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LeoLabs Federal, Inc.'s Response to:

Department of Commerce
Office of Space Commerce

Request for Information on
Scope of Civil Space Situational Awareness Services

RFI Number: 2023-01556

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RFI Response

All of the basic Space Situational Awareness (SSA) safety services identified in this request are readily accessible to owners and operators of spacecraft from the current U.S. SSA industry. These services are affordable to owners and operators of spacecraft. It is important to note that scientific and student satellite missions are typically funded by large government organizations, such as NASA and the NSF. Thus, these organizations should ensure budget for the acquisition of SSA safety services. LeoLabs currently serves 60% of this market in low Earth orbit, with the SSA products described in detail below.

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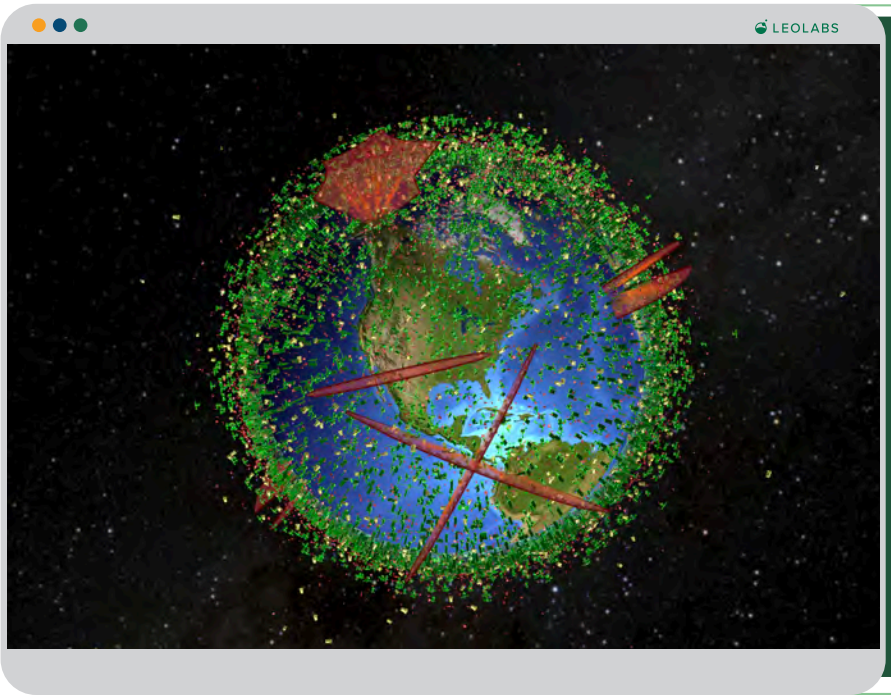
1. Satellite Attributes, Capabilities, Status, and Point of Contact (Included).

To maintain a database of primary (protected) assets, which contains basic satellite attributes (approximate dimensions, mass), indicates satellite trajectory change capabilities and current status, and includes 24/7/365 contact information to coordinate mitigation actions for conjunctions between active satellites.

LeoLabs maintains a database of all rocket bodies and payloads in LEO to include mass, shape, minimum dimension, and maximum dimension. We agree that this should be included in a basic service, and we can easily expand the current parameters to other operationally relevant factors as needed. This is a product readily available from the current U.S. SSA industry.



2. Receipt and Sharing of Predictions O/Os Ephemerides (Included).

To receive predicted ephemerides from O/Os, store them in a manner that makes them available for download by other interested O/Os, and use them as the representation of the primary object for collision assessments (CA) screenings, risk assessment, and (when appropriate) mitigation planning.

LeoLabs' LeoShare product does exactly this and it was successfully beta tested in August 2022. This test proved our ability to safely receive, store, and share predicted ephemerides between owner/operators around the world. This service improves space safety, transparency, and cybersecurity by simplifying the sharing of operational ephemerides in an independent, separate, stand-alone platform. It also enables operators to assess potential maneuvers and coordinate necessary mitigative actions with the other affected party. LeoShare goes beyond the DoD's current offering, making it easier for owner/operators to share ephemeris files without the need for bilateral agreements or other arrangements.

