

Reducing the Challenges Posed by Titan Missions

Presentation to the
Satellites Panel of the Planetary Science Decadal
Survey

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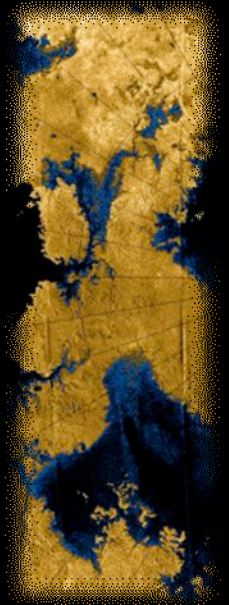
Jet Propulsion Laboratory California Institute of Technology

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Titan: A complex world of high priority

- Cassini-Huygens has found lakes, seas, rivers, clouds, rain, and in the extended mission strong evidence for a dynamic changing climate system and interior ocean
- Titan is the only world besides Earth with an active climate/hydrology cycle: methane vs water (hydrology)
- Titan's wealth of organic molecules and diverse sources of free energy make it of high priority for exploring chemistry that preceded life's origin on Earth, and possible exotic life in the methane seas

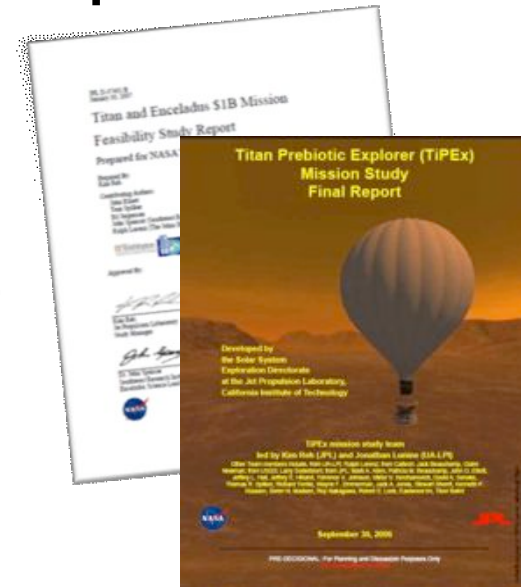


- High priority science questions remain unanswered



Studies have identified key elements needed to address science questions

- NASA mission studies focused on science
 - Various studies in the 1990s
 - 2002 Aerocapture Systems Analysis Study
 - 2004 Titan Organic Exploration Study (TOES) under NASA's Vision Missions Program
 - 2006 Titan Prebiotic Explorer (TiPEX) study
 - 2007 "Billion Dollar Box" study
- Technology development to retire risk
 - Focused on balloon and *in situ* elements
- 2007 APL-led Titan Explorer study confirmed the **Orbiter, Lander and Balloon** as key elements for a flagship mission to Titan ==> basis for 2008 NASA-ESA joint OPFM studies





2008 NASA-ESA studies focused on joint mission to Titan and Enceladus

- Following from NASA's 2007 Titan Explorer study and ESA's TandEM study, NASA and ESA (with CNES participation) initiated a joint mission study
- The 2008 concept was shaped by results from previous NASA and ESA studies and driven by NASA ground rules
- Key driving NASA ground rules
 - Level 1 science requirements include Titan, Saturn's Enceladus
 - NASA provides orbiter and ESA provides *in situ* elements
 - Orbiter must deliver and support the *in situ* elements
 - Must achieve Titan orbit without using aerocapture
 - Must achieve best balance of science, cost, and risk

