ORION ENTRY MONITOR

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NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION

MISSION BACKGROUND

- Exploration Mission 1 - 2018
- Entry Interface Conditions: 36000+ ft/s
- Orion's first precision-guided skip entry

WHAT IS THE ENTRY MONITOR?

- Entry Monitor is a collection of algorithms that work in concert to transform trajectory data into decisional information.

- Entry Monitor answers:
  - Where is the entry guidance system taking me?
  - If I abort now, where will I land?
  - Can I still reach my intended target?
  - If I can't reach my target anymore, where should I land?

TRAJECTORY PREDICTION

- Common trajectory propagator algorithm
- Runge-Kutta 45 variable step integrator
- 4-degree-of-freedom equations of motion: J_2 gravity, lift, drag
  - Load relief bank-controller algorithm built-in to the equations of motion to prevent excessive deceleration.

CONSTANT BANK ANGLE PREDICTION

- Where is the entry guidance system taking me?

- If the current bank angle command were constantly flown from now until parachute deployment, what kind of trajectory would result?
  - Skip-Out?
  - Land on land? Water?
  - How far from the target?

- Allows the crew to monitor the health and status of the primary entry guidance system.

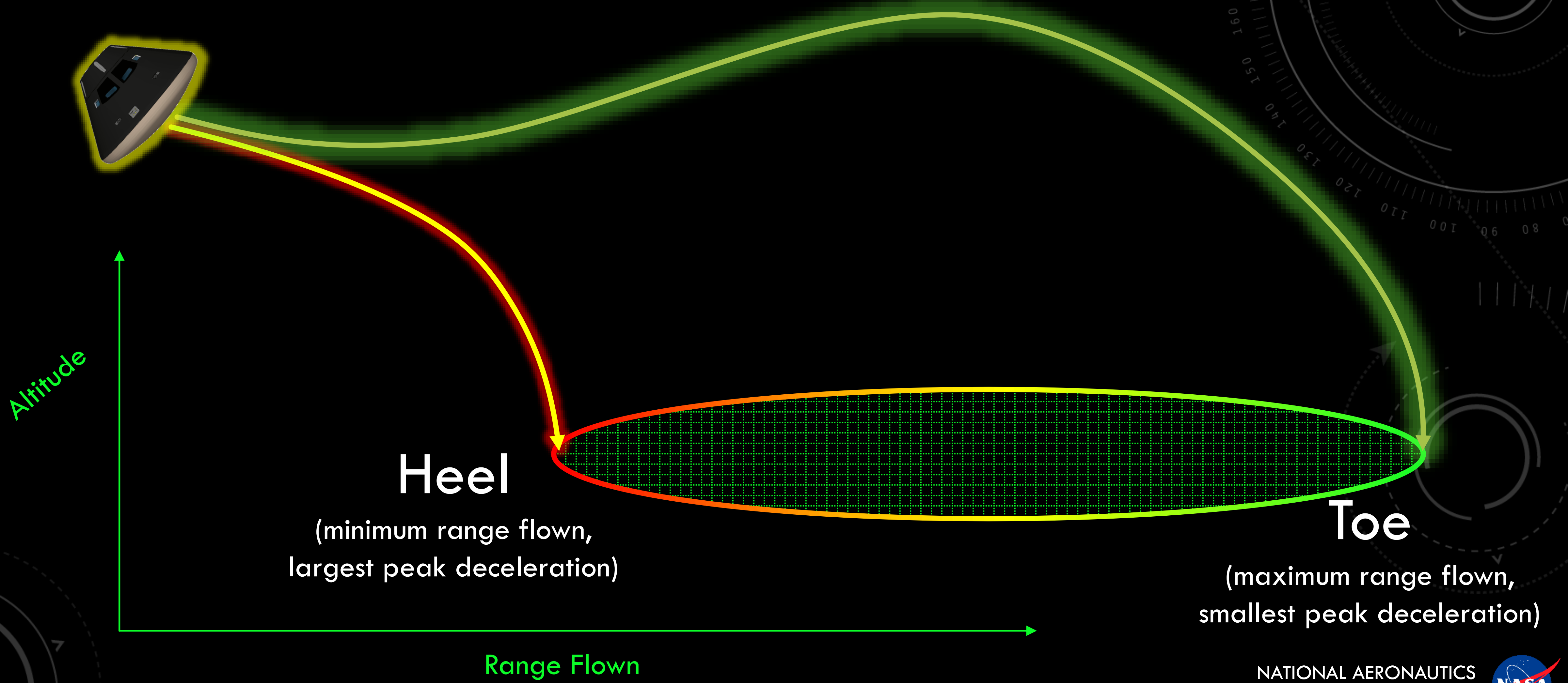
BALLISTIC INSTANTANEOUS IMPACT POINT

- If I abort now, where will I land?
- If I perform a ballistic abort from my current state …
    - Will I capture in the atmosphere?
    - Land on water? Land on land?
    - How far from my target will I land?
    - What kind of G-loads can I expect?
- Models spin-up maneuver from current attitude state to targeted ballistic spin rate.
- Produces time-history of trajectory and terminal state for crew displays and telemetry.

VEHICLE CAPABILITY FOOTPRINT

- Where could I land? How far away could I divert?
- The vehicle capability footprint defines the boundaries of the area reachable through atmospheric maneuvering.
- Straightforward to approximate for capsule returning from LEO. Trickier when skip-capable.
- 3 stage algorithm with dynamic workload allocation:
  1) Skip-out search priming
  2) Skip-out search (Root-finding)
  3) Backfill Stage

FOOTPRINT TERMINOLOGY



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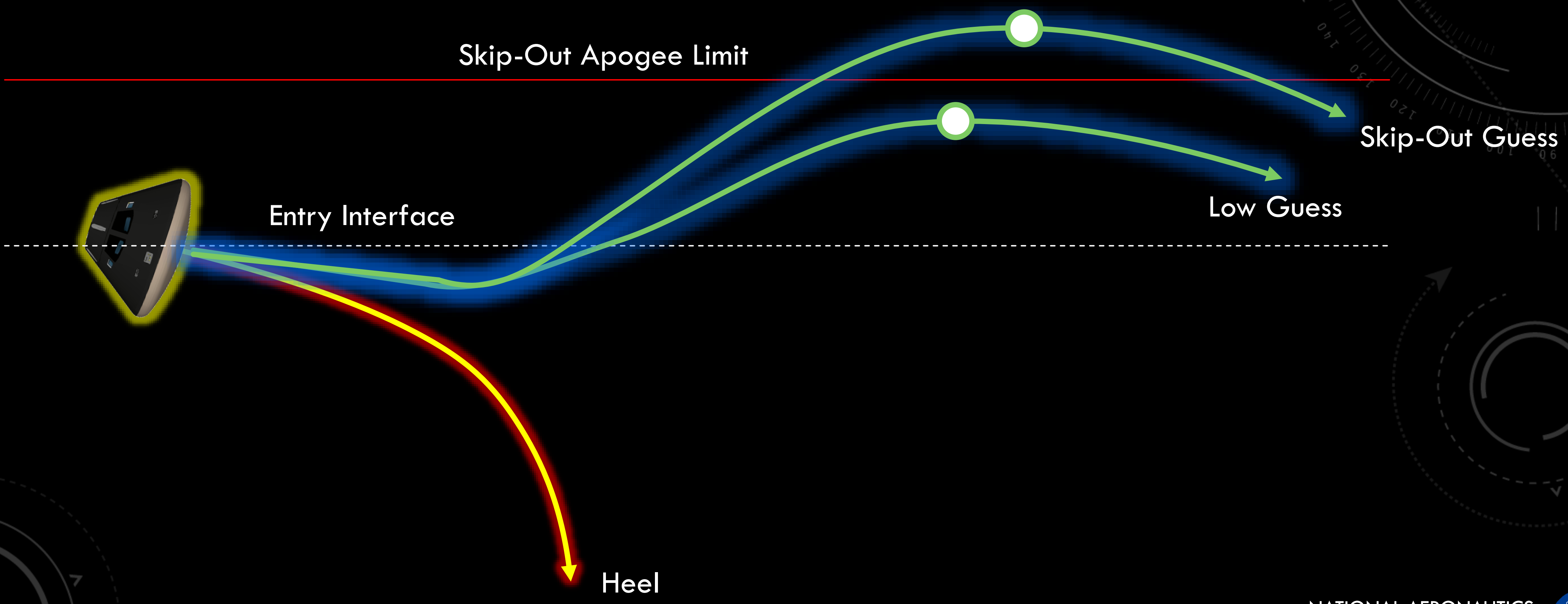
FOOTPRINT ALGORITHM OVERVIEW

