ARTEMIS II MISSION MEDICAL RISK: A COMPARISON OF THE IMPACT AND IMM MODELING TOOLS

Human Research Program

Aerospace Medical Association & Undersea Hyperbaric Medical Society – June 5, 2025

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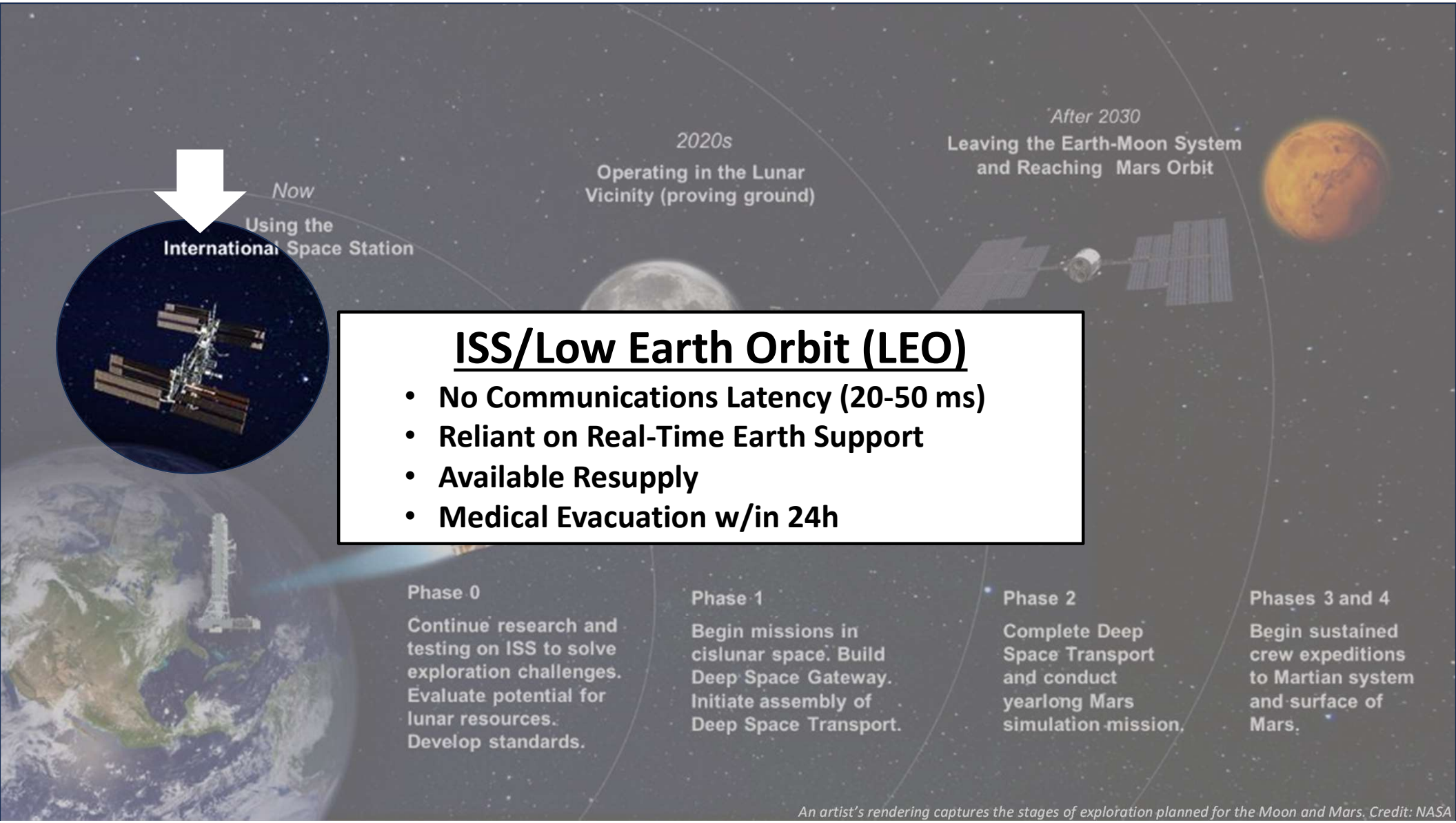
"Expanding the Boundaries of Space Medicine and Technology"

