Phoenix:
Initial Technical Elements and Interfaces

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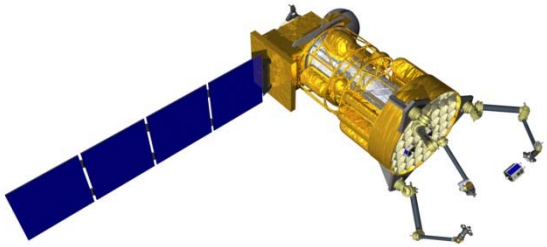
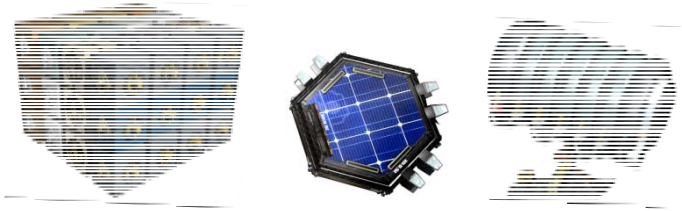
Three basic concepts combine to create the Phoenix architecture

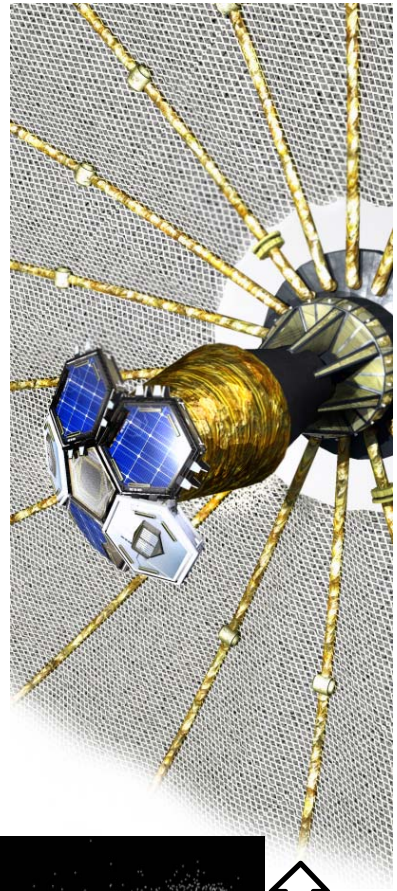
Tele-presence control of Robotic Servicer/Tender



Aggregation of "Satlet's"



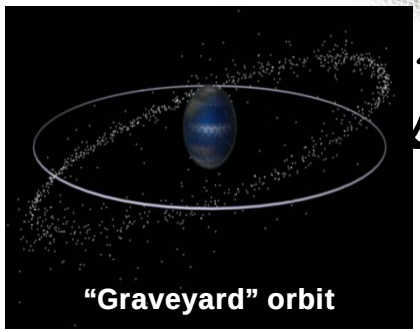
Repurposing retired components into value added systems or services



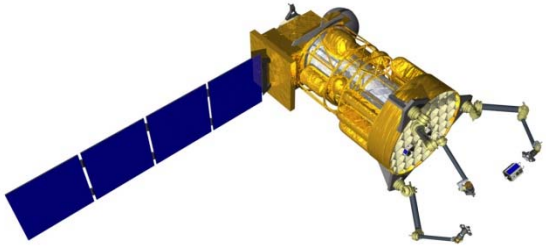
Dispensing payloads via existing Commercial Hosted Payloads service

SES-2, host to CHIRP

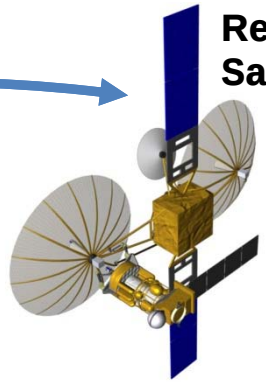
Intelsat 14, host to the IP Router In Space (IRIS) Joint Capability Technology Demonstration



The concepts are then broken into individual technical elements

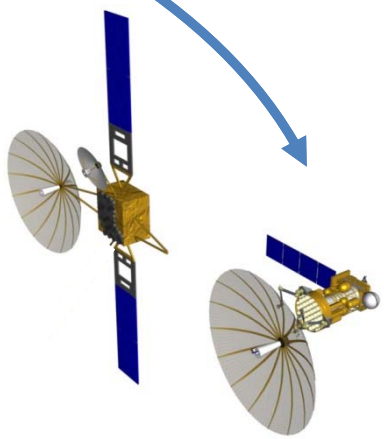


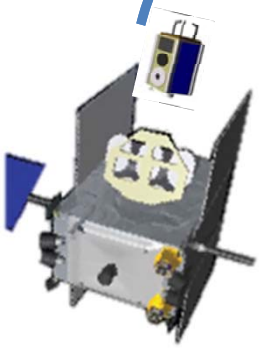
Retired Communications Satellite



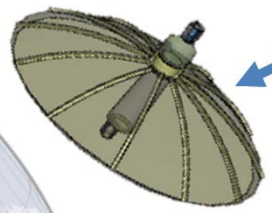
Tender/Servicer Spacecraft

- Spacecraft Bus.
- RPO Sensors.
- Primary Robotics (FREND Arms).
- Tools/end effectors and Tool Changers.
- Next generation hyper-dexterous manipulators
- Toolbelt and/or Toolcaddy.
- High performance Ground-Servicer/Tender Comms.
- Tele-presence algorithms and S/W.





Commercial Communications Satellite to host Ridealong PODs



New Technologies

- PODs (Payload Orbital Delivery system).
- Satlets (contained within PODs containers).

On Earth

- Ground Communication Facility for Service/Tender.
- Ground Operations Facility for Robotics Payload Suite.
- N-DOF Test Facility for Robotic and Ops Validation.

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Notional breakdown of technical elements/components for the Phoenix Program

Major Interface Elements		Gov't Supported	Bids or Partners
Tender/Servicer Integration		✓	
- Spacecraft bus modifications and completion		✓	
- Rendezvous sensor suite			✓
- Robotics Payload Integration		✓	
	Primary Robotic Arm (FREND)	✓	
	- Tools (i.e. secondary end effectors, saws, grips, changers etc.)		✓
	- High performance Ground-to-Servicer/Tender communications		✓
	- Tele-presence algorithms and S/W (Training and validation)		✓
	- Next generation hyper-dexterous manipulators		✓
Toolbelt and/or Toolcaddy			✓
Satlets (Multiple variants)			✓
PODs			✓
Commercial bus ridealong slot (to host PODs)			✓
Retired Communications Satellite		✓	
	- Retired aperture	✓	
N-DOF Test Facility for Robotic and Ops Validation			✓
Ground Communication Facility for Servicer/Tender			✓
Ground Operations facility for Robotics Payload			✓

