COE CST Third Annual Technical Meeting

Task 244: Autonomous Rendezvous & Docking for Space Debris Mitigation

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Center of Excellence for Commercial Space Transportation

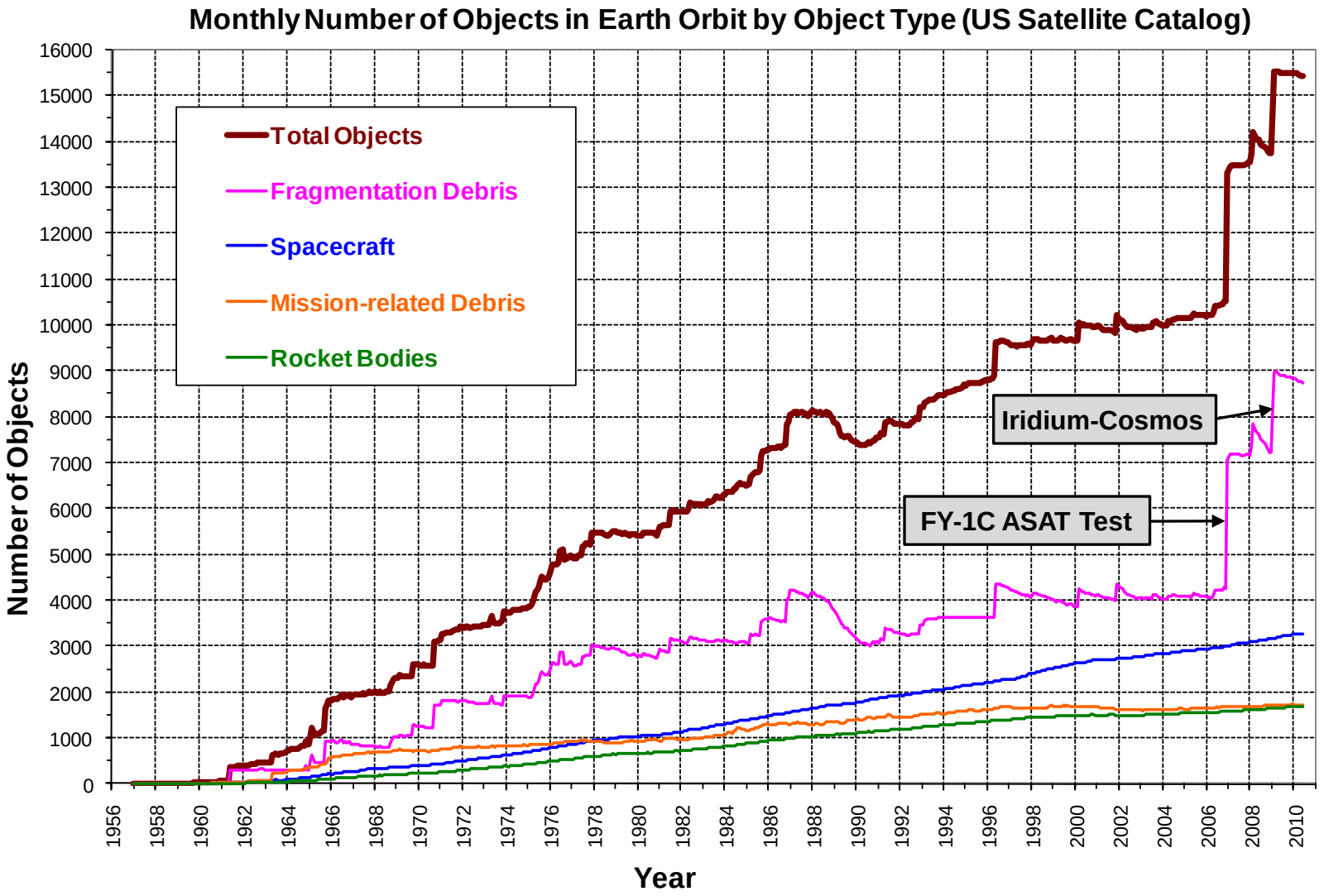
Overview

- Team Members
- Purpose of Task
- Research Methodology
- Results/Summary
- Next Steps
- Contact Information

