# The Common Spacecraft Bus and Lunar Commercialization

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# Summary

- **November 2006 Common Spacecraft Bus (CSB) rapid design and prototyping process begins leading to the development of the Hover Test Vehicle (HTV) and LADEE**

- **Since the announcement of the Google Lunar X Prize (GLXP) in September 2007 numerous teams have independently approached NASA Ames requesting access to the HTV and CSB technology**

- **This week (May 12, 2008) NASA releases term sheet for reimbursable Space Act Agreements (SAA) enabling private sector to access Common Bus team expertise, facilities and technology**

# SMALL SPACECRAFT INTRODUCTION

- **Commercial Electronics Have Enabled Small Spacecraft (Moore's Law)**
- **Several Countries Are Using Small Spacecraft In Civil And Military Space**
- **Significant Available Functionality From Wide DoD Investment**

## Key Features

- **Low Mission Costs ($50-100M), Short Schedule <24Months**
- **Low Mass < 300kg, Low Cost Launch Vehicles**

## Benefits

- **Lower Cost Enables Increased Number Of Missions**
- **Faster Learning Cycle, Leads to Lower Costs**
- **Demonstrate New Technology Sooner, Lowers Cost of Large Missions**
- **Lower Overall Program Risk by Providing Several Flight Opportunities for Critical Experiments**
- **Smaller Teams, Fewer Interfaces, Improved Collaboration**

## Drawbacks

- **Size, Mass Eliminate Some Missions for Small Spacecraft**
- **Higher Individual Risk Of Missions compared with $1B Spacecraft**
- **Use of "Yet To Be Proven" Launch Vehicles, or Fly as a Secondary Payload**

# Common Bus Project Guidelines

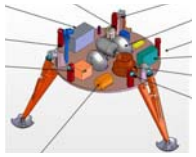
- **SSO-1: Develop Missions with destinations within the inner solar system.**
  **Rational: The Common Components/Modular Bus capability can deliver payloads to destinations such as lunar orbit, lunar landing, Earth-Moon Lagrange points, and rendezvous with Near Earth Objects (NEO).**
- **SSO-2: Develop low cost missions. This includes costs for small spacecraft development, launch vehicle, mission specific services/integration, instruments, operations, reserves, & inflation.**
- **SSO-3: Utilize cost effective launch vehicles and launch opportunities (e.g. Falcon-1, Minotaur V, ESPA).**
- **SSO-4: Develop missions within a short (< 36-month) period.**
- **SSO-5: Use a "Design to Capability" approach.**
- **SSO-6: Manage Projects as a NASA Category III, Risk Classification D Mission.**
- **SSO-7: Use the following priority in hardware selection:**
  - A) Existing hardware with space flight history.
  - B) Existing or developing hardware designed for space flight.
  - C) Appropriate Commercial Off the Shelf (COTS) Hardware.
  - D) New design.
- **SSO-8: Utilize technologies developed by other government technology programs (DOE, DoD, etc.).**
- **SSO-9: Develop and operate multiple simultaneous projects that are appropriately phased.**

# Common Bus Mission Requirements

- Spacecraft Bus to be compatible with either Falcon-1, Minotaur V, or ESPA launch vehicles
  - **Critical mass and volume constraints derived from Falcon-1 LV and ESPA**
- Mission durations:
  - **Orbiter: 2 Years as Orbiter or Free-Flyer**
  - **Lander: Operational during lunar day**
- Spacecraft design to be modular to support multiple configurations
  - **Pay NRE only once, then reuse design**
- Targets:
  - **Lunar Orbit**
  - **Lunar Surface (equatorial or polar sites)**
  - **Earth-Moon Lagrange points**
  - **Near Earth Objects (NEO)**

# Design Evolution

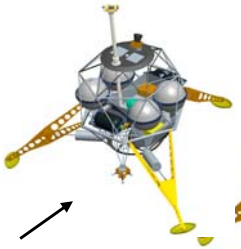
## Lander Design Evolution



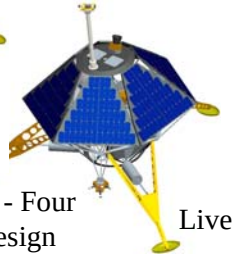
Project Start

Lander Conceptual Design Start

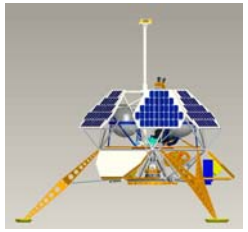
Initial Design Presentation



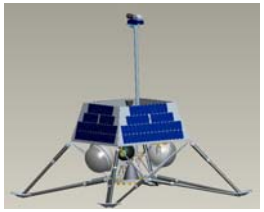
Live Bug - Four Tank Design



Live Bug – Strut Leg Option



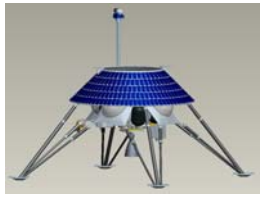
Live Bug- Add Radiators



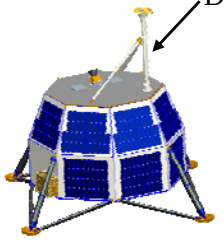
Live Bug II Segmented Design

Initiated Dead Bug - Four Tank Design

Dead Bug II Lower CG

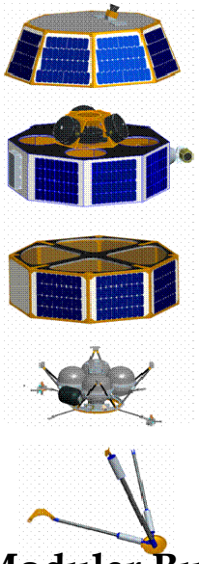


Dead Bug III More Solar Power Centralized Equipment



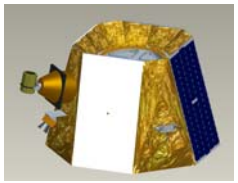
Live Bug 3.0 **Baselined Design**

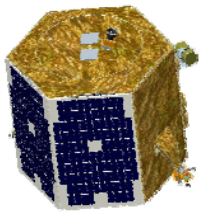
Featherweight Design (Falcon Option)