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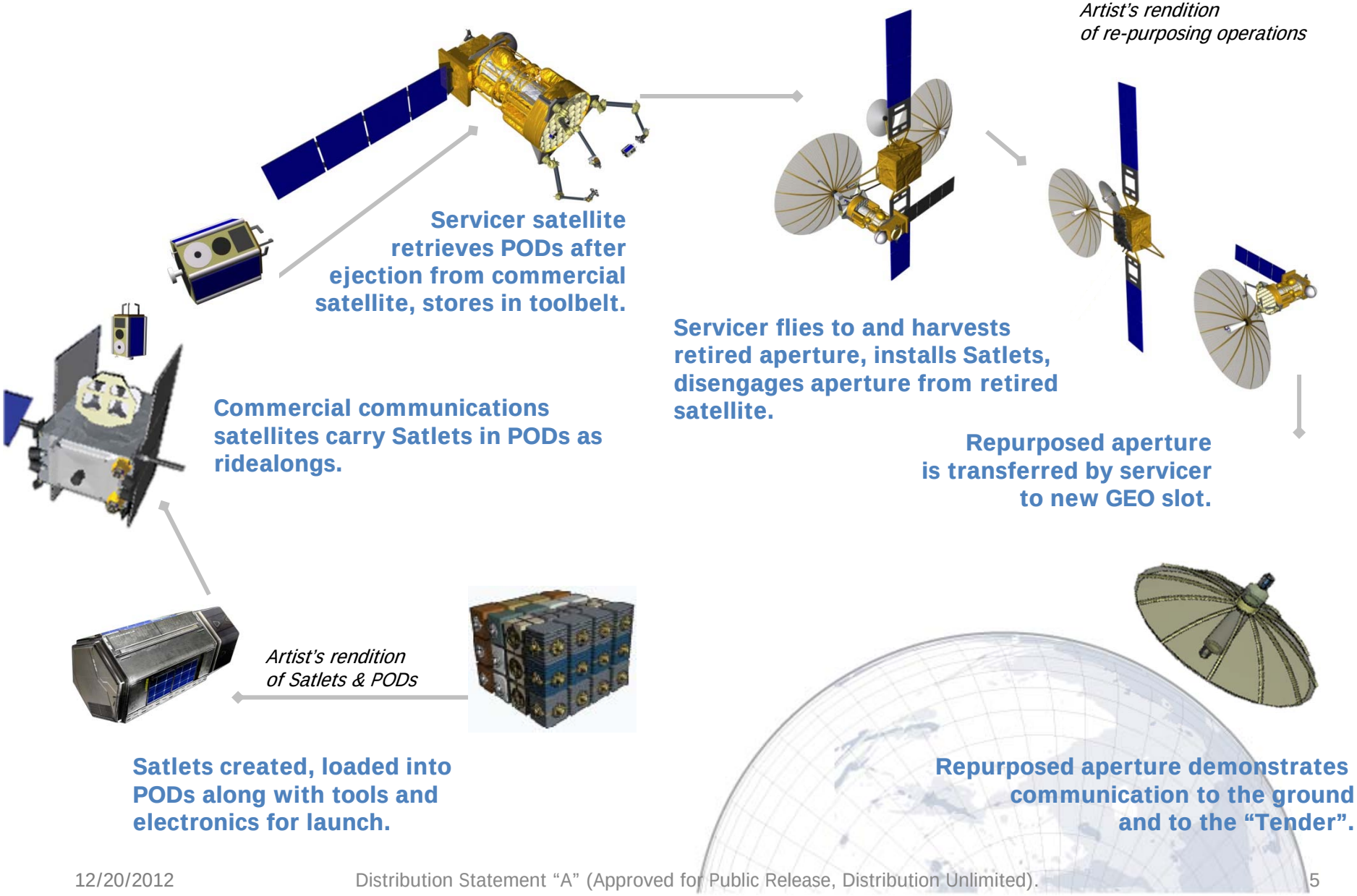
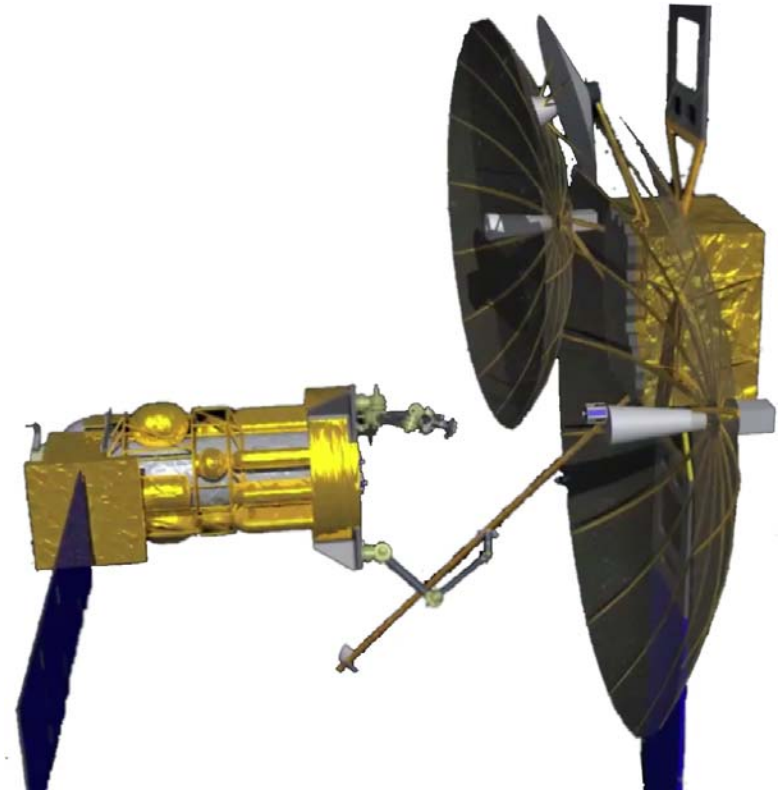
Phoenix demonstration notional concept of operations

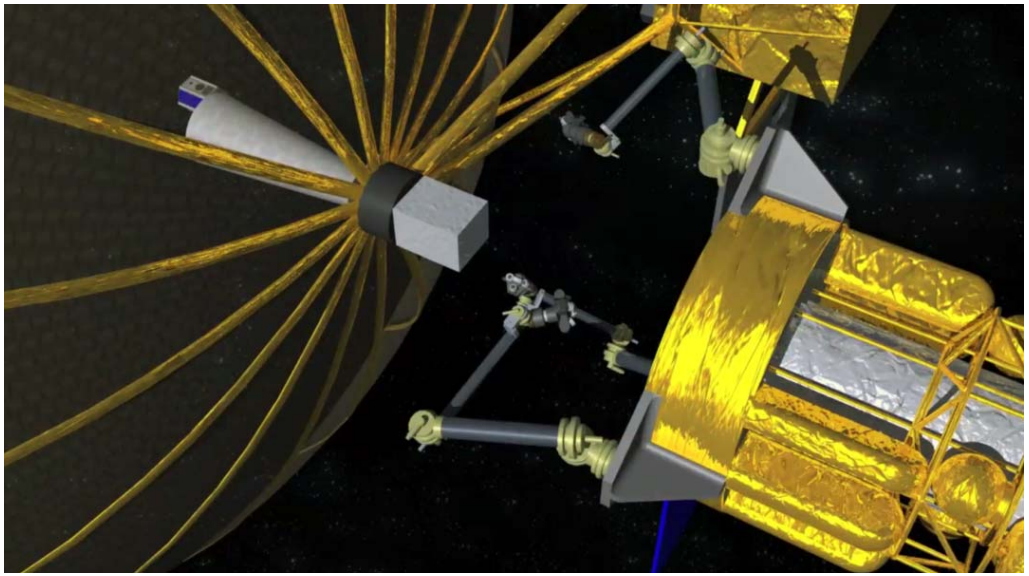


Example of detailed considerations in proximity operations

Servicer/Tender proximity operations (partial list):

- Local obstacle avoidance inputs for tele-presence operators.
- Variety of structural attach points.
- Optimal location to dis-engage aperture from satellite.
- Multi-arm grappling requirements and/or scenarios.