- Entry Monitor computes a constrained capability footprint.

- Constraints:
  - Skip-Out Apogee < Apogee Limit (PredGuid limitation)
  - Peak G-Load < Peak G Limit

SKIP-OUT PRIMING



SKIP-OUT SEARCH

- Numerical Predictor Corrector iterates on $\cos\sigma$ to satisfy skip-out apogee radius constraint within some tolerance.

- Switches corrector logic between bisection, secant, and quadratic interpolation depending on the number of usable *a priori* data points. Initial testing demonstrates convergence superior to Brent's method.

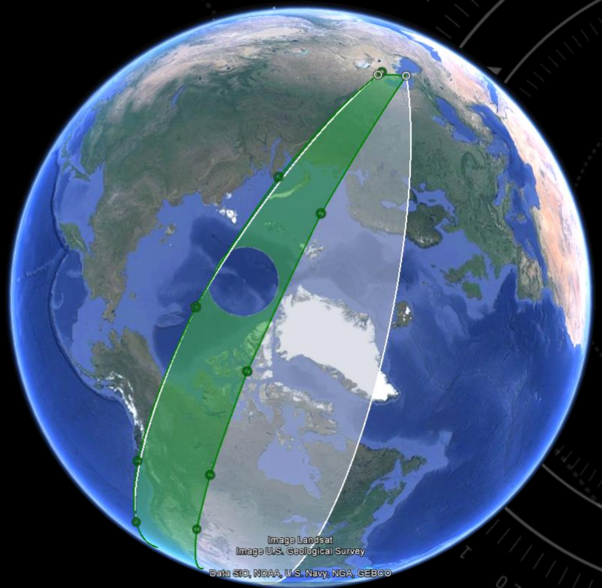
- If convergence cannot be completed within prescribed number of iterations, then final iterate from execution cycle i will be used as initial guess for execution cycle $i+1$ skip-out search priming.

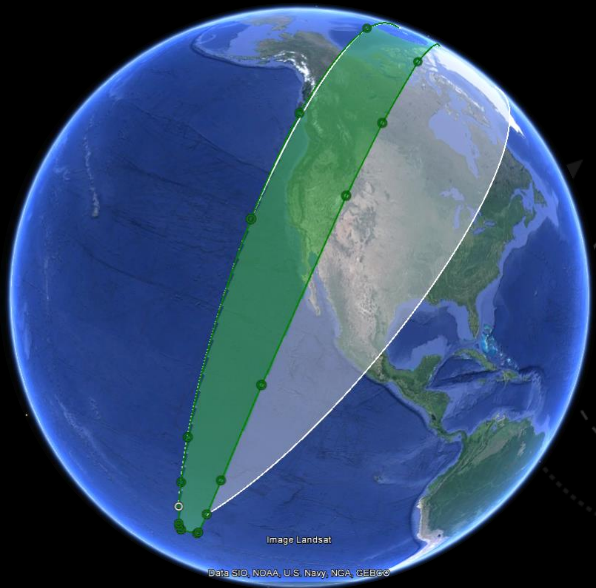
BACKFILL

- Backfill was created because rapid convergence in previous step may result in very sparsely defined footprint.