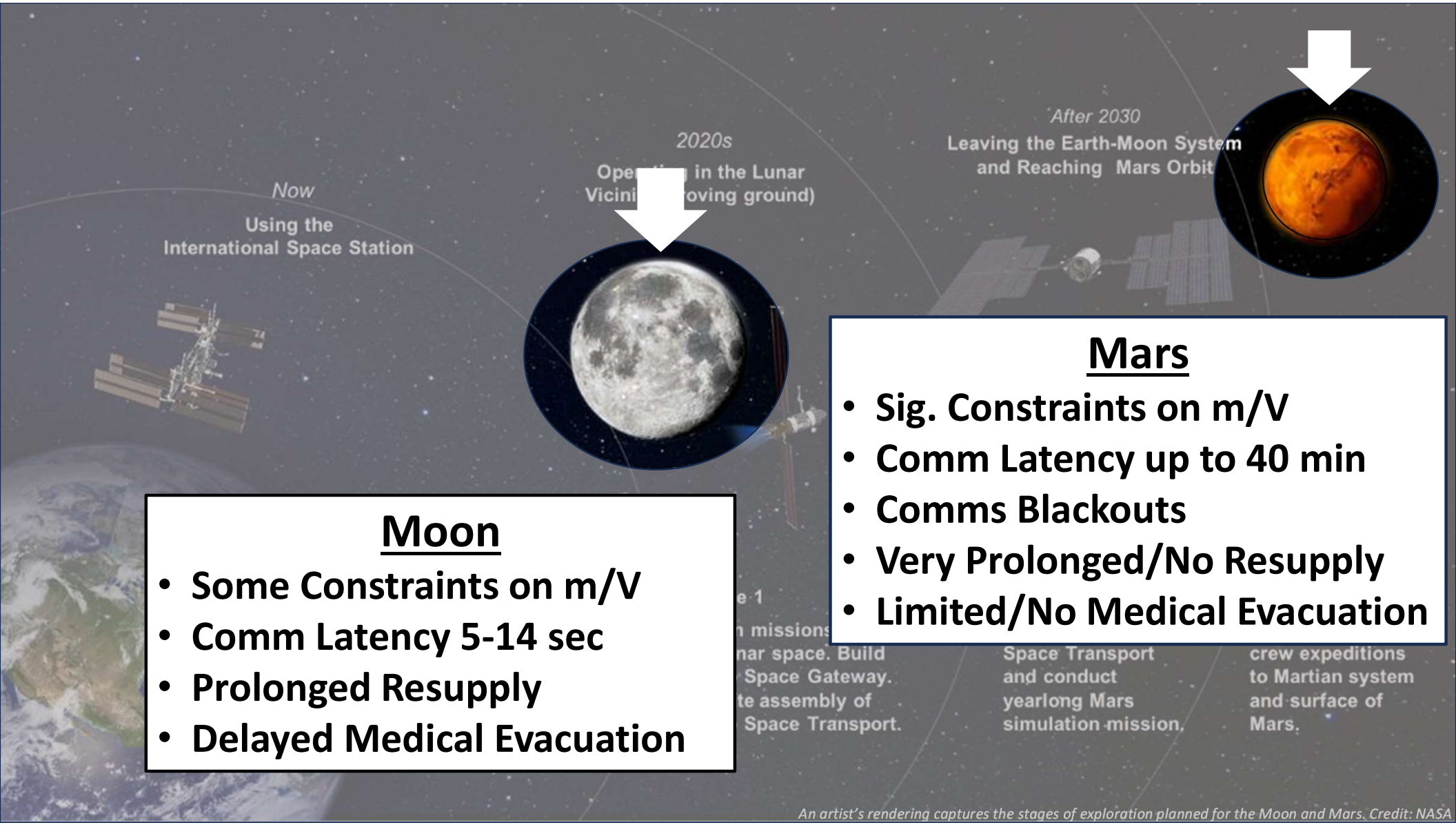
Agenda

- Background
- Medical Modeling Introduction
- Integrated Medical Model (IMM)
- Informing Mission Planners via Analysis of Complex Trade Spaces (IMPACT)
- Methods
- Results
- Next Steps

https://www.nasa.gov/mission/artemis-ii/



An artist's rendering captures the stages of exploration planned for the Moon and Mars. Credit: NASA



Moon

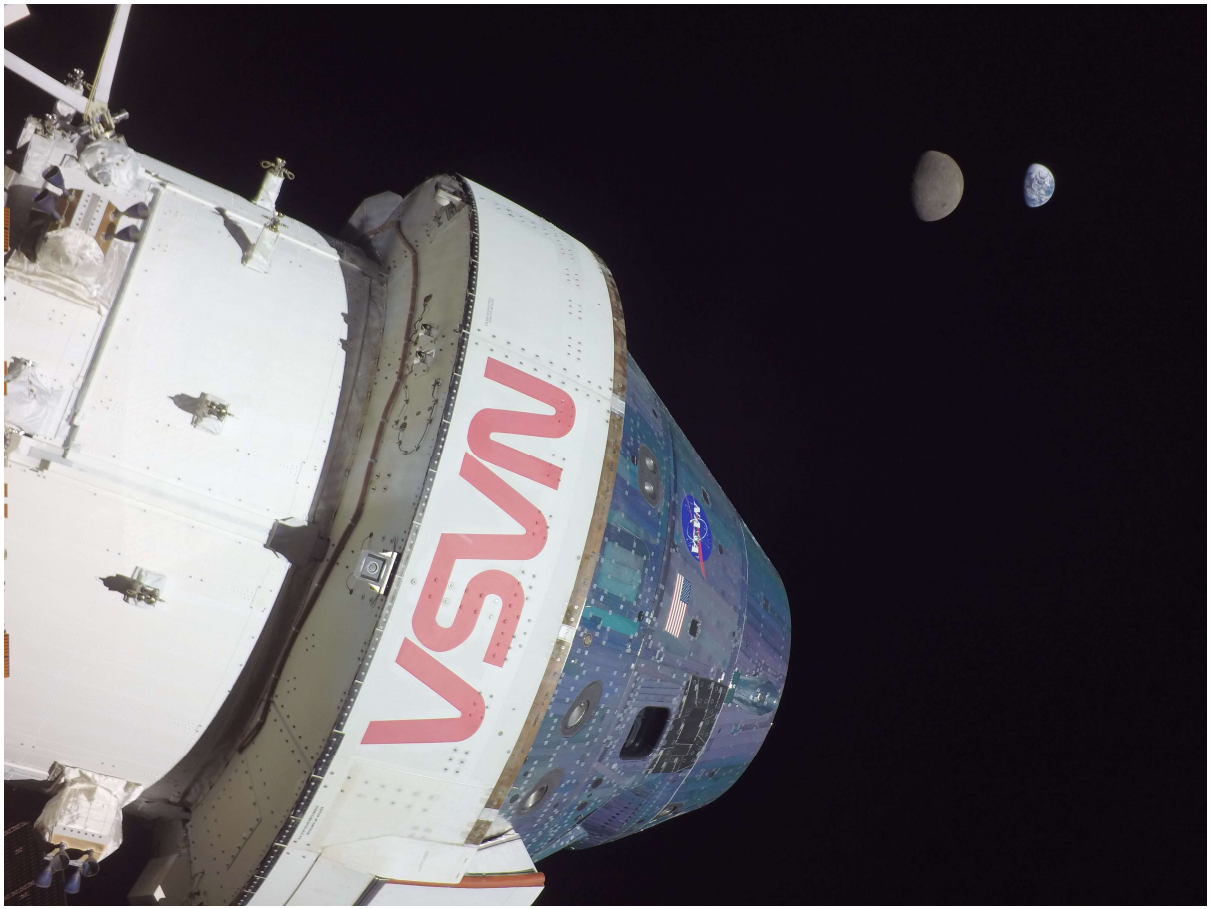
- Some Constraints on m/V
- Comm Latency 5-14 sec
- Prolonged Resupply
- Delayed Medical Evacuation

