DEFINING OPERATIONAL FOR UNCREWED SYSTEMS (UXS)

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UxS Mature Technology Working Group

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Executive Summary

The Uncrewed Systems (UxS) Mature Technology Working Group was created by the UxS Executive Oversight Board (EOB) in January 2024, with the objective to: Establish consensus regarding use of the terms “Readiness Level 9” and “Operational” when referencing mature UxS technologies. The task was expected to be completed by the end of FY24.

The final proposed definition of “Operational” as agreed to by the UxS Mature Technology Working Group is as follows:

> *“Meets end-user-defined mission needs and is in use as needed at the intended scale of operation. Project outcome has been quality tested and has met end user transition criteria. The necessary funding, personnel, and infrastructure to routinely operate and maintain the project outcome are available. Researchers and developers have provided end users with all required tools, techniques, information, and documentation for operation, which may include training materials, knowledge and understanding of Operational procedures, data management plans, and required maintenance information.”*

This definition is mission-focused, meaning the determination that something is Operational hinges on whether the technology meets the end user's mission needs. As such, the same technologies can be Operational for one purpose, but non-operational for another based on the different mission objectives.

1. Contributions

The Uncrewed Systems (UxS) Mature Technology Working Group was created by the UxS Executive Oversight Board (EOB) in January 2024. The EOB goal as defined at the January 2024 meeting was to:

> *Establish what is "consensus" on mature UxS technologies and use of the terms "Readiness Level 9" and "Operational" with regards to UxS by the end of FY24.*

This initiative built upon and expanded the work of the Readiness Level Training Task Force (RLTTF) to define readiness levels (RL) 8/9 more clearly. Members from each of NOAA's Line Offices were represented within the working group in order to ensure a holistic definition of Operational for all of NOAA. While this working group's Operational definition is primarily directed towards UxS, its scope can be extended to all research and development within NOAA.

2. Background

2.1 Uncrewed Systems

UxS are vehicles that can operate without a person onboard. They are typically controllable or programmable observing platforms. While some UxS can operate fully autonomously, or without the oversight of anyone, others require remote guidance from an operator. That guidance can be someone piloting remotely in real-time, a pre-programmed path or task, or other oversight directed by a person.

NOAA categorizes its UxS by the main environments they operate in – the air (Uncrewed Aircraft Systems, or UAS), and the water (Uncrewed Marine Systems, or UMS). Within these categories, there are many types of UxS that vary based on the task they are meant to complete.

UxS range widely in size (some are the size of carry-on luggage to allow for portability while others are the length of a tractor trailer), power source (some are solar powered, rechargeable, or diesel powered), speed (some can move faster than a crewed ship or plane), tasking, and other features.

NOAA Principal Investigators continue to evaluate the utility of UxS for various NOAA missions. UxS enables the sustainable collection of a great number of environmental parameters at increased resolutions often in remote or harsh environments. Measurements obtained via UxS support a broad range of investigations into biological, chemical, geological, atmospheric, and physical properties that can show rates and implications of changes in the environments they observe. By delivering information otherwise difficult or impossible to obtain for researchers and decision makers, UxS meet both immediate Operational and long-term research needs. The importance of data obtained via UxS cannot be overstated, as they are and will provide the basis for decisions that affect sustainable fisheries management, climate monitoring assessments, and high-impact weather forecasting, cutting across commercial sectors such as, health, transportation, and security amongst others, to meet NOAA's mission objectives to benefit the public.

2.2 Data Management

Data management—to include acquisition, transmission, processing—can be a different prospect for UxS, as compared to their crewed counterparts. This is not always the case, but frequently, shifting to an uncrewed paradigm can mean a change in real-time data quality control and acquisition practices, as well as a change in data transmission.

There are various considerations for data management when implementing UxS. In some cases, using UxS entails automating or remotely operating data acquisition processes that have previously been accomplished by operators in-situ. If this is the case for a particular system, are there any environmental cues that have traditionally been used to aid the collection of adequate data that remote operators or automated tools may not have access to? Does this necessitate any changes to the data acquisition process or processing pipeline? Are there any new (to end-users) data handling and transmission considerations or constraints associated with the prospective platform? This may include infrastructure (antennas, internet links, etc), tempo (how frequently can data be accessed), and IT boundary concerns.