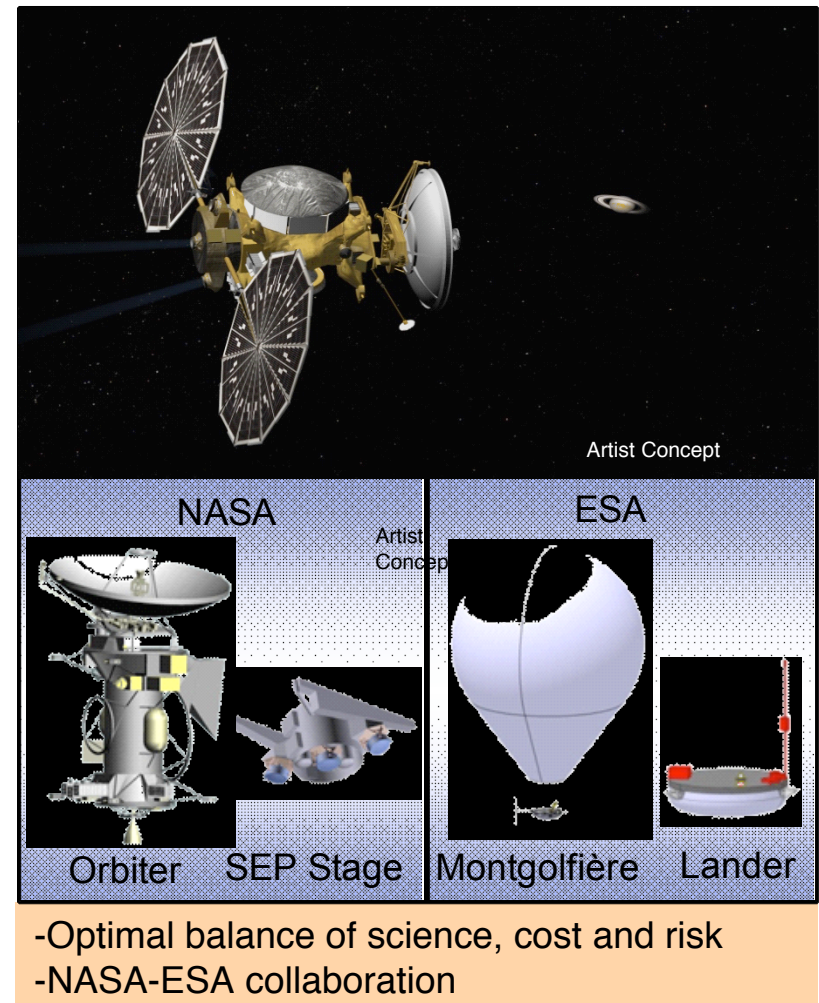


9/21/2009 The Titan Saturn System Mission (TSSM) emerged



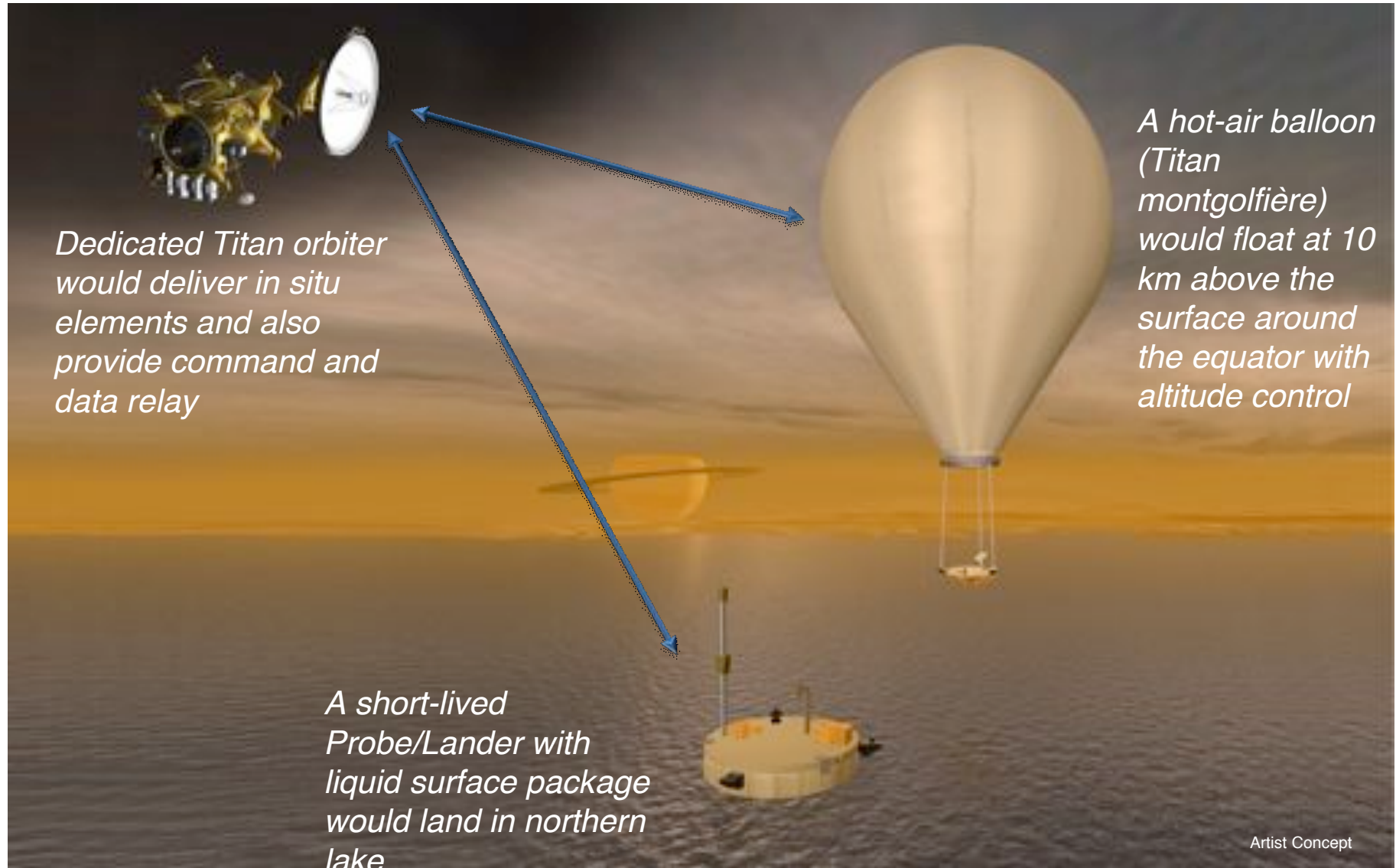
2008 TSSM Overview

- Titan, Enceladus and Saturn system science
- Mission Design
 - 2020 Launch to Gravity Assist SEP trajectory
 - 9 years to Saturn arrival
 - SEP stage released ~5 yrs after launch
 - Montgolfière released on 1st Titan flyby, Lander on 2nd Titan flyby
 - ~4 yr mission: 2 yr Saturn tour with Enceladus, 2 mo Titan aerosampling; 20 mo Titan orbit
- NASA Orbiter and Launcher
 - ASRG power baselined (MMRTG compatible)
 - Solar Electric Propulsion (SEP)
 - 6 Instruments + Radio Science
 - NASA provided Launch Vehicle and RPS
- ESA *In situ* Elements
 - Lake Lander – battery powered
 - 4 instruments + Radio Science
 - Montgolfière – MMRTG powered





