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Single-Event Effects Criticality Analysis
"SEECA"

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- NASA Goddard Electrical Engineering Division
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https://nepp.nasa.gov/

https://www.nasa.gov/nesc

https://etd.gsfc.nasa.gov/560/index.php

Important References

- NASA Avionics Radiation Hardness Assurance Guidelines [Primary Reference]
  - Published July 2021, document link

- Other items of potential interest
  - Recommendations on Use of Commercial-Off-The-Shelf Electrical, Electronic, and Electromechanical Parts for NASA Missions *(Phase I report)*
    - Published December 2020, document link
  - NASA Electrical, Electronic, Electromechanical, and Electro-Optical Parts Selection, Testing, and Derating Standard
    - Planning early 2023 initial release & follow-on full standard release, overview link
  - Development of a NASA Radiation Hardness Assurance Standard
    - Planning late 2023 release, overview link

Agenda

- ❑ Impact and return on investment—why do we care?
- ❑ Define and introduce SEECA
- ❑ Discuss SEECA application examples
- ❑ Summary & wrap up

Stop and ask questions, no need to wait until the end

Mr. Anthony Sanders

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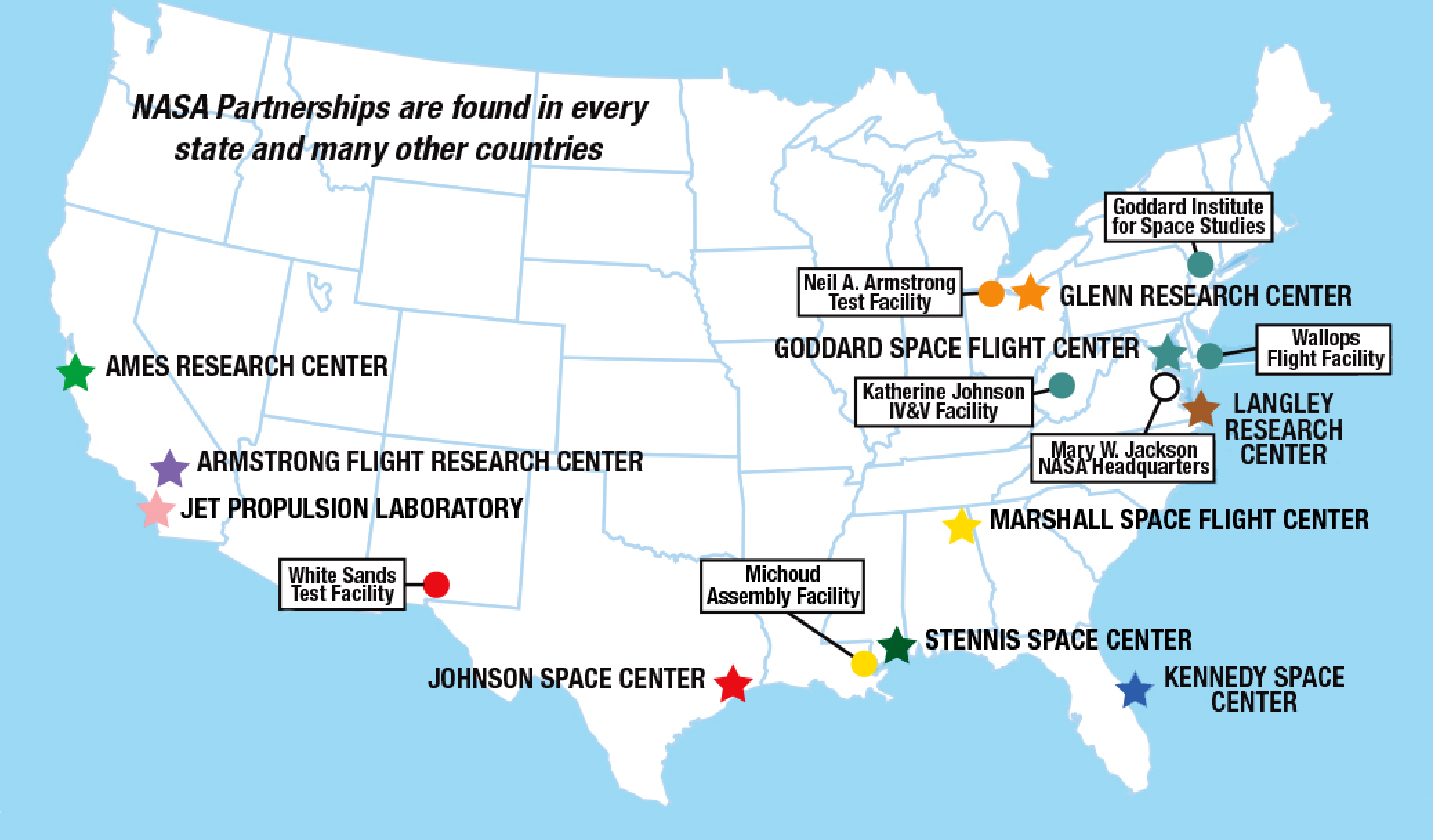
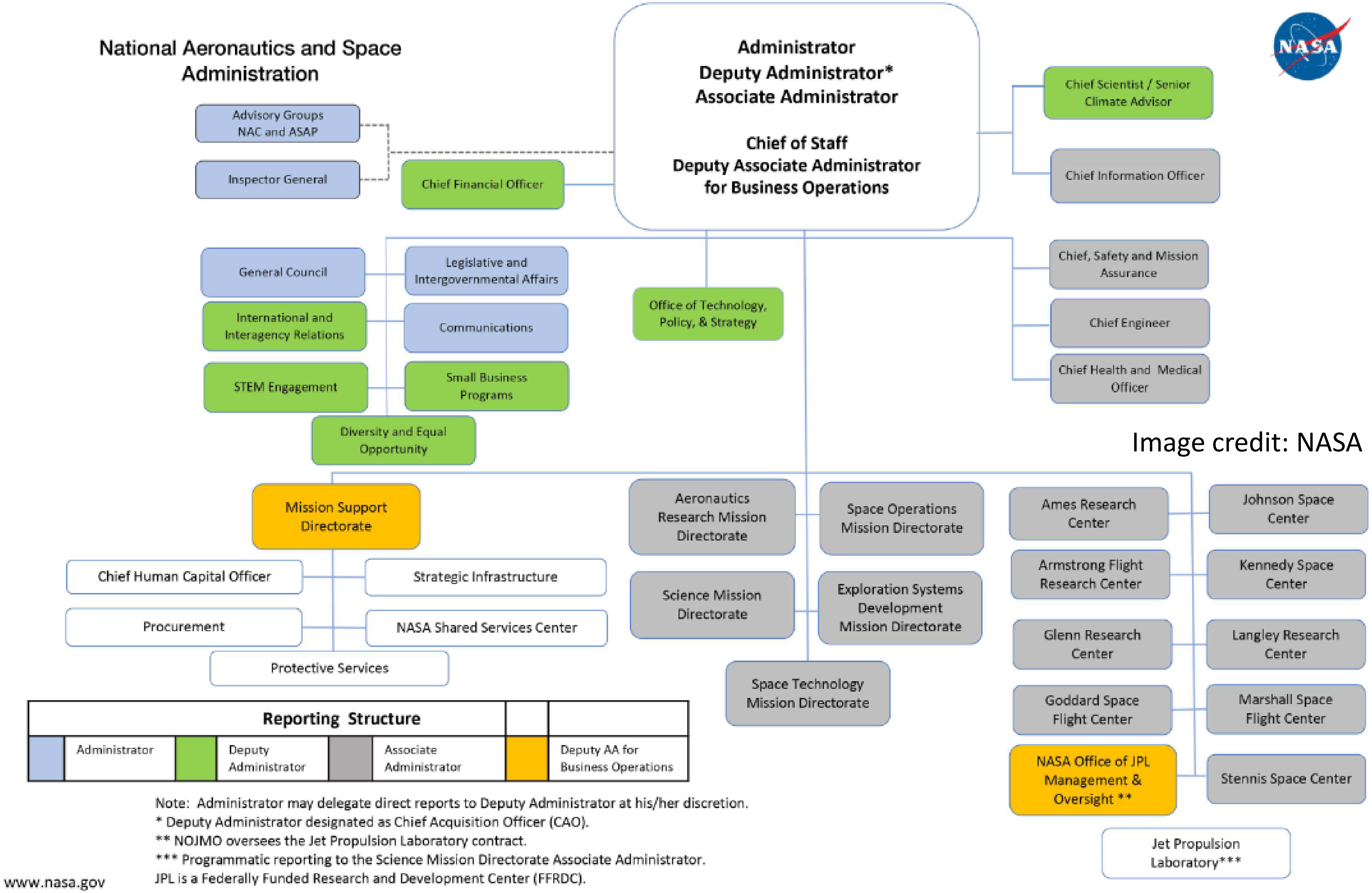
Image credit: NASA





