COE CST Fourth Annual Technical Meeting

Autonomous Rendezvous and Docking

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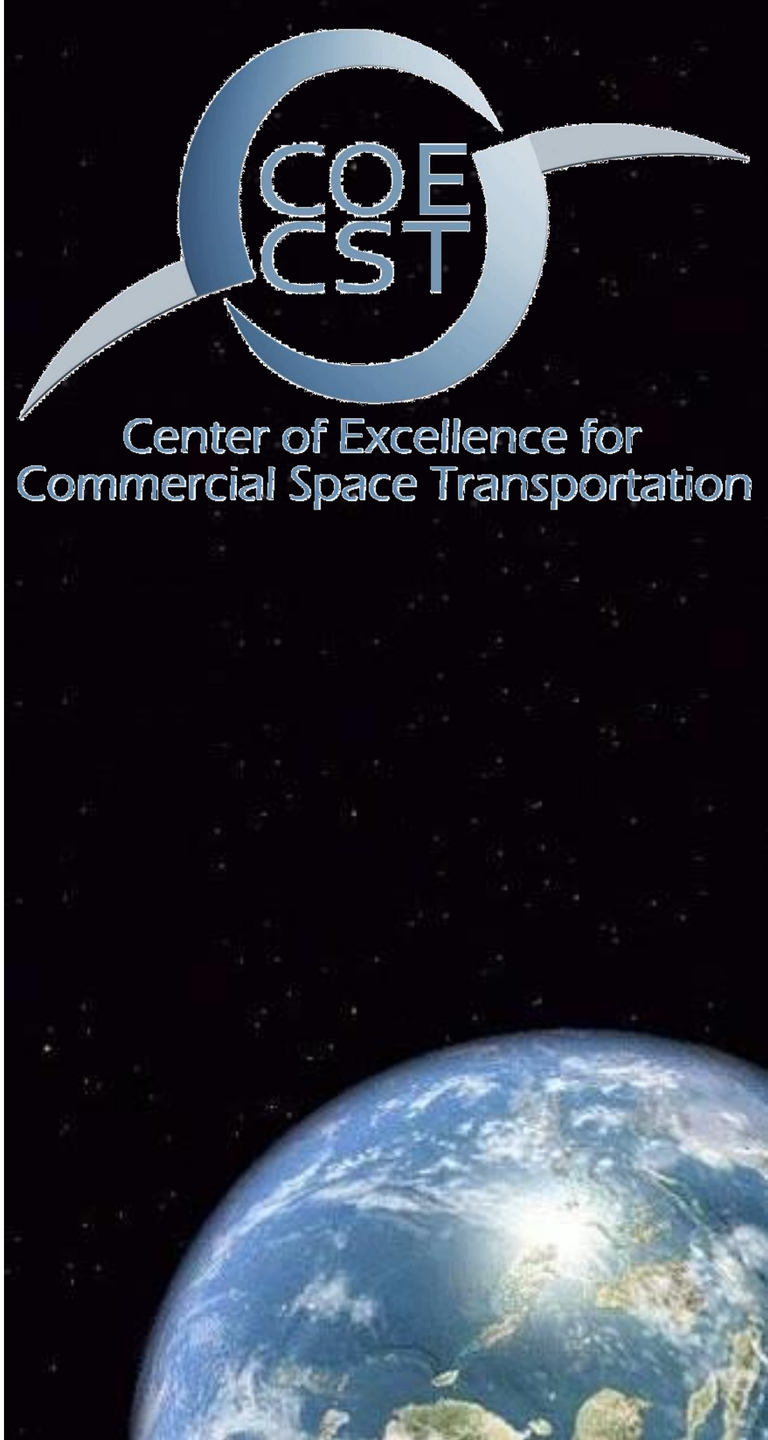
Washington, DC



Agenda

- Team Members
- Task Description
- Schedule
- Goals
- Results
- Conclusions and Future Work

Team Members

- PI: Dr. Penina Axelrad, University of Colorado Boulder
- Dr. Jay McMahon
- Students: Aerospace Engineering Sciences
  Heather LoCrasto (MS student)
  Steve Gehly (PhD student)
  Caleb Lipscomb, Ricky Rohr (Undergraduate students)

- Industry Partner: Ball Aerospace

Task Description

- Understand the requirements for autonomous rendezvous and docking of commercial spacecraft in LEO for the purposes of material transfer, servicing, or retirement.
- Develop description, requirements, and list of key technologies for ARD mission phases.
- Provide tools for the FAA to establish architecture, requirements, and processes for future ARD operations.
- Evaluate FLASH LIDAR as key technology for ARD and investigate performance for relative navigation and attitude estimation.

