

Any **Assembly of Kinematic Modules** may be directly operated in the system by click-and-drag direct manipulation. Here the canonical configuration of two Tri-ATHLETE modules and one pallet is operated in lifting (A), sliding (B), and tilting (C) motions.

true modular robot operator interface. This workflow is extremely time-consuming, and is not suited for use in an operations context. Current operator interfaces, both at JPL and in the

broader exploration robotics community, are largely focused on non-reconfigurable hardware.

Reconfigurable modular hardware such as Tri-ATHLETE promises to ex-

tend greatly the capability of future exploration missions for a relatively small additional cost. Whereas existing missions based on monolithic hardware can only perform a limited set of pre-defined operations, modular hardware can potentially be reconnected and recombined to serve a range of functions. The full realization of these promises is contingent not just on the development of the hardware itself, but also upon the availability of corresponding software systems with algorithms that enable operators to rapidly specify, visualize, simulate, and control particular assemblies of modules. In the case of articulated, reconnectable hardware like Tri-ATHLETE, operators also can determine feasible motions of the assembly, and disconnect/reconnect actions that change assembly topology.

This work was done by Jeffrey S. Norris of Caltech, Marsette A. Vona of Northeastern University, and Daniela Rus of MIT for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

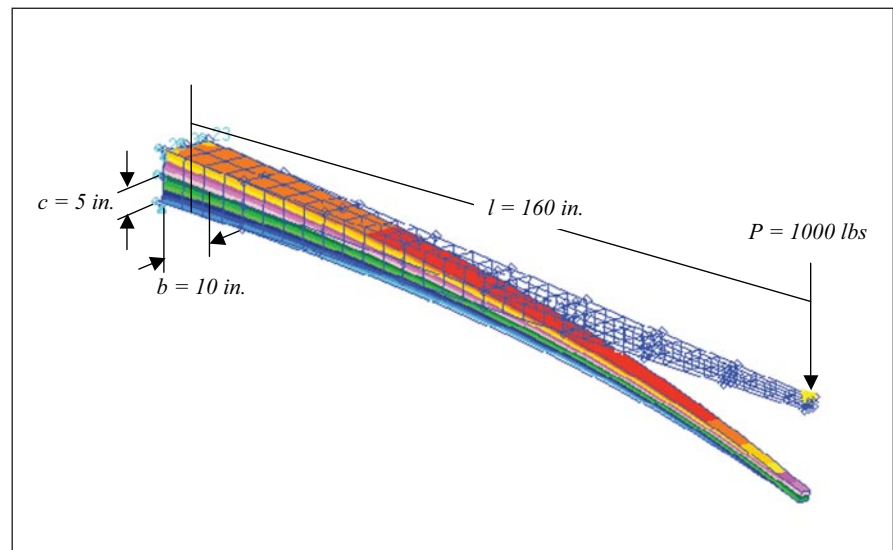
This software is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-47777.

▶ Algorithms for Determining Physical Responses of Structures Under Load

Structure can be monitored in real time while in actual service.

Dryden Flight Research Center, Edwards, California

Ultra-efficient real-time structural monitoring algorithms have been developed to provide extensive information about the physical response of structures under load. These algorithms are driven by actual strain data to measure accurately local strains at multiple locations on the surface of a structure. Through a single point load calibration test, these structural strains are then used to calculate key physical properties of the structure at each measurement location. Such properties include the structure's flexural rigidity (the product of the structure's modulus of elasticity, and its moment of inertia) and the section modulus (the moment of inertia divided by the structure's half-depth). The resulting structural properties at each location can be used to determine the structure's bending moment, shear, and



Cantilever Beam of tapered cross section subjected to tip loading.

structural loads in real time while the structure is in service.

The amount of structural information can be maximized through the use of highly multiplexed fiber Bragg grating technology using optical time domain reflectometry and optical frequency domain reflectometry, which can provide a local strain measurement every 10 mm on a single hair-sized optical fiber. Since local strain is used as input to the algorithms, this system

serves multiple purposes of measuring strains and displacements, as well as determining structural bending moment, shear, and loads for assessing real-time structural health.

The first step is to install a series of strain sensors on the structure's surface in such a way as to measure bending strains at desired locations. The next step is to perform a simple ground test calibration. For a beam of length l (see example), discretized into n sections

and subjected to a tip load of P that places the beam in bending, the flexural rigidity of the beam can be experimentally determined at each measurement location x . The bending moment at each station can then be determined for any general set of loads applied during operation.

This work was done by W. Lance Richards and William L. Ko of Dryden Flight Research Center. Further information is contained in a TSP (see page 1). DRC-008-023

Mission Analysis, Operations, and Navigation Toolkit Environment (Monte) Version 040

NASA's Jet Propulsion Laboratory, Pasadena, California

Monte is a software set designed for use in mission design and spacecraft navigation operations. The system can process measurement data, design optimal trajectories and maneuvers, and do orbit determination, all in one application. For the first time, a single software set can be used for mission design and navigation operations. This eliminates problems due to different models and fidelities used in legacy mission design and navigation software.

The unique features of Monte 040 include a blowdown thruster model for GRAIL (Gravity Recovery and Interior Laboratory) with associated pressure models, as well as an updated, optimal-search capability (COSMIC) that facilitated mission design for ARTEMIS. Existing legacy software lacked the capabilities necessary for these two missions. There is also a mean orbital element propagator and an osculating to mean element converter that allows long-term orbital stability analysis for the first time in compiled code.

The optimized trajectory search tool COSMIC allows users to place constraints and controls on their searches without any restrictions. Constraints may be user-defined and depend on trajectory information either forward or backwards in time. In addition, a long-term orbit stability analysis tool (morbiter) existed previously as a set of scripts on top of Monte.

Monte is becoming the primary tool for navigation operations, a core competency at JPL. The mission design capabilities in Monte are becoming mature enough for use in project proposals as well as post-phase A mission design.

Monte has three distinct advantages over existing software. First, it is being

developed in a modern paradigm: object-oriented C++ and Python. Second, the software has been developed as a toolkit, which allows users to customize their own applications and allows the development team to implement requirements quickly, efficiently, and with minimal bugs. Finally, the software is managed in accordance with the CMMI (Capability Maturity Model Integration), where it has been appraised at maturity level 3.

This work was done by Richard F. Sunseri, Hsi-Cheng Wu, Scott E. Evans, James R. Evans, Theodore R. Drain, and Michelle M. Guevara of Caltech for NASA's Jet Propulsion Laboratory.

This software is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-48184.

Autonomous Rover Traverse and Precise Arm Placement on Remotely Designated Targets

NASA's Jet Propulsion Laboratory, Pasadena, California

This software controls a rover platform to traverse rocky terrain autonomously, plan paths, and avoid obstacles using its stereo hazard and navigation cameras. It does so while continuously tracking a target of interest selected from 10–20 m away. The rover drives and tracks the target until it reaches the vicinity of the target. The rover then positions itself to approach the target, deploys its robotic arm, and places the end effector in-

strument on the designated target to within 2–3-cm accuracy of the originally selected target.

This software features continuous navigation in a fairly rocky field in an outdoor environment and the ability to enable the rover to avoid large rocks and traverse over smaller ones. Using point-and-click mouse commands, a scientist designates targets in the initial imagery acquired from the rover's mast cameras. The navigation software uses

stereo imaging, traversability analysis, path planning, trajectory generation, and trajectory execution. It also includes visual target tracking of a designated target selected from 10 m away while continuously navigating the rocky terrain.

Improvements in this design include steering while driving, which uses continuous curvature paths. There are also several improvements to the traversability analyzer, including improved data fu-