Team Members

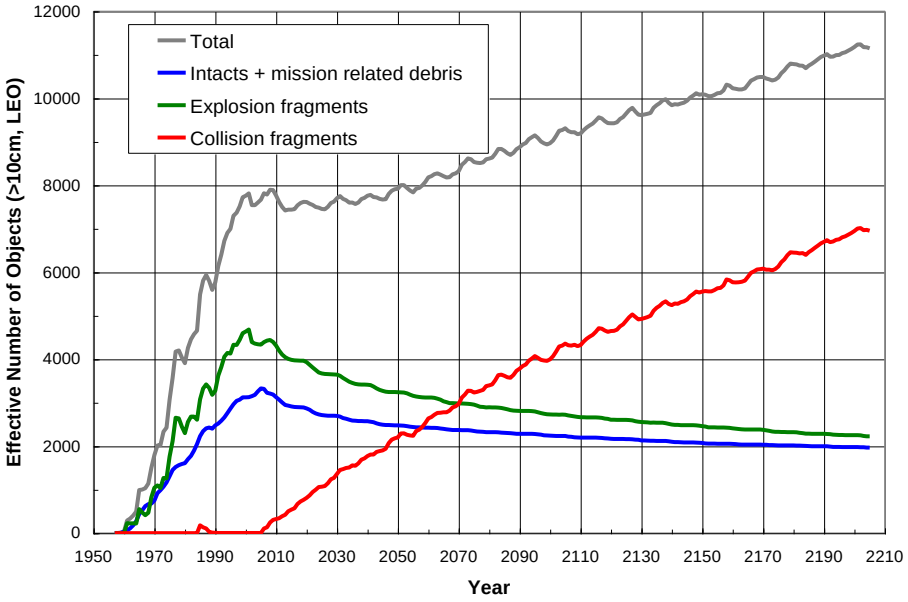
- PI: Norman Fitz-Coy (MAE Dept. Univ. of Florida)
- Students
  - Takashi Hiramatsu (graduated 2012)
  - Kathryn Cason (accepted job)
  - Tristan Newman (new)
- Related Activity
  - DebriSat for NASA's ODPO (update to the 1992 SOCIT experiment)

Purpose of Task



Purpose of Task

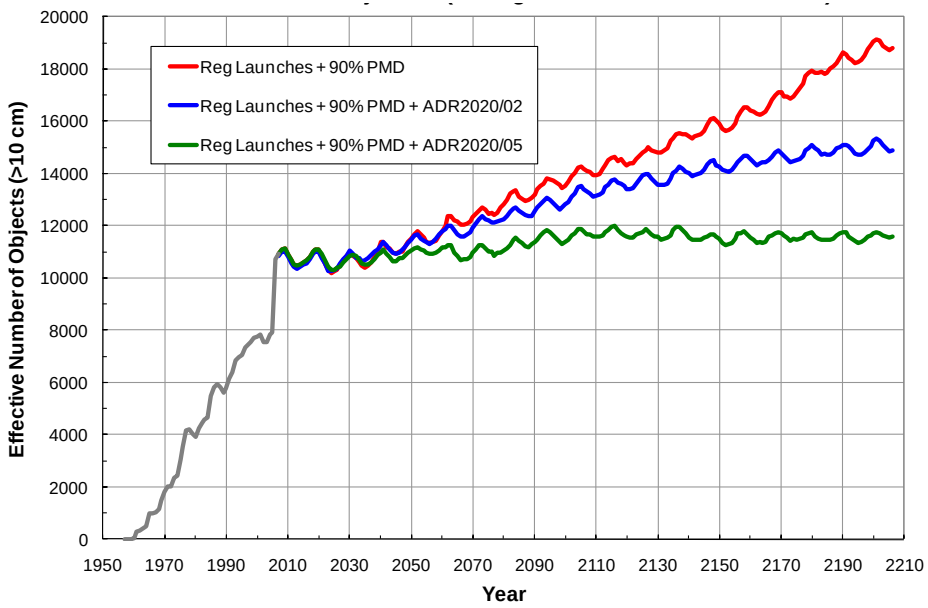
NASA study on debris considering no new launches after 1/1/2006



- **Collision fragments replace other decaying debris through the next 50 years, keeping the total population approximately constant**
- **Beyond 2055, the rate of decaying debris decreases, leading to a net increase in the overall satellite population due to collisions**

(Liou and Johnson, *Science,* 2006)

Justification for Active Debris Removal (ADR)