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3. Routine Collision Assessment (CA) Screening and Conjunction Data Message (CDM) Production (Included).

To screen primary objects against a robust satellite catalog, both routinely and on demand; and to generate CDMs for objects that violate the particular physical volumes used for the screening activity.

LeoLabs has provided routine CA screening and CDM production since 2020 through our LeoSafe product. All objects, including primaries, are screened against the LeoLabs-maintained catalog, which contains an estimated 20,000 routinely tracked objects and all O/O ephemerides provided to LeoLabs. Ongoing upgrades to radar sensitivity and new radar locations will continue to increase object catalog robustness over time. Full catalog screenings occur for all objects upon creation of a new state vector, which is generated by both radar tracking and new O/O operational ephemerides uploaded to LeoLabs. These screenings produce CDMs, which are distributed to users via the LeoLabs UI and API within minutes of state vector creation. Similarly, CDMs generated from on-demand screenings are available for op-

erational ephemerides and maneuver planning ephemerides within minutes of user upload via the LeoLabs UI or API. The default physical screening volume available for all LeoSafe users is 2 km radial, 50 km in-track, and 50 km cross-track. LeoLabs' LeoSafe product surpasses the current DoD service by providing object screenings with every state update and on-demand screenings within minutes, continuously. The larger screening volume provides more in-depth situational awareness for operators.

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4. Special CA Screening and CDM Production (Included).

To perform an on-demand screening against a robust satellite catalog for a particular submitted ephemeris or set of ephemerides (usually for a confirmatory or speculative screening as part of maneuver planning).

LeoLabs' LeoSafe product allows on-demand screening for multiple O/O ephemerides against the LeoLabs catalog with resultant CDMs available for download through the UI or API within minutes. For results filtering, users have flexibility to add specificity — narrowing results by factors such as the maximum miss distance, minimum probability of collision, and maximum Mahalanobis distance within the screening volume. Further, when submitting an on-demand screening, an HBR size for the primary can be specified to programmatically evaluate how a planned attitude adjustment (typically a slew) will change resultant probability of collision. Numerous standard ephemeris formats may be accepted for screening. Once the on-demand screening is completed, users

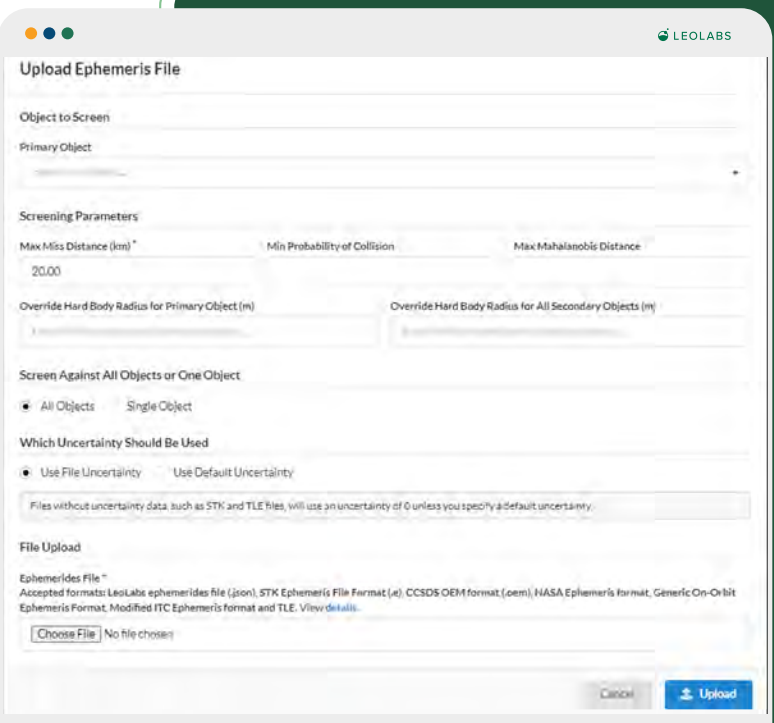

Figure 1 - A look at our on-demand screening UI where users can submit their ephemerides for screening. This shows the different options available to the user when submitting a screening.

can evaluate a screening summary of events with the aggregate Probability of Collision (Pc), as well as view and download individual events. Screenings submitted via the LeoLabs API allow the flexibility of automatically importing data into user tools for evaluation. LeoLabs' LeoSafe product surpasses the current DoD service by providing on-demand screenings within minutes, which allows quick iteration on potential maneuver plans. Moreover, the larger screening volume available with the LeoSafe product provides additional detailed situational awareness for operators.

