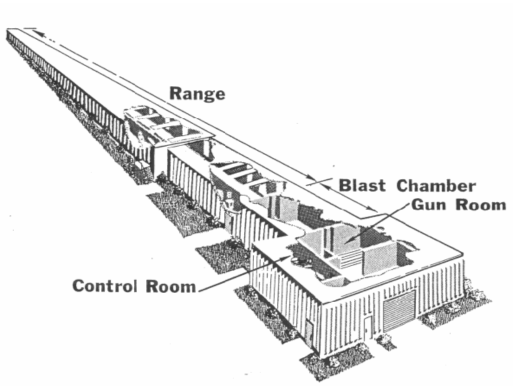
- **Goals**
  - Determine the survivability and performance of various fabric TPS lay-ups
  - Validate thermal performance modeling
- **Model Configurations**
  - Heat Shield Materials (outer layer)
    - Nextel
    - Carbon Cloth
    - Refrasil
  - Insulators
    - Pyrogel
    - Refrasil
  - Gas Barrier
    - Kapton
    - Upilex
- **12 lay-ups per run / 5-10 runs**

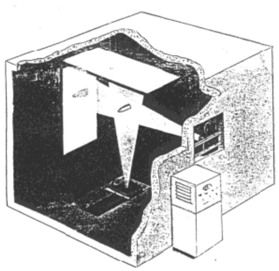


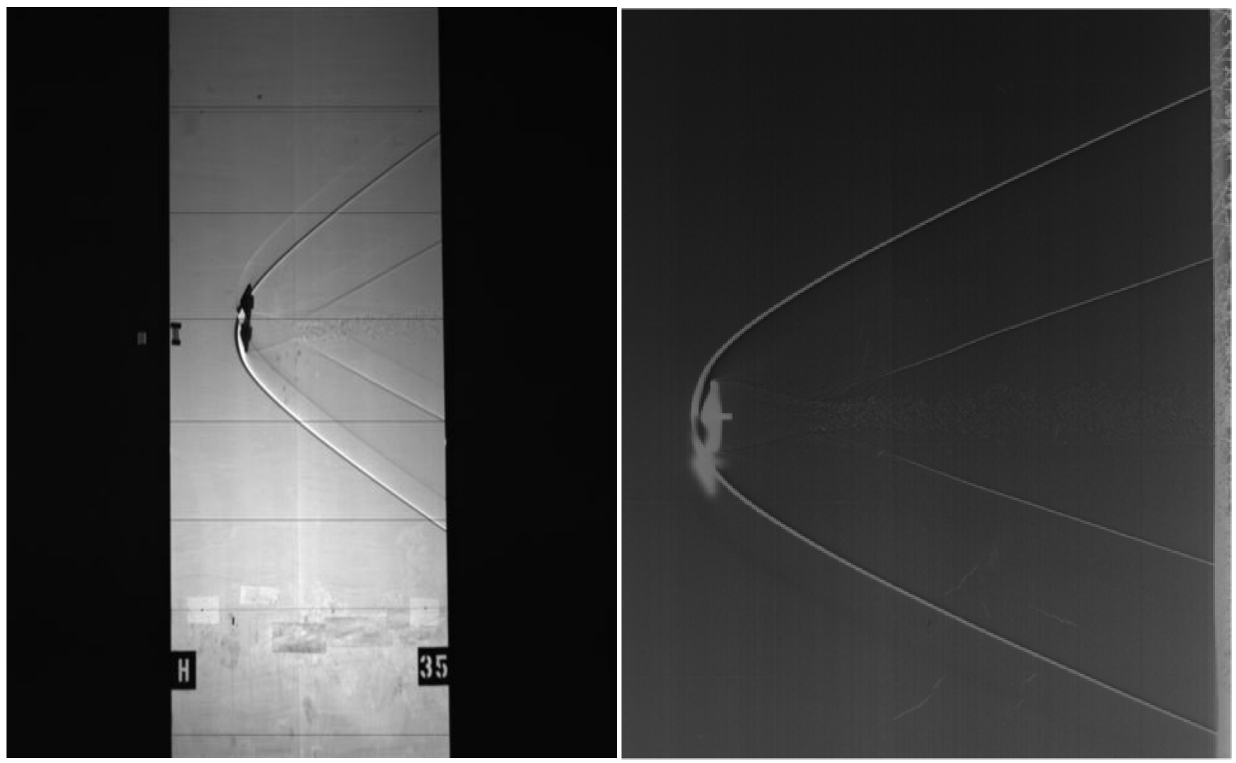
- **Test Conditions**
  - Achieved by variation in sled angle of attack
  - High surface pressures
  - Mission relevant heat flux (4 – 40 W/cm^2)

Ballistic Range Testing

- Tucked body vehicles have shown best dynamic stability
- No (or minimal) aftbody for flow to impinge on
- How tucked does aftbody need to be?
- Testing to examine variations is vehicle dynamic stability due to changes in aft-body aspect ratio (cylinder diameter to height)
- Testing also to examine dynamic stability benefits of sharpening shoulder radius







PAIDAE Status

- **Ballistic Range Testing**
  - 40 test shots to be conducted
  - Test Completed July 9
- **8' High Temperature Tunnel TPS testing**
  - Test Planning, Coupon/Sled Fabrication underway
  - Testing expected to commence in late-August / early-September
- **Studies**
  - Roadmapping kick-off at LaRC in late May
  - Application & Structural configuration studies underway

Relevance to Rapid Eye

- **Low Ballistic Coefficient Inflatable Decelerator may be a solution for meeting the Rapid Eye Entry requirements**
- **Some technology development work has been done in this area, but is a low TRL technology**
- **Technical Risks**
  - Aeroshell Packing
    - Aeroshell damage
    - Mass properties / c.g. offset
  - Aeroshell rigidity vs. mass trade-off
  - Inflation system performance vs. volume vs. mass vs. complexity
  - Material Properties at condition
  - Aerothermal elasticity analysis

- **Ten Technology Development Areas**

8. Health Monitoring Systems
9. GNC – Implications of the Inflatable
10. Payload Separation System

Questions?

Airborne Deployment of Wings & Surfaces on Unmanned Air Vehicles

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Unclassified

NRL Small UAVs – 1979 to Present

- 57 Programs
- 230+ Air vehicles
- $160M Navy Technology Investment
- $62M+ Non-Navy Sponsorship

Outline

1. Design Considerations
2. Examples of NRL Technology Demonstrators
    - LODED
    - FLYRT
    - FINDER
    - Extender
    - Matador
    - Adler
    - Spotlight
3. Summary

Design Considerations

Mission Requirements
Gross Weight
Propulsion & Prime Power
Aircraft Configuration

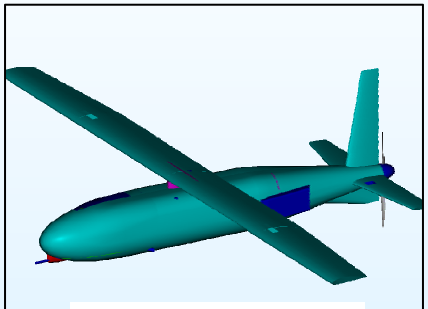
Package Volume
Package Shape
Package Mass
Folding Rigid vs. Inflatable Structure*
Airborne Deployment

All Aircraft

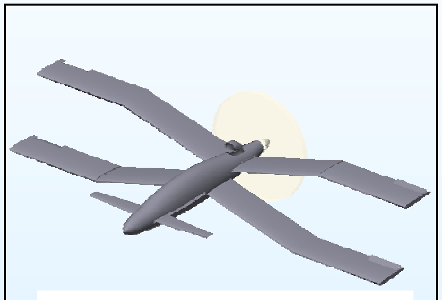
Air-Deployable Aircraft

Aircraft Configuration

Conventional vs. Non-Conventional: What is a Conventional Configuration?

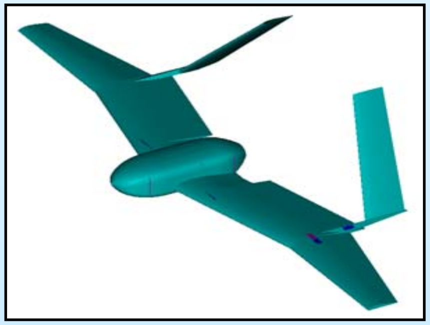


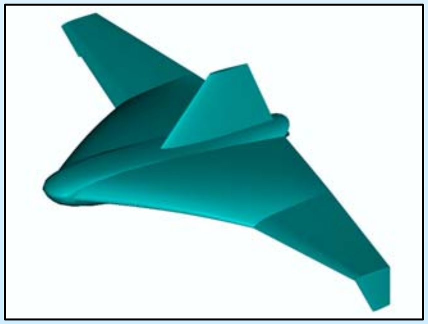
CONVENTIONAL



NON-CONVENTIONAL

What about these?

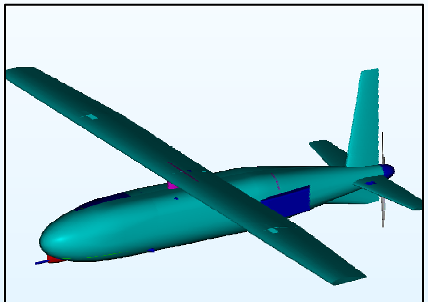




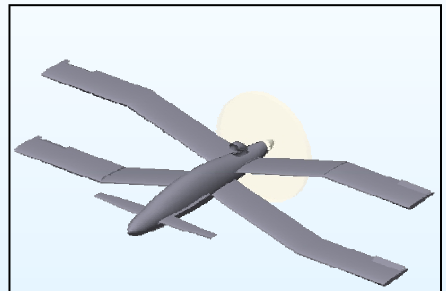
Aircraft Configuration

Conventional vs. Non-Conventional: What is a Conventional Configuration?

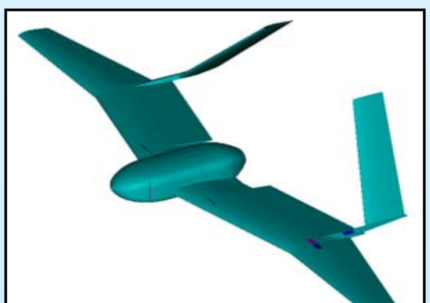
If "Conventional" is defined as vertical and horizontal stabilizers aft of primary lifting surfaces, then…



CONVENTIONAL

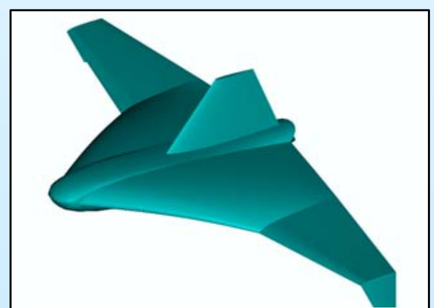


NON-CONVENTIONAL



CONVENTIONAL

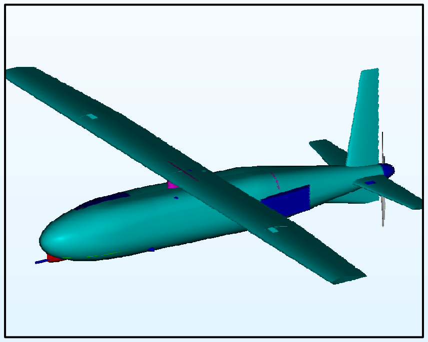
CONVENTIONAL

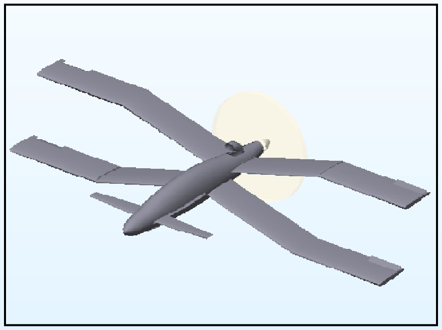


NON-CONVENTIONAL

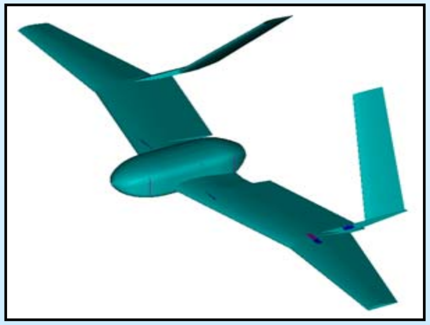
Aircraft Configuration

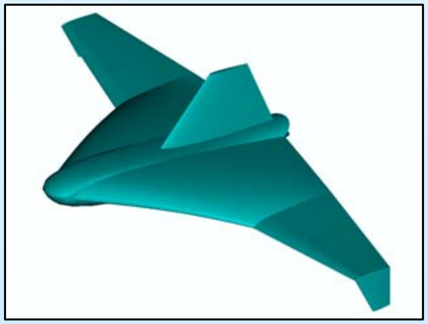
Conventional vs. Non-Conventional: What is a Conventional Configuration?



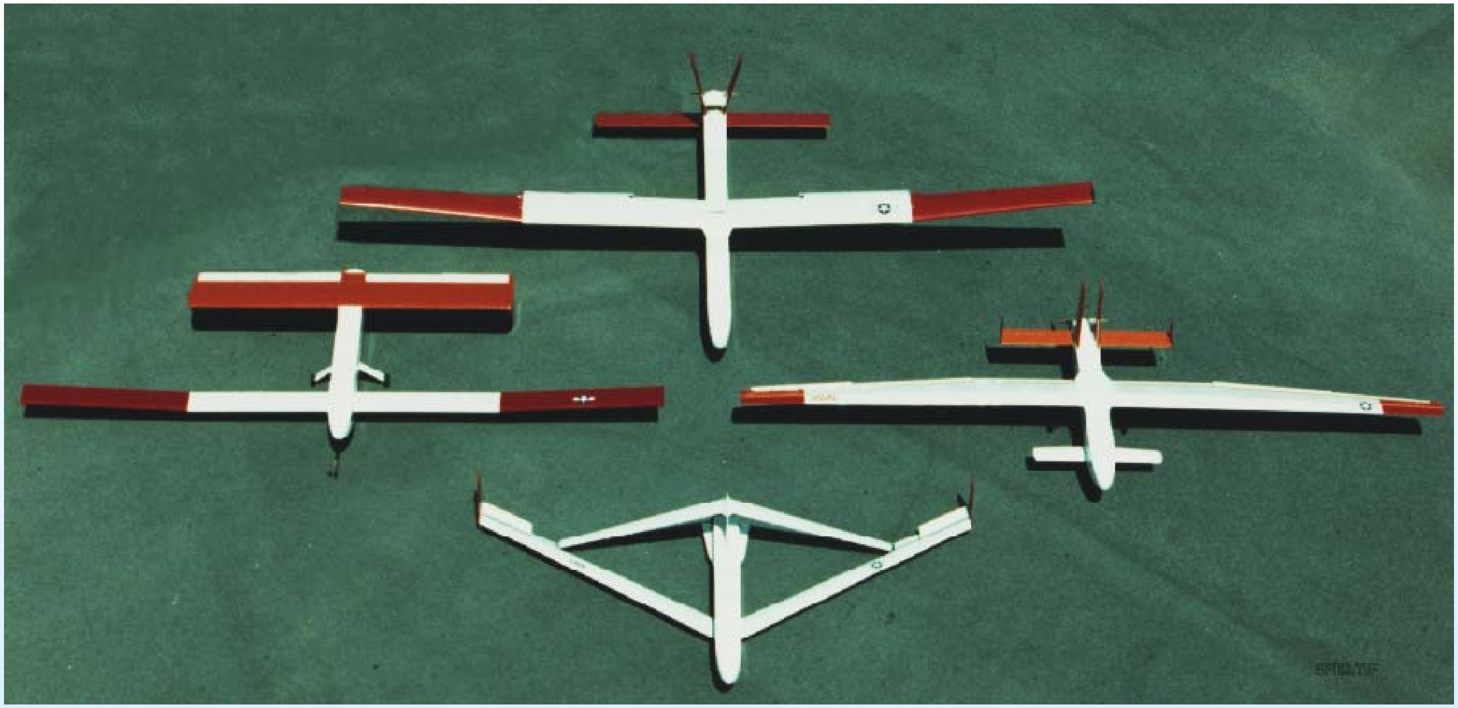


What is the cost to aero performance when packaging/deployment drive Configuration?





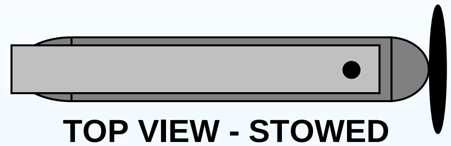
Low Altitude/ Airspeed Unmanned Research Aircraft (LAURA) 1985-1990



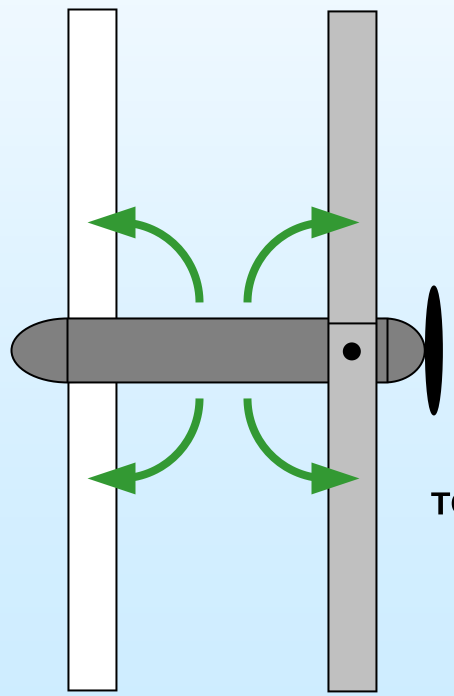
Specifications

Wing Span	15 ft to 26 ft
Gross Weight	45 lb to 60 lb
Mission Payload Weight	15 lb to 20 lb
Maximum Speed	50 kt
Cruise Speed	20 kt to 25 kt
Endurance (est.)	40 hr to 60 hr
Container Size	1.5 ft X 1.5 ft X 6.5 ft

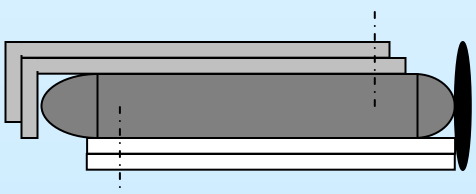
Long Endurance Expendable Decoy (LODED)
1978-1982



TOP VIEW - STOWED



TOP VIEW - DEPLOYED



SIDE VIEW - STOWED

Flying Radar Target (FLYRT)
Advanced Technology Demonstration 1991-1993

Purpose:
- Demonstrate the capability to rapidly deploy from an unmodified MK-36 DLS launcher, a sophisticated electronic decoy for ships defense against advanced RF-guided anti-ship missiles.