Mars

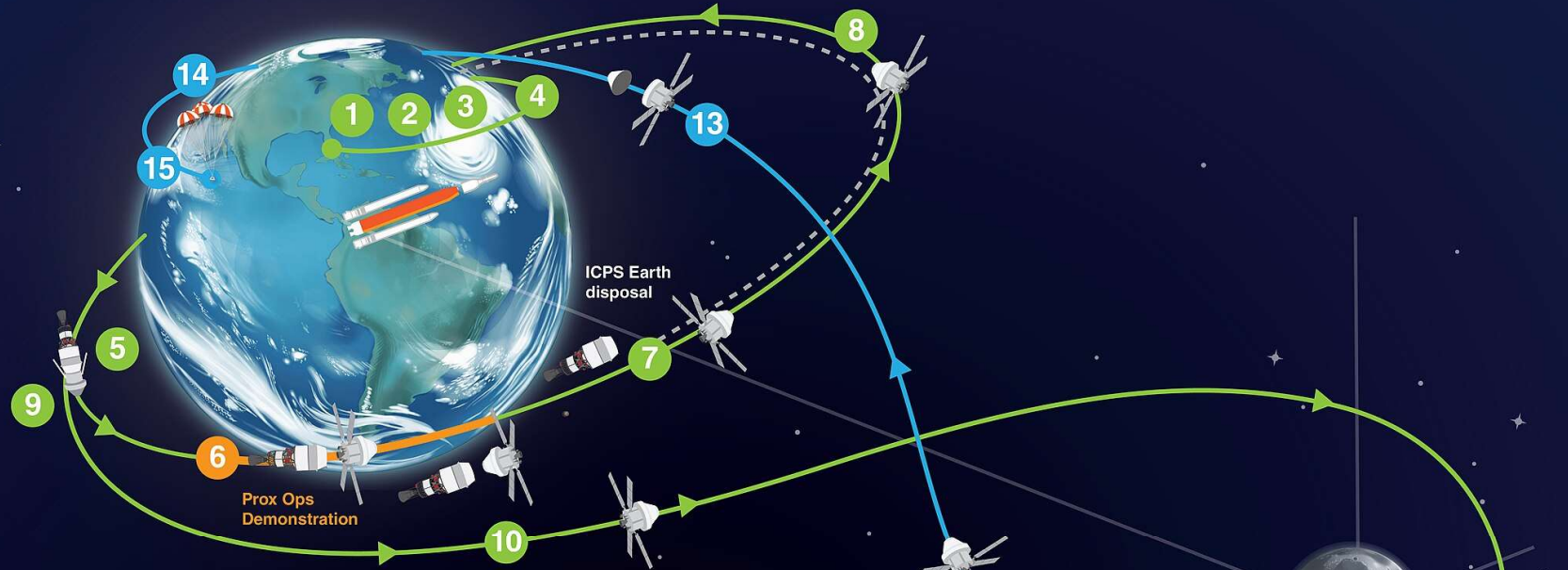
- Sig. Constraints on m/V
- Comm Latency up to 40 min
- Comms Blackouts
- Very Prolonged/No Resupply
- Limited/No Medical Evacuation

An artist's rendering captures the stages of exploration planned for the Moon and Mars. Credit: NASA

Artemis Program



https://www.nasa.gov/wp-content/uploads/2022/12/artemis_i_earth_moon_side_by_side.jpg



ARTEMIS II

First Crewed Test Flight to the Moon Since Apollo

1 LAUNCH
Astronauts lift off from pad 39B at Kennedy Space Center.

2 JETTISON SOLID ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM

3 CORE STAGE MAIN ENGINE CUT OFF
With separation.

4 PERIGEE RAISE MANEUVER

5 APOGEE RAISE BURN TO HIGH EARTH ORBIT
Begin 23.5 hour checkout of spacecraft.

6 ORION SEPARATION FROM INTERIM CRYOGENIC PROPULSION STAGE (ICPS) FOLLOWED BY PROX OPS DEMO
Plus manual handling qualities assessment for up to 2 hours.