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5. Data Quality Evaluation (Included).

To perform a first-order evaluation of the orbit determination and propagation of the (usually secondary but in principle both) objects' state estimates and covariances in order to determine whether these inputs are of sufficient quality to serve as a basis for a durable risk assessment calculation.

LeoLabs utilizes an automated validation and verification process to ensure data quality meets customer needs. LeoLabs compares its range and Doppler measurements to International Laser Ranging Service (ILRS) reference ephemeris published for approximately 10 on-orbit satellites. This gives 10-20 passes per day at each radar to develop an average bias to apply for that radar during the next 24-hour cycle. LeoLabs also uses the ILRS reference ephemeris as the truth data source to determine range and Doppler residuals to show the accuracy and precision of measurements at each radar.

Although LeoLabs does this organically, we understand the need to have a 3rd party perform data quality assessments to avoid conflicts of interest. There are many other commercial entities who perform validation and verification assessments similar to or with slight variation from the methodology described above.

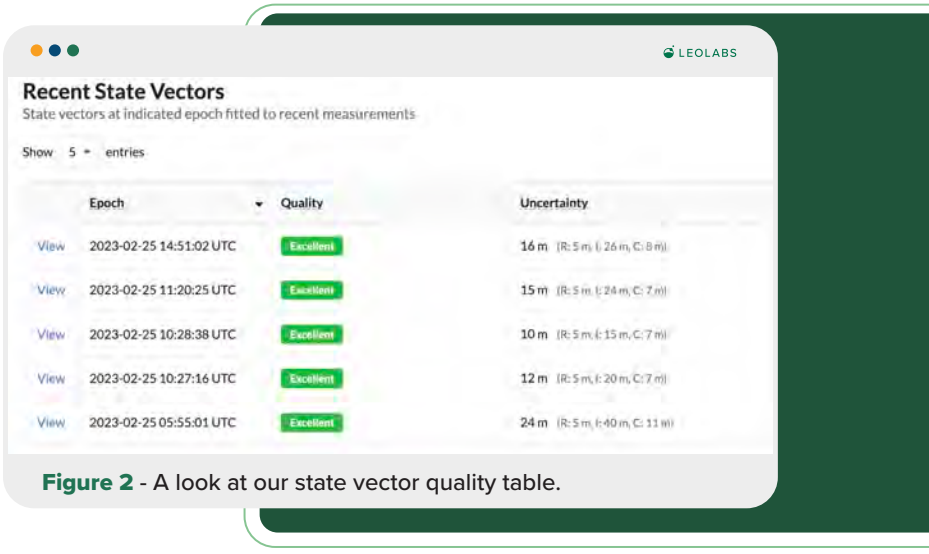

Figure 2 - A look at our state vector quality table.

6. Launch Collision Avoidance (COLA) Screenings (Included).

To perform timely screenings of a set of launch nominals against a robust satellite catalog in order to identify specific launch times during a launch window that would create unacceptably high collision risk and therefore should not be used.

LeoLabs provides a current operational capability for Launch Collision Avoidance (COLA) screenings in its LeoClear product. LeoLabs is capable of screening TLEs, State Vectors, and a wide variety of ephemeris formats against our catalog utilizing our "On-Demand Screening" service. Our screenings can be produced within minutes via direct interaction with our platform through an easy to utilize REST API. This allows for several launch times to be screened simultaneously and efficiently. In addition to our screening service, LeoLabs also provides an intuitive dashboard, showcasing conjunction results. For multi-payload launches, these results are organized to showcase conjunctions with the highest Pc and the lowest calculated Miss Distance. This allows an operator to quickly assess the data with a cursory glance if the aggregate or max Pc of a launch exceeds a safety threshold for the mission. LeoLaunch can inform an operator of their mission's risk within minutes, providing flexibility in launch operations that has been historically absent.

