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Sandia National Laboratories

Hypersonic Trajectory Generation Using Stabilized Continuation

Introduction / Motivation

- Hypersonic Trajectory generation is an active area of research due to the highly nonlinear nature the dynamics
- Indirect Optimal Control methods convert the trajectory problem into a Two Point Boundary Value Problem
- Continuation methods can take a known solution to a given TPBVP and transform it into a desired solution
- Continuation Methods can encounter singularities where the relationship between two trajectories is ill-conditioned

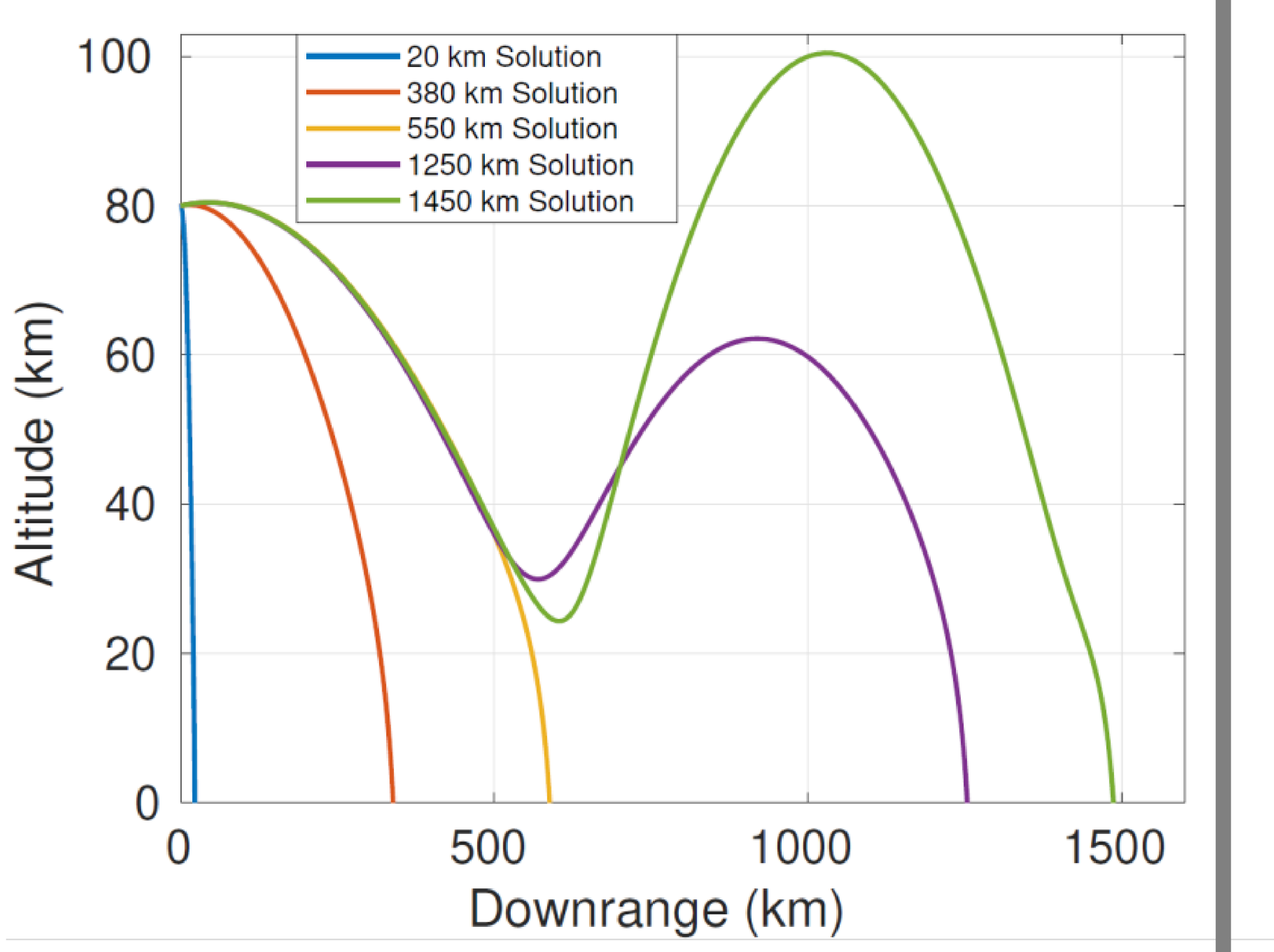


Figure 1: A simple straight down trajectory being transformed into a skip trajectory using continuation methods

