National Aeronautics and Space Administration

System Level Autonomy to Enable Autonomous Mapping Missions of Small Solar System Bodies

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Program: Strategic Initiative

Project Objective

The objective of this task is to enable a novel mission capability to autonomously investigate highly dynamic and uncertain environments, such as those occurring during low altitude small solar system body mapping. **Although this research focused on demonstrating autonomous small body science operations, the systems autonomy framework and reference architecture developed in this study can be used for missions ranging from cryobots, aerial systems, observatories, deep space servicing, etc.**

The Benefit of Systems Autonomy

Systems autonomy integrates traditional control and functional autonomy, e.g. where decisions are made specific to a task, so a mission system can accomplish its goals without ground intervention. Systems autonomy can:

- Enable brand new missions architectures and new science
- Improve science return
- Regain functionality in the event of fault
- Ultimately, reduce the cost of operations

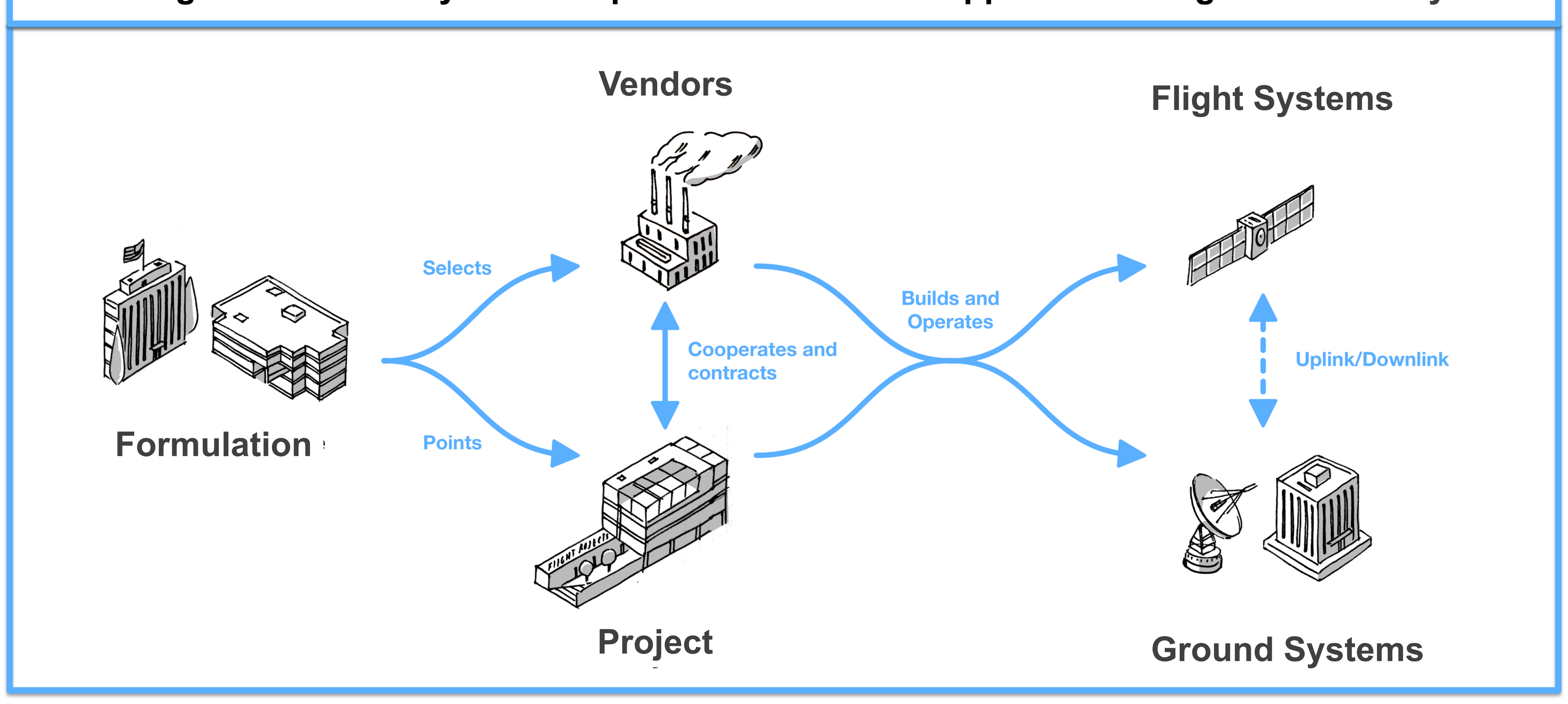
The Benefit of FRESCO

The Framework for Robust Execution and Scheduling of Commands On-board (FRESCO) was derived from decades of JPL work on autonomy and defines high-level principles for developing architectures that:

- Integrate traditional controllers and function-level decision-making (e.g. path planning, science data analysis, robotics) with system-level decision-making and fault protection
- Have consistent interfaces and components with verifiable functions that can be designed, built, and tested more reliably than ad hoc approaches

Study Results

Infusing autonomous systems requires a coordinated approach throughout the lifecycle.



Formulation

In order to support the infusion of system-level autonomy, this task has supported formulation efforts, including:

- **ASTERIA** Technology Demonstration Mission & SR&TD
- Five JNEXT concepts, including **Aerocapture** and **CHROWE**
- CIF proposal for JPL-Caltech-NASA GSFC study of **Deep Space Servicing**
- Submitted an **Astrophysics Decadal White Paper**

Vendors

JPL does not build most of the space systems for its missions. Instead, systems for competed missions are typically build by industry vendors. While on-board controllers capable of conditional sequence block execution are used by vendors, planning/execution called for in FRESCO is not. Therefore, partnerships and technology transfer are critical to infusing system-level autonomy.

A **pilot study with Utah State University Space Dynamics Laboratory** has been proposed to understand what changes are required technically and institutionally to partner on autonomous missions.

Project

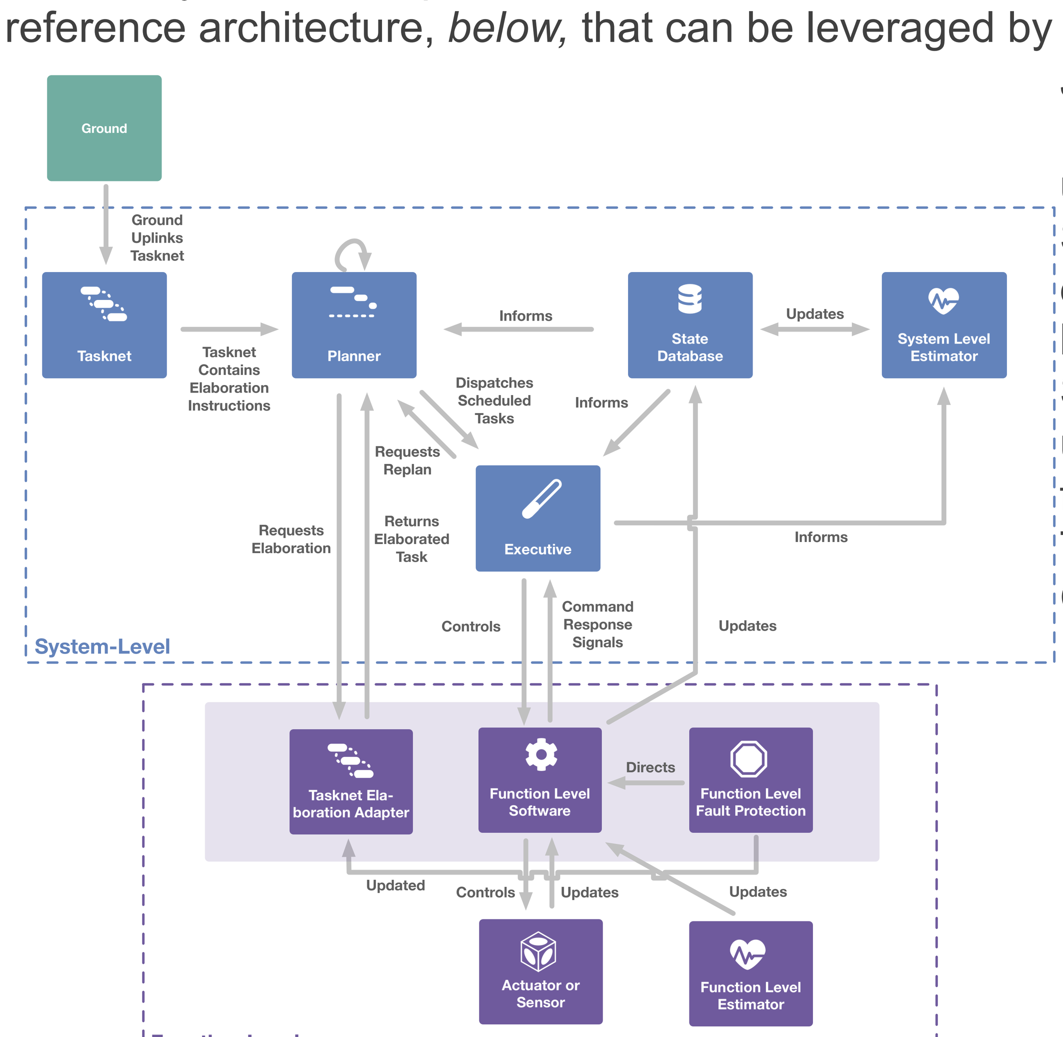
To address the perception that system-level autonomy requires a change in systems, process, and lifecycle products, this study has produced the **Spacecraft Autonomy Recommended Practices document**. For missions using autonomous systems, it recommends:

