Research project meeting summary: Trajectory Module for Launcher MDAO

Jorge L. Valderrama [1]
Dr. Annafederica Urbano [2] Dr. Mathieu Balesdent [3] Dr. Loïc Brevault [4]

[1]ISAE-SUPAERO, MSc. in Aerospace Engineering
[2]ISAE-SUPAERO, DCAS [3]ONERA, DTIS [4]ONERA, DTIS

September 1, 2020

Plan:

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

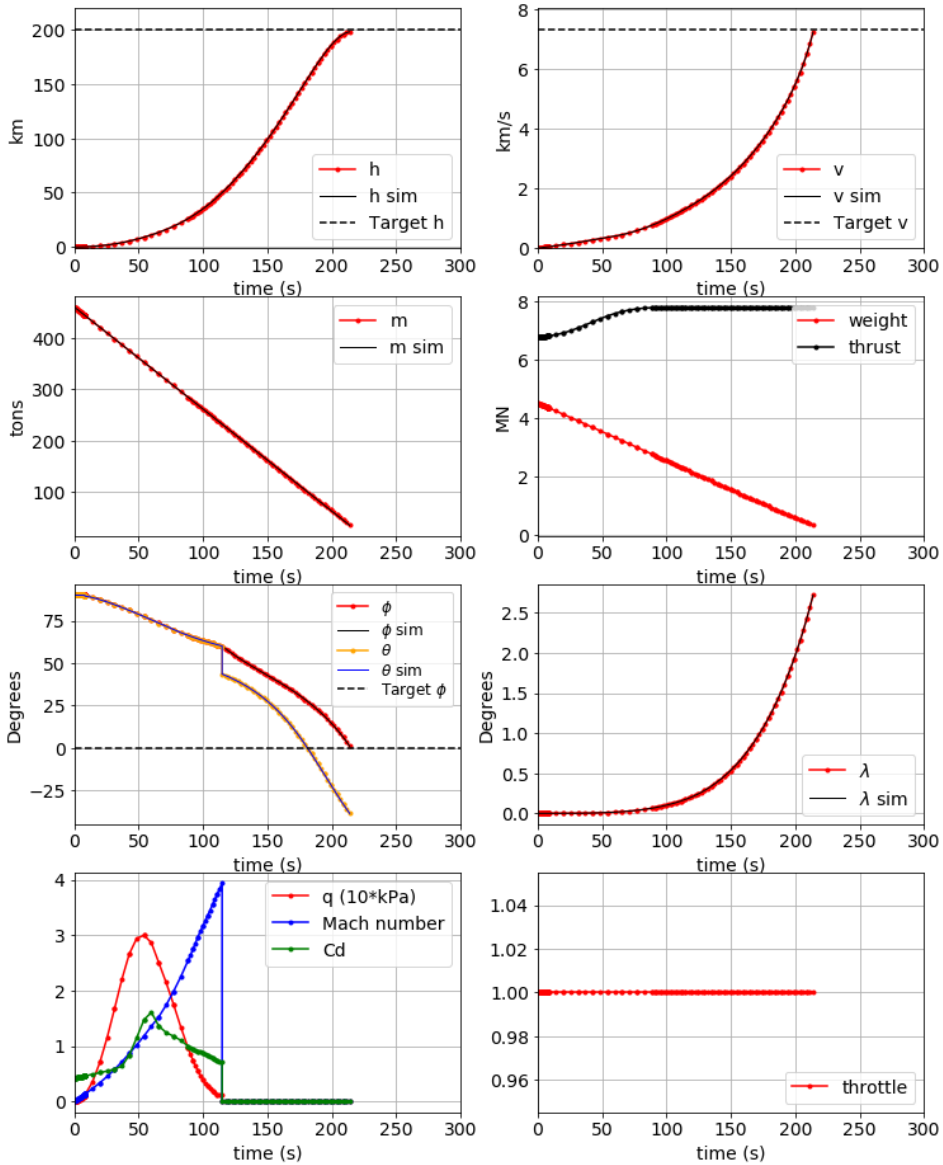
Review of previous work

Validation of results with ”simulate” method

- I solved the noisy pitch angle of the exoatmos phase by defining the jacobian using the set time option ”duration targets”. The Jacobian size is not predefined.
- Now I’m using the 1976 US atmosphere instead of the exponential model. I took the script from the Dymos repository, it uses Akima interpolation.
- Cd Vs. Mach model using Pchip interpolator as suggested in previous meeting.
- I’m now modeling thrust as a function of atmospheric pressure and nozzle exit area.
- Newton’s gravity model already implemented