The NOAA Data Strategy ensures data governance aligns with federal requirements, detailing management and partnership policies, and NOAA Administrative Orders (NAO 212-15B, NAO 216-112). The Data Management Planning Procedural Directive directs all NOAA Programs or Systems that produce or collect environmental data to develop Data Management Plans for the data they produce internally or commission via contracts or grants. Operational data will comply with these policies.

2.3 Readiness Levels

Systematic metrics are necessary to descriptively assess the maturity of a particular technology used in research and development (R&D) and allow for the consistent comparison between different types of technology. NASA and the Department of Defense have used the Technical Readiness Level (TRL)[1] approach to manage and

[1] https://api.army.mil/e2/c/downloads/404585.pdf

mitigate technical risk. However, instead of referring to this designation as TRL, NOAA simply refers to this metric as “Readiness Level”, since it is often the progress toward integrated system applications and transition that is being measured, as opposed to a single, physical piece of technology.

RLs are defined in the NAO 126-105B: Policy on Research and development transitions and corresponding handbook (Handbook_NAO216-105B_03-21-17) and range from basic research (RL1), to fully transitioned (RL9) (Figure 1). NOAA has implemented this system to describe and track the maturity of, in this case, observing platforms, sensor payloads, and the actual observing system applications—“how it’s used”—for those integrated components, as these capabilities transition from research to operations or intended use. These systematic metrics allow for the consistent comparison between different types of R&D. Additionally, RLs are used to compare the maturity of different categories of components of a technology.

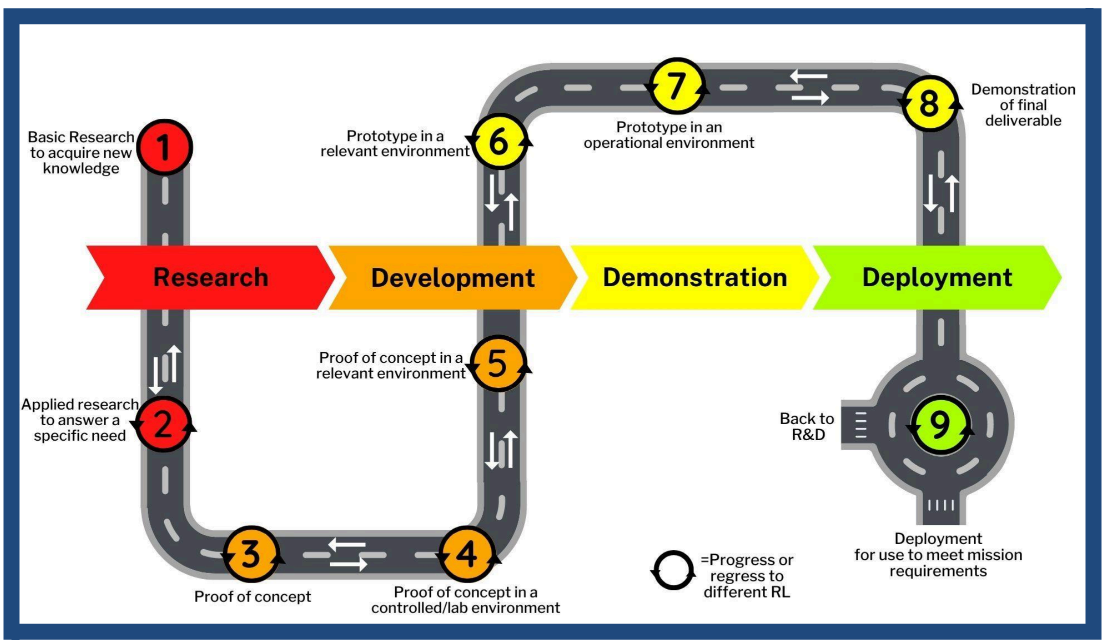

Figure 1: Assessing Maturity Through NOAA Readiness Levels

When discussing UxS, RLs can be grouped into three related categories that relate to the entire UxS unit:

1. Platform(s)
2. Sensor(s)
3. Observing System Application (i.e., Combination of platform + sensors payload for a specific observational purpose)

While it is important that each component be tracked accurately, it is the "Observing System Application" that is most relevant in defining a project and what the end goal of a project might be, advancing the technology toward routine operations or application as an observational solution capability.

UxS platforms and sensor payloads can be evaluated individually as singular components. However, Observing System Applications represent the:

- Integration of a particular platform,
- With a particular sensor payload,
- Operated for a specific application.