Features:
- Low "g" (50 max) solid fuel rocket motor
- 1.5 Hp brushless DC-electric motor
- Silver-Zinc batteries for extended flight endurance
- In-flight deployable wings, tails, propeller, and antenna
- NRL-designed high efficiency molded composite propeller
- Autonomous flight control featuring a state-of-the-art NRL developed low-cost fiber-optic gyro sensor

Flying Radar Target (FLYRT)
Deployment Sequence

NRL Code 5704
25 July 2007

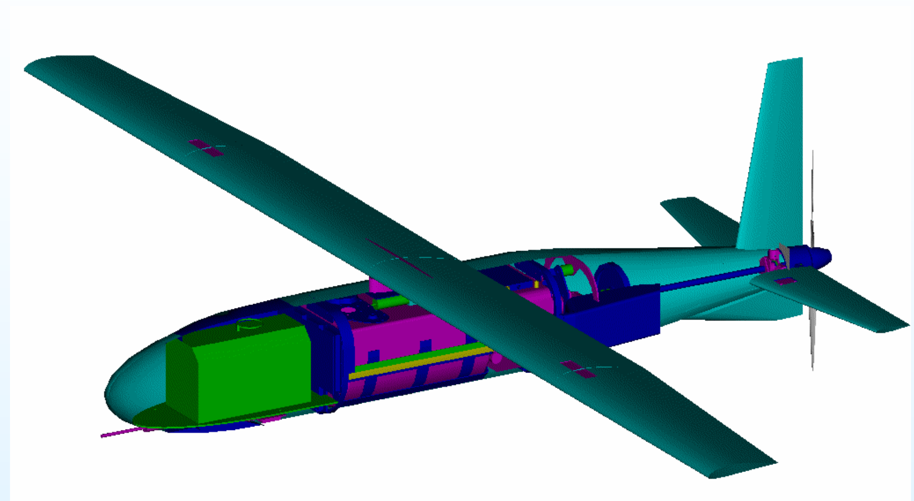
Unclassified

Flight Inserted Detector Expendable for Reconnaissance
2000 - Present

FINDER
DTRA CP-2 ACTD

Post-strike chemical agent point sensor deployed from Predator UAV

FINDER

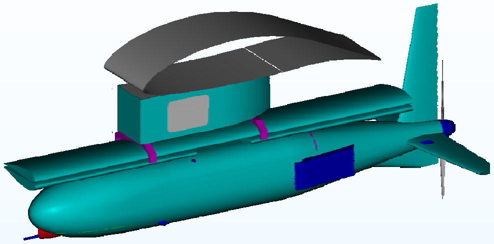


General Characteristics

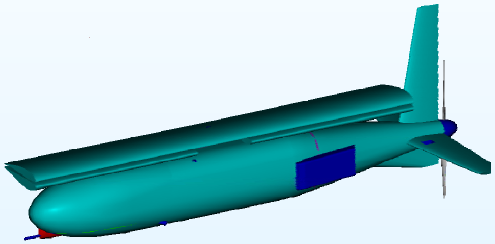
Ingress Range	50 nmi	Wing Area	5.4 ft^2	Length (folded)	65 in
Loiter	2 hr	Aspect Ratio	13.8	(open)	63 in
Egress Range	337 nmi	L/D (cruise)	16	Wing Span	103 in
Cruise Speed	65 KIAS	Gross Weight	60.5 lbs	Fuselage Dia	8.75 in
Loiter Speed	57 KIAS	Payload Weight	11.3 lbs	Power (cruise)	990 W
Maximum Speed	100 KIAS	Fuel Capacity	2.4 gal	(payload+avionics)	200 W

Deployment Sequence

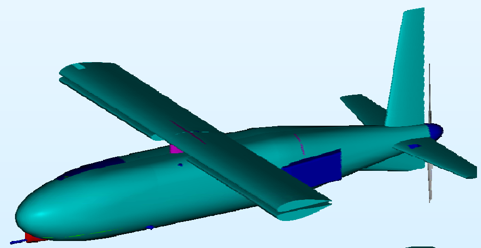
Predator/ FINDER



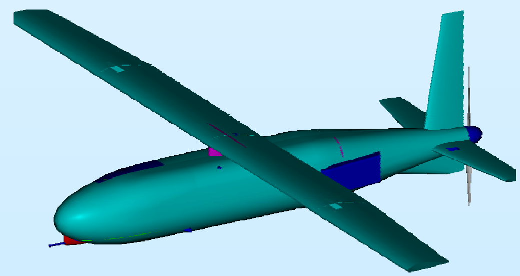
Stowed



Release from Pylon



Wing Pivot



Outer Panels Open

Extender

U.S. NAVY P-3 DEPLOYMENT

NRL Code 5704
25 July 2007

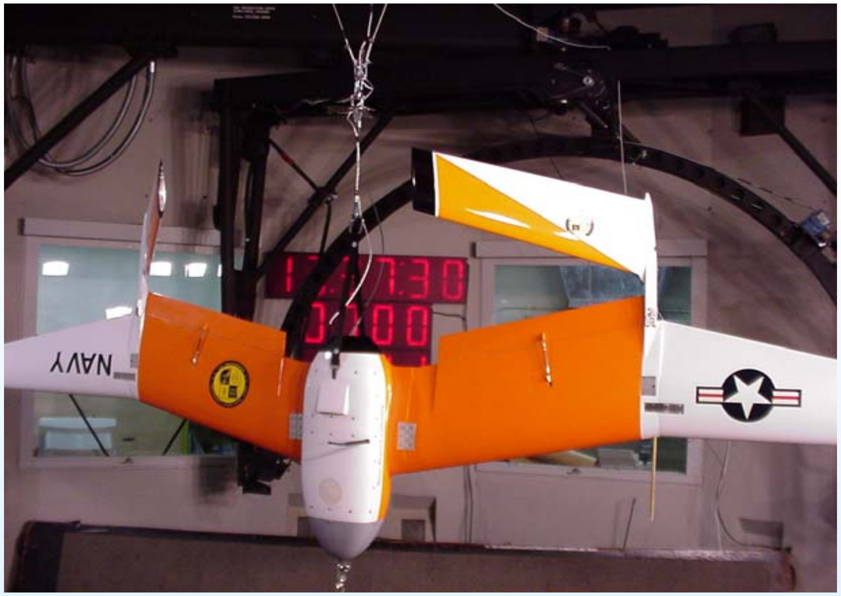
Unclassified

AN 3-30-99

Extender
Air-Deployable UAV 1998-2000

WINGSPAN	10.2 FT	ENDURANCE (Absolute)	2.3 HOURS
OVERALL LENGTH	2.5 FT	RANGE (Absolute)	84 NM.
GROSS WEIGHT	31 LB	CRUISE AIRSPEED	45 KT
PAYLOAD CAPACITY	288 CU IN, 7.5 LB	MAXIMUM AIRSPEED	70 KT
SYSTEM PACKAGES IN	30”x30”x18”	LANDING AIRSPEED	37 KT
AIR DEPLOYMENT	PARAFOIL		

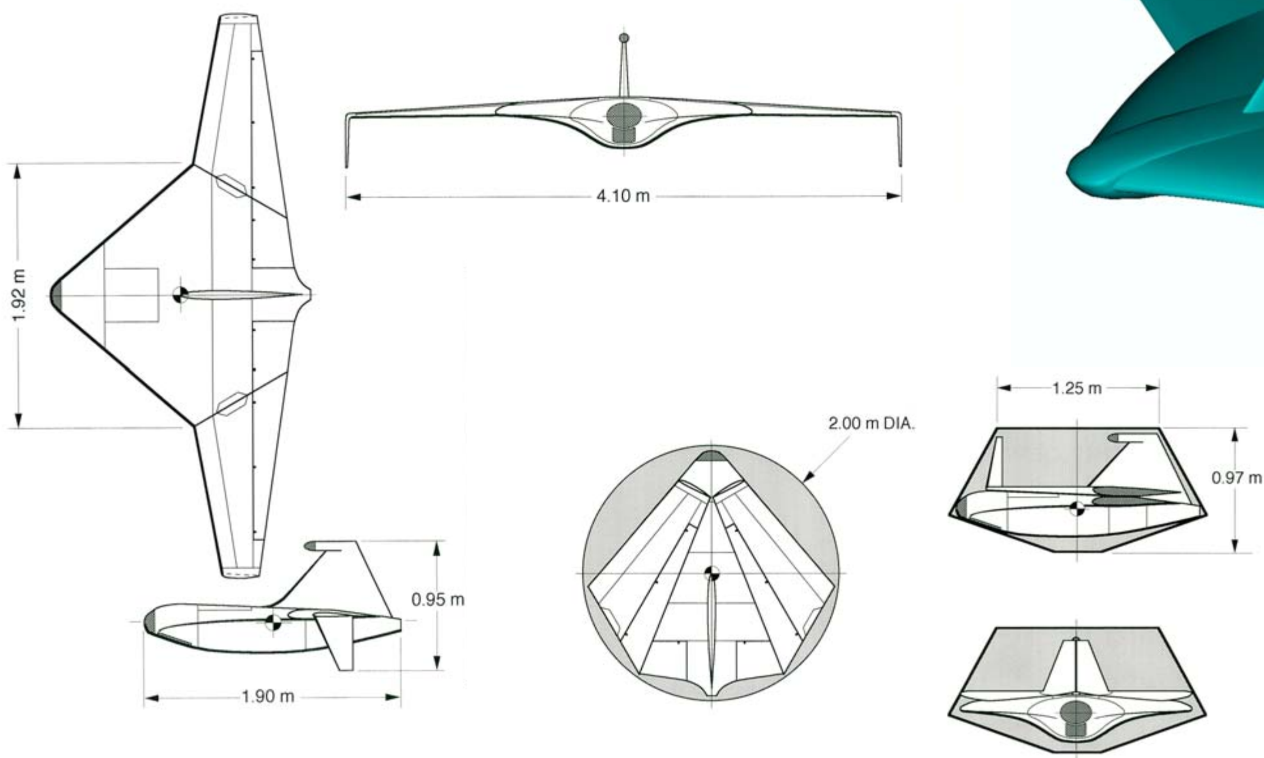
Extender

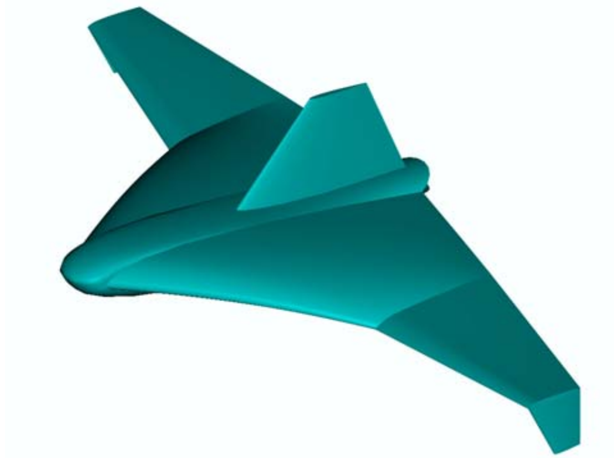


NRL Code 5704
25 July 2007
AN 3-9-99

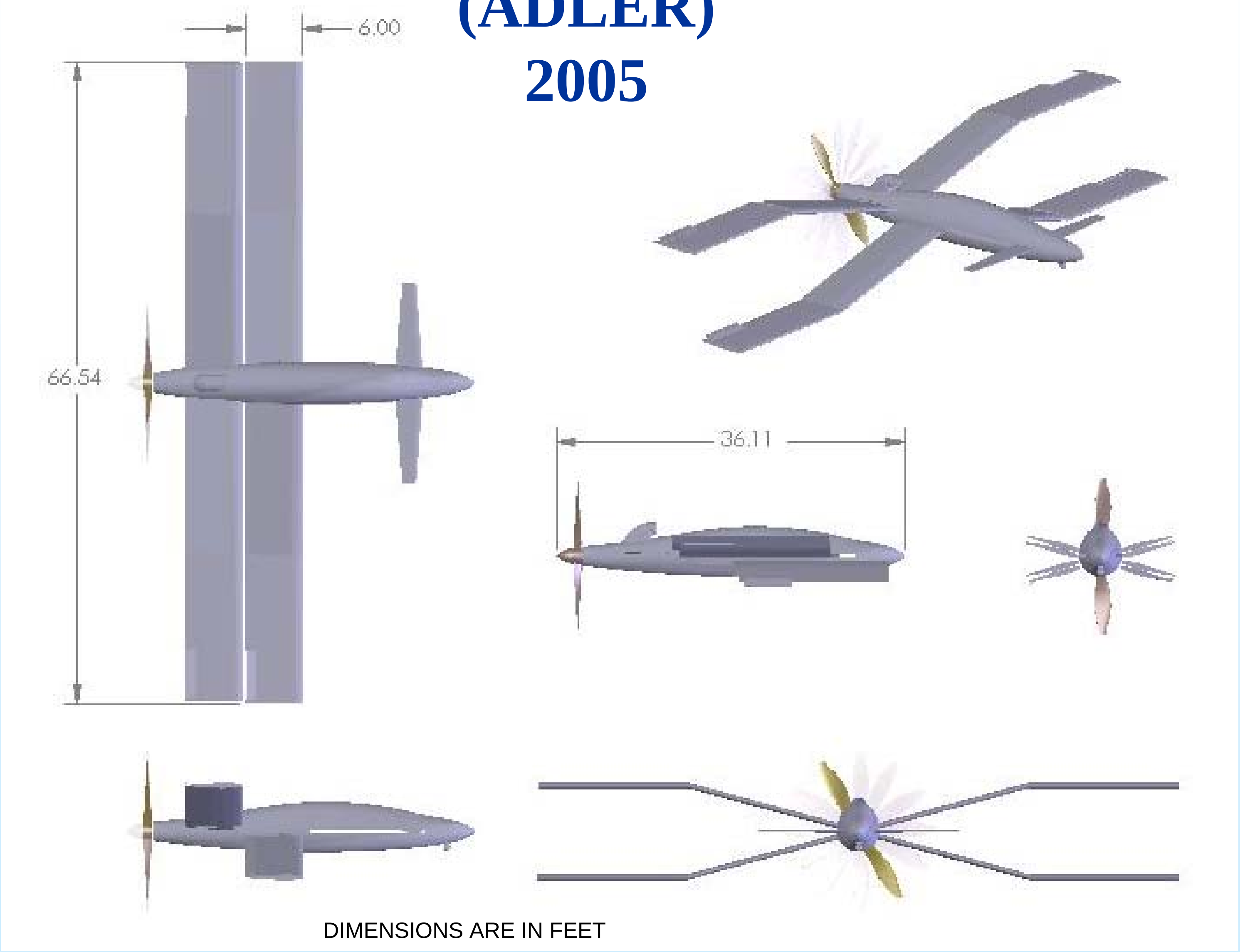
Unclassified

Matador Mars Airplane Design
Packaged within 2.0 m diameter EV
2003 - Present



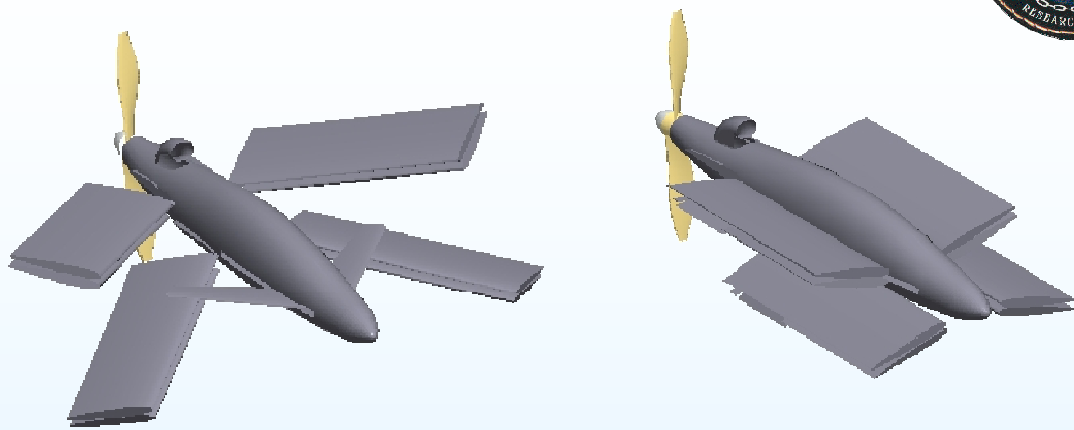


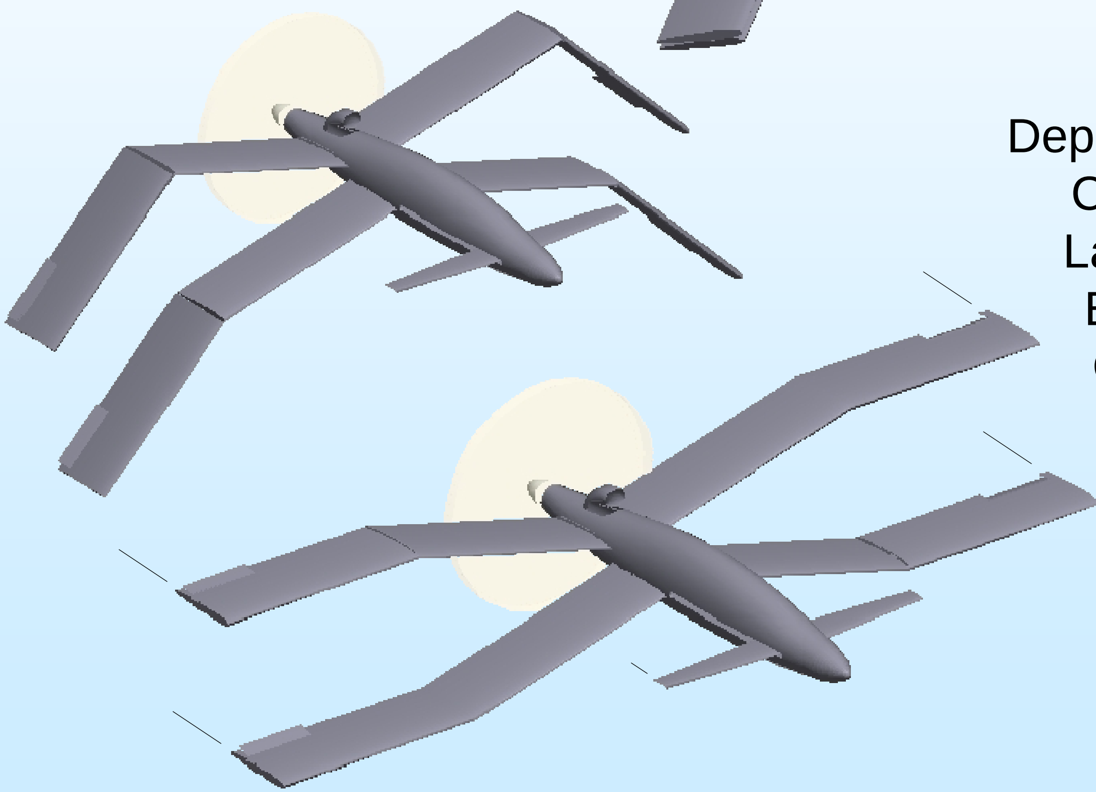
Air Deployed Long Endurance Reconnaissance (ADLER) 2005



Unclassified

ADLER Deployment

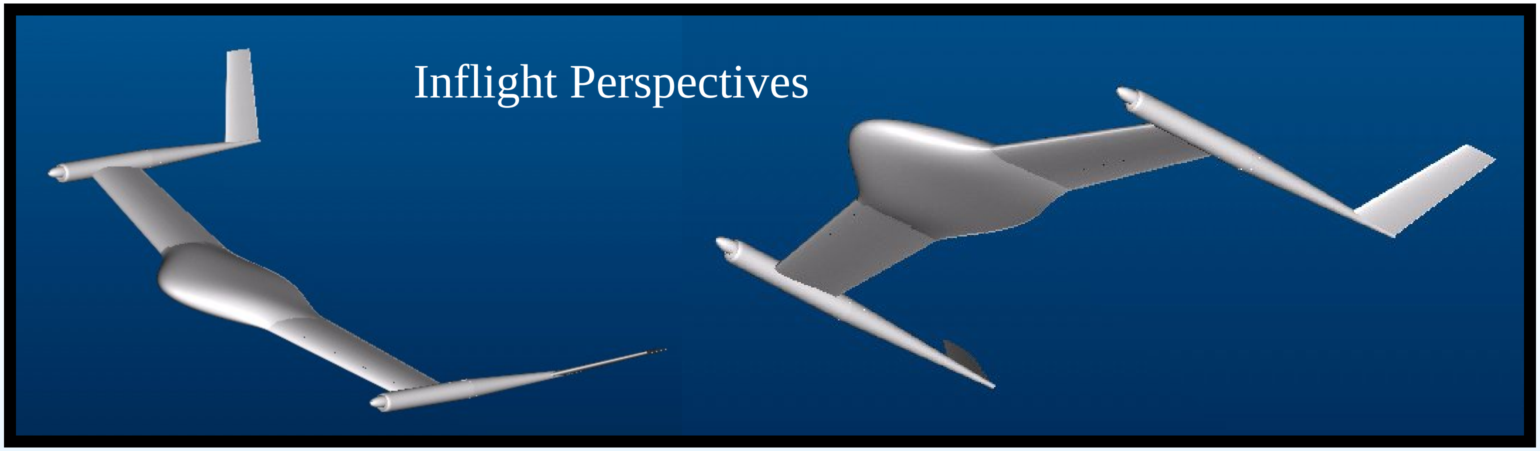


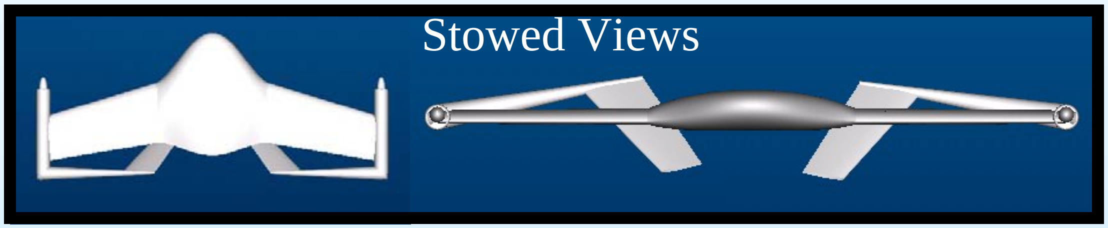


Characteristics

Deployed Altitude:	54,000 ft
Cruise Altitude:	65,000 ft
Launch Weight:	7,500 lbs
Empty Weight:	1,875 lbs
Cruise Speed:	240 KTAS
Endurance:	6 days
Payload:	250 lbs
Wing Span:	66 ft
Length:	36 ft

Spotlight (2004)





General Characteristics

Ingress Range	10 mi	Wing Area	4.2 ft^2	Box Size (folded)	
Loiter	28 min	Aspect Ratio	6	62.5 x 26.5 x 9.5 in	
Egress Range	10 mi	L/D (cruise)	11	Power	
Cruise Speed	50 mph	Gross Weight	12 lbs	propulsion	142 W
Loiter Speed	40 mph	Payload Capacity	3 lbs	payload+avionics	50 W

What About Inflatable Structures?