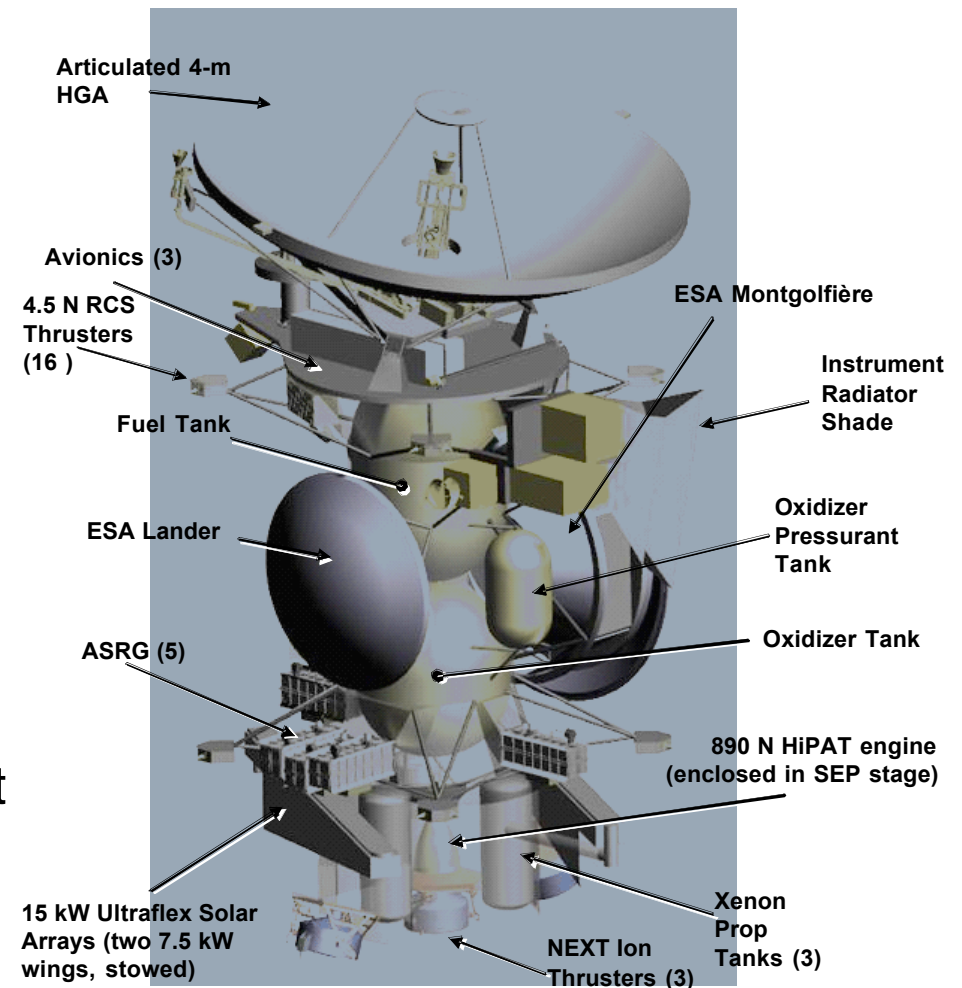
Baseline mission elements





Baseline orbiter overview

- Design leaned heavily on heritage and lessons learned from Cassini, MRO and Dawn
- Orbiter dry mass 1613 kg including 33% margin
 - 165 kg allocated to orbiter instruments
 - *In situ* mass allocation 833 kg
 - 600 kg for montgolfiere
 - 190 kg for lander
 - 43 kg for support equipment (spin-eject device)
- SEP stage built around launch vehicle adapter leverages current development programs
 - NEXT ion thrusters
 - Orion-derived solar arrays

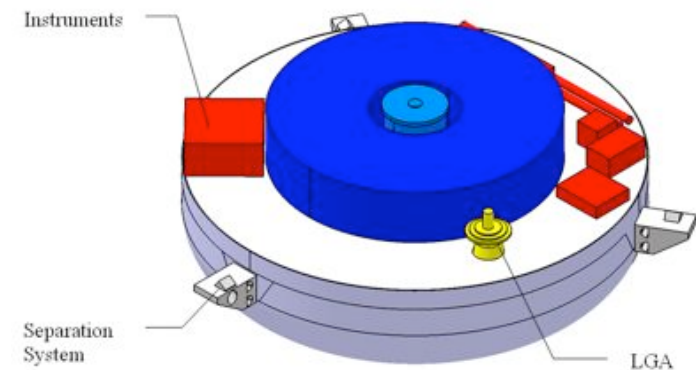
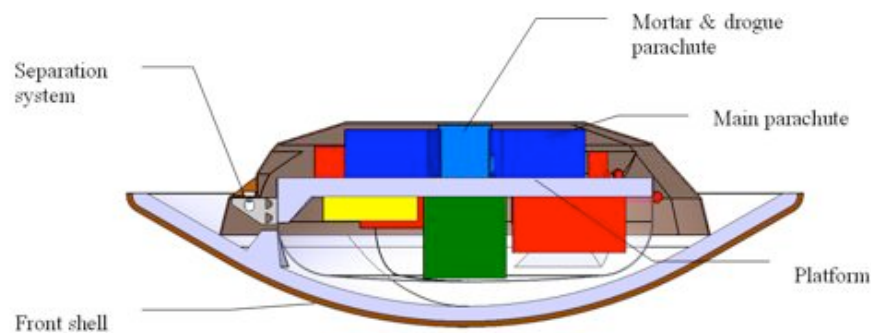
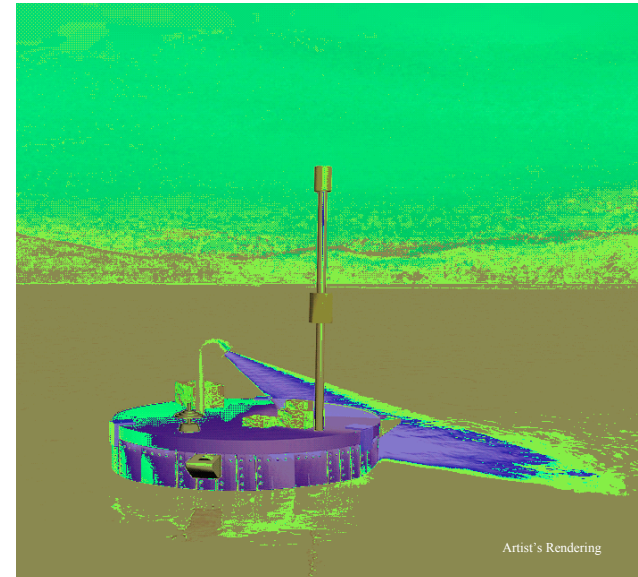


Conceptual Design



Baseline lander overview

- System and Mission design built upon Huygens heritage
- Landed mass 85 kg, including 23 kg instrumentation
- Target: Kraken Mare (72°N)—floating capability
- Battery powered
- Lifetime: 6 hours descent and 3 hours on surface
- Delivery on 2nd Titan flyby—orbiter in close vicinity