7 ORION UPPER STAGE SEPARATION (USS) BURN
Begins high Earth orbit checkout. Life support, exercise, and habitation equipment evaluations.

8 PERIGEE RAISE BURN

9 TRANS-LUNAR INJECTION (TLI) BY ORION'S MAIN ENGINE
Lunar free return trajectory initiated with European service module.

10 OUTBOUND TRANSIT TO MOON
Outbound Trajectory Correction (OTC) burns as necessary for Lunar free return trajectory; travel time approximately 4 days.

11 LUNAR FLYBY
6,479 miles / 10,427 km (mean) lunar farside altitude.

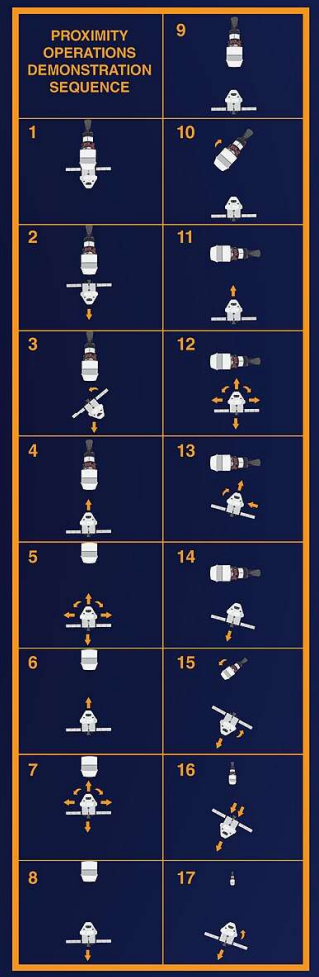
12 TRANS-EARTH RETURN
Return Trajectory Correction (RTC) burns as necessary to aim for Earth's atmosphere; travel time approximately 4 days.

13 CREW MODULE SEPARATION FROM SERVICE MODULE

14 ENTRY INTERFACE (EI)
Enter Earth's atmosphere.

15 SPLASHDOWN
Ship recovers astronauts and capsule.

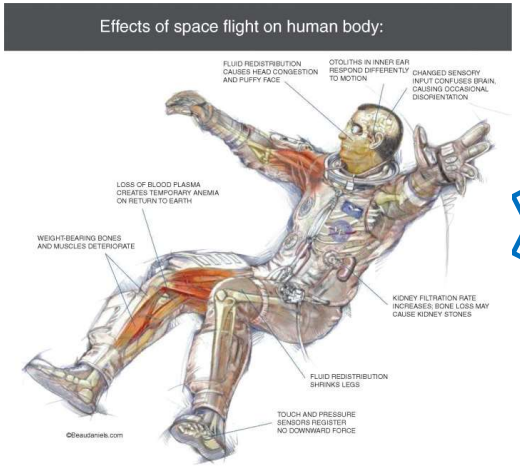
NASA ARTEMIS



https://www.nasa.gov/image-article/artemis-ii-map-2/

Medical Risk Modeling Tools

Medical Risk Modeling



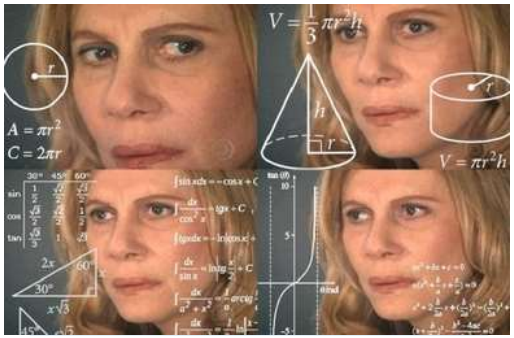
Mission Risk Metrics

- Loss of Crew Life (LOCL)
- EVAC/Removal to Definitive Care (RTDC)
- Task Time Lost (TTL)
- Resource Utilization

P.D. Hodkinson, R.A. Anderton, B.N. Posselt, K.J. Fong, An overview of space medicine, British Journal of Anaesthesia, Volume 119, Supplement 1, 2017, Pages i143-i153, ISSN 0007-0912,https://doi.org/10.1093/bja/aex336.

Scaling Up to Mission Risk

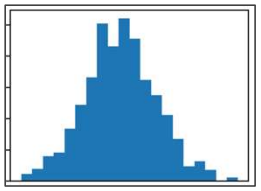
Database of
Medical Literature



Mission Parameters

- Mass and Volume
- Crew Characteristics
- Mission Duration
- Mission Segments
- Resources

100K – 500K Trials



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https://entretenimento.uol.com.br/noticias/redacao/2019/04/27/meme-da-nazare-confusa-foi-parar-em-uma-materia-do-mashable-sobre-vingadores.htm

Integrated Medical Model (IMM)

