FINAL REPORT OF THE OSAM-1 INDEPENDENT REVIEW BOARD

29 FEBRUARY 2024

Background

The OSAM-1 project is a Technology Demonstration Mission within the Space Technology Mission Directorate (STMD), which is managed by Technology Development Missions Program Office at the Marshall Spaceflight Center (MSFC). The project was initiated in 2015 as RESTORE-L (Robotic Servicing Demonstration Mission).

Building on a history of demonstrations to lead to a capability to upgrade and maintain assets in space, NASA's OSAM-1 project seeks to rendezvous with, refuel, and relocate a United States Government-owned satellite, Landsat 7, to demonstrate the feasibility of on-orbit refueling, satellite relocation, and life extension. The project also intends to demonstrate assembly of a communications antenna using a robotic arm. The project has incurred substantial cost increases and schedule delays since its inception.

In late 2023, the Space Technology Mission Directorate (STMD) requested an independent Continuation Review to assess project programmatic and technical performance as well as return on investment (ROI) to NASA of technology gains from the OSAM-1 mission, to include benchmarking of the current government and commercial satellite servicing market environment. The independent review board (IRB) was directed to offer its own assessment of project cost and schedule 'to go.' The IRB's **Terms of Reference (TOR)** are appended (**Appendix A**).

Executive Summary

During the period November 2023 – February 2024, the IRB conducted a series of interviews with both OSAM-1 project personnel and defense and commercial industry representatives (e.g., Space Force, US Space Command, Maxar, Northrop Grumman, OrbitFab, Astroscale). The board subsequently performed both a data review and cost/schedule analysis and has produced a set of observations, findings, and consensus recommendations.

The board's evaluation of the project's cost-to-go is in-family (albeit higher) than both the project's own forecast and the assessment of the project's Standing Review Board (SRB). The IRB conducted an analysis – based on existing project cost assessment tools – and concluded that OSAM-1's estimate at complete is $2,380M. Note that OSAM-1 had spent approximately $1,400M by November 2023 – suggesting a cost-to-go of **$980M**.

Paired with the cost-to-go evaluation, the IRB found that the 'most likely' (70% confidence) Launch Readiness Date will occur later than both the project and SRB currently forecast: **March 2028**. The IRB included additional risks and risk factors to arrive at this finding.

The IRB also assessed the status of various project elements and/or systems, including the OSAM-1 spacecraft, its two-arm Servicing Payload (SP), SPIDER (Space Infrastructure Dexterous Robot, a secondary payload intended to demonstrate on-orbit RF antenna assembly), its rendezvous and proximity operations (RPO) sensors and algorithms, mission operations, integration and test, systems engineering, mission assurance, project management, and launch. **The IRB assesses that there is substantial remaining technical, cost, and schedule risk in the project** – particularly in the project's efforts to complete its Kodiak LiDAR, SP build, spacecraft flight software, and translation of test procedures owing to the project's decision to use its own ground system environment rather than that of its prime contractor.[1] NASA's decision to delay acquisition of a launch vehicle for OSAM-1 is an additional source of schedule risk which must be addressed as soon as possible should the project go forward.

The IRB interviewed numerous civil, defense, and private sector stakeholders to assess the 'return on investment' or downstream applicability of OSAM-1 to future missions and architectures. The board's consensus evaluation is that the U.S. space industry, particularly from a national security space perspective, **has evolved beyond OSAM-1's primary objective of legacy space vehicle refueling** – stakeholders generally expect future national security spacecraft to be refueled via prepared interfaces.

The value to future NASA, civil and commercial spacecraft being refueled by legacy fill and drain valves was unclear. The IRB does believe that dexterous robotic servicing will be an important national capability in the future, and that successful completion of the OSAM-1 mission would enable NASA to lay claim to demonstrating some of its key aspects. However, the community's widely held understanding is that the OSAM-1 mission is overly focused on delivering propellant to an aged LandSat-7 spacecraft. **This mission goal is not perceived to be of value, particularly when paired with the high cost-to-go and pace at which the program is executing.**

Based on the board's findings, as well as its subsequent deliberations, the **IRB recommends the OSAM-1 project be discontinued**. This effort, originally forecast to cost no more than $750M and launch by 2020, is seven to eight years behind schedule and $1,500M over budget – and it is demonstrating satellite servicing capabilities with few strong links to future civil, defense, or commercial plans.

Project Execution Overview

The IRB interviewed project personnel and affiliated individuals over the course of its investigation, assembling a number of observations, findings, and recommendations regarding OSAM-1 project execution. Findings and recommendations were assembled through consensus during board deliberations. Those identified for special emphasis are discussed below.

Principal Observations

[1] ASIST/FEDS (Advanced Spacecraft Integration and System Test (ASIST)/Front End Data System (FEDS)), Goddard Space Flight Center's common telemetry and command system intended for use throughout all phases of a project's lifecycle, from inception through on-orbit operations. See https://sed.gsfc.nasa.gov/etd/583/tech/asist.

1. **Launch**. The project's previous launch vehicle procurement **was allowed to expire**. A new one will have to be initiated, but had not been approved as of the IRB's report publication and is unlikely to happen until after a successful KDP-D. The project reported that the minimum time (i.e., granting authority to proceed to launch readiness data or LRD) to obtain a booster is 18 months, although after further inquiry, the board believes that a 24-month schedule appears more likely.[2] The decision to re-start a launch vehicle acquisition resides at the Associate Administrator level. Multiple interviewees commented that the price of the launch vehicle would be adversely affected by specific requirements levied by NASA.

2. **Risk Identification, Evaluation, Burndown**. Project leadership has bucketed numerous technical, schedule, and cost risks in the "1 x 5" (very low likelihood of realization, loss of mission if realized) category, making prioritization for mitigation difficult. The project's Standing Review Board made note of this issue during the November 2023 System Integration Review.

3. **Programming and Budgeting.** Projected cost of OSAM-1 has risen from **$1,780M** in 2020 (launch-ready by **September 2025**) to **$2,280M (+$500M)** in November 2023 (launch-ready by **July 2027**). Project personnel indicate they retain zero margin to these latest estimates.

4. **General Program Management**. OSAM-1 organic (GSFC) head count in November was at or near 600 full time equivalent personnel (80% contract support and 20% civil servant). Program leadership notes it is rapidly working to reduce this figure substantially – it incurs a burn rate of $13-14M/month (annual burn of **$156-168M**).

   Multiple interviewees remarked on the perceived mismatch between mission assurance class designation and technology demonstration objectives, Goddard's alleged "Class B" culture, and the resulting team confusion and dissonance this has generated.

5. **Integration and Test (I&T).** The IRB was impressed by project personnel's comprehensive planning in support of OSAM-1 I&T. The board repeatedly heard that translating MAXAR test procedures into Goddard's ground environment will be the most significant driver to schedule. I&T will be conducted at numerous physical locations on a number of testbeds (e.g, AutoCapture Testbed, FlatSat Testbed, LiDAR vacuum testing at a Marshall Space Flight Center facility).

6. **Mission Operations**. The availability of Tracking and Data Relay Satellite (TDRS) to support OSAM-1's checkout and on-orbit operations is a potential problem. The vehicle's forecast launch (now April 2026) a potential problem – only TDRS #8, #10, #11, #12, and #13 remain and their operational state in the timeframe of interest is uncertain. The program is undertaking mitigation via ACCESS,[3] since OSAM-1 requires near-continuous Ka-band access to execute successfully. Operations are conducted in multiple, collaborating ops centers.

[2] OSAM-1 was designed for compatibility with both SpaceX Falcon 9 and United Launch Alliance Vulcan launch vehicles.
[3] https://esc.gsfc.nasa.gov/projects/ACCESS

7. **Spacecraft**. To obtain a spacecraft, project personnel allocated $131M to Maxar Space of Palo Alto, California, on a firm fixed price effort – now substantially overrun. OSAM-1's satellite bus is a modified SSL 1300 GEO bus intended for specialized servicing operations in Low Earth Orbit (LEO). The SSL 1300 bus is a design with substantial flight heritage, its first instantiations having flown in the late 1980s and early 1990s. The SSL 1300 was selected by the project partially because of this heritage; it was hoped that cost savings could be reaped by opting for a commercial bus. Multiple interviewees highlighted the 1300 design as optimized for use in geosynchronous earth orbit, not low earth orbit (where the OSAM-1 mission will be conducted); this has led to hardware and software design modifications which has impacted cost and schedule.

   The program approved an early delivery of the bus to Goddard prior to completion of their Reference Performance Test (RPT) – the vehicle is therefore "shipped" but not officially "delivered" (i.e., performance validated). Due to the overrun it has sustained, Maxar is triaging additional work effort requested by Goddard; at the time of this writing, project personnel were negotiating an IDIQ (Indefinite Delivery, Indefinite Quantity) contract with options for task orders to prioritize specific efforts for completion.

   Goddard is lacking key test scripts for upcoming vehicle tests – scripts which must be translated from Maxar's ITAC to Goddard's ASIST/FEDS environment. The project made the decision to fly with ASIST/FEDS in 2018). Flight software, which will arrive in multiple 'drops,' has yet to be delivered – the first 'drop' is expected no earlier than March 2024.

8. **SPIDER**.[4] SPIDER, a secondary payload and late add to the mission, is a $146M effort to place MAXAR's Dragonfly Tipping Point RF antenna on-orbit assembly experiment on the OSAM-1 bus. SPIDER's robotic arms are slated to arrive extremely late in the integration and test flow (i.e., post-thermal vacuum testing, or TVAC). In multiple interviews, program personnel expressed ambivalence about SPIDER's value to NASA.

9. **Kodiak LiDAR**. Goddard's Kodiak LiDAR was a late add to the OSAM-1 mission[5] – an in-house build incorporated in response to stated need for multiple rendezvous and proximity operations sensor phenomenologies, and, according to several team members, to mitigate the "lost in space" issue encountered during DARPA's 2007 Orbital Express mission.[6] Team strength at the time of the board's interview cycle was approximately 50 personnel. Approximately 11 months behind schedule as of November 2023; intended to deliver a primary and backup LiDAR (for range determination and pose estimation) by **June/July 2024**. Commercial LiDAR from Jena

[4] Space Infrastructure Dexterous Robot, https://www.nasa.gov/news-release/nasa-funds-demonstration-of-assembly-and-manufacturing-in-space/

[5] KODIAK replaced a Ball Aerospace flash LiDAR, which was cancelled.

[6] On May 12, 2007, the Orbital Express mission experienced an anomaly which resulted in a large, unplanned separation (up to and perhaps slightly greater than 6 km) between the servicing satellite ASTRO and client satellite NextSat. The servicer's relative navigation filter became corrupted and the mission operations team was forced to rely on Haystack Observatory observations to determine the relative location(s) of the two vehicles. Subsequently, DARPA recommended ultra-wide-field-of-view sensor capabilities (i.e., 4-pi steradian capable radar) as a means to mitigate this problem on future servicing missions.