Schedule for task completion

- No-cost extension provided through May 2015.
- Complete remaining mission phase requirements and technology gap analysis by Dec 2014.
- Complete LIDAR image processing to be integrated with OLTAE algorithms by Dec 2014.
- Establish complete case study for LIDAR use in approach phases by February 2015.
- Evaluate methods and requirements for non-cooperative unknown targets by May 2015.

Goals

- **Motivation**:
  - Standards are required to enable the FAA to license multiple vendor vehicle systems to make orbital rendezvous and docking a routine and safe activity.
  - These standards must be established to define appropriate requirements for safe operations without specifying a particular design.
  - Increase autonomy, improve flexibility, robustness, reduce cost
- **Goals**
  - Develop an approach for ARD standards and identify/resolve key technology gaps for automated rendezvous and docking of vehicles in LEO/GEO encompassing approach trajectories, sensing, estimation, guidance and control, and human interaction.
  - Systems engineering analysis for draft standards
  - Feasibility of Flash LIDAR based relative position and attitude

Commercial AR&D Mission Types

Increasing Challenge →

Knowledge	Marked	Drawings	None	
Controlled	Active	Passive Stable	Tumbling	
Cooperative	Maneuvers	Measurements 2-way Comm	2-way Comm	None

Configuration	Knowledge	Controlled	Cooperative
Refuel/Material Delivery	Marked	Active	2-way Comm
	Drawings		None
Repair/Retire	Marked	Passive Stable	None
	Drawings		
Debris Disposal	None	Tumbling	None

Mission Phases

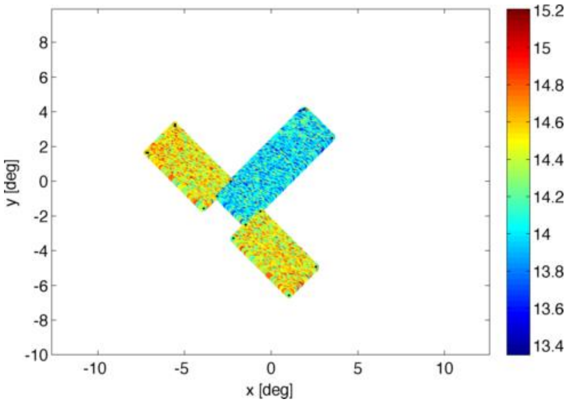
Phase	~Range	Objective	Sensor	Safety
Launch	>10,000 km	• Insert chaser into orbit in same orbit plane, below target	GPS	Resume mission on nav failure
Phasing	>5 km	• Reduce range to target • Chaser acquires initial aimpoint for approach	GPS	
Homing/Closing	3500-250 m	• Relnav • Reach then enter approach ellipsoid	Radar, Lidar, RGPS	• Preclude collision • Maintain target sensing
Final Approach	0-250 m	• Chaser achieves docking capture conditions • Interfaces within docking range	Optical, RF, LIDAR	• Preclude collision • Low velocity • Keep-out zone • Avoid plume impingement

