



## NASA SBIR 2020 Phase I Solicitation

### H9.03 Flight Dynamics and Navigation Technology

Lead Center: GSFC

Participating Center(s): JSC, MSFC

Technology Area: TA5 Communication and Navigation

#### Scope Title

Advanced Techniques for Trajectory Optimization

#### Scope Description

Future NASA missions will require precision landing, rendezvous, formation flying, cooperative robotics, proximity operations (e.g., servicing) and coordinated platform operations. This drives the need for increased precision in absolute and relative navigation solutions and more advanced algorithms for both ground and onboard navigation, guidance and control. This sub-topic seeks advancements in flight dynamics and navigation technology for applications in Earth orbit, lunar, and deep space that enables future NASA missions. In particular, technology relating to autonomous onboard navigation, guidance, and control, and trajectory optimization are solicited. See Reference 1 below for NASA Technical Area (TA) roadmaps:

- Low-thrust trajectory optimization in a multi-body dynamical environment (TA 5.4.2.1)
- Advanced deep-space trajectory design techniques. (TA 5.4.2.7) and rapid trajectory design near small bodies (TA 5.4.5.1)
- Tools and techniques for orbit/trajectory design for distributed space missions including constellations and formations (TA 11.2.6)

Proposals that leverage state-of-the-art capabilities already developed by NASA, or that can optionally integrate with those packages, such as the General Mission Analysis Tool (GMAT), Copernicus, Evolutionary Mission Trajectory Generator (EMTG), Mission Analysis Low-Thrust Optimization (MALTO), Monte, and Optimal Trajectories by Implicit Simulation (OTIS), or other available software tools are encouraged. Proposers who contemplate licensing NASA technologies are highly encouraged to coordinate with the appropriate NASA technology transfer offices prior to submission of their proposals.

#### References

1. NASA Space Technology Roadmaps (2015): <https://www.nasa.gov/offices/oct/home/roadmaps/index.html>
2. General Mission Analysis Tool (GMAT): <http://gmatcentral.org/display/GW/GMAT+Wiki+Home>
3. Evolutionary Mission Trajectory Generator (EMTG): <https://software.nasa.gov/software/GSC-16824-1>

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4. Copernicus: <https://www.nasa.gov/centers/johnson/copernicus/index.html>
  5. Mission Analysis Low-Thrust Optimization (MALTO): <https://software.nasa.gov/software/NPO-43625-1>
  6. Monte: <https://montepy.jpl.nasa.gov/>

**Expected TRL or TRL range at completion of the project:** 3 to 6

### **Desired Deliverables of Phase II**

Prototype, Analysis, Software, Research

### **Desired Deliverables Description**

Phase 1 research should be conducted to demonstrate technical feasibility, with preliminary software being delivered for NASA testing, as well as show a plan towards Phase 2 integration. Phase 2 new technology development efforts shall deliver components at the Technology Readiness Level (TRL) 5-6 level with mature algorithms and software components complete and preliminary integration and testing in an operational environment.

### **State of the Art and Critical Gaps**

Algorithms and software for rapid and robust preliminary and high-fidelity design and optimization of low thrust trajectories in a multi-body dynamical environment (such as cislunar space) currently do not exist. Designing trajectories for these types of missions relies heavily on hands-on work by very experienced people. That works reasonably well for designing a single reference trajectory but not as well for exploring trade spaces or when designing thousands of trajectories for a Monte-Carlo or missed-thrust robustness analysis.

### **Relevance / Science Traceability**

- Lunar Orbital Platform-Gateway
- WFIRST
- Europa Clipper
- Lucy
- Psyche

Trajectory design for these complex missions can take weeks or months to generate a single reference trajectory. Providing algorithms and software to speed up this process will enable missions to more fully explore trade spaces and more quickly respond to changes in the mission.

### **Scope Title**

Autonomous Onboard Spacecraft Navigation, Guidance and Control

### **Scope Description**

Future NASA missions require precision landing, rendezvous, formation flying, proximity operations (e.g., servicing and assembly), non-cooperative object capture and coordinated platform operations in Earth orbit, cislunar space, libration orbits and deep space. These missions require a high degree of autonomy. The subtopic seeks advancements in autonomous spacecraft navigation and maneuvering technologies for applications in Earth orbit, lunar, cislunar, libration and deep space to reduce dependence on ground-based tracking, orbit determination and maneuver planning. See Reference 1 for NASA Technical Area (TA) roadmaps:

- Advanced autonomous spacecraft navigation techniques including devices and systems that support