While the capability of a particular UxS "platform + sensor payload" combination may have been previously demonstrated—or even fully transitioned into operations—for one specific application (e.g., "Platform A + Sensor B" for terrestrial land cover observation), the RL assessment will likely need to be reset/re-evaluated when the same combined observing system is being examined for a significantly new Observing System Application (e.g., "Platform A + Sensor B" for arctic observations of marine mammals).

RL assessments for an observing system application may never exceed the RL assessment for any of its individual platform or sensor components. For example, if a newly developed UAS Platform prototype is independently assessed at RL6, and the particular camera payload to be used is independently assessed at RL9, then the Observing System Application cannot exceed an assessment of RL6. Thus, RLs are not fixed in a forward direction because they can mature or regress depending upon how the project progresses and possible future enhancements. It should be noted that as components of a project mature the overarching project RL may be adjusted to depict the new overall system maturity. For transitions of technology, NOAA considers the intended application as well as the separate platform components, which might be commercially available off the shelf (COTS). COTS components are typically considered RL9, or ready for use. However, the use of a COTS component for anything other than their off the shelf use must be tested for specific applications, in which case the RL may be adjusted accordingly if continued R&D is necessary for specific application.

RLs provide outcome based benchmarks for project maturity. RL's "flatten the intellectual curve", enabling scientists, engineers, and project managers to understand how a technology is evolving regardless of their background or expertise, improving communication between stakeholders.

2.4 Research and Development and End User(s)/Adopter(s) Roles

End users play a critical role in determining the readiness of R&D efforts for Operational use. Early engagement with end users is essential and can be facilitated by a transition or program plan that provides the vision for the project. By enabling end users to communicate their requirements, transition plans enable R&D outcomes to better align with mission needs. Upon acceptance, end users are responsible for necessary resources to support implementation.

2.5 Transition Acceptance Criteria

Before any R&D outcome is transitioned, it must meet the end user(s)/adopter(s) defined transition acceptance criteria. This criteria is any part(s) of the R&D outcome that the end user(s)/adopter(s) deem as necessary to meet before the R&D outcome can be transitioned. This information should be provided directly by the corresponding line office(s)/partner(s)/end user(s)/adopter team(s) and should include (when relevant) quantified information regarding required product specifications, data accuracy metrics, capability performance characteristics, survey satisfaction thresholds, etc. This can include setting quality standards, ensuring data format is ingestible in existing models, and systems are usable by end user(s)/adopter(s) for their intended purposes. This transition acceptance criteria can also be addressed in what are sometimes referred to as program plans.

2.6 Other Agency "Operational" Definitions and Comments

2.6.1 Naval Information Warfare Center Pacific Technical Director, Unmanned Maritime Vehicles Lab

"Full Operational Capability is the full capability to employ effectively a system of approved specific characteristics, and which is manned and operated by an adequately trained, equipped and supported unit." (Full Operational Capability is defined by the JP 1-02).

"Operational readiness — The capability of a unit/formation, ship, weapon system, or equipment to perform the missions or functions for which it is organized or designed."

2.6.2 Naval Meteorology and Oceanography Command

The Naval Meteorology and Oceanography Command indicated that their definition for 'Operational' would include: "Meets operator-defined capability requirements, and targeted use cases."

3. RL9 / Operational Relationship

As per current official guidelines, RL8 indicates that the final system, service, or product (e.g. UxS observing system) has been demonstrated in the operational (or intended) environment. The final, fully integrated system is "mission qualified" upon demonstration in the operational environment for which the application has been developed. By this stage, all system development has been completed and fully integrated with any existing hardware and software systems for its intended use. All functionality has been tested in simulated and operational scenarios, and ‘verification and validation’ has also been completed. Most user documentation, which includes training and maintenance documentation, has been developed at this point. RL8 is the final stage before the technology becomes fully Operational and used to meet the end user(s) mission needs.

RL9 means that the final, fully integrated system is adopted by the end user(s) and successfully transitioned into routine mission operations or is used “as needed” for target applications. It is fully integrated with existing Operational hardware and software systems, and sustained engineering maintenance and/or budgetary support have been arranged by the adopting end user(s). In addition, the data or observations have passed the end user(s) criteria for transition acceptance. However, if R&D is still ongoing in order for data to meet that specific mission need then the combined observing system is not at an RL9. At RL9 all functionality has been thoroughly tested in its operational environment with proven mission success. All user documentation which includes training and maintenance is complete.

