Advanced, Autonomous, Unaided Spacecraft Grappling

“Front End Robotic Enabling Near-Term Demonstration (FREND) Technologies and Associated Servicing Architecture”

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FRIEND

• FREND = Front-End Robotics Enabling Near-Term Demonstration
  – The DARPA program to develop and demonstrate a flight robotic arm with associated end-effectors and algorithms that can perform autonomous, unaided grappling
  – Focused on “Space Tow Truck” Operations At GEO (Life Extension, Disposal, Slot Changes, …)

• Three Key FREND Technologies Apply to On-Orbit Robotic Servicing
  – In-Situ Characterization
  – Hold Relative Pose at Close Range
  – Autonomous Robotic Capture

No A-Priori Knowledge of Customer Required
No Standard Targets/Interfaces Required on Customer
In-Situ Characterization

- Techniques to perform in-situ characterization of customer satellites necessary to generate a detailed approach and grapple plan.
  - Forced Motion Circumnavigation while collecting Visual, IR, and LiDAR Data
  - Bring Data to ground to build 3D in-situ model, characterize tumble rates, and build rendezvous, approach, and capture plan
  - Initial demonstration of 3D model building from scanning LiDAR data
Hold Relative Pose at Close Range

- Techniques to actively hold relative pose at ranges of less than 2 meters with objects tumbling up to 1 deg/sec in any axis.
  - 1 pound thrusters support fine 6DOF bus control
  - Wide FOV LiDAR provides precision 6DOF Relative Pose at 5Hz rate
  - Designed, Simulated, and Demonstrated active relative pose control using simulated bus dynamics and scanning LiDAR with 6DOF Relative Pose Algorithm

TriDAR in Proximity Operations Testbed
Autonomous Robotic Capture

• Developed robotic hardware and control algorithms to autonomously grapple a variety of hard points.
  – Use 6DOF pose data for coarse positioning
  – Use end-effector cameras and machine vision algorithms for final grapple positioning
  – Force-Torque sensor and compliance control algorithm provide “virtual soft docking”
  – Changeable end-effectors support marman rings, bolt holes, and other structural hard points

Fully Autonomous Grapple Was A Program Requirement To Support Tumbling Debris That May Prevent Ground Communications

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Algorithms for Autonomous Capture

- **Mission Sequencer** - payload functional coordination
  - Provides payload function control and FDIR
- **Grapple Feature Tracking** - precision arm guidance
  - Designed for specific structural grapple points
  - Has been tested with bolt holes and marman rings
- **Trajectory Planner** – real-time collision avoidance
- **Compliance Control** – virtual “soft dock” during grapple
  - Algorithm reduces forces at contact to minimize customer disturbances, risk of damage, and to increase time for grapple
# Notional Flight Demonstration Phases

## Phase 0: Initial On-Orbit Deployment, Checkout, and Calibration

## Phase 1: Acquire & Rendezvous
- 1.1: Long Range Navigation to 20 km Client Range and Bearing
- 1.2: Rendezvous 20 km ⇒ 1 km

## Phase 2: Survey & Inspection
- 2.1: Customer Survey
- 2.2: Data Downlink/Ground Process
- 2.3: Grapple Interface Detailed Survey

## Phase 3: Approach to Capture
- 3.1: Grapple Final Preparation
- 3.2: Approach to Capture Box

## Phase 4: Grapple
- 4.1: First Arm Grapple
- 4.2: Three Arm Grapple
- 4.3: Grapple Rigidization

## Phase 5: Orbit Modification
- 5.1: Coupled Vehicle Checkout
- 5.2: Coupled Vehicle Steady State
- 5.3: Coupled Vehicle Thrusting

## Phase 6: Safe Retreat
- 6.1: Nominal Grapple Release
- 6.2: Nominal Bus Retreat

## Phase 7: Intra-Mission On-Orbit Hold

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**FREND Demo**

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Demonstration #4 Video