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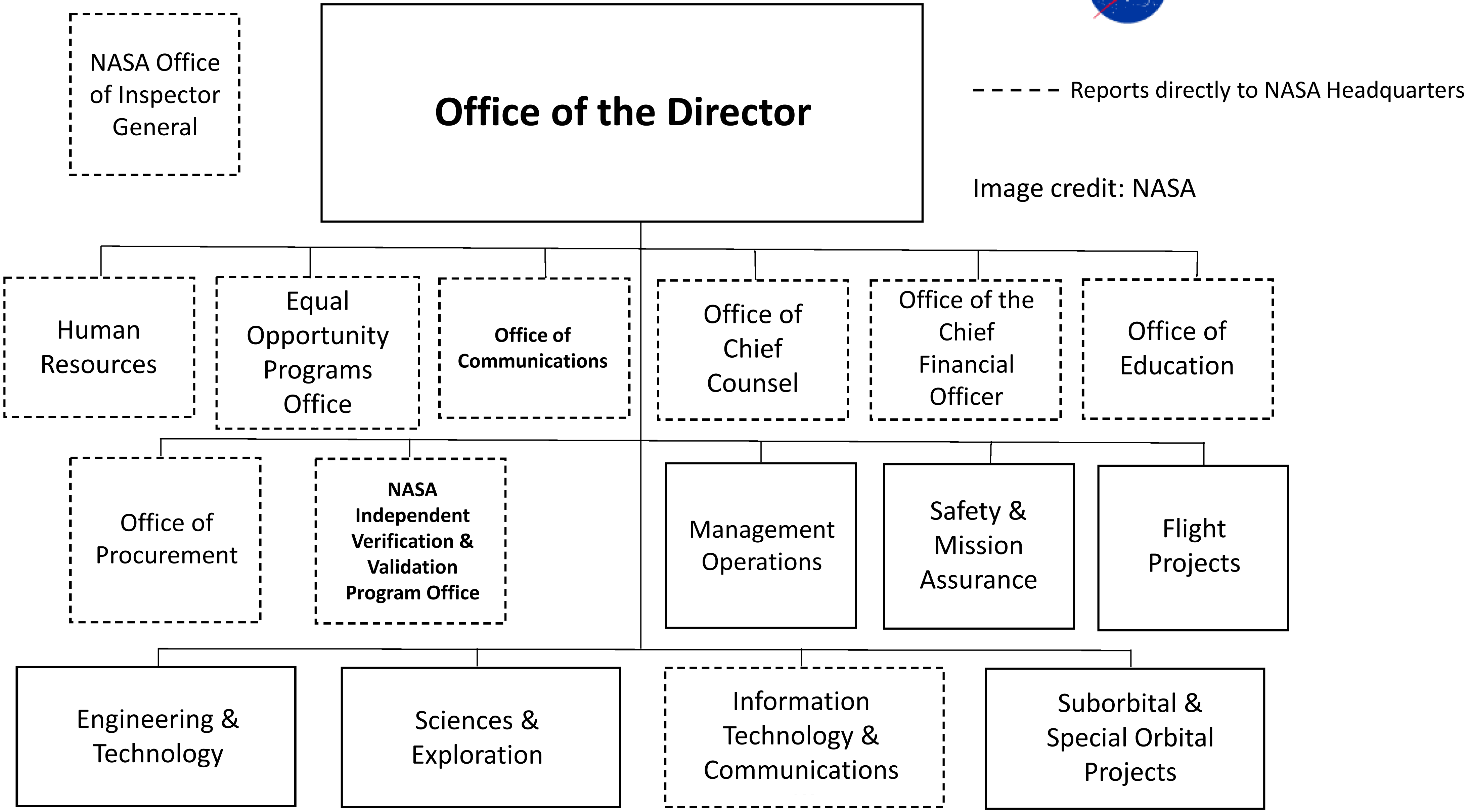