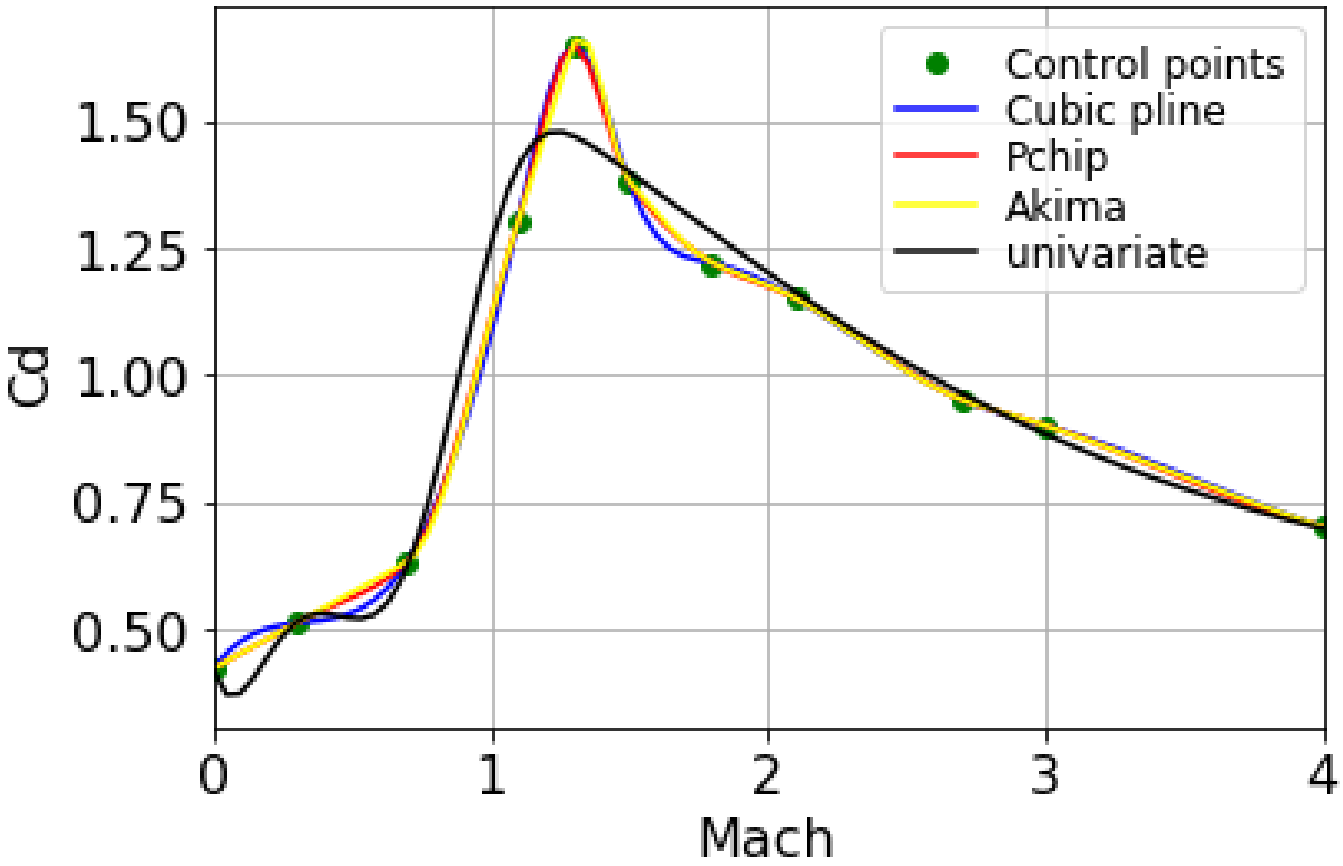
Review of previous work

Validation of results with "simulate" method. $m_{t_0} = 460.5 \quad ton$



Cd Vs. Mach interpolation

Comparison of different interpolators



Cd Vs. Mach interpolation

C_2 continuity

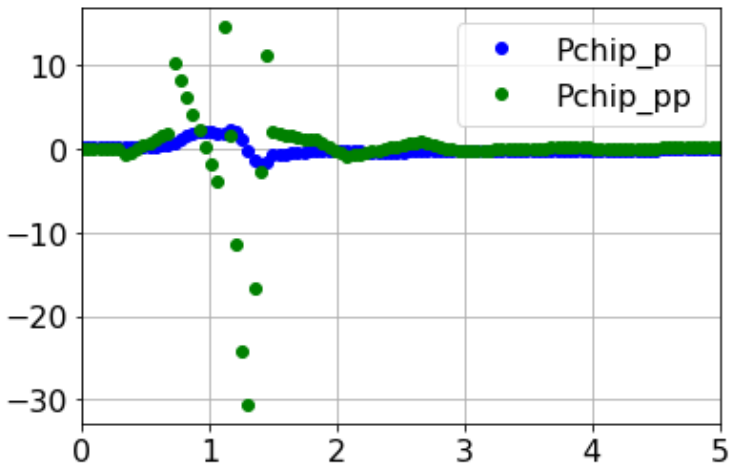


Figure: Pchip

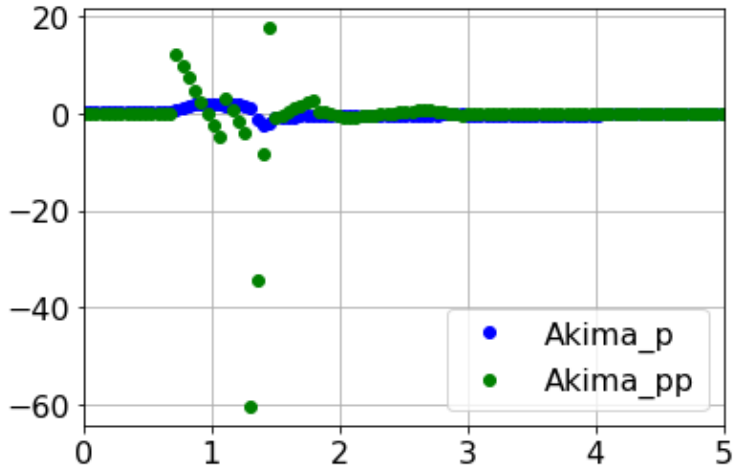


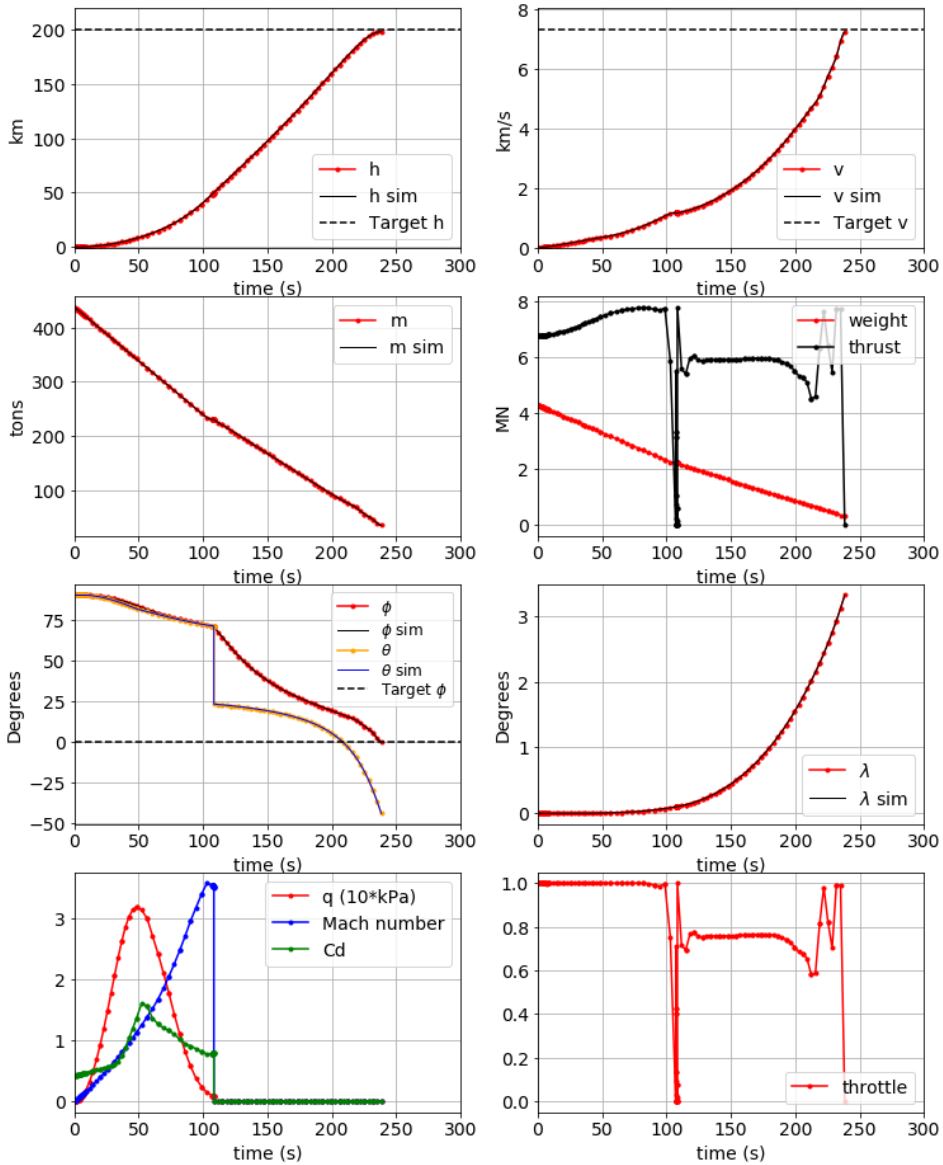
Figure: Akima

”The first derivatives are guaranteed to be continuous, but the second derivatives may jump” Pchip - scipy

”The Akima spline is a C1 differentiable function but, in general, will have a discontinuous second derivative at the knot points” Akima - Wikipedia

Review of previous work

Thrust as Dynamic control. $m_{t_0} = 437.8 \quad ton$



Key points discussed

- Scaling: The code is really sensitive to scaling, sometimes it leads to a different state history. Right now it takes less time to solve when I don't scale the last phase for thrust as static parameter.
- I still have to define properly $\Delta\theta$ between gravity turn and exoatmos phase. Right now I just let it take a value in $[-90, 90]$ *deg*. Ask on Github.
- When thrust is a dynamic control it takes way more time to solve due to the increase of NLP variables. Possibility of forcing continuity. In the future this could be implemented with real engine constraints.
- Use of OpenMDAO goups may help to write a simpler code
- Check mag of "check partials" method is always zero for the interpolators, leading to relative error.
- Validation with single shooting COBYLA method will happen after implementation of TSTO.

Key points discussed

- Next step will consist of implementation of a TSTO. Launcher used for reference will be Falcon 9 and the guidance program based on Castellini's. Fairing Jettison will happen during second stage flight with heat flux limit to 1135 $\frac{W}{m^2}$.
- Dr. Balesdent and Dr. Brevault will provide equations for orbit injection to define the second engine cutoff before insertion.

Future actions

- Tabulate Falcon 9 data
- Start implementing TSTO
- After the TSTO we will start working on the sensitivity of the pseudostpectral method to scaling and the initial guess before continuing with MDAO.