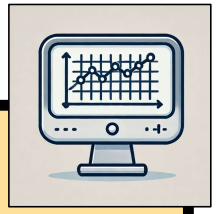
Scenario Definition/
Design Reference Mission (DRM)

iMED
Database

100 Medical Conditions:
ISS low earth orbit (LEO)

Integrated Medical Model

Probabilistic Risk Assessment/
Monte Carlo Simulation

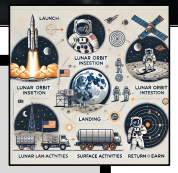


Estimated Mission Risk Metrics:

- Medical Events
- Crew Impairment
- Crew Health Index (CHI)
- EVAC
- LOCL
- Resources Utilized

IMPACT

Scenario Definition/
Design Reference Mission (DRM)

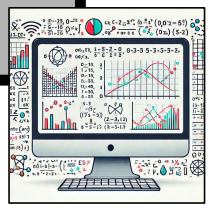


Evidence
Library (EvLib)

119 Medical Conditions:
Long-duration
exploration missions

IMPACT

Advanced Probabilistic Risk Assessment/
Monte Carlo Simulation (MEDPRAT)



Estimated Mission Risk Metrics:

- Medical Events
- Task Impairment
- Crew Task Index (CTI)
- RTDC
- LOCL
- Resources Utilized

The IMPACT Probabilistic Risk Assessment (PRA) tool is under active development. All results are preliminary, subject to change, and must not be used for mission planning, operational decisions, or formal analysis. These results are provided solely for feedback and discussion purposes to support tool improvement.

Comparison IMM and IMPACT

https://plus.nasa.gov/video/artemis-ii-meet-the-astronauts-who-will-fly-around-the-moon-official-nasa-video/

- IMM
  - Designed for IS
  - Strong track re
  - Has informed r
    development
  - Expert evaluati
  - Can't do advan
    needed for exp

Artemis II Mission

- Microgravity Environment
- No EVAs
- Lunar Orbital Mission
- Beginning of Exploration Missions

- IMPACT
  - leling capabilities
  - dition list and
  - base using best
    nce
  - uration Lunar
    ment

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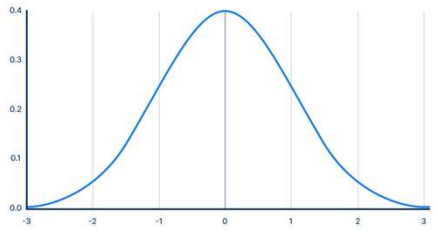
Methods

- **Artemis 2 Design Reference Mission**
  - 9-day lunar orbital mission
  - 4 Crew (3M, 1F)
  - No EVAs
  - Medical system of 13.3 kg
  - Optimized to minimize TTL

- **Mission Simulations (IMM and IMPACT)**
  - 500,000 trials for IMM to reach convergence
  - 200,000 trials for IMPACT to reach convergence



https://www.nasa.gov/wp-content/uploads/2023/06/jsc2023e016431.jpg?w=1638

Results

Risk Metric	IMM	IMPACT
Total Medical Events	13.2	14.5
LOCL (events/mission)	0.0001	0.0002
EVAC/RTDC (events/mission)	0.003	0.006
CHI/CTI	95.64%	94.06%

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Medical Events

Condition Occurrence by Modeling Tool

IMM		IMPACT	
Space Motion Sickness	2.85	Space Motion Sickness	2.85
Nasal Congestion (SAS)	2.27	Nasal Congestion (SAS)	2.27
Back Pain (SAS)	1.95	Back Pain (SAS)	1.96
Insomnia (SAS)	1.89	Insomnia (SAS)	1.89
Headache (SAS)	1.39	Headache (SAS)	1.36
Constipation (SAS)	0.75	Constipation (SAS)	0.75
Sleep Disturbance	0.5	Sleep Disturbance	0.49
Skin Abrasions	0.27	Spaceflight Rash	0.25
Spaceflight Rash	0.26	Headache	0.25
Headache	0.16	Corneal Abrasion	0.2

The IMPACT Probabilistic Risk Aactive development. All results are preliminary, subject to change, and must not be used for mission planning, operational decisions, or formal analysis. These results are provided solely for feedback and discussion ssessment (PRA) tool is under purposes to support tool improvement.

Loss Of Crew Life (events/mission)

IMM	LOCL	IMPACT	LOCL
Sepsis	0.00009	Skin Infection	0.00002
Stroke	0.00005	Dental Abscess	0.000012
Appendicitis	0.00004	**Toxic Inhalation (Combustion)**	0.000014
Anaphylaxis	0.00001	Respiratory Failure	0.00001
Medication Overdose	0.00001	Upper Respiratory Infection	0.000008
Choking	0.000008	Lower Respiratory Infection	0.000006
Burns	0.000006	**Medication Overdose**	0.000004
Toxic Inhalation (Combustion)	0.000004	**Anaphylaxis**	0.000004

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EVAC/RTDC (events/mission)

IMM	EVAC	IMPACT	RTDC
UTI	0.0005	Eye Foreign Body	0.002
Headache CO2	0.0004	Epistaxis (SAS)	0.0006
Nephrolithiasis	0.0003	Corneal Abrasion	0.0006
Skin Infection	0.0002	Toxic Exposure	0.0005
Skin Laceration	0.0002	Eye Chemical Burn	0.0004
Diarrhea	0.0002	**Skin Infection**	0.0003
Gastroenteritis	0.0002	**Gastroenteritis**	0.0002
Sepsis	0.0001	Spaceflight Rash	0.0002