- **PMD scenario predicts the LEO populations would increase by ~75% in 200 years**
- **LEO environment can be stabilized with PMD and a removal rate of ~5 objects/year**

(Liou, Johnson, and Hill 2010)

Purpose of Task

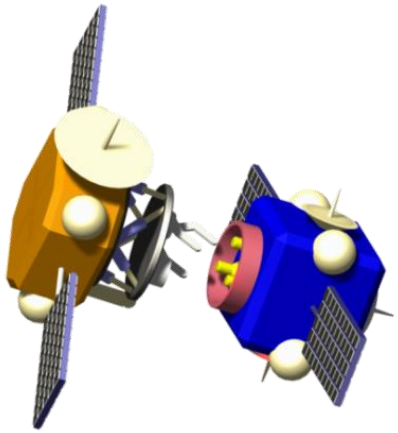
- Active debris removal is required
- Interests in small satellites (e.g., CubeSats) especially by new space entrant leads to:
  - More spacecraft $\Rightarrow$ more failure (debris)
  - Debris likely to be non-cooperative

Objective

- Develop strategies to minimize interactions during removal of non-cooperative debris
- Develop strategies for safe proximity operations / collision avoidance during removal

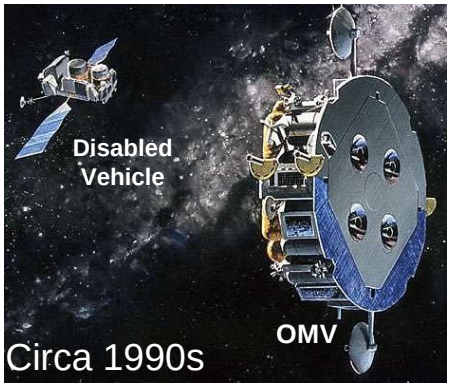
Research Methodology

- Debris Size
  - < 0.5 cm (not practical)
  - 0.5 – 10 cm (not tracked/not retrieved)
  - 10 cm – 1 m (tracked but not retrieved)
  - > 1 m (tracked and can be retrieved)
- Removal concepts
  - Space Tugs
  - Tethers
  - Lasers



Research Methodology

- Space Tug Concept
  - Use a space tug (ST) to maneuver larger disabled satellite (debris) into disposal orbit
  - ConOPs:
    - Autonomous proximity operations
    - Autonomous capture of target
    - Minimizing interactions between ST and non-cooperative debris



On-orbit repair of
Intelsat 603 (May 1992)

Research Methodology

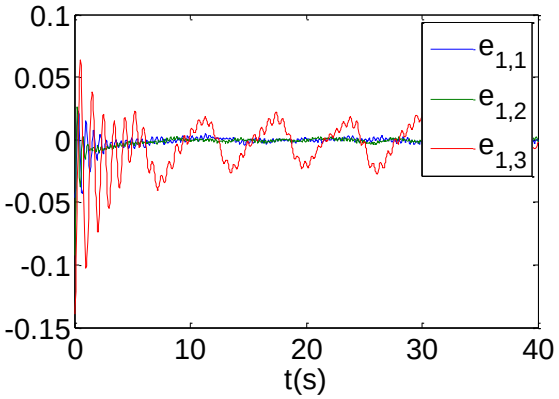
- Game theoretic approach
  - Formulate a two player game between the space tug (ST) and the debris
  - Use a hierarchical approach with the debris as the leader and ST as the follower (i.e., ST minimizes interaction with a non-cooperative debris)
  - Develop appropriate strategy (Stackelberg)
- Solve differential game problem

Research Methodology

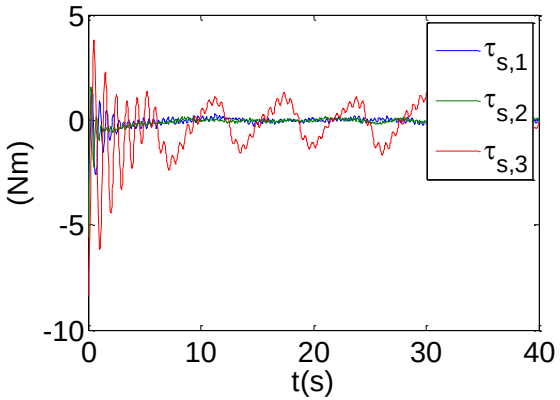
- Indirect solution method
  - Currently the only way to find a solution in general
  - Only known existing solution (LQ case only)
- Direct solution method
  - Solution algorithms for bilevel programming are not as mature as those for nonlinear programming
- Approach: Start with a LQ game and extend by adding more complexities; i.e.,
  - Linear dynamic model (small perturbations)
  - Nonlinear dynamics with linear error model (RISE)