Optronik in process for award by 1 March 2024, but delivery will require 17+ months (July 2025 or later). This late delivery poses problems for integration (most of the spacecraft and its subsystems will have undergone essentially all functional and environmental testing efforts by the time the Jena LiDAR arrives).[7]

10. **Servicing Payload (SP).** The SP is a Goddard's in-house effort, comprised of robotic arms, sensors, rendezvous and proximity operations algorithms, and end effectors (i.e., tools) designed to expose Landsat 7 propellant fill and drain valves, refuel the spacecraft, and install additional hardware to facilitate/demonstrate ease of future refueling. Six of 16 subsystems had been delivered for integration as of November 2023. The project's ternary critical path ran through its SP robotic arm assembly (RAA).

Principal Findings

Cost and Schedule 'To Go.' The IRB expects the project to face additional challenges as it proceeds into Integration and Test, which are likely to add to the current cost estimate of $2.25B[8] and launch ready date (LRD) of July 2027. The IRB added four discrete risks, a "risk factor" for thermal vacuum testing, adjusted time-dependent cost uncertainties to align with current program Earned Value Management (EVM) performance, and has concluded that the program as constituted will likely not be ready for launch until **March 2028** – at a total cost of **$2.38B**. This finding is in family with program and Standing Review Board estimates. Additional information regarding the IRB's cost and schedule analysis can be found in **Appendix B**.

2. **Workforce.** OSAM-1 is operating at very high spending rates driven by a large in-house 'standing army' of contract and civil servant staff and – if it were to be required to complete inside its 2020 target cost – would have to lower that spend rate to ~$8M/month through February 2026.[9] This would necessitate an immediate reduction to 400 heads (assuming a February 2026 LRD). This would have to fall even further, to 225 heads, if a delay through 2028 is unavoidable.

3. **Launch**. The program has set aside substantial monies (slightly more than $100M) to cover the cost of a NASA-procured launch vehicle – funds which could be used to re-establish **program margin** were the program to be continued. This would require the sole-source commercial-style acquisition of a Falcon 9 booster, which should be obtainable for substantially less than $100M. While other options exist (e.g., contribution of a 'free' launch vehicle from the Space Force via such venues as DOD's Space Experiments Review Board (SERB) or Space Prototyping Review Board (SPRB)), these will likely cause NASA to lose control of its project schedule – with implications for incurring downstream 'standing army' costs.

[7] The project has attempted to obtain an existing LiDAR from other programs contracting with Jena, to no avail. High-level headquarters advocacy does not appear to have been explicitly solicited.
[8] Cumulative program spend was approximately $1,400M (November 2023).
[9] With 36 months remaining, mean monthly spend will have to be maintained below $8.5M/month to deliver inside the 2020 forecast of $1.78B (this assumes a $50M set-aside for launch vehicle procurement and $20M for Maxar IDIQ tasks). If the program is permitted to stretch to March 2028, mean monthly spend will have to maintained at a significantly lower level (~$4.5M/month) to achieve its 2020 target cost.

4. **Prime contractor performance.** While the prime contractor, Maxar, has suffered substantial delays and has incurred a significant overrun on its spacecraft contract, the IRB was unable to draw a clear cause-and-effect relationship between that delay and overrun and the roughly **$1.5-billion increase** in the OSAM-1 estimate-at-complete (and **seven- to eight-year delay**) since inception. If NASA decides to move forward with the project, the proposed IDIQ contract should be augmented **as necessary** to permit the prime to complete its work.

5. **Kodiak**. In the event of continuation, the program's **Kodiak LiDAR** effort should be deemed non-essential and sidelined if it is unable to meet its schedule objectives. All RPO operations envisioned by the project should be capable of being conducted by a combination of visible and infrared cameras (with the possible need for a range-finding capability, which does not demand full LiDAR functionality).

6. **SPIDER**. While considered a secondary experiment by the Goddard team, the IRB concluded that SPIDER's assembly demonstration is at least as useful as (if not more useful than) an unprepared servicing test. As such, the board did not find that a descope of SPIDER would be warranted in the event of program continuation. However, SPIDER remains a significant cost driver and programmatic 'guardrails' need to be put in place to ensure it does not cause additional delays and cost growth.

Recommendations

In light of the IRB's findings – both regarding project execution and return on investment (detailed in the next section) – the board is unable to recommend project continuation. Both cost- and schedule-to-go are substantial and the risk for further schedule decay and cost increases remains high. The board nevertheless recognizes that NASA may opt to continue the project despite these concerns; as a result, the IRB decided to offer 'continuation' recommendations (i.e., proposed conditions for proceeding). The board recognizes that some of the conditions may be perceived as onerous – but nevertheless believes that imposition of these conditions is essential to successful project completion.[10]

1. **The IRB recommends the OSAM-1 mission not continue.**

2. **The board recommends neither revisions nor rescoping of the OSAM-1 mission.** Redefining the mission to enhance its relevance with respect to future civil, defense, and commercial applications **will be difficult if not impossible to achieve inside current budget and schedule constraints.**

3. **The board recommends NASA proceed with the project only if the following conditions can be met**:

[10] The IRB notes that these continuation recommendations are based primarily on an assessment of the project's execution status, go-forward plans, and cost-/schedule-to-go. ROI considerations will also impact NASA's decision to continue or discontinue OSAM-1.

(a) OSAM-1 project leadership **conduct a two-week stand-down** to immediately downsize organic Goddard operations to no more than **200** personnel (FTEs);[11]
(b) **Accept the spacecraft bus "as is" and proceed with integration and test**; approve waivers as necessary to allow this to happen;
(c) **Remove the Kodiak LiDAR from the critical path.** Stand up a tiger team (Goddard and independent experts) to modify OSAM-1's existing rendezvous and proximity operations (RPO) algorithms to support machine vision-only "lunge" and docking;
(d) **Remove the SPIDER payload from the critical path.** Set no-later-than (NLT) target dates for delivery, installation, and test campaign completion. If the dates are not met, fly the SPIDER demonstration as a mass simulator (i.e., no functionality). Preparations to allow safe flight and operations with a "dummy" SPIDER must be performed.
(e) **Create urgency by establishing a "date certain" for OSAM-1 launch readiness** – the IRB recommends NLT **1 February 2026**. The board recommends NASA obtain necessary approvals to initiate launch contracting tasks immediately. The focus would be on obtaining a launcher commercially, demanding no special accommodations to NASA safety requirements.

Return on investment (ROI) Overview

The satellite industry, particularly from a national security space perspective, has moved past the prime OSAM-1 objective of legacy space vehicle refueling, preparing future national security spacecraft to be refueled via prepared interfaces. The value to future NASA, civil and commercial spacecraft being refueled by legacy fill and drain valves is also not clear. It is clear that the capability of advanced dexterous robotic servicing is widely believed to be understood to be an important national capability in the future, and one that OSAM-1 could demonstrate. However, the widely held understanding is that the OSAM-1 mission is focused on delivering fuel to an aged LandSat-7 spacecraft, and that this particular mission objective is not perceived to be of value, particularly in light of the project's high cost and delayed pacing.

Review of OSAM-1 Level 1 Requirements

As presented at the OSAM-1 SIR at NASA GSFC in November 2023, the Level 1 Requirements for OSAM-1 are:

1. **Rendezvous –** rendezvous with a spacecraft not designed for servicing in low Earth orbit to within 40 meters
2. **Inspection -** inspect a spacecraft not designed for servicing in low Earth orbit by detecting 1 cm features from a distance of at least 80 meters
3. **Autonomously Capture -** autonomously capture a spacecraft not designed for servicing in Low Earth Orbit (LEO)
4. **Telerobotic Servicing** - perform tele-operated robotic servicing tasks on a captured spacecraft in low Earth orbit allowing refueling of that spacecraft
5. **Refueling -** transfer at least 40 kilograms of hydrazine monopropellant to a captured spacecraft in low Earth orbit to enhance mission lifetime or assist in disposal

[11] The IRB consensus is that this number is **more than adequate**, based on its members' experiences with analogous projects conducted elsewhere.

6. **Relocation -** relocate a captured spacecraft by altering its orbit a minimum velocity change (delta-V) of 1 meter/second
7. **Release and Departure -** safely release and depart from a captured spacecraft in low Earth orbit without adversely affecting the client's ability to return to an operational state
8. ~~**Technology Infusion -** demonstrate technologies that can be used directly by Orion~~
9. **On-Orbit Assembly** –demonstrate on-orbit assembly of a 3m antenna with a surface error of less than 0.03 cm RMS
10. ~~**On-Orbit Manufacturing** –demonstrate on-orbit manufacturing of a 10m structural beam with stiffness greater than 1.25 N/m~~

Of these requirements, most have either already been demonstrated or will have been demonstrated by the time OSAM-1 launches.

Arguably, both **Rendezvous** (#1) and **Inspection** (#2) requirements were successful met by DARPA's Orbital Express mission in 2007 and will have been executed in GEO pending successful launch and execution of the DARPA/Northrop Grumman Robotic Servicing of Geosynchronous Satellites (RSGS)/Mission Robotic Vehicle (MRV) mission, slated to launch in 2025.[12] Note that RSGS and MRV are actually the same mission, referred to by two different commonly used names.

Requirements for **Autonomously Capture** (#3), **Relocation** (#6), and **Release/Departure** (#7) will have also been completed by RSGS, planned to launch at least a year ahead of OSAM-1, albeit in GEO instead of in LEO.

Telerobotic Servicing (#4) is a fully unique OSAM-1 requirement, and a successful OSAM-1 would be anticipated to be the first mission to execute this capability of refueling an unprepared client spacecraft.

Refueling (#5), as written, was partially demonstrated by DARPA's Orbital Express. Fuel transfer to an unprepared client makes it unique, but directly associated with Requirement #4 above.

On-Orbit Assembly (#9) is unique to OSAM-1 and would demonstrate a new national capability. The IRB observed that this capability is being treated as a lower priority Level 1 requirement by NASA Goddard and is at some programmatic risk for deletion.

Of the two primary areas of OSAM-1 unique requirements, the IRB has not been able to validate that there is any interest in legacy space vehicle refueling in the U.S. space community but has seen some interest in on-orbit assembly. On-orbit assembly of a 3-meter reflector is clearly of commercial interest to Maxar and is expected that it would be of ongoing interest to civil space exploration missions, such as for lunar or planetary exploration where both mass and volume savings could be enabled by assembling antenna's larger than could be stowed or with better surface properties than could be unfurled.

[12] https://spacenews.com/darpas-robot-could-start-servicing-satellites-in-2025/

NASA Robotic Refueling Mission (RRM) Activities

NASA demonstrated tools, technologies, and techniques to robotically refuel and repair satellites in space on-board the International Space Station circa 2012-2015. The activity utilized the station's twin-armed Dextre robot arm. Dextre picked up RRM tools and practiced tasks on RRM's components and boards. Activities include cutting and peeling back protective thermal blankets, unscrewing caps, accessing valves, and transferring fluid.

Applicability of OSAM-1 developed technologies to NASA Missions

The Office of Science and Technology Policy released a National strategy for In-space Servicing, Assembly, and Manufacturing (ISAM)[13] in April 2022. The six goals stated in the report are: (1) advancing ISAM research and development; (2) prioritizing the expansion of scalable infrastructure; (3) accelerating the emerging ISAM commercial industry; (4) promoting international collaboration and cooperation to achieve ISAM goals; (5) prioritizing environmental sustainability as we move forward with ISAM capabilities; and (6) inspiring a diverse future workforce as a potential outcome of ISAM innovation.