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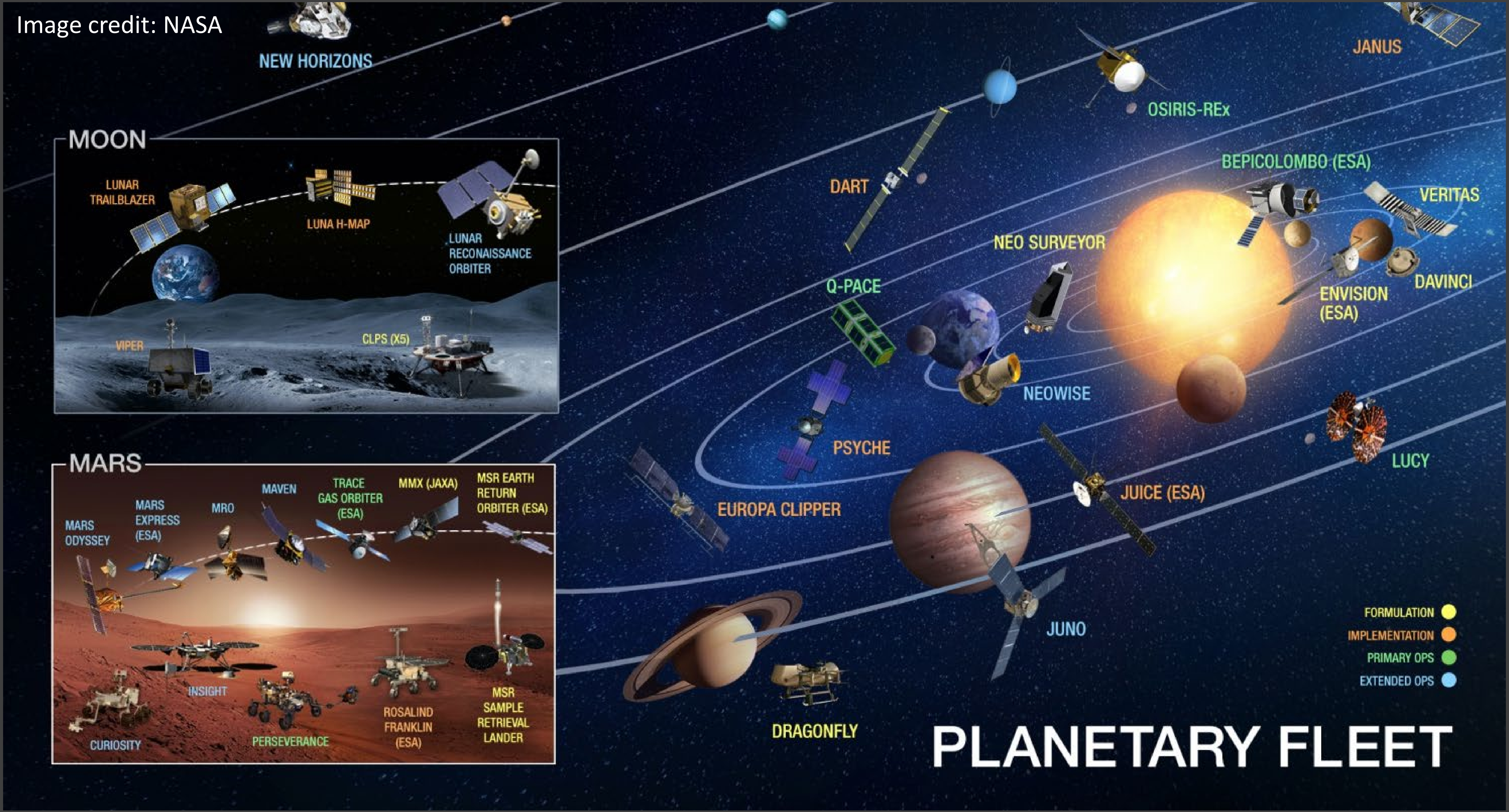
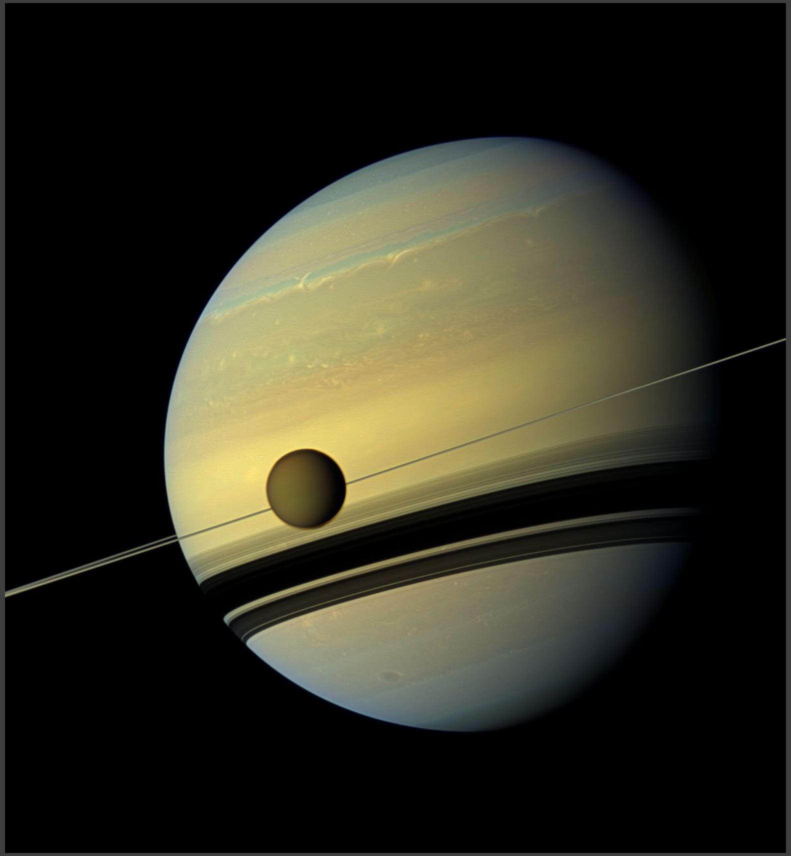