Simple concepts with many un-explored technical challenges

Environment

- Unknown static discharge state of the retired satellite and/or aperture.
- Very high radiation dosage on electronics.

Retired Satellite

- Unknown tumble rate(s).
- Unknown dynamics for extended structure(s).
- Unknown condition of metal or structures to be used for grappling.
- Unknown propellant load and associated dynamics.

Retired Aperture

- Non-consistent supports (e.g. material and different construction frames, i.e. tubular, square, I-Beam etc).
- Varying Feed collectors (center, offset, on satellite etc).
- Unknown state of the antenna collection mesh/substrate.

Operations in Space

- Delay time for Robotic tele-presence control.
- Local tele-operator situational awareness limitations.
- Limitations in degrees-of-freedom vs. manipulation needs.
- Mitigation of multiple RF emissions between different elements, simultaneously.

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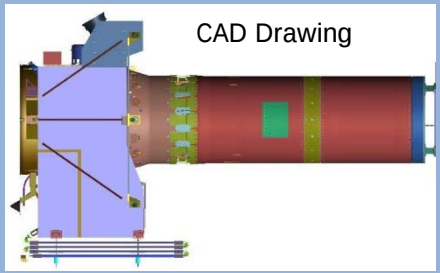
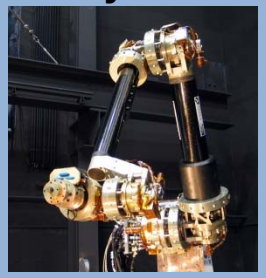
Representations of major elements that flow from Phoenix concepts

Servicer / Tender



Example retired satellite with aperture

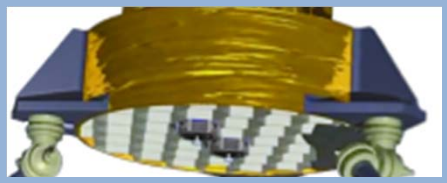
Primary Robotics



Tools

Image from Web

Toolbelt / Toolcaddy



Artist's Concept

High performance communications

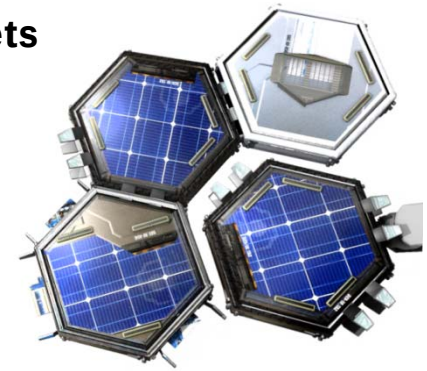
Next generation hyper-dexterous manipulators

DARPA INSPACE 2006 AFRL Contract

PODs

Artist's Concept

Satlets

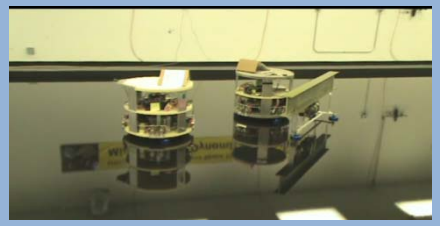


Artist's Concept

Tele-presence Control

Image from Web

N-DOF Testbeds



AIAA-2009-6443

Servicer/Tender: Functions and nomenclature

"Servicer" refers to functions that the GEO spacecraft does to affect actions to another object. These include:

- Rendezvous and proximity operations.
- Transfer from GEO to Graveyard orbit.
- Robotic operations.
- Storing PODs and Satlets and Tools.

"Tender" refers to functions that the GEO spacecraft does after or beyond "servicing." These include:

- Stable standoff up to 1 km from the repurposed aperture.
- RF collection and re-transmission from the repurposed aperture.
- Inspection of the re-purposed aperture after release.

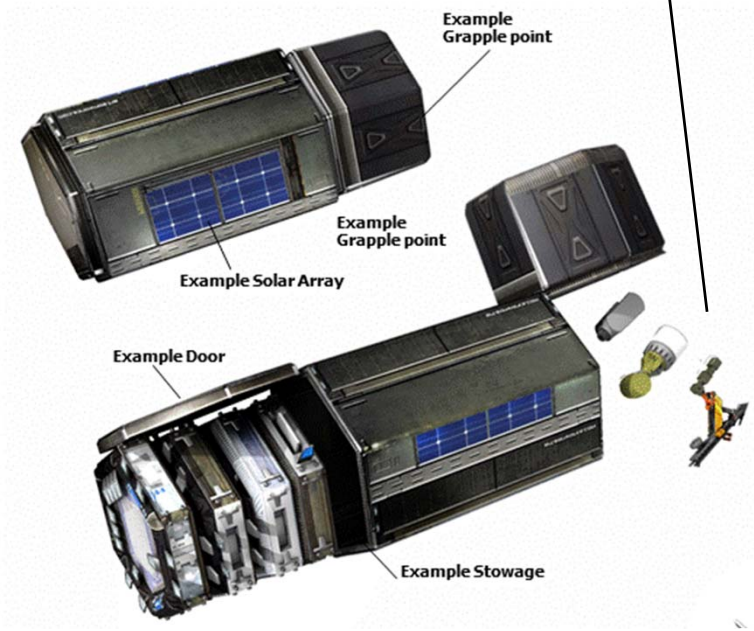
PODs: Nomenclature

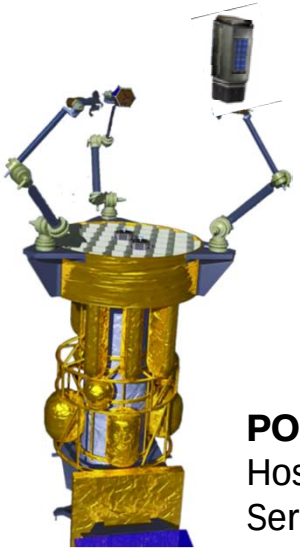
PODs (Payload Orbital Delivery System)

- Structural container that supports Satlets, tools, electronics, etc. during launch on a hose communications satellite.
- Can be dispensed into space to be picked by the Servicer/Tender.

PODs are meant to contain multiple Satlets, tools, electronic boxes all of varying sizes and shapes.

Multiple tools for Servicer/Tender stored in the PODs.





PODs have multiple interfaces to contend with: Host communications satellite, grapple tools on Servicer/Tender, toolbelt on Servicer/Tender.