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- significant advances in independence from Earth supervision while minimizing spacecraft burden by requiring low power and minimal mass and volume (TA 5.4.2.4, TA 5.4.2.6, TA 5.4.2.8).
- Onboard spacecraft trajectory planning and optimization algorithms for real-time mission re-sequencing, on-board computation of large divert maneuvers (TA 5.4.2.3, TA 5.4.2.5, TA 5.4.2.6, TA 9.2.6) primitive body/lunar proximity operations and pinpoint landing (TA 5.4.6.1), including the concept of robust onboard trajectory planning and optimization algorithms that account for system uncertainty (i.e., navigation errors, maneuver execution errors, etc.).
  - Onboard relative and proximity navigation (TA 5.4.4) multi-platform relative navigation (relative position, velocity and attitude or pose) which support cooperative and collaborative space operations such as satellite servicing and in-space assembly.
  - Rendezvous targeting (TA 4.6.2.1) Proximity Operations/Capture/ Docking Guidance (TA 4.6.2.2)
  - Advanced filtering techniques (TA 5.4.2.4) that address rendezvous and proximity operations as a multi-sensor, multi-target tracking problem; handle non-Gaussian uncertainty; or incorporate multiple-model estimation.
  - Advanced algorithms for safe precision landing on small bodies, planets and moons, including real-time three-dimensional (3D) terrain mapping (TA 9.2.8.1, 9.2.8.3), autonomous hazard detection and avoidance (TA 9.2.8.4), terrain relative navigation (TA 9.2.8.2), small body proximity operations (TA 9.2.8.8).
  - Machine vision techniques to support optical/terrain relative navigation and/or spacecraft rendezvous/proximity operations.

Proposals that leverage state-of-the-art capabilities already developed by NASA, or that can optionally integrate with those packages, such as the Goddard Enhanced Onboard Navigation System (GEONS) (<https://software.nasa.gov/software/GSC-14687-1>), Navigator ([http://itpo.gsfc.nasa.gov/wp-content/uploads/gsc\\_14793\\_1\\_navigator.pdf](http://itpo.gsfc.nasa.gov/wp-content/uploads/gsc_14793_1_navigator.pdf)), NavCube (<https://goo.gl/bdobb9>) or other available NASA hardware and software tools are encouraged. Proposers who contemplate licensing NASA technologies are highly encouraged to coordinate with the appropriate NASA technology transfer offices prior to submission of their proposals.

## References

1. NASA Space Technology Roadmaps (2015): <https://www.nasa.gov/offices/oct/home/roadmaps/index.html>
2. Goddard Enhanced Onboard Navigation System (GEONS), (<https://software.nasa.gov/software/GSC-14687-1>), (<https://goo.gl/TbVZ7G>)
3. Mission Analysis, Operations, and Navigation Toolkit Environment (MONTE), (<https://montepy.jpl.nasa.gov/>)
4. Navigator ([http://itpo.gsfc.nasa.gov/wp-content/uploads/gsc\\_14793\\_1\\_navigator.pdf](http://itpo.gsfc.nasa.gov/wp-content/uploads/gsc_14793_1_navigator.pdf))
5. NavCube (<https://goo.gl/bdobb9>)

**Expected TRL or TRL range at completion of the project:** 3 to 6

## Desired Deliverables of Phase II

Prototype, Analysis, Hardware, Software, Research

## Desired Deliverables Description

Phase 1 research should be conducted to demonstrate technical feasibility, with preliminary software being delivered for NASA testing, as well as show a plan towards Phase 2 integration. For proposals that include hardware development, delivery of a prototype under the Phase 1 contract is preferred, but not necessary. Phase 2 new technology development efforts shall deliver components at the TRL 5-6 level with mature algorithms and software components complete and preliminary integration and testing in an operational environment.

## State of the Art and Critical Gaps

Currently navigation, guidance and control functions rely heavily on the ground for tracking data, data processing and decision making. As NASA operates farther from Earth and performs more complex operations requiring

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coordination between vehicles, round trip communication time delays make it is necessary to reduce reliance on Earth for navigation solutions and maneuver planning. Spacecraft that arrive at a near-Earth asteroid (NEA) or a planetary surface, may have limited ground inputs and no surface or orbiting navigational aids. NASA currently does not have the navigational, trajectory and attitude flight control technologies that permit fully autonomous approach, proximity operations and landing without navigation support from Earth.

### **Relevance / Science Traceability**

- Lunar Orbital Platform-Gateway
- Orion Multi-Purpose Crew Vehicle
- Wide Field Infrared Survey Telescope (WFIRST)
- Europa Clipper
- Lucy
- Psyche

These complex, deep space missions require a high degree of autonomy. The technology produced in this subtopic enables these kinds of missions by reducing or eliminating reliance on the ground for navigation and maneuver planning. The subtopic aims to reduce the burden of routine navigational support and communications requirements on network services, increase operational agility, and enable near real-time re-planning and opportunistic science. It also aims to enable classes of missions that would otherwise not be possible due to round-trip light time constraints.