Major advances were made for inflatable aircraft structures during the past decade. Inflatable structures appear to be a viable alternative to unfolding rigid structures for many applications.
NRL has not yet investigated this promising technology.

Potential Advantages
- Increased volumetric packing efficiency enables deployment of a larger wing per a given storage volume
- Easier to pack into cubic or spherical spaces
- System becomes a mass limited before volume limited package

New Design Considerations
- Cannot carry fuel in wing(s) while stowed
- Less deterministic behavior during deployment

Summary

Lessons Learned

- Aircraft configuration has major impact on deployment & packaging (shape, mass, vol.)
- Aircraft configuration has minor impact on aerodynamic performance
- Hinges & pivots are more reliable than sliding or telescoping
- Reliability inversely proportional to the number of deployment events
- Aerodynamic and inertial loads can be exploited to aid deployment
- Packaging folding rigid-structure aircraft becomes volume limited before mass limited

Research Overview: Inflatable-Wing UAVs and BIG BLUE Mars Airplane Project

Suzanne Weaver Smith
University of Kentucky
and
Jamey D. Jacob
Oklahoma State University

July 25, 2007

Outline

Inflatable Wing Introduction

Historical Perspective

Inflatable Wing Research Overview

BIG BLUE Mars Airplane Project Overview

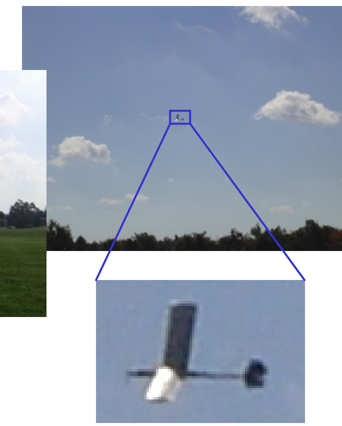
Acknowledgements

Contact Information

Inflatable Wing Introduction

Wing warping for roll control
March 4, 2005

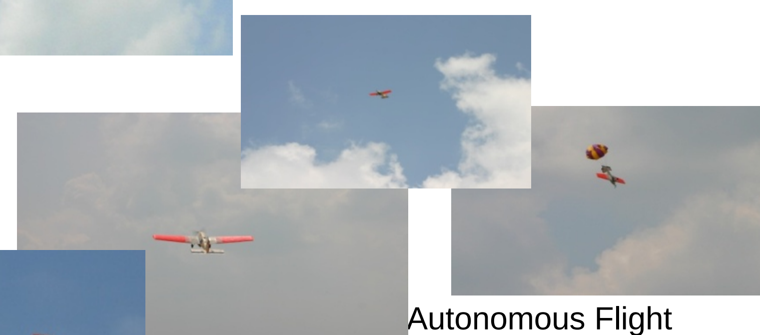
Inflatable/rigidizable wings
October 15, 2003



Backpack UAV
Spring 2006

Flight Testing
Summer 2006

Flight Testing
March 2007



Autonomous Flight
July 3, 2007

University of Kentucky
Oklahoma State University
UAS Partnership

Historical Perspective


Goodyear Inflatoplane 1956-1973

ILC Dover Apteron 1970s

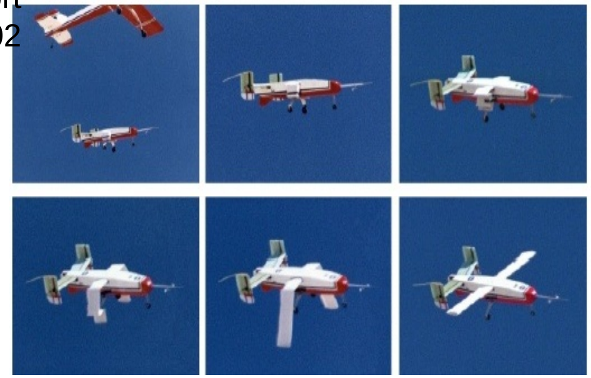
Vertigo
Gun Launched
Observation Vehicle
(GLOV) 2001

Prospective Concepts
Stingray 1998-present

ILC Forward Air Support
Munitions (FASM) 2002

L"Garde Inflatable Antenna
Experiment (IAE) 1996

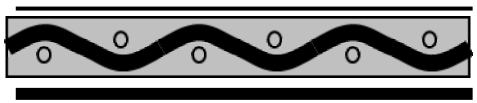
Loitering Electronic
Warfare Killer (LEWK) 2001

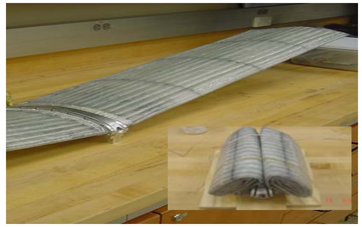


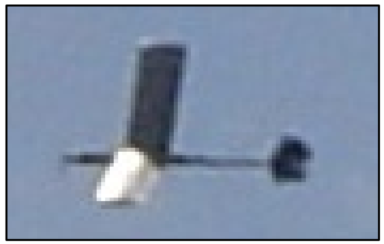
NASA Dryden I2000 2001

Material and Wing Configurations

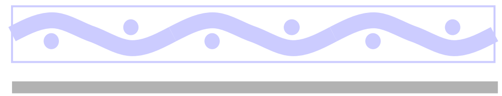
Rigidizable Fabric w/ Bladder and Wrap







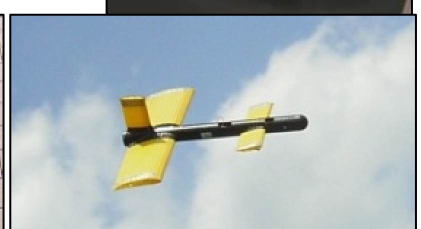
Bladder & Restraint



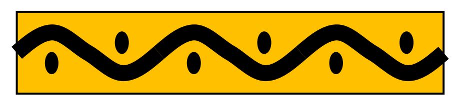
40x40 200d Vectran,10 mil PU

Coated Fabric

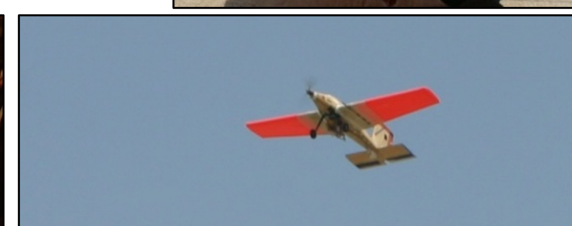
Polyurethane (PU) Coated Nylon



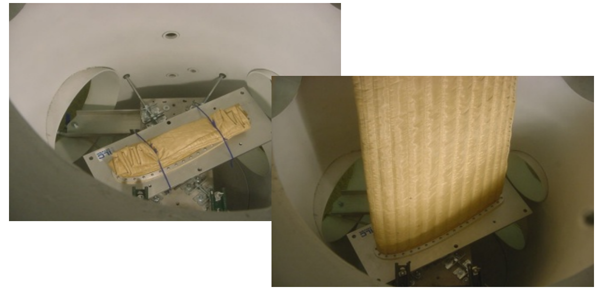
Coated Fabric

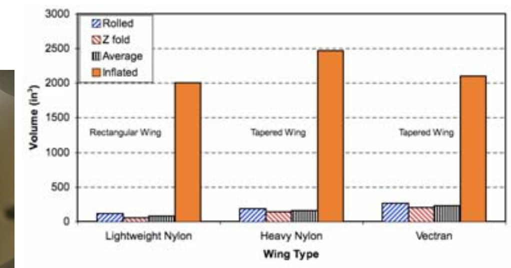


Polyurethane Coated Nylon

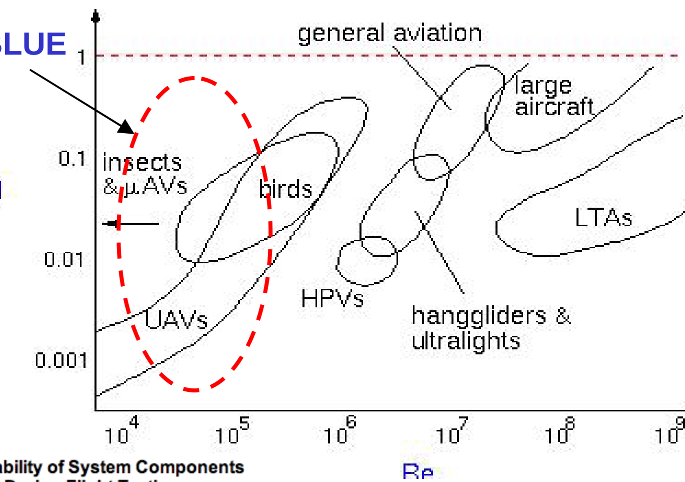


Inflatable Wing Design/Research Topics

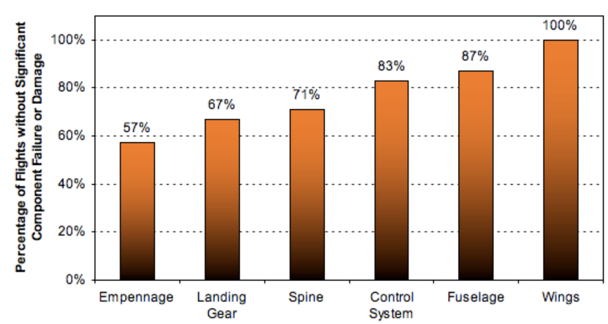




- Small Packed Volume
- Rapid Deployment
- Low Re Aerodynamics
- Wing Warping for Roll Control
- Aspect Ratio Morphing
- Verified Structural Analysis
- Computational Fluid Dynamics
- Demonstrated Survivability



Survivability of System Components During Flight Testing



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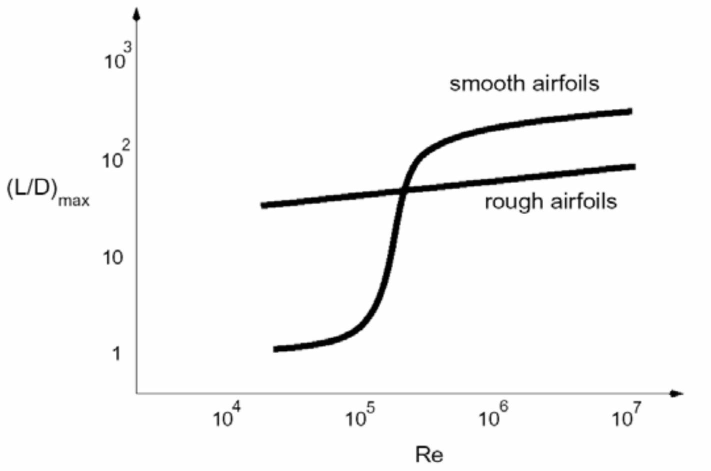
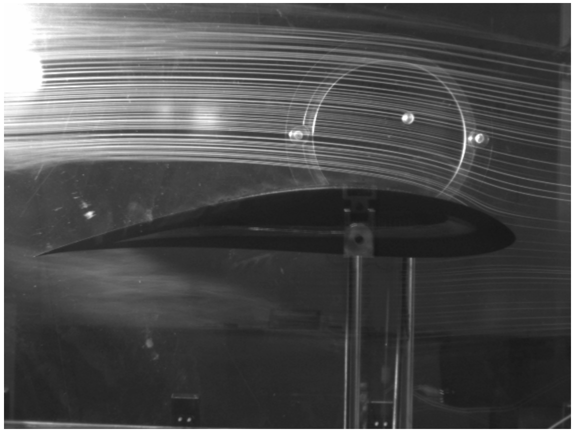
Low Re Aerodynamics

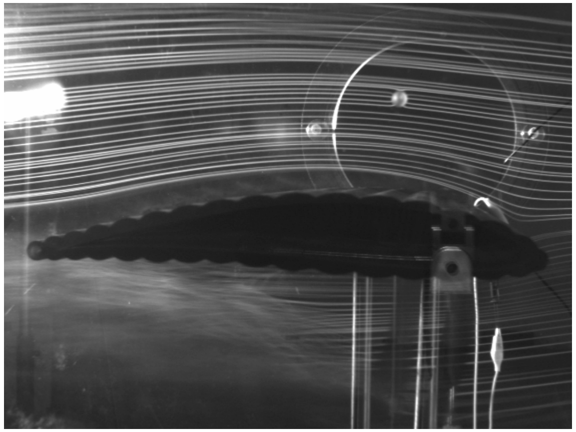
Low Re and Geometry

- Profiles trip flow at low Re to keep flow attached, but can be covered for high speed flight
- Flow visualization by the smoke wire technique in low speed wind tunnel at Re matching high altitude conditions

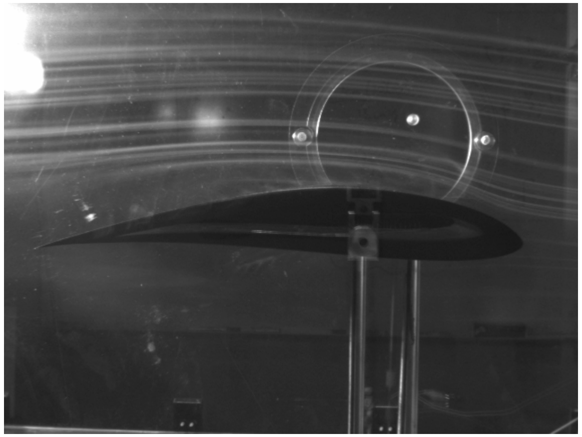




Ideal wing, Re 50,000 AoA=0°

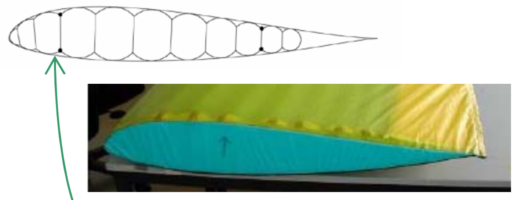


Inflatable wing, Re 50,000 AoA=0°

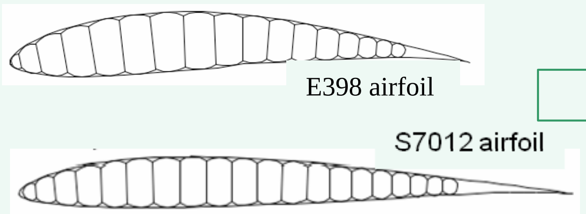


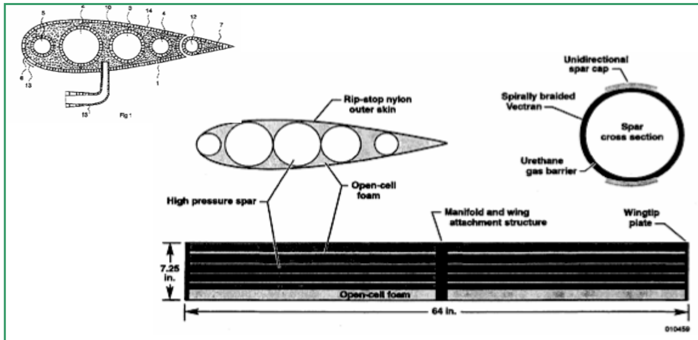
Ideal wing w/ trip, Re 50,000 AoA=0°

Design Considerations

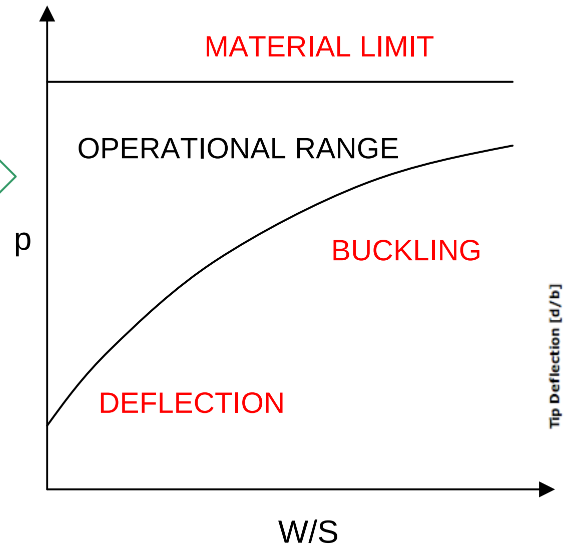


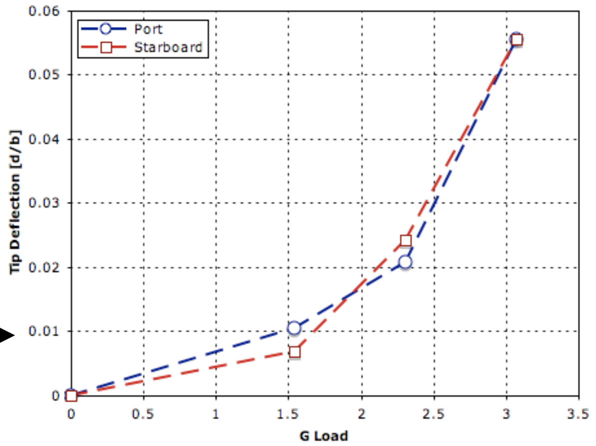
withTensairity structures





- Bending stiffness and wing loading increases as internal pressure increases up to the material limit. Heavier materials allow higher pressures and greater wing loading.





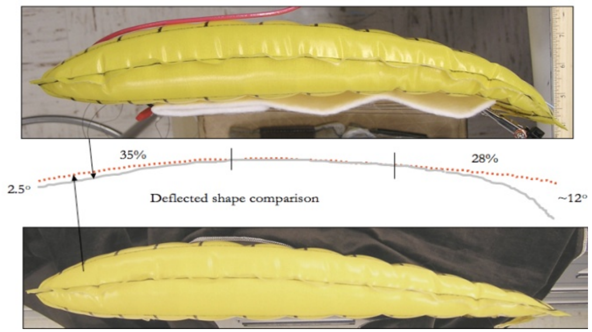
Brown, G. R. Haggard and B. Norton, "Inflatable Structures for Deployable Wings," AIAA-2001-2068, AIAA Aerodynamic Decelerator Systems Technology Conference and Seminar, 16th, Boston, MA, May 21-24, 2001.