This working group determined that RL9 and the term Operational are synonymous, with some specific clarifications. Due to the broad scope of R&D projects to which RLs are assessed, the definition of RL9 needs to be equally as broad. However, our definition of Operational for UxS can be more specific. This will be addressed in the next sections as far as the definition and clarifications when conveying information on Operational status.

4. Operational Definition

To develop preliminary Operational definitions for UxS, working group members participated in an exercise with each line office representative, independently formulating an Operational definition and then comparing the commonalities and differences between definitions. Four main areas were common among these definitions:

1. End user interaction
2. Usability/quality of the R&D outcome
3. Resource limitation
4. Final purpose

These main components were combined and expanded upon to create the final proposed Operational definition:

> *"Meets end-user-defined mission needs and is in use as needed at the intended scale of operation. Project outcome has been quality tested and has met end user transition criteria. The necessary funding, personnel, and infrastructure to routinely operate and maintain the project outcome are available. Researchers and developers have provided end users with all required tools, techniques, information, and documentation for operation, which may include training materials, knowledge and understanding of Operational procedures, data management plans, and required maintenance information."*

While the intent of this definition is to define what Operational is for UxS, the definition is intentionally broad and generic in order to encompass most applications and be as forward and backward compatible with related policies as possible. UxS are used for a plethora of diverse, unrelated applications. As such, adding too many specifics into an Operational definition may cause disagreement on the usability of the definition for various UxS applications. Additionally, we acknowledge the importance of Operational labeling in acquiring funding and gaining situational awareness for various projects and do not wish to limit projects that may not meet a more specific Operational definition.

There are those who will differ on what parts of an asset make its entirety Operational but our Operational designation is based on specific needs and mission application. The proposed definition is focused on meeting an end user's mission application (scientific need) or hardware requirement. For example, is a drone deployed from a NOAA aircraft defined as "Operational" if it is successfully launched and flies as designed without consideration for the data that is collected to meet the scientific application need? When one uses the word "Operational" there may be a need to provide clarifications so ambiguity is narrowed, as there may be multiple end users at different stages that consider parts as Operational versus the ultimate scientific application.

5. Clarifications to the Operational Definition

In this section, we introduce a set of clarifications and considerations that expand upon the definition of "Operational" presented above. The concepts presented here are not intended to be prescriptive or comprehensive; but rather are intended to aid users in applying the general definition of Operational to specific, real-world cases.

5.1 Defining R&D and Operational Reference Terms

It is important to make the distinction between certain R&D and Operations terms that may lead to confusion about the overall RL of an effort. These terms are often used in place of late stage RLs as described in NAO 126-105B.

Ready for Operations, Operational, Initial Operating Capability, and Full Operating Capability, describe the steps between and after RL8 and RL9. Ready for Operations describes when a R&D outcome has been proven usable through the demonstration of its success. This is synonymous with RL8. When a UxS platform can sustain operations and maintenance costs and is fully usable by the end user(s) without the assistance of the R&D entity, it is considered Operational or RL9.

One of the most compelling benefits of UxS is the potential for scalability beyond what is often possible for crewed systems. UxS operational models are often designed to involve multiple systems, working in conjunction, with fewer personnel than would be required for the crewed equivalent. As such, when considering if a UxS technology is Operational, it is critical to also consider the scale at which it has already been deployed and proven, and compare it to the scale at which it is intended to operate moving forward.

Two Defense Acquisition Terms can be used to further describe Operational. Within RL9, a UxS platform can be considered Operational but may not be fully implemented on the spatial or temporal scales desired due to funding, personnel, or infrastructure (not R&D support), this is defined as the Initial Operating Capability (IOC). When an Operational effort is fully implemented at the scale intended, it is considered to have reached its Full Operating Capability (FOC).

There are instances when high value R&D projects are unable to cross the “valley of death,” the term that describes the gap that exists between R&D and operations, mission needs, applications, and other uses. The term “Crossing the Valley of Death” was outlined in a National Academy of Sciences publication in 2000 as a “fundamental challenge for research and development to implementation.” Still to this day, it is not uncommon for impactful innovative technology projects to stall or stagnate in the transition process at high RLs due to funding shortfalls or missing pieces on collaboration with end users and/or development of a transition plan. This can be, and is, the case with some NOAA technologies that are Ready for Operations (RL8) to bridge the “valley of death” gap to become Operational (RL9/IOC/FOC) as well as Operational technologies that have reached their Initial Operating Capability but require more resources to reach Full Operational Capability.