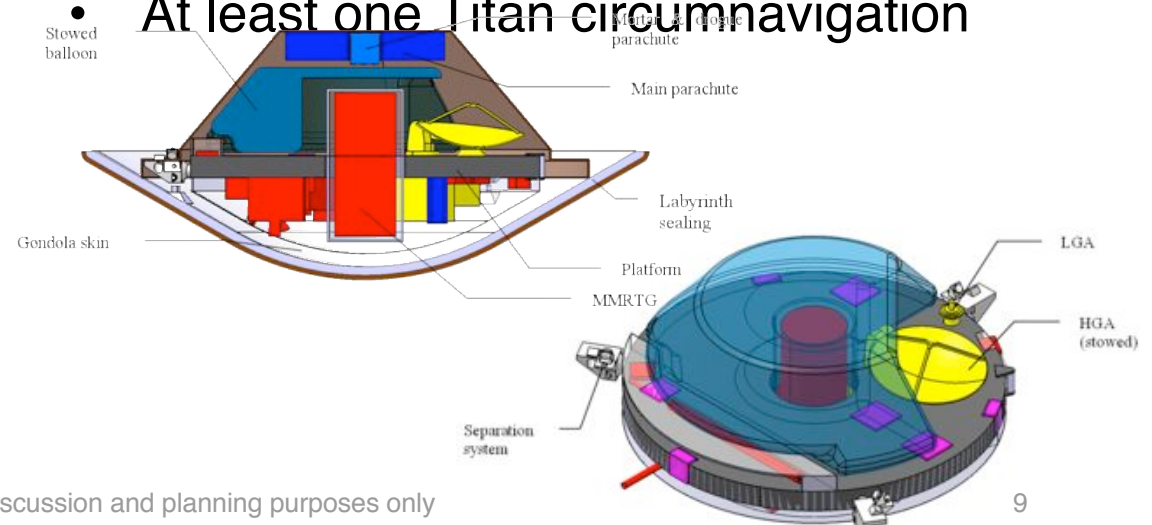




Baseline montgolfière overview



- Balloon envelope: 10.5 m diameter (~130 kg); heating by single MMRTG
- Gondola: 144 kg, incl. 21.5 kg instrumentation
- Power and buoyancy generation by MMRTG ($100 W_{el}$, $\sim 1700 W_t$ at Titan)
- Floating altitude 10 km; only altitude control
- Prime mission 6 months (+6 months extended)
- At least one Titan circumnavigation





Path forward from 2008 Studies

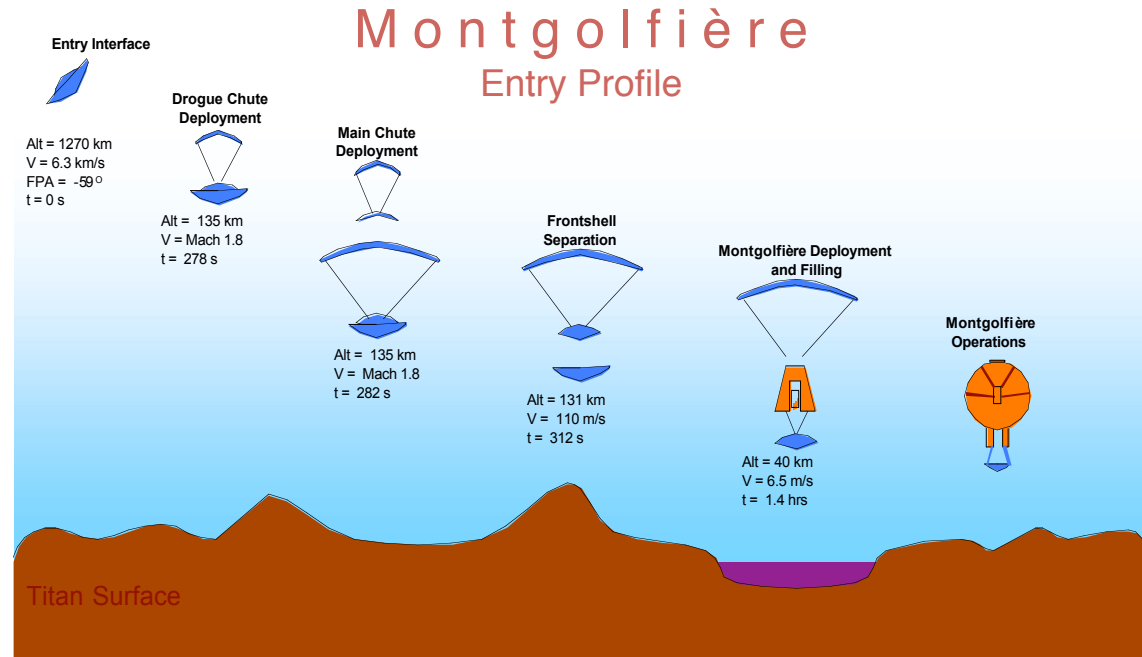
- The TSSM science panels and review boards confirmed that *in situ* elements are needed for a highly capable flagship mission to Titan
- NASA TMC panel and ESA review board identified risks needing further attention
 - Orbiter and lake lander risks can be mitigated in formulation
 - Technical risks related to the montgolfière call for early mitigation:
 - Balloon deployment and inflation upon arrival at Titan
 - Balloon packaging and thermal mgmt. inside the aeroshell
 - Interface complexity between balloon, RPS and aeroshell
 - Integration of the NASA provided MMRTG
 - Additional areas of risk reduction identified by the TSSM team include development of *in situ* instrument systems for the cryogenic environment and high performance orbiter remote sensing instruments
 - Sampling systems and chemical analyzers (1-600 Da mass spec.)
 - Hi res. IR Imager/Spec. (<50m/pixel) and Mass Spec. ($M/\Delta M < 10^5$ for masses up to 10,000 Da)
- To advance readiness of the montgolfière, NASA and CNES are discussing a joint risk reduction effort directed at a Titan aerobot