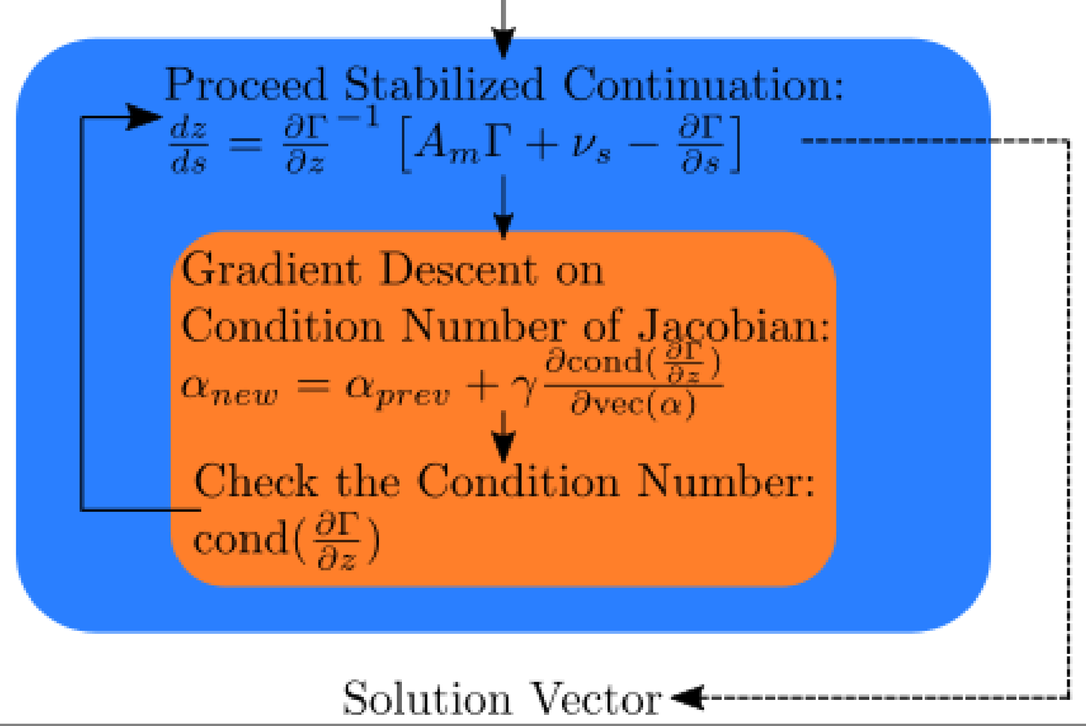
Approach

- We generalize the approach to nonlinear homotopy functions using Theory of Functional Connections [Wang and Topputo 2019]
- We find the best nonlinear path to automatically switch to using condition number as our criteria.

Nonlinear Root Solving with Continuation:

$F(z) = 0 \rightarrow \Gamma_0(s, z) = sF(z) + (1 - s)G(z)$

$\Gamma = \Gamma_0 + \alpha\Gamma_h \leftarrow$ Nonlinear pertubation parameterized by α



