The ORION Lab: Space and Aerial Robotics Research at Florida Institute of Technology

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The ORION Lab

O RBITAL
R OBOTIC
I NTERACTION,
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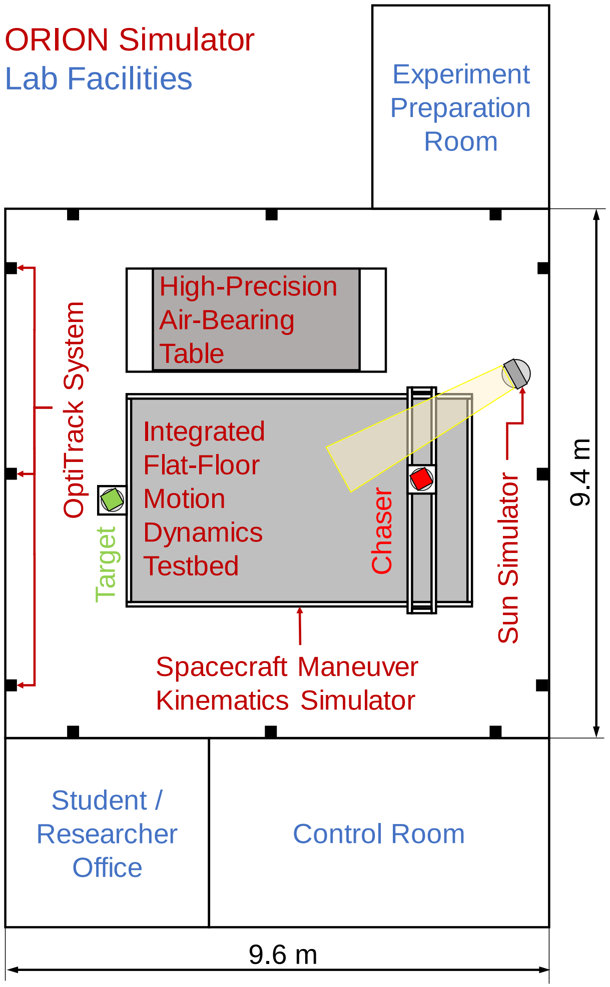
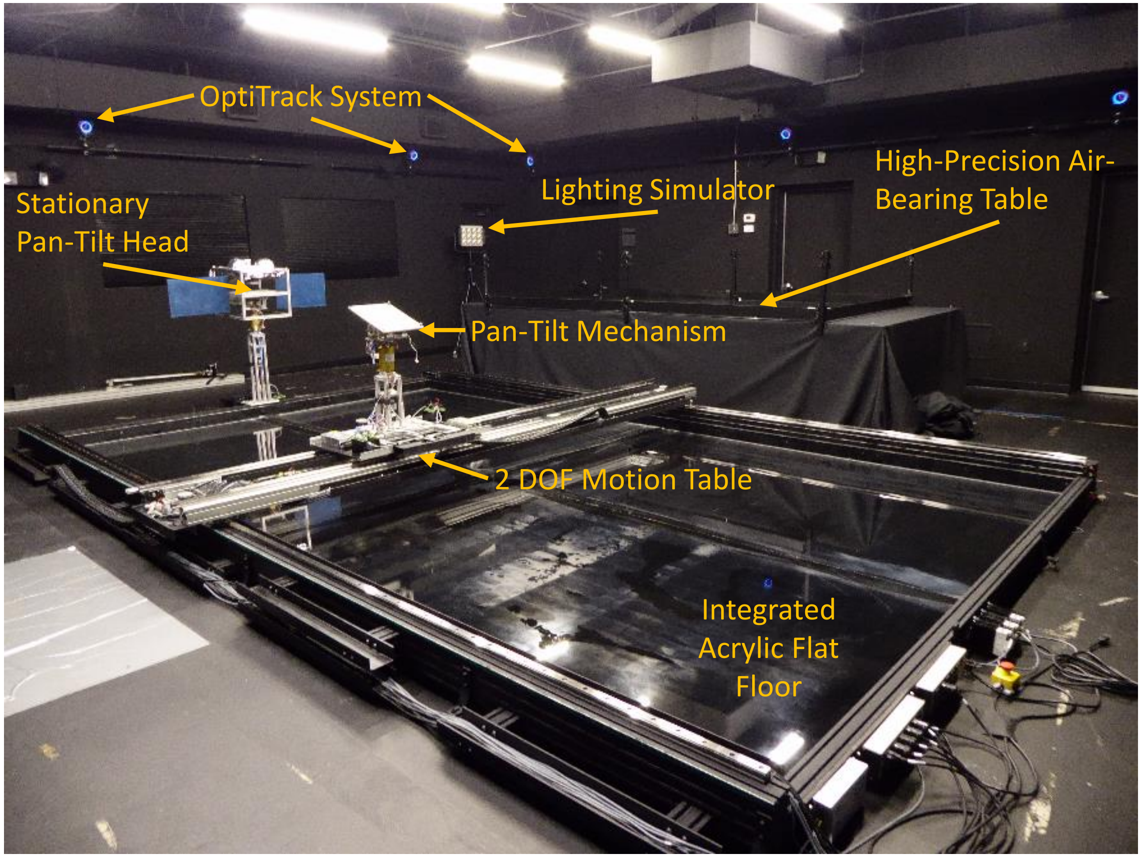
N AVIGATION