NOAA needs to ensure its R&D keeps the agency and the U.S. as the global leader in environmental science, monitoring, and observing. Support for transitioning R&D into operations, applications, commercialization, and other uses helps ensure NOAA, and thus the Federal government, receives the best possible return on its investment in the R&D realm. This concept is aligned with the Federal Government administration's efforts to tap into America's scientists, and work towards acquiring additional funding, to lead innovation around the globe.

5.2 Knowledge and Understanding of Operational Procedures

While UxS are broadly integrated into NOAA's mission, many potential field users do not necessarily have in-depth expertise with UxS operations. In fact, it is common for operators of crewed systems to receive cross-training on UxS to augment their otherwise crewed work. Ensuring that prospective field operators have the requisite knowledge and understanding of operational procedures is critical to considering whether or not a system is Operational. For UxS this step can be, and often is, more challenging and involved than crewed alternatives where there may already be a high degree of operational experience.

Below are possible considerations for evaluating the knowledge and understanding of UxS operational procedures for a particular platform.

- Knowledge
    - Have operators and users received appropriate and effective training on the system in question?
    - Is there procedural documentation in place? Is this documentation complete?
    - Is there a gap between the procedural documentation and the actual practice of the operators?
- Understanding
    - Have prospective operators had the opportunity to build a wide enough base of operational experience under supervision to operate the UxS safely and effectively on their own, without supervision?
    - Do operators have the ability to reliably maintain and operate the UxS in expected real-world conditions?

5.3 Required Maintenance Information

By definition, UxS do not have the advantage of an onboard operator to observe the systems' characteristics in the field. When operating crewed systems, a trained operator—for example a small boat coxswain or aircraft pilot—is attuned to a diverse variety of sounds, sights, smells, and feedback mechanisms that can provide early warning of equipment failure. In place of an operator, UxS generally rely on a suite of sensors to relay diagnostic information to remote operators or automated monitoring systems. This separation of operator and craft can and does introduce a unique challenge for UxS, as compared to their crewed counterparts. One strategy to address this challenge is through rigorous and robust preventative maintenance, that may be more involved and different than what end-users are accustomed to with crewed systems. The list below is a set of possible considerations for preventative maintenance, failure detection, and troubleshooting to aid in assessing whether or not a system is Operational.

- Review the preventative maintenance plan, if applicable. Based on field-operator experience, are there any overlooked failure points that need to be addressed? Does the recommended interval agree with in-house expertise?
- What onboard failure detection and mitigation capabilities are in-place on the UxS (ex: cameras in the engine room, battery heat sensors, fire detection systems, bilge sensors, etc.)? Are there any likely failures that could go undetected for a long period of time or result in a catastrophic failure? If so, is it appropriate to address it with preventative maintenance?

5.4 Funding Availability

Funding is a common barrier to operationalizing an R&D output. Without the necessary funding to use a R&D outcome as intended, it can only be identified as "ready for operations" and not "Operational" (see Example 6.3). It is imperative that the transition plan team engage the end user(s)/adopter(s) of the R&D and provide a vision of the estimated costs associated with operationalizing the technology in order to have a successful transition to operations. This engagement may require labs, offices, and/or line offices to consider line items in their budgets.

As part of the transition process, the transition team must lay out a roadmap or vision for their project describing its entire intended evolution. The "Valley of Death" caused by funding shortfalls may be overcome through the establishment of an official bridging program that provides funding to projects in order to cross them over from "ready for operations" into "Operations". This bridging program would help accelerate transitions in NOAA and ensure that NOAA receives the best possible return on its investment in R&D.

5.5 Hardware

Many UxS have hardware that has already been tested and considered Operational for specific capabilities, but is considered non-operational when used in an application other than what operational testing was completed for (see Examples 6.1-6.2). With few exceptions, most UxS COTS platforms and sensors are widely available with manufacturer-specified environmental operation limits and published documentation, and have been vetted by a sizable consumer base. To that end, most individual COTS UXS platforms and sensors need to be assessed to see if they meet NOAA specific mission needs as defined by the end user(s)/adopter(s) before they can be considered Operational.

Newly customized UxS platforms and sensors, including COTS platforms, that are significantly augmented for or during a project, would likely be assessed at lower RL ratings (non-operational) during initial testing and evaluation. These platforms would progress through RLs as a project matures.