Satlet: Concept and nomenclature

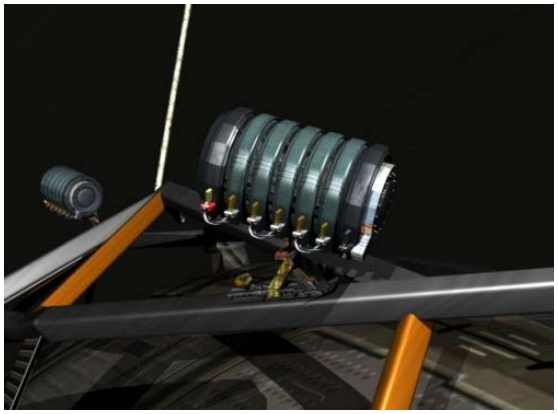
"Satlet"

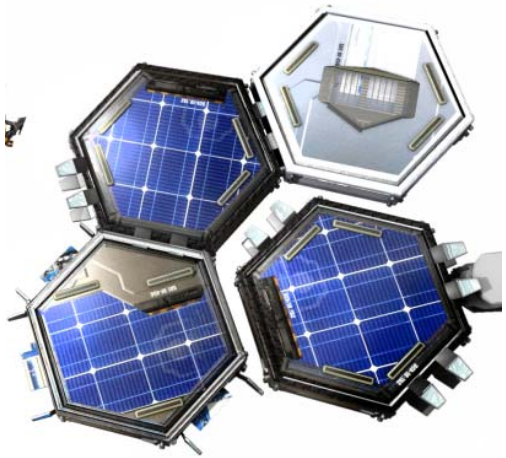
- Individual "cell" used to provide a specific function, either singularly or aggregated with others.

Notional Satlet functional variants for Phoenix:

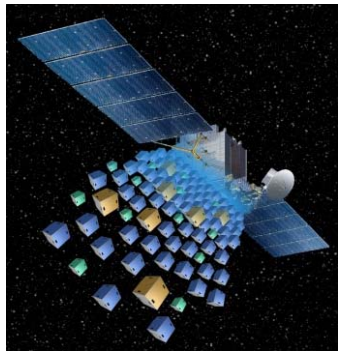
- RF energy collector at feedhorn of existing aperture.
- Attitude control stabilization of aperture.
- Momentum management of aperture.
- Power generation and/or transfer.

Satlet examples

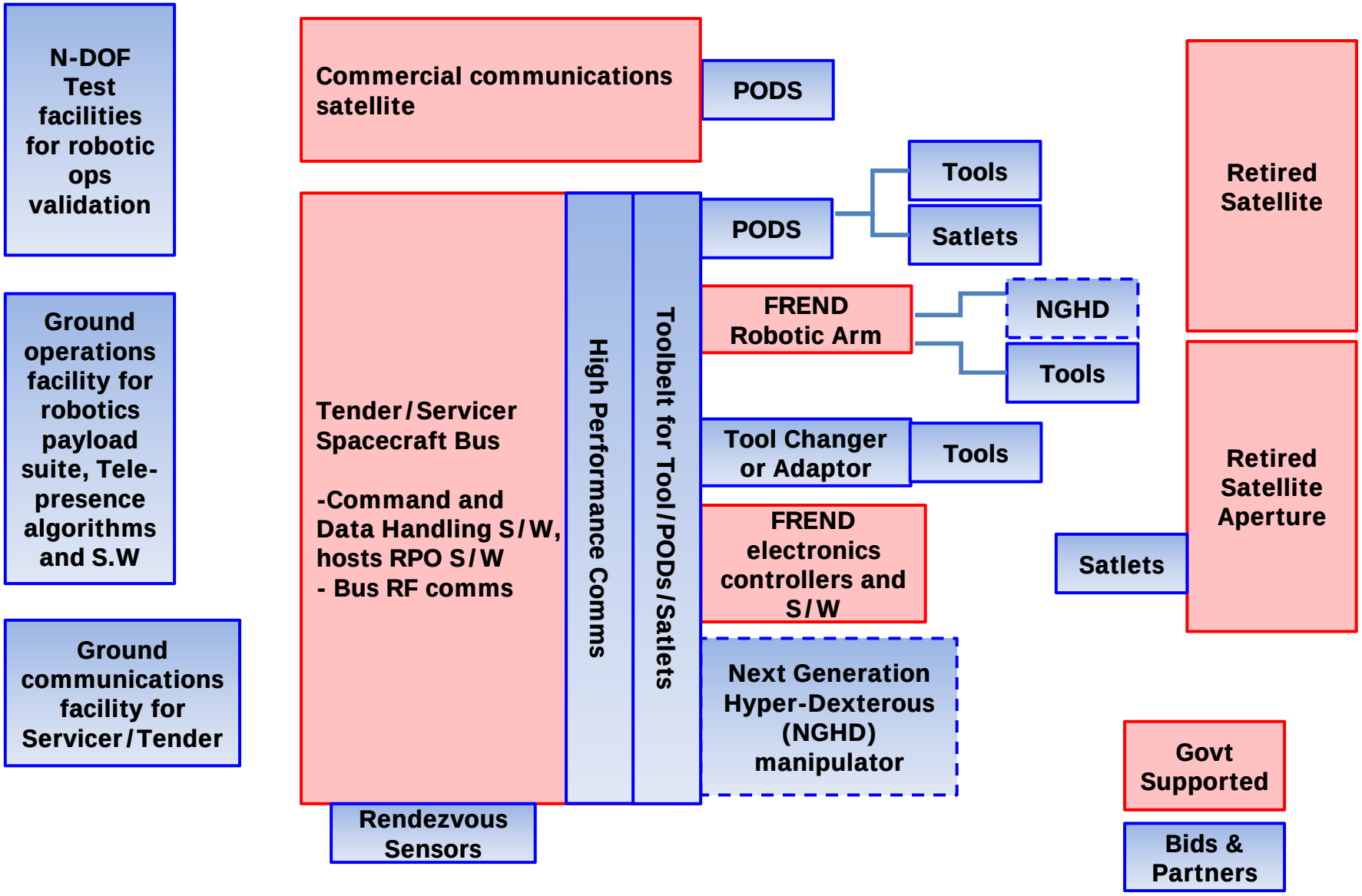




Artist's Concepts



Notional functional interface diagram



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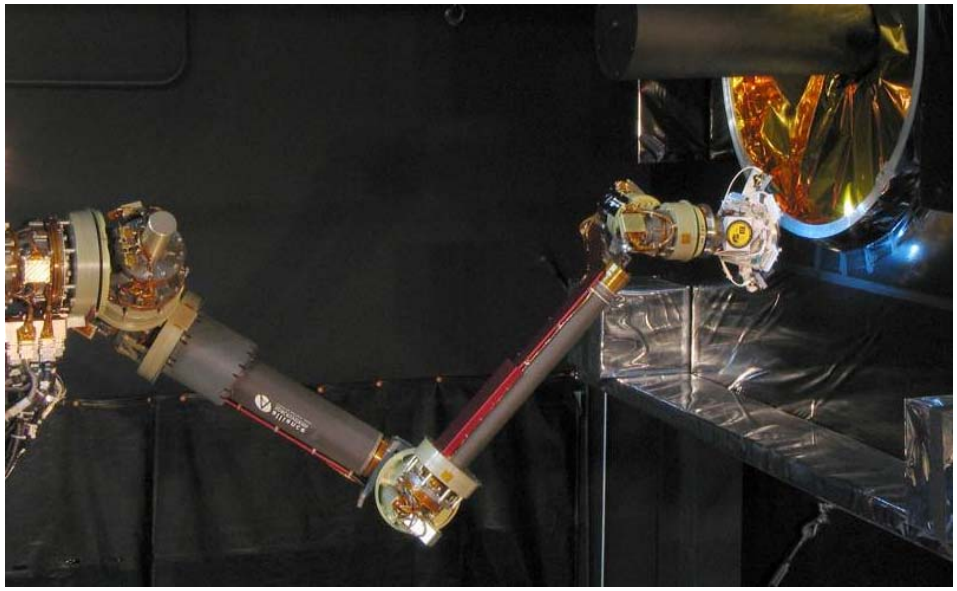
Element: FREND Robotics Arm