The report states further, "The USG recognizes the commercial sector's capability, capacity, competency, and capitalization for rapid innovation. The sector seeks to expand and accelerate the development and delivery of ISAM capabilities and services in this growing market. The United States considers the development of a strong ISAM commercial base important to U.S. goals in space as described in the U.S. Space Priorities Framework."

Analysis of the NASA on-orbit assembly, servicing and manufacturing roadmaps as presented to the National Academies Committee on NASA Mission Critical Workforce, Infrastructure on December 1, 2023, and Technology and presentations made by NASA STMD at the NASA SpaceTech Event on August 17, 2023 suggest that there is broad applicability in refueling, servicing and assembly capabilities but there does not appear to be a focused capability roadmap timeline of when activities should be demonstrated to be infused into NASA missions and the broader servicing industry. The IRB did not find dependency by those we interviewed in NOAA, Space Force, SPACECOM, NASA's Science Mission Directorate, and NASA's Exploration Mission Directorate. We did not find specific needs and technology gaps identified with proposed plans to reduce risk and fill the identified gaps.

Typically for unknown capabilities that are needed a decade in the future, technology investments would be in the NASA Technology Readiness Level (TRL) 1-6 stage with a focus on developing needed technology in the laboratory and or ground. High-investment on-orbit demonstrations are reserved for those technologies ready to be infused into missions and operations. TDM activities should have an infusion plan for NASA missions and/or the industrial base.

NASA may want to consider a roadmap construct along the following construct:

- Focus on development and infusion of prepared interfaces into upcoming missions and spacecraft;

[13] https://www.whitehouse.gov/wp-content/uploads/2022/04/04-2022-ISAM-National-Strategy-Final.pdf

- Develop and infuse into industry widely applicable and affordable Rendezvous and Proximity Operations (RPO) capabilities (sensors and algorithms);

- Demonstrate on-orbit fuel transfer and on-orbit fuel storage capabilities and infuse into industry;

- Develop robust and affordable dexterous robotic operations through ground test facilities and potentially on-board the ISS;

- Demonstrate on-orbit dexterous robotic operations using low-cost platforms such as small spacecraft (ESPA-class or smaller);

- Capitalize on capabilities demonstrated by the RSGS mission; and

- Through the OSAM-1 consortium, develop standard robotic assembly and repair interfaces and procedures

    - Leverage existing and upcoming missions to demonstrate technology and capabilities in a focused and planned approach leading to a 4th generation epoch where assembly and manufacturing operations become routine.

Applicability of OSAM-1 developed technologies to National Security Space Missions

Discussions with key personnel in the national security space arena has made it clear that the Department of Defense (DOD) space components are very interested in 'Dynamic Space Operations (DSO)'[14] as a relatively new term-of-art for the ability of the DOD to be able to execute missions without restrictions imposed by limited commodities such as fuel. Allowing satellites to execute sustained maneuver and/or to be highly maneuverable has an opportunity to allow military advantage in space via competitive endurance but is not consistent with present day space architectures that do not include refueling or other types of replenishment available to them. The limitations imposed by fuel limitations (and other consumables) constrain space operations in a way that is undesirable to national security leadership. The solution space to achieve Dynamic Space Operations is still open, with refueling space systems a primary option, as is developing new space systems that are designed to be replaced at a rapid cadence, so that exhausting the capability of a space vehicle is not mission limiting, as it's replacement will be available to be quickly on station.

In response to this capability need, the IRB identified two investment activities by the Space Force Space Systems Command (SSC), the Air Force Research Laboratory (AFRL), the Space Enterprise Consortium, and the Defense Innovation Unit (DIU) that total approximately $75M. The first is Tetra-5, an effort that seeks to demonstrate on-orbit refueling of small satellites in geostationary orbit. Orion Space Systems is the Tetra-5 prime contractor and passed a critical design review in January

[14] https://www.spacecom.mil/Newsroom/News/Article-Display/Article/3370546/usspacecom-outlines-requirements-for-sustained-maneuver-dynamic-space-operations/

2024.[15] The second activity is a $25.5M contract to Astroscale U.S. for co-development of an on-orbit refueling vehicle.[16] The IRB also noted a call from a White House official, Diane Howard, National Space Council head of commercial space policy calling on further and significant investment in space mobility by the DOD and Space Force and other executive branch agencies in January 2024.[17]

The DOD Air Force Space Mobility and Logistics (SML) presentation by Maj Gen Stephen Purdy SQ Military Deputy on October 12, 2023 presents a space architecture that primarily depends on industry capabilities.[18] The IRB consistently found DoD officials expressing the opinion that industry offerings – rather than organically developed capability – would be sourced to meet DOD space servicing needs.

While the call for Dynamic Space Operations is at first look a beneficiary of OSAM-1 developed technologies, the timeline of OSAM-1 having deployed, demonstrated and be able to field an operational legacy refueling capability is not. The DOD interests are looking to jump past legacy space vehicle refueling and have space systems able to be refueling/replenished via much simpler built-in cooperative refueling interfaces on future systems that will be fielded ahead of the OSAM-1 team being able to deliver or perform technology transfer of their legacy refueling capability. The DOD is already funding and preparing initial on-orbit demonstrations of cooperative refueling interfaces. The value of legacy refueling to the DOD is presently assessed as minimal and decreasing.

The IRB was unable to identify any DOD stakeholder interested in the OSAM-1 antenna assembly mission capability, and the board surmises that this is likely because antenna assembly does not directly benefit Dynamic Space Operations and is viewed as being a capability that will take longer before it's in widespread use than the deployment of cooperative space vehicle refueling. DOD personnel interviewed stated that antenna assembly was much more likely applicable to civil exploration missions (such as on the lunar surface) than to national security space missions.

While refueling is not the only on-orbit servicing that is of interest to the DOD, it was also clear amongst the national security personnel interviewed that the DOD's interest on OSAM/ISAM technologies is much more in geostationary orbit (GEO) than in low-earth orbit (LEO). Other servicing capabilities that would be of interest to the DOD are already planned to be deployed by the RSGS/MRV mission and other commercial capabilities that are moving to demonstration presently.

DOD personnel interviewed did express concerns about the implications to the broader U.S. space industrial base if OSAM-1 were it to not continue. The development of new national capabilities

[15] https://www.satellitetoday.com/government-military/2024/01/03/orion-space-completes-cdr-for-tetra-5-on-orbit-demonstration-mission/
[16] https://spacenews.com/u-s-space-force-and-astroscale-to-co-invest-in-a-refueling-satellite/
[17] https://breakingdefense.com/2024/01/white-house-official-urges-more-real-pentagon-investment-in-space-mobility/
[18] Office of the Assistant Secretary of the Air Force for Space Acquisition and Integration (SAF/SQ) Space Mobility & Logistics (SML) in National Security Maj Gen Stephen Purdy SQ Military Deputy 12 Oct 23

related to OSM/ISAM is viewed to be fragile and is also viewed that it will not achieve the promises of a robust multi-orbit satellite servicing capability without both sustained government indicators to use commercially available services and investment in the maturation of those technologies.

In light of the expected cost and schedule to achieve on-orbit operations based on the current program plan, the board found that these same interviewees were consistent in their view that the high cost, relatively short operational life, the mission orbit in LEO and OSAM-1's own inability to be refueled did not make their industrial impact concerns override consideration of program termination or substantial redirection.

Industry Servicing Summary

The IRB interviews and study of industry participants found Rendezvous and Proximity Operations (RPO) capabilities exist within industry with a focus on geosynchronous orbit (GEO). Participants suggested that up to 20 companies exist that provide turnkey RPO capabilities on offer to service providers. In addition, the IRB found that unprepared servicing concepts rely on the attachment of a servicing module or spacecraft to provide the needed propulsion to extend the lifetime of the client. This appears to be a more cost-effective approach in contract to refueling the client spacecraft. The IRB findings are shown in **Table 1**.

Table 1. Industry Servicing Summary

Northrup Grumman Space Logistics Mission Extension Vehicle
Two ongoing commercial missions MEV-1 in 2020 and MEV-2 in 2021
Serviced geostationary orbit satellites
Utilizes a docking system allowing the MEV to extend the service of the client satellite
Roadmap Overview
• 1st epoch: Unprepared refueling MEV concept & MRV and extension pod concept
• 2nd epoch: Prepared interfaces for servicing (e.g., power, refueling)
• 3rd epoch: Persistent robotic capabilities in geosynchronous orbit (prepared interfaces)
• 4th epoch: In-orbit assembly & manufacturing
Lockheed Martin
Lockheed Martin In-space Upgrade Satellite System (Linuss) demonstrated close proximity and other technologies in geostationary orbit April 2023
Lockheed Martin has long-term plans to develop servicing vehicles for the commercial and government markets. "Our future vehicles will be able to dock with either a cooperative or uncooperative satellite and do any required upgrades or servicing." SpaceNews Sandra Erwin April 17, 2023
DARPA Robotic Servicing of Geosynchronous Satellites (RSGS)

Scheduled to launch in 2025 with a 10-year lifetime, two arms on a NG spacecraft will support NG Space Logistics system installing mission extension pods onto client spacecraft
• Utilizes attachment to the client spacecraft engine aperture (TBC)
Astroscale
End-of-Life Services demonstration (ELSA-d) successfully completed controlled close-approach rendezvous operations May 2022
Space Systems Command funding for Astroscale Prototype Servicer-Refueling underway with delivery in 2026
Blue Origin
Developing a 'Blue Ring' transfer vehicle that could also serve as a fuel depot and possibly possess robotic arms

Prepared Refueling

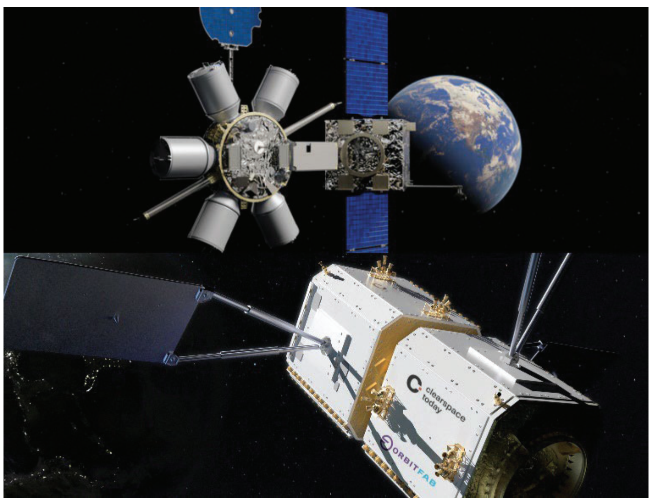


Figure 1. Northrop Grumman Geosynchronous Auxiliary Support Tanker, or GAS-T (https://www.airandspaceforces.com/refueling-satellites-space-force-choices/)

The United States Space Force (USSF) has funded at least two concepts for prepared fluid transfer interfaces. The Rapid Attachable Fluid Transfer Interface (RAFTI) concept is provided by OrbitFab and the Passive Refueling Module is provided by Northrop Grumman. Development of both interfaces are funded in the Tetra-5 program run by the Space Enterprise Consortium.[19]

OSAM-1 In-space Robotic Assembly

As show in Figure 3, OSAM-1 plans to demonstrate the assembly of a 3m reflector. The IRB did find general interest in the SPIDER demonstration of in-space assembly capabilities. In particular, Maxar provided a description of the benefits of demonstrated assembly on-orbit[20]. They suggested the demonstrated assembly would lead to lower cost and risk solutions for both the Commercial Low earth orbit Destinations (CLD) and Artemis missions, reduce risk for hi-strength/hi-torque actuators, scalable 1-g and 0-g arms, and direct benefit to Maxar's support for NASA's Lightbender program. Lightbender is a low-TRL NASA Innovative Advanced Concepts (NIAC) funded effort by the Space Technology Mission Directorate[21]. The IRB did note that the benefit of the capability is likely further in the future with further risk reduction to be performed before the capability is infused into a mission.