Balloon deployment and inflation

- Montgolfière entry and initial deployment is similar to Huygens parachute deployment
 - Complicated by deployment of MMRTG
- Inflation of balloon and establishment of buoyancy will require validation and demonstration of flight configuration
 - 2008 testing has shown positive results



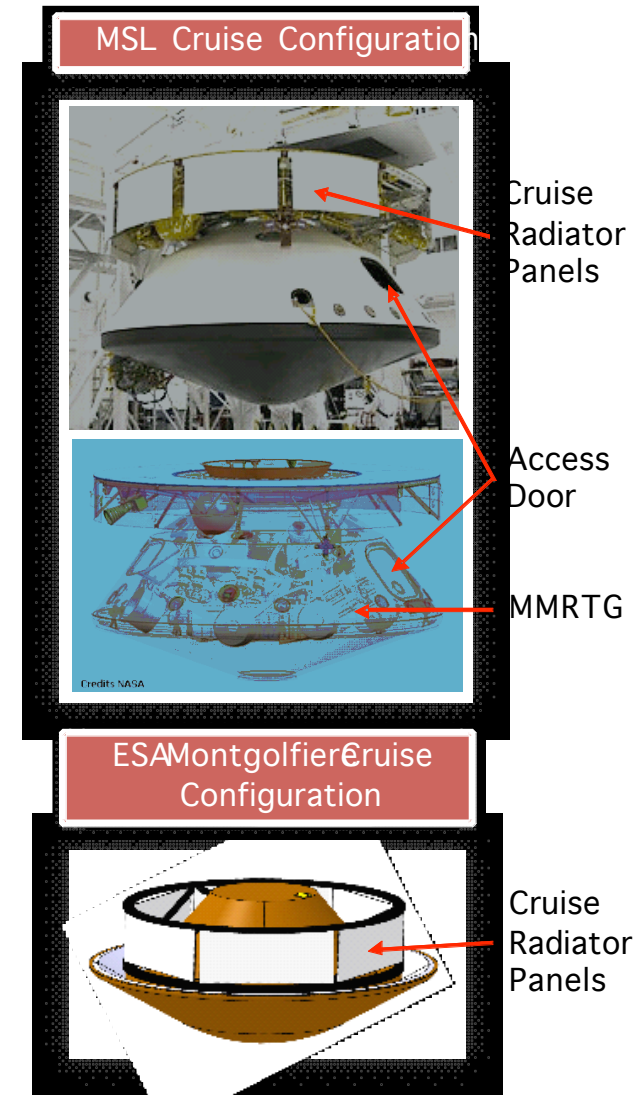
Successful aerial deployment and inflation test on 4.5 m balloon (300-400 meter altitude)





Balloon packaging and thermal management

- Packaging within the limited space available in the aeroshell is a challenge that will continue to be addressed as the montgolfière design is further developed
- Heat rejection from the MMRTG during cruise must be robust to the requirements of a potentially long cruise duration
 - This issue is currently being addressed by MSL, which shares the same heat rejection challenge over shorter period of time
- Design for insertion of the MMRTG at the launch site will also be a focus
 - Also addressed by MSL
 - 2008 montgolfière design not optimized





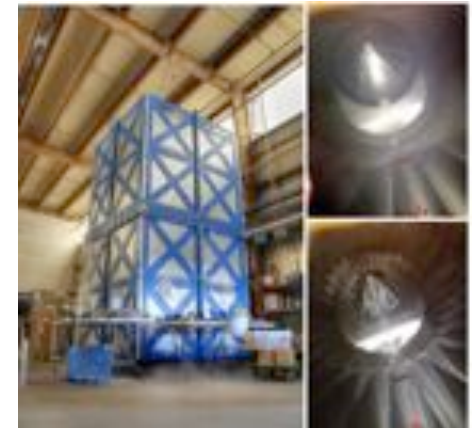
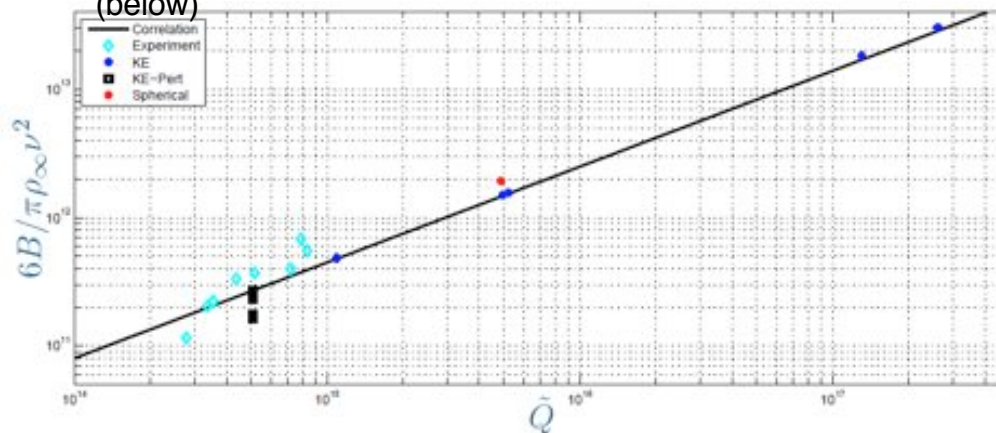
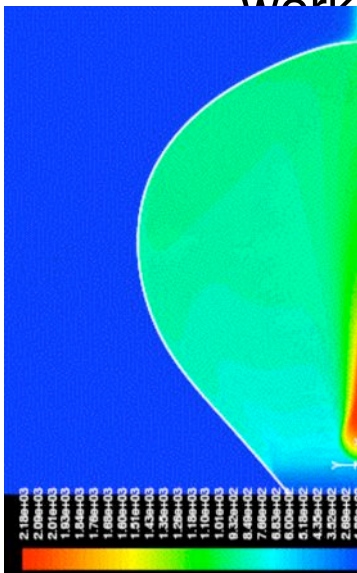
Montgolfière performance modeling and testing