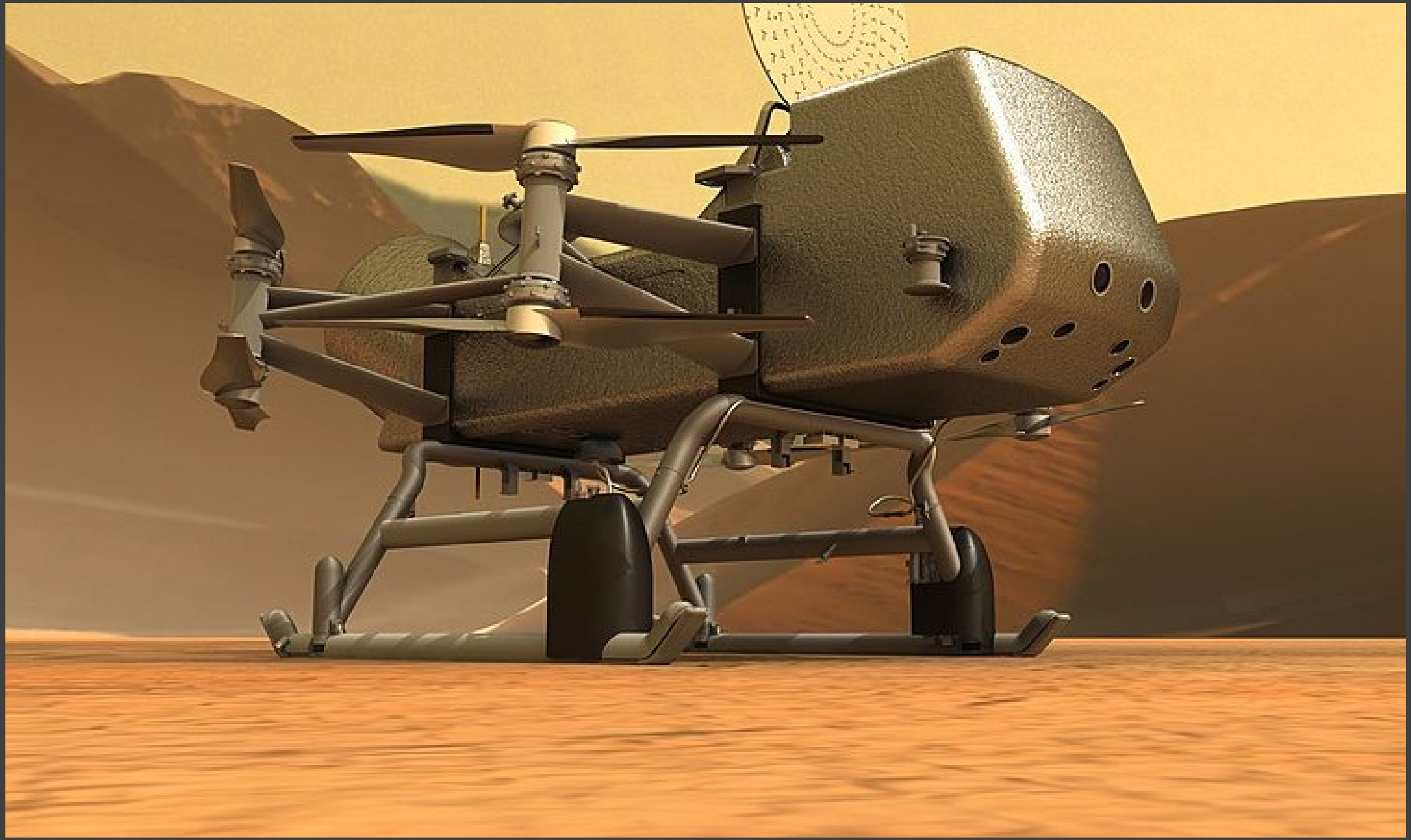


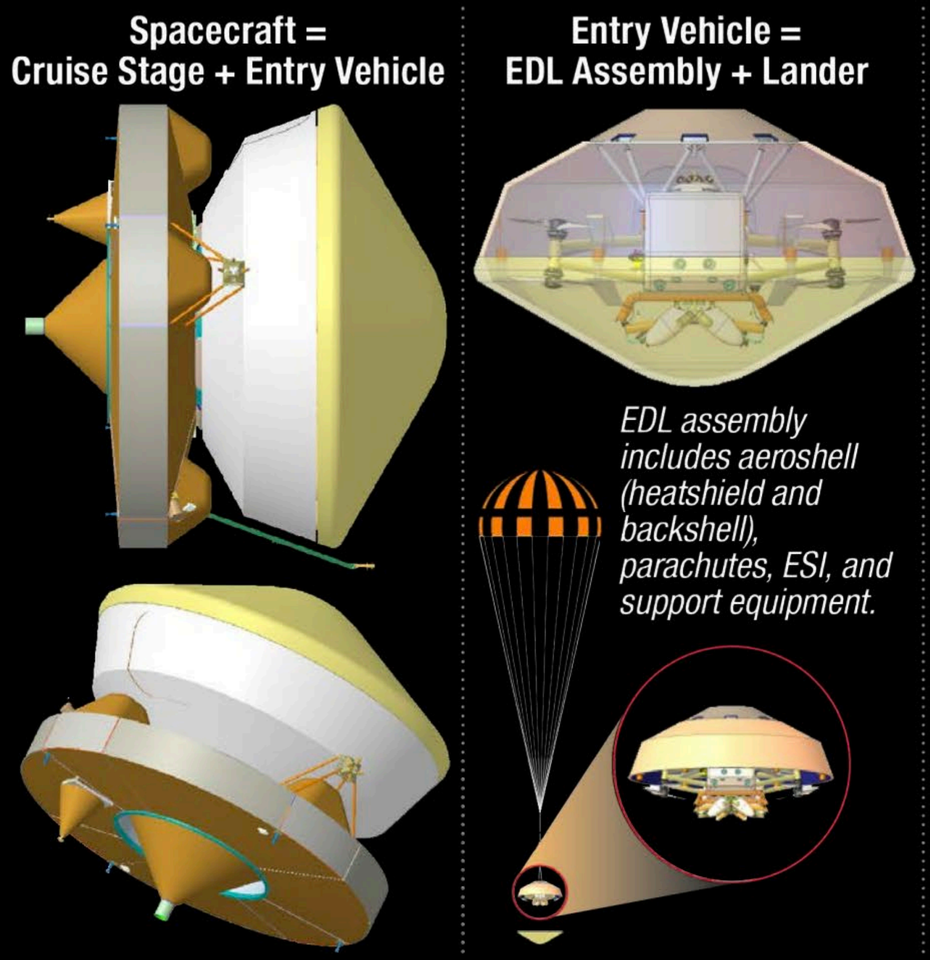
Image credit: NASA

Saturn Titan Moon

Dragonfly – Rotorcraft Lander

- Dragonfly is a quadcopter drone with a nominal mass of 400 to 450 kg
- Roughly the size of the largest Mars rovers.
- Launch date no earlier than 2027

Dragonfly mission elements



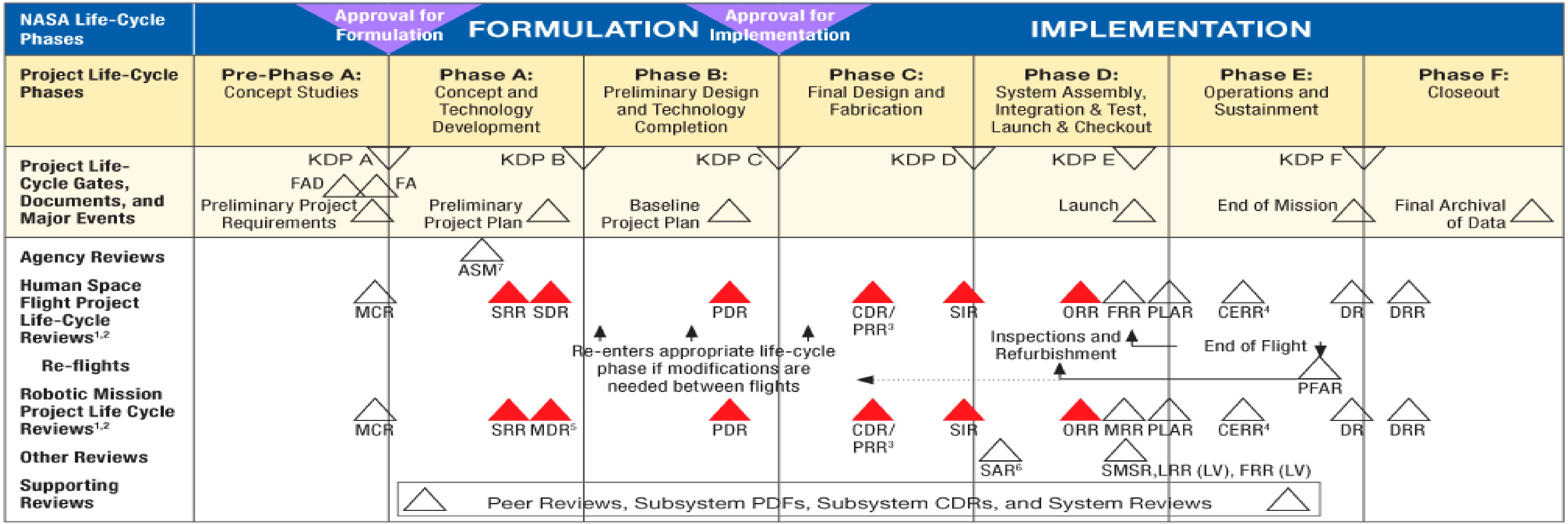
Rotorcraft Lander
Surface configuration with HGA deployed

- MMRTG
  - Charges battery to power flight and science activities
  - Waste heat maintains nominal thermal environment in lander
- Direct-to-Earth communication
  - HGA articulation used to target cameras for panoramas of surrounding terrain
- Measurements on surface and in flight
  - Aerial imaging
  - Atmospheric profiles

Image credit: NASA

Image credit: NASA

- It flies using 8 rotors, attached as four pairs to outriggers mounted on the side of the body.
- The craft can fly at about 10 m/s, and reach altitudes of 4000 m.
- Dragonfly will have the ability to fly for approximately half an hour and cover distances up roughly 10 km on a single (8-day) battery charge.
- Scout flight, cruise, and imaging from target landing area to candidate landing zone.



FOOTNOTES

1. Flexibility is allowed as to the timing, number, and content of reviews as long as the equivalent information is provided at each KDP and the approach is fully documented in the Project Plan.
2. Life-cycle review objectives and expected maturity states for these reviews and the attendant KDPs are contained in Table 2-5 and Appendix D Table D-3 of this handbook
3. PRR is needed only when there are multiple copies of systems. It does not require an SRB. Timing is notional.
4. CERRs are established at the discretion of program .
5. For robotic missions, the SRR and the MDR may be combined.
6. SAR generally applies to human space flight.
7. Timing of the ASM is determined by the MDAA. It may take place at any time during Phase A.

▲ Red triangles represent life-cycle reviews that require SRBs. The Decision Authority, Administrator, MDAA, or Center Director may request the SRB to conduct other reviews.