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Task Time Lost (Days)

IMM	TTL	IMPACT	TTL
Space Motion Sickness	0.62	**Insomnia (SAS)**	0.45
Back Pain (SAS)	0.20	**Space Motion Sickness**	0.44
Nasal Congestion (SAS)	0.18	**Back Pain (SAS)**	0.27
Insomnia (SAS)	0.15	Sleep Disturbance	0.23
Constipation (SAS)	0.09	**Nasal Congestion (SAS)**	0.12
Headache (SAS)	0.06	**Constipation (SAS)**	0.08
Skin Abrasion	0.04	Upper Ext Strain	0.07
Skin Rash	0.04	Spaceflight Rash	0.06

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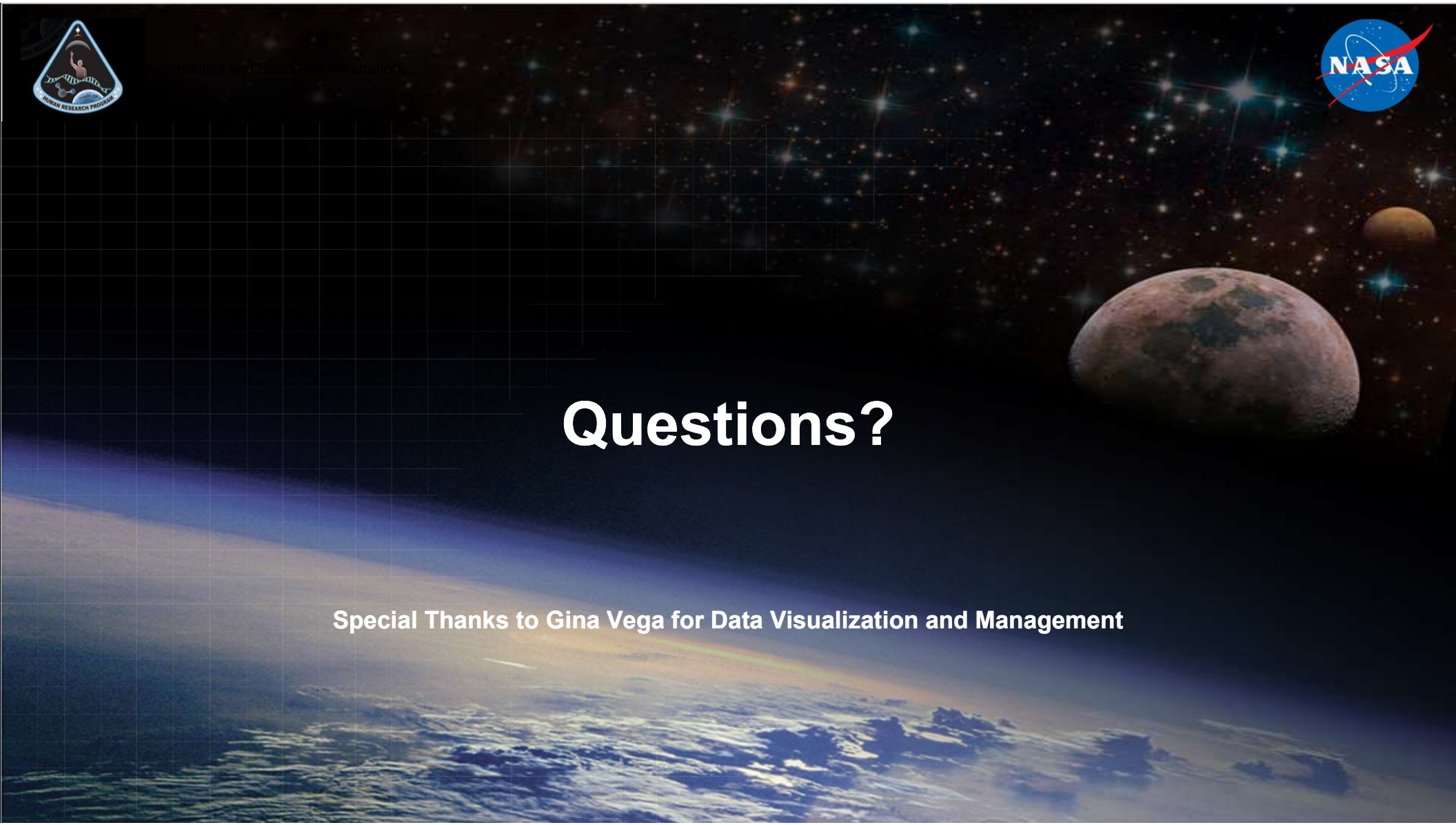
Discussion

- **Medical risk for Artemis II projected to be low**
  - Microgravity environment
  - No EVAs
  - Relatively robust medical system (13.3 kg)
  - Does not include engineering failures
- **IMM and IMPACT produce similar results**
  - Similar medical conditions and risk metrics
  - Similar datasets
  - Most commonly occurring conditions nearly identical
  - Conditions influencing TTL nearly identical
  - LOCL and RTDC are similar order of magnitude
    - IMM designed for LEO/IMPACT designed for exploration missions
    - Additional medical conditions included in IMPACT
    - EVAC and RTDC defined differently

Conclusions & Future Directions

- **IMM Built for LOE/IMPACT Built for Exploration**
  - Similar results for this mission
- **Comparison Modeling of Artemis III, IV, and V**
  - More complex mission profiles
  - Likely to see much larger differences
- **IMPACT is iterative; Continuing to be updated**
  - Increased fidelity, datasets, resources, etc…
- **Partner with Commercial Spaceflight Companies**
  - Dataset may need to be adapted to consider pre-existing conditions

The IMPACT Probabilistic Risk Assessment (PRA) tool is under active development. All results are preliminary, subject to change, and must not be used for mission planning, operational decisions, or formal analysis. These results are provided solely for feedback and discussion purposes to support tool improvement.


