**Part 1: PROBLEM DEFINITION**

**Problem Being Solved.** Rendezvous Proximity Operations (RPO) is an enabling, yet cost prohibitive, technology. For decades we have relied on conservative methodologies rooted in heritage from a handful of consulting agencies. As such, we propose a low-cost RPO software and sensor suite, designed in an in-house 6 degree-of-freedom (6DoF) simulator. The industry is at the cusp of a change in mission architecture that rapid prototyping and deployment of an inexpensive RPO system could enable.

In the process of developing these algorithms, new mathematical and analytical tools will inevitably be developed that give the Air Force greater in-space capabilities. For example, current “state-of-the-art” approaches often include padding on uncertainty onto a vehicle in an open-loop fashion. However, the next generation of spacecraft require innovations in uncertainty analysis, control in contested environments, and navigation techniques.

Whether the application is on-orbit servicing or inspection of anomalous, uncooperative space vehicles, the guiding principle is to support the Air Force through timely and sustainable access to missions that require proximity operations; in other words, our goal is to take a step in the way we approach space.

**Product Summary.** As Maxar, we are in the unique position to offer an end-to-end solution for the Air Force, from consulting and software design of RPO to integration on (say) our Legion-class bus or robotic arms. That said, the product here is primarily the RPO software, designed to be modular and based off the specific spacecraft or mission requirements. The Air Force is not limited to our buses, but is instead buying into the capability; that includes algorithm, architectural, or analytical design.

In addition, we plan to offer a 6-DoF simulator that gives the Air Force the ability to rapidly prototype rendezvous missions. Mission design for RPO can take several years to realize, primarily because the industry lacks companies that produce spacecraft entirely in-house and can couple RPO software with preexisting “day-in-the-life” simulators. Typically, collaboration has to happen between a company that provides RPO and another company that provides the bus itself.

Finally, an intangible but equally important products are the mathematical tools and analytical techniques that Maxar has to develop to enable low-cost RPO. For example, the LIDAR is an expensive sensor that we could potentially retire for more cost-effective solutions. But as a result, we have to innovate on how we perform navigation on a spacecraft for proximity ops. These innovations ultimately serve to enhance our in-space assets.

**Part 2: RELEVANCE TO AFRL NEEDS**

**Problem Alignment.** Our primary developmental thrust directly addresses **Topic Area 1:** We enable game-changing improvements through the affordability of RPO software and sensor suite. The proposed work directly addresses improvements to techniques in guidance, navigation, control, and autonomy, with applications to on-orbit servicing, monitoring of uncooperative spacecraft, space debris mitigation, and more. Additionally, we see gains in support for space operations: reliable and responsive access to space, and ultimately the development of novel designs to enable the above while maintaining a value proposition.

Additionally, the Full-Scale simulation that has to be developed would also allow rapid response to potentially new mission concepts. This would mean reliable prototyping of in-space services and a means to inform future decisions. In essence, the Air Force would procure an affordable and quickly accessible test-bed that we could use to address other applications of RPO. Thus, we also address **Topic Area 2**.

**Problem Magnitude.** Although space rendezvous has existed since the 1970’s and the commercial resupply programs have seen several successful RPO mission, the prohibitive cost and developmental time has always been the main shortcoming. Perhaps even fewer commercial agencies offer an entirely in-house developed spacecraft, from bus and payload integration to software development. To truly enable affordable access to RPO would allow the air force to respond to several types of missions with substantially lower cost burden. It changes the way they approach the mission. Regardless of the application, giving affordable access to our airmen and future space operators enables execution of agile missions and opportunities to respond to growing space-based threats.

**Operational Impact.** There are several Air Force assets that airmen currently depend on or have national security interest over. From communication satellites to anomalous resident space objects. Yet, the cost of rendezvous is just another reason why not designing a satellite to be serviced or simply launching a new satellite might ultimately be cheaper. In other words, the airmen today require time-critical responses to their own missions that a commercially oriented company could provide. There is a shift in the current space-race paradigm that RPO becomes an enabling technology for.

**Scale.** An argument can be made that if our architecture was realized, then the cost of a RPO (which could range in the millions per vehicle), could be realized for hundreds of thousands, potentially an order of magnitude of cost savings. These architectural changes will drastically affect the way our airmen approach their missions. We see improved control of the space domain, how we launch future assets will change, and what we consider as “possible” in space will shift.

As an example of an operational scenario, airmen may need to respond to a foreign, uncooperative spacecraft through inspection. Rapid fielding via a full-scale simulation (such as the one we propose) may be a key capability for the Air Force. A fully mature product is synonymous with repeatability and reusability, to the point where the air force can perform RPO to the point where it becomes unremarkable.

**Degree of Innovation.** Due to the natural conservatism of the aerospace industry, agencies that have heritage have become the de facto standard when it comes to a particularly desired asset, whether it is delivery of a GEO bus or designing RPO software. The difference here is cost, the significantly shorter time-scale during RPO design, the sensor suite, the way we leverage analytical tools for a timely response, and the potential for an end-to-end solution for the Air Force.