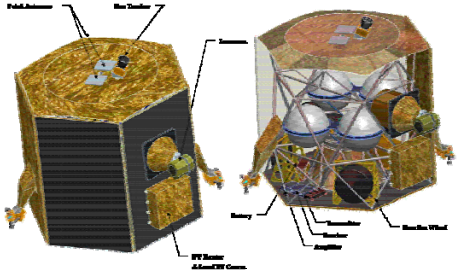


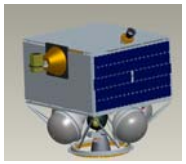
**Modular Bus Design**

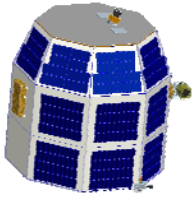
## Orbiter Design Evolution





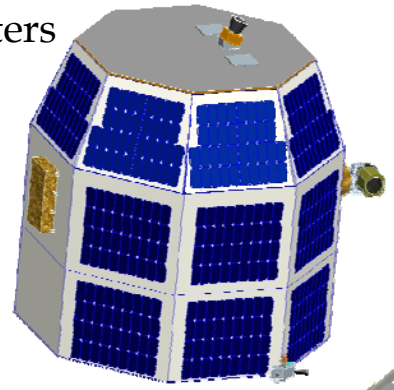


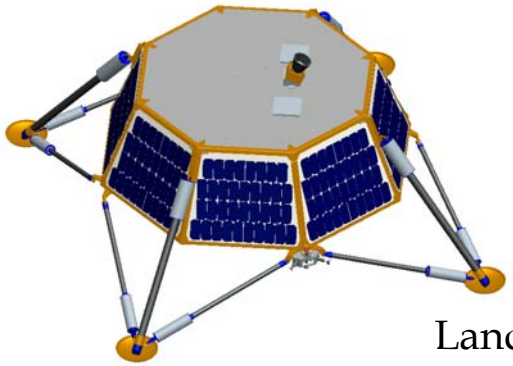


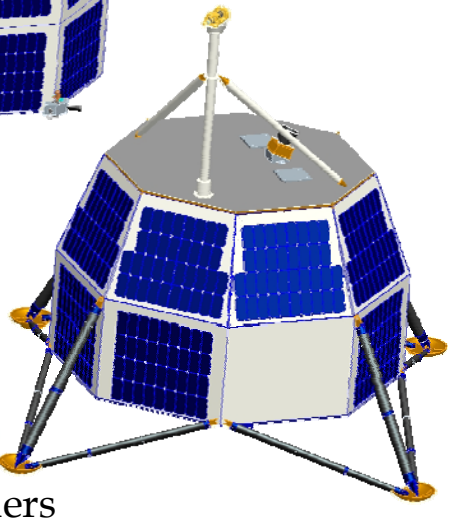


# Common Spacecraft Bus – Modular Approach

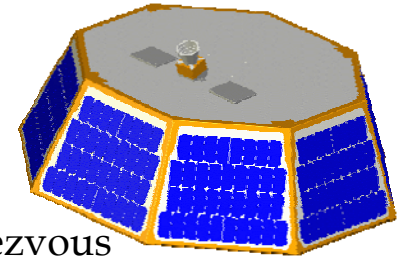
Orbiters



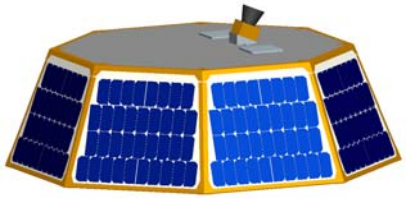




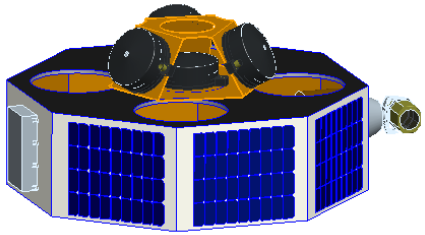
Landers



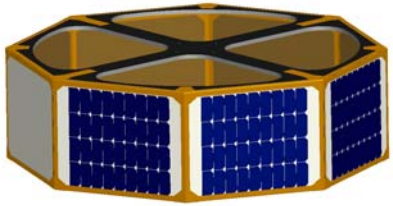
NEO Rendezvous



- Bus Module



- Payload Module



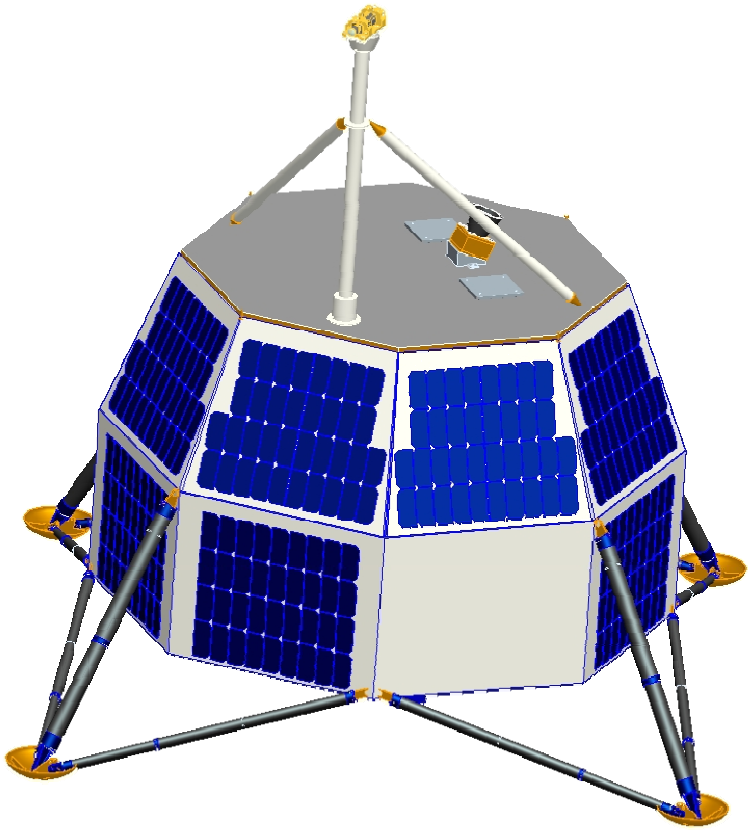
- Extension Module

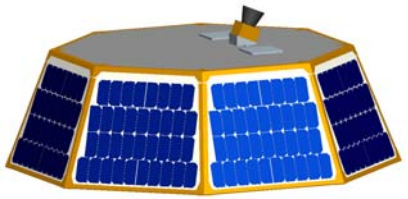
- Propulsion Module

- Legs

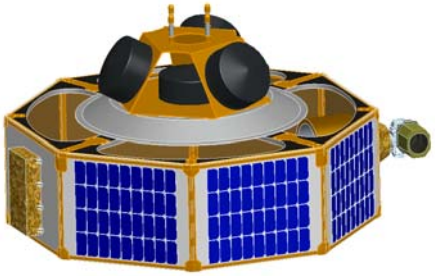
**Multi-Mission Capability enabled by Modular Bus Design – Select Modules to meet Mission Requirements**