5.6 Mission Specific Use

The whole R&D outcome is considered when determining Operational status, not only hardware/software but also data validation/quality control, distribution, and management when applicable to meet the end user(s) mission needs. A platform deemed Operational for one specific use may not be considered Operational for another use based on an end user(s) mission needs and transition acceptance criteria. Similarly, an Operational platform may revert to a non-operational status; requiring additional R&D once non-operational payloads are added on. The focus of the term Operational is to meet the mission needs of the end user(s). Therefore, technologies may be considered Operational for one end user and not another depending on the specific mission need.

5.7 Data Buys

Data buys can be considered Operational for missions when the end user(s)/adopter(s) have evaluated and determined that the technology via data quality, usability in models, etc. meet the mission needs as contracted. For example the Office of Ocean Exploration and Research has determined and verified that in some cases bathymetry observations obtained via UxS data buys meet their criteria of International Hydrographic Organization standards, etc. that technology that supports the data buys is Operational.

However, when a data buy is considered in order to obtain observations in support of R&D to evaluate the use of UxS data or other technology in which additional work is required, the data buy is considered non-operational. To become Operational the maturity of the technology/observations must be assessed and transitioned to its intended use when and if mission acceptance criteria are met.

6. Examples

6.1 Small Uncrewed Aircraft Systems (sUAS)

It is important to consider the potential for multiple operational applications resulting from one UxS platform. For example, NOAA is testing several small crewed aircraft systems (sUAS) designed to enhance data coverage of the critically important, yet sparsely-sampled, tropical cyclone (TC) boundary layer. The technology itself is currently at a mature RL after successful flights into TCs. The goal is to transition the technology to the Office of Marine and Aviation Operations (OMAO) Aircraft Operations Center (AOC), the asset operator. However, the longer term, more critical goals include additional operational end use applications, specifically data integration into the National Weather Service's (NWS) National Hurricane Center's (NHC) visualization tools and data assimilation (DA) into the NWS' Environmental Modeling Center (EMC) hurricane forecast models. The former application (NHC) was demonstrated via ad hoc data distribution methods in near real time and hence is at moderately mature RLs, whereas the DA efforts (EMC) are at a relatively low RL as that effort requires additional substantial testing and evaluation in the models and may take years to reach RL9.

6.2 Saildrone

Saildrones provide uncrewed observations of the upper ocean and near-surface atmosphere for improved hurricane intensity prediction. While the saildrone sensors, data acquisition/transfer, and standard platforms might be close to RL9 when used in low-moderate winds, for extreme weather uses RLs are closer to 6-7. For example, in hurricanes Fiona and Ian there were wing/sensor failures in strong winds/waves that Saildrone, Inc. is addressing; these were previously considered Operational for milder weather conditions. Additionally, real-time data transmission improvements continue to evolve.

In another case, saildrones are considered Operational (RL9) to meet National Data Buoy Center (NDBC) mission needs of collecting observations to temporarily replace malfunctioning moored buoys and permanent buoy replacements within National Marine Sanctuaries (NMS). NDBC has enhanced its capabilities of the moored buoy data observation system which augments the continuation of critical observing requirements for NOAA and the National Weather Service. The goal of these types of projects is to have the ability, on an as-needed basis, to use UMS as stand-ins for buoys that have malfunctioned as well as to replace moored buoys within NMS to mitigate potential damage to their sensitive ecosystems.

Although the functional capability of the short-wing saildrone Uncrewed Surface Vehicle (USV) as a standalone observation platform is relatively mature, the application of data collected from saildrones for assimilation into NOAA's numerical weather prediction (NWP) TC forecast models is not yet Operational, as more testing and evaluation is needed/ongoing.

6.3 High-altitude AirCore Retrieval System (HORUS) for Atmospheric Greenhouse Gas Profiling

HORUS has been designed, tested, and "ready for operations" (RL8) under the definition that flight has been demonstrated in controlled airspace in Northeastern Colorado alongside with full documentation of operating procedures and flight protocols. HORUS is now ready to be put into regular use to meet mission needs and become Operational (RL9).

The acceptance criteria for transition of the HORUS to operations specify that the HORUS must be successfully proven via deployment in its intended operational environment in northeastern Colorado to 28 km (90,000 ft) MSL. Additionally, the full science payload should be nominally functioning and providing high-quality AirCore and meteorological observations without significant biases, data dropouts, or errors. These criteria were met as of May 2023.