LABORATORY

- Guidance, navigation and control systems for air and space robots require testing and experimental verification using maneuver kinematics and dynamics testbeds.
- The test capabilities available at universities are typically limited to small air-bearing flat floors. Large-scale kinematics and dynamics test facilities available at NRL, NASA, and Lockheed-Martin have scheduling restrictions and are expensive to operate.
- The ORION Lab is unique for an university facility. Its combination of maneuver kinematics and dynamics simulation capabilities approaches that of large-scale facilities, while being smaller in scale, cheaper to operate, and easy to adapt and customize.
- The ORION Lab is designed for testing, verification, and operational risk reduction of control systems for spacecraft robotics and remotely piloted aircraft. The lab can be used to quickly and inexpensively demonstrate the performance of such control systems and to find and eliminate errors identified during testing.
- The programmatic risks are minimal, as the ORION Lab is fully supported by FIT faculty and graduate students and can easily be adapted and customized to meet project goals.
- $100,000 buys 12 months in the ORION Lab (including supplies, 2000 hours of grad student work, and 1 month of faculty time)
- The ORION Lab can be adapted to specific project needs within days or weeks, depending on the required customizations.

Maneuver Kinematics and Dynamics Testbed

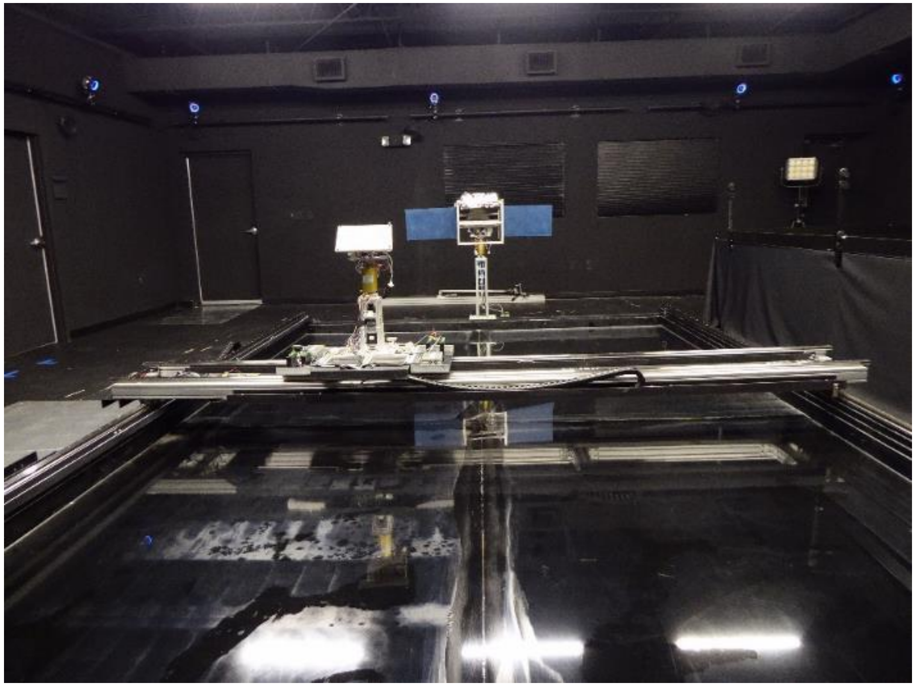


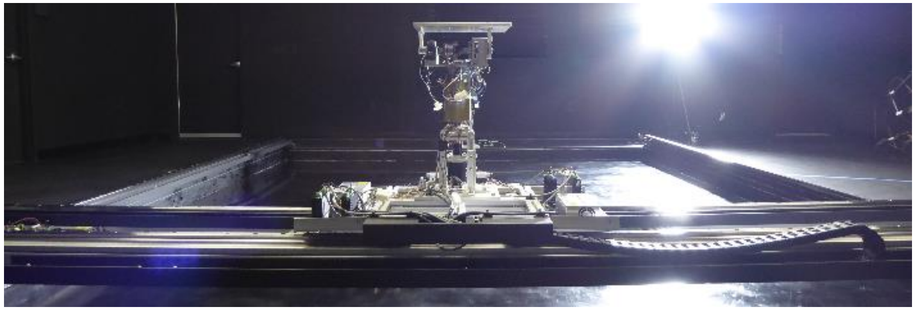


Maneuver Kinematics Simulator

- Planar, gantry-based simulator for relative orbital dynamics between two spacecraft
- Combination of motion table and pan-tilt mechanisms enable simulation of 3D viewing conditions.
- Workspace: 5.5 m x 3.5 m
- Pan-tilt mechanisms for test articles of up to 20 kg, supplied with 120 V AC and Ethernet
- Pan-tilt heads can be removed to support other mechanisms, such as robotic manipulators
- Enables sensor testing, GNC law verification, teleoperation experiments, etc.
- Total 6 degrees of freedom

Degree of Freedom	Motion Range	Max. Vel.	Max. Accel.
Chaser x translation	5.5 m	0.25 m/s	1 m/s^2
Chaser y translation	3.5 m	0.25 m/s	1 m/s^2
Chaser pitch	±90°	60°/s	60°/s^2
Chaser yaw	inf.	60°/s	60°/s^2
Target pitch	±90°	60°/s	60°/s^2
Target yaw	inf.	60°/s	60°/s^2