ACRONYMS

ASM – Acquisition Strategy Meeting
CDR – Critical Design Review
CERR – Critical Events Readiness Review
DR – Decommissioning Review
DRR – Disposal Readiness Review
FA – Formulation Agreement
FAD – Formulation Authorization Document
FRR – Flight Readiness Review
KDP – Key Decision Point
LRR – Launch Readiness Review
LV – Launch Vehicle
MCR – Mission Concept Review
MDR – Mission Definition Review
MRR – Mission Readiness Review
ORR – Operational Readiness Review
PDR – Preliminary Design Review
PFAR – Post-Flight Assessment Review
PLAR – Post-Launch Assessment Review
PRR – Production Readiness Review
SAR – System Acceptance Review
SDR – System Definition Review
SIR – System Integration Review
SMSR – Safety and Mission Success Review
SRB – Standing Review Board
SRR – System Requirements Review

Image credit: NASA

FIGURE 3.0-1 NASA Space Flight Project Life Cycle from NPR 7120.5E

Dragonfly Challenges

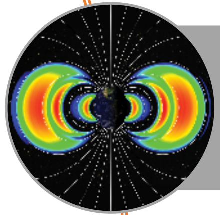
- Talent
  - Difficult to find specialized skilled employees
  - Succession planning evolving
    - Rethinking recruitment strategies
      - e.g., Texas A&M University Single-Event Effects Bootcamp
- Mass
  - Mass allocation reduction
  - Changing requirements
- Cost and Schedule
  - Reduced budgets
  - Encouraged to take more risks
    - **Reduce parts testing and incorporate new approaches**
- Custom build vs. Product line
  - Predicting actual costs difficult for innovative one-of-a-kind flight projects

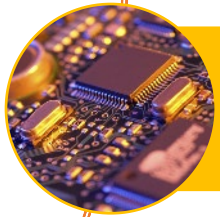
What is a Single-Event Effects Criticality Analysis (SEECA)?

Radiation Effects System-Level Viewpoint

M
E
A
L


Mission


Environment


Application


Lifetime

- ❑ Who and why?
- ❑ Where?
- ❑ Doing what?
- ❑ For how long?
- ❑ What is success / failure?

Dialogue with the customer

- ❑ Other considerations:
  - Product line / replicas vs. custom
  - Are there trades to limit / shrink non-recurring engineering?

This is why radiation engineers often say "it depends…"

Adapted from NASA Technical Report TM-2018-220074

What is SEECA?

- **<u>SEECA definition</u>**: a methodology (*a tool*) to identify the impact of single-event effects (SEE) on mission, system, and subsystem availability and reliability
- Developed in the mid-1990s to cope with new SEE and with growth of commercial off the shelf (COTS) technologies
- Provides a <u>self-consistent</u> approach to analyze and catalog SEE for full systems (parts-to-boards-to-boxes)
- SEE depend on MEAL, so a particular SEECA retains the same dependence

Radiation Hardness Assurance (RHA) & SEECA

- RHA is the collection of engineering processes that ensures electronics and materials of a space system <u>perform according to their design specifications</u> after exposure to the space radiation environment
  - Includes mission requirements, environment definition, all radiation effects, part selection & testing, spacecraft layout, radiation-tolerant design, worst case analysis, mitigation, etc.
- SEECA gives engineers a tool to address radiation impacts on reliability, availability, [survivability, and matainability]

Environmental Requirements
- Mission documentation
- Modeling & simulation tools

→

Systems Engineering
- Performance and availability requirements
- MEAL

→

Radiation Hardness Assurance
- Derived radiation requirements
- Notional risks
- Goals for SEECA