- Additional montgolfière performance modeling and testing are necessary to understand margins needed to ensure desired performance given expected environmental uncertainties
 - Would build on significant body of development work already accomplished

Indoor propane-heated flight of 9 m prototype montgolfière balloon

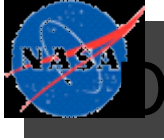


CFD modeling of Titan montgolfiere balloon thermodynamics (left), cryogenic testing of 1 m diameter balloon by Julian Nott (lower right) and comparison of buoyancy vs heat transfer data (below)



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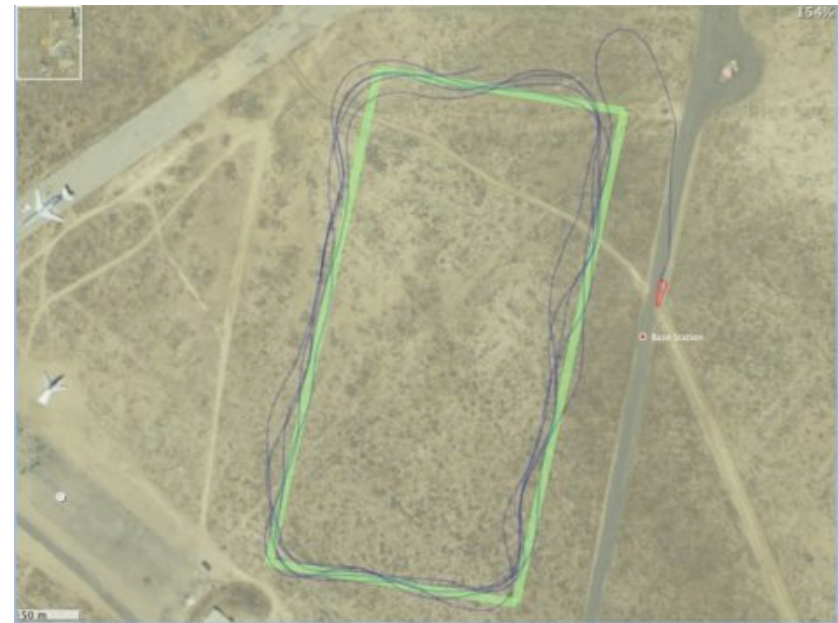


Development of autonomous operation capabilities

- Autonomous operation capability has potential to greatly expand science value
- Approach is to build on currently ongoing aerobot autonomy flight experiments
 - Powered blimp testbed flown in the Mojave desert
 - Integrated sensor, actuator and software system for autonomous flight controls and vision-based navigation
 - Demonstrated autonomous waypoint navigation and trajectory following for repeated 30 minute flights (time limited by fuel depletion)



Real-time operator control interface



Example of repeated "racetrack" trajectories



Development of surface sampling capabilities



- Addition of surface sampling capability on the aerobot could significantly increase science return
- Aerobot surface sample acquisition experiments have recently been performed with a tethered “harpoon” device
 - Proof-of-concept experiments using the JPL powered blimp testbed
 - The “harpoon” was an aluminum tube-like structure that falls by gravity and embeds itself in the surface
 - The harpoon is retrieved by winching on the tether
 - A total of 8 acquisition flights so far, small (10s of grams) amounts of surface dirt acquired each time
 - Drop altitudes ranged from 15 to 70 m, ground relative speeds up to 5 m/s



Harpoon and tether assembly



Pre-flight preparations

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At the drop altitude

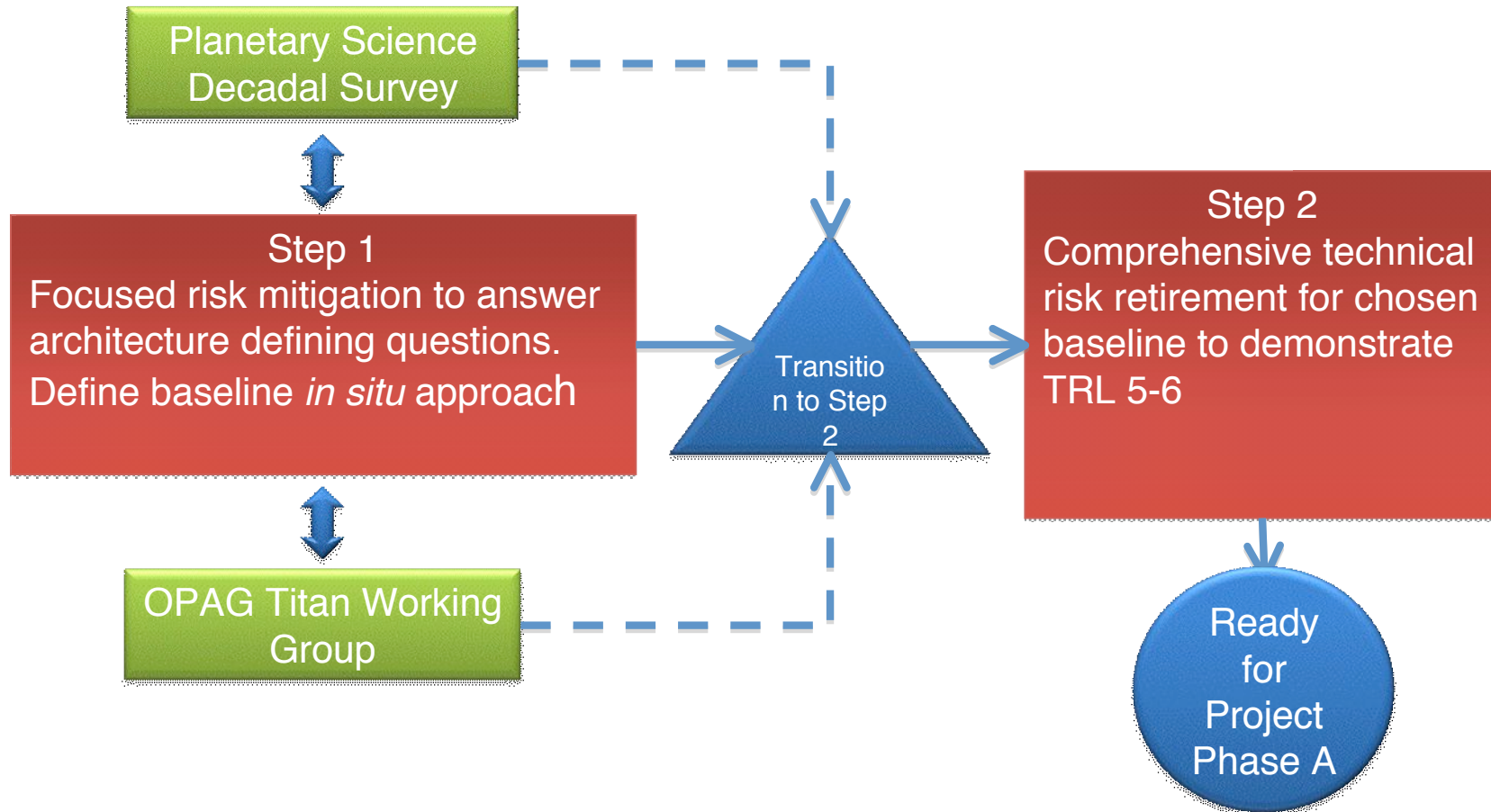
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Close-up view of impact site