Results / Summary

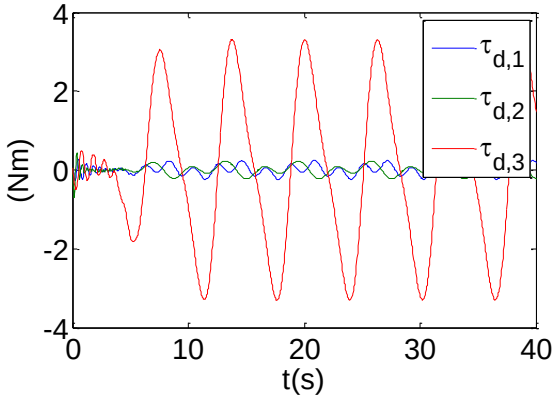
Attitude Error



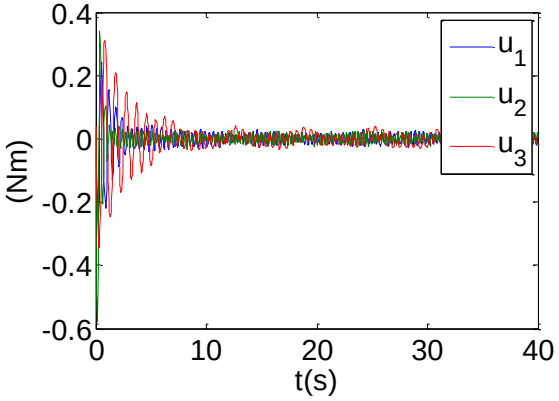
Interaction



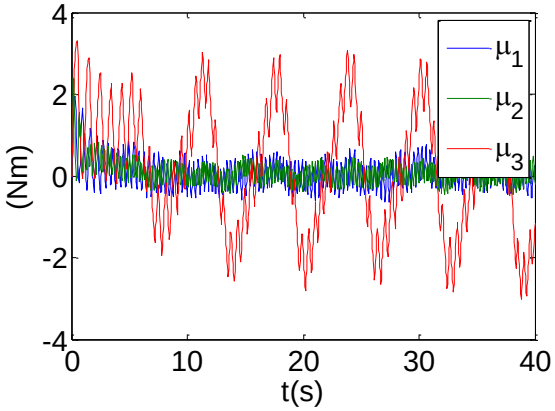
Debris's Torque



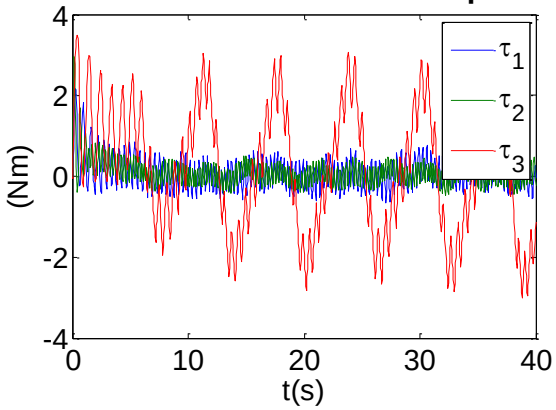
Game Controller



Feedback Linearizer



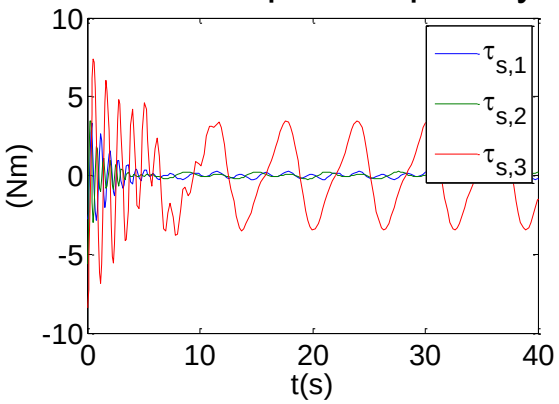
Total Control Torque



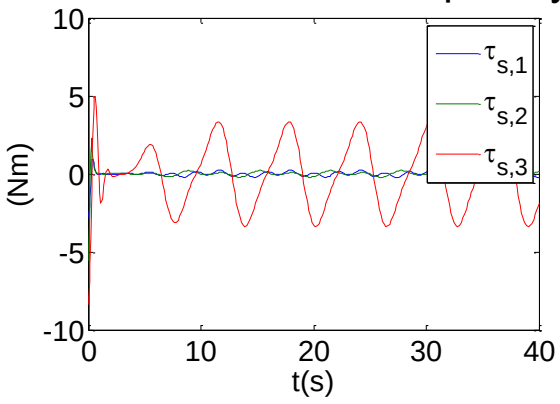
Total momentum input $\left(\sum_{i=1}^{3}\int \tau_i dt\right) = 73.32\ \mathrm{N\cdot m\cdot s}$

Results / Summary

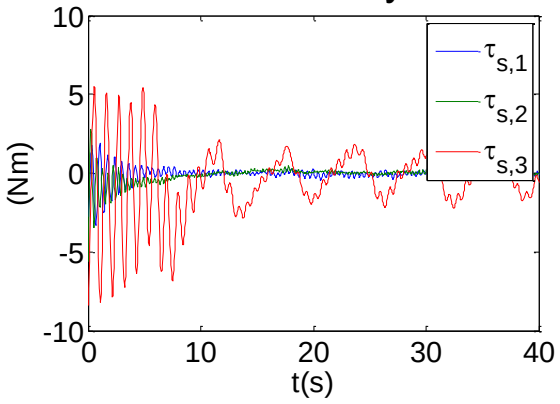
Game Open-loop “only”



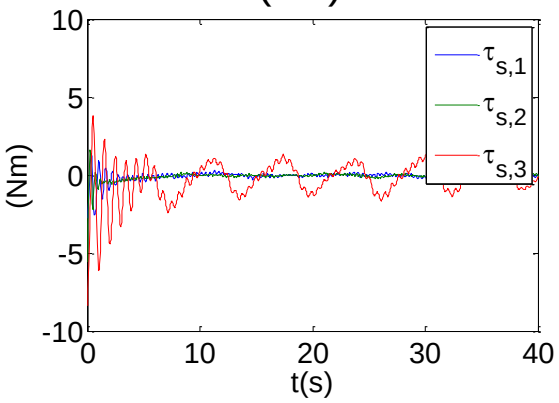
Game Closed-loop “only”



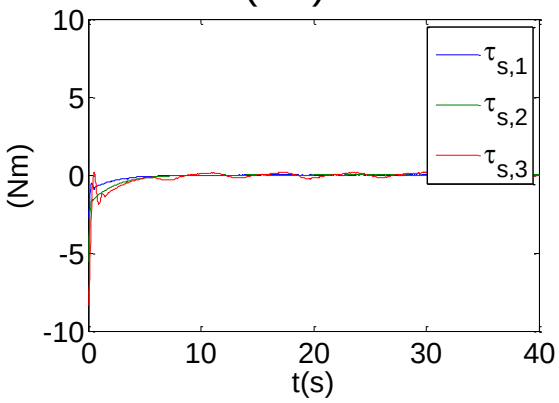
RISE “only”



Game (OL) + RISE



Game (CL) + RISE



Summary of Interaction/Input

Momenta	Interaction	Input
RISE “only”	83	73
Open-loop game + RISE	72	72
Closed-loop game + RISE	46	71
Open-loop game “only”	104	8
Closed-loop game “only”	82	19

Results / Summary

- Demonstrated the viability of game theoretic approach for removal of non-cooperative debris
  - Linearized dynamic model (restrictive)
  - Nonlinear dynamic model (via linearized error model)
- Investigated open-loop and closed-loop Stackelberg strategies
  - Both open- and closed-loop strategies when combined with RISE “linearizer” appear to produce lower interactions
  - Closed-loop + RISE appears to be best overall

Next Steps

- Continue assessment of game-theoretic methods to reduce interactions with non-cooperative debris
  - Explore multiplicative attitude error
  - Further investigate numerical approaches to solving static games / bilevel programming
- Initiate vision-based APFG for proximity operations and collision avoidance
- Collaborate with NASA ODPO (e.g., in situ characterization of LEO debris)

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