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7. O/O Ephemeris Generation and Curation with Covariance (Included).

To use O/O telemetry and on-board GPS state information, as well as potentially other commercial tracking information, to generate a reliable predicted O/O ephemeris that includes covariance at each ephemeris point and incorporates planned maneuvers (and maneuver execution error).

Due to the rapidly changing LEO landscape (including satellite bus and thruster technologies), LeoLabs believes it should be the responsibility of the Owner/Operator to generate its own Ephemeris and Curation with Covariance and should not be part of the basic service. This ephemeris should be validated and there should be best practices to follow. In non-nominal situations where they are unable to provide this ephemeris due to inability to track, failed GPS, or other anomalies, the tracking data already purchased by the DoC should suffice. Downloading operator telemetry and fusing it is an expensive exercise that will deliver very little, if any, added value.

8. Re-entry Management and Assessment (Included).

To perform re-entry forecasting and event pacing assistance for primary objects undergoing either natural decays or managed deorbits in order to assist the DoD in orchestrating the overall decay and decataloguing process.

While LeoLabs does not currently have a product for re-entry management and assessment, we agree it should be included in a basic service in the interest of public safety and that this is a product readily available from the current U.S. SSA industry.

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9. Precision Probability of Collision Calculation (Included).

To include in each generated CDM a Probability of Collision (Pc) calculation that uses more advanced approaches for determining the appropriate hard-body radius (HBR) and employs a calculation technique appropriate to the particular dynamics of the encounter.

Yes, this SSA safety service is available from LeoLabs today. LeoLabs uses the proven 2D Alfano Probability of Collision (Pc) calculation method in its LeoSafe product, with the results included in each CDM generated. This approach uses a one-dimensional probability density function expressed as two error functions and one exponential term, providing a faster calculation than some methods. Pc is always provided assuming covariance is available and positive-definite, and it uses combined hard-body radius (HBR) based on values derived from several sources to provide a combined size as accurate as possible. Additionally, LeoLabs is currently working to implement the NASA CARA 3D Pc Hall approach for low relative velocity events, providing a tailored calculation technique appropriate to the particular dynamics of each encounter.

For HBR, a custom value is used by LeoLabs when (O/O) provided as-built specifications or reliable open-source data can be obtained (e.g., for a customer spacecraft or an upper stage rocket body with well-documented dimensions). When these values are not available, LeoLabs applies tailored estimates for HBR based on the object type, (e.g., 0.5m for debris fragments). LeoLabs also retains the ability to make size estimates based on radar cross section under certain conditions. The HBR provides the 2D integral limits used when calculating Pc. As the predicted miss distance for an event decreases, the HBR used for the Pc calculation will have an increasingly outsized effect. Pc scales with the HBR used, such that an accurate HBR value is important to ensure precise Pc for an event (i.e., not higher than expected for events with a small debris object, or lower than expected for an event with two large objects).

10. Collision Consequence and Debris Production Potentials (Included).

To calculate, using an appropriate model, an estimate of the number of trackable debris fragments that would be generated if a particular conjunction were to result in a collision.

Yes, this SSA safety service is available from LeoLabs today within the LeoRisk product. Trackable debris fragment estimates are made using LeoLabs' utilities, considering many parameters, including object type, relative impact velocity, and mass. Many conjunctions are hypervelocity (> 6 km/s) where very large amounts of debris can be created, dominated by the kinetic energy and mass involved. Some conjunctions are non-hypervelocity (< 6 km/s) where fewer debris may be created, dominated by the construction of the objects. However, significant momentum transfer can cause changes in orbits for large fragments. The initial conditions of a particular conjunction are provided by LeoLabs CDMs.

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11. Conjunction Object Solution Improvements with Additional Tracking (Included).

To obtain additional tracking on the satellites involved in conjunctions of interest (typically the secondary objects), improve these objects' predicted states at the conjunction time of closest approach (TCA), and calculate higher-fidelity risk assessment metrics with this improved information.