# Small Lander Configuration

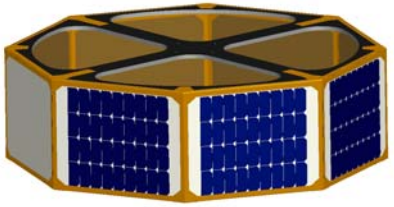




- Bus Module



- Payload Module



- Extension Module

- Propulsion Module

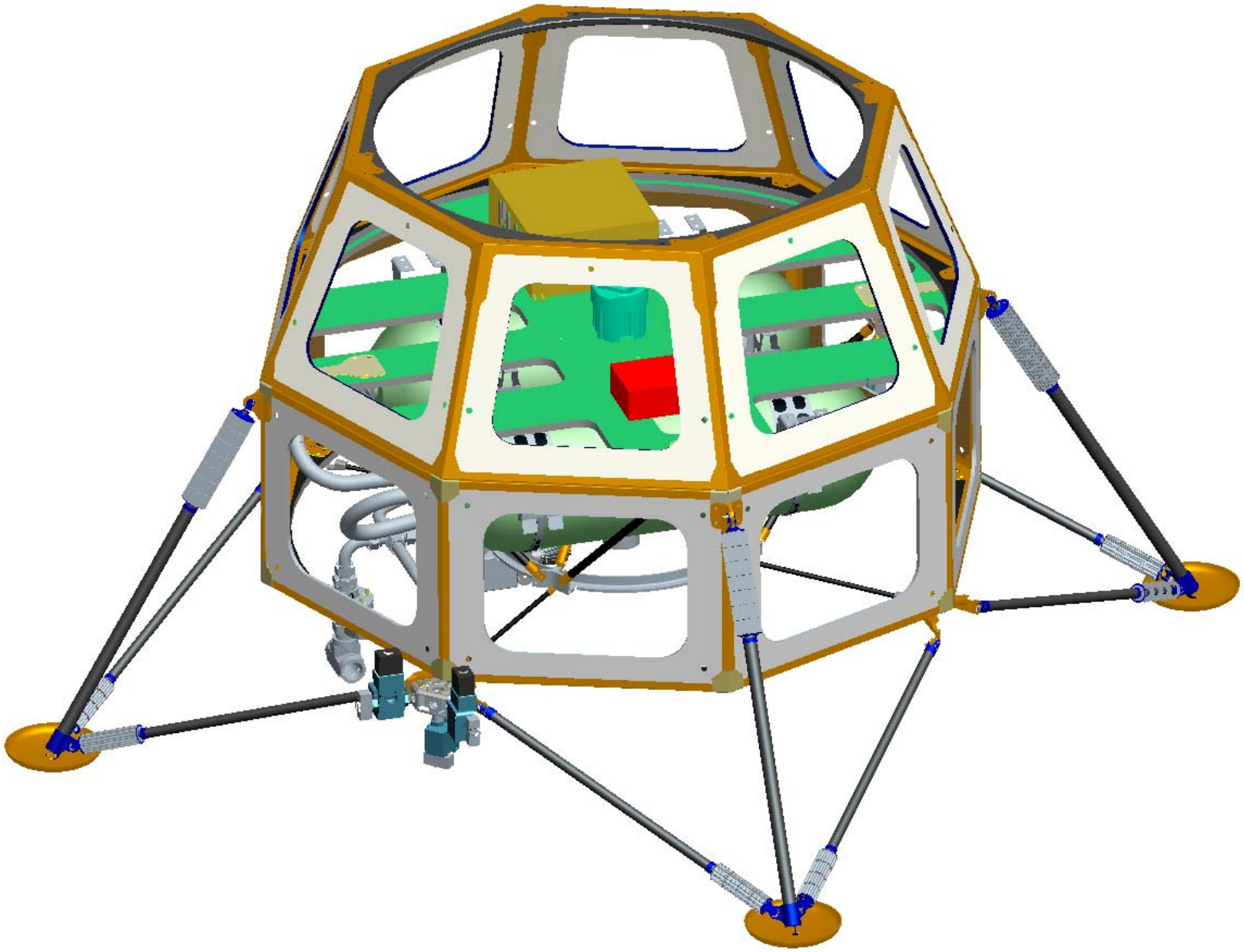
- Legs

# Early Hardware Integration Testing

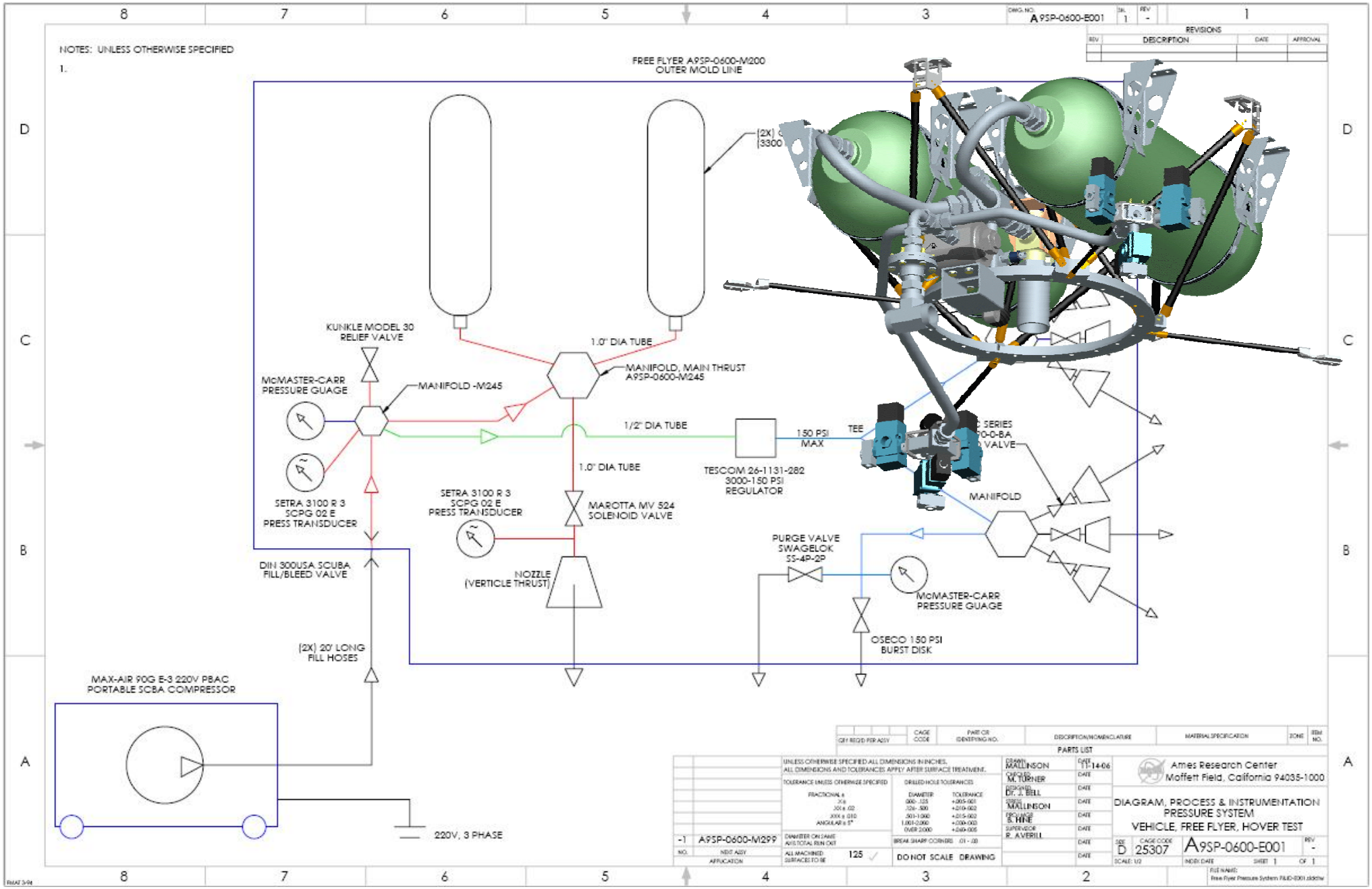
- **HTV is a hardware integration step in the CSB rapid prototyping process.**

- **Early and Frequent Hardware Integration Testing is a key to Rapid Development Schedules:**
  - Software-in-the-Loop Testing
  - Hardware-in-the-Loop Testing
  - Propulsion System Characterization
  - Sensor-Actuator Closed Loop Testing
    - Cold-Gas Floater Testing – Closing IMU and Thrusters
    - String Testing – Closing Star Trackers and Reaction Wheels
    - Free-Flight Testing – Full 3D Attitude Control Testing