[19] https://spacenews.com/space-force-seeks-to-clear-up-confusion-over-selection-of-northrop-grummans-refueling-tech/
[20] Email from Mr. Chuck Hulme, OSAM-1/SPIDER Program Manager, Maxar to Dr. Fred Kennedy, OSAM-1 IRB Chair, on January 12, 2024 (see **Appendix D**).
[21] https://www.nasa.gov/general/light-bender/

OSAM-1 Technology License Overview

The IRB found three technologies listed in the OSAM-1 technology transfer database: Kodiak Scanning Lidar, a gripper tool, and the client berthing system.[22]

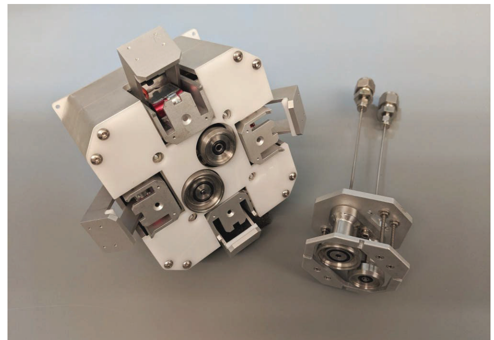


Figure 2. Orbit Fab's RAFTI (Rapidly Attachable Fluid Transfer Interface).

The IRB interviewed the licensees and found that the organizations have assessed the technology is not viable to their application or that they have matured the technology using internal investment and are not dependent on the OSAM-1 mission demonstration.

In regard to the Kodiak Lidar system, the IRB did not find dependency on the system within NASA nor industry. The IRB notes that the use of the Jena-Optronik's RVS 3000 is fairly common and is used by Northup Grumman's SpaceLogistics business[23] and Astroscale.[24] The IRB also noted competition to JennaOptronik's system is present in industry, largely addressing a lower size-weight-and power (SWAP) system.

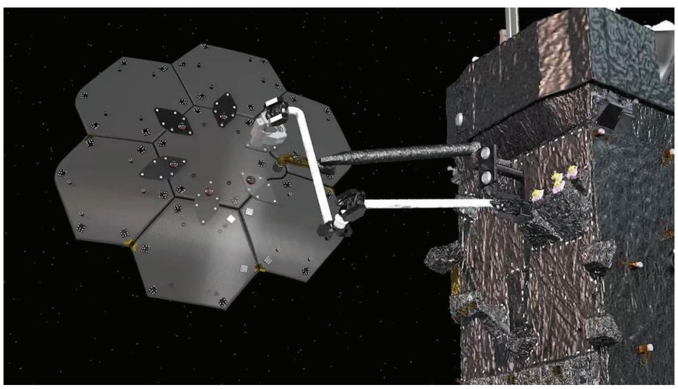


Figure 3. Artist's rendering of NASA's OSAM-1 SPIDER Demonstration.

Potential OSAM-1 Restructure

It is viewed by the IRB that the capability of developing dexterous robotic servicing will well serve national capabilities and be critical to a future state desired by a broad swath of the U.S. space community, where missions enabled by ISAM create strategic advantage giving the U.S. space capabilities well beyond what we have today, where space systems are routinely refueled, refreshed, assembled on-orbit and ultimately made more resilient. However, the high cost remaining and limited impact that OSAM-1 can contribute to the broader national space community should are considerations for NASA as it deliberates over project continuation.

Recommendations

In light of the IRB's overall **recommendation to discontinue the project**, the board offers four ROI-centric recommendations for consideration. These are options to consider following a termination or restructuring, as NASA directs.

[22] Email from Ms. Trudy Kortes, NASA STMD Director of Technology Demonstrations to Dr. Michael Gazarik, IRB Deputy Chair, on November 17, 2023

[23] https://www.jena-optronik.de/products/rendezvous-sensors/rvs-3000-3d.html

[24] https://spaceref.com/space-commerce/astroscale-selects-lidar-from-jena-optronik-for-innovative-space-debris-removal-mission-elsa-m/

Establishment of a University Consortium

The IRB proposes NASA conduct a community workshop to identify how best to use the hardware and experience gained on the to-date OSAM-1 development. For example, similar to university consortia sponsored by NASA's Space and Technology Mission Directorate (focused on specific technology areas), a consortium could be formed to both identify opportunities and provide a training pipeline for next-gen on-orbit servicing professionals.

National On-orbit Testbed

NASA should also consider deployment of a national on-orbit testbed, cost-shared by commercial and/or defense organizations – similar to Japan's ETS-VII servicing demonstrator (1997-2002). The Japanese ETS-VII mission provides a model for what OSAM-1 could become if it is restructured to be a National Test Bed mission. ETS-VII was an experimental mission consisting of a LEO spacecraft with a 2-meter class robot arm and a separable smaller test vehicle, much like DARPA's Orbital Express mission (2007). JAXA had a planned set of rendezvous, grapple and robotic experiments. After the planned set of experiments was completed, JAXA allowed both domestic and foreign proposers to propose extended operations. Winning proposals were given time on the space vehicle to carry out their proposal on-orbit.

NASA could consider proposals from any U.S. organization (such as the members of the new COSMIC consortium) to propose additional operations, much in the same way the proposals are considered for Hubble Space Telescope observing time. Under this paradigm, providing both valuable on-orbit experience and lessons learned to the broader national space capabilities would be central to NASA's mission. It is expected that all of national security space, civil space, commercial space, academia and primary/secondary education could and should be encouraged to propose to have on-orbit operations time. This could greatly accelerate the advancement of the industrial base in the U.S. as it did in Japan on ETS-VII. It is the opinion of the IRB that there would be many small companies that would benefit from the on-orbit expertise that such a testbed would provide. This concept was discussed within the national security space members that the IRB interviewed and found nearly unanimous strong support for what this would accomplish within both government and industry. And it could be expected this would be invaluable to STEM interests, with opportunities to perform limited robotic control potentially extremely engaging to primary school students, such as key STEM contest winners even at the elementary school level.

Collaboration with DOD and Intelligence Communities

The IRB suggests NASA engage the USSF and National Reconnaissance Organization (NRO) to collaborate on topics of mutual interest, such as prepared refueling and cislunar access and identify joint opportunities that would leverage the existing OSAM-1 system and capabilities. This activity should also develop a specific roadmap with needs, technology and system capability gaps along a 10-year timeline. Such a roadmap could be reviewed by the National Academy of Engineering.

Servicing, Refueling, and Assembly Roadmap

Finally, the IRB suggests that NASA engage the commercial space industry to develop a joint roadmap to address its servicing, assembly, and manufacturing needs. There is an existing strong industrial base with developing capabilities for on-orbit refueling, servicing, and assembly operations. NASA STMD should consider identifying the highest-risk areas faced by the Nation's industry base and develop focused investments on reducing risk in those areas and maturing the needed technology and capabilities that will serve the Nation. NASA STMD should also consider constructs such as consortiums and frequent workshops to strengthen awareness within NASA and alignment of the emerging in-space market and high-risk areas requiring government investment.

APPENDIX A: OSAM-1 INDEPENDENT REVIEW BOARD TERMS OF REFERENCE

1.0 Introduction

On-Orbit Servicing, Assembly, and Manufacturing -1 (OSAM-1) is a Category 1, Class C Technology Demonstration Mission (TDM) within NASA's Space Technology Mission Directorate. Building on a history of demonstrations to lead to a capability to upgrade and maintain assets in space, the OSAM-1 project seeks to rendezvous with, refuel, and relocate a United States Government-owned satellite, Landsat 7,[25] to demonstrate the feasibility of on-orbit refueling, satellite relocation, and life extension. The project also intends to demonstrate assembly of a communications antenna using a robotic arm. If successful, OSAM-1 capabilities will give satellite operators new ways to manage their fleets more efficiently and derive more value from their initial investment by enabling such in-space maintenance to extend the operational life of satellites, which also helps mitigate the growing problem of orbital debris. Successful completion of this mission would demonstrate several servicing technologies and capabilities that could then be available for future missions. NASA intends to transfer OSAM-1 technologies to commercial entities to help jumpstart a new domestic spacecraft servicing industry.

1.1 Purpose

The Space Technology Mission Directorate (STMD) requests an independent Continuation Review to assess programmatic and technical performance as well as return on investment (ROI) to NASA of technology gains from the OSAM-1 mission, to include benchmarking of the current government and commercial satellite servicing market environment. The independent team should assess the cost-to-complete.

1.2 Background

In 2016 NASA awarded the first contract in support of Robotic Servicing Demonstration Mission, called Restore-L,[26] to demonstrate in-orbit robotic servicing and refueling to enable a satellite to function for years beyond its designed operational life. The project was assigned to the Goddard Space Flight Center (GSFC). In April 2020, with the addition of the Space Infrastructure Dexterous Robot (SPIDER) payload, NASA changed the mission's name to OSAM-1 to reflect the expanded scope of the first autonomous robotic in-orbit satellite servicing, assembly, and manufacturing mission.

In April 2017, Restore-L passed Key Decision Point (KDP)-B of the Formulation Phase with an estimated cost for the project between $626 million and $753 million with a targeted launch readiness date between June and December 2020. Over the subsequent 2 years, Restore-L experienced cost increases and schedule delays, as well as an evolution of overall scope to add on-orbit antenna assembly and beam manufacturing to the demonstration. Specifically, during formulation, the project had insufficient cost reserves to address risks and workforce shortages that led to delays in some of Restore-L's subsystems, including the robotic arm system. By June 2018, the project's preliminary cost estimate had grown to $1.04 billion. In March 2019, Space Technology Mission Directorate (STMD) officials directed the project to incorporate SPIDER, a payload developed under a NASA STMD Tipping Point firm

[25] https://www.usgs.gov/landsat-missions/landsat-7
[26] https://www.nasa.gov/wp-content/uploads/2015/05/restore-l-info_nnh15heomd001_r7.pdf

fixed price procurement to advance technologies needed for an in-space robotic manufacturing and assembly capability to increase the project's value proposition.[27] The project continued to experience challenges.