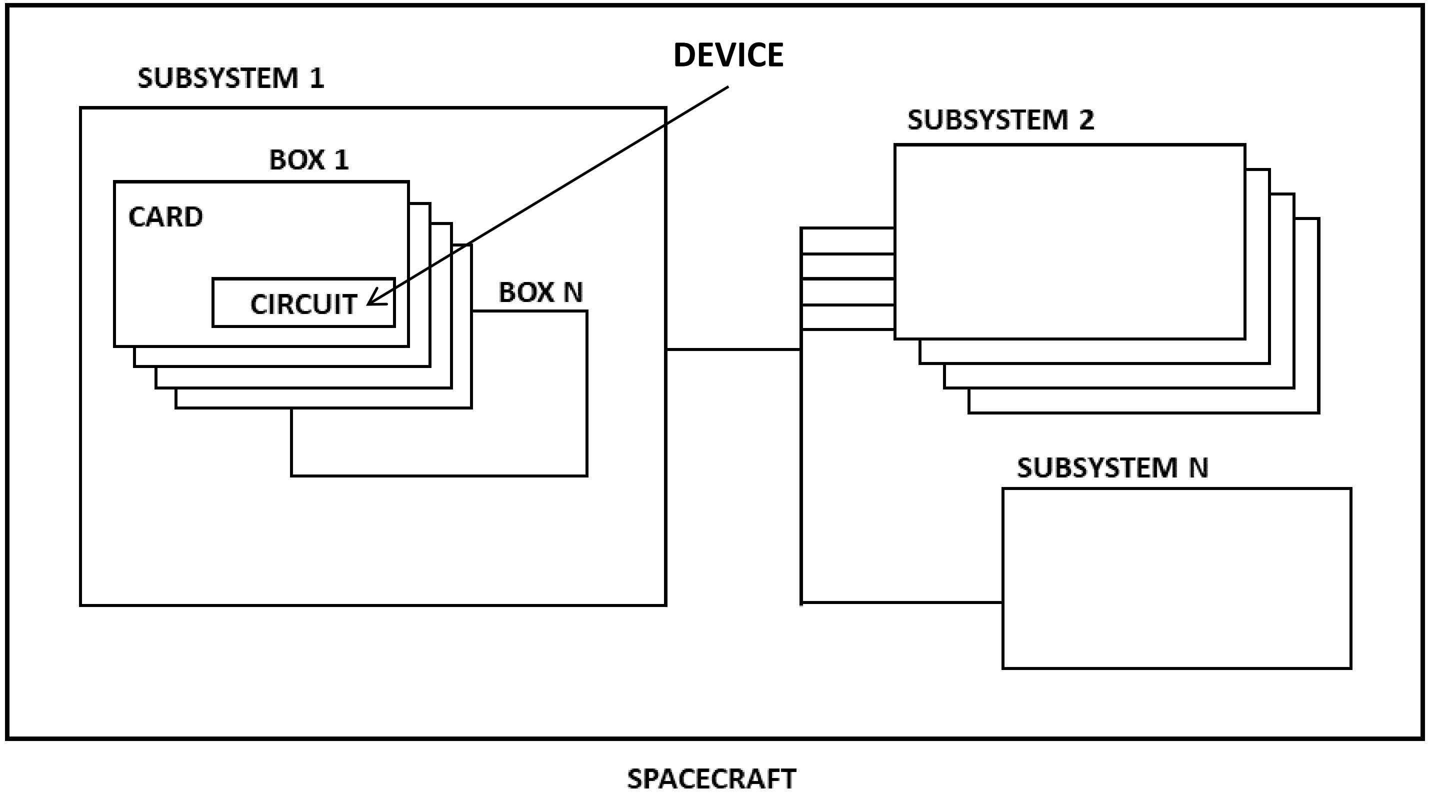
→

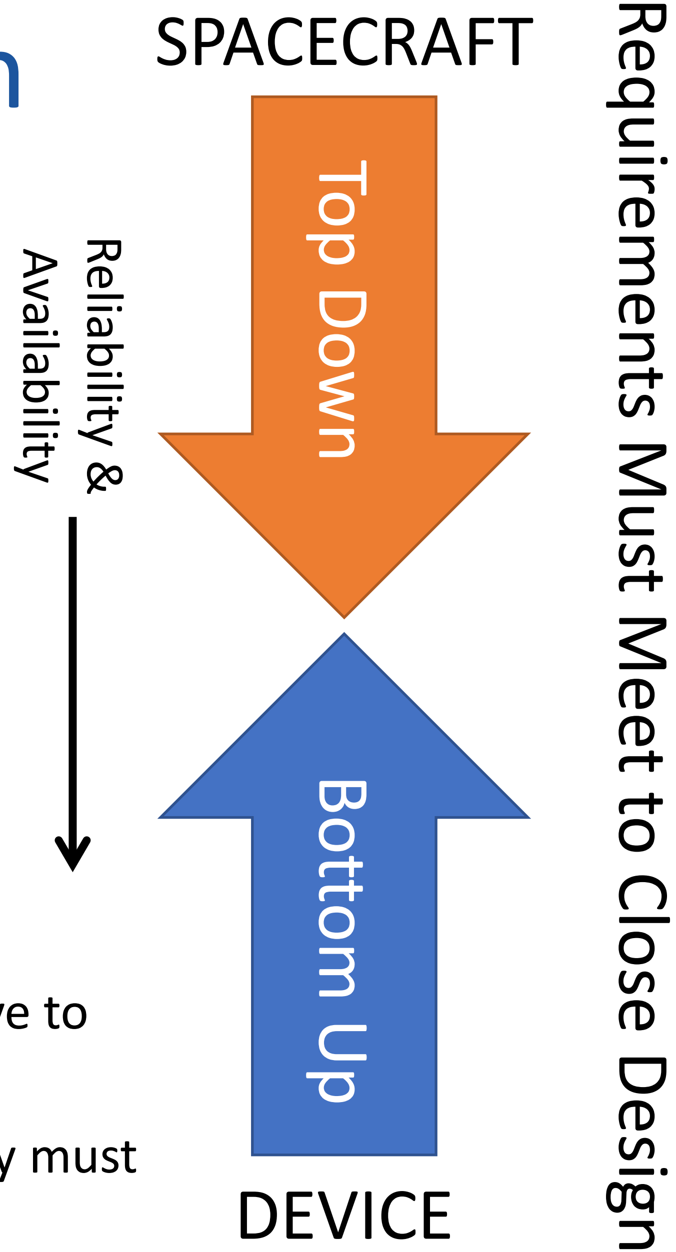
SEECA Buildup
- Process for evaluating design and/or system implementation for SEECA goals

→

SEECA Implementation
- <u>Criticality classification</u>
- Reliability & maintainability practices

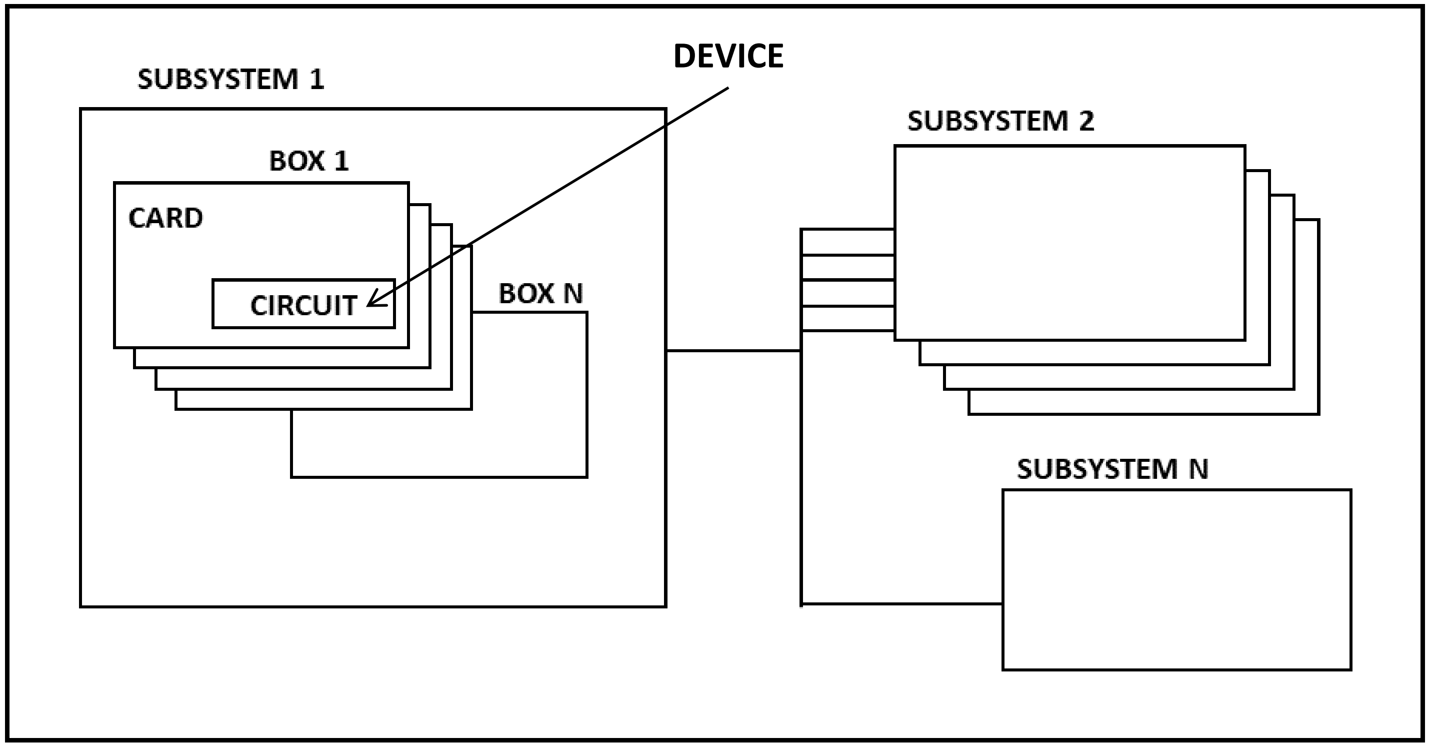
SEE at Different Levels of Integration



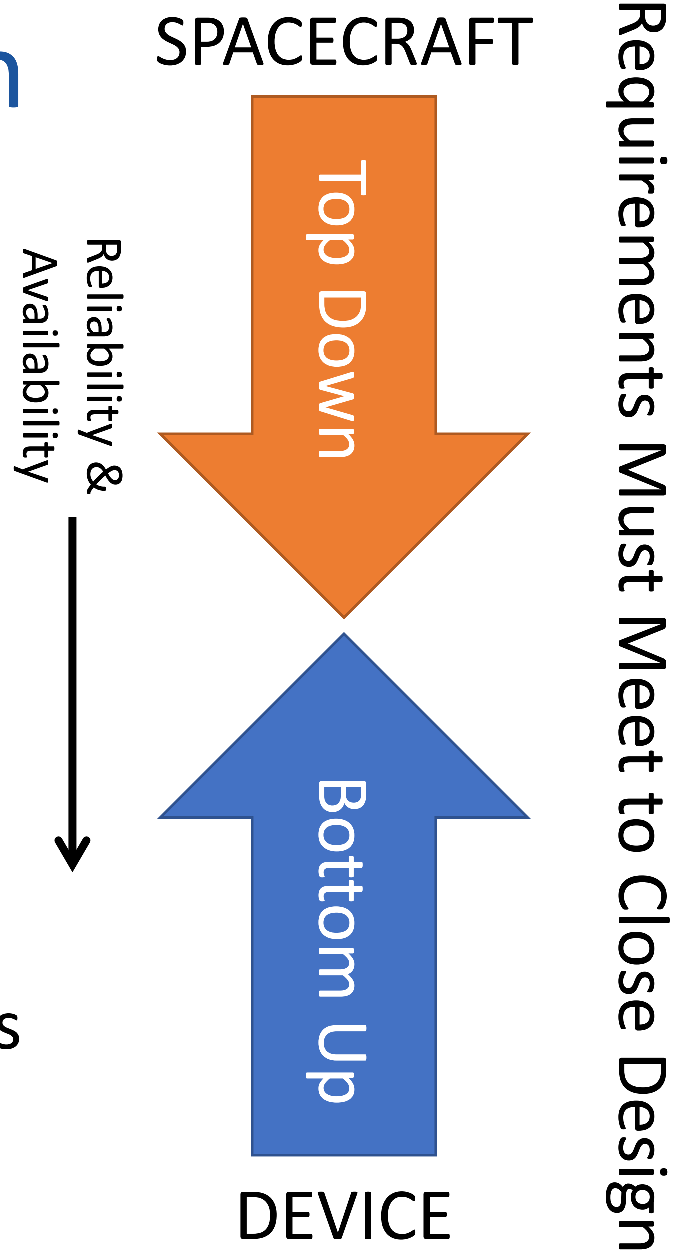


- To understand system-level response, SEE response and any mitigations have to be considered locally
- For SEECA to be effective, system requirements for reliability and availability must be known / assumed