LeoLabs' LeoTrack product provides both automated tasking increases for high Pc events and an avenue for operators to obtain increased tasking on objects of interest. This increased tasking improves the likelihood of additional tracking data and thus provides higher-fidelity risk assessment metrics. The ability to provide increased tasking improves as our radar network grows while decreasing in necessity as objects receive more tracking by default. The ability for users to request increased tasking from LeoLabs surpasses that of the DoD which currently does not have a mechanism for operator feedback.

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12. Expected Tracking Determination (Included).

To generate a pass schedule and probabilities of detection for obtaining additional commercial tracking for conjunction-related objects, so that O/Os can infer the potential benefit of additional tracking and be able to schedule mitigation action decision points appropriately.

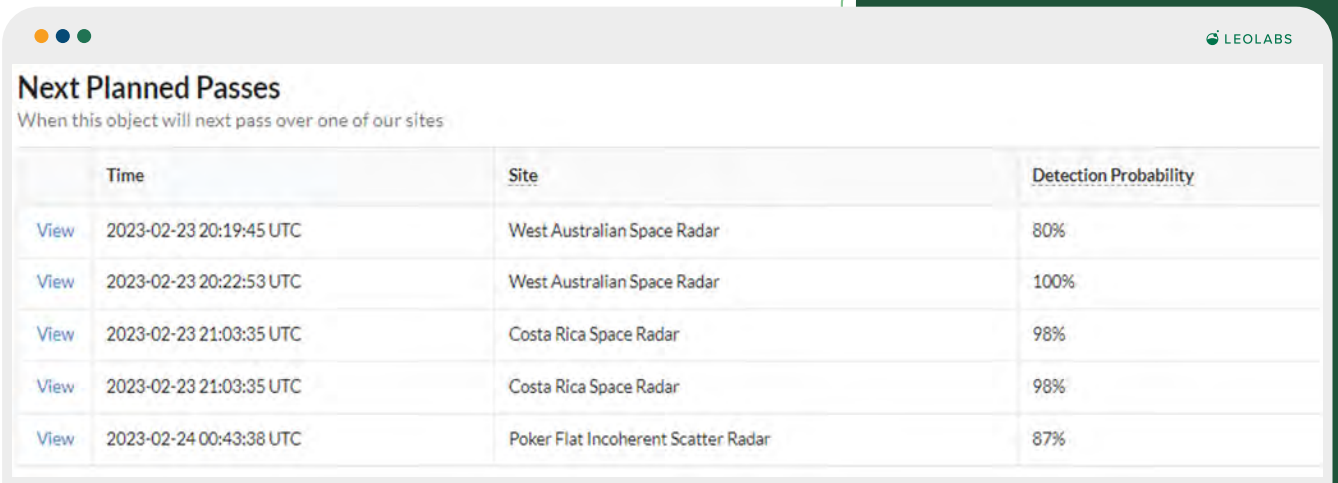

Figure 3 - The "Next Planned Passes" chart shows the time of the potential pass, the radar site, and the detection probability for the next five passes.

Planned pass information is currently offered for all products on the LeoLabs Vertex platform. The "Next Planned Passes" chart shows the time of the potential pass, the radar site, and the detection probability for the next five passes. The information is available for both objects involved in the conjunction. The Probability of Detection is based on several factors to include historical tracking information, object information (e.g., orbital altitude, inclination, size, etc.) and radar limitations. This detailed information allows operators to plan their maneuver commit points based on future tracking opportunities. The DoD does not currently offer a probability of detection assessment to the public.

13. Risk Assessment Time History Plots (Included).

To produce time-history plots of conjunction risk assessment parameters of interest to allow assessment of conjunction event phasing and stability.

LeoLabs' LeoSafe user interface provides several risk assessment time history plots. Time history plots include miss distance, probability of collision, TCA change, primary and secondary relative state and covariance change, and error ellipse comparison. Users can zoom in/out and select/deselect data sources for dynamic plots that can improve operator analysis of events.