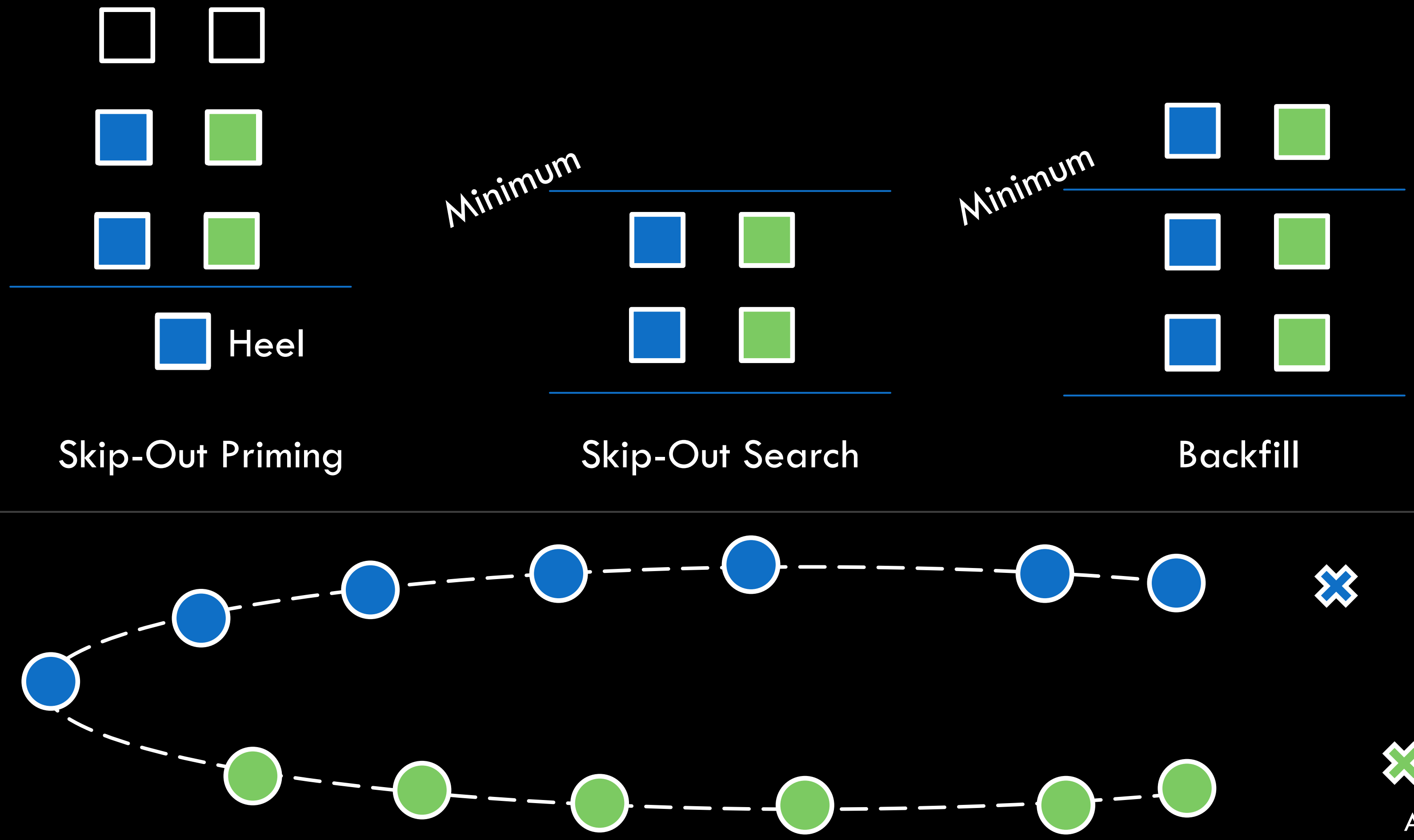
- If previous stage (skip-out search) converges in fewer iterations than allocated, Backfill will use the surplus (unused) propagations to attempt to refine the footprint vertices.