Cadogan, D., Smith, T., Lee, R., Scarborough, S., and Graziosi, D. "Inflatable and Rigidizable Wing Components for Unmanned Aerial Vehicles," AIAA No. AIAA-2003-6630, 44th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference, Norfolk, VA, April 2003.

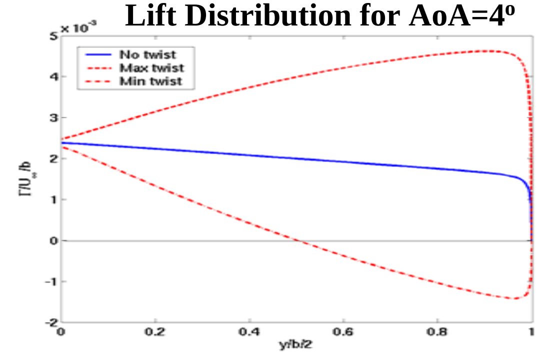
Wing Warping for Roll Control

- Both wing warping and conventional ailerons have been used for roll control, however the former has significant aerodynamic advantages

Warping Using Smart Material Actuators

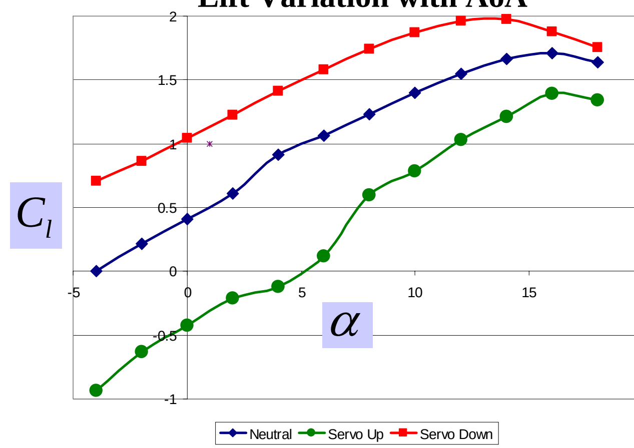


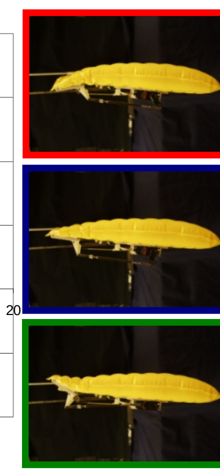
Lift Distribution for AoA=4º



Wing warping for roll control flown successfully March 4, 2005

Lift Variation with AoA



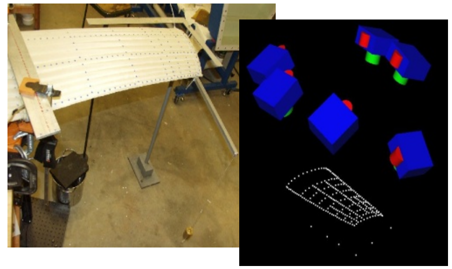


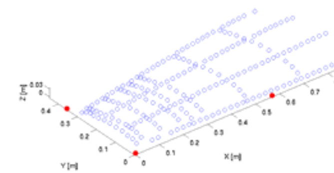
Simpson, A., Jacob, J., and Smith, S. "Flight Control of a UAV with Inflatable Wings with Wing Warping," AIAA-2006-2831, 24th AIAA Applied Aerodynamics Conference, San Francisco, CA, Jun. 5-8, 2006.

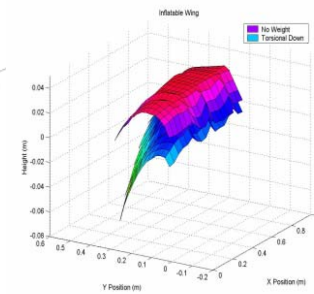
Understanding Inflatable-Wing Warping

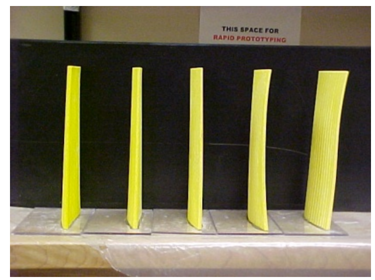
Laboratory testing

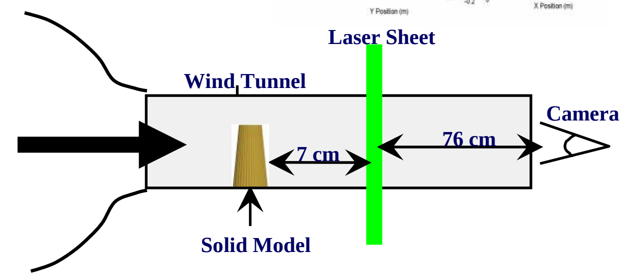
- Deflected surface geometry measured by multi-camera photogrammetry
- Modeling software and 3-D printer constructed solid models for PIV measurements
- Circulation calculated at a range of distances from the vortex center





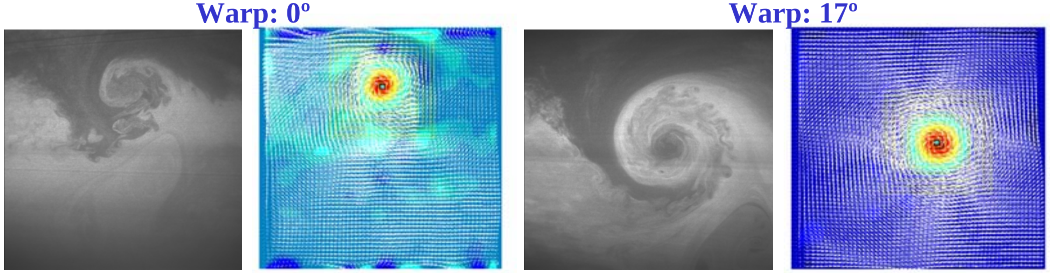


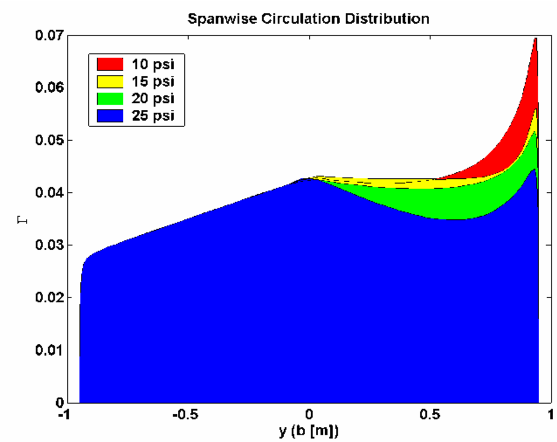




Reynolds Number: $50\cdot10^3$
Angle of Attack: 4°
Warp: 0°

Reynolds Number: $50\cdot10^3$
Angle of Attack: 4°
Warp: 17°



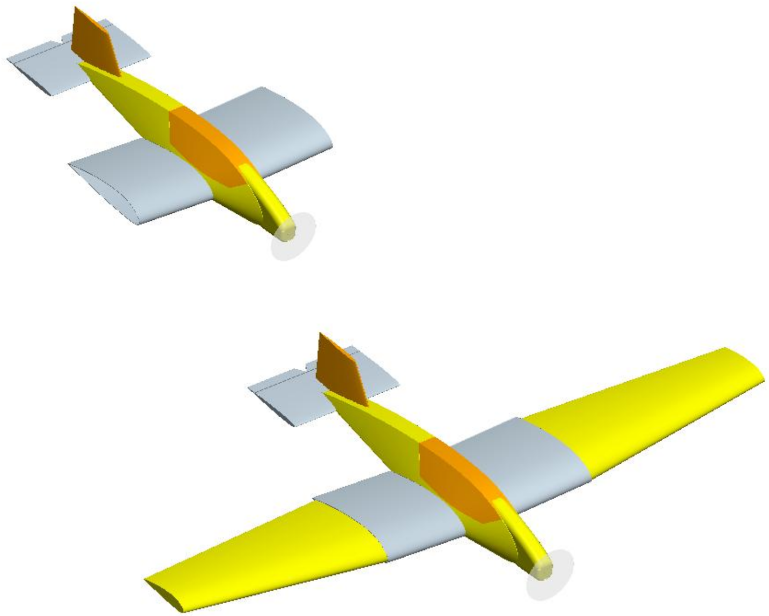


Simpson, A., Smith, S., and Jacob, J. "Aeroelastic Behavior of Inflatable Wings: Wind Tunnel and Flight Testing," AIAA-2007-1069, 45th AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV, January 2007.

Lifting line predictions from 3-D surface geometry show 33% increase in lift at 10 psi and 23% increase in lift at 20 psi

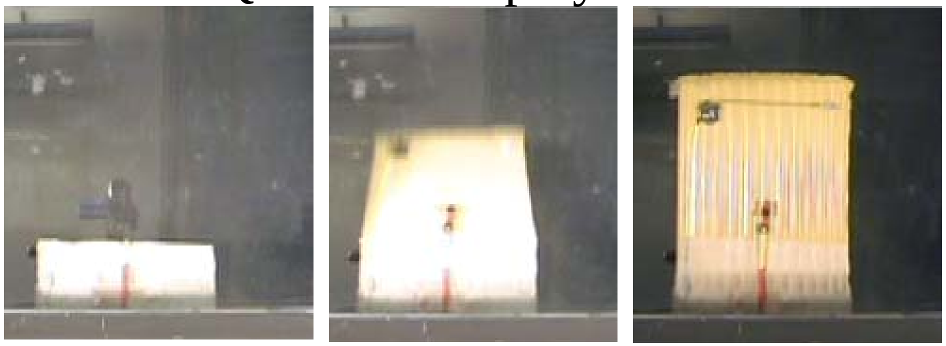
Aspect Ratio Morphing

- Deployment Concept



Wind-tunnel deployment experiments
Oklahoma State University
Summer 2007

Quiescent Deployment



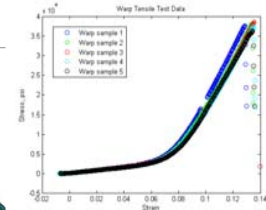
Deployment at 64 kts

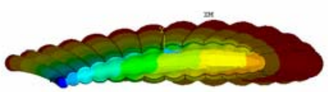
Cadogan, D., T. Smith, F. Uhelsky and M. MacKusick, "Morphing Inflatable Wing Development for Compact Package Unmanned Aerial Vehicles," AIAA 2004-1807, 12th AIAA/ASME/AHS Adaptive Structures Conference, Palm Springs, CA, April 2004.

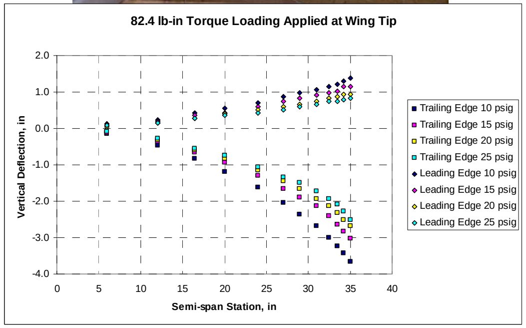
Verified Structural Analysis

Loads and Dynamics Correlation

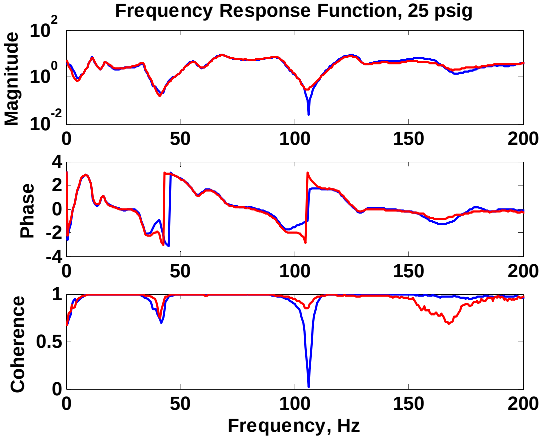
Finite-element models including nonlinear material behavior, internal pressure loading and external warping or aerodynamic loads.

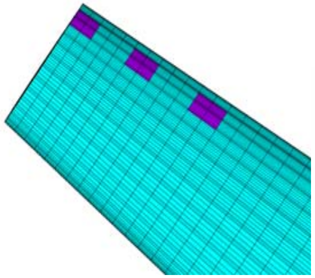


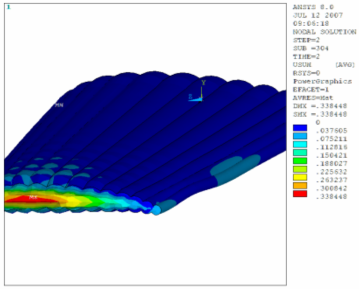


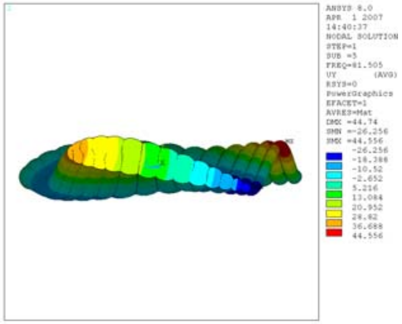


Phased verification using static bending and torsion experimental data, along with modal response.









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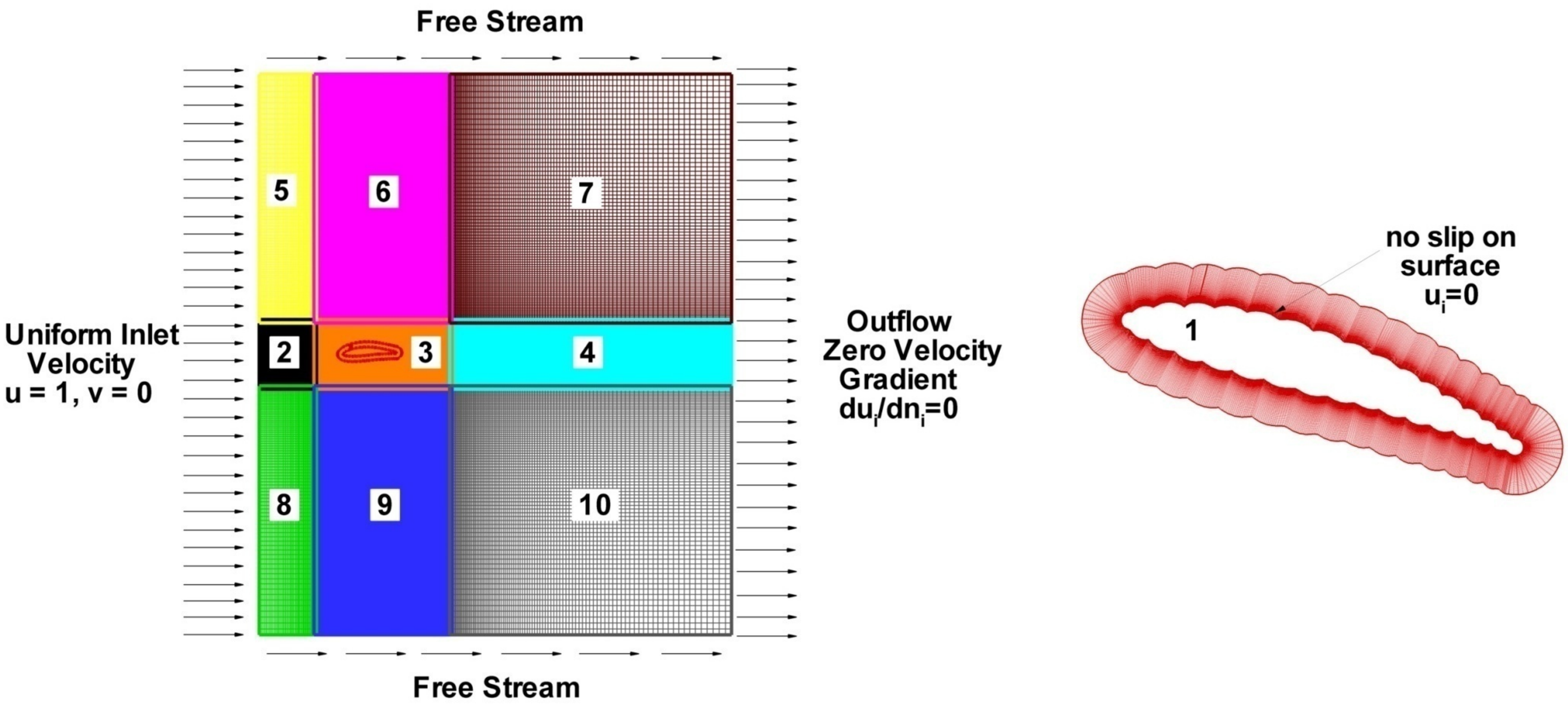
Rowe, J. and S. Smith, "Challenges of Modeling Inflatable Wings," AIAA-2007-1848, 48th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Honolulu, Hawaii, Apr. 23-26, 2007.

Computational Fluid Dynamics



Reasor, D. and R. LeBeau, "Numerical Study of Bumpy Airfoil Flow Control for Low Reynolds Numbers," AIAA-2007-4100, 37th AIAA Fluid Dynamics Conference, Miami, FL, June 25-18, 2007.