Proposed plan for moving forward involves a two-step risk reduction approach



Two-step approach maintains alignment with ongoing Planetary Science Decadal Survey while advancing readiness for potential

project start

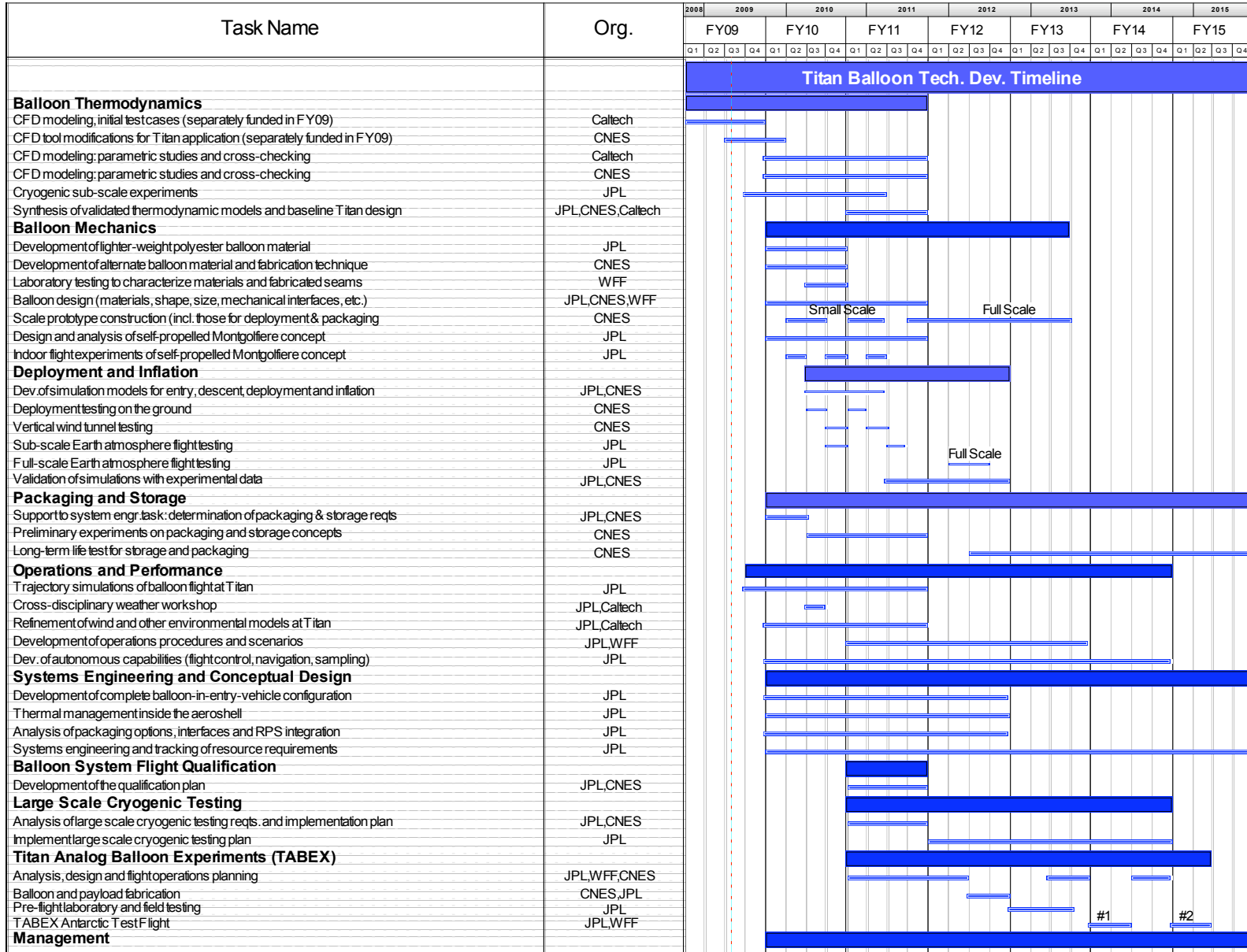


Key Products from 2-Step plan

- **Step 1**
 - Determination of balloon thermodynamic feasibility and quantification of expected performance margins for alternative architectures
 - Selection of baseline balloon material
 - Preliminary flight balloon qualification plan
 - Plans for Earth atmosphere Titan analog balloon experiments (TABEX)
 - Definition of baseline aerobot architecture
- **Step 2**
 - Detailed concept definition
 - Manufacturing feasibility proven with full scale prototypes
 - Packaging and storage approach validated with life testing
 - Deployment and inflation approach validated with simulation and experiments
 - Operational performance measured with long duration Titan analog balloon experiments