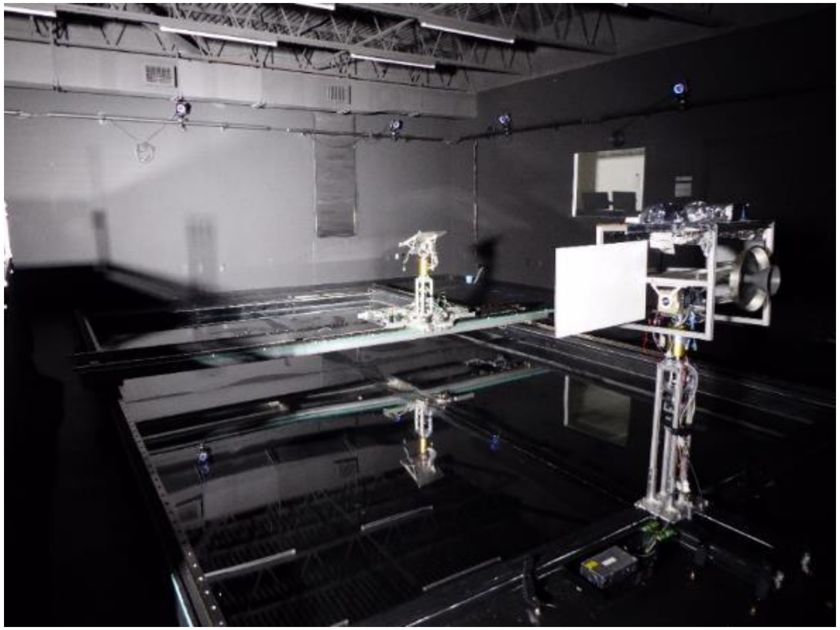


Maneuver Dynamics Simulators

Two air-bearing motion dynamics testbeds enable friction-free experiments of maneuver dynamics and contact dynamics of air-bearing vehicles.

Integrated Flat Floor

- 5.9 m x 3.6 m acrylic flat floor within the frames of the Maneuver Kinematics Simulator
- Enables coordinated use of gantry mechanism with air-bearing vehicles for kinematics/dynamics experiments such as robotic capture of debris objects

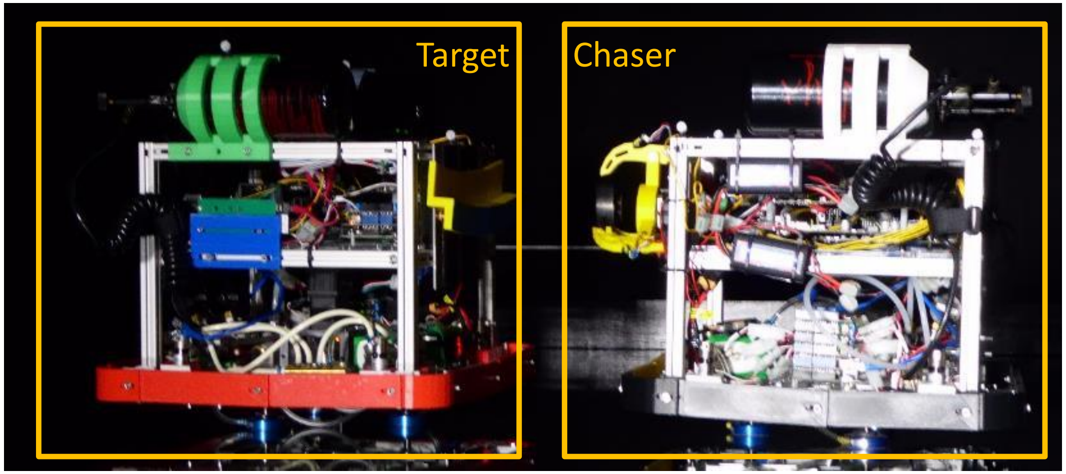


High-Precision Air-Bearing Table

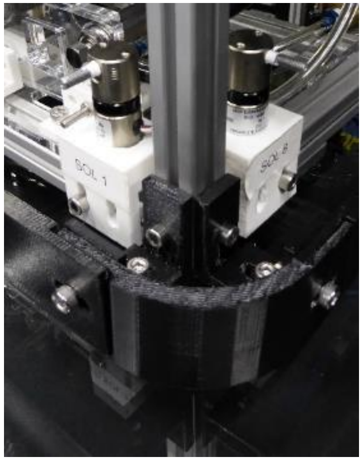
- 3.6 m x 1.8 m tempered glass plate on optical bench with pneumatic vibration isolators
- Enables experiments in contact dynamics, spacecraft controls, formation flight, docking/capture, etc

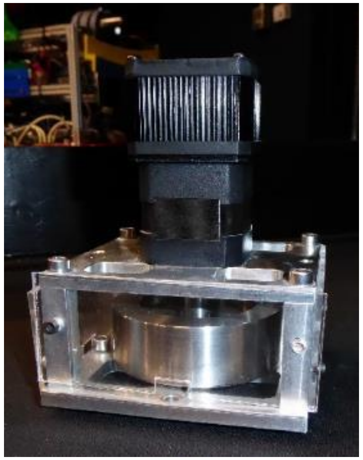
Planar Air-Bearing Vehicles

- Planar air-bearing vehicles (ABV) are used for formation flight and docking/capture experiments
- Propulsion: custom thrusters using compressed N_2
- Attitude control: Thrusters or custom reaction wheels
- On-board computer: Intel i5
- Endurance: ∼20 minutes
- Aluminum frame allows easy attachment of capture tools, docking interfaces, sensors, robot manipulators, etc.



