Research project meeting summary: Trajectory Module for Launcher MDAO

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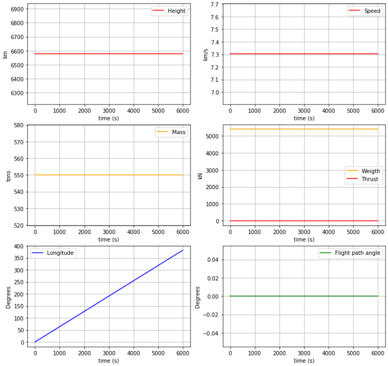
April 15, 2020

Plan:

1. Review of previous work
2. Key points discussed
3. Future actions

Orbital test of 2D EoM

Simulation of an orbital trajectory with a rotating planet to prove that the inertial velocity (v_I) is equal to the velocity parameter used in the simulation (v) plus $\omega \times r_0$

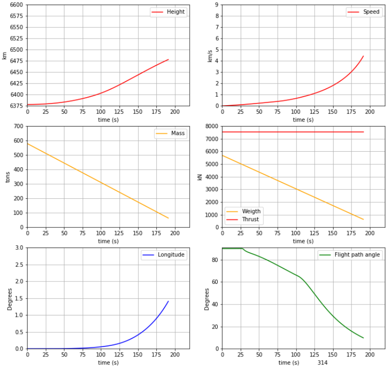


h	r	v	λ	ϕ	mfr
200 km	earth.r0 + h	earth.orbitalSpeed(h) - ω *(r_0)	0	0	0

Optimization using COBYLA

Phases

1. Lift-off: $h_{end-of-lift-off}$
2. Pitch over: $dt_{pitch-over}$, $d\theta_{pitch-over}$. Linear increase and exponential decay with duration $3 \times d\theta_{pitch-over}$
3. Gravity turn: $\phi_{end-of-gravity-turn}$
4. Bilinear tangent law: ξ, $dt_{bilinear-tangent-law}$



cost function

$$J = mass_{consumed} * error_{orbital-speed} * error_h * error_\phi \quad (1)$$

Remarks

- The solver seems to find a ”path” quite early and sticks to it. Tolerance control do not affect this behavior (Show animation)
- It seems dependent on the initial guess
- the final point boundary conditions are treated in the objective function with an error parameter to be minimized. So far, it does bring the altitude parameter to the desired value, but fails to do so with ϕ and v

Review of previous work

- Regularization of the optimization parameters so that all of them are within the same scale. This is because COBYLA takes steps of the same size at the beginning for all the parameters
- Some phases are finished because maximum time is exceeded and not because of triggered events. I am treating those with high cost function values
- My SSTO is a Falcon 9, that is why I am ussing $h = 100km$... IT would be a better idea to take parameters of a real SSTO

- Reading of Dymos documentation (40%) and SSTO Example
- Reading of MDO slides from Dr. Balesdent (50%)
  Fixed point iteration not very clear for me
  SUPAERO's course on MDAO is online now

Key points discussed

- The cost function should contain sum terms instead of product terms. This is the cause for my optimization to reach the objective height and then get stuck without decreasing the error for the velocity nor flight path angle parameters.
- The end of the gravity turn should be constrained in height and not in flight path angle values. This allows to use the $\theta_{initial}$ parameter as on optimization parameter and create the discontinuity called ”Dog leg”.
- Difference between bounds and constraints. SciPy COBYLA does not have bounds apparently but the PyOpt version may have them.
- final point boundary conditions are usually treated as equality constraints but can also be defined as inequality ones with a certain tolerance.
- Increasing thrust is a good strategy when trajectories are not feasible.

Future actions

- Look at PyOpt COBYLA to see if it allows bounds. Otherswise, find a gradient-free optimizer allowing bounds and inequality constraints
- Redefine treatment of final point boundary conditions as constraints instead of as error terms in the objective function
- Redefine end of gravity turn with a height-constrained event
- Use $\theta_{initial}$ as an optimization parameter and allow ”dog leg” discontinuity.