LeoRisk further aggregates conjunction data across the entire catalog over years to provide depiction of time history of how clouds of fragments and derelict objects pose collision risk to operational satellites and between operational satellites. This permits an analysis of the effec-

tiveness of debris mitigation activities, collision avoidance maneuver results, and evolution of the catalog population.

Neither of these services are currently provided by the DoD. They would benefit spacecraft operators by enabling them to evaluate and take action during high-risk conjunction events.

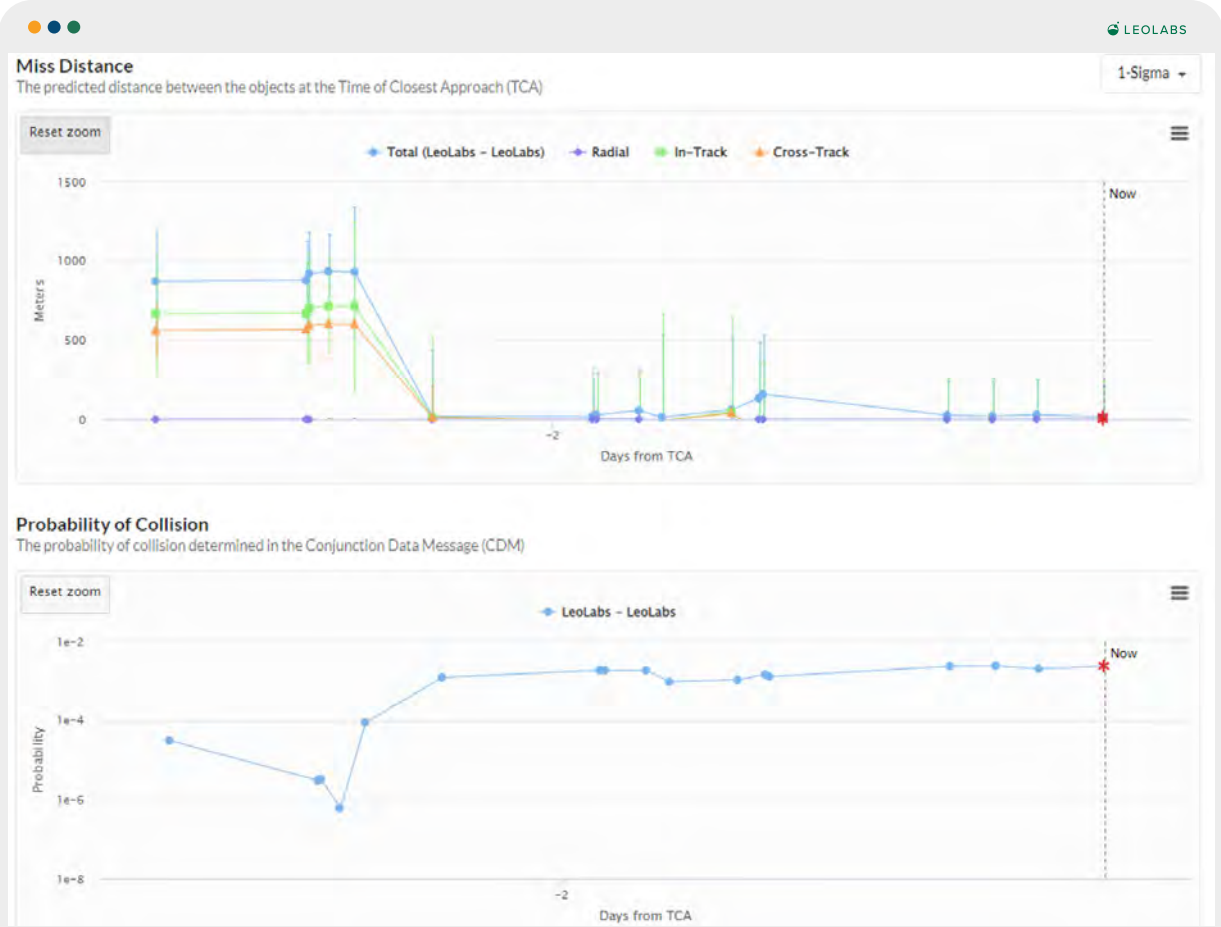

Figure 4 - Time history plots for miss distance and miss components, and probability of collision.