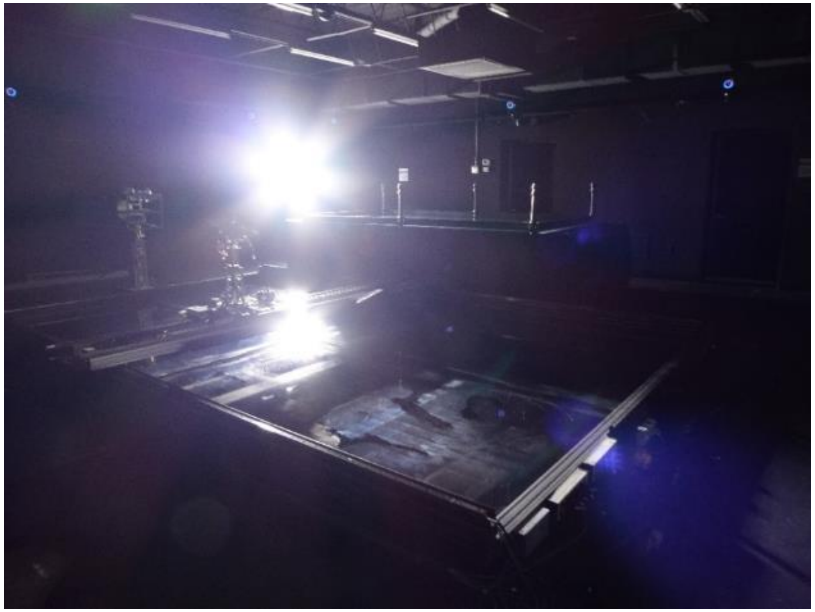
Chaser and target air-bearing vehicles (ABV)


Custom N_2 thrusters


Custom reaction wheel

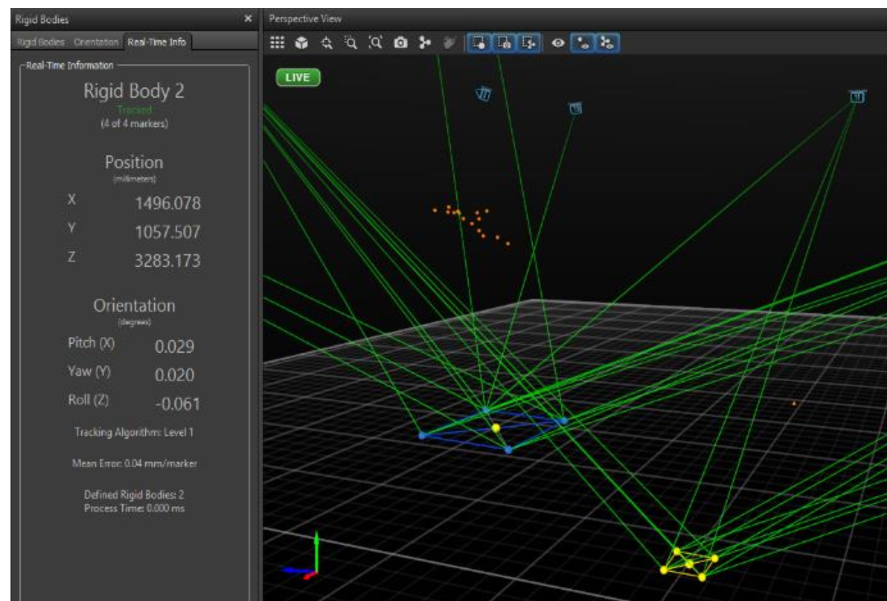
Lighting Simulation

- Hilio D12 LED high-intensity light panel used to simulate orbital lighting conditions
- Light panel is daylight balanced
- Equivalent to 2000 W incandescent light
- Intensity sufficient to oversaturate dynamic range of cameras, produce stark light/shadow differences, and blind laser range finders.
- Lens inserts used to change the beam angle between 15° and 60°.



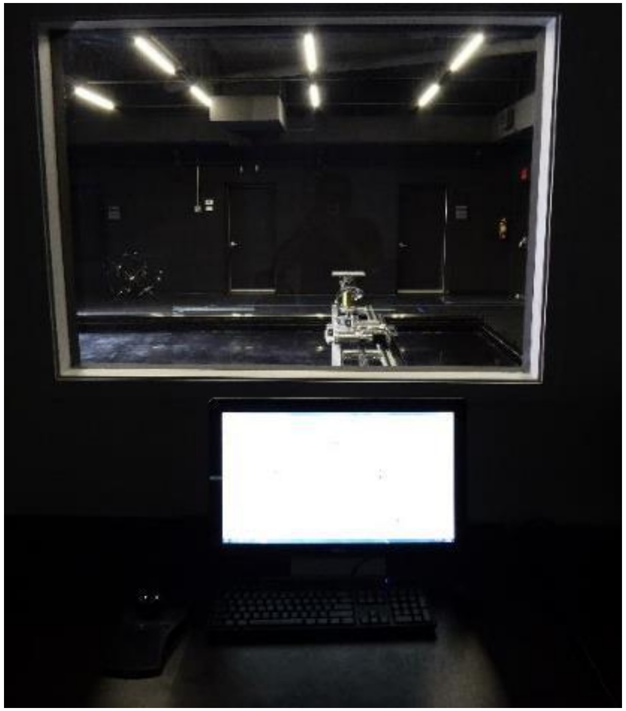
OptiTrack System

- 12-camera OptiTrack Prime 17W system tracks objects within the ORION Lab with sub-millimeter and sub-degree accuracy
- Objects are defined by four infrared reflectors
- Real-time streaming of tracking data on the lab network
- Used in closed-loop control of the Maneuver Kinematics Simulator
- For formation flight and docking experiments, OptiTrack can be used as stand-in for relative navigation sensors
- For sensor testing, the OptiTrack data serves as ground truth