**Part 3: SCIENTIFIC AND ENGINEERING VIABILITY**

**Scientific Feasibility.** Rendezvous Proximity Operations have been around since the 1970’s. However, Maxar’s goal here is to provide a commercial mindset and an economically viable access to these types of missions. The main degree of innovation comes from leveraging a different sensor suite over ones that we clinically choose (e.g the LIDAR) and the analysis that comes with that navigation system. That said, advances in sensors such as vision-based navigation, has allowed autonomous cars to distinguish and perform corrective action in often much lower time frames. Because LIDAR essentially builds a particle map that the vehicle uses for SLAM (simultaneous localization and mapping). The statistical foundations of vision based estimation versus infrared have mathematical parallels. This perception-action-loop has seen much success in terrestrial applications and the goal is to enable that on a spacecraft.

Studies by NASA has concluded that the technology exists today to perform Autonomous Rendezvous and Capture (AR&C). A sensor package can be assembled to perform AR&C and, in the extreme case, used to perform rendezvous on a tumbling client. Lastly, how we develop maneuvers (guidance) or the way we realize actuator commands (controls) are based upon stable and heritage techniques. For example, the Clohessy-Wiltshire equations or Linear Quadratic Gaussian control.

**Enabling Technologies.** Retiring sensors such as the LIDAR does introduce added risk. However, as previously mentioned, heritage mathematical techniques and efficient algorithms we use every day for modern robotics can mitigate these potential issues. We will also consider approaching the Charles Starke Draper Laboratory as a consulting agency as we design our software suite. Although seemingly a Catch-22, Draper Laboratories is a non-for-profit agency that may work with us as a part of a funded study.

**Alternative Technical Approaches.** The quickest alternative is to approach an agency that has heritage experience, such as Draper. Moreover, a perfectly viable solution is to continuing paying the higher price and perhaps have yourself a “guarantee” in some sense. However, our objective is to substantially lower cost and schedule without compromising the quality to the extent that deters the Air Force. Leveraging our current platform with Restore-L and full-scale simulation designed for WorldView Legion ensures this.

**Technical Personnel.** We have both the GN&C Systems Engineering Team, the Dynamics and Controls Analysis, and the Flight software team to provide the technical capability required to develop this product. Moreover, we have teams from Radiant Solution or Maxar – Colorado that we could consult for knowledge in robotic perception. From experts in rigid and flexibile body dynamics to navigation algorithms, the technical staff at Maxar has the required background. However, even if Draper is unable to participate, several other consulting agencies exist, include personnel from academia.

**Part 4: PROJECT PLAN**

**Project schedule.** To properly scope this work, we’re primarily focused on the software development and simulation of RPO for the first phase of this work. A proposed timeline of one years is shown below:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Milestone | Q1 2021 | Q2 2021 | Q3 2021 | Q4 2021 |
| **Systems&Requirements Review** | |  |  | | --- | --- | |  |  | |  |  |  |
| **Sensor Suite Study** | |  |  | | --- | --- | |  |  | |  |  |  |
| **6DoF Simulator (disturbance environments, appropriate dynamics models, etc.)** |  |  |  |  |
| **Guidance Algorithms** |  |  |  |  |
| **Navigation Algorithms** |  |  |  |  |
| **Control Algorithms** |  | |  |  | | --- | --- | |  |  | |  |  |
| **Design Review** |  |  |  |  |

**ROM Cost Estimate.** Man-hours make up the majority of this work for the proposed study.

Estimate for a 1 year, software-only development (including sensor suite study):

5 Analyst x 261 working days x 20 hrs = 26,100 man hours or approximately ***$1.5 million – $2 million requested***

**Hypothesis, Testing, Measurement.** This project will demonstrate the ability to perform RPO via software developed by Maxar and for a competitive cost. Design reviews will be held that demonstrates, through simulations, the ability to meet mission requirements for the three major subsystems: Guidance and Targeting, Navigation, and Control.

**Appropriateness of Measurement.**

* Currently working on coming up with a list of key KPI’s
* **Main Challenges Product addresses**: Cost of RPO is too high, deployment of RPO software takes too long, sensor package or analytical techniques are too conservative
* **Measurable Gains:** Cost and time to enable RPO, time spent analyzing vs implementing, design reviews, validation of truth models and simulations through ground testing

**Part 5: VALUE / COST**

**Benefit to the Air Force.** The Air Force will essentially gain access to a cost effective method to perform rendezvous or proximity operations. For that same cost, we demonstrate the capability to rapidly respond to missions with full-scale , 6DoF simulations, and perform new analytical techniques that enable greater spacecraft autonomy, precision, and maneuverability.

**Funding Availability.** We believe the current proposal to be cost efficient. However, if external funding is required, there is currently a parallel with internal IRAD opportunities to contribute to this development.