NASA SBIR 2021 Phase I Solicitation

H9.03 Flight Dynamics and Navigation Technologies

Lead Center: GSFC

Participating Center(s): JSC, MSFC

Scope Title:

Advanced Techniques for Trajectory Design and Optimization

Scope Description:

NASA seeks innovative advancements in trajectory design and optimization for Earth orbit, cislunar, and interplanetary missions, including:

- Low-thrust trajectories in a multibody dynamical environment.
- Small-body (moons, asteroids, and comets) exploration.
- Distributed space systems (swarms, constellations, or formations).

In particular, NASA is seeking innovative techniques for optimization of trajectories that account for:

- System uncertainties (i.e., navigation errors, maneuver execution errors, etc.).
- Spacecraft and operational constraints (power, communications, thermal, etc.).
- Trajectory impacts on ability to make required navigational and/or science observations.

Furthermore, innovative techniques that allow rapid exploration of mission design trade spaces, address high-dimensionality optimization problems (i.e., multimoon/multibody tours;Â low thrust, multispiralÂ Earth orbits),Â apply novel artificial intelligence/machine learning (AI/ML) algorithms or provide unique methods for visualizing and manipulating trajectory designs are sought.

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), Collocation Stand Alone Library and Toolkit (CSALT), Copernicus, Evolutionary Mission Trajectory Generator (EMTG), Mission Analysis Low-Thrust Optimization (MALTO), Mission Analysis, Operations, and Navigation (MONTE), and Optimal Trajectories by Implicit Simulation (OTIS), or other available software tools are encouraged.Â Proposers who contemplate licensing NASA technologies are highly encouraged to coordinate with the appropriate NASA technology transfer offices prior to submission of their proposals.

Expected TRL or TRL Range at completion of the Project:Â 3 to 6Â
Primary Technology Taxonomy:Â
Level 1: TX 15 Flight Vehicle SystemsÂ
Level 2: TX 15.2 Flight Mechanics**Â**
Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Software

Desired Deliverables Description:

Phase I research shouldÂ demonstrate technical feasibility, with preliminary software being delivered for NASA testing, as well as show a plan towards Phase II integration.

Phase II new technology development efforts shall deliver components at the TRLÂ 5 to 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 optimizing trajectories while considering system uncertainties, spacecraft and operational constraints, and trajectory impacts on making navigational or science observations, do not currently exist. In addition, designing trajectories for complex missions, such as low-thrust cislunar or multibody tour missionsÂ relyÂ 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:

Relevant missions include:

- Artemis - Lunar Gateway.
- Europa Clipper.
- Lucy.
- Psyche.
- Dragonfly.
- Lunar IceCube.
- Roman Space Telescope.

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.

References:

1. General Mission Analysis Tool (GMAT):Â https://software.nasa.gov/software/GSC-18094-1,Â

https://gmat.atlassian.net/wiki/spaces/GW/overview?mode=global.

2. Collocation Stand Alone Library and Toolkit (CSALT):Â https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170003690.pdf
3. Evolutionary Mission Trajectory Generator (EMTG):Â https://software.nasa.gov/software/GSC-16824-1,Â https://github.com/nasa/EMTG.
4. Copernicus:Â https://software.nasa.gov/software/MSC-26673-1,Â https://www.nasa.gov/centers/johnson/copernicus/index.html.
5. Mission Analysis Low-Thrust Optimization (MALTO):Â https://software.nasa.gov/software/NPO-43625-1
6. Mission Analysis, Operations, and Navigation (MONTE):Â https://montepy.jpl.nasa.gov/

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), noncooperative 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, onboard spacecraft navigation and maneuver planningÂ and execution technologies for applications in Earth orbit, lunar, cislunar, libration, and deep space to reduce dependence on ground-based tracking, orbit determination, and maneuver planning, including:

- Onboard relative and proximity navigation, multiplatform relative navigation (relative position, velocity and attitude, or pose), which support cooperative and collaborative space operations such as On-orbit Servicing, Assembly, and Manufacturing (OSAM).
- Advanced filtering techniques that address rendezvous and proximity operations as a multisensor, multitarget tracking problem; handle nonGaussian uncertainty; or incorporate multiple-model estimation.
- Advanced algorithms for safe, precision landing on small bodies, planets, and moons, including real-time 3DÂ terrain mapping, autonomous hazard detection and avoidance, terrain relative navigation, and small body proximity operations.
- Machine vision techniques to support optical/terrain relative navigation and/or spacecraft rendezvous/proximity operations in low and variable lighting conditions, including artificial intelligence/machine learning (AI/ML) algorithms.
- Onboard spacecraft trajectory planning and optimization algorithms for real-time mission resequencing, onboard computation of large divert maneuvers, primitive body/lunar proximity operations, and pinpoint landing, including robust onboard trajectory planning and optimization algorithms that account for system uncertainty (i.e., navigation errors, maneuver execution errors, etc.).