- Find the largest gap between adjacent vertices. Guess a bank angle (bisection) that will result in a point that “fills” that gap.





DYNAMIC WORKLOAD ALLOCATION



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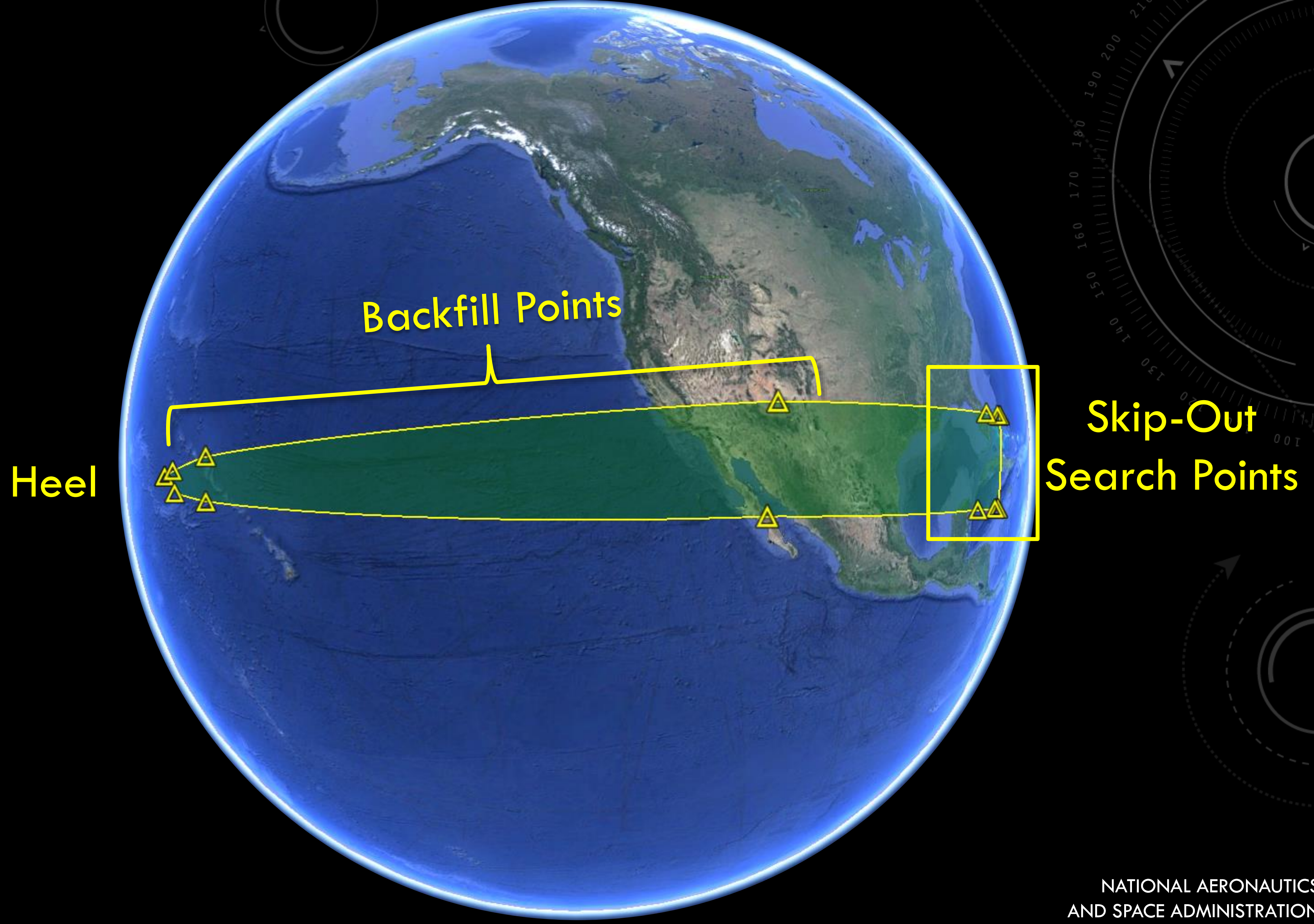
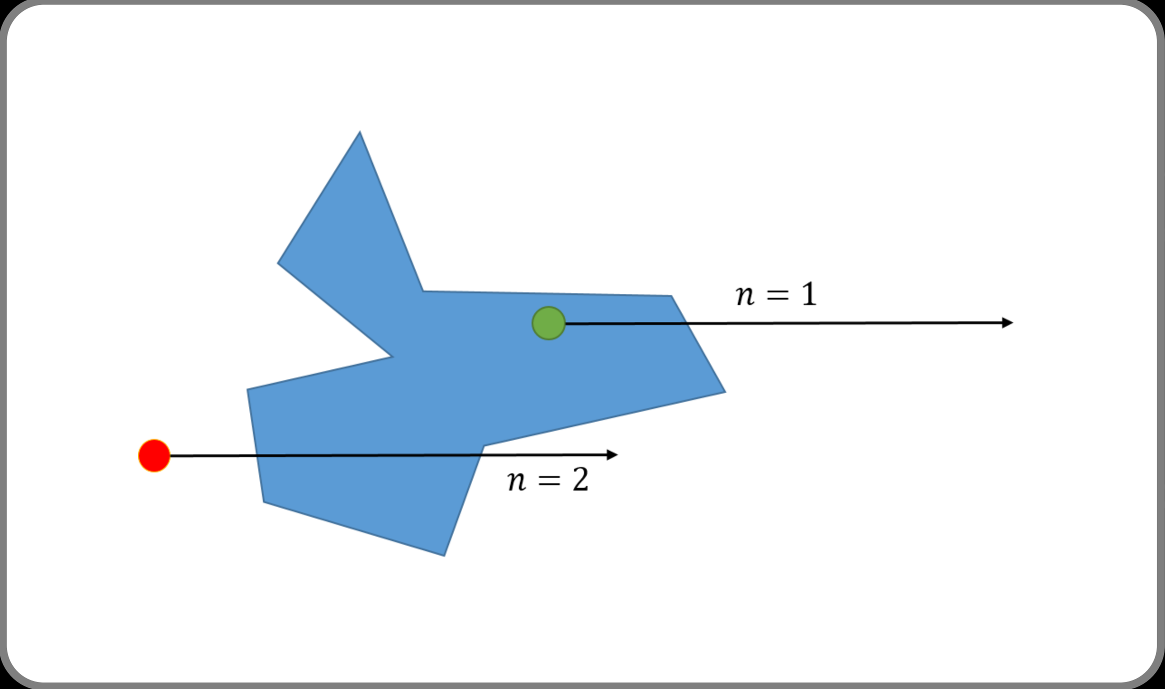