In May 2020, the STMD Directorate Program Management Council (DPMC) evaluated the readiness of the project to proceed to Phase C of its life cycle development. Based on the Program Management Council review, the project was approved to enter Phase C with an Agency Baseline Commitment (ABC) development estimate of $974.4 million and a launch readiness date of no later than September 2025; however, GSFC and STMD leadership approved the project to proceed with 15 percent cost reserves at baseline instead of the Goddard Procedural Requirements (GPR) recommended level of 25 percent, given a higher accepted risk posture for STMD technology demonstrations. With the approved KDP-C development estimate of $974.4 million, and the mission complexity and external visibility, the NASA Associate Administrator provided direction to categorize the project as a Category 1.[28] As a technology demonstration mission with acceptable risk tolerance, the project remained Class C, with tailoring as appropriate to incorporate Class B approaches, while remaining mindful of increasing complexities and cost and schedule constraints.[29]

OSAM-1 was one of the first NASA projects to go through a KDP milestone during the COVID-19 pandemic, with an approved KPD-C in May 2020. Because of this, Agency and project officials determined that COVID-19 impacts could not be fully incorporated into the project baseline at that time. Per the KDP-C decision memorandum, cost and schedule did not include impacts associated with the pandemic, stating that the project and GSFC will assess impacts in a "reasonable timeframe" and provide budget and schedule updates to the Technology Demonstration Missions (TDM) Program. Following the May 2020 KDP-C, the project experienced schedule delays and cost increases due to the government and contractor shutdowns, supply chain challenges, as well as non-COVID impacts characterized by project officials as technical, programmatic, and scope changes. In January 2022, the Associate Administrator for STMD issued an official breach notification to Congress because the Agency expected the OSAM-1 project to exceed its baseline development cost by more than 15 percent and its launch readiness date by more than 6 months. These cost and schedule overruns necessitated a project rebaseline and new Agency Baseline Commitment (ABC). In April 2022, the Agency rebaselined OSAM-1 at a revised development estimate of $1.244B (an increase of approximately $270 million over the May 2020 development estimate) and extended the launch date from September 2025 to December 2026 (15 months).

Since the April 2022 rebaseline, the OSAM-1 project has continued to be challenged to meet cost and schedule commitments. At the Agency Baseline Performance Review (BPR) held on April 27, 2023, STMD informed the Associate Administrator that a recent Project assessment indicates low confidence in meeting the April 2022 rebaselined development estimate and launch readiness date. The project undertook assessment of possible descopes. At the August 23, 2023 DPMC, STMD leadership reviewed the OSAM-1 project cost and schedule information, including updated Joint Confidence Level data, along with independent cost and schedule analyses performed by the GSFC Requirements Assessment Office, Standing Review Board, and Aerospace Corporation. The results indicated the project was very likely to exceed the April 2022 rebaselined development estimate and launch readiness date.

[27] https://www.nasa.gov/news-release/nasa-funds-demonstration-of-assembly-and-manufacturing-in-space/
[28] Program lifecycle cost in excess of $1B, human spaceflight, or "significant radioactive material."
[29] https://explorers.larc.nasa.gov/2021APMIDEX/pdf_files/NPR_8705_4A.pdf

Subsequently, the project status was briefed during the August 24, 2023 BPR, and the project presented the latest status to the Agency Program Management Council (APMC) on September 7, 2023. The APMC Chair directed the OSAM-1 project to (a) "hold" on procuring a launch vehicle, and (b) continue to work towards the January 2024 KDP-D, while continuing to assess performance. Additionally, STMD was directed to conduct an independent Continuation Review prior to KDP-D.

1.3 Scope

This Terms of Reference (ToR) covers the Independent Review Board pertaining to the purpose listed above. This review and team are separate and independent from the existing OSAM-1 Standing Review Board (SRB).

This continuation review will evaluate two main topics:

1. Assess project cost and schedule performance including the cost-to-go for completion of the project with an independent, probabilistic cost and schedule analysis to ensure a realistic assessment of costs-to-go. Has the OSAM-1 project shown enough improved performance in the last six months, and fully estimate the challenges in the next integration activity, to provide confidence that the project can be completed without further significant cost growth and schedule erosion or delay?

2. Assess return on investment to NASA compared to technology gains, given the current satellite servicing market environment. Does the advancement of technologies in in-space servicing, assembly, and manufacturing justify the cost to continue to fund OSAM-1? Are there any special considerations such as workforce impact or on-the job training opportunities NASA should consider?

2.0 Study Objectives

The Board will:

- Assess project performance. Assess OSAM-1 cost-to-go for completion of the project and performance against plan with respect to schedule, cost, and technical achievements over the last 6 months. Evaluate the program's plans for the next phase and confidence in schedule and cost including an independent analysis if the board deems this necessary.

- Assess return on investment. Evaluate OSAM-1 technologies to be demonstrated as compared to current state of the art for in space servicing, manufacturing, and assembly.

- Identify and raise other issues that might be crucial for mission success not yet recognized by the project and identify specific corrective actions to prevent reoccurrence of identified issues in OSAM-1.

- Identify any additional programmatic solutions the board believes are required to bring the project to a timely launch readiness.

- Identify any considerations and impacts to help NASA determine a decision to redirect, continue, or terminate the project.

3.0 Study Conduct

3.1 Method

This is a non-consensus board. The conclusions drawn will be majority opinion yet dissenting or outlying conclusions can be captured.

Board members will perform a study that includes consideration of schedule, technical, and programmatic plans, activities, and risks. The board members will conduct open discussion and interviews with relevant personnel. Interviews with past and present OSAM-1 team members should be conducted as needed. Board members will be invited to participate in the OSAM-1 System Integration review (SIR), currently scheduled November 15-17, 2023.

Board members will assess each of OSAM-1's developing technologies against similar developments in in-space servicing, assembly, and manufacturing. Questions to be answered include: Where else is this technology being developed? When will it be demonstrated, and will it be demonstrated in space? What unique technologies does OSAM-1 offer, and how will they impact industry? The board members will conduct open discussion and interviews with relevant OSAM-1 personnel, industry, academia, and other government agencies as needed.

Three briefings to NASA are expected. The first will be a snapshot briefing of the continuation review to the APMC Chair which will serve as an outbrief to OSAM-1 stakeholders, the second will be to a combined informational STMD DPMC/Agency PMC (TBR), and the third is the decisional Continuation Review APMC which is due prior to the KDP-D APMC.

One final report to NASA is expected. This document will be delivered to STMD and APMC decision authority.

Board membership is identified in Appendix 1 (below).

OSAM-1 Technologies are identified in Appendix 2 (not included).

Applicable documents and reference documents are identified in Appendix 3 (not included).

Approval of IRB membership and individual biographies are identified in Appendix 4 (not included).

3.2 Schedule

Event	Completion
TOR & Chair concurrence	October 5, 2023
Final Board nominations submitted for vetting and contracting	October 10, 2023
Kick-Off	Week of October 23, 2023
OSAM-1 SIR @ GSFC	November 14-17, 2023

Continuation Review / Snapshot Report Outbrief	January 2024
STMD DPMC: Continuation Review Report (Informational)	January 2024
OSAM-1 KDP-D @ GSFC CMC (TBD)	January 2024
Agency APMC: Continuation Review and KDP-D Outbriefs (decisional)	February 2024

Appendix 1- IRB membership

Fred Kennedy, Ph.D., Chair (Dark Fission Space Systems, Inc.)
Michael Gazarik, Ph.D. Deputy Chair (University of Colorado)
Bernard Kelm, Board Member, Naval Research Laboratory
Timothy Cook, Board Member, Cutting Edge Communications (formerly Boeing Company)
Stuart McClung, Board Member, NASA Johnson Space Center
Brett Kennedy, Board Member, NASA Jet Propulsion Laboratory

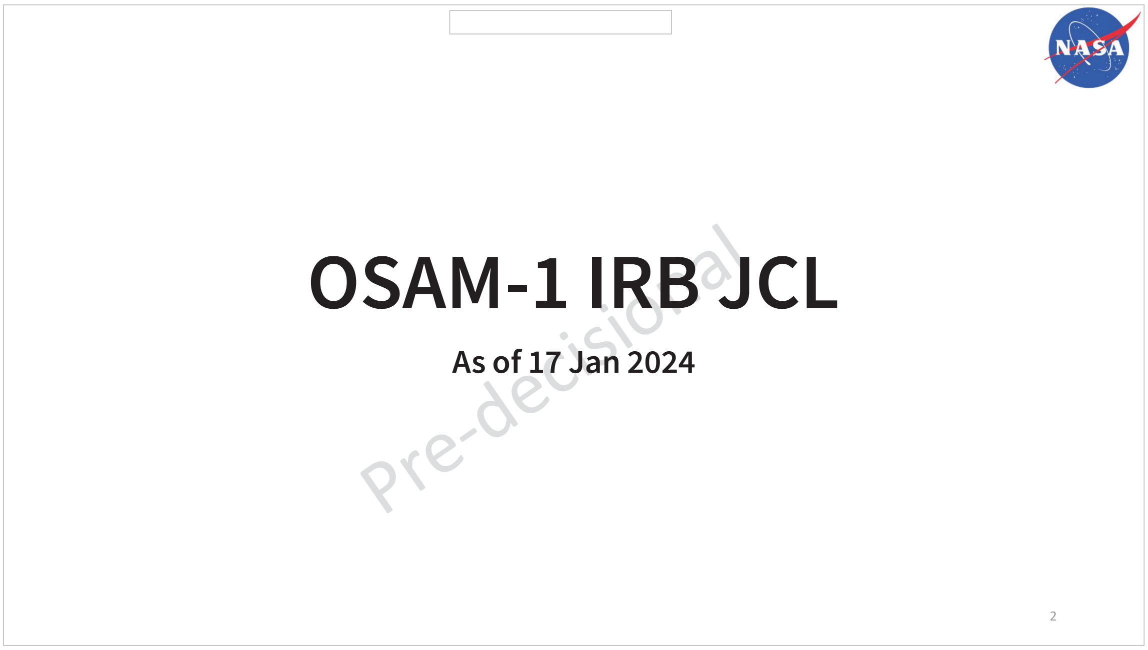
David McGowan, IRB Advisor, NASA Langley Research Center
James Johnson, IRB Advisor, NASA Office of the Chief Financial Officer
Ellen Stigberg, IRB Advisor, NASA Office of the Chief Program Management Officer
Scott Darpel, IRB Advisor, NASA Glenn Research Center
Joseph Carsten, IRB Advisor, NASA Jet Propulsion Laboratory