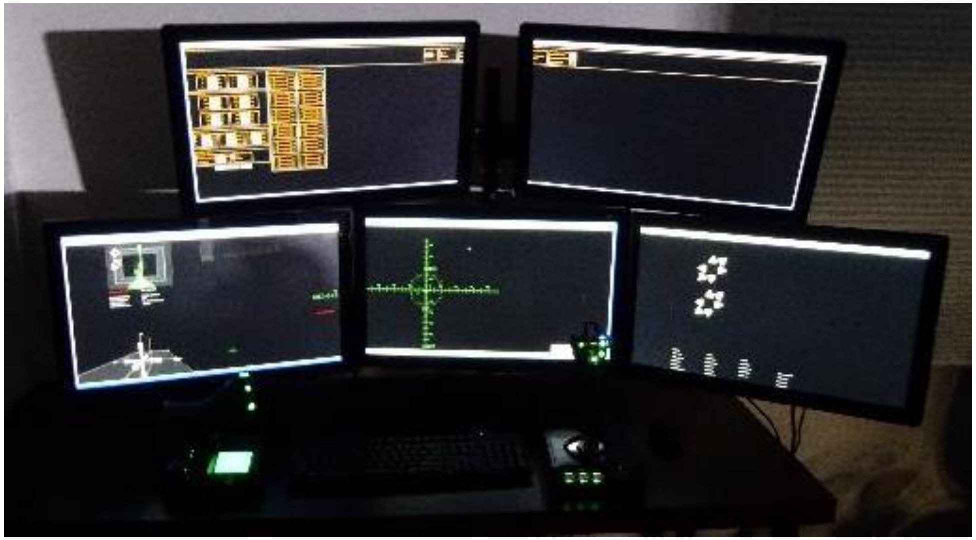


Control Station

- ORION Control Room has a control station for the testbed and multiple workstations for equipment operators and test engineers
- Teleoperation console equipped with multiple input devices to support experiments in the teleoperation of ground, air, and space robots and vehicles.
- Operator at teleoperation console do not have direct sight of the testbed and all video and telemetry channels can feature artificial time delays.



Control Station



Teleoperation Console

Research Themes

- Enhancing space system capabilities and resiliency
  - In-space inspection and repair
  - Refueling of satellites and upper stages
  - Space debris removal and recycling for space-based additive manufacturing

- Advancing UAV maneuvering capabilities
  - Omnidirectional flight vehicles
  - Perching maneuvers for expanded flight envelopes
  - UAV/UGV cooperation

- Increasing robotic flexibility and adaptivity
  - Teleoperation in uncertain environments and with significant time delays
  - Automated control authority allocation between robot and human operator
  - Use of fuzzy logic and cascaded control laws for dynamic tasks in unstructured environments

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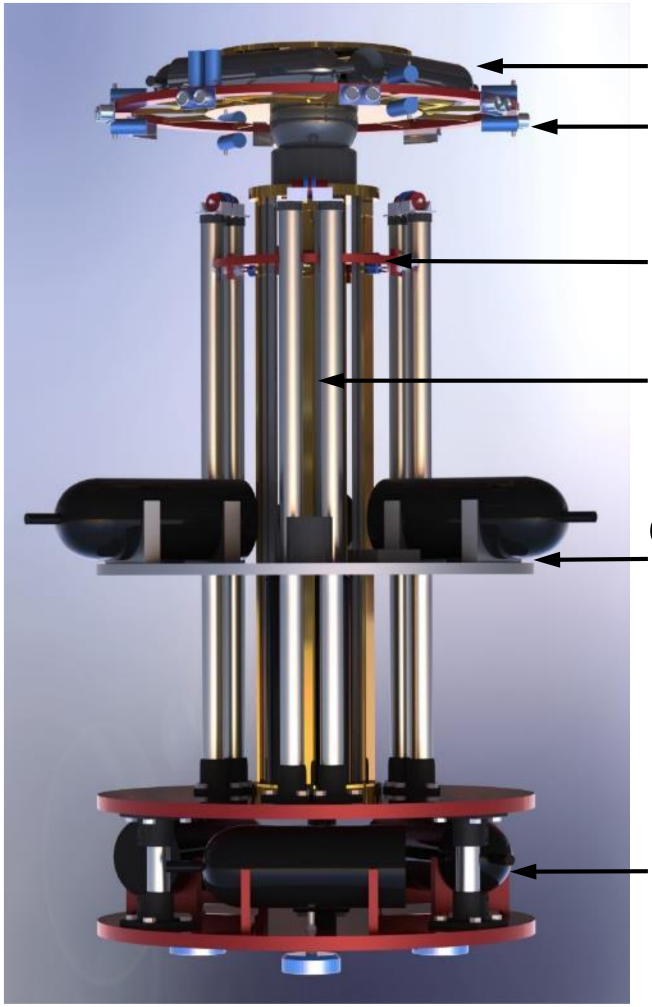
RESEARCH EXAMPLES