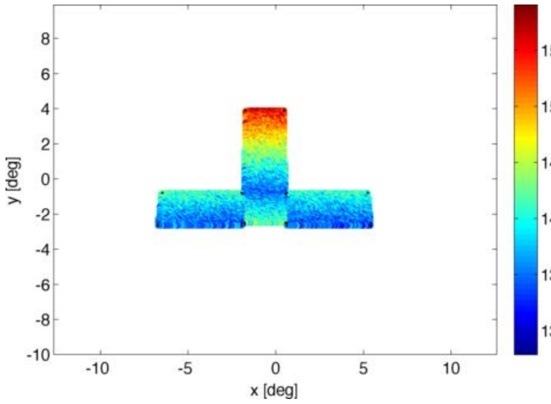
Key Concepts for Requirements

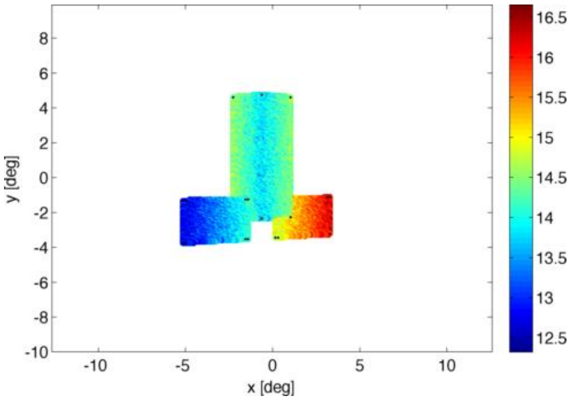
- Availability of sensors for long-range phases not required 100% because hold can be used
- Closing phases require 100% availability
- Use of passive-safe trajectories in final approach phase.
  - When aimpoint is at the target
  - Thruster failure only to off
  - Loss of communications or sensors (stops thruster firing)
- Timing of ARD is flexible if visual sensors and ground monitoring are not required
- Max relative velocity for final approach, mating, & joint maneuvers, must be determined to avoid damage to vehicles

Flash LIDAR Use for ARD

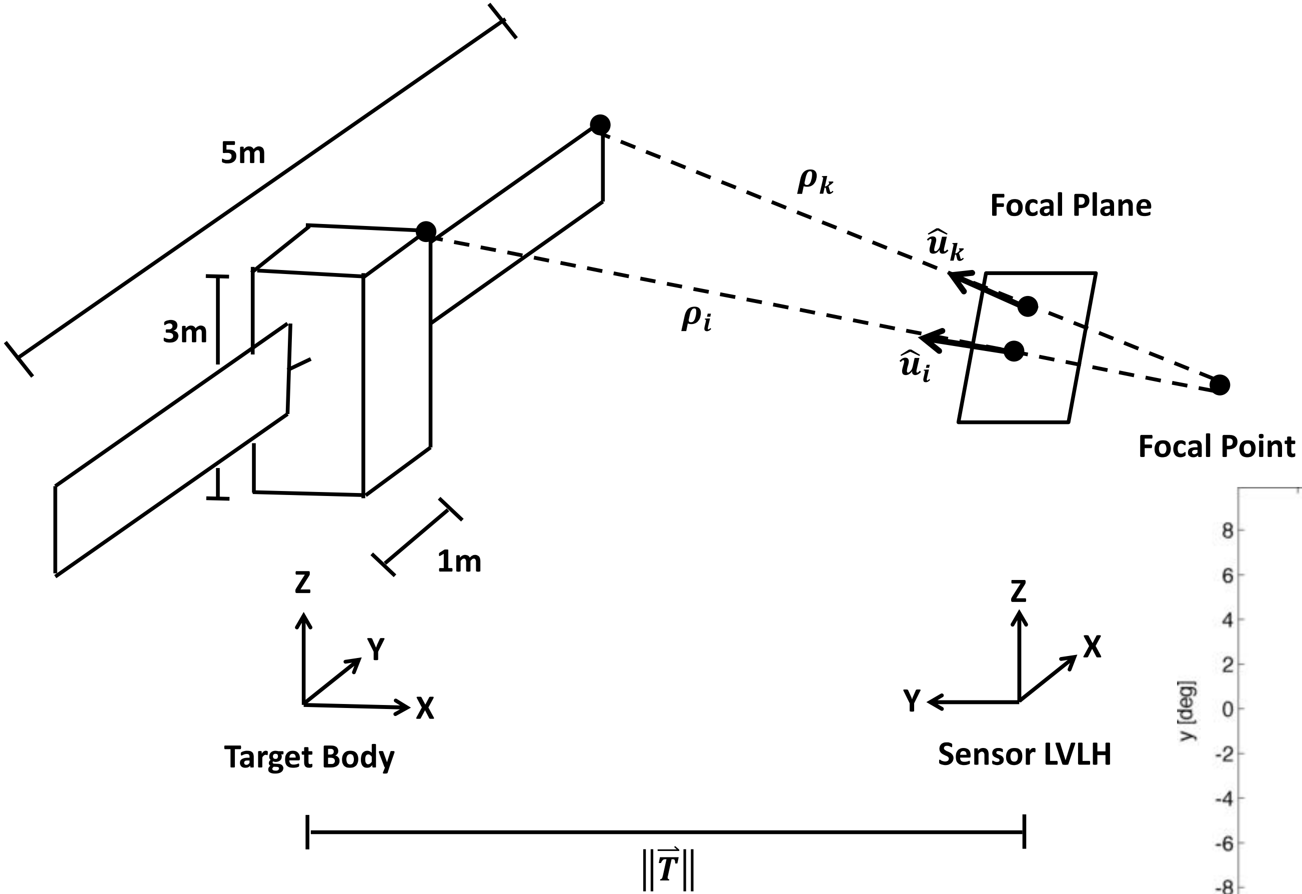
- Flash LIDAR instrument serves as a "3D Camera" with intensity and range for each pixel
- High frame rates (up to ~30 Hz)
- Eliminates slewing/pointing/search requirements of single-beam systems
- Not dependent on ambient lighting conditions
- Can be used from mating to few km range