Backfill Points
Heel
Skip-Out
Search Points

TARGET FEASIBILITY EVALUATOR

- Can I still reach my primary landing target?
- Is my primary landing target (point) inside my capability footprint (polygon)?
- Uses standard ray-casting algorithm to solve the point-in-polygon problem.

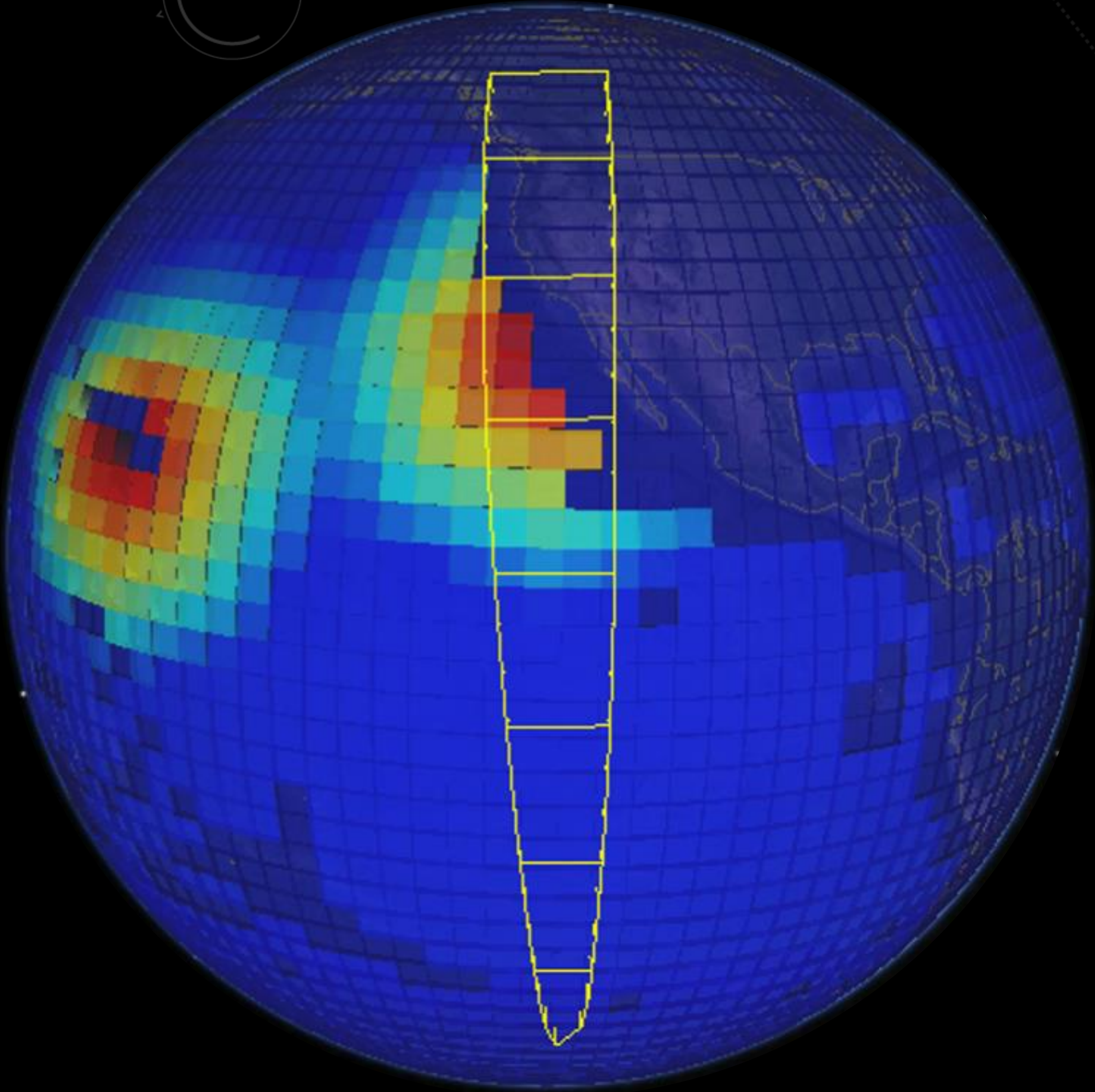


INTELLIGENT TARGET RECOMMENDATION

- If I can't reach my primary landing site, where should I go?

- Recommendations come from two sources:
  - Primary – Pre-screened set of landing sites provided by ground controllers.
  - Secondary – Querying a global map of landing suitability, which blends proximity to recovery forces, avoiding landmass, and favorable sea conditions.

- If not enough recommendations can be produced from the primary source, then the secondary source is utilized to meet the required number of recommendations.



Entry Monitor Output Visualized in Google Earth

Scenario: 4800 nautical mile polar entry from lunar return conditions

Prepared for 26th AAS/AIAA Space Flight Mechanics Meeting, February 2016

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SUMMARY

- Entry Monitor provides real-time decisional information to the crew during hypersonic entry when communication with the ground may be impossible due to radio blackout.

- Entry Monitor is powered by an efficient trajectory propagation algorithm.

- Entry Monitor will be first flown on Exploration Mission 1 in 2018.