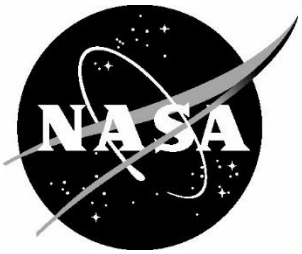
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Earth Independent Medical Operations [EIMO] Definition Workshop

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February 2024

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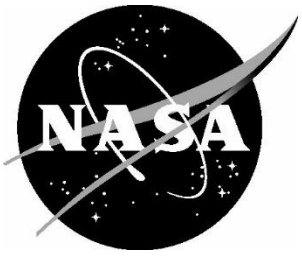
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1 BACKGROUND

This brief conceptual background of the concept of EIMO was given to participants prior to the leadership meeting.

As the vanguard of human spaceflight increasingly transitions from one of low Earth orbit (LEO) to Lunar and subsequently Martian missions, there is a commensurate imperative for Earth-based medical authority to transition to space-based assets for the continued assurance of optimal astronaut health and performance. The transition to *Earth Independent Medical Operations* (EIMO) will be a process that enables progressively resilient systems and crews to reduce risk and enhance wellness and overall mission success for deep space exploration. Terrestrial assets will continue to be paramount in pre-mission screening, planning, maintenance, and prevention. Yet on-board care, response to unexpected medical events, and management of communication delays and dropouts will increasingly become the purview of the crew for primary management.

As with many developments in space medicine, EIMO will build upon historical successes and innovations. Mission support for Mercury and Gemini taught valuable lessons when designing support for Apollo, which in turn informed Skylab, Shuttle, Mir-Shuttle, and later the International Space Station (ISS). However, while lessons from each previous program informed the next, few would argue that Mercury era medical support could meet the needs of today's ISS.

Just as each past program required a rethinking of the interaction between ground-based controllers and space-based crew, so too will future missions to the Moon and Mars. The communication delays, restricted data channel capacity, limited or absent resupply, operational challenges, and prolonged evacuation times will necessitate an unprecedented degree of independence from Earth. To achieve this, exploration mission planners must anticipate mission needs and design systems and procedures to support the increased autonomy, technological advancement, and expanded medical capability required in the exploration environment.

Previous meetings within the ExMC Element have proposed that the definition of Earth Independent Medical Operations could be the transition of medical authority from terrestrial to space-based assets to enable support of astronaut health and performance. From this broad definition, ExMC has defined the constituent elements of EIMO within the following categories:

1.1 Pre-Mission Planning

Compared with current LEO operations, pre-mission planning is likely to be even more critical with EIMO. Based on the established Concept of Operations for Artemis and Mars missions, we anticipate several high yield areas of pre-mission planning for EIMO which will require further conceptualization and build upon current standard operations products. The first includes maturation and operational integration of the IMPACT probabilistic risk assessment and trade space tool, to better quantify medical risks across a broad swath of medical conditions. The second is a likewise maturation and implementation of onboard routine medical training/practice modules as well as Just-In-Time Training (JITT) for diagnostic and therapeutic interventions.

Such systems can also be augmented to provide estimations of the optimal crew *knowledge, skills and abilities* (KSA), details of what ground and JITT training may be most beneficial, set research priorities for risk reduction, and help reallocate remaining in-flight resources to achieve the lowest possible risk based on updated in-mission data.

1.2 Acute and Emergent Management Decision Making

Distance, communication latency, and reduced data channel capacity for ground-based assistance will necessitate that the onboard KSA must be at the minimum level required to stabilize and manage the initial stages of any anticipated conditions. Given these realities, there exists an imperative to enhance an onboard medical provider's skills via JITT, decision support tools, knowledge databases, and through mixed reality augmentation. Previous experimental studies have demonstrated that well-designed clinical decision support systems (CDSS) can drastically increase the number of anticipated medical conditions that can be proficiently treated in space without direct support from the ground.

1.3 Prolonged Medical Management Decision Making

Non emergent conditions are often manageable via telemedicine and may not require immediate subject matter expert (SME) input. In deep space, a lack of continuous availability of SME input, significant response latency, and lower data transmission rates will affect the ability to transmit high resolution images, video, and other telemedical data to aid in prevention, early detection, or mitigation of new conditions. Thus, even for non-emergent medical problems, there will be a requirement for high onboard KSA—via a skilled medical practitioner and/or a highly functional CDSS.

1.4 Supplies and Resource Management

Medical resourcing has historically been chosen via expert clinical opinion. Any supplies/use mismatches were mitigated by either the short duration of the mission or by sending additional supplies into orbit on the next resupply mission. Exploration class missions will not be able to rely on resupply and will have to confront expired or reduced efficacy medications. This means supplies must be carefully chosen to account for mass and volume restrictions, medication stability, and their potential for re-use. In addition to the aforementioned trade space tools for risk mitigation, innovation into regenerable or on-demand resourcing such as 3D printers or plant based pharmaceutical "farms" could significantly enhance the resilience of exploration medical systems.