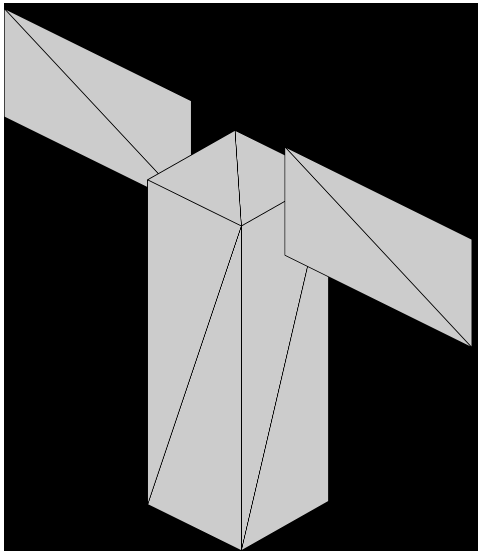


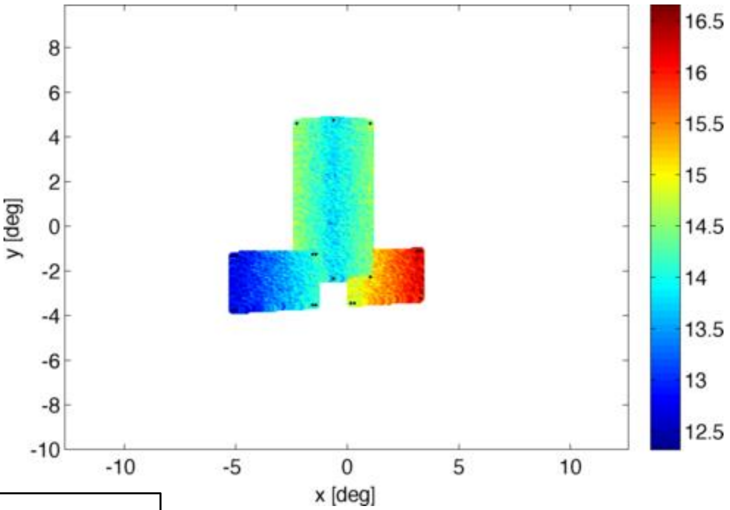




FLASH LIDAR & TARGET S/C

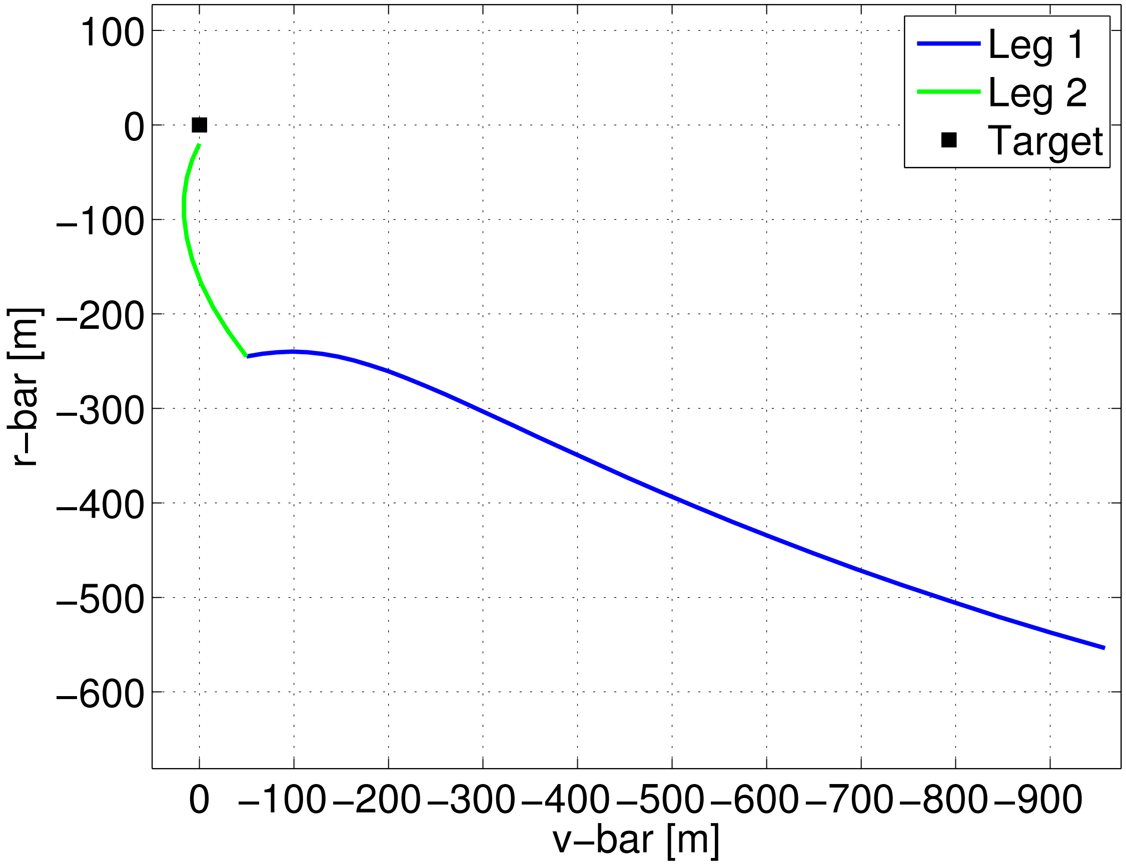






128 x 128 pixels, 20 degree FoV, 30 Hz
Range noise ~ 1% of range (from R. Rohrschneider at Ball)