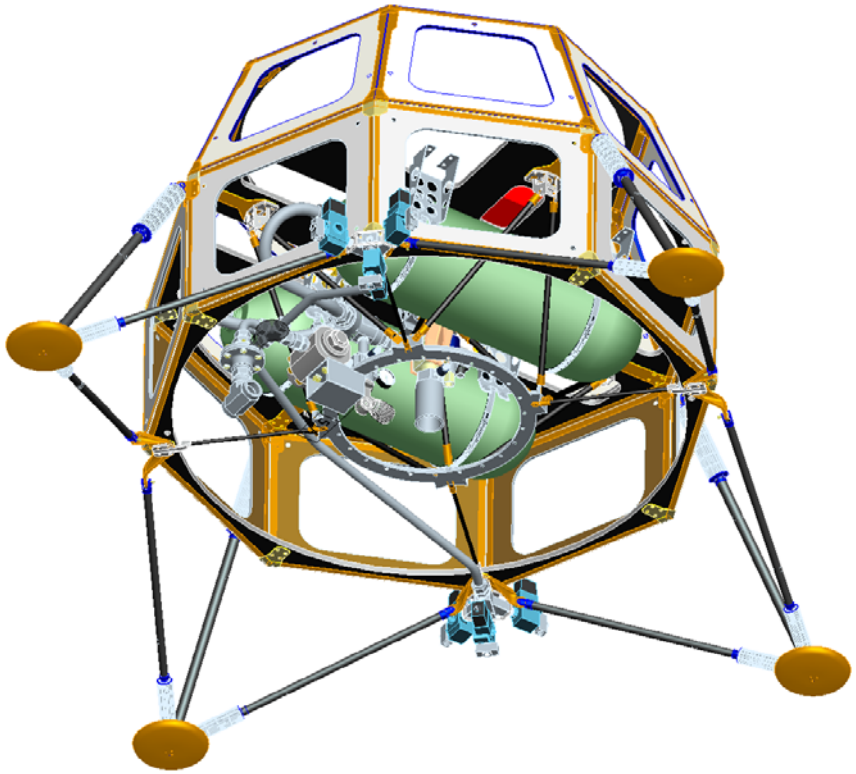
# Hardware Integration Test Bed

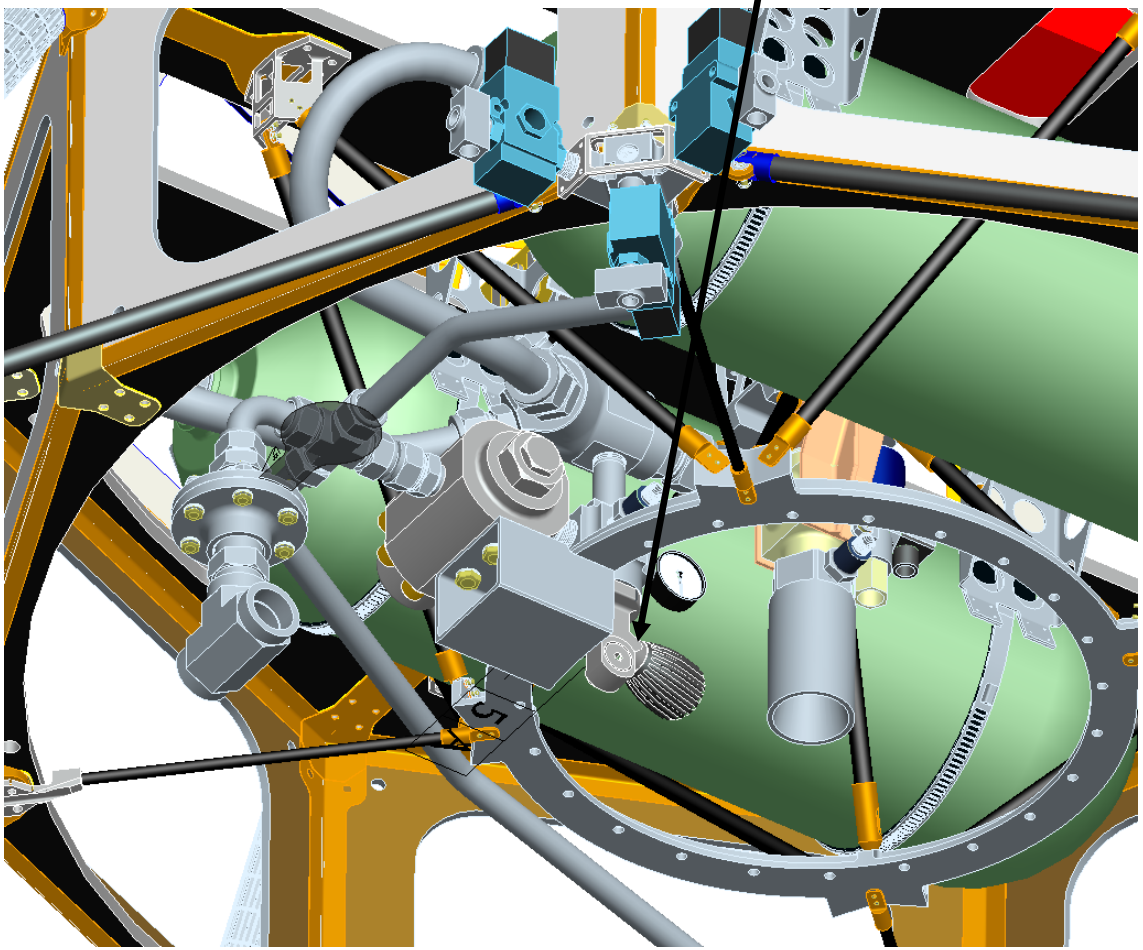


# Cold Gas Propulsion System

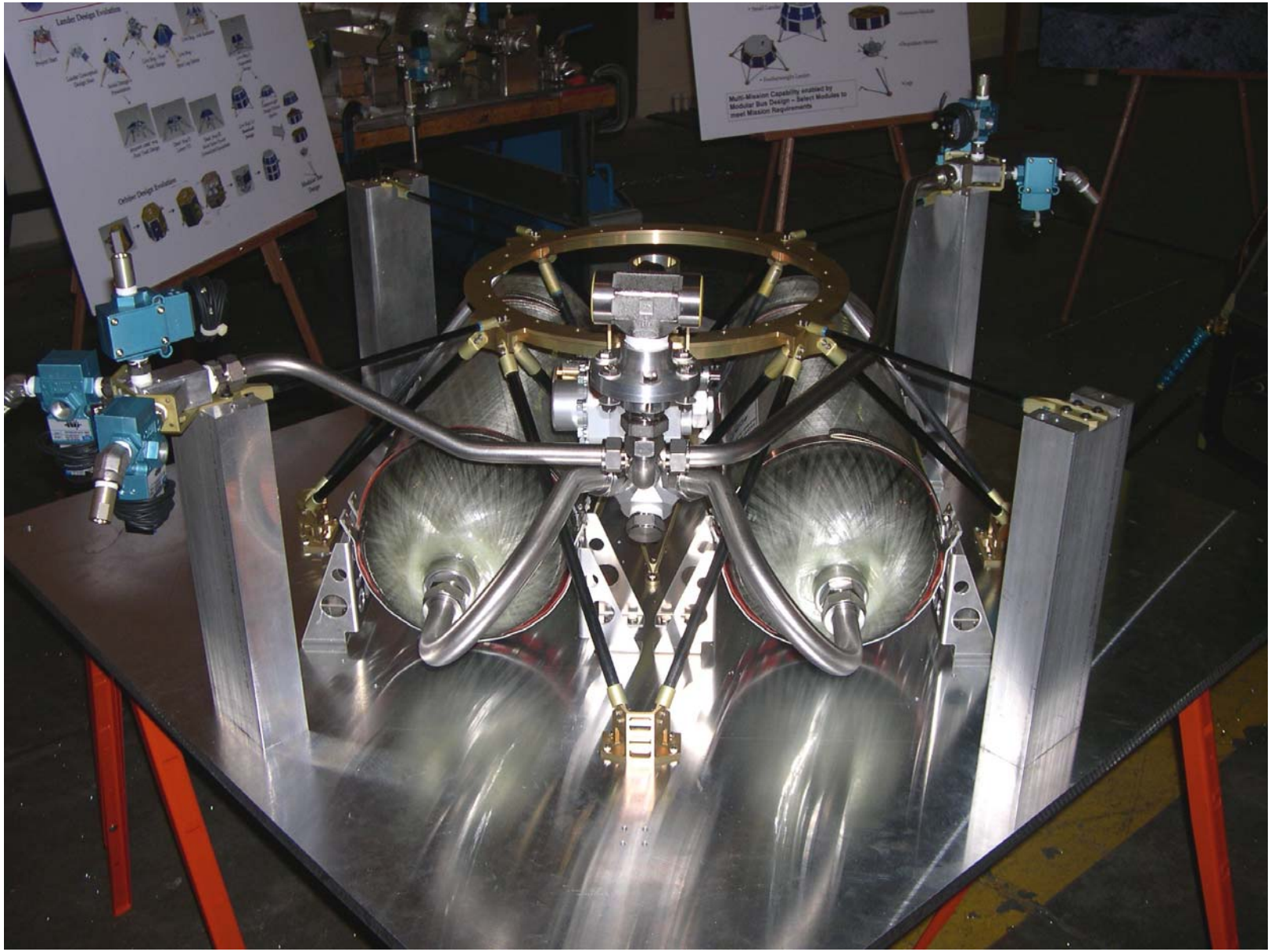


# Cold Gas Propulsion

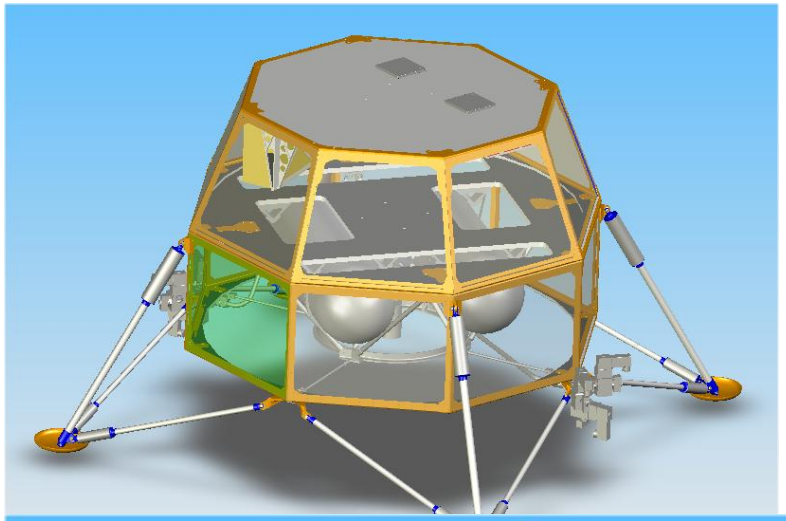


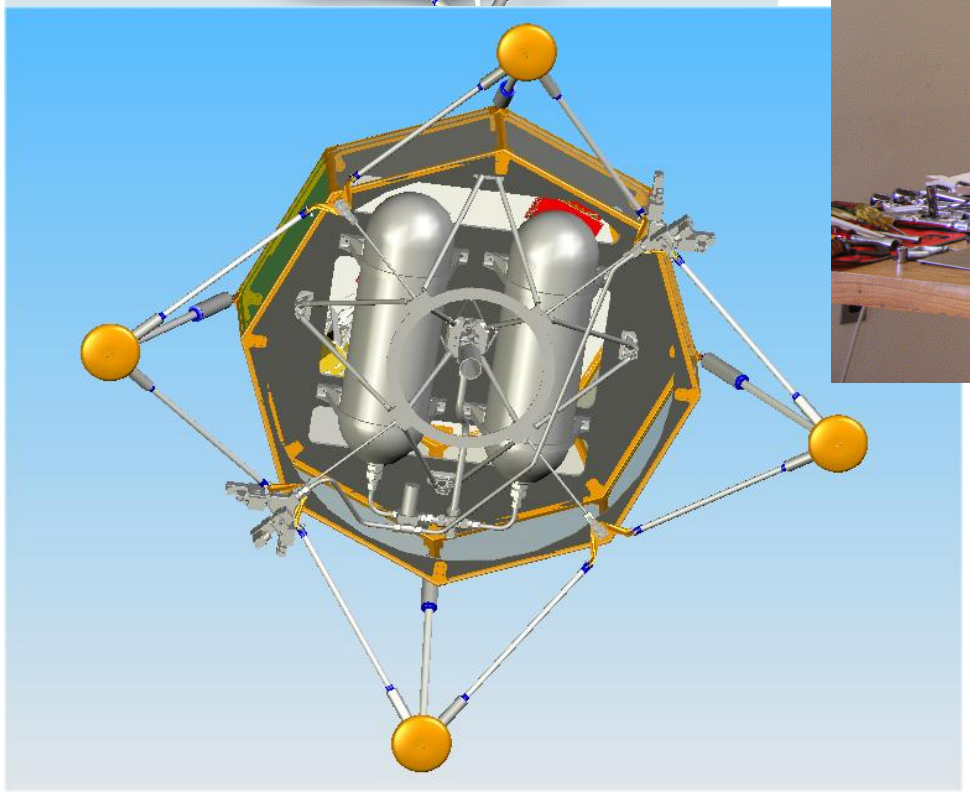


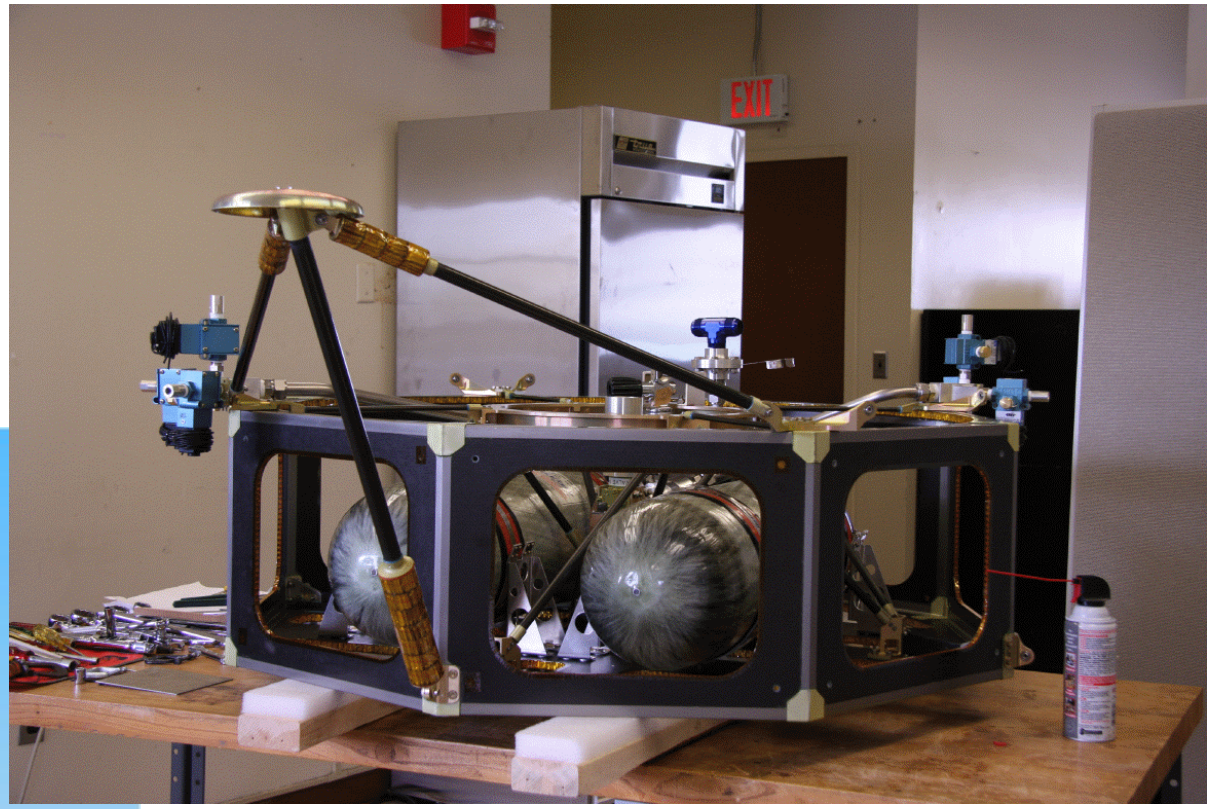
# Cold Gas Propulsion Hardware



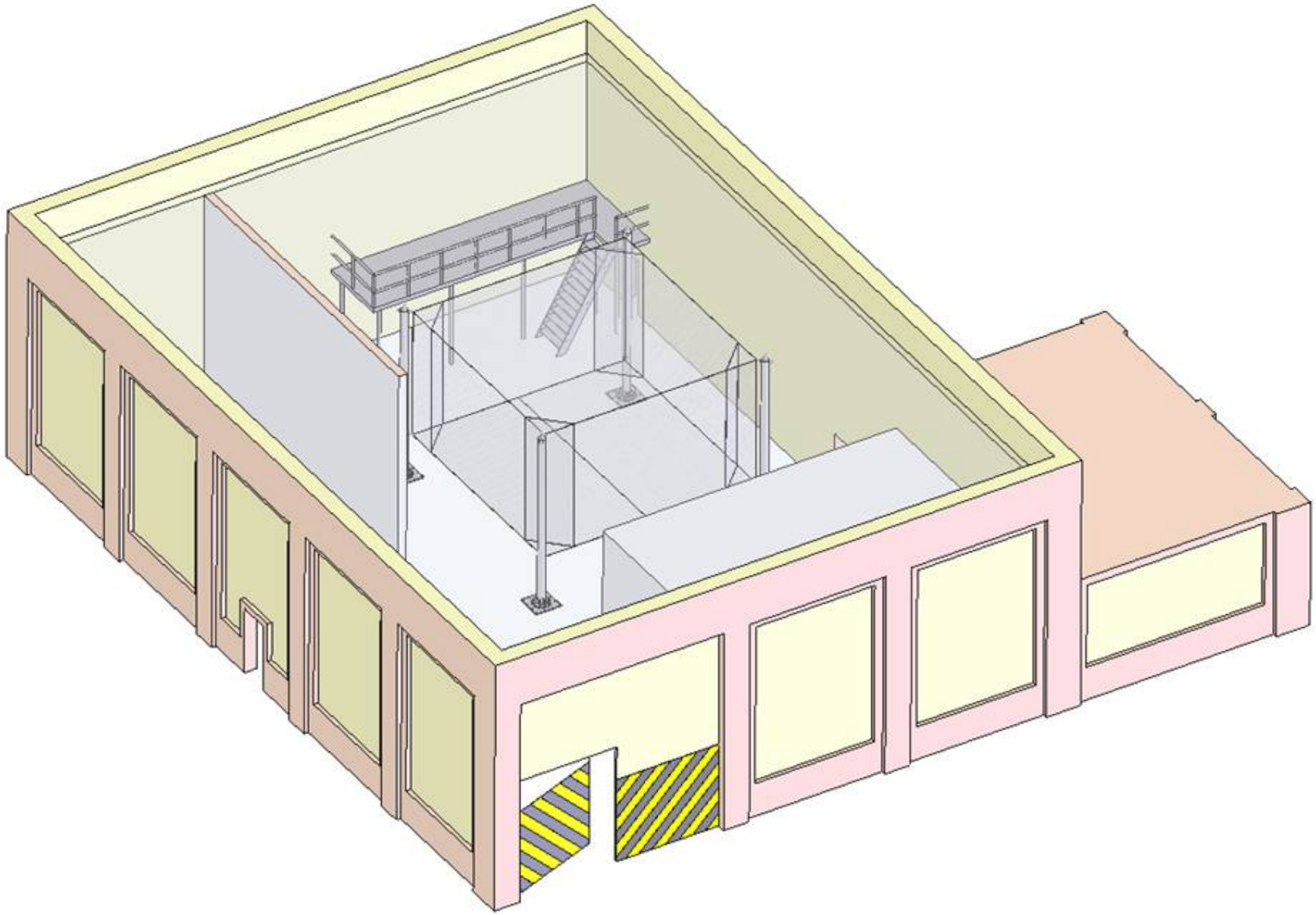
# Hover Test Vehicle Integration



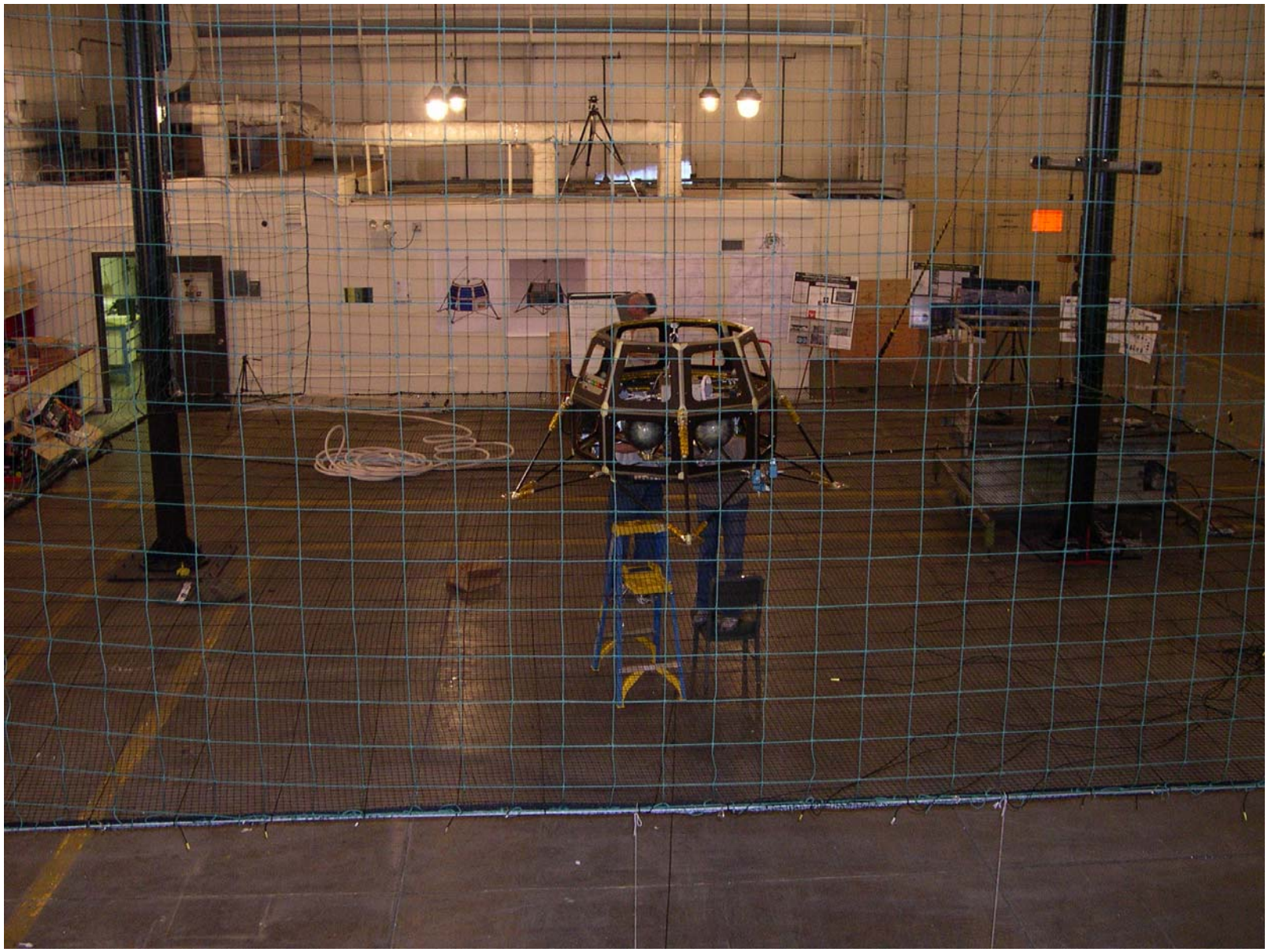




# Hover Test Facility



# Hover Test Vehicle and Facility



# Hover Test Vehicle Video

# Free Flight Testing

# Assisting the Private Sector

- **In furtherance of commercial space initiatives, NASA is offering the private