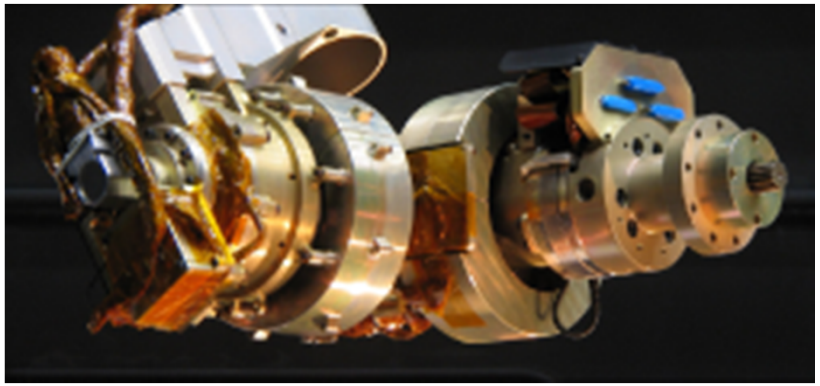
- Description: GFE arm designed for autonomous and tele-operated positioning of PHOENIX end-effector tools:
  - FREND robotic arm and tools have been tested in 1-G for ground validation.
- Number of FREND arms on Phoenix demo TBD pending USG mission analysis.

Notional Attributes
Tool Drive Mechanical / Electrical Interfaces
Software Interfaces for Autonomous Control
Software Interfaces for Teleoperated Control
Volume stowed
Control methodology
Lifetime

FREND Robotics

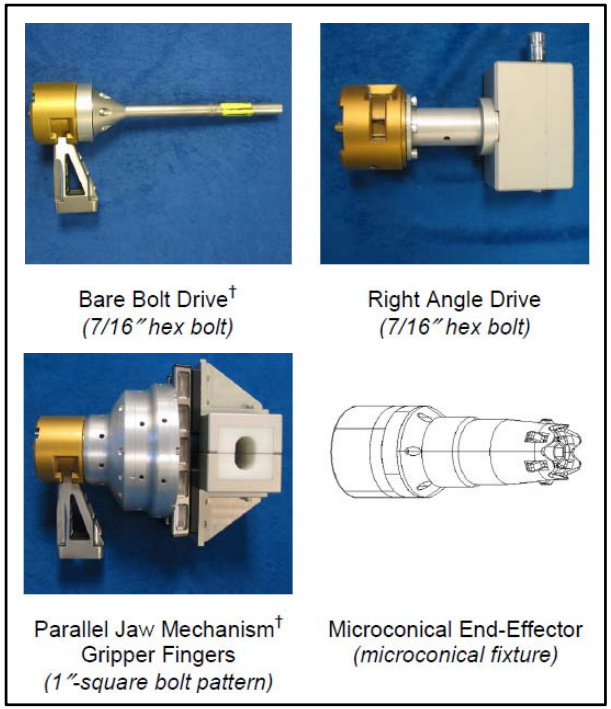


FREND Tool Drive / End-Effector Interface



Element: Tools (i.e. variety of end effectors)

- Potential functions: Grasp PODs in free space, place PODs in tender toolbelt, remove Satlets from PODs/toolbelt, place Satlet on focal point of aperture, grasp retired satellite and antenna, removal of antenna, stow in toolbelt, interface with tool changer mechanism, etc.
- Multiple tools will be required for grasping, cutting, and other functions…



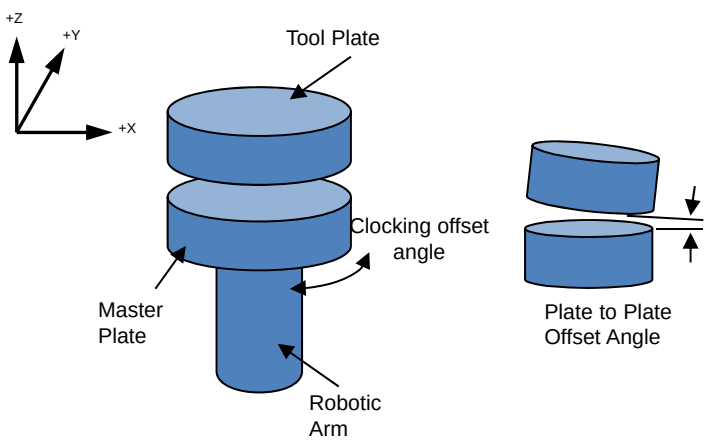
Example end-effectors

(UofMD Ranger End Effectors shown)

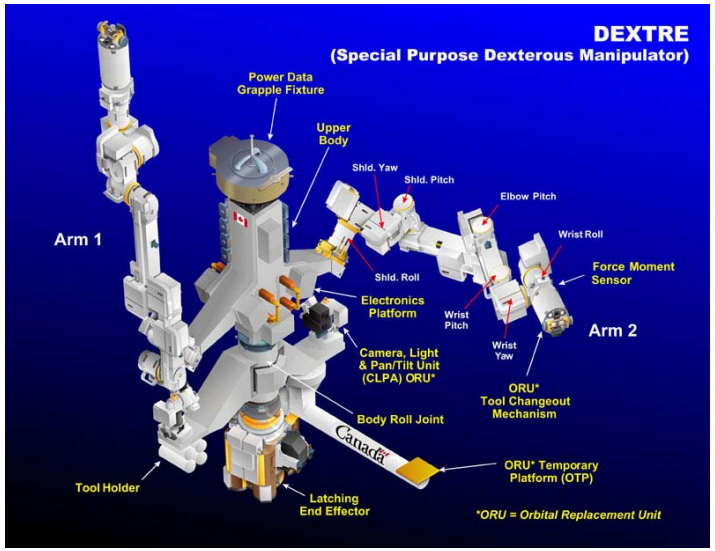
Notional Attributes
Power
Mechanical Interface
Grip force/torque
Grasp targets
Electrical Interface
Delivery
Volume stowed
Control methodology
Life at GEO
Imaging

Element: Tool changer

- Description: Capable of mating to tools, effecting mate/de-mate operations:
  - Consideration for passing power and signals to end effectors.
  - Consideration of physical guidance features
  - Capable of multiple mechanical mate/demate actions compatible with end effectors.