Approach Trajectory

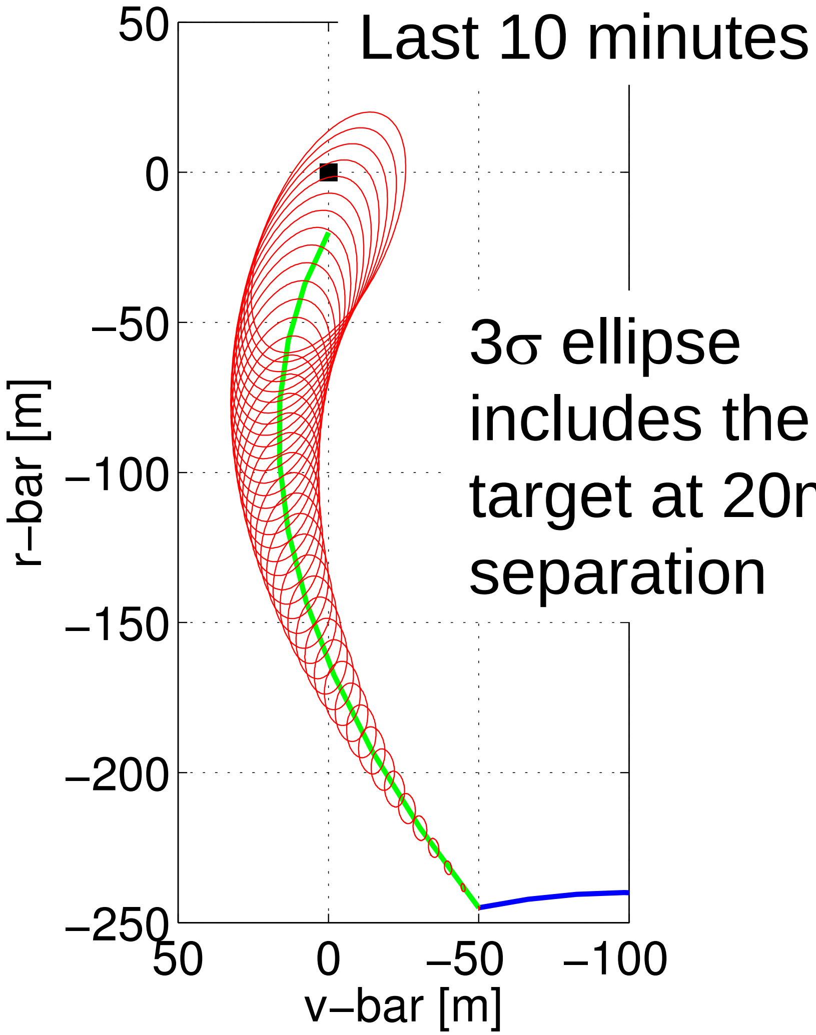


- **Leg 1:** 1.1km to 250m in 30 minutes
- **Leg 2:** 250m to 20m in 10 minutes

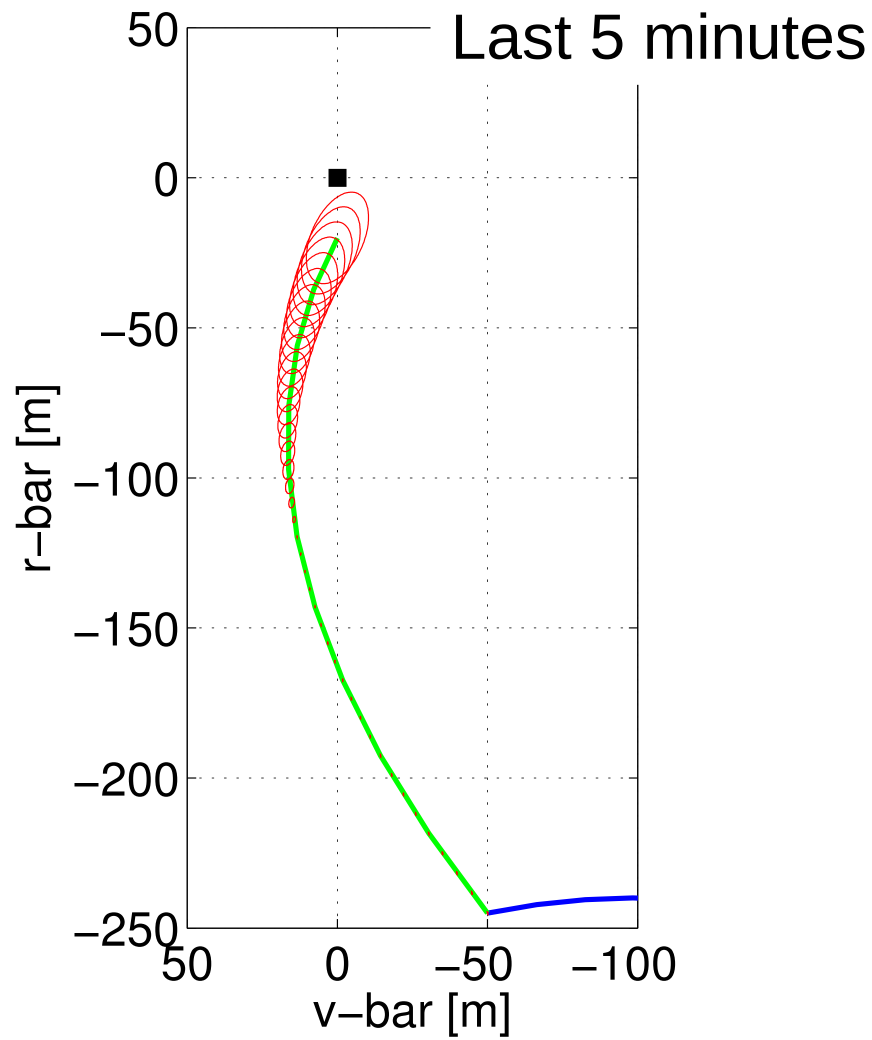
- For most of the approach target dimension is negligible
- Estimate the position of the center of figure, which is offset from the true center of mass.
- Accuracy is well within requirements with continuous observations