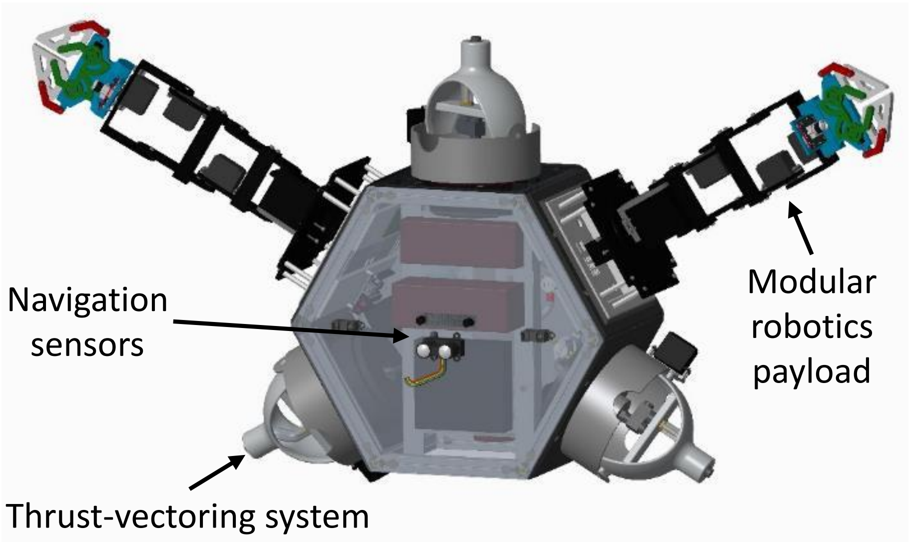
6 DOF Air-Bearing Vehicle

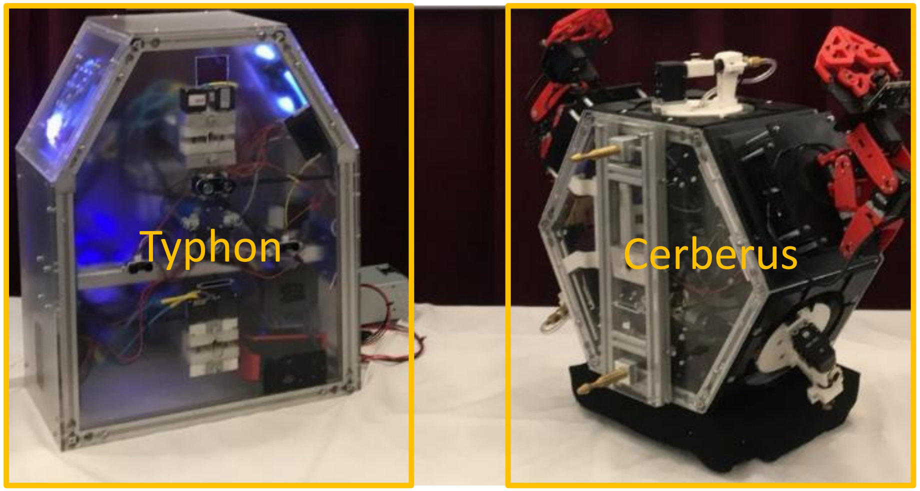
- Inspired by ADAMUS at the University of Florida, a team of undergraduate and graduate students is developing a 6DOF air-bearing vehicle
- Objective: Add vertical, friction free motion capability to the ORION Lab
- Project DAWN started in 2015 as a capstone design project
- Current focus: reducing the mass of the system and on controlling the vertical motion of the counterbalancing system



Piggy-Back Inspection and Repair Satellites

- Laboratory prototype for a remora-like inspection and repair satellite for large and expensive space assets.
- Vision: Equip major space assets with this inspection/repair/protection capability.
- Research objectives:
  - Demonstrate capability for inspection and repair.
  - Demonstrate safety of autonomous and teleoperated control laws.
- *Cerberus*: small inspection and repair satellite equipped with modular robot manipulators and sensor packages, controlled by thrust-vectoring cold-gas system.
- *Typhon*: Support system for Cerberus, capable of capturing the inspection satellite, refueling its propellant tank and recharging its battery.