14. Space Weather Sensitivity (Included).

To provide warnings about space weather perturbative events and to assess the effects the perturbation-induced atmospheric density uncertainty will have on conjunction risk assessment parameters.

Our staff has extensive experience in satellite operations and they have analyzed numerous conjunctions for space weather sensitivity. In their experience, satellite maneuver plans are almost

never changed based on space weather sensitivity analyses. Therefore, LeoLabs recommends it not be included as part of the basic service. Space weather warnings can be flagged from existing NOAA atmospheric predictions. In fact, these are used by LeoLabs for state propagation. LeoLabs does not currently provide a tool for analyzing space weather perturbative events and their impact on conjunction risk assessment parameters. However, the flexibility and scalability of the LeoLabs platform enables the implementation of such tools. Further, by leveraging our in-house state propagation and Pc calculations, LeoLabs can create a trade space. One way to do this is by varying the ballistic coefficient of the two objects and repropagating/recalculating Pc to reflect a potential change in trajectory due to a space weather event. However, this is not a service currently provided by the DoD, and in our operational experience, has not improved the operator's situational awareness during an event and aided in decision-making because of the variability of the atmospheric impact of such events.

For commercial SSA service providers, does the current SSA capability offered by the DoD have any impacts on your current or future product offerings?

The current SSA capability offered by the DoD does not have any impacts on our current or future product offerings. LeoLabs was founded and has grown because the SSA capability offered by the DoD was not sufficient in supporting spacecraft owner/operators. LeoLabs has found that the market requires more automation, timeliness, and transparency than what the DoD currently offers to ensure safe and efficient operations in space.

However, if the TraCSS basic service described above was expanded to cover collision avoidance for smaller debris, that would negatively impact LeoLabs business. We're in business to add value to owner/operators by protecting them from small debris and that capability needs to be viewed as an Advanced TraCSS Service.

For commercial SSA service providers, do any of the basic SSA safety services identified for inclusion in TraCSS have any impacts or implications on your current or future product offerings? If so, which services proposed to be part of TraCSS would have an impact on your offerings and why?

Yes, primarily #1 (Satellite Attributes, Capabilities, Status, and Point of Contact) and #8 (Reentry Management and Assessement).

LeoLabs is developing a satellite attribute catalog as part of its immediate product roadmap. Current LeoLabs customers will be able to provide their spacecraft capabilities, dimensions,

and mass. For capabilities, users can expand beyond the standard "maneuverable or non-maneuverable." If "maneuverable", customers are able to define the maneuver capabilities (e.g., autonomous, thruster type (ion, chemical), differential drag, or slew). If a spacecraft is only able to slew, the operator will input the smallest and largest Hard Body Radius (HBR) values for their spacecraft. Additionally, users can outline any spacecraft limitations (if applicable) and provide their preferred method of contact. To promote transparency, there will be no option to make contact information private; therefore, all information provided will be available to all users. For rocket bodies and debris objects, size information will be pulled from LeoLabs' database of objects, which is based on known (open source) data and/or Radar Cross Section (RCS) calculations. This information is pertinent for space safety and is beyond what the DoD offers.

Currently, LeoLabs is also prototyping re-entry management and assessment tools as part of a new feature set within its LeoRisk product, engineered to service both breakup and re-entry events. As a requirement to be part of TraCSS, LeoLabs will prioritize development of a minimum viable product to show potential customers at the Department of Commerce and elsewhere to receive user feedback to incorporate into future product development.

With regards to #3: (Routine Collision Assessment (CA) Screening and Conjunction Data Message (CDM) Production), LeoLabs was founded to protect satellites from small debris (less than 10 centimeters in diameter). We have made major investments in infrastructure and software to make this possible. LeoLabs views tracking small debris and generating CDMs for small debris as an advanced service. If the TraCSS service were to expand to include small debris that would negatively impact our business.

Are there unique advantages to the government purchasing and redistributing certain commercial services rather than leaving these to the commercial marketplace?

The primary unique advantage that LeoLabs has identified is that it would create a standard level of safety expected of all satellite operators.