3σ pos err < 1m at 100m range, vel err < 10cm/s with 1-s updates

Loss of Measurements

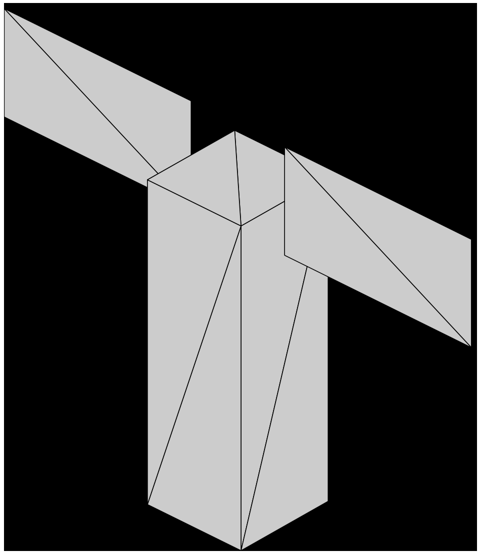


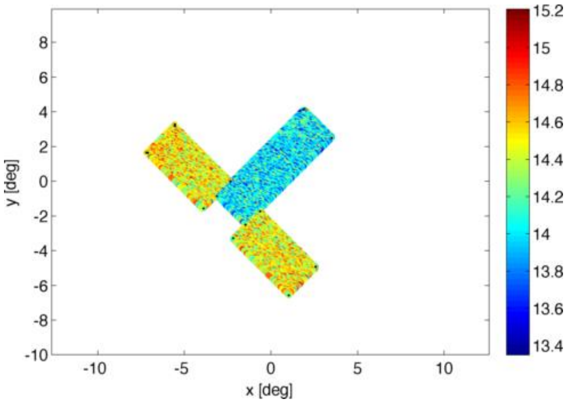
3σ ellipse includes the target at 20m separation

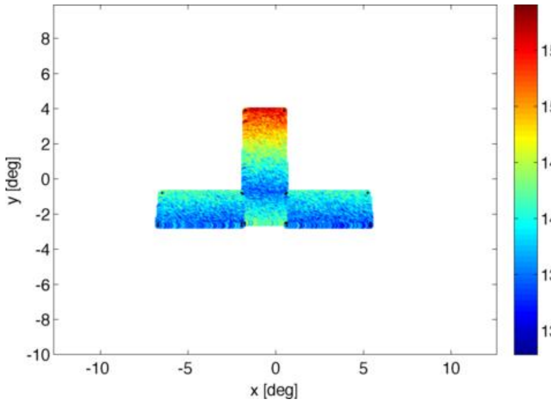


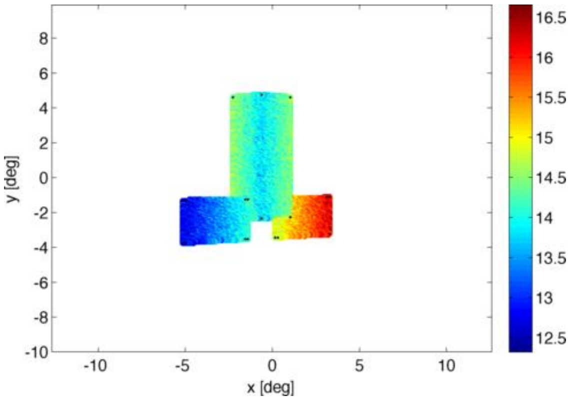
Relative Position and Attitude

- Within 250 m start solving for pos + attitude
- Use corners of s/c as feature points
- Assume 1cm 1-σ ranging errors, and 1 pixel 1-σ angle errors
- Range from 20 m to 5 m in 90 s
- We assume features are matched
- Use OLTAE algorithm to get point solution