SEE at Different Levels of Integration

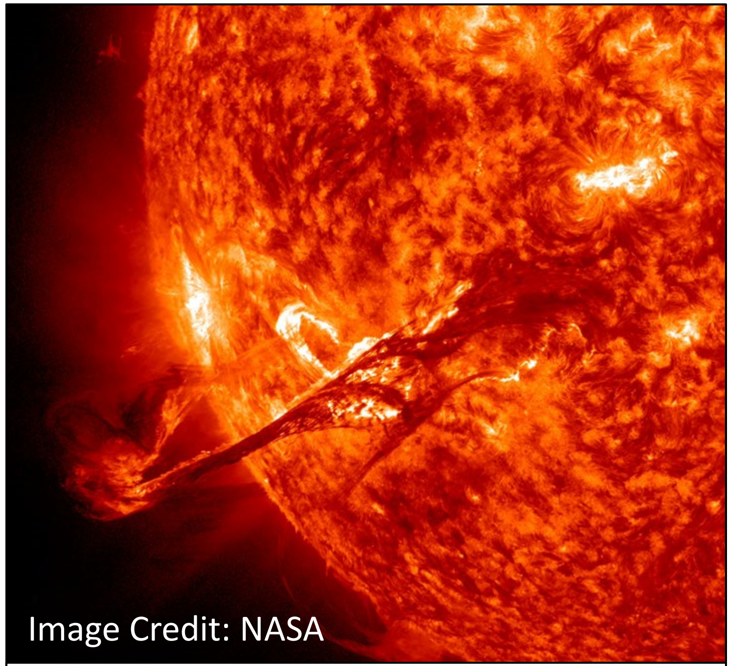


SPACECRAFT



- Too expensive / complex to test and analyze a system's entire state space
  - SEECA can help highlight / focus on areas of concern

SEE Hazards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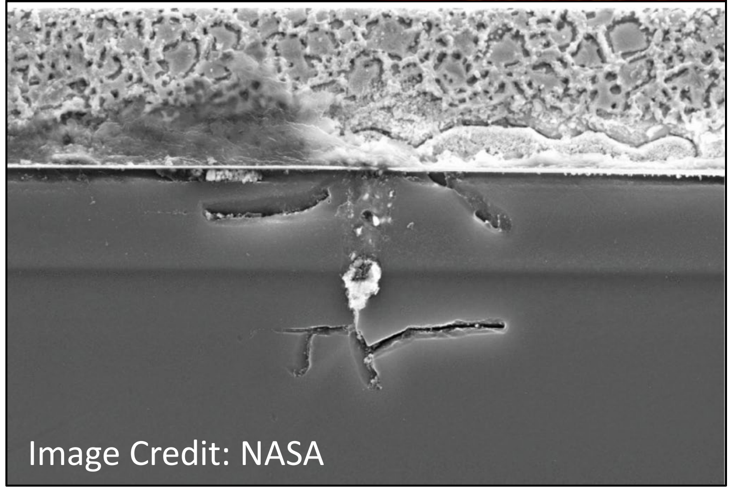
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Outcomes → Hazard ← Environment

Propagation ↓

- Device-level
- Circuit-level
- Box-level
- Subsystem-level
- Spacecraft-level

Hazard

- Galactic cosmic rays
- Trapped particles
- Solar particle events
- Radioactive sources
- Accelerators

- ❑ Charge deposition in devices and integrated circuits can lead to adverse operations or failures
- ❑ Combination of outcomes and environment present the SEE hazard—outcomes are application-specific
- ❑ Mitigation can reduce consequences / likelihood of outcomes

Functional Analysis & Criticality Classification

- SEECA is based on functional requirements, which can span multiple cards or boxes within a system. Functions may include:
  - Critical subsystems throughout the mission (e.g., guidance, navigation, & control (GNC), power management, etc.), or
  - Science objectives (e.g., data storage / transmission, sensor performance, etc.)
- SEECA does not simply aggregate SEE responses for each part in a system—it uses system-level concerns (where SEE meet requirements) to identify and categorize system impacts

Functional Analysis & Criticality Classification

Error-Functional

- Function may be unaffected by SEE; large probability of events may be acceptable (e.g., data retention / transmission, detector “noise,” etc.)

Error-Vulnerable

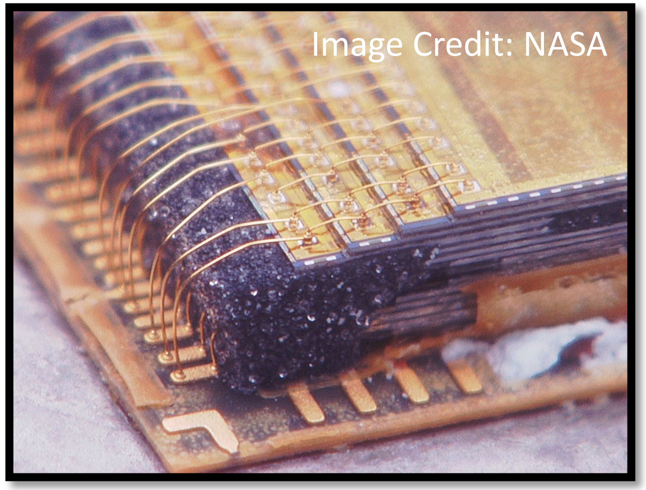
- Function where a low probability for SEE is required; response with mitigation or risk of SEE is permissible (e.g., power management, data transmission, on-board processor, etc.)

Error-Critical

- Function where SEE are unacceptable (e.g., power management, GNC, pyro events, environmental control and life support systems, etc.)

Functional Analysis & Criticality Classification

- Decision options:
  - Do nothing—indicates that the risk of the type of SEE occurring is acceptable, or that the SEE is acceptable or does not affect the design operation
  - Do something—indicates that the outcome of an SEE <u>is anticipated</u> and that the system can be returned to a <u>known state</u>, or that the error can be corrected without diminishing the functional objective (operational mitigation)
    - Selective function utilization or disabling the function for a given environment or operational phase
  - Remove or replace something—alternate parts selection to accomplish the function, design simplification, etc. (architectural mitigation)