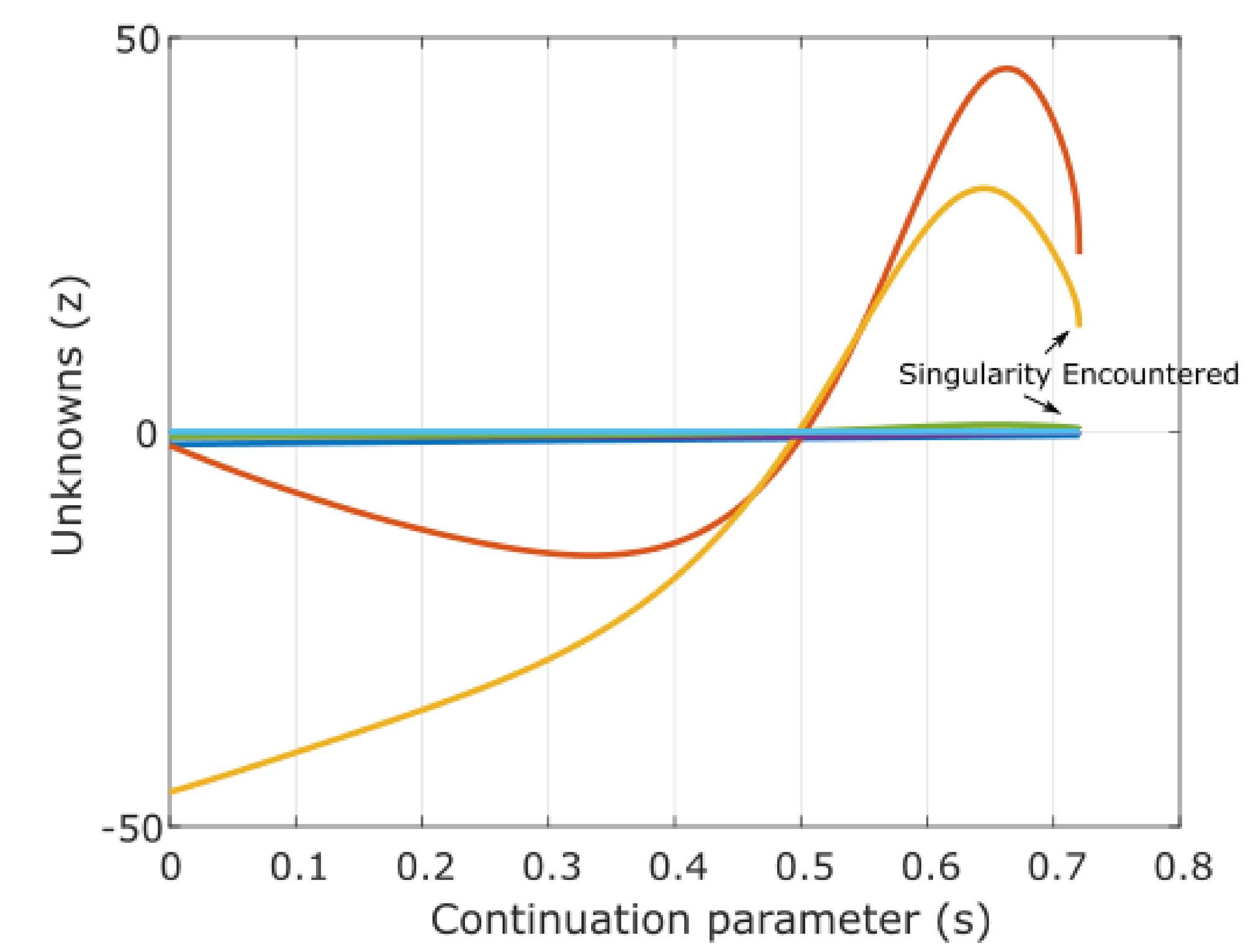


Figure 2: Continuation method failing to find a solution due to a singularity.