sector the opportunity to access unique facilities, personnel, expertise and/or equipment for Common Spacecraft Bus development.**

- **GLXP participants can, under a Space Act Agreement, access NASA engineering and technical expertise regarding:**
  - Hover Test Vehicle plans, parts and replication
  - Common Spacecraft Bus plans, parts and development
  - Testing of HTV and CSB using unique Hover Test Facility (HTF) at Ames

# HTV/CSB and the Private Sector

- **Term Sheet delineating options/range of possible support developed by NASA Ames and HQ to assure level playing field, set expectations, anticipate key factors (costs, ITAR, etc.)**
- **Technical/Business Team assembled to orchestrate public-private collaboration**
  - Sid Sun, Chris Boshuizen, Phil Davies (Butler Hine)
- **Term Sheet released and interactions commence week of May 12, 2008**
- **Technical Report on HTV to be published openly**
- **Specific agreements to be processed as SAAs**

# HTV and Lunar Commercialization Strategy

- **Lunar commercialization has very high barriers to entry**
- **High barriers to entry restrict competition and stifle market development**
- **Two ways to encourage private entities to overcome high barriers to entry**
  - Increase incentives: increasing pay-off for overcoming barrier (Google Lunar X Prize)
  - Decrease barriers to entry: in this case transferring enabling technology to private entities (subject to ITAR regulations) and providing access to engineering expertise and capabilities (NASA/NACA)

# Conclusion

- **NASA is looking to lower the barriers to lunar commercialization by allowing private enterprise access to the Common Spacecraft Bus design, facilities and expertise**

- **The Google Lunar X Prize is an opportunity for NASA to continue it's NACA-tradition of performing aggressive research and development and then transferring the knowledge and techniques gained to industry so that it can drive commercial growth**

- **Commercial partnerships (like Google Lunar X Prize and CSB development) also increase opportunity for NASA to iterate and improve on design concepts and provide additional opportunities to test evolving systems**