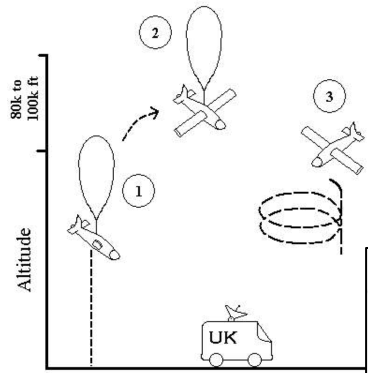
BIG BLUE Project

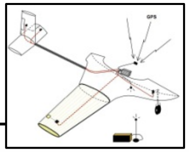
A NASA Workforce Development Project

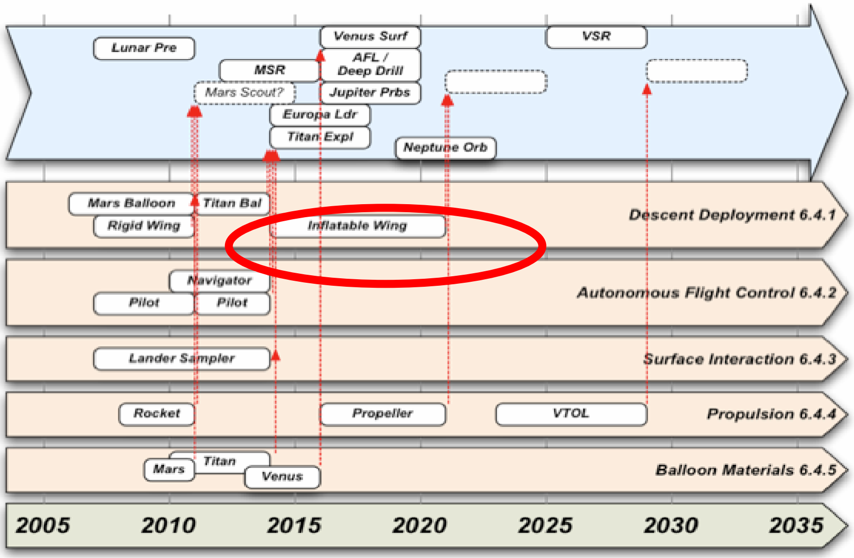
Including design, testing, flight and data analysis of a complex aerospace prototype experiment for experience with multidisciplinary (and multi-university) teamwork and systems engineering

Project Objectives: 1) To verify the feasibility of inflatable wings for Mars exploration, 2) To conduct phased high-altitude and flight testing to demonstrate the successful inflation and flight of high-quality wings capable of use in an autonomous aircraft in the Martian environment and 3) To learn to fly – 100 years after the Wright Brothers

Related UAS Technology R&D: 1) To develop and verify autonomous flight capability with only tail control and with wing warping or wing control surfaces and 2) To develop and evaluate new approaches for laboratory and flight testing, for modeling and analysis and for design of reliable small UAVs







August 2005 – Release of NASA Science Directorate Report on Technologies for Planetary Exploration which includes inflatable wings at **TRL 4-5**

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Oklahoma State University
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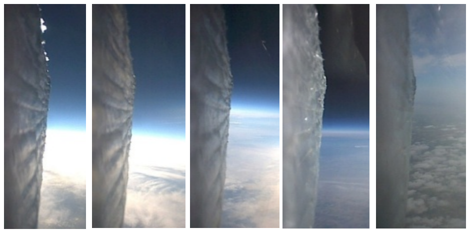
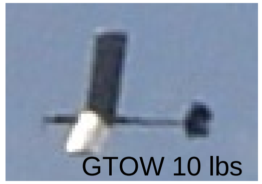
BIG BLUE Project

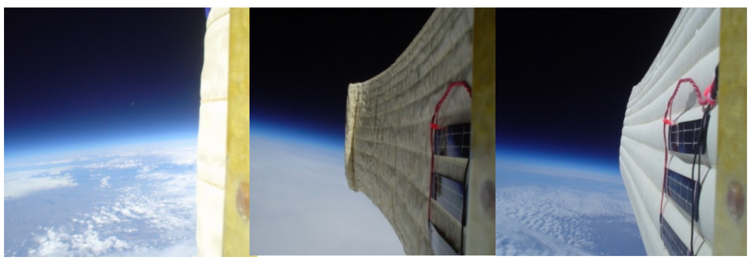


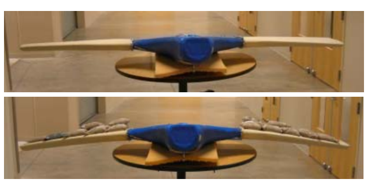
58,000 ft 63,000 ft 86,000 ft 89,000 ft 17,000 ft



GTOW 10 lbs

GTOW 14 lbs





GTOW 39 lbs

Accomplishments

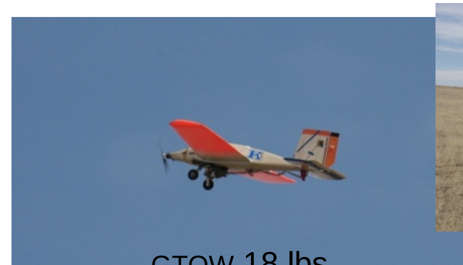
2003: 55k-89k deployment of UV-rigidizable wings (*Space News*, 5/19/2003); flight testing of inflatable/rigidizable wings

2004: 55k-60k deployment of UV-rigidizable wings (Smithsonian *Extreme Textiles* exhibit, 2005)

2005: 95k deployment of Vectran wings; design and flight testing of AIRCAT rigid-wing aircraft (NASA TRL 4-5 in Robotic Exploration report, 2005)

2006: flight testing of AIRCAT w/ inflatable wings

2007: 70k deployment of urethane-coated wings; autonomous flight of inflatable-wing aircraft (Research Channel *Flying on Air,* 2007)



GTOW 18 lbs

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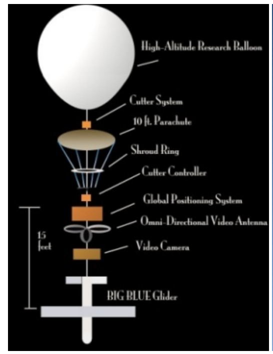
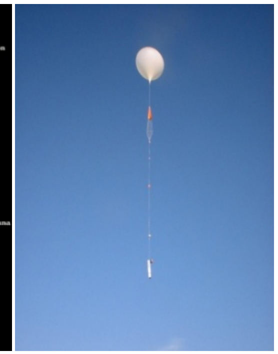
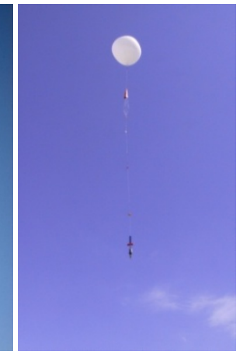
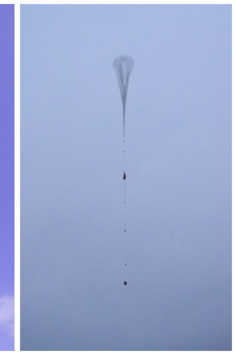
High-Altitude Experiments 2003 - 2007

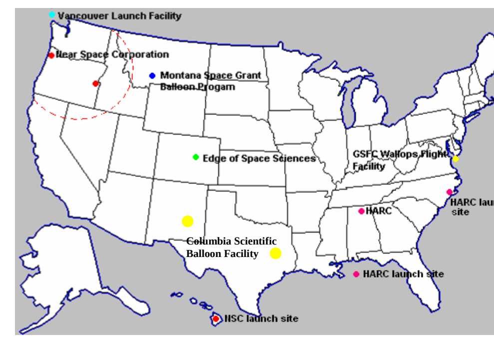


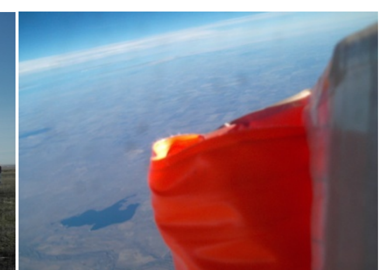






BIG BLUE Balloon Launches





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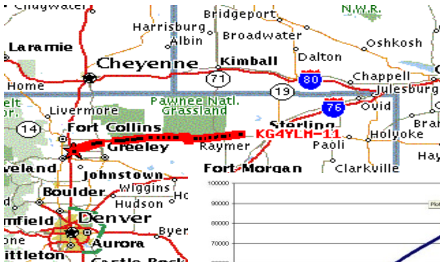
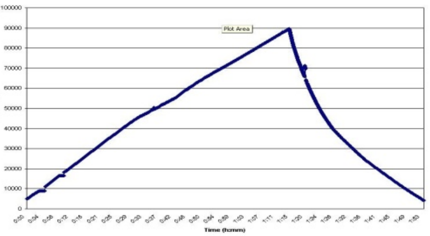
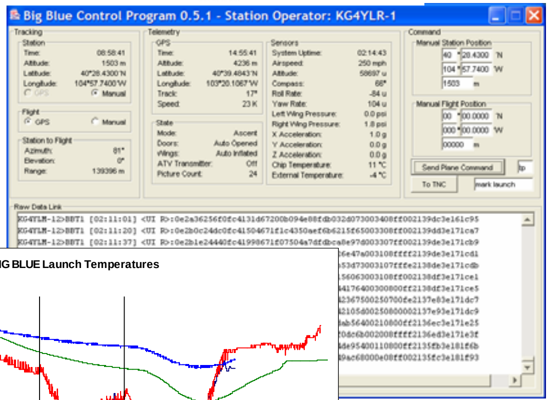
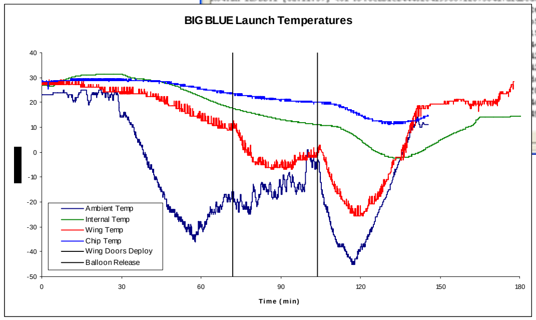
High-Altitude Experiments 2003 - 2007



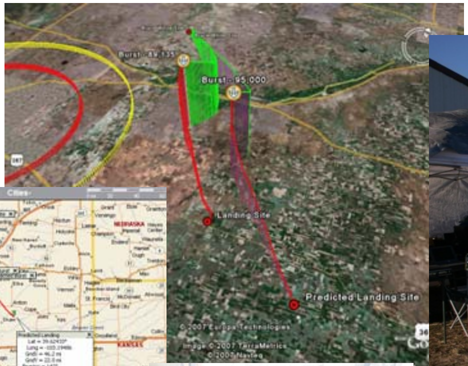
BIG BLUE I
May 3, 2003

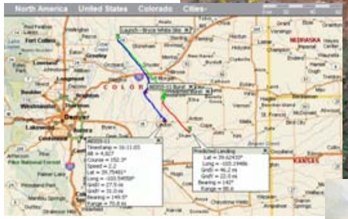






BIG BLUE II
May 1, 2004





BIG BLUE V
March 17, 2007

BIG BLUE On-board Camera Deployment Images

BIG BLUE 3
April 30, 2005

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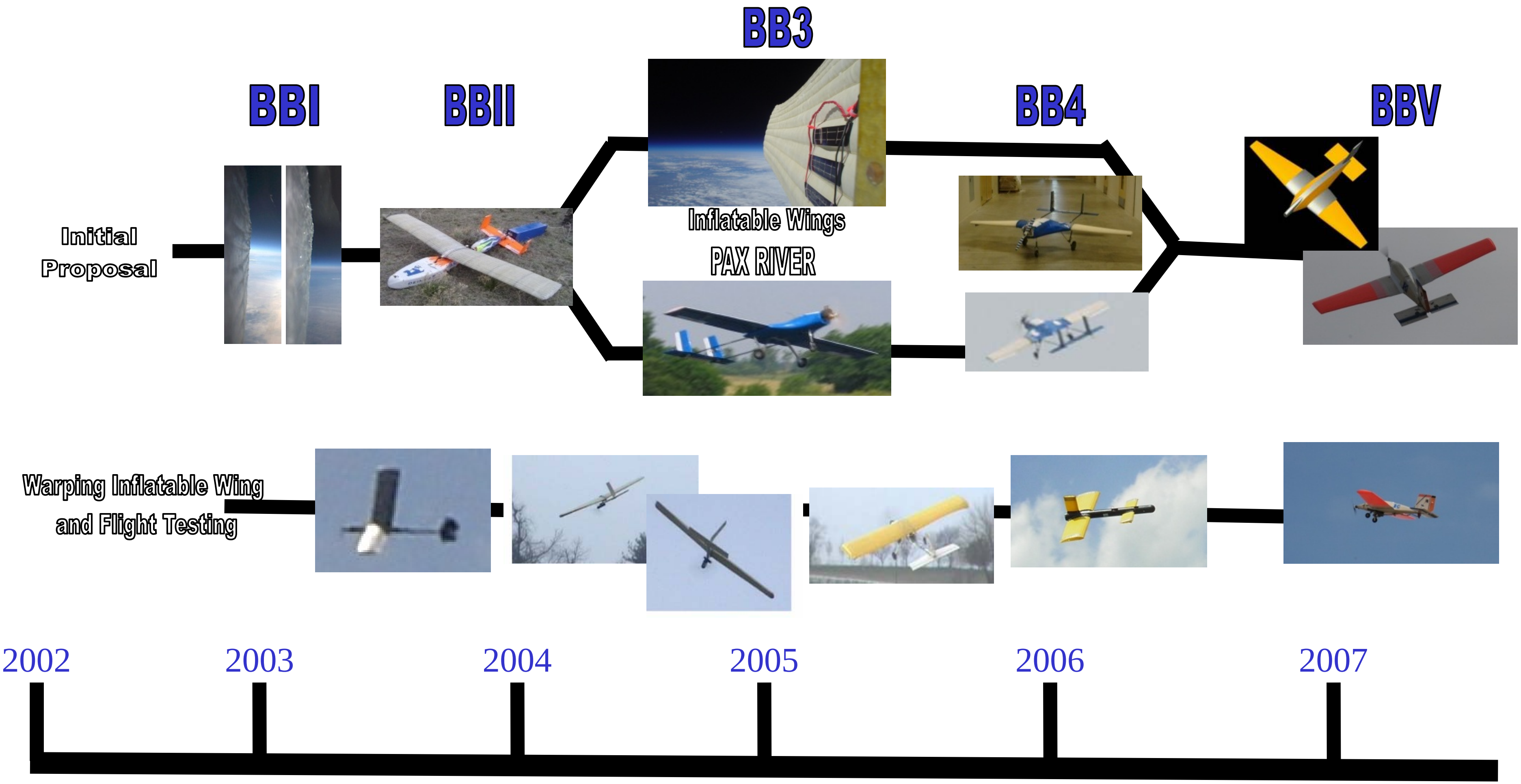
Inflatable-Wing Research Timeline



Acknowledgements

Faculty

- William T. Smith (ECE), Communications
- James E. Lumpp (ECE), Embedded Control
- T. Michael Seigler (ME), Flight Control
- Raymond LeBeau (ME), CFD
- Daniel L. Lau (ECE), Image Processing
- Brent Seales (CS), Archive/Data Base

Sponsors

- NASA/Kentucky Space Grant Consortium
- NASA EPSCoR
- Center for Justice and Safety / Homeland Security

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Oklahoma State University
jdjacob@okstate.edu
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High Altitude UAV Propulsion Options

Christopher A. Kuhl
NASA Langley Research Center

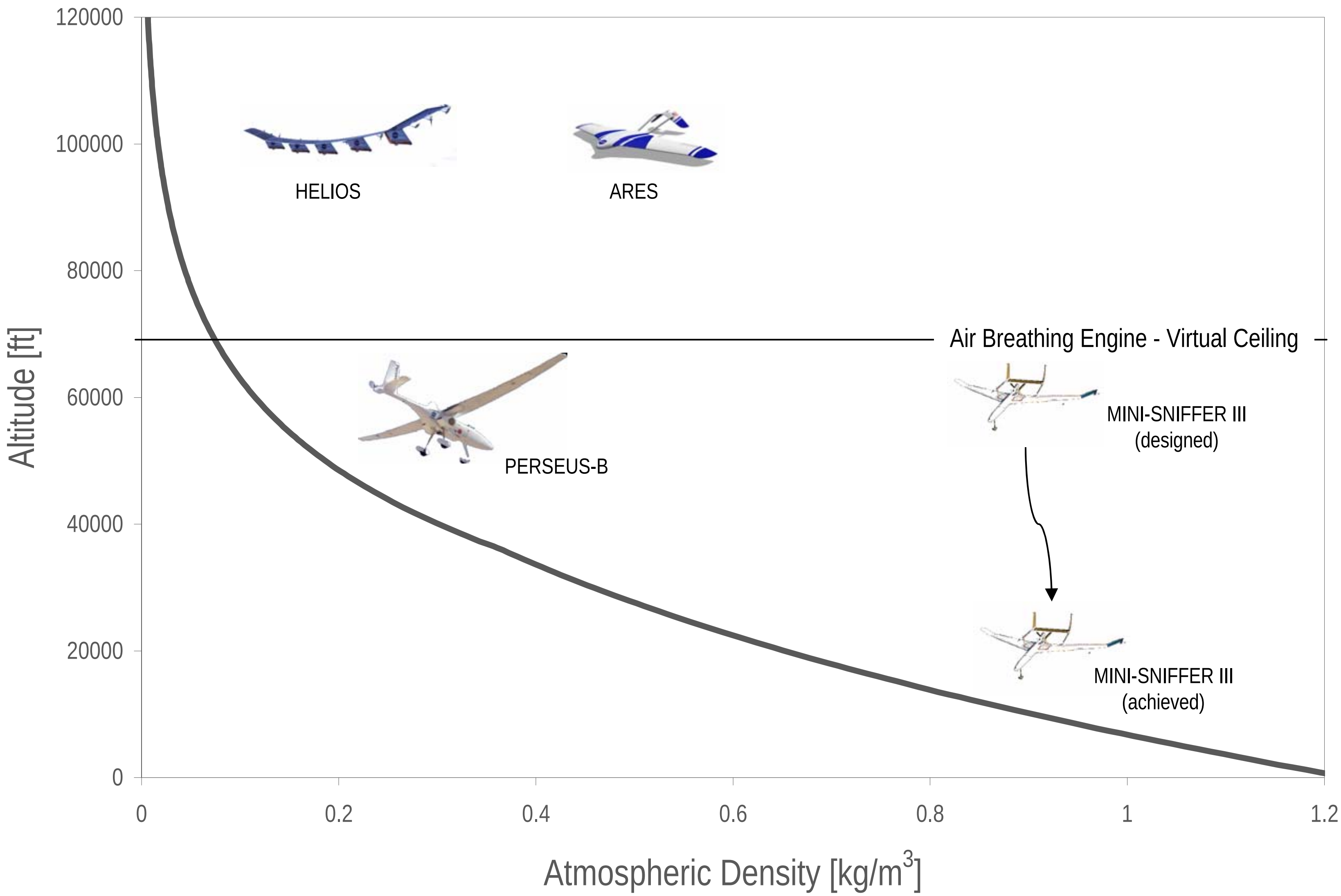
DARPA Rapid Eye Industry Day
July 25, 2007

High Altitude Propulsion Options

- Objective: Examine available propulsion technologies
  - Independent of airplane design (specific performance)
  - Moderate to high TRL technology (TRL > 4)

- Rocket Propulsion
  - Monopropellant Rockets
  - Bipropellant Rockets
- Propeller Driven
  - Electric Motors
    - Battery Systems
    - Fuel Cell Systems
  - Combustion Engines
    - Air Breathing
    - Monopropellant (Catalytic fuel decomposition)
    - Bipropellant (Oxidizer carried on-board)

Standard Atmospheric Density



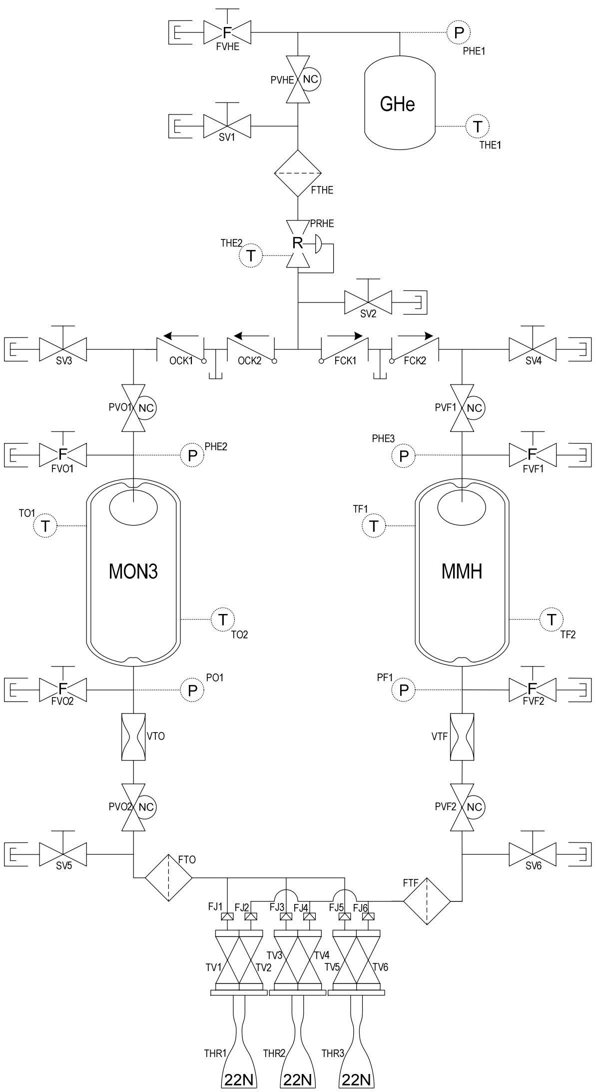
Rocket Propulsion

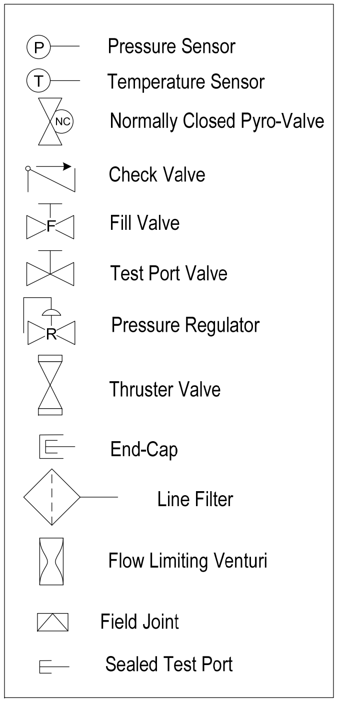
- Highly Reliable but Highly Inefficient!
- Excellent long term storage before activation
- Specific Impulse: 150 – 350 s
- TSFC Ranging from 1000 to 2500 g/hr-N
- ARES Biprop Propulsion System Achieves 1-hr flight on Mars with 48kg Propellants