Successful transition to an Operational level requires (quarterly to monthly) mission use of the platform with full science payload, alongside refined and solidified operating procedures over the course of a year.

It is anticipated that the HORUS system will cost approximately $10,000 per flight with up to 12 flights per year that equate to approximately $120,000 per year in operating costs. The cost to cross the "Valley of Death" is at this point in time an impediment as Global Monitoring Laboratory (GML), who is the end user, has not yet committed to allocate the necessary funding to enable this technology to become Operational. As such, it remains "ready for operations" (RL8) but not yet Operational (RL9) even though the HORUS itself has met the end user defined transition acceptance criteria.

6.4 Fisheries Surveys

As another example, but not UxS related, NOAA ships are operationally used for fish surveys by the National Marine Fisheries Service (NMFS). The ships themselves are considered Operational to meet the mission needs of OMAO, however they still occasionally experience malfunctions. The presence of a malfunction on a NOAA ship does not revoke the ship's Operational status to meet OMAO's mission needs.

However, if planned fish surveys are cut short due to NOAA ship malfunctions the Operational use of the survey data is impacted. The NMFS Stock Assessment Review panel (STAR) deems any partial survey data as non-usable to meet their mission needs. Thus, although the Operational status of NOAA ship usage for OMAO is not impacted, the Operational status of the survey data collected is considered non-operational to meet the mission needs of NMFS. This exemplifies how the use of the term Operational is mission specific.

7. Summary

As indicated, the Uncrewed Systems (UxS) Mature Technology Working Group was created by the UxS Executive Oversight Board (EOB) in January 2024, with the objective to: Establish consensus on use of the terms 'Readiness Level 9' and 'Operational' with regards to mature UxS technologies by the end of FY24. Over the following months, the working group met on a bi-weekly basis to review the various NOAA Administrative orders, guidelines, and best practices/lessons learned until coming to an agreement on a concise, yet broadly applicable, definition for what can be considered "Operational" for UxS projects. While this working group's Operational definition is primarily directed towards UxS, its scope can be extended to all research and development within NOAA.

The final proposed definition of "Operational" is as follows:

> *"Meets end-user-defined mission needs and is in use as needed at the intended scale of operation. Project outcome has been quality tested and has met end user transition criteria. The necessary funding, personnel, and infrastructure routinely operate and maintain the project outcome are available. Researchers and developers have provided end users with all required tools, techniques, information, and documentation for operation, which may include training materials, knowledge and understanding of Operational procedures, data management plans, and required maintenance information."*

While the intent of this definition is to define what is Operational for UxS, the definition is intentionally broad and generic in order to encompass most applications and be as forward and backward compatible with related policies as possible. Caveats may exist when indicating that something is "Operational" because one person's mission needs for a specific application may be different than others.

It is important to make the distinction between "Operational" and "ready for operations". While an R&D outcome can be proven usable through the demonstration of its success by R&D entities it cannot be considered “Operational” until it is fully usable by the end user(s) without the continued assistance of the transitioning researchers and developers.

A special thanks goes out to all those who served on the Uncrewed Systems (UxS) Mature Technology Working Group, which were representatives from each of the line offices who provided their expertise and assistance throughout all aspects of our study and agreement on what “Operational” means in the realm of UxS projects.

8. List of Acronyms

COTS	Commercially Available Off the Shelf
DA	Data Assimilation
EMC	Environmental Modeling Center
EOB	Executive Oversight Board
FOC	Full Operational Capability
GML	Global Monitoring Laboratory
HORUS	High-altitude AirCore Retrieval System
IOC	Initial Operational Capability
NDBC	National Data Buoy Center
NHC	National Hurricane Center
NMFS	National Marine Fisheries Service
NMS	National Marine Sanctuaries
NWP	Numerical Weather Prediction
NWS	National Weather Service
OMAO	Office of Marine and Aviation Operations
R&D	Research and Development
RL	Readiness Levels
RLTTF	Readiness Level Training Task Force
STAR	Stock Assessment Review Panel
sUAS	Small Uncrewed Aircraft Systems
TC	Tropical Cyclone
TRL	Technical Readiness Level
UAS	Uncrewed Aircraft Systems
UMS	Uncrewed Marine Systems
USV	Uncrewed Surface Vehicle
UxS	Uncrewed Systems

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