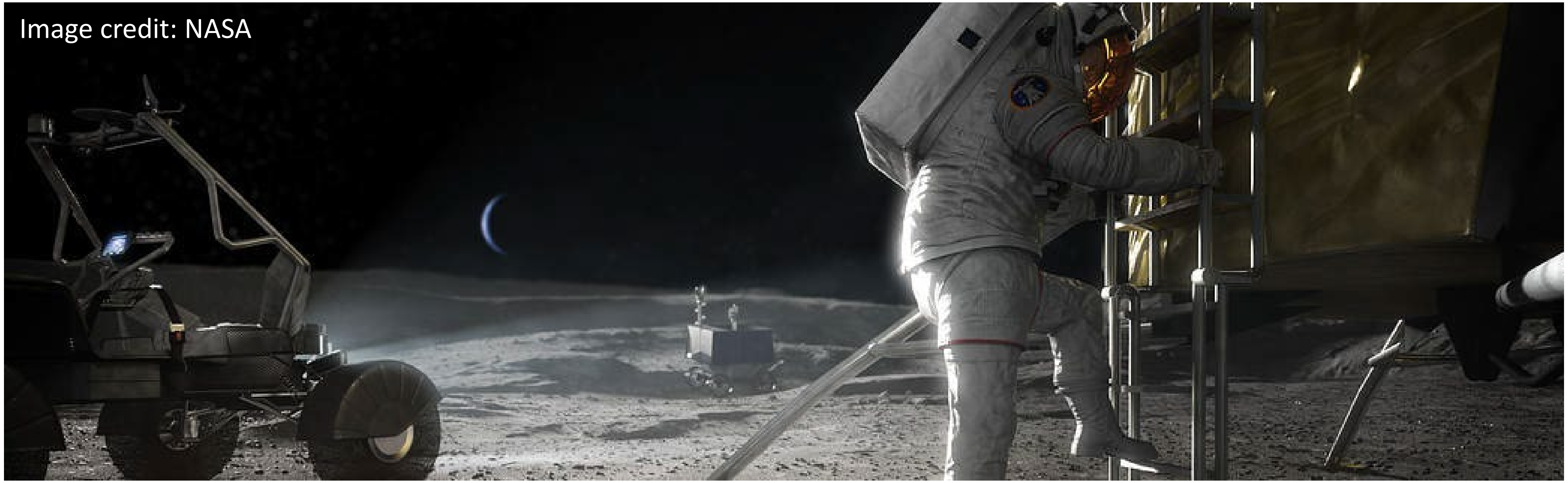
Discussion Examples

Guidance for SEECA Implementation

1. Define the mission environment (i.e., external and internal to the spacecraft) for each mission phase.
2. Identify critical functions in each phase for the CONOPS. (Concept of Operations)
3. Establish system architectural dependencies: Identify the systems and subsystems tied to the functions that are critical for mission success.
4. Tie mission requirements for each unique availability mode to the CONOPS.
5. Translate functional requirements into SEE requirements at the level the analysis is being done (parts/boards/boxes).
6. Determine criticality: categorize SEE severity as critical, vulnerable, or functional within a function.
7. Weigh and analyze consequence versus criticality, with respect to goal of availability or reliability.
8. Determine recourse or engineering trades.
9. Collect evidence: capture assumptions, analyze data (e.g., testing, similarity, heritage, or lack thereof), and verify functional requirements.
10. Finalize a radiation analysis (e.g., verified requirements, criticality classifications, rate calculations where needed).
11. Follow RHA principles on new data or changes in the design with iterations to the analysis and trade space, update requirements or environment models, if necessary.

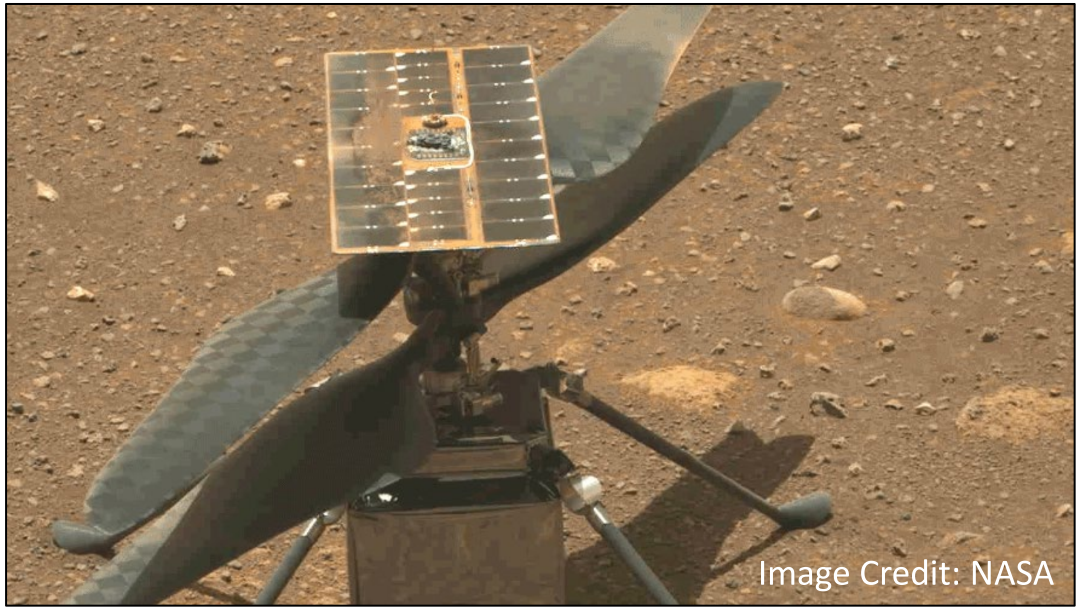
Potential SEECA Examples—Vote to Pick One…

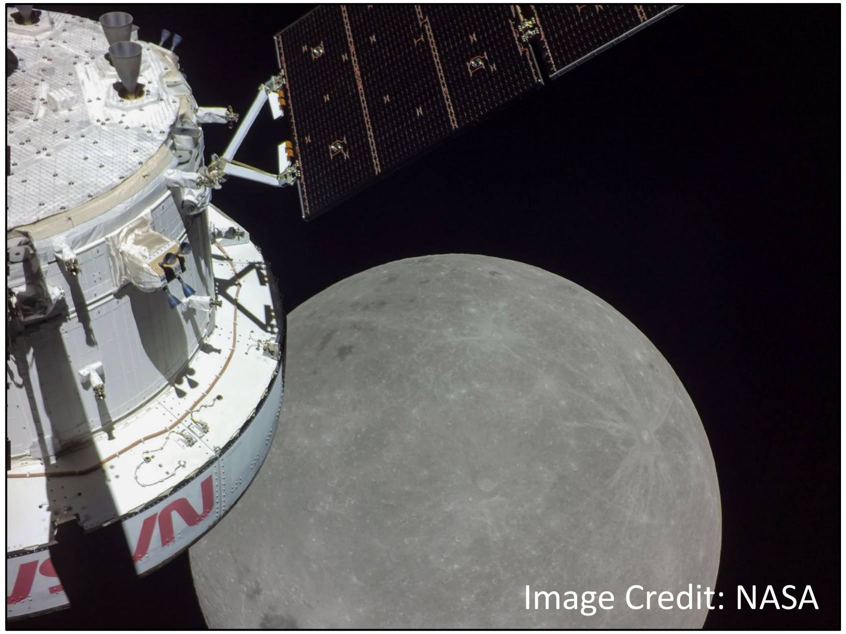
- ❑ Science data retention and transmission
- ❑ Power management and distribution throughout the mission
- ❑ Guidance, navigation, and control during a critical maneuver



Summary and Conclusions

- SEECA is a RHA tool—not a mitigation solution
- SEECA mimics what is already done in classical reliability analyses (e.g., failure mode, effects, and criticality analysis; fault trees; etc.)—lots of existing analogs
- SEECA's three criticality classes enable self-consistent management and handling of SEE outcomes
  - Goal is to be engineer-independent
- SEECA must be deployed early in the project lifecycle to maximize effectiveness
  - RHA gets more expensive (cost, schedule, mitigations) the later you start
- SEECA facilitates the incorporation of application-specific information derived from new radiation testing or existing results—maximize leverage!





Acronyms

Abbreviation	Definition
CERN	European Organization for Nuclear Research
CONOPS	Concept of Operations
COTS	Commercial Off The Shelf
EDL	Entry, Descent, and Landing
GNC	Guidance, Navigation, and Control
HGA	High-Gain Antenna
MEAL	Mission, Environment, Application, and Lifetime
MMRTG	Multi-Mission Radioisotope Thermoelectric Generator
NASA	National Aeronautics and Space Administration
NEPP	NASA Electronic Parts and Packaging (Program)
NESC	NASA Engineering and Safety Center
RHA	Radiation Hardness Assurance
SEE	Single-Event Effects
SEECA	Single-Event Effects Criticality Analysis
SERESSA	School on the Effects of Radiation on Embedded Systems for Space Applications