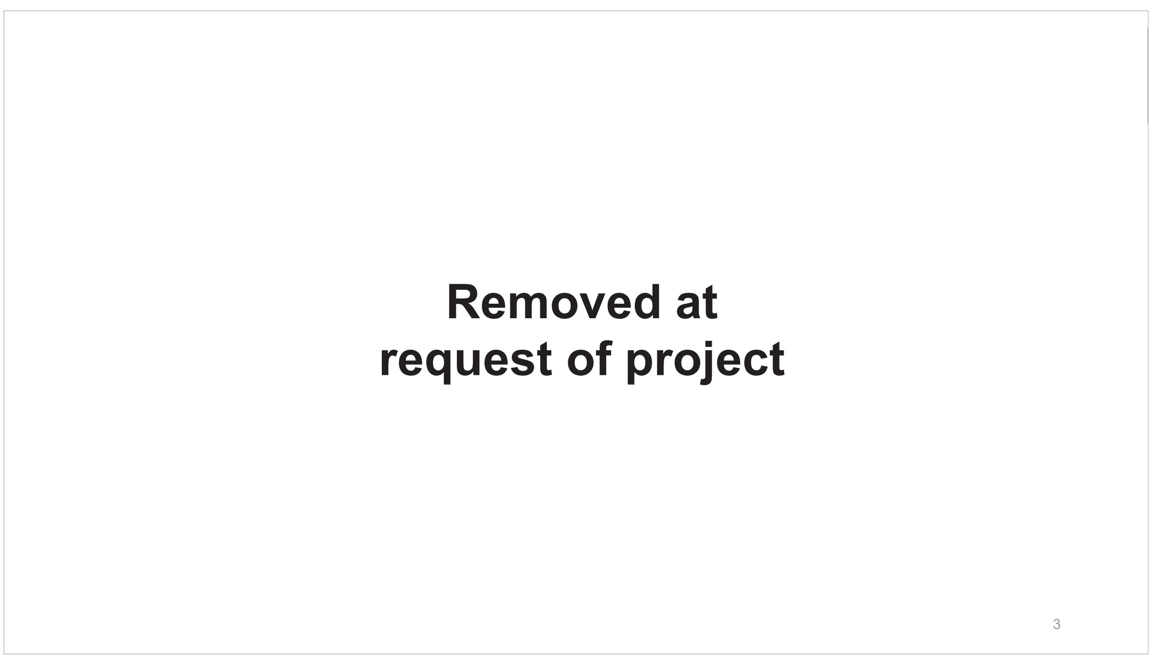
Michael Effinger, IRB Review Manager, Marshall Space Flight Center

Tupper Hyde, IRB Observer, Goddard Space Flight Center

APPENDIX B: JOINT CONFIDENCE LEVEL ANALYSIS/METHODOLOGY

Appended are briefing materials prepared by the IRB (Mr. James Johnson) regarding its analytical efforts to establish a cost-to-go and schedule-to-go for OSAM-1.





IRB Changes to Project JCL

- Add 4 “Red” Discrete Risks (6–9 month impacts)
  - Kodiak Late Delivery, Spider Late Delivery, Rework due to Testing, and LV Procurement Delays
  - Include TI Cost range of $500K- $2M on Rework due to Testing
    - $2M based on Project Risk data shown at SIR for 2 instances of damage ($2M/ ea)
- Add 1 Risk Factor to TVAC Activities durations
- Include Project Risks
  - RPO Schedule, RE10, 4300, 4301, 4299, 4260
- Include Project LV Cost Risk
- Adjust all TD Cost Uncertainty for current EVM performance
  - From +5% at Mean to +25%

IRB Compared to SRB

- SRB added 6 risks
  - Range from 15d to 80d, this is more risks, but less than IRB riskimpacts
- SRB modified some Project Risks
- SRB also added the Project LV Cost Risk
  - Same as IRB, utilized Project estimate of $17.5M
- SRB also modified TD Cost Uncertainty
  - Both SRB and IRB are using EVM performance to adjust TD Cost Uncertainty for growth
  - SRB used most recent CPI of .83, for +20% growth at mean
  - IRB is using avg CPI of .80, for +25% growth at mean (Project was +5%)
- SRB concurred with Project that multiple risks are “included in Uncertainty”
  - SRB & Project assume that Late SPIDER delivery is included in Uncertainty; IRB does not
  - Duration Uncertainty distributions created by Project are conservative, but reflect the delays already incurred and uncertainty in activity duration; IRB Risks are based on further delays (for example, IRB Risk Rework due to Testing)
  - IRB understands that this is conservative/pessimistic; discussions, Interviews, and recent LiDAR CDR update indicate further delays are possible
  - Thus, IRB finds it acceptable to add Discrete Risks for Late Deliveries in addition to the Duration Uncertainty already provided by the Project
    - IRB did not adjust Duration Uncertainty provided by Project ; SRB did increase Duration Uncertainty in various areas such as Robot, REU, and SVINT that appear low/optimistic.

Background

- IRB is performing an assessment of Project JCL from SIR (10/2023)
  - HQ OCFO is supporting IRB as Consultant/Ex-Officio, James Johnson
- IRB has identified adjustments and additions to Project JCL
  - IRB has identified specific risks with likelihood and impact values, etc.
  - IRB inputs based on discussions, Interviews, Project SIR, assessments, etc.
- IRB has met with SRB POCs for discussions on Project JCL
  - IRB results are separate from the SRB
  - IRB and SRB are both starting from same Project JCL model (JCL_354_October 2023)
- IRB JCL presentation includes results, drivers, and comparison(s)

Removed at request of project

Project JCL: General Comments

- It is the IRB understanding that the Project believes these Uncertainty Distributions also include the Risks and Threats
  - The Project has selected a variety of "High" Uncertainty Distributions that will increase the schedule duration of many activities:
    - Mechanical, KODIAK, ATDS, ROBOT, SPINT, Spacecraft, SPIDER, SPINT, etc. (see next slide)
- The SRB appears to concur that many risks, including late deliveries of key components are included in the duration uncertainty
- The Project bases some Uncertainty Distributions on performance -to-date and others on a rating menu/scorecard

Late REU Delivery

Late SC Delivery

Late SPIDER Delivery

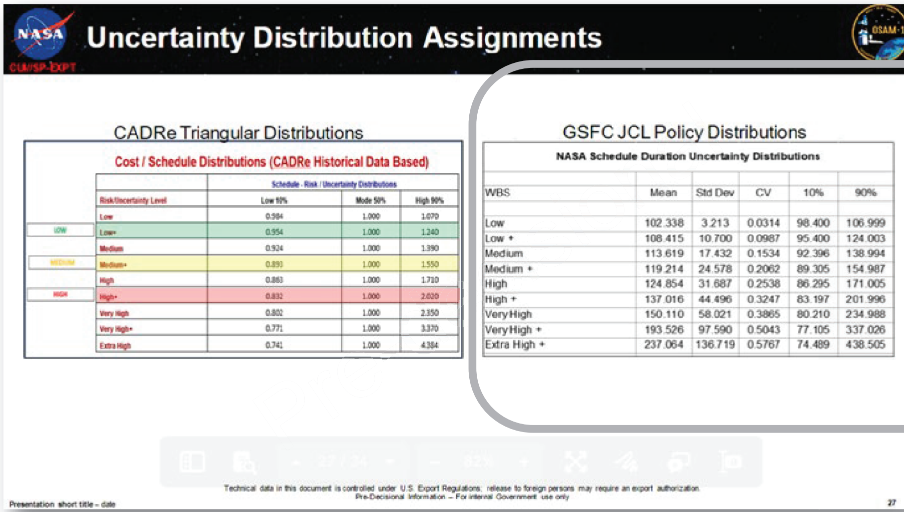
Discrete Risks (Covered via Duration Uncertainty)

- SRB concurs that the Following Risks/Issues are accounted with Duration Uncertainty

ID	Category	Summary	Risk Status	Risk Type	L	C	Color	Project's JCL Impact	Impact / Task(s) Impacted
4237	SV	Uncertainty in completing Spacecraft Acceptance testing	(as of 11/20/23) RPT aprox89% complete. BDR complete. FSW build 2.4 uploaded. New database delivered. Prop testing completed.	Cost, Schedule	[illegible]	3	Yellow	Addressed in Task Uncertainty	Spacecraft Tasks 345-347 is High +
3794	Payload: REU	Late Robot Electronic Unit (REU) deliverables	Elevated to Issue #4249	Cost, Schedule	1	4	Green	Addressed in Task Uncertainty	RRS#1 is High / RRS#2 is Medium +
3851	I&T: SC	Late Spacecraft Delivery	risk had be elevated to issue by Project Management for the monthly status reporting cycle. Concern is now being tracked as a Project Issue.	Schedule	[illegible]	[illegible]	Yellow	Addressed in Task Uncertainty	Spacecraft Tasks 345-347 is High +
3565	SPIDER	Late SPIDER Robot Arm System (RAS) Delivery	Elevated to Issue # 4254. Based on April 2023 SPIDER monthly report RAS delivery is holding 2/8/2024, but at risk of slipping due to actuator test delays, actuator encoder delivery delays, and MAA motor delivery delays.	Schedule	3	4	Yellow	Addressed in Task Uncertainty	SPIDER: Build RAS w/ DEE, Boom Assy, RF Feed, Stack 1, Stack 2 = Very High, SPIDER SVINT = Medium?
4193	SPIDER	SPIDER Modular Antenna Assembly schedule	Elevated to Issue# 4254	Schedule	3	[illegible]	Yellow	Addressed in Task Uncertainty	SPIDER: Build RAS w/ DEE, Boom Assy, RF Feed, Stack 1, Stack 2 = Very High, SPIDER SVINT = Medium?
No Risk ID	LIDAR	Servicing Payload LIDAR development (#4252)	Issue #4252. 5. Complete scaring of Servicing Payload for commercial LIDAR (In-progress) (March 2024) 6, Commercial LIDAR under contract (In-progress)(Feb 2024)					Addressed in Task Uncertainty	LIDAR1 High+, LIDAR2 Med+

Removed at request of project

Project Duration Uncertainty Inputs (Menu)



Uncertainty Distribution Assignments

CADRe Triangular Distributions

Cost / Schedule Distributions (CADRe Historical Data Based)

	Risk/Uncertainty Level	Low 10%	Mode 50%	High 90%
	Low	0.984	1.000	1.070
LOW	Low+	0.954	1.000	1.240
	Medium	0.924	1.000	1.390
MEDIUM	Medium+	0.893	1.000	1.550
	High	0.863	1.000	1.710
HIGH	High+	0.832	1.000	2.020
	Very High	0.802	1.000	2.350
	Very High+	0.771	1.000	3.370
	Extra High	0.741	1.000	4.384

(Column group heading: Schedule - Risk / Uncertainty Distributions)

GSFC JCL Policy Distributions

NASA Schedule Duration Uncertainty Distributions

WBS	Mean	Std Dev	CV	10%	90%
Low	102.338	3.213	0.0314	98.400	106.999
Low +	108.415	10.700	0.0987	95.400	124.003
Medium	113.619	17.432	0.1534	92.396	138.994
Medium +	119.214	24.578	0.2062	89.305	154.987
High	124.854	31.687	0.2538	86.295	171.005
High +	137.016	44.496	0.3247	83.197	201.996
Very High	150.110	58.021	0.3865	80.210	234.988
Very High +	193.526	97.590	0.5043	77.105	337.026
Extra High +	237.064	136.719	0.5767	74.489	438.505

Technical data in this document is controlled under U.S. Export Regulations; release to foreign persons may require an export authorization.
Pre-Decisional Information – For internal Government use only