Aeronautics and Space Administration
NASA
Questions?
Special Thanks to Gina Vega for Data Visualization and Management

Back-up Slides

CTI and CHI

Crew Task Index and Crew Health Index are similar in that they both are based on time loss from impairment divided by total mission duration, giving a percentage that represents how functional the crew is.

- Crew Task Impairment (CTI) is an IMPACT metric that reports the percentage of the available crew time when the crew is healthy enough to perform tasks. Task Time Lost (TTL) represents the amount of time that the crew is functionally impaired, with a subsequent impediment^ to their ability to perform tasks.

$$\text{CTI (\%)} = \left(1 - \frac{TTL}{mission\ duration\ x\ number\ of\ crew}\right) * 100$$

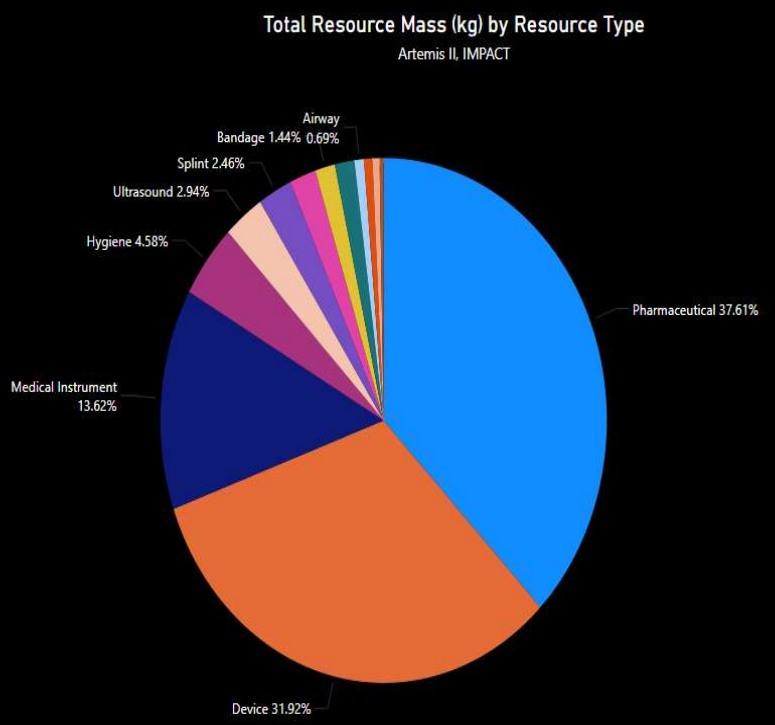
- Crew Health Index (CHI) is an IMM metric that reports the percent quality adjusted time and is calculated by using mission length *L* and total Quality Time Lost (QTL) by crew members.

$$\text{mCHI (\%)} = \left(1 - \frac{mQTL}{L}\right) * 100$$

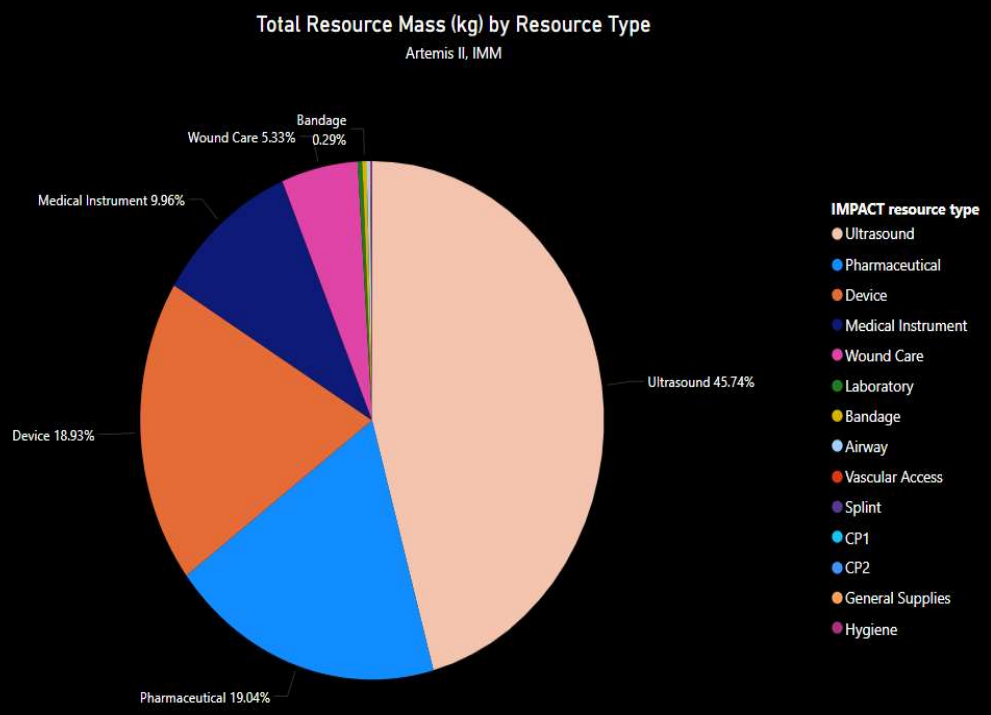
^Note: Task time lost is more accurately described as task time affected, as crewmembers will not be completely incapacitated, but rather work efficiency will be reduced by a certain decrement