Notional tool changer schematic



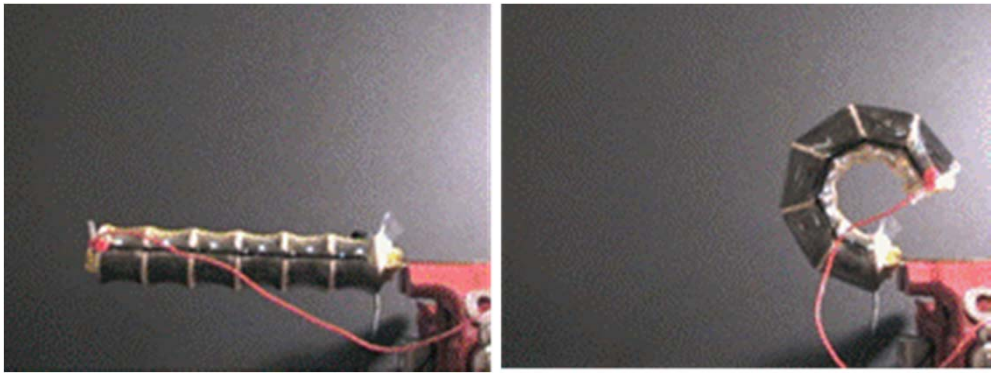
DEXTRE robot and integrated tool changeout mechanism (From CSA Website)

Notional Attributes
Grip force/torque
Mating/Demating
Operational
Size/Mass
Power
Mounting platen
Electrical interface
Control methodology
Life at GEO
Delivery

Element: Next generation hyper-dexterous manipulator

- Description: Multi-segmented multi-jointed non-mechanically controlled manipulators
- Considerations: Acting as primary or secondary with another robotic arm (i.e. FREND), control electronics required, state of development or TRL, etc..

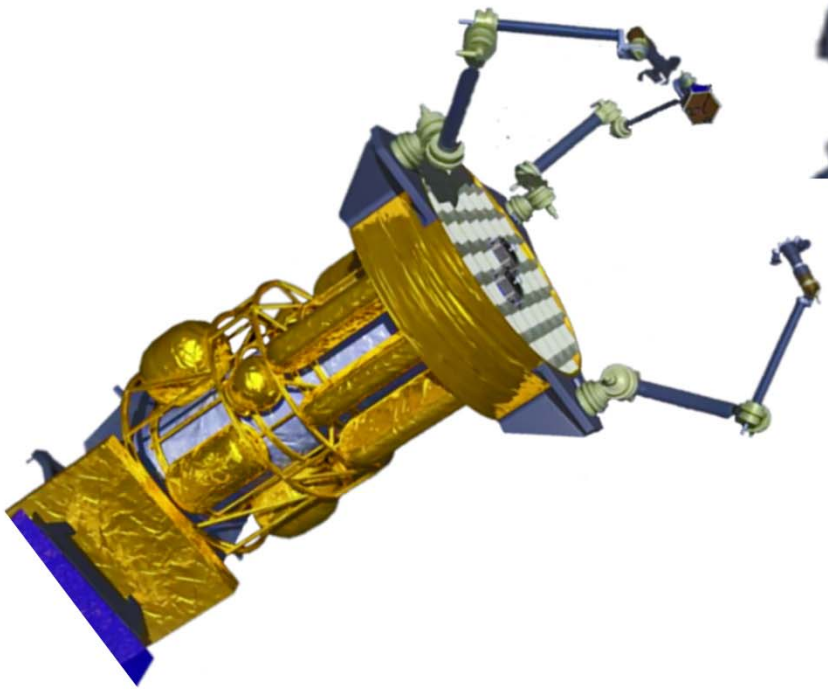
Notional Attributes
Tool Drive Mechanical / Electrical Interfaces
Software Interfaces for Autonomous Control
Software Interfaces for Tele-operated Control
Volume stowed
Control methodology
Lifetime at GEO

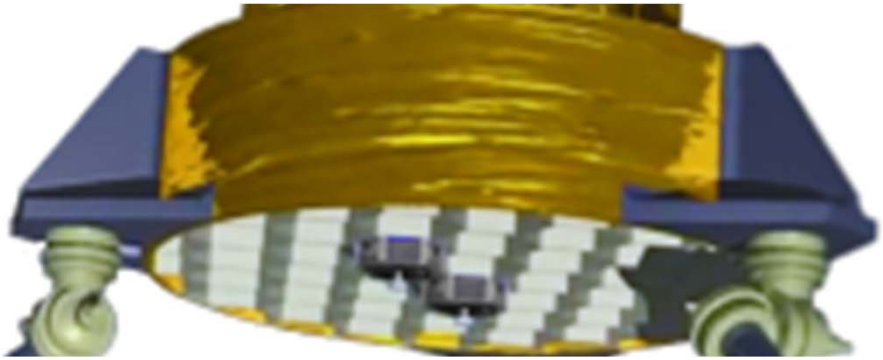


DARPA INSPACE 2006
AFRL Contract for
dexterous manipulators

Element: Toolbelt and/or toolcaddy

- Description: Holds PODs and/or tools while not in use.
  - Toolbelt may hold a separate toolcaddy specifically for FREND tools.





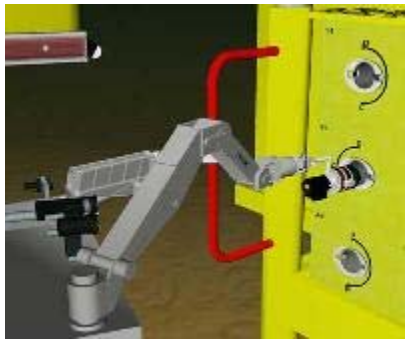
Artist's rendition of toolbelt

Notional Attributes
Thermal
Size
Operations
Telemetry
Other
Power
Electrical/Data Connections

Element: Tele-robotic control and algorithms

- Description: Command and control via a human operator using remote tele-presence operations from ground to Servicer/Tender robotics.
- Considerations:
  - High performance RF communications capability (secure or non-secure)
  - Latency control
  - Simulation-before-operation
  - Balance between Autonomous/manual operation capability.
  - "Safing."
  - Human-in-the-loop (HITL) feedback mechanisms (i.e. tactile, visual, electrical, RF etc.
  - Other.