Presentation short title – date 27

- Project selects Lognormal Distribution for Duration Uncertainty from Menu

Removed at request of project

IRB Risks

IRB Risk Title	Type	Likelihood	Impact TI Cost	Impact Duration	Activities Impacted	Impacting CP
TVAC Challenges	Risk Factor	75%		+50%	Multiple	
KODIAK LiDAR Late Delivery	Discrete Risk	75%		9 Months	#154-#155, Kodiak: #1 Deliver to I&T	Yes
Rework Due to Testing	Discrete Risk	35%	$500K - $2M	3 – 6 Months	#416-#417, SVINT Closeout, CPT, Stray Light	Yes
SPIDER Late Delivery	Discrete Risk	35%		6 Months	#386-#403, SPIDER: Build, Unpack, Inspect	Yes
LV Procurement Delays	Discrete Risk	35%		6 Months	#379-#380, SC Accept Test, Review	Yes

IRB Risks

JACS - Risk Register

	Activate	Risk ID	Risk Description	Likelihood (%)	Duration Impact	TI Cost Impact	TD Cost Impact	Activities Impacted
646	☐		Risk Event Register	0				
647	☑		RPO Schedule Risk	20	60			334
648	☑	4113	Launch Vehicle Cost Risk	0		17535000		462
649	☐	3846	OMES III Transition Impact - Robot	20	20			304
650	☐	3846	OMES III Transition Impact - REU1	20	20			224
651	☐	3846	OMES III Transition Impact - REU2	20	20			237
652	☐	3846	OMES III Transition Impact - ATDS	20	20			258
653	☐	3846	OMES III Transition Impact - LiDAR	20	20			148
654	☐	3846	OMES III Transition Impact - RPO	20	20			334
655	☑	RE10	Commercial LiDAR	100	7	6000000		433
656	☑	4300	RAA Flex cables damaged at robot rm aft bulk head	20	15			312
657	☑	4301	ATDS/RA HW damaged from launch lock cup misalignments	40	15			312
658	☑	4299	Flight harness WOA build closeout	20	5	50000		435
659	☑	4260	Whitehouse floor loading analysis	20	0	300000		403
660	☑	IRB01	KODIAK LiDAR Late Delivery	75	180			154
661	☑	IRB02	Rework due to testing	35	Uni(60,120,15,85)	Uni(500000,2000000,15,85)		416
662	☑	IRB03	SPIDER Late Delivery	35	120			386
663	☑	IRB04	LV Procurement Delays	35	120			379

IRB Added Risks

LiDAR CDR Update – IRB Assessment

- Basis of Estimate for IRB Lidar Late Delivery Risk (75% Likelihood, 9 month impact):
- IRB observed and inquired about multiple activities from LiDAR CDR:
- (1) MEMS cards not complete, supposed to finish 12/19 & 12/20, 25 days late and counting to 10/31 SIR schedule;
- (2) Receiver backend card #1 12 days late and counting to 1/3 forecast (10/31 SIR schedule);
- (3) Receiver backend card #2 - no report, forecast is 1/25 but if they haven't finished #1, then why would #2 be any better;
- (4) LRF Detector Card #1, forecast 12/8, so 38 days late to SIR plan and counting;
- (5) LRF Detector Card #2 in test, forecast ready date 1/31 (?);
- (6) Imaging Detector Card #1 in queue behind LRF DC #2, forecast 1/9, 6 days late and counting;
- (7) Imaging Detector Card #2 forecast ready 2/29 (what confidence do we have in this date?);
- (8) FEIC #1 - anomaly in testing, waiting on new support equipment (?) - forecast date not shown;
- (9) FEIC #2 forecast ready 1/12, so a few days late and counting but see (8);
- (10) Clock cards are on hold for test, forecast ready dates 11/6 and 11/17, so both are ~ 60 days late and counting to the SIR schedule (!);
- (11) Backplanes - appear complete.

Status Period Ending: 10/31/2023

LiDAR Boards	Total Slack	- 1 Mo Var	2023–2024 (Sep 2023 – Dec 2024)
LiDAR: FLT FEB & PSD Cards			
LiDAR: FLT #1 MEMS Card Ready for I&T	-35 d	-14 d	12/19
LiDAR: FLT #2 MEMS Card Ready for I&T	4.5 d	-14 d	12/20
LiDAR: FLT #1 FEB Backend Card Ready for I&T	-1 d	-14 d	1/3
LiDAR: FLT #2 FEB Backend Card Ready for I&T	24.5 d	-14 d	1/25
LiDAR: FLT FEB PSD Card FLT #1 Ready for I&T	13 d	-10 d	10/30
LiDAR: FLT FEB PSD Card FLT #2 Ready for I&T	48.5 d	-10 d	10/27
LiDAR: FLT #1 LRF FEB Detector Card Ready for I&T	13 d	-6 d	12/8
LiDAR: FLT #2 LRF FEB Detector Card Ready for I&T	18.5 d	-6 d	1/31
LiDAR: FLT #1 Imaging Detector Card Ready for I&T	-10 d	-6 d	1/9
LiDAR: FLT #2 Imaging Detector Card Ready for I&T	-4.5 d	-6 d	2/29
LiDAR: FLT #1 FEIC Ready for MEB I&T	-31.5 d	-17 d	
LiDAR: FLT #2 FEIC Ready for MEB I&T	20.5 d	5 d	1/12
LiDAR: FLT #1 Laser Elec Card Ready for Laser I&T	-19 d	-20 d	10/20
LiDAR: FLT #2 Laser Elec Card Ready for Laser I&T	1.5 d	-20 d	11/20
LiDAR: FLT #1 Laser Diode Card Ready for Laser I&T	-36 d	-29 d	12/15
LiDAR: FLT #2 Laser Diode Card Ready for Laser I&T	-31.5 d	-29 d	1/22
LiDAR: FLT #2 Laser Ready for MEB I&T	-31.5 d	-29 d	3/14
LiDAR: FLT #2 Laser Ready for MEB I&T	-31.5 d	-29 d	3/14
LiDAR: FLT #1 MEB I&T Ready	-36 d	4 d	3/15
LiDAR: FLT #2 MEB I&T Ready	-31.5 d	0 d	3/28
LiDAR: FLT #1 FEB Ready for Testing	-43 d	0 d	3/7
LiDAR: FLT #2 FEB Ready for Testing	-29.5 d	0 d	4/15
LiDAR: FLT #1 Power Card Ready for I&T	-5 d	0 d	12/8
LiDAR: FLT #2 Power Card Ready for I&T	20.5 d	0 d	1/2
LiDAR: FLT #1 Digitizer and Clock Ready for MEB I&T	-49 d	-17 d	2/16
LiDAR: FLT #2 Digitizer and Clock Ready for MEB I&T	-16.5 d	0 d	2/29
LiDAR: FLT #1 Clock Card Ready for Digitizer I&T	-4 d	0 d	11/17
LiDAR: FLT #2 Clock Card Ready for Digitizer I&T	46.5 d	0 d	11/6
LiDAR: FLT #1 Backplane Ready for I&T	23 d	0 d	10/25
LiDAR: FLT #2 Backplane Ready for I&T	48.5 d	0 d	11/16

Prep | Fab / Proc | Integration | Test | Environmental | MS Start / MS Fin | COVID Impact

Status Update indicates slip

IRB Risk Factor: TVAC Challenges

- Risk Factor is impacting: (red on CP)
  - #429 – SVINT: TVAC Teardown
  - #428 – SVINT: TVAC Cycles 2-4 w/SV CPT at Hot&Cold Plateaus + SPh Special Test
  - #427 – SVINT: TVAC in SES up to chamber break
  - #426 – SVINT: TVAC Test Prep TCs Test Blankets etc
  - #372 – PRSCT TVAC Prep
  - #373 – PRSCT TVAC 2 Cycles Test Execution
  - #327 – RRS2 Robot FLT2 TVAC Test
  - #317 – RRS1 Robot TVAC Test
  - #316 – RRS1 Enviro Testing Transfer and Config for TVAC
  - #315 – RRS1 Enviro Testing Robot Config change for TVAC

Removed at request of project

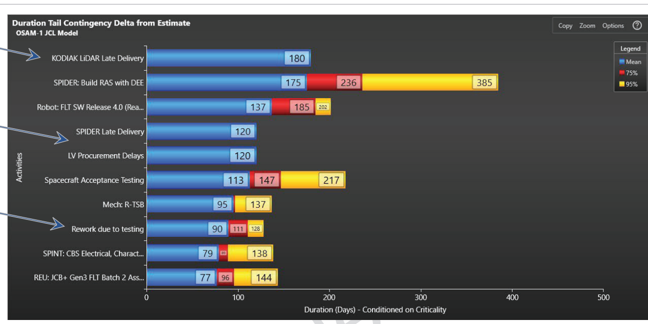
Driver Comparison: Project vs IRB

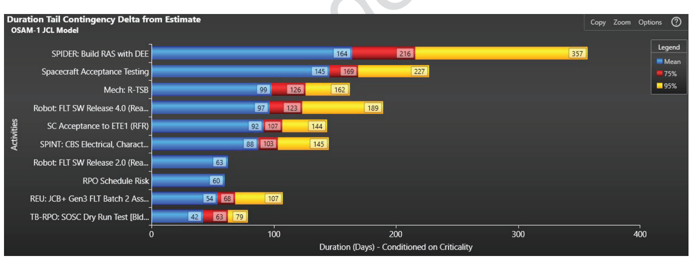
New IRB Risk

New IRB Risks

New IRB Risk

- Robot FLT SW 4.0 Increasing





- Driver Comparison of IRB (top) vs Project (bottom)
- Numbers are days (duration) added to the Activity Finish Date at the Mean (blue), 75%-tile (red) and 95%-tile (yellow)
- Long bars indicate Activities with extended delays to their Finish Date
- Activities shown are ranked in order of Criticality (impact to the Critical Path)
- Discrete Risks added by IRB are impacting Critical Path

Why FSW 4.0 is Increasing/Driving

- Project already had FSW as #4 critical in results
  - Both FSW Release #4 and Release #2 are critical in Project results
- FSW 4.0 has 191d Activity Duration
  - Final planned build
- FSW 4.0 Activity Finish Date changes by…..
  - 97d / 123d / 189d at the Mean / 75% / 95%-tile
  - Example: Finish end of May 2025….to….Finish in October 2025 (65% -tile)
  - This is a large change in Finish Date
- Schedule Logic for FSW:
  - Successors:
    - HFCS R4 Rec/Integ Flight Baseline from Robot
    - HFCS R4 System Development
    - HFCS Complete R4
      - Baseline Finish Date: Sept 2025
    - SVINT Post-Enviro CPT
- FSW issue identified by Project during previousRebaseline
  - Current EVM data indicates FSW continues to be a challenge (very low CPI, .53 avg)