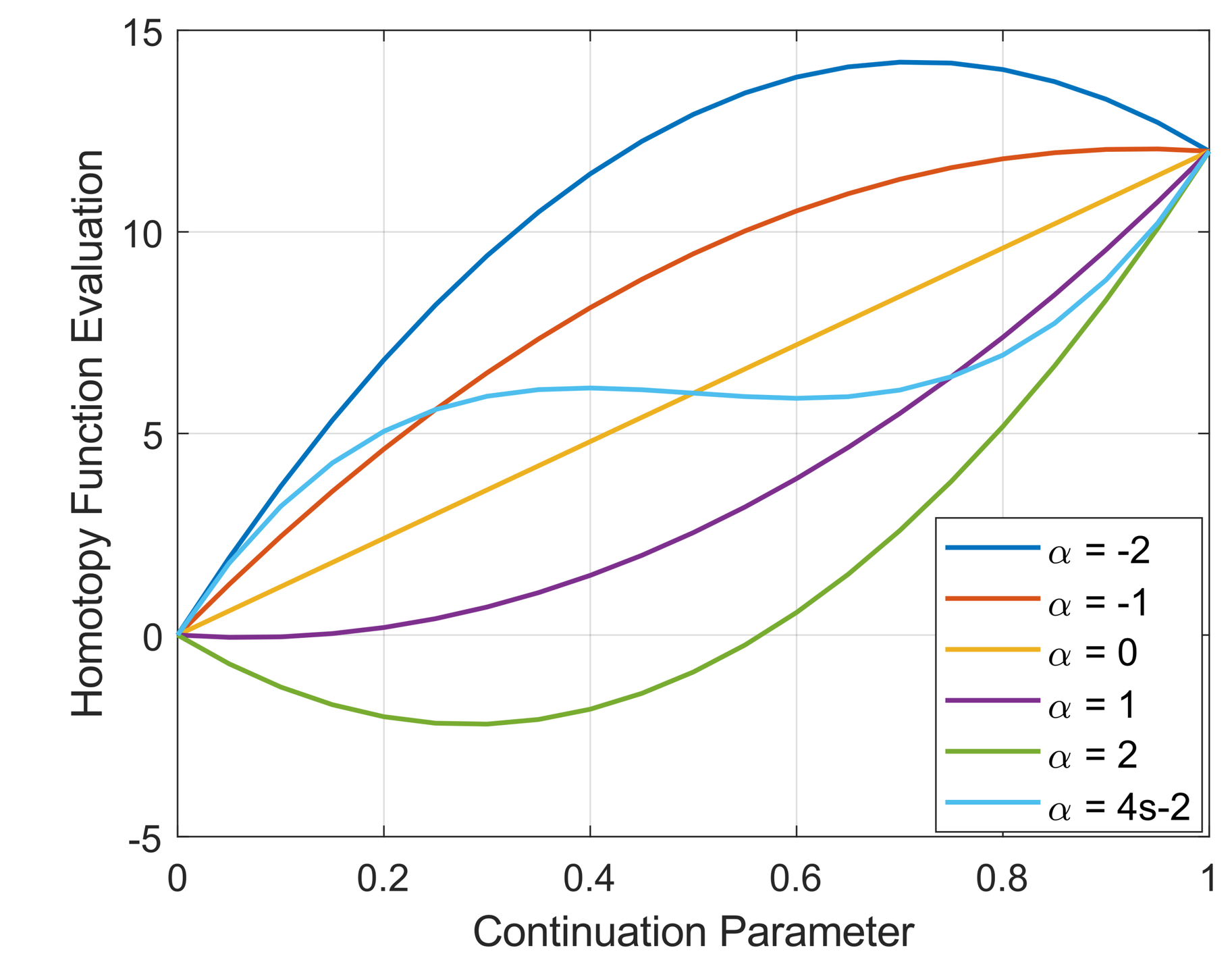


Figure 3: A few of the infinitely many possible nonlinear homotopy functions given by Theory of Functional Connections

Current Status/ Results (If any)

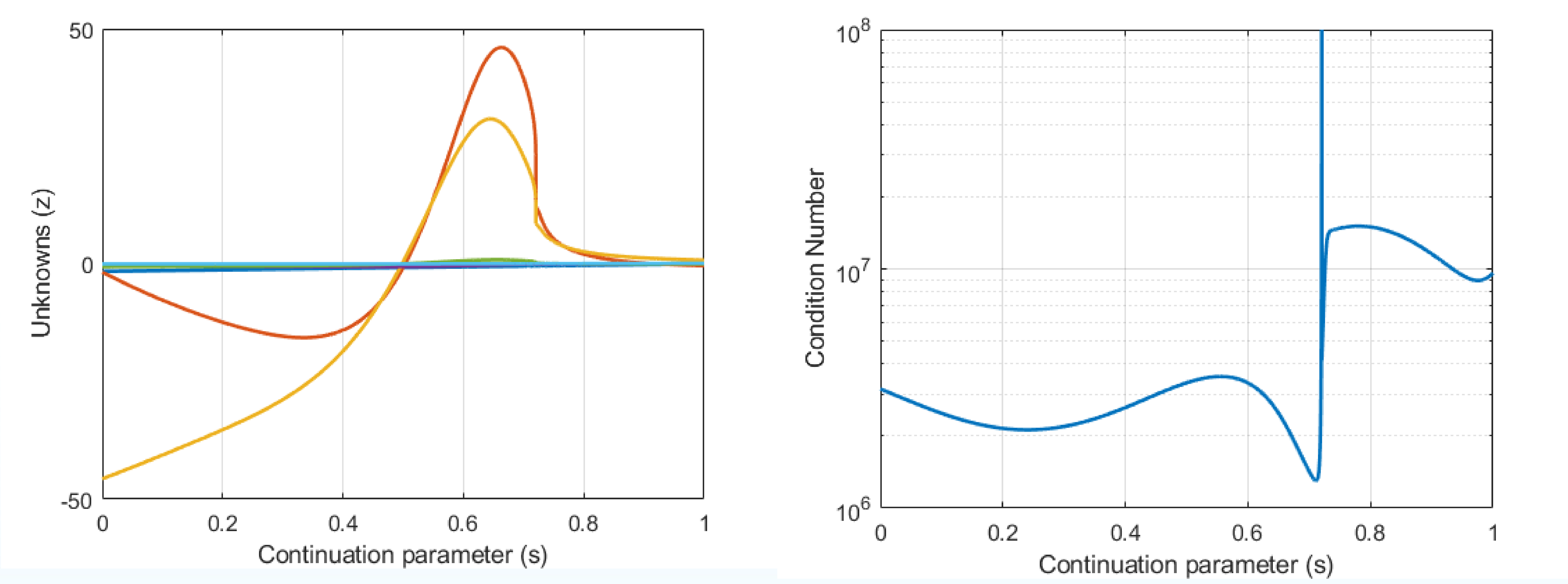


Figure 3: Automated Homotopy Path Tuning Method successfully finds a new path to switch to with no designer intervention

Challenges

- Computing the gradient of the condition number with respect to the nonlinear terms is highly sensitive
- Switching paths occurs near singularities, causing the secondary continuation to be ill-conditioned

Next Steps/ Future Work

- Implement other approaches for the switching mechanism.
  - Line Search
  - Nonlinear Root solving
- Evaluate this approach on more problems to test robustness, including the 3DOF and 6DOF state-constrained hypersonic trajectory generation problems.

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