Resource Comparison

IMPACT



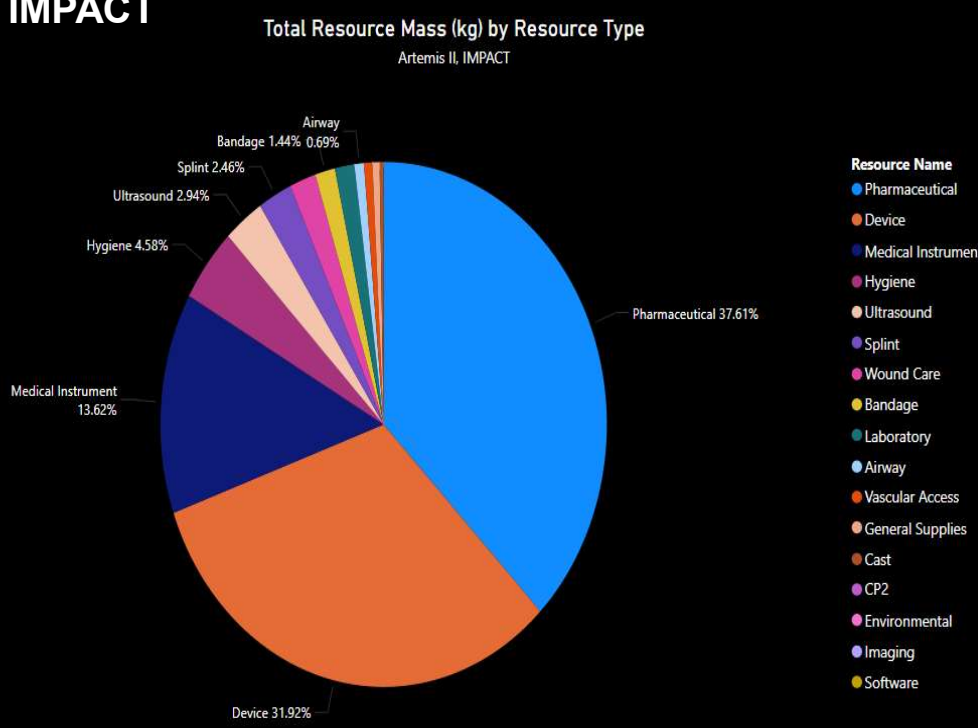
IMM



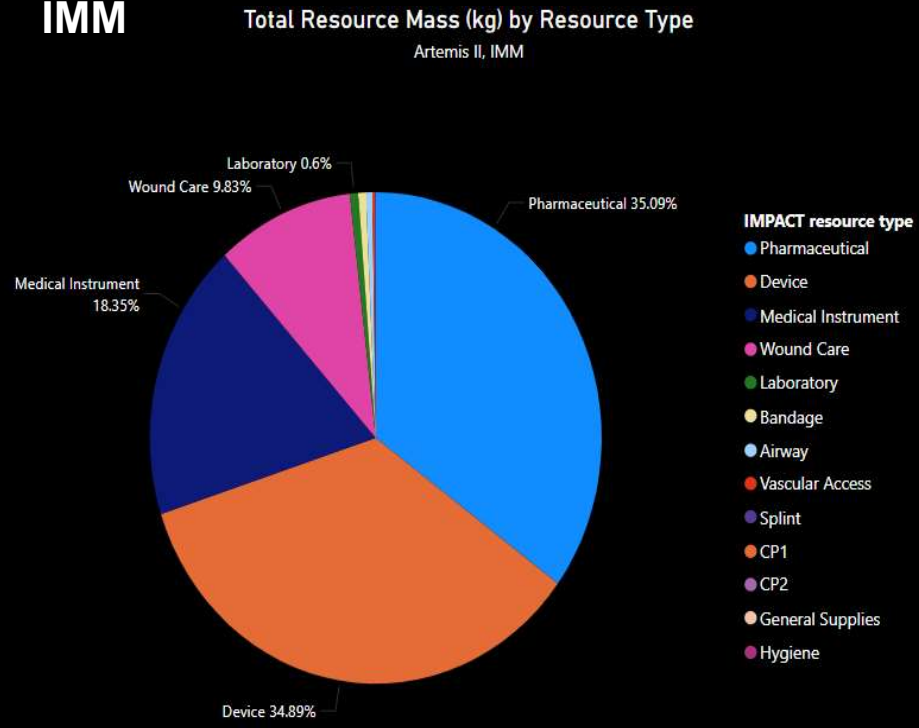
* The ultrasound in iMED weighs 6kg, the butterfly ultrasound in MedID weighs 0.309kg

Resource Comparison

IMPACT



IMM



Removing Ultrasound from IMM kit