### **Scope Title**

Conjunction Assessment Risk Analysis (CARA)

### **Scope Description**

The U.S. Space Surveillance Network currently tracks more than 22,000 objects larger than 10 centimeters and the number of objects in orbit is steadily increasing which causes an increasing threat to human spaceflight and robotic missions in the near-Earth environment. The NASA Conjunction Assessment Risk Analysis (CARA) team receives screening data from the 18th Space Control Squadron concerning predicted close approaches between NASA satellites and other space objects. CARA determines the risk posed by those events and recommends risk mitigation strategies, including collision avoidance maneuvers, to protect NASA non-human-spaceflight assets in Earth orbit. The ability to perform CARA more accurately and rapidly will improve space safety for all near-Earth operations. This subtopic seeks innovative technologies to improve the CARA process including (see Reference 1 for NASA Technical Area (TA) roadmaps):

- Event evolution prediction methods, models and algorithms with improved ability to predict characteristics for single and ensemble risk assessment, especially using artificial intelligence/machine learning (TA 5.5.3).
- Methods for combining commercial data (observations or ephemerides) with 18 SPCS –derived solutions (available as Vector Covariance Messages, Conjunction Data Messages, or Astrodynamics Support Workstation output) to create a single improved orbit determination solution including more data sources.

### **References**

1. NASA Space Technology Roadmaps (2015): <https://www.nasa.gov/offices/oct/home/roadmaps/index.html>
2. NASA Conjunction Assessment Risk Analysis (CARA) Office: <https://satellitesafety.gsfc.nasa.gov/cara.html>
3. NASA Orbital Debris Program Office: <https://www.orbitaldebris.jsc.nasa.gov/>
3. Newman, Lauri, K., "The NASA robotic conjunction assessment process: Overview and operational experiences," Acta Astronautica, Vol. 66, Issues 7-8, Apr-May 2010, pp. 1253-1261, <https://www.sciencedirect.com/science/article/pii/S0094576509004913>.

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4. Newman, Lauri K., et al. "Evolution and Implementation of the NASA Robotic Conjunction Assessment Risk Analysis Concept of Operations." (2014). <https://ntrs.nasa.gov/search.jsp?R=20150000159>
  5. Newman, Lauri K., and Matthew D. Hejduk. "NASA Conjunction Assessment Organizational Approach and the Associated Determination of Screening Volume Sizes." (2015). <https://ntrs.nasa.gov/search.jsp?R=20150011461>

**Expected TRL or TRL range at completion of the project:** 2 to 5

### **Desired Deliverables of Phase II**

Prototype, Analysis, Software, Research

### **Desired Deliverables Description**

Phase 1 research should be conducted to demonstrate technical feasibility, with preliminary software being delivered for NASA testing, as well as show a plan toward Phase 2 integration. Phase 2 new technology development efforts shall deliver components at the TRL 5-6 level with mature algorithms and software components complete and preliminary integration and testing in a quasi-operational environment.

### **State of the Art and Critical Gaps**

Current state of the art has been adequate in performing conjunction assessment and collision mitigation for space objects that fall under the high interest events (HIE). With the incorporation of the Space Fence, the number of objects tracked and assessed for conjunctions will increase by one or more orders of magnitude, this presents a critical gap in which current approaches may not suffice. Thus, smarter ways to perform conjunction analysis and assessments such as methods for bundling events and performing ensemble risk assessment, Middle-duration risk assessment (longer duration than possible for discrete events but shorter than decades-long analyses that use gas dynamics assumptions), Improved Conjunction Assessment (CA) event evolution prediction, Machine learning / Artificial Intelligence (AI) applied to CA risk assessment parameters and/or event evolution are needed. The decision space for collision avoidance relies on not only the quality of the data (state and covariance) but also the tools and techniques for conjunction assessment.

Collision avoidance maneuver decisions are based on predicted close approach distance and probability of collision. The accuracy of these numbers depend on underlying measurements and mathematics used in estimation. Current methods assume Gaussian distributions for errors and that all objects are shaped like cannon balls for non-gravitational force computations. These assumptions and others cause inaccurate estimates which can lead decision makers to perform unnecessary collision avoidance maneuvers, thus wasting propellant. Better techniques are needed for orbit prediction and covariance characterization and propagation. Better modeling of non-gravitational force effects is needed to improve orbit prediction. Modeling of non-gravitational forces relies on knowledge of individual object characteristics.

### **Relevance / Science Traceability**

This technology is relevant and needed for all human spaceflight and robotic missions in the near-Earth environment. The ability to perform CARA more accurately will improve space safety for all near-Earth operations, improve operational support by providing more accurate and longer term predictions and reduce propellant usage for collision avoidance maneuvers.