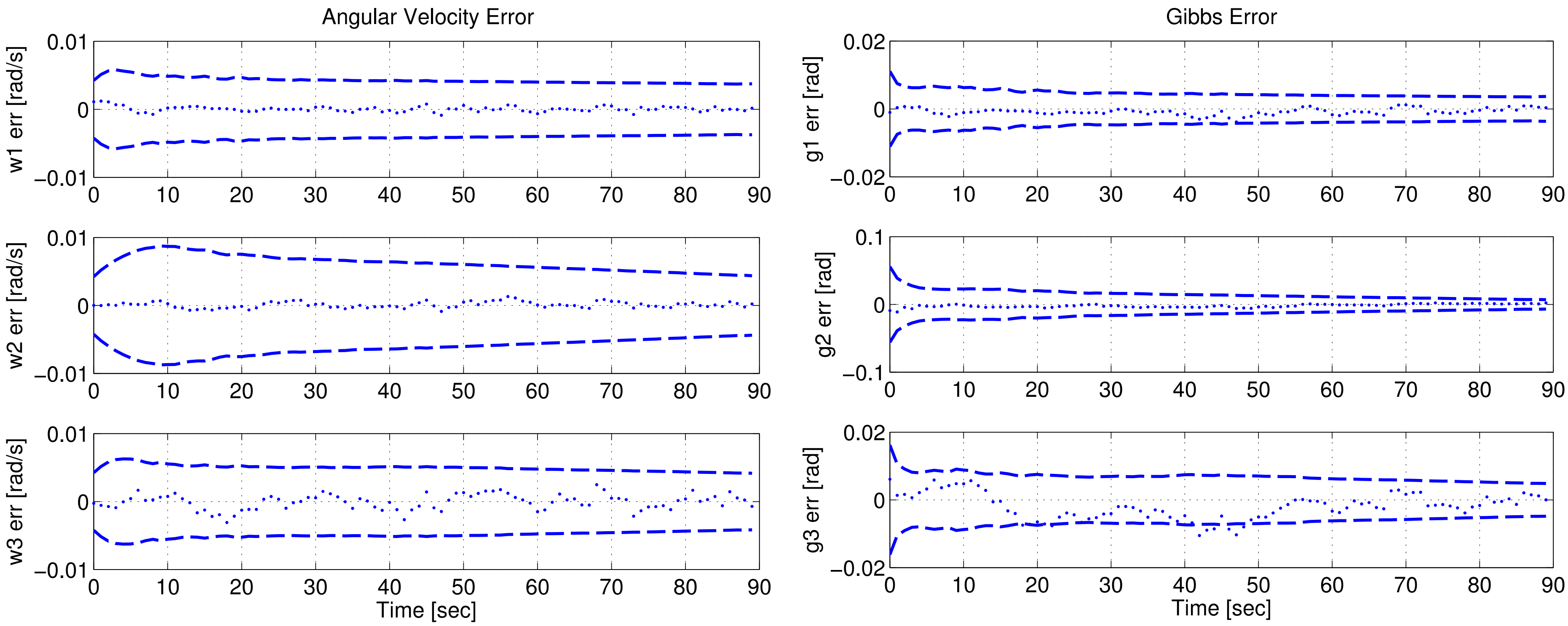






Filtering

- Use EKF or UKF with OLTAE solutions for position and Gibbs vector as measurements



Reports and Papers

- McMahon, J., S. Gehly, and P. Axelrad, “Enhancing Relative Attitude and Trajectory Estimation for Autonomous Rendezvous Using Flash LIDAR,” *AIAA/AAS Astrodynamics Specialist Conference*, San Diego, CA, August 4-8, 2014.

LoCrasto, H. and P. Axelrad

- CU_FAA_Task244_Background_Summary_Report_2013-06-19
- CU_FAA_Task244_Mission_Phases_Report_2013-10-01
- CU_FAA_Task244_Requirements_Report_2014-07-24

Conclusions and Future Work

- Continuing to work to identify and quantify key requirements for ARD missions using existing requirements and standards documents and lessons learned from past missions
- Optimize approach trajectories for maximum information gain/robustness
- Currently working on Flash LIDAR image processing for feature identification, using Argos P100 time-of-flight camera