1.5 Task Load Management

Another significant consideration for EIMO will be task switching and cognitive load. LEO operations allow crew members to offload many medical decisions, monitoring, and other tasks to ground based flight surgeons, specialists, and biomedical engineers. This allows the Crew Medical Officer (CMO) to focus directly on patient care and avoid task saturation and increased stress during both routine and acute care scenarios. EIMO, however, will require CMO's to

perform these functions largely on their own which will create higher task demand, increased task switching, and higher cognitive load. This has been shown to impair decision making and affect the quality of patient care which in turn may affect the success of a mission.

One solution to this is to identify tasks which can be delegated to computerized tools integrated with the onboard medical system. Such a CDSS could assist with tasks such as inventory management, locating resources, storing and retrieving medical records, highlighting trends in recorded data, scheduling and reminders, record keeping, and even diagnostic and treatment suggestions. Such tools are now integrated in terrestrial electronic medical records and, when designed well, can substantially reduce the task burden on a provider. A system designed for EIMO missions must be easy to use, intuitive, reliable, and fast. More advanced systems may even be able to passively monitor crew for early signs of behavioral or medical anomalies, provide diagnostic assistance, autonomously suggest treatments, and guide crew members through procedures. In this sense, a comprehensive CDSS could enhance many aspects of care that are currently provided by Mission Control and be the cornerstone of effective Earth independent medical care.

2 EIMO LEADERSHIP MEETING

On January 10th, 2023, ExMC convened a panel of NASA leadership, broadly representing the Human Research Program, Medical Operations, the Human Health and Performance Directorate (SA) at JSC, the Health and Medical Technical Authority, the Flight Operations Directorate, and other stakeholders to discuss EIMO, and how to strategically advance the concept throughout NASA and with stakeholders.

A series of questions were posed to the participants and the most salient points of the conversation summarized below:

2.1 What other factors might drive a need for a new paradigm? What we are we missing? What have we left out?

- While EIMO systems will need to be designed for robustness, there is a concomitant need for systems that are nimble, malleable, and with the capacity to evolve over time. Crew health and performance will need to be supported across multiple habitats, vehicles, and suits, in some cases designed over many years and with differing requirements. The importance of information flow throughout the systems via an integrated data architecture cannot be overstated.
- Communication latency is a well know challenge to EIMO, yet there will be an imperative to address a less-well understood impact on behavioral and team dynamics from these communication delays with Earth.
- Another factor that needs to be considered are the training paradigms best suited for advancing EIMO. Specifically, to what degree do we train toward technical specialization and expertise versus just hiring a ‘MacGyver,’ i.e. selecting for improvisational proficiency and just-in-time learning. This consideration will be key in not only astronaut selection, but in training, policies, and procedures for ground support for this new paradigm.

- NASA has never before faced the possibility of flying a space mission from which evacuation is, for all intents and purposes, impossible. Once the transit to Mars phase of the first Mars mission begins, the crew will have to rely on their abilities, vehicle, systems, and onboard resources to manage any and all medical events that may occur (with as much ground support as is possible and practical).
- A final consideration is the need to account for Martian surface environments and changes from prolonged microgravity exposure. Current operational health paradigms are not designed for the increased risk of prolonged environmental exposures in longer duration missions [ex: <12 months on ISS versus 2+ years for Mars].

2.2 How to strike the right balance between medical risk reduction and exploration mission resource constraints?

Probabilistic risk assessment has demonstrated that medical risk in long duration, explorations missions will be significantly greater than anything in NASA's historical experience; accordingly, it will be important to have transparent communications regarding the medical risk and a shared understanding amongst mission-planning and vehicle design stakeholders. NASA is not resigned to merely assume a 'black box' in estimating risk for these missions, but rather tools like IMPACT will be able to help systematically quantify medical risk for these novel missions. Moreover, these types of tools will help to facilitate conversations with appropriate stakeholders about the trade-offs between medical risk and medical system resource allocations. It is widely assumed that initial medical risks will be formidable but will decline over subsequent missions with increased experience and medical system refinement.

In balancing the trade-off between medical risk and resources, there are two potential approaches, *top-down* and *bottom-up*, that can help in defining risk envelopes. Regarding the former, medical system design teams may consider everything we could potentially want in capabilities and resources, and then begin a process of tailoring to specific missions and vehicles. From the bottom-up, we may consider the truly essential 'must-have' systems and resources via OCHMO and NASA 3001 standards. Each approach will generate different estimates of medical risk, and the approaches can then be integrated to bring medical risk and resource utilization into acceptable ranges. As these medical system designs are refined, EIMO will push the evolution of the conversation from that of the paradigm of '*what's in our medical kit to treat the astronaut?'* to that of '*how redundant, sophisticated and resilient is our medical system, such that it can include autonomous medical support and be integrated with crew health and performance integrated data architectures?*' A final consideration, reiterating on the likelihood of diminishing risk with lessons learned from each successful mission, is the importance of prospectively planning for medical system evolution and change across missions (both for the Moon and for Mars).

One potential communications strategy for advancing EIMO efforts is to couch medical risk reductions as a means to increase in-flight human performance and therefore, improve the chances of mission success.