Lochaber College UHI, offers 18 week ROV training course with hands on experience of flying a vehicle and training in lifelike conditions (from Web)

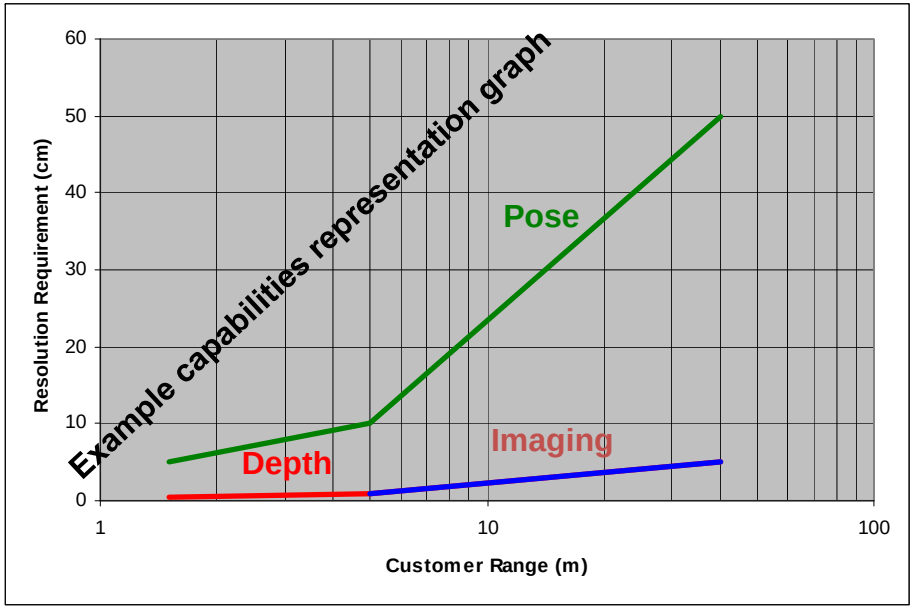


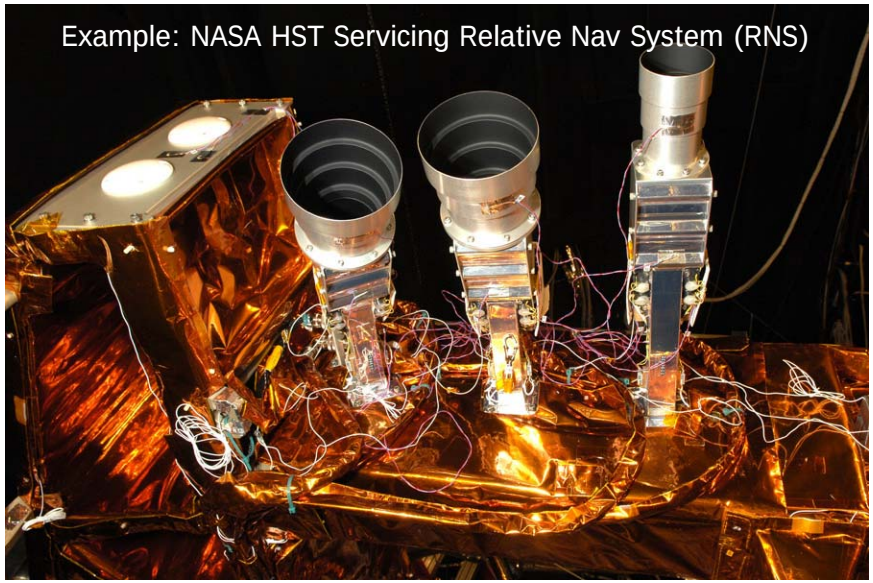
General Robotics Limited (GRL), introducing Version 4.0 of ROVolution ROV pilot training and mission planning simulator. (from Web)

Notional Attributes
Latency in Command Uplink and downlink video
Safe-hold or abort capability
Balance between autonomous operations and manual
Ground operator situational awareness
Ground operator human factor interface

Element: Rendezvous & proximity operations sensors

- Description: Provide relative navigation data during various ranges of proximity between Servicer/Tender, PODs, retired satellite and aperture(s):
  - RPO info should consider development of pose, fidelity of image generated (ie feature recognition), depth mapping, variable frame rate for pose tracking of tumble or non-static object, etc. over a range of lighting conditions.

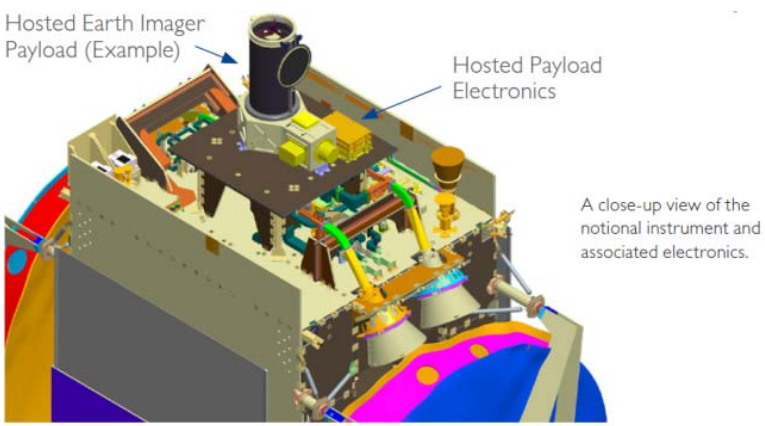




Notional Attributes
Power to RPO Sensor
Navigation Data from RPO Sensor
Mechanical Interface to Servicer/Tender Bus
Software Interfaces for Autonomous Control
Volume
Control methodology
Life at GEO

Element: Commercial host bus for PODs

- Definition: Commercial satellite that provides hosted payload mass and volume that could support Phoenix PODs.
- Considerations: Control of ejection of PODs (upon receipt of dispense request from Phoenix ground control station, or from Servicer/Tender or from Arm), velocity of ejection, location in GEO belt for ejection, RF frequency assignment for active obstacle avoidance, etc.



Core Features

Payload Mass Capability:	Approx. 60 kg, dependent on size of primary payload (STAR Bus can carry 430 kg total payload mass)
Avail. Payload Vol.:	Approx. 25" x 30" x 28"; can be tailored as necessary based on payload and specific host spacecraft
Orbit:	Geosynchronous
Launch Vehicle:	Ariane, Soyuz, Land Launch, Proton, and similar
Typical Mission Life:	1 to 4 years
Program Schedule:	24 months from ATP to launch

Example of Hosted Payload accommodations
(Orbital Sciences hosted payload fact sheet)

Element: Retired US owned spacecraft

- Definition: A retired US owned cooperating satellite with various antennas and in the best possible stable condition.
- Considerations: Location in graveyard (for DeltaV), control status, tumble rates, configuration antennas (both for performance objectives of repurposing and minimizing obstacle avoidance risks), etc.

TDRSS example retired GEO satellite

Notional Attributes
Legal status
Antenna configuration(s)
End of life status and report
Estimated or known tumble rate
Propellant load at end of life
State of electrical system
Other

Element: Retired US owned antenna

- Description: Deployable radio frequency parabolic dish antenna that currently sits on a retired US owned satellite.
- Considerations:
  - Condition of mesh (if applicable)
  - Condition and dynamics of structural attachment to satellite
  - Condition of supporting struts/wires etc
  - Condition/existence of feed horn assembly
  - Etc.

Notional Attributes
Maximum diameter
Estimated or known mass
Support structures (materials and configuration)
Support structures sizes
Stiffness (estimated)
Maximum torque possible on structures etc

Example TDRSS deployable antenna

Element: High performance RF communications

- Definition: High bandwidth and throughput RF system that can support ground to Servicer/Tender communications for payload (i.e. robotics) operations.
- Considerations: SWaP for Servicer/Tender, location of antenna, gimballing or fixed mount, number of channels, frequency, total bandwidth (determined by live video feeds required, ground antenna required, location of ground antenna(s) on ground to support drift around GEO or graveyard latitude variations, etc.