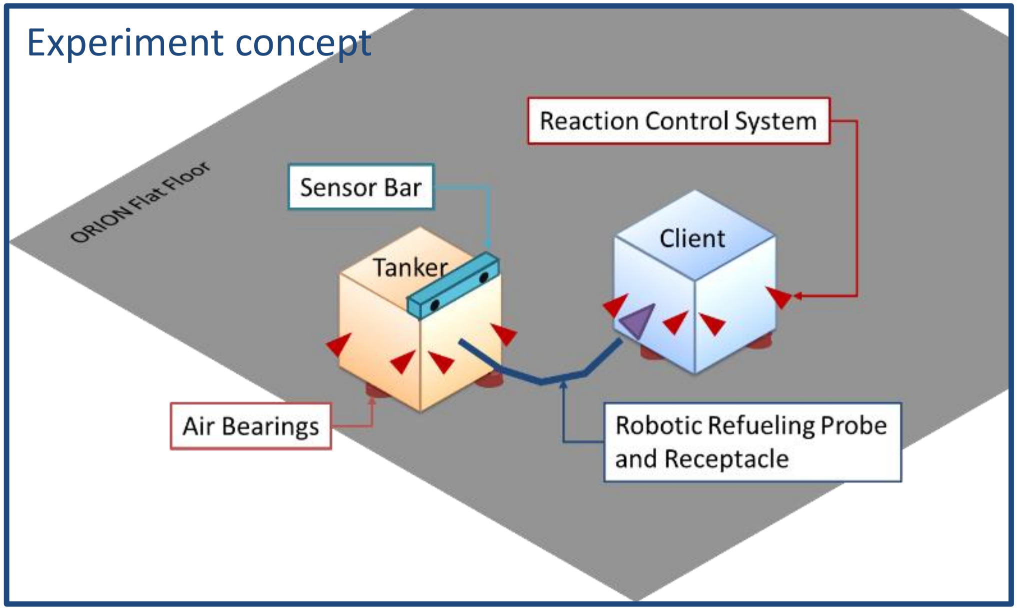




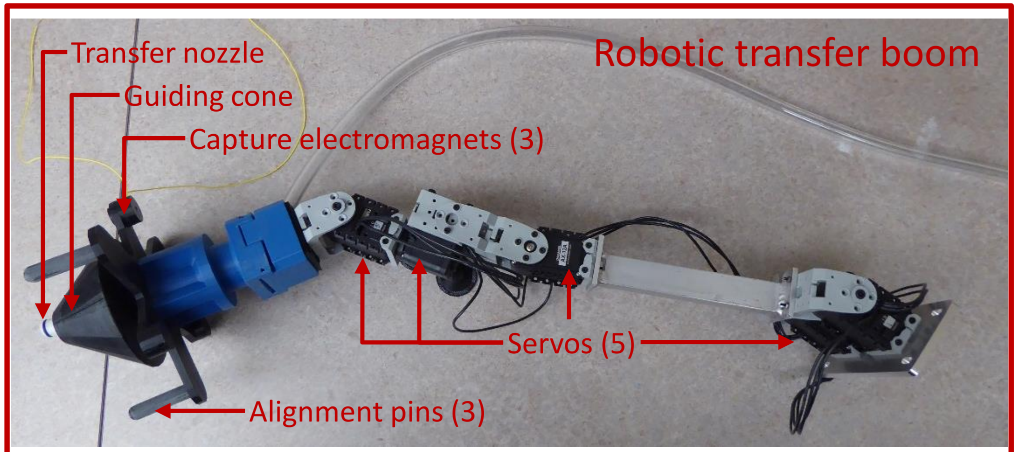
Spacecraft Refueling

- Proof-of-concept experiment for large-fraction fuel transfer during formation flight under constant thrust
- Vision: Refueling of cryogenic upper stages
- Research objectives:
  1. Optical relative navigation for spacecraft rendezvous / formation flight and insertion of refueling probe
  2. ZEM-ZEV path planning for rendezvous and formation flight
  3. Development of robotic fuel transfer boom
  4. Control system for boom deployment and insertion
  5. Fuel transfer during formation flight under settling thrust