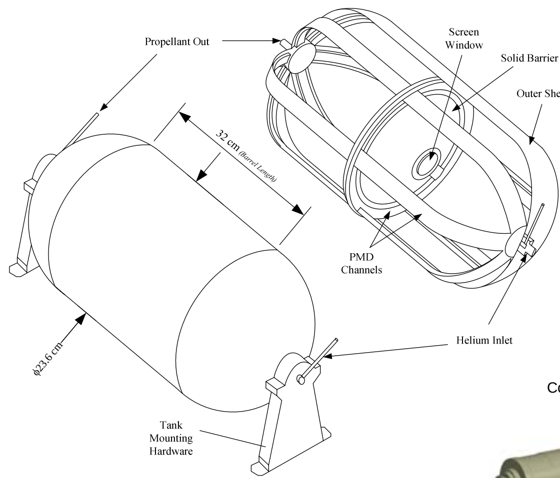
Typical Rocket Propellants

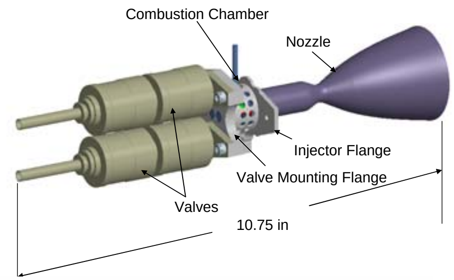
Fuel	Oxidizer	Reaction	Isp (sec)	TSFC (g/hr-N)
Hydrogen Peroxide (98% H_2O_2 2% H_2O)	-	Catalytic	161	2282
Hydrazine (N_2H_4)	-	Catalytic	199	1846
Hydrogen (H_2)	Oxygen (O_2)	Ignition	381	964
RP-1 ($C_{11.74}H_{21.83}$) (Kerosene)	Nitrogen Tetroxide (N_2O_4) (MON3)	Ignition	267	1376
Monomethyl Hydrazine (N_2H_6C)	Nitrogen Tetroxide (N_2O_4) (MON3)	Hypergolic	295	1245
Unsymmetrical Dimethyl Hydrazine ($N_2H_8C_2$)	Nitrogen Tetroxide (N_2O_4) (MON3)	Hypergolic	277	1326

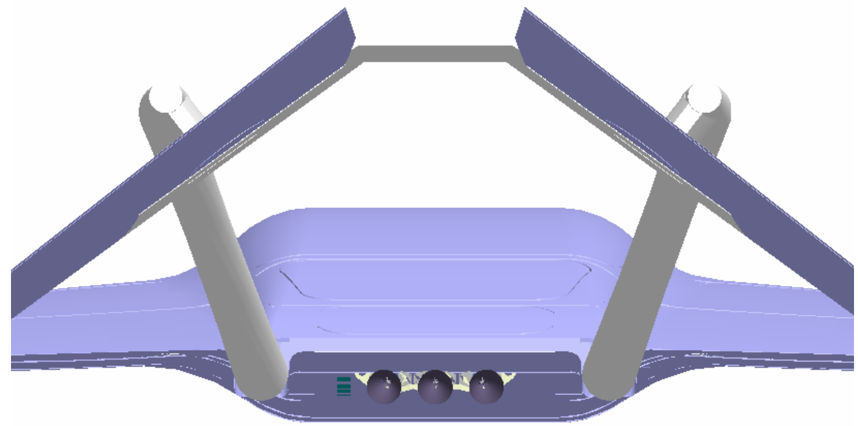
ARES Bipropellant Rocket System



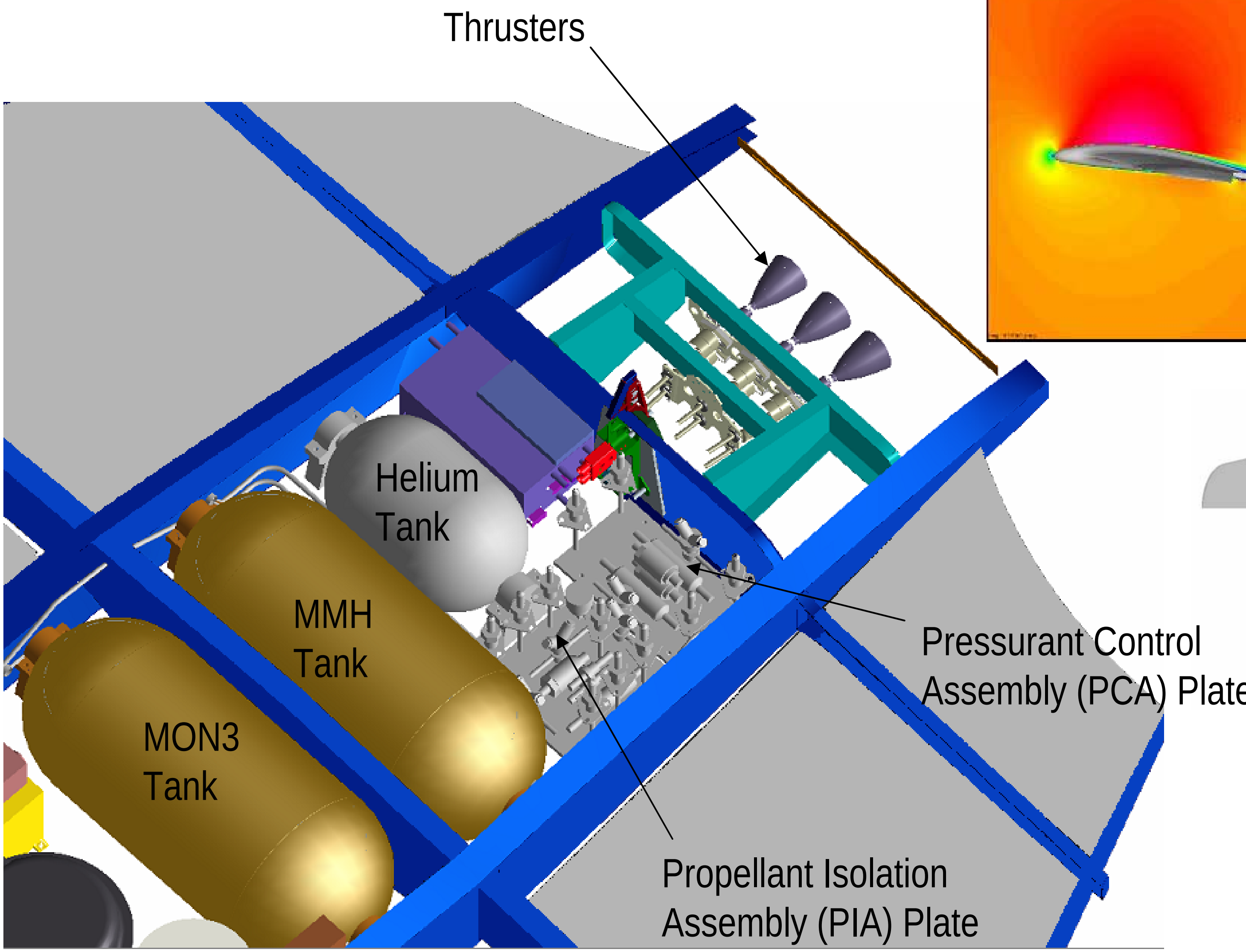


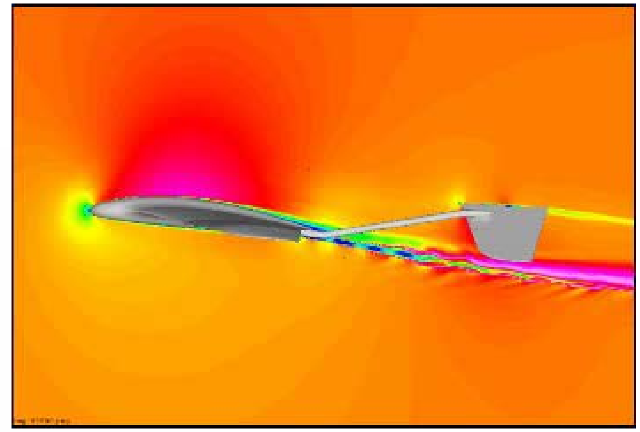


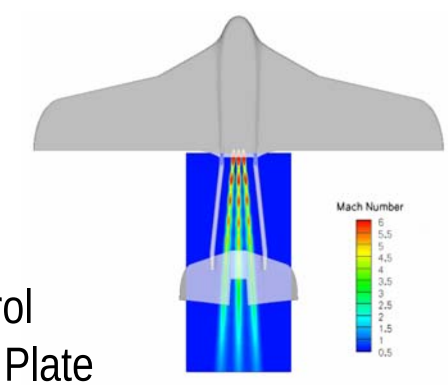




ARES Bipropellant Propulsion System Packaging



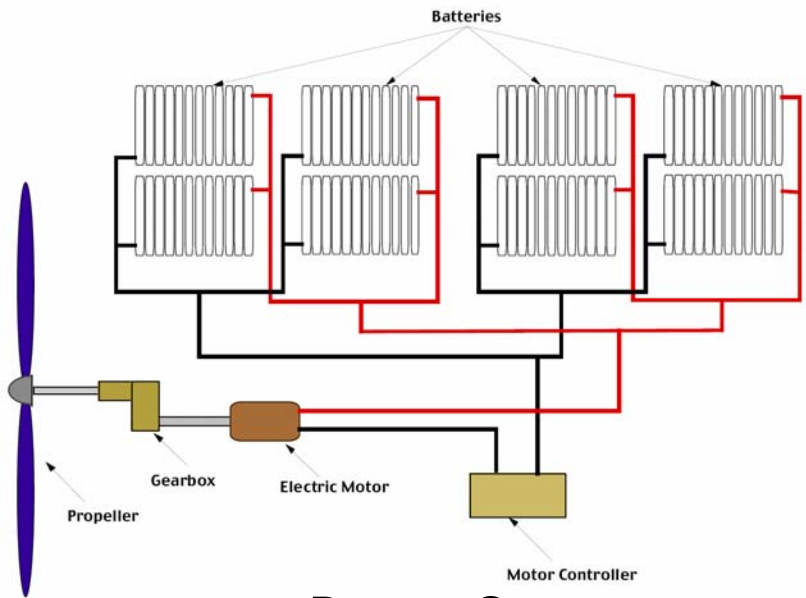




Propeller Driven Propulsion

- Electric Motors
  - Batteries
  - Fuel Cells
- Combustion Engines
  - Fuel / Air combustion (conventional)
  - Fuel / Oxidizer (on-board O_2 or air supply)
  - Hypergolic Propellants (bipropellants)
  - Catalytic Decomposition (monopropellants)

Electric Motor Driven Propulsion

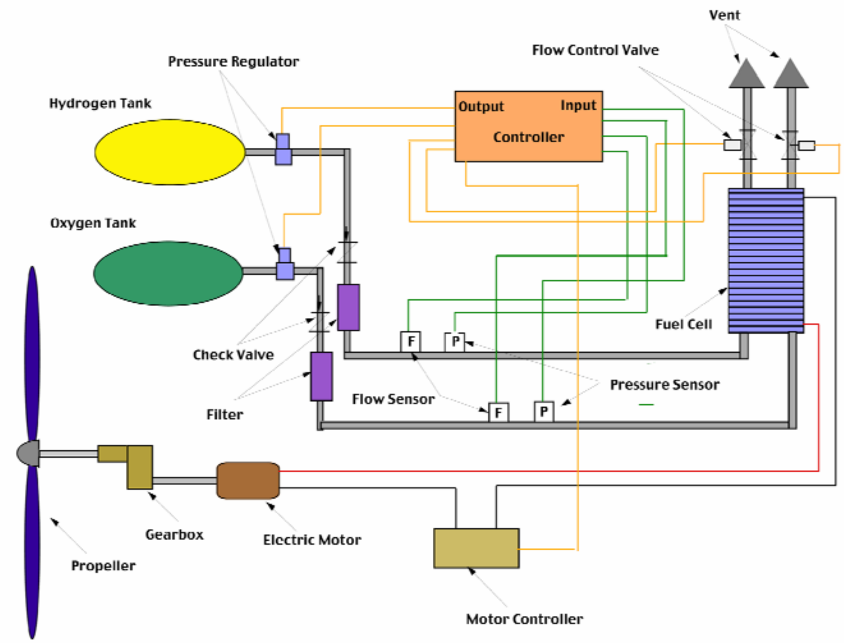


Battery Systems

- High TSFC
- Typically low current withdrawal rates that are not sufficient to meet power demands

	Energy Density (Full Discharge) [W-hr/kg]	Effective TSFC [gm/hr-N]
Li Sulfur Chloride / Electrochem	444	135.1
Li Bromine Complex / Electrochem	369	162.6
Li Ion/ Yardney	145	413.8
Ni-Cad Eagle Pitcher	36.5	1643.8
Silver Zinc / BST Systems	150	400.0

$$TSFC_{eff} = \frac{V_{airspeed}}{EnergyDensity} \cdot 1000$$



Fuel Cell Systems

- Long term leakage of high-pressure oxygen and hydrogen a problem
- Complicated system leads to higher dry mass

Fuel Cell Efficiency	TSFC [gm/hr-N]
25%	136
50%	68
75%	45
100%	34

*TSFC based on 51 m/s, η_{prop}=85%

Combustion Engines - Conventional

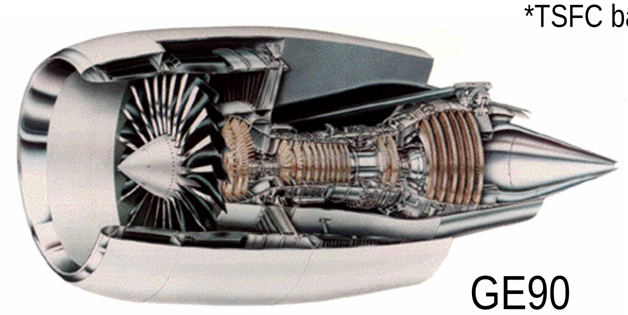
- Typical airplane engine performance ranges from 14 gm/hr-N for UAV engines to 47 gm/hr-N for jetliners.
- Virtual operating ceiling of 65,000 ft due to thin atmosphere.
- Option to carry O_2 at high altitudes
  - Oxygen load will be ~3.4 times the fuel load resulting in 4.4 times the TSFC
  - High pressure or cryogenic storage required

Rotax 912 ULS

Lycoming O-360-A

		PSFC [lb/hp-hr]	TSFC [gm/hr-N]
Propeller	Rotax 912 UAV engine	0.47	17.1
	Rotax 912 Engine with Botted O2	2.07	75.4
	Piper with Lycoming O-360-A	0.44	15.9
Jet	Cessna CJ1 with Williams FJ44	0.46	46.5
	Boeing 777 with GE90	0.69	25.2