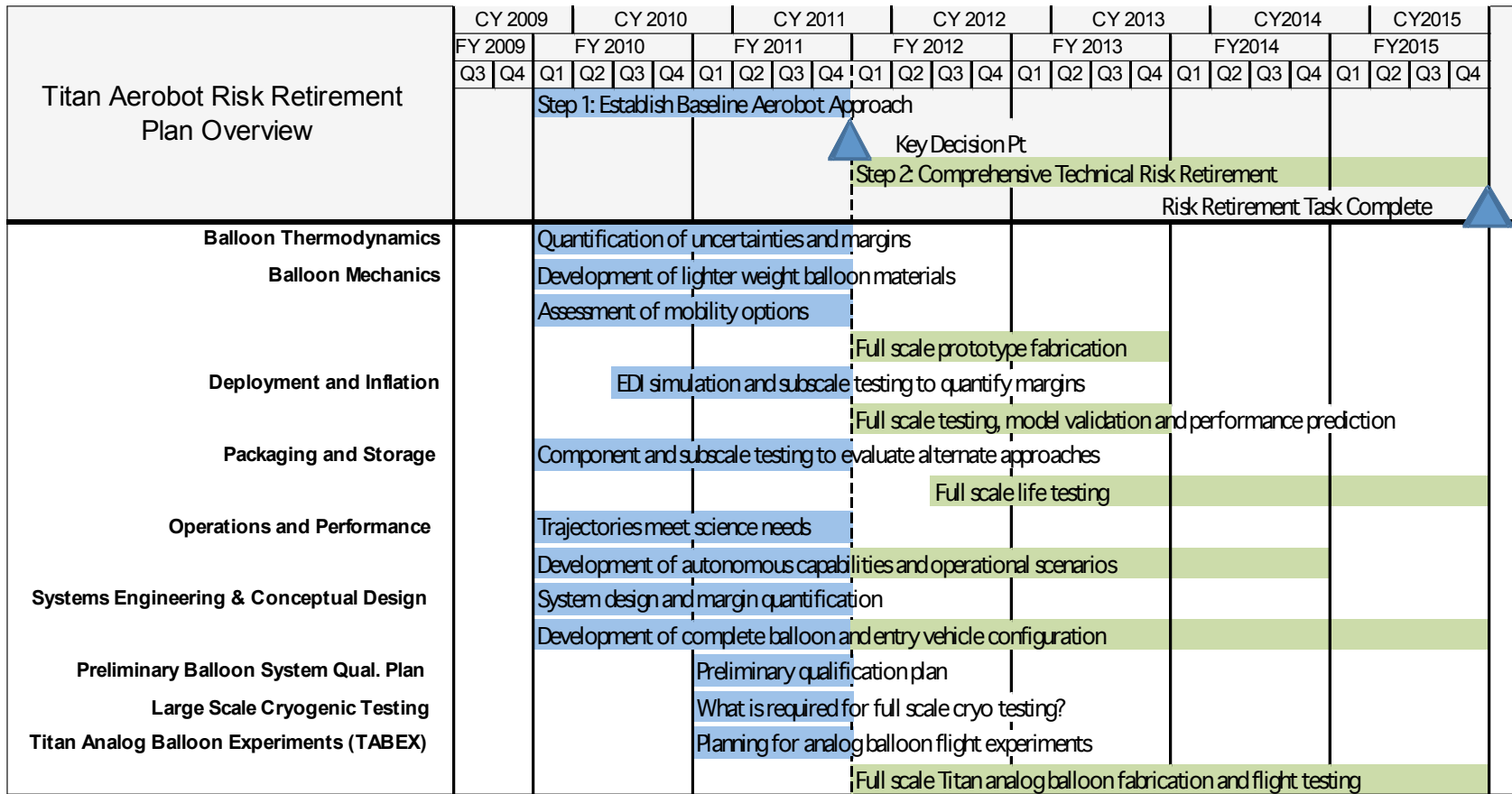


NASA/JPL and CNES Collaboration plan is currently being discussed





Top level schedule



Architectural defining questions are answered early, allowing definition of baseline approach and comprehensive risk mitigation



How could the Decadal Survey help to further Titan mission risk reduction efforts

- NASA Funding for proposed risk reduction activities might not be at the level requested to address all aspects of the current plan
- A separately funded in-depth study of the montgolfière mission architecture could provide additional focus for planned technical risk reduction activities
 - Study would be complementary to what has been done
 - Further assess and identify montgolfière architecture options that address major risks identified by the TSSM review boards
 - Determine system margins needed to provide a design that would be robust to potentially dynamic and uncertain environments at Titan
 - Further assess and identify montgolfière operability options that increase science return
- Results would inform the Satellites panel further on what is needed to reduce challenges posed by Titan missions



Summary

- A number of studies have been performed by JPL, NASA and ESA over the past decade assessing architecture options for a Titan exploration mission
 - A common element of all of these studies has been the recommendation of an aerial element for in-situ exploration
- Balloon concepts for Titan have been the object of considerable technology development activities
 - Major questions have been answered, but significant additional testing and risk reduction activities are needed to ensure mission readiness
- A collaborative aerial vehicle risk reduction plan that responds directly to NASA and ESA review board findings is being discussed between NASA and CNES
 - Plans are also being developed to address *in situ* and remote sensing instrument system challenges
- Elements key to reducing challenges posed by Titan missions are:
 - Focused studies of Titan balloon options to concentrate on selection of architecture(s) that best enable the achievement of highest priority decadal science
 - Focused risk reduction efforts needed to mature a Titan balloon for flight readiness
 - Focused risk reduction efforts to demonstrate readiness of *in situ* and remote sensing instruments