Experiment concept

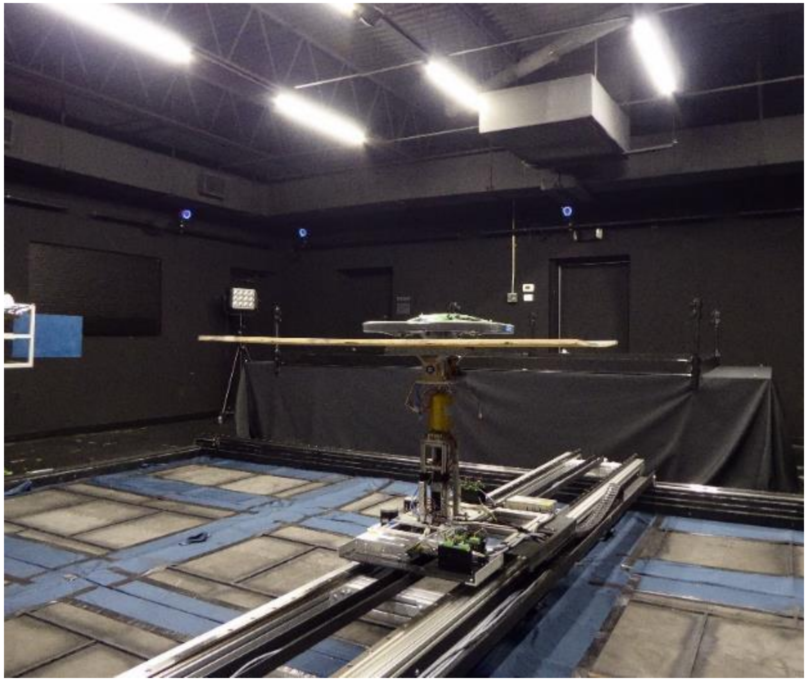


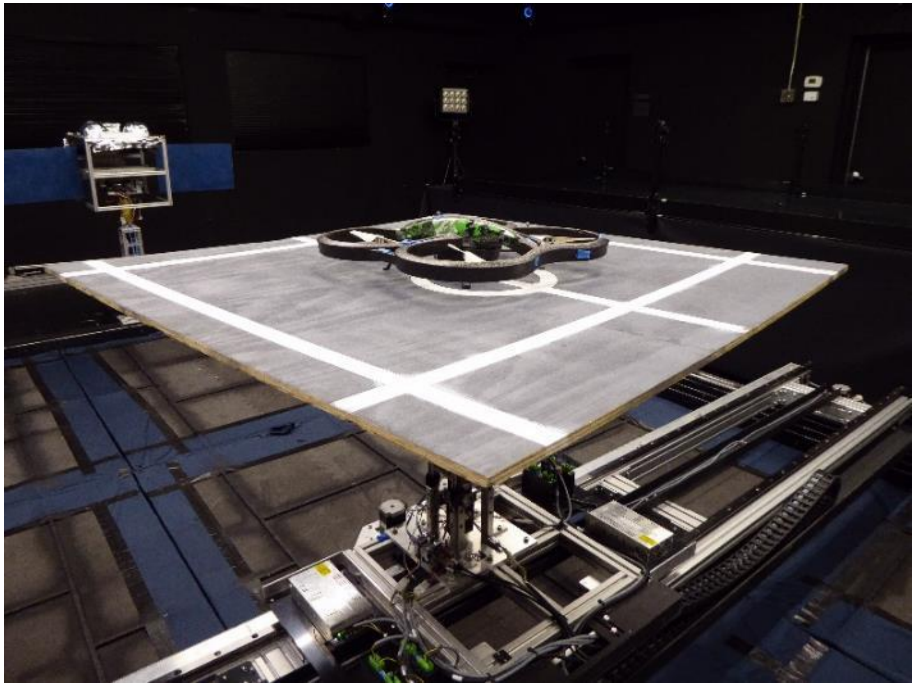
Robotic transfer boom



Landing UAV in Dynamic Environments

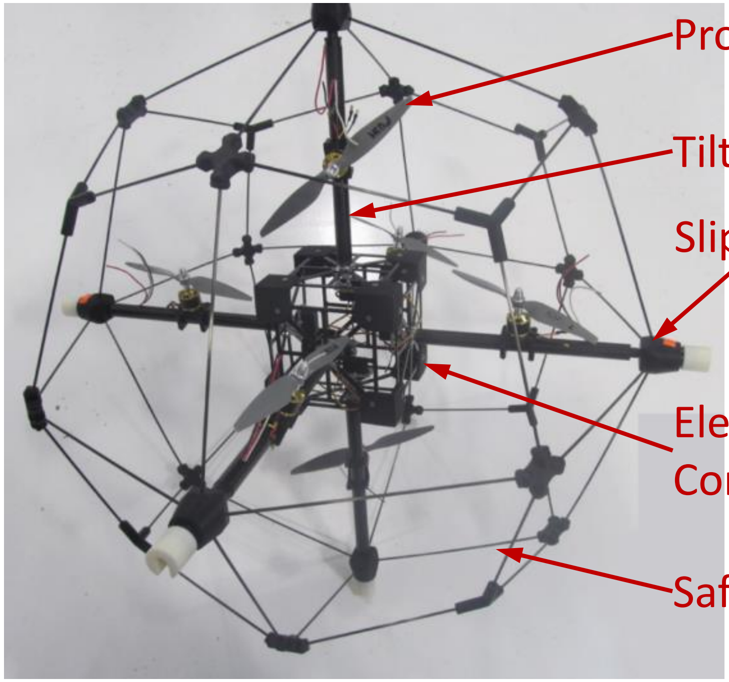
- Development and verification of ZEM/ZEV controllers for landing quadcopters on a pitching flight deck
- Demonstration of predictive displays to teleoperate quadcopters through obstacle courses and dynamic landings under multi-second time delays
- Use of the Maneuver Kinematics Simulator to generate flight deck motion





AirBall: Omnidirectional Flying Vehicle

- Spherical flying vehicle for decoupled linear and rotary motion.
- Vision: UAV capable of rolling into confined spaces, taking off and landing in any orientation, and flying in any direction without required reorientation
- Research objective: Development and test of control laws for a vehicle propelled by six tilting propellers
- Applications:
  - Infrastructure inspection
  - Search and rescue
  - Military operations in urban terrain
  - Planetary exploration



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APART: Arial Recharging of UAVs

- Prototype system for UAV range and endurance extension
- Two vehicle system:
  - High-endurance, gas-powered “Mothership”
  - Agile, electric “Parasite”
- Parasite can dock to Mothership using docking booms
- Batteries can be recharged from Mothership using inductive coupling

Off-the-Shelf Parasite

Custom-built Mothership

Summary

- The ORION Lab provides a unique combination of maneuver kinematics and dynamics simulation capabilities.
- ORION enables experimental research in
  - Spacecraft formation flight, rendezvous and proximity operations
  - Robotic operations for space debris removal and on-orbit servicing
  - Autonomous, teleoperated, and hybrid control systems for ground, air and space systems
  - Guidance, navigation, and control in dynamic and unstructured environments
  - Prediction algorithms and compensation methods for contact dynamics of complex bodies
  - Human-machine interaction in uncertain environments and under time delay
- ORION can quickly be adapted and customized to meet specific project needs
- Short-notice test scheduling and low operating cost
- ORION projects are supported by Florida Tech faculty and graduate students with wide range of expertise and experience

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