*TSFC based on 51 m/s, η_{prop}=85%



GE90

Williams FJ44

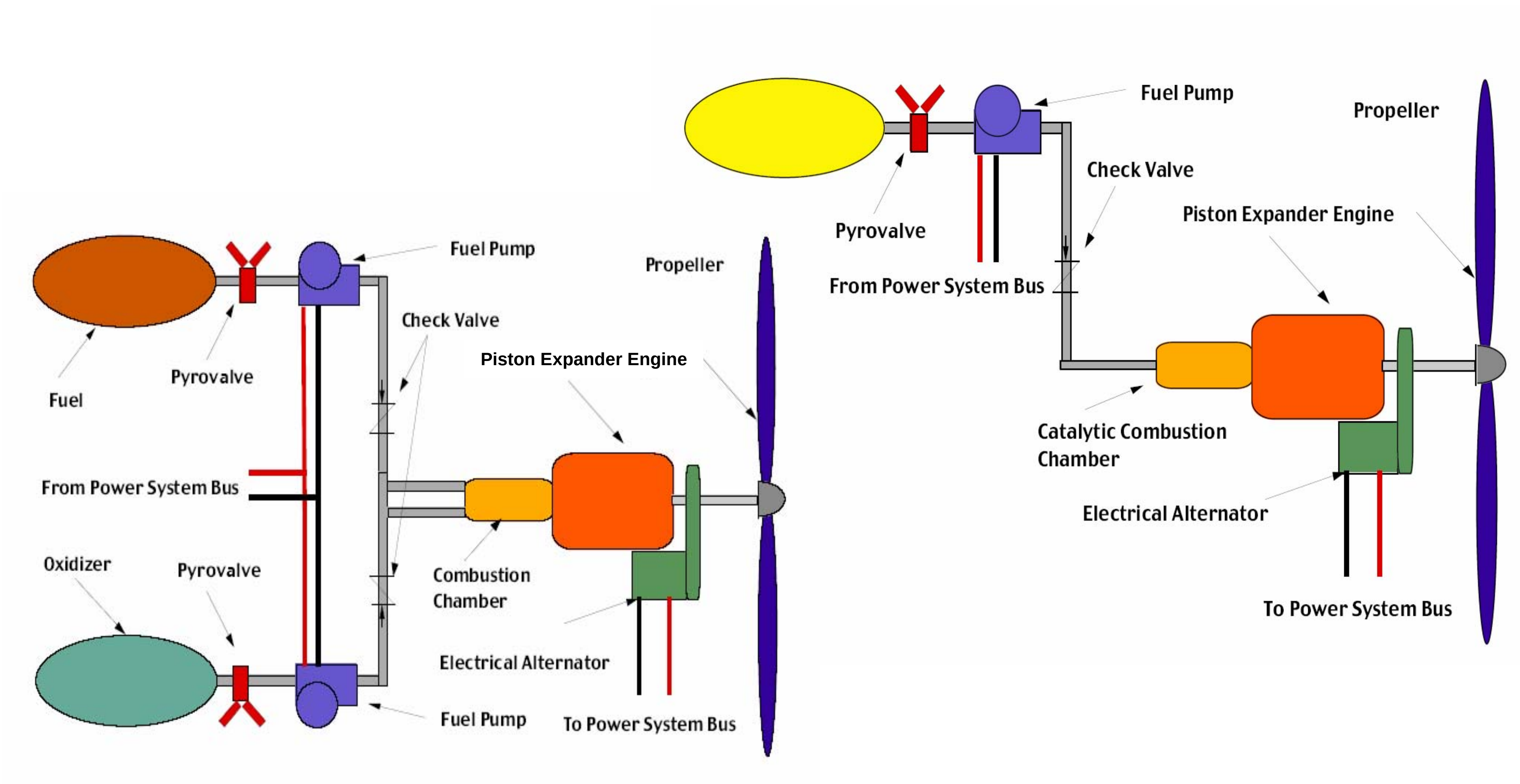
Non Air Breathing Engines

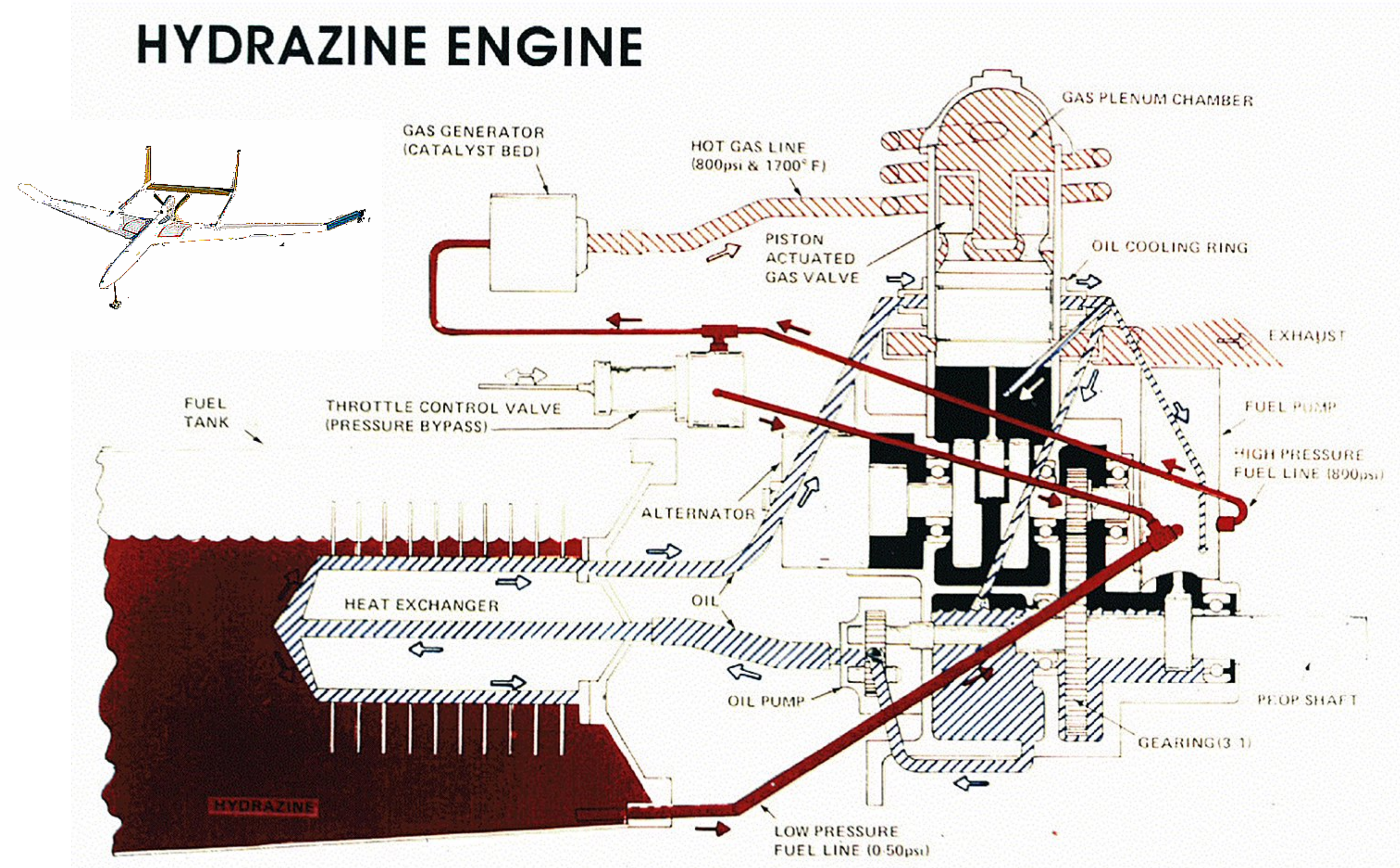
- Utilize the heats of combustion of propellants to run an engine
- Monopropellants – Heat and gas from catalytic decomposition
  - Akkerman Engine (Mini Sniffer III) (7% thermal efficiency)
- Bipropellants – Heat and gas from hypergolic or ignited reaction
  - Prototype ERAST Piston Expander Engine based on torpedo technology
- Significantly more efficient than rocket systems (thermal efficiency assumed to be 10%)
- Start and restart may require additional system mass (electric start motors)
- Waste heat is large and dissipation is a major challenge at high altitudes

Fuel	Oxidizer	Reaction	Thruster TSFC (g/hr-N)	Engine TSFC (g/hr-N)
Hydrogen Peroxide (98% H_2O_2 2% H_2O)	-	Catalytic	2282	764
Nitromethane (CH_3NO_2)	-	Catalytic	1846	186
Hydrazine (N_2H_4)	-	Catalytic	964	111
Hydrogen (H_2)	Oxygen (O_2)	Ignition	1376	18
RP-1 ($C_{11.74}H_{21.83}$) (Kerosene)	Nitrogen Tetroxide (N_2O_4) (MON3)	Ignition	1245	50
Monomethyl Hydrazine (N_2H_6C)	Nitrogen Tetroxide (N_2O_4) (MON3)	Hypergolic	1326	76
Unsymmetrical Dimethyl Hydrazine ($N_2H_8C_2$)	Nitrogen Tetroxide (N_2O_4) (MON3)	Hypergolic	2282	71

*TSFC based on 51 m/s, 10% Thermal efficiency, η_{prop}= 85%

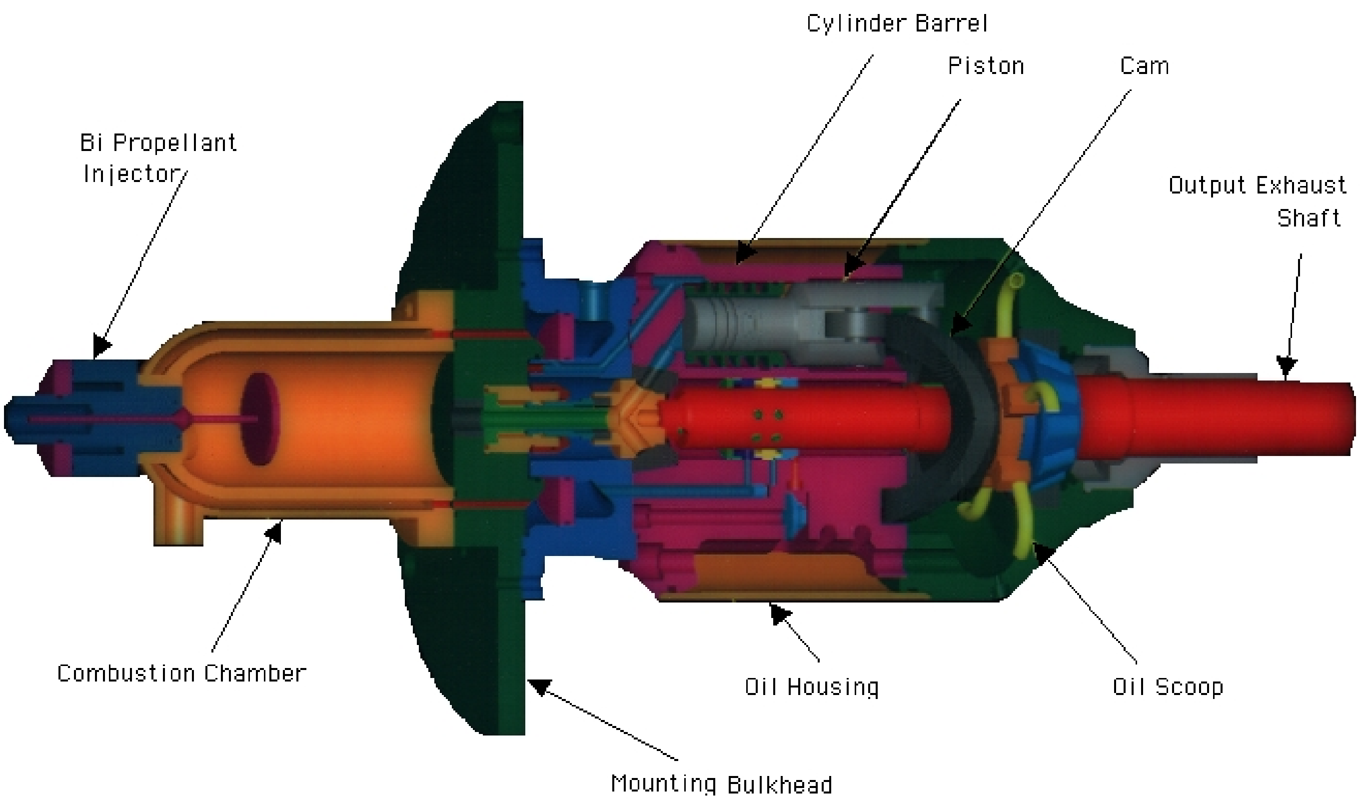
Bipropellant and Monopropellant Engines




HYDRAZINE ENGINE
GAS GENERATOR (CATALYST BED)
HOT GAS LINE (800psi & 1700° F)
GAS PLENUM CHAMBER
PISTON ACTUATED GAS VALVE
OIL COOLING RING
EXHAUST
FUEL TANK
THROTTLE CONTROL VALVE (PRESSURE BYPASS)
FUEL PUMP
HIGH PRESSURE FUEL LINE (890psi)
ALTERNATOR
HEAT EXCHANGER
OIL
OIL PUMP
PROP SHAFT
GEARING (3:1)
HYDRAZINE
LOW PRESSURE FUEL LINE (0-50psi)

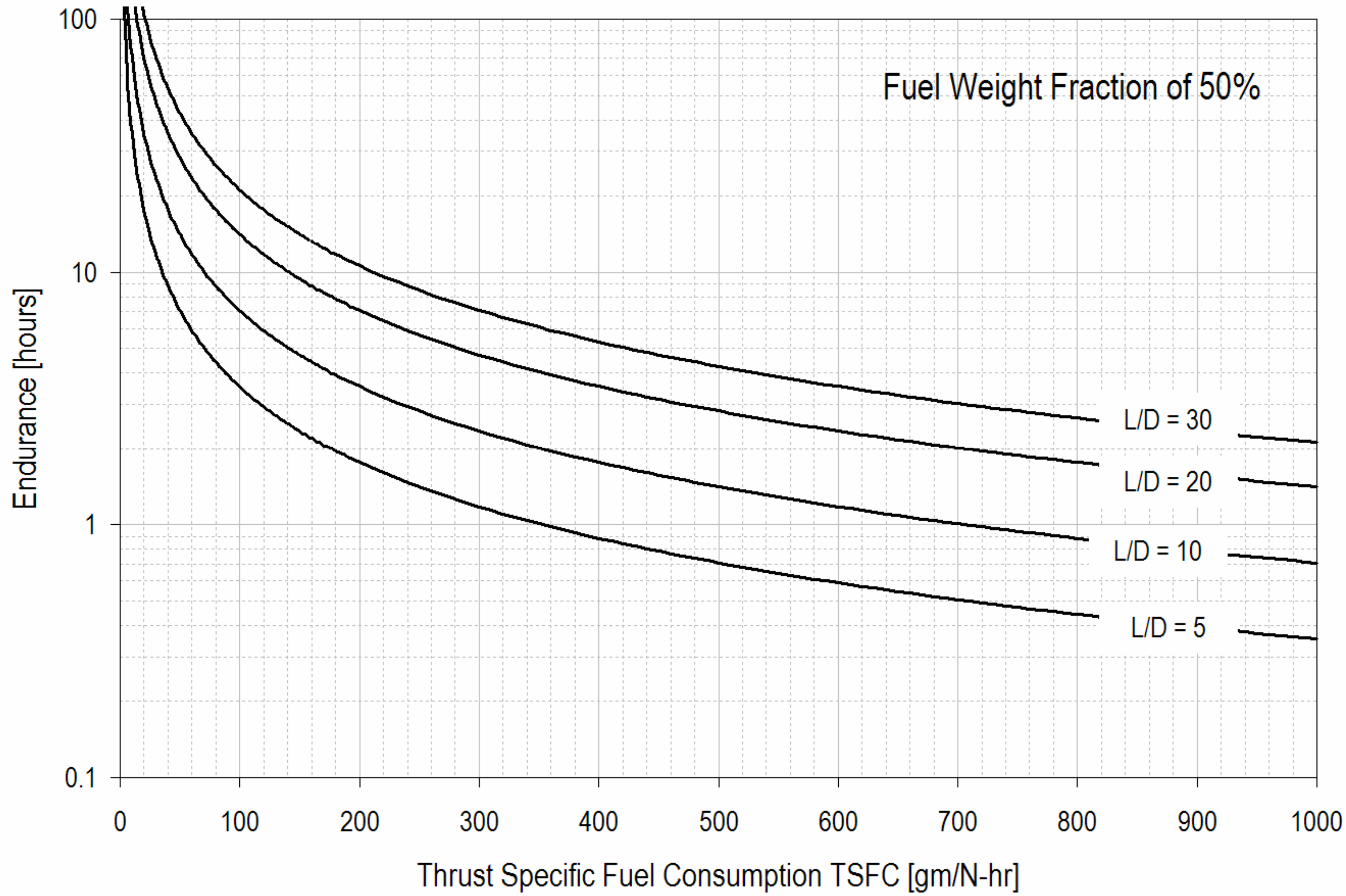
ERAST Bipropellant Engine - Torpedo Technology

NASA Engine Prototype 5.2 Cu In 80 HP

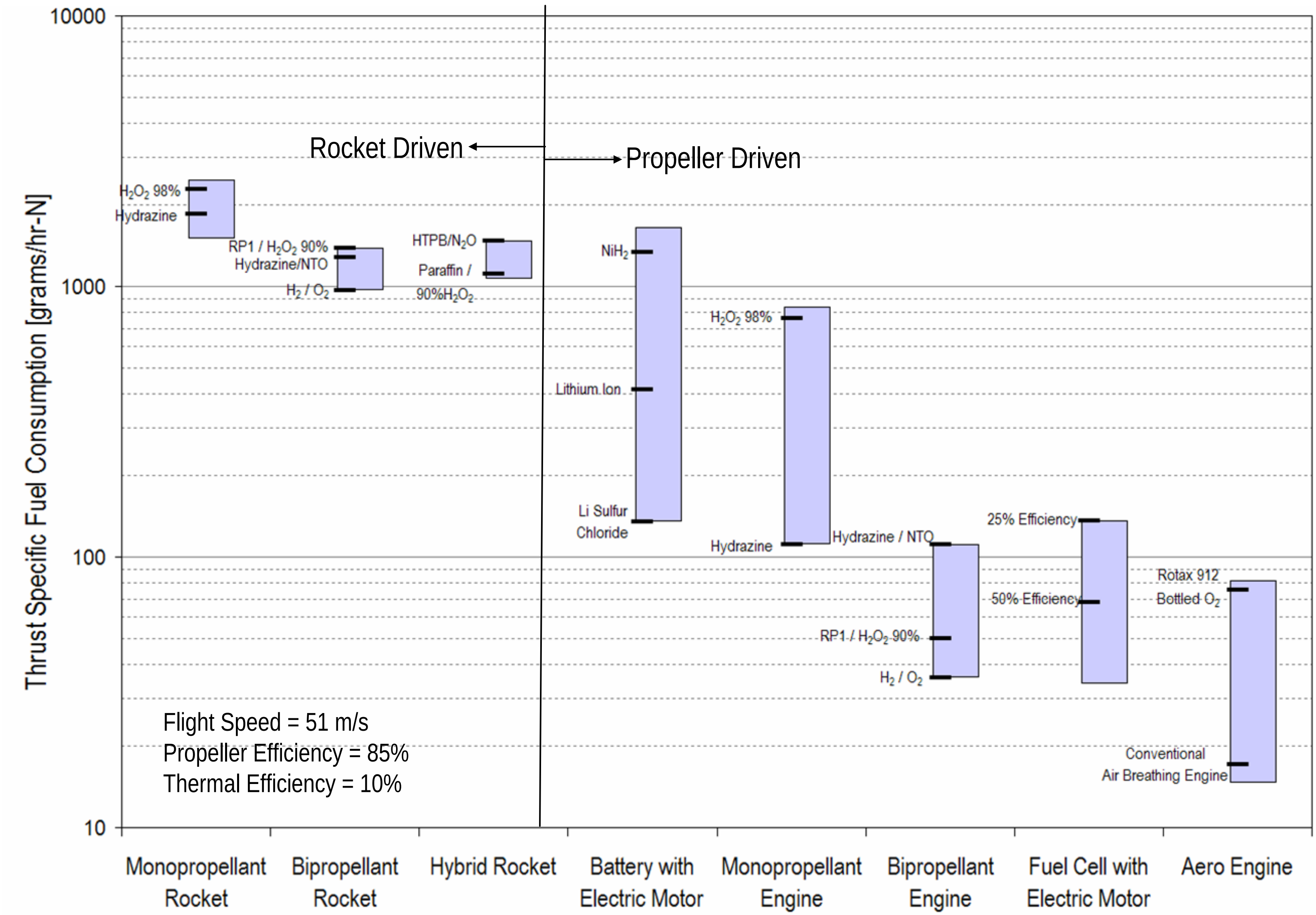


Required Propulsion Performance

- Low TSFC and high L/D required to achieve high endurance

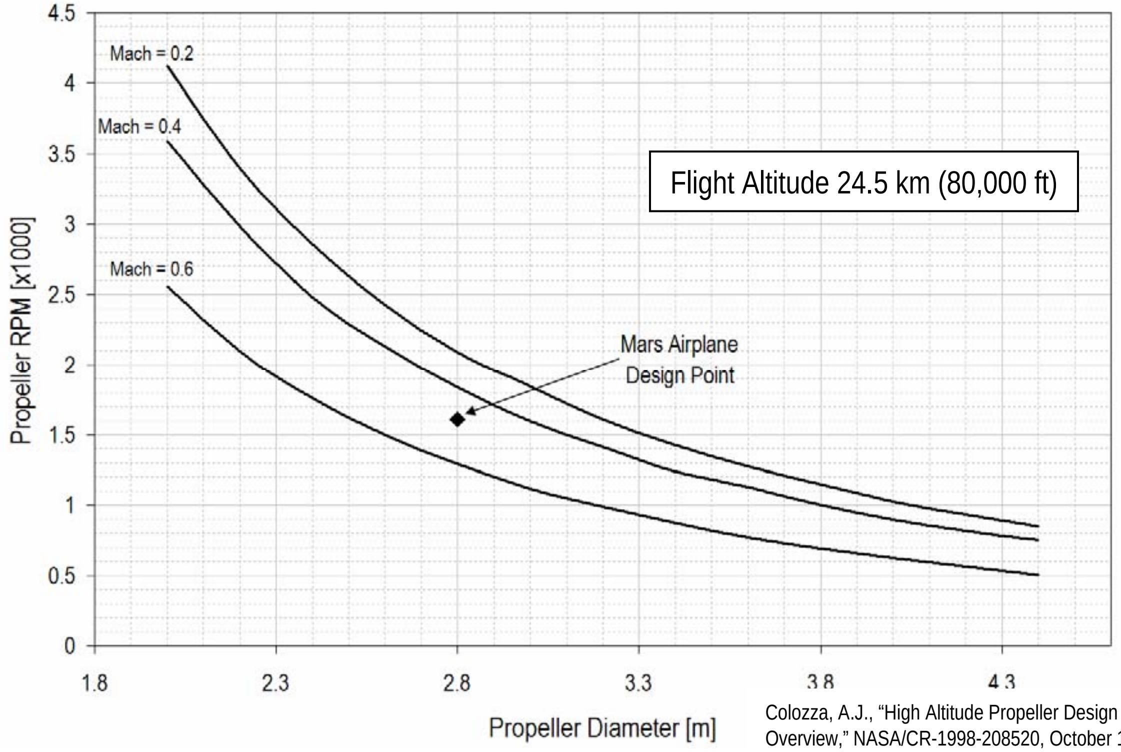


Propulsion Systems - Performance Comparison



High Altitude Propeller Design Challenges

- Power transferred to air-stream at 80,000 ft is about 1/30th that transferred at sea level
- Aside from geometry, main design drivers are diameter and RPM
  - RPM is limited by tip Mach number (M < 0.75)
  - Trade between blade diameter and RPM to achieve power output needed
- Large propeller will make packaging and deployment difficult



Colozza, A.J., "High Altitude Propeller Design and Analysis Overview," NASA/CR-1998-208520, October 1998

PRE-DECISIONAL DRAFT - For Planning and Discussion Purposes Only

Conclusions

- First order analysis suggests propeller driven propulsion is required
  - Propeller will likely have a large diameter
  - Trades needed between blade diameter and RPM to achieve power output
- System mass of each propulsion technology will vary depending on airplane design
  - Trade between system mass, propulsion efficiency (TSFC) required based on specific airplane design and flight envelope
- Volume efficiencies of hardware and fuel/propellants will be a major driver in selecting final propulsion system
- Thermal Issues – Significant waste heat will be produced from IC engines with little atmosphere available for a convective heat sink

Contact / References

- Christopher A. Kuhl

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  Christopher.a.kuhl@nasa.gov

  757-864-6941

- “Comparison of Mars Aircraft Propulsion Systems,” Colozza, A.J., NASA CR-2003-212350, May 2003.
- “Liquid Rocket Propulsion for Atmospheric Flight in the Proposed ARES Mars Scout Mission,” C. Kuhl, H. Wright, C. Hunter, C. Guernsey, A. Colozza, AIAA-2004-3696. 40th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Fort Lauderdale, Florida, July 11-14, 2004.
- Reed, R.D. (1978), “High-Flying Mini-Sniffer RPV: Mars Bound,” Astronautics and Aeronautics, Vol. 16, No. 6, pp 26-39.
- “High Altitude Propeller Design and Analysis Overview,” Anthony Colozza, Federal Data Systems, March 1998.