Removed at request of project

Removed at request of project

Removed at request of project

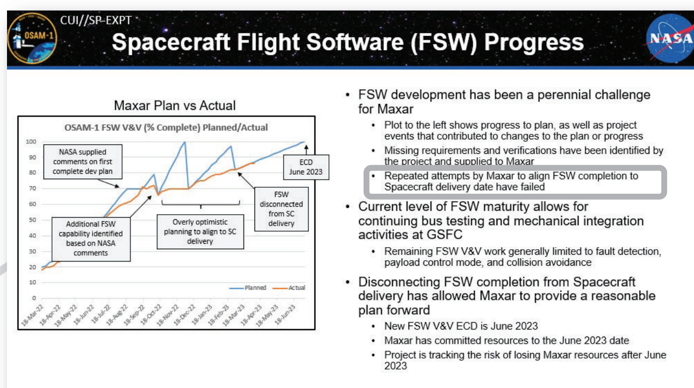
Removed at
request of project

Removed at
request of project

BACKUP

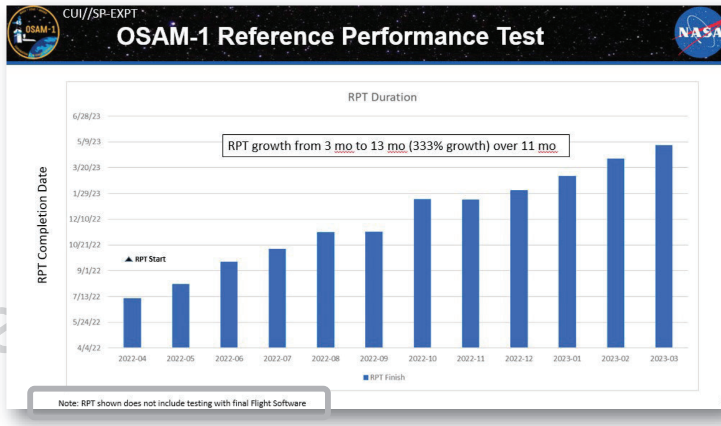
Maxar Observations: FSW Challenges

- Flight Software challenges at Maxar
  - Project has reported missing requirements and verifications
  - Project has repeatedly tried to align FSW completion to SC delivery
- IRB results illustrate how FSW for OSAM-1 is Increasing/Driving
  - SRB added a Red 60%,80d Risk for FSW V&V



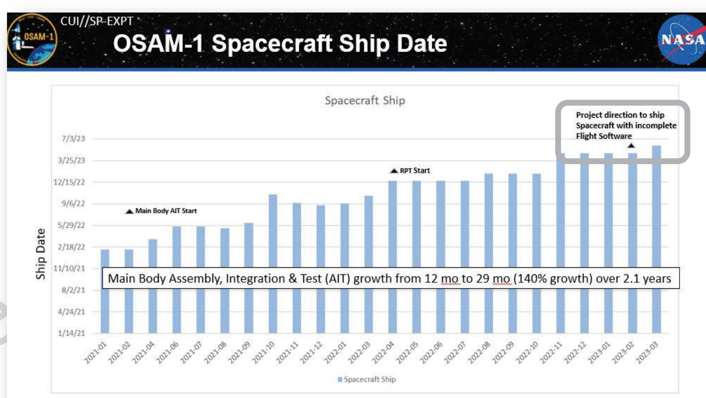
Maxar Observations: RPT Delays

- Reference Performance Test (RPT) growth has been significant and highlighted by Project
- Important Note at bottom: RPT growth shown does NOT include testing with final FSW

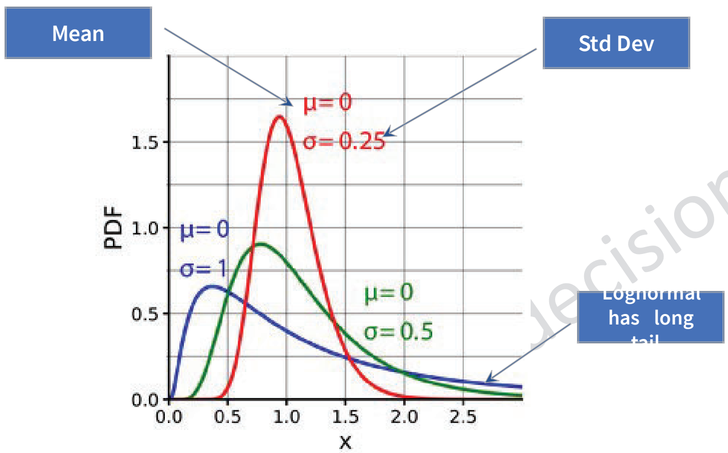


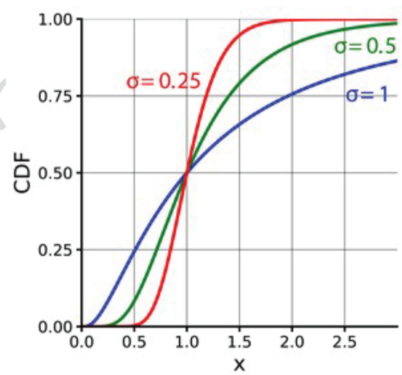
Maxar Observations: Spacecraft Delays

- Project received Spacecraft with incomplete Flight Software
- IG report also highlights this issue and increased costs:
  - ffSpecificallyz between January ųƴųų and May ųƴųħ NASA provided laborz such as assistance with flight soŭware and systems engineering supportz valued at approximately ”Aų million to help reduce impacts to the mission schedulezI
  - NASA partially concurred and, ffNASA will attempt to recoup costs through discussions with Maxar on potential equitable adjustmentsI



Lognormal Distribution (Visual)





Credit: Wikipedia

- CV = Std Dev / Mean, ..the Coefficient of Variance describes the "scatter", higher CV equals a wider scatter, lower CV equals a tight scatter
- Graph shows how an identical Mean value can be impacted by changes to the Std Dev (changes to CV)(blue highest CV w/highest S td Dev)
- Project JCL inputs are using Lognormal distributions for Duration Uncertainty with CV's ranging from .1 (low) to .5 (very hig h)
- These inputs at SIR indicate a high degree of uncertainty in the work to -go and produce a wide scatter result

APPENDIX C: INTERVIEW ROSTER

Table 2. IRB Interviewees

Organization	Participants	Date	Engagement Type
Psionic LLC	Steve Sandford	November 22, 2023	Phone call
Astroscale	Ron Lopez	November 29, 2023	Phone call
Northrop Grumman Space Logistics	Joe Anderson	November 29, 2023, January 11, 2023	Phone call and facility visit
Lockheed Martin Space Systems	Robert Chambers and Kate Watts	December 6, 2023	Zoom call
Orbit Fab	Daniel Faber, Adam Harris and team	December 14, 2023	Facility visit
Maxar Robotics	Chris Johnson, Justin Silver, Chuck Hulme, Artak Argelian, Dave Marlowe, Nick Wisnewski	December 11, 2023	Facility visit
Maxar Space	David Pigeon, Rick Sanborn, Tony Harris, Chuck Hulme, Justin Silver	December 12, 2023	Facility visit
Defense Innovation Unit	Maj. David Ryan, Cullen Greenfield, Rex Ridenoure, Dennis Poulos, Nick Jernigan, Omar Pimentel	December 13, 2023	Facility visit

Space Force Space Systems Command	Maj. Frank Clark (USSF) and Joshua Davis (Aerospace)	December 11, 2023	Facility visit (Aerospace Campus)
Naval Research Laboratory	Bill Vincent and Glen Henshaw	January 11, 2024	Facility visit
Johns Hopkins University Applied Physics Laboratory	Glenn Creamer	February 28, 2024	Phone call
US SPACECOM	Col. Ferguson USSPACECOM	December 14, 2023	Facility visit
USSF Space Test Range	Maj. Westcott USSF	December 14, 2023	Facility visit
NASA Space Technology Mission Directorate	Bo Naasz	November 29, 2023	In-person
NASA Space Technology Mission Directorate	Jeffrey Sheehy	December 4, 2023	Phone call
NASA Goddard Space Flight Center (current and legacy members of OSAM-1 Project Team)	Betsy Park (Program Manager), Ross Henry, Mark Bailey, Russ Roder, Erik Andrews, Robert Dedaris, Jesse Leitner, Jason Emperador, Milton Davis, John Higinbotham, Brian Thomas, James Perry, et. al.	Various Dates	In-person and phone/video calls
OSAM-1 Standing Review Board	Frank Martin, Pete Pinetta, Billy Carson, Steve Battel, Chris Blake	December 4, 2023 and December 6, 2023	Phone calls

APPENDIX D: EMAIL CORRESPONDENCE (MR. CHUCK HULME TO DR. FRED KENNEDY)

SPIDER Robotic Arm

The SPIDER mission intends to demonstrate free flyer capture, semi-autonomous robotic operation, and on-orbit assembly. In support of this mission, Maxar Space Robotics is developing the SPIDER assembly arm. These development efforts have enabled several key technologies and capabilities, thereby allowing us to propose lower cost/risk solutions in support of both CLD and Artemis missions now and in the future. Examples of these capabilities are: hi-strength/hi-torque actuators, scalable 1-g and 0-g arms, 0-g ground testing off-loader utilizing a multi-point off loader, analysis/simulation tools for dynamic robotic systems, compliance control, and visual control.

Although the scope of the SPIDER mission is limited to assembly, we believe the technologies enable lower cost solutions to a wider range of markets. For example, on-orbit assembly allows for space and mass efficient satellite/spacecraft design that can be assembled or fueled on-orbit. This capability means larger instruments can be designed and launched, such as the successor to JWST. Additionally, it allows for mission expansion and upgrading via payload or sensor swapping and/or additions. These can lead to cost savings and shorter program durations for NASA missions/programs.

We are already seeing the benefit, for both NASA and the commercial space industry. An example of a direct benefit to NASA from the SPIDER arm is NASA Langley's Lightbender program we are currently supporting through an ACO. The aim of this program is to use robotics to assemble a modular mirror reflector that would redirect sunlight to the necessary areas around the moon. Robotically, it is almost an identical mission to SPIDER – grasp reflector segments and assemble the reflector. Therefore SPIDER program advances capabilities and TRL required for Lightbender as part of the Artemis program. Commercially, the development of the 0G arm and 0G off-loader (enabling ground testing of 0G arms) will allow us to offer lower risk and cost solutions to the primes vying to build the next Space Station as part of the CLD programs.

Modular Antenna

The SPIDER mission set the stage for both near term and long term satellite architecture changes that improve a satellite owner's bottom line. In the near term, in-space antenna assembly gains operators a large increase in throughput and/or coverage, both of which bring increased revenue for a lower life cycle cost. This near term economic benefit will attract satellite owners to the value of in-space assembly and the reconfiguration opportunities it brings, and set the course towards the next generation of satellite architectures. Enabled by in-space assembly, the next generation of satellites will embody a vibrant, evolvable architecture that leverages in-situ fabrication, on-demand precision antenna assembly, shared platform resources, and payload technology refresh.

Strategic technology refresh allows satellite owners to rapidly upgrade a small part of existing satellites to capitalize on emerging market needs, such as 5G mobile communications, and respond to market changes driven by technology advancements on the ground, such as over-the-top video. Technology refresh mitigates equipment obsolescence that erodes revenue potential as a satellite ages.

Chuck Hulme

OSAM-1 / SPIDER Program Manager
Program Management Office