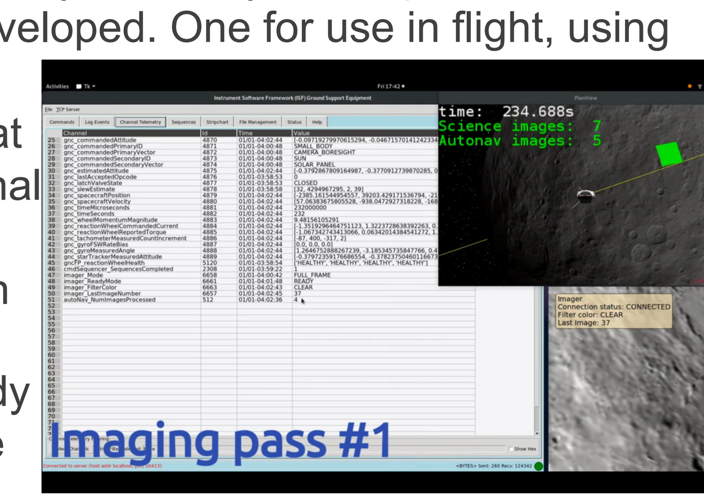
- Guidelines for the developing verifiable FRESCO architectures
- Contributions to existing lifecycle products and impact to processes
- Lessons learned from this study

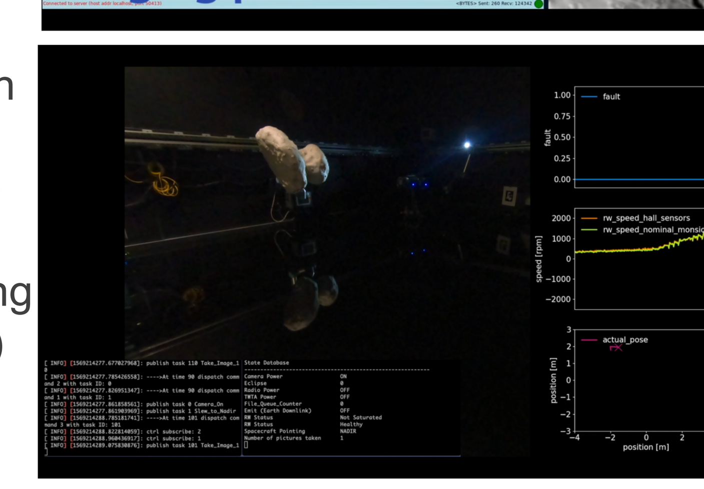
Flight Systems

This study has developed the **Framework for Robust Execution and Scheduling of Commands On-board (FRESCO)** and implemented a reference architecture, *below,* that can be leveraged by other missions. Two software architectures were developed. One for use in flight, using JPL's **F Prime** flight software (FSW), Multi-mission Executive (**MEXEC**) planning/execution software that uses tasknets, and Okean's Model-based Off-Nominal State Isolation and Detection (**MONSID**) fault diagnosis software. Another architecture is for use in laboratory environments using Robotic Operating System (**ROS**) instead of F Prime. In FY19, this study used both software architectures to demonstrate the following in **DARTS** (Dynamics Algorithms for Real-Time Simulation) and **hardware testbeds** at Caltech CAST:

- Diagnosis of reaction wheel friction build up to trigger fault protection
- Small body mapping, while interleaving imaging required for on-board orbit determination (OD)
- Restoration of science operations after RWA fault
- Automated downlink of science imaging
- Trajectory correction maneuver (TCM) to maintain desired orbit following OD



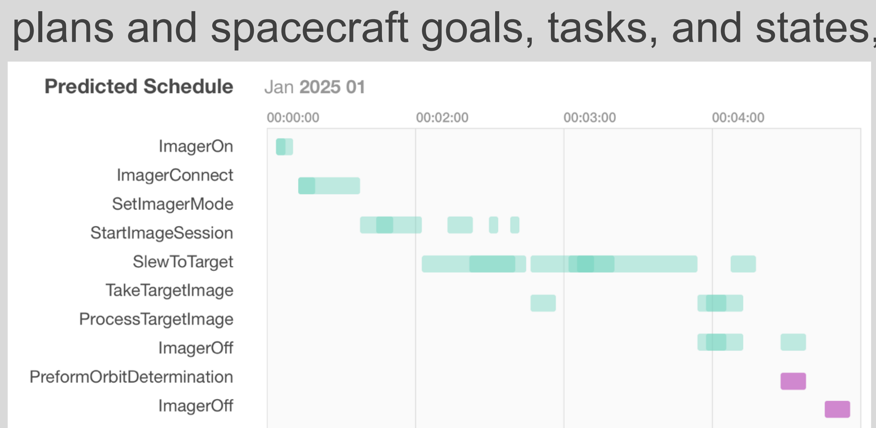




Testing small body mapping operations in DARTS, top, and using Caltech CAST's physical testbeds, below.

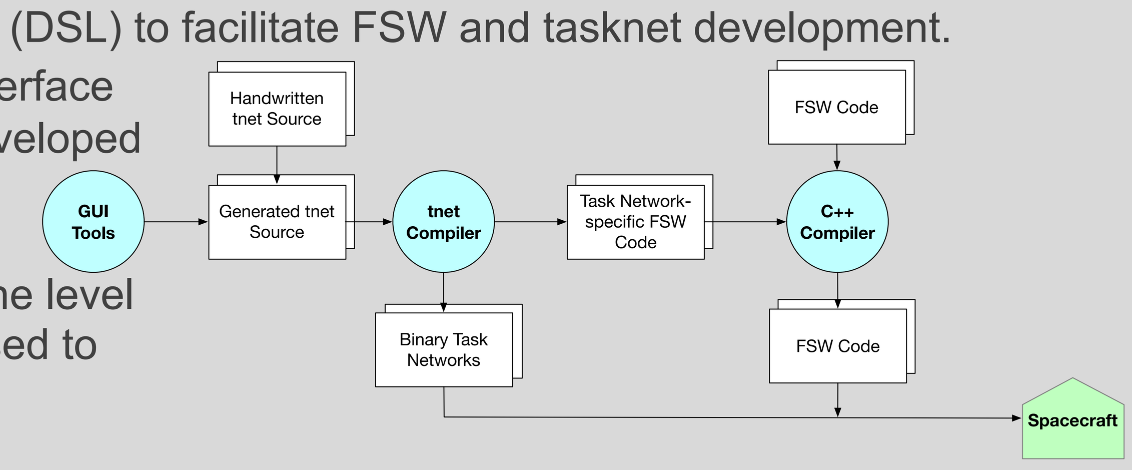
Ground Systems

A preliminary investigation of the impact of on-board autonomy to ground tools and processes was performed. We prototyped a **GUI Ground Tool** that defines mission plans and spacecraft goals, tasks, and states, similar to APGEN. We also developed **tnet domain-specific language** (DSL) to facilitate FSW and tasknet development.



The GUI Ground Tool, *left*, prototype includes provisions for an interface to V&V scripts that can verify a plan's solvency. A mission plan developed in the GUI tool is converted to tnet.

As experienced during our study, using tnet DSL , *right,* reduces the level of effort in developing tasknets for use during operations and is used to autogenerate FSW code for F Prime software architectures.



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