Rapid Eye Demonstration System

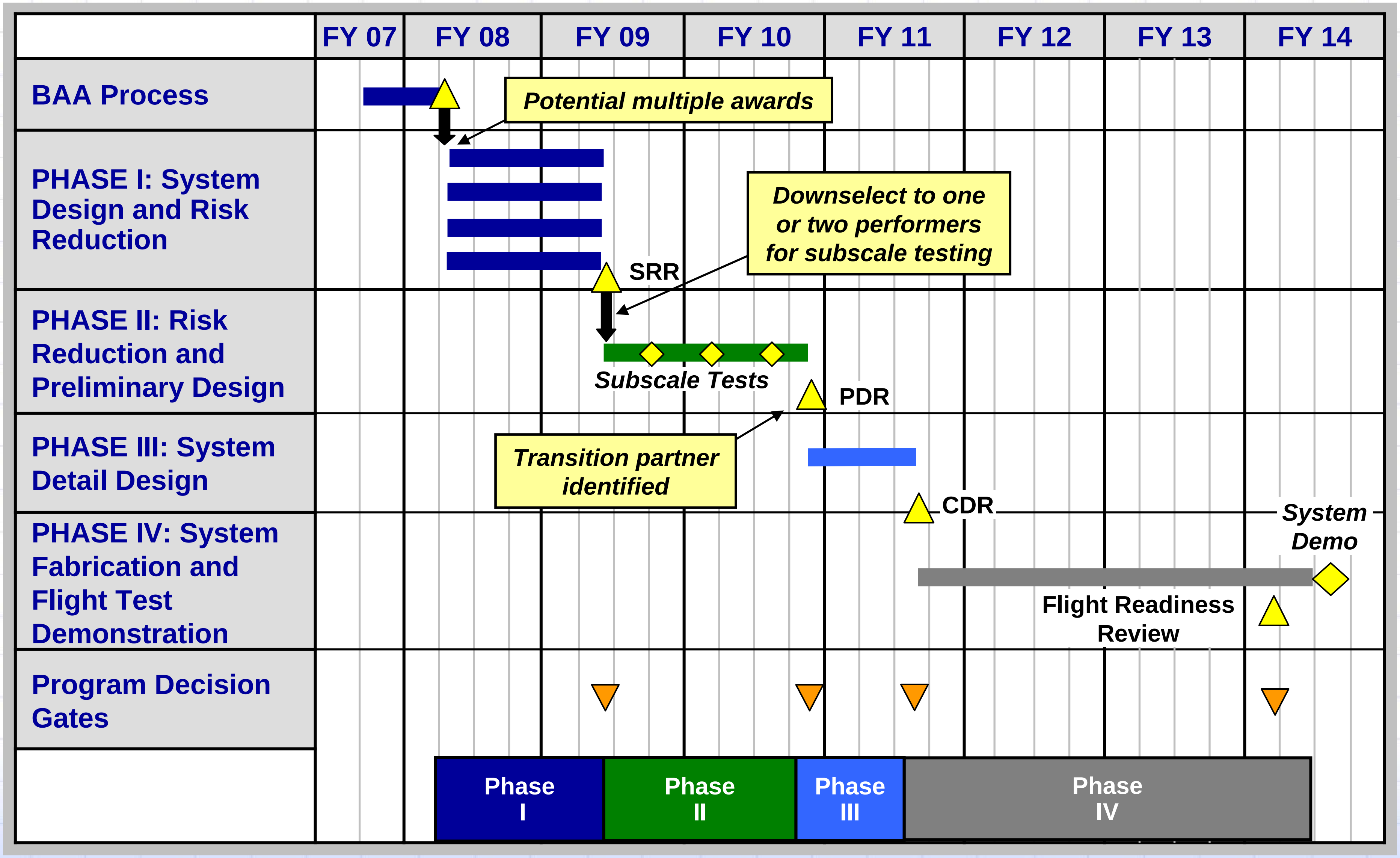
- **Non-Tradable Requirements**
  - Worldwide-delivery of ISR capability from alert pad < 2 orbits
  - Use existing solid-rocket launch systems (limited fairing work allowed)
  - Use only two START-compliant launch sites
  - Time on station > 7+ hours
  - Loiter speed > 99% winds
  - Payload > 500 lbs, 5 kW
  - Must be airborne flight; no buoyant flight
  - No radioactive power solutions

- **Key Tradable Attributes**
  - Operating altitude, timeline to area of operation, and global coverage
  - Recovery strategy
  - System reliability vs. affordability
  - Disposal of final rocket stage and decelerator
  - Level of autonomy/mission management approach

Acquisition Strategy

- **Four-phase program:**
  - **Phase I: System Design and Risk Reduction**
    - Multiple performers in Phase I
    - Risk reduction AoA in propulsion, structures, decelerator
    - Continued laboratory development of LiH technology
    - Complete SRR
  - **Phase II: Risk Reduction and Preliminary Design**
    - One or two performers
    - Conduct subscale tests in key risk areas
    - Complete preliminary design review
  - **Phase III: System Detail Design**
    - Complete critical design review
  - **Phase IV: System Fabrication and Flight Test Demonstration**
    - Demonstration of the Rapid Eye system
- **Single full and open competition via BAA to address all program phases**
- **Progression to subsequent phases of program contingent on meeting established Go/No-Go criteria and availability of funds**

Notional Program Plan
(Timeline is Notional)

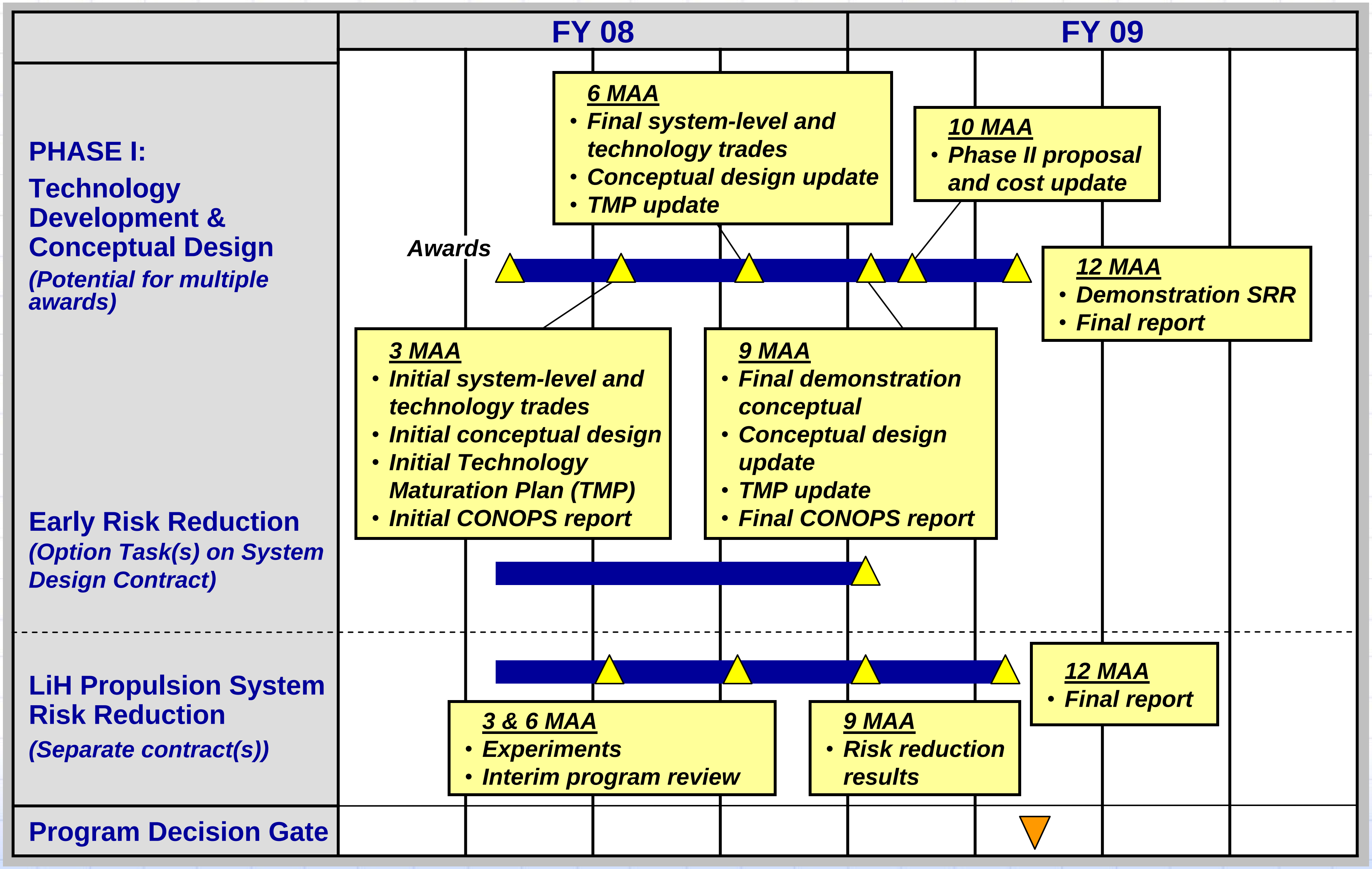


Rapid Eye Phase I Program Plan

- **Phase I – System Design and Risk Reduction (~12 months)**
  - **Objectives**
    - Conduct system-level design, CONOPS, and military utility trade studies
    - Conduct detailed technology trade studies, including propulsion, deployable structures, and reentry decelerator
    - Develop system design culminating in SRR for demonstration system
    - Develop a detailed Technology Maturation Plan that provides an integrated strategy for progressively reducing the risk in all critical technology areas and defines all major risk reduction events culminating in system flight test demonstration in Phase IV
    - Optionally perform other high-risk/high-payoff technologies
    - Jumpstart risk reduction for LiH
  - **Deliverables**
    - Results of system level and technology trade studies
    - Interim design reviews for demonstration system
    - System requirements review of demonstration system
    - Technology maturation plan for Phases II-IV, including IMS and cost estimates for each phase
    - Updated Phase II SOW and cost proposal
    - Results of Phase I risk reduction activities
  - **Criteria for Following Phase**
    - Closed design that meets non-tradable requirements
    - Quantifiable success criteria for risk reduction activities
    - Credible Phase II technical development and test plan

Balance Desire for Competition with Need for Early Risk Reduction

Notional Phase I Schedule

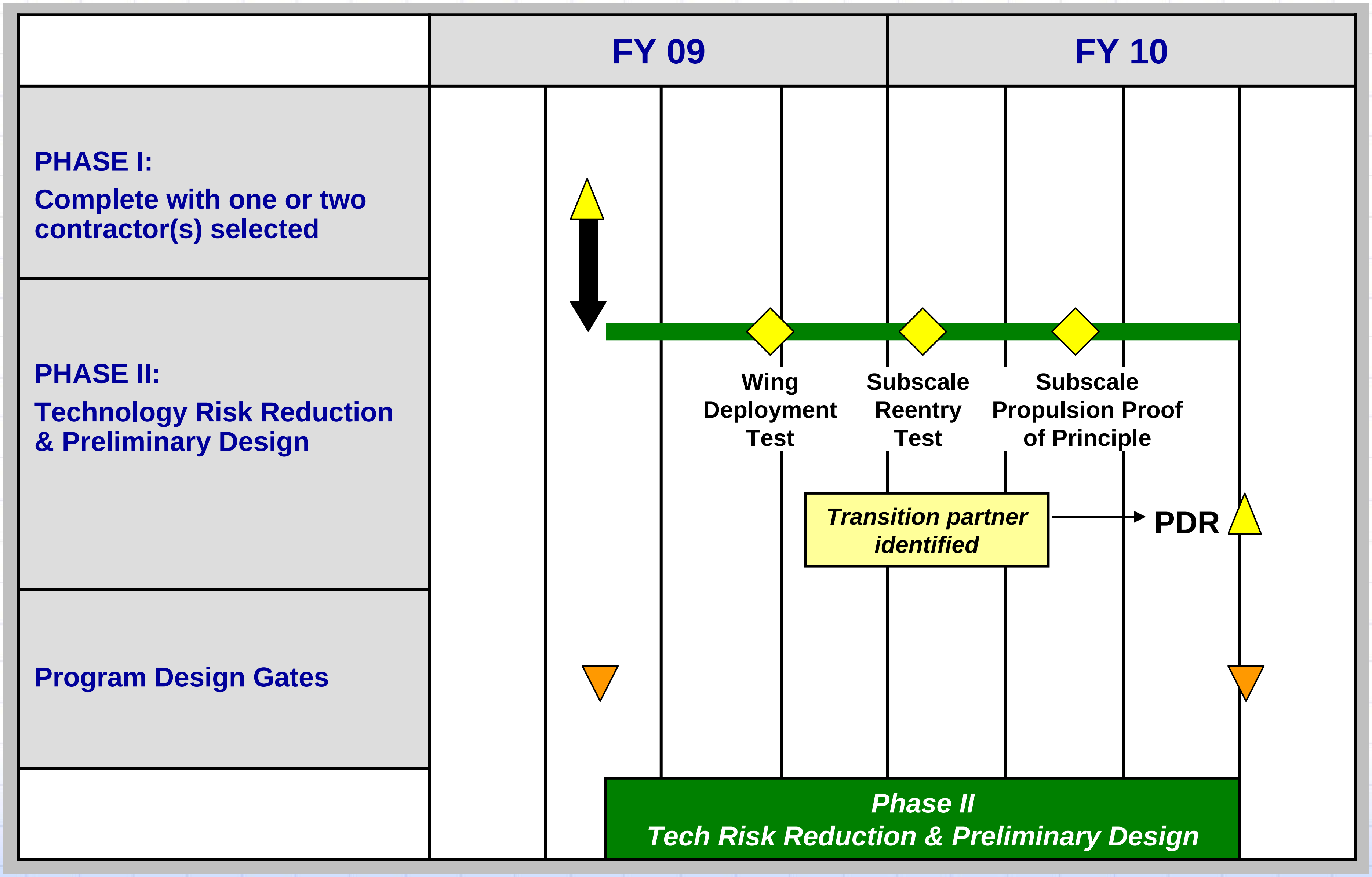


Approved for public release; Distribution is unlimited

Rapid Eye Phase II Program Plan
(Timeline is Notional)

- Phase II – Technology Risk Reduction and Preliminary Design (~18 months)
  - Objectives
    - Execute technology maturation plan, including key sub-system tests
      - Stored wing deployment, wind tunnel and drop tests
      - Subscale decelerator reentry test
      - Engine performance tests in appropriate conditions
    - Determine remaining maturation issues
    - Finalize system-level design, CONOPS, and military utility trade studies
    - Complete preliminary design culminating in PDR
  - Deliverables
    - Preliminary design data package
    - Results of Phase II risk reduction activities
    - Updated technology maturation plan for Phases III and IV, including IMS and cost estimates for each phase
    - Updated Phase III SOW and cost proposal
  - Criteria for Following Phase
    - Identification of transition partner

Notional Phase II Schedule
(Timeline is Notional)



Tentative Acquisition Schedule

Industry Day	25 July 2007
BAA Release	28 Aug 2007
Proposals Due	14 Oct 2007
Evaluation Complete	30 Nov 2007
Negotiations & Awards	Dec 2007

http://www.darpa.mil/tto/solicitations.htm

Please submit all questions to BAA07-57@darpa.mil.

Phase I BAA Overview

- Offerors may respond in one or both of the following areas:
  - System Design and Risk Reduction
  - LiH Risk Reduction

- System Design and Risk Reduction responses anticipated to include:
  - Executive Summary
  - Point of Departure Concept and CONOPS
  - Overall Scientific Approach
    - Technical Approach
    - Technology Maturation
    - Phase I Statement of Work (SOW) and Integrated Master Schedule (IMS)
    - Phase II, III and IV Program Plans
  - Management
    - Program Team Composition
    - Key Personnel
  - Cost
  - Risk Reduction Options
    - Separately priced option for individual risk reduction activities
    - May include LiH or other high risk/high payoff activities
    - Provide SOW, IMS and cost estimate for each option as well as rationale for why it is beneficial to perform this work prior to completing system requirements review

Phase I BAA Overview (cont.)

- LiH Risk Reduction responses anticipated to include:
  - Executive Summary
  - Technical Approach
  - Risk Reduction Success Metrics
  - Statement of Work and Integrated Master Schedule
  - Cost

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BAA PROCESS

ELEMENTS OF THE BAA

- Synopsis in FEDBIZOPPS
- BAA covers all info needed to propose
- TIME PERIOD – BAA is open for **45 days**

ELIGIBILITY

- All interested/qualified sources
- Foreign participants/resources may participate to the extent authorized by applicable Security Regulations, Export Laws, etc.
- Government agencies/labs, FFRDC's, can respond unless otherwise restricted from doing so by law/regulation and/or agency specific policy

CMO

BAA PROCESS

PROPOSAL PREPARATION/SUBMISSION

- Instructions are detailed in the BAA (**Follow closely**)
- **ALL** questions to BAA07-57@DARPA.mil
- Q&A and BAA information available on http://www.darpa.mil/tto/solicitations.htm (**Read Regularly**)
- Funding instruments = primarily contract(s), no assistance instruments (grants, cooperative agreements), OTA for Prototype may be proposed in addition to a contract, but must adhere to OTA guidance http://www.acq.osd.mil/dpap/Docs/policy/otherTransactions/current%20otguideconformed%20Jan%202001.doc
- Assert rights to **all** technical data & computer software generated, developed, and/or delivered to which the Government will receive less than Unlimited Rights
  - Assertions that apply to Prime and Subs
  - Use defined “Basis of Assertion” and “Rights Category”
  - **Justify** “Basis of Assertion”
  - **This information is assessed during evaluations**

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BAA PROCESS

- Tech Prop - Mind Page Limitations (**don't use Cost Prop for overflow**)
  - Tech Prop – SOW (by phase, WBS, milestones, deliverables, exit criteria)
  - Cost Prop – Provide **all** Cover Page info
  - Cost Prop – Develop using the same common WBS
  - Cost Prop - FAR Part 15/Table 15-2 (suggested format/content)
  - Provide BOE(s) to support proposed costs (labor & material)
  - Have **all** subcontract proposals ready to submit immediately upon request after BAA closing date

- **Following the proposal instructions assists the evaluation team to clearly understand what is being proposed.**

- **Following the proposal instructions supports a timely negotiation.**

BAA PROCESS

CMO

- Be aware of:
  - Organizational Conflict of Interest & Procurement Integrity language
  - CCR, ORCA, & WAWF
  - Export Control language
  - Subcontracting Plan

BAA PROCESS

- EVALUATION/AWARD
  - Government reserves the right to select for award all, some, or none of the proposals received and to award without discussions
  - Government anticipates making multiple awards
  - No common Statement of Work - Proposals evaluated on individual merit and relevance as it relates to the stated research goals/objectives rather than against each other
  - Only a duly authorized Contracting Officer may obligate the Government

BAA PROCESS

- COMMUNICATIONS
  - Prior to Issuing BAA – No restrictions, however Gov't (PM) shall not dictate solutions or transfer technology
  - After Issuing the BAA – No restrictions, however Gov't (PM/PCO) shall not dictate solutions or transfer technology
  - After Receipt of Proposals – Government (PM/PCO) may communicate with offerors in order to understand the meaning of some aspect of the proposal that is not clear or to obtain confirmation or substantiation of a proposed approach, solution, or cost estimate