2.3 When do we know that we've achieved EIMO? What does success look like?

When considering endpoints for EIMO—what does success look like? There was some debate on whether there really should be a hard endpoint for EIMO or if it is instead a constant pursuit for medical system improvement. However, milestones will indeed be useful, and discrete re-evaluations of medical capabilities will be needed as the Artemis missions progress, in order to advance and refine EIMO concepts.

Another approach raised was to think about EIMO as a solution space for a discrete set of challenges. For example, regarding anticipated communication delays: consider forgoing a fully-independent EIMO solution in favor of doing what is necessary to 'off-load' the crew from the communication disruption, while keeping things as ground supported as possible. This point brings up a question of whether EIMO should be an aspirational goal or a coordinated effort to accomplish only those functions that are absolutely necessary. In summary, it was generally agreed that EIMO should be conceived less as an endpoint, but more as a spectrum.

2.4 Clarifying 'as much as possible' versus 'as much as necessary'

Some of the core components of EIMO were articulated as:

- Emergency response to illness and injury
- Initiation and maintenance of diagnosis and treatment activities onboard
- Gathering of relevant medical information needed to solicit SME inputs from Earth
- Inherent capacity for re-evaluation and updating of medical assessment and plan

In this essential understanding of EIMO, it follows that there will always be a subset of medical conditions that will need to be handled emergently, with a time-sensitive window for intervention, driving EIMO through diagnoses and timelines as a means to determine what capacities and resources are absolutely necessary. Simulations will be integral in prototyping responses to medical conditions and determining onboard capabilities in order to characterize how an autonomous approach will impact crew and mission outcomes based on different medical conditions. Likewise, there should be a clear understanding within EIMO for the delineation of medical needs [mitigation of illness & injury] versus broader crew health and performance needs.

2.5 What other stakeholders/organizations are not represented today that we need to hear their voices as SMEs?

Numerous stakeholders and additional voices will need to be added to the conversation, with recognition that diverse and disparate subject matter experts will bring unique skillsets and assumptions to the scope of EIMO.

They include perspectives in:

- Astronauts – greater inputs from the Crew Office
- Analog time-delay and human factors experts
- Biomedical engineering (BMEs)
- Commercial spaceflight partners
- Specialty areas such as dentistry, nursing, robotics, rehabilitation
- Ethics and policy experts
- New Moon to Mars Program Office
- NASA HQ

2.6 What do long term collaborations and specific outputs for EIMO look like?

For transparency and awareness, a capability gap list and a dynamic, integrated EIMO roadmap is needed that details which organizations have which responsibilities under the EIMO umbrella. A near term goal will be an EIMO Concept of Operations that outlines the EIMO vision, the high level stakeholder needs, goals, and objectives for EIMO, along with representative scenarios that can be used begin the work of defining future EIMO requirements. This EIMO ConOps should be supported by other products for dissemination of EIMO information such as a centralized online domain, white papers, shared presentations, SME-TIM transcripts, and other resources for education and outreach. Also in the near term, sequential subject matter expert TIMs will be advantageous to further define EIMO, identify the capability gaps, and develop the roadmap. Ultimately, EIMO efforts should lead to the development and acceptance of requirements for a Mars-level medical system (primary target = Transit Habitat) that enables progressive Earth independence and autonomy.

Roadshow presentations to relevant forums, to include at least SA, HSRB, and HMTA, will be necessary for communicating work to Agency stakeholders.

3 CONCLUSION

Updated definition of Earth Independent Medical Operations:

The gradual transition of medical care and decision making from terrestrial to space-based assets, enabling support of astronaut health and performance and reducing overall mission risk.

We are grateful to all the participants in providing their time and energy to these deliberations, and for providing further clarity to the concept of EIMO. It's clear that EIMO is not a binary state with terrestrial support or the antonym of LEO medical operations, but rather a *gradual shift* in the balance of medical responsibility, management, and authority from terrestrial to space-based assets. It embodies a process of optimization of medical system autonomy for deep space missions. A precondition for EIMO is that it advances the prime metric of a lower overall

mission risk, and therefore must be integrated with all Agency efforts to achieve the more comprehensive Earth independent operations necessary to successfully complete a human mission to Mars. It is our hope, that through these conversations, we can create a shared EIMO paradigm and strategic vision for advancing medical system design through novel technologies, training, protocols, and support capabilities, built upon the spirit of successful strategies and innovations over the past six decades of space medical practice.

Attendees:

- Andrew Abercrombie (SK)
- Serena Aunon-Chancellor (CB)
- David Baumann (SA)
- Gary Beven (SD)
- Steve Davidson/John Allen (CN)
- Ben Easter (SD)
- Nancy Fleming (SF)
- Jeremy Frank (TI)
- Michelle Frieling (SA)
- Kris Lehnhardt (SD)
- Jay Lemery (SD)
- Kevin MacNeill (SF)
- Andrea Marchica (MSX)
- Torin McCoy (SK)
- Michelle Rucker (XM)
- Clarence Sams (SD)
- Rahul Suresh (SD)
- Moriah Thompson (SD)
- Denise Varga (BF)
- Sharmi Watkins (SA)
- Neil Zapp/Debbie Berdich (QA/QA)

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