Notional Attributes
Gimbal/Fixed Mount
SWaP
No of simultaneous feeds available
Frequency
Ground antenna locations
Ease of frequency allocation
Security of link
Other

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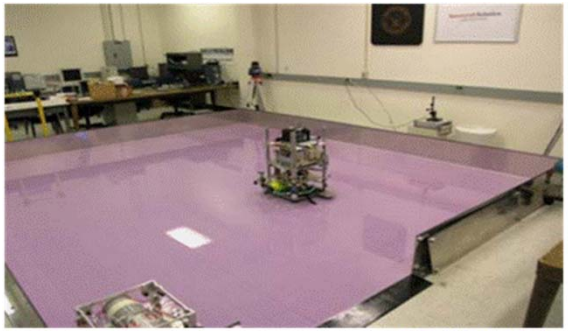
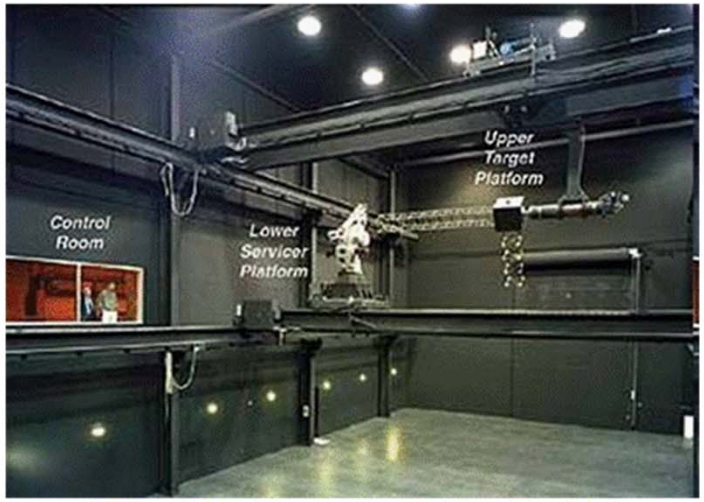
Element: N-DOF ground demo and validation support

- Description: A N-DOF facility and infrastructure that can support various tests and validations for all aspects of the Phoenix demonstration mission
- Considerations: Internet connectivity to other sites, capability and interoperability of N-DOF simulation (interaction internal to existing facility and to external facilities), No's of DOF, test articles for facility, No. of nominal and off-nominal scenario's that can be supported in facility, levels of hardware integration available (for Phoenix prototype and flight hardware), ability to act as proxy payload robotic control or validation center, etc.



NPS- 12'x 12'

GT 8'-12'

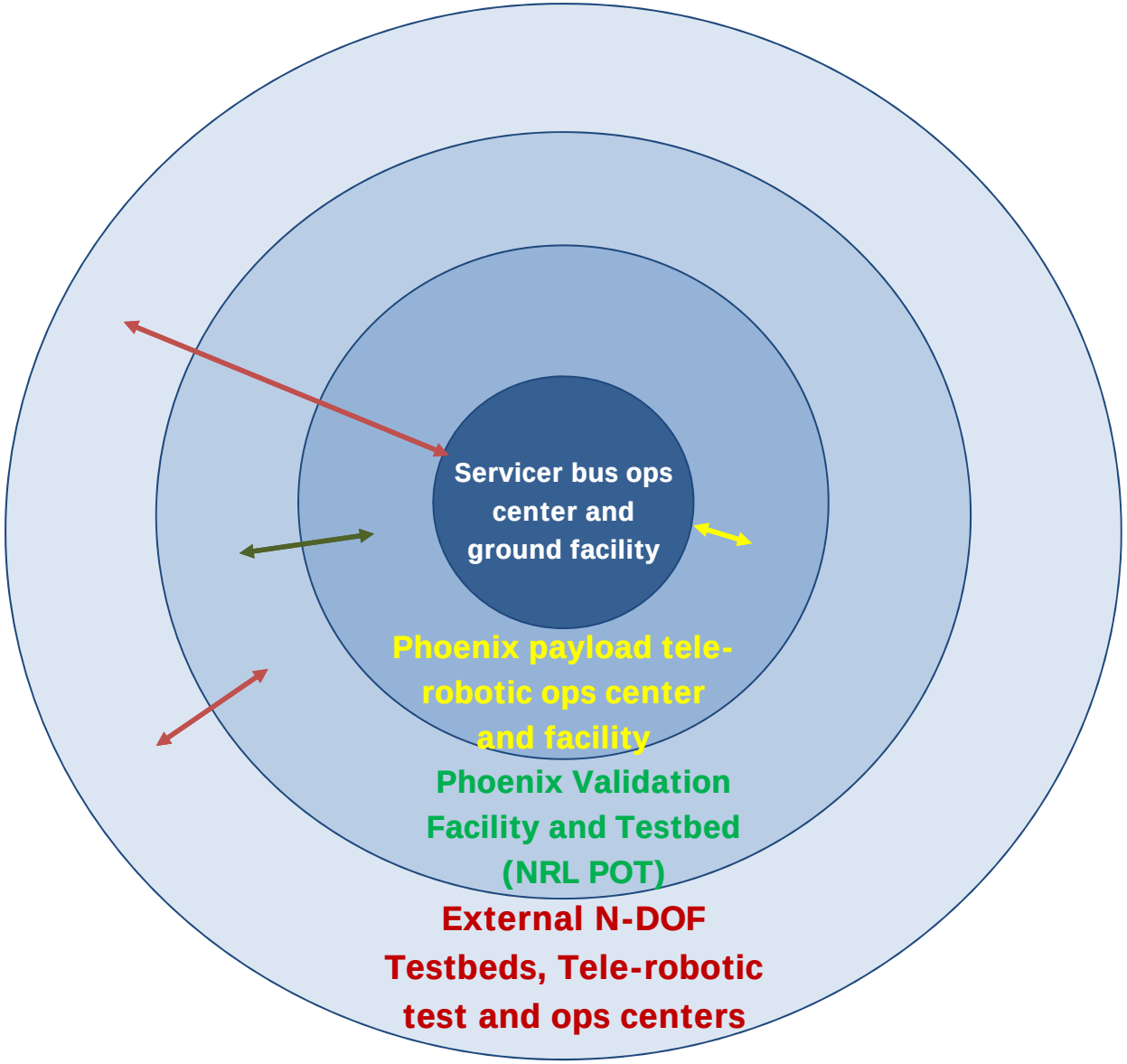


NRL – 30 m long x 13 m wide x 5 m high

Limited examples of existing N-DOF facilities

Interaction between test, training and on-orbit operations

- Goal is to develop a suitable control interface between the Phoenix robotic systems onboard and various testbeds and operations centers, worldwide.
- A classic "front room/backroom" style is considered to facilitate both the ground test and validation requirements, along with actual on-orbit operations.
  - Allows a single operations center (ie "front room) to command/control the "bus."
  - Allows separate payload/telerobotic locations (i.e. "backrooms") to interface with the bus ops center and/or ground test facilities Storing PODs and Satlets and Tools.



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