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), NavigatorÂ NavCube, core Flight System (cFS), 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.

Expected TRL or TRL Range at completion of the Project:Â 3 to 6Â
Primary Technology Taxonomy:Â
Level 1: TX 17 Guidance, Navigation, and Control (GN&C)Â
Level 2: TX 17.2 Navigation Technologies**Â**
Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Hardware
- Software

Desired Deliverables Description:

Phase I research should demonstrate technical feasibility, with preliminary software being delivered for NASA testing, as well as show a plan towards Phase II integration. For proposals that include hardware development, delivery of a prototype under the Phase I contract is preferred, but not necessary.

Phase II new technology development efforts shall deliver components at the TRLÂ 5 to 6 level with mature algorithms and software components with 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 coordination between vehicles, round trip communication time delays make it 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, and may require rapid navigation updates to feed autonomous trajectory guidance updates and control. 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-based resources.

Relevance / Science Traceability:

Relevant missions include:

- Artemis (Lunar Gateway, Orion Multi-Purpose Crew Vehicle, Human Landing Systems).
- On-orbit Servicing, Assembly and Manufacturing (OSAM).
- LunaNet.
- autonomous Navigation, Guidance and Control (autoNGC).
- Roman Space Telescope.
- 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 replanning and opportunistic science. It also aims to enable classes of missions that would otherwise not be possible due to round-trip light time constraints.

References:

1. Goddard Enhanced Onboard Navigation System (GEONS): (https://software.nasa.gov/software/GSC-14687-1), (https://goo.gl/TbVZ7G)
2. Navigator:Â Â (http://itpo.gsfc.nasa.gov/wp-content/uploads/gsc_14793_1_navigator.pdf)
3. NavCube: Â (https://goo.gl/bdobb9)
4. core Flight System (cFS):Â https://cfs.gsfc.nasa.gov/
5. On-orbit Servicing, Assembly, and Manufacturing (OSAM):Â https://nexis.gsfc.nasa.gov/osam/index.html
6. LunaNet:Â https://esc.gsfc.nasa.gov/news/_LunaNetConcept
7. autonomous Navigation, Guidance and Control (autoNGC):Â https://techport.nasa.gov/view/94817

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 cmÂ 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 CARAÂ 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:

- Improved conjunction assessment (CA) 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 (AI/ML).
- AI/MLÂ applied to CA risk assessment parameters.
- Middle-duration risk assessment (longer duration than possible for discrete events but shorter than decades-long analyses that use gas dynamics assumptions).Â
- Methods for combining commercial data (observations or ephemerides) with 18th Space Control Squadron (18Â 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.

Expected TRL or TRL Range at completion of the Project:Â 2 to 5Â
Primary Technology Taxonomy:Â
Level 1: TX 05 Communications, Navigation, and Orbital Debris Tracking and Characterization SystemsÂ
Level 2: TX 05.6 Networking and Ground Based Orbital Debris Tracking and Management**Â**
Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Software

Desired Deliverables Description:

Phase I research shouldÂ demonstrate technical feasibility, with preliminary software being delivered for NASA testing, as well as show a plan toward Phase II integration.

Phase II new technology development efforts shall deliver components at the TRLÂ 5 to 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 CA and collision mitigation for space objects that fall under the high interest events (HIE). With the incorporation of the Space Fence and the deployment of large constellations, the number of objects tracked and assessed for conjunctions is expected to greatly increase. 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), improvedÂ CAÂ event evolution prediction, and AI/MLÂ 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 CA.

Collision avoidance maneuver decisions are based on predicted close approach distance and probability of collision. TheÂ 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 nongravitational force computations. These assumptions and others cause inaccurate estimates thatÂ 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 nongravitational force effects is needed to improve orbit prediction. Modeling of nongravitational 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, cislunar, and lunar environments. 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.

References:

1. NASA Conjunction Assessment Risk Analysis (CARA) Office:Â https://satellitesafety.gsfc.nasa.gov/cara.html.
2. NASA Orbital Debris Program Office:Â 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,Â
   https://www.sciencedirect.com/science/article/pii/S0094576509004913.
4. Newman, Lauri K., et al. "Evolution and Implementation of the NASA Robotic Conjunction Assessment Risk Analysis Concept of Operations."
   (2014).Â 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).Â https://ntrs.nasa.gov/search.jsp?R=20150011461.
6. Office of Safety and Mission Assurance, â€œNASA Procedural Requirements for Limiting Orbital Debris and Evaluating the Meteoroid and Orbital Debris Environmentsâ€, NPR
   8715.6B,Â https://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=8715&s=6B.

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