Research project meeting summary: Trajectory Module for Launcher MDAO

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Plan:

1. Review of previous work
   - Updates on the use of Rocket CEA
   - Changes on Propulsion XDSM
   - Validation of Propulsion module
   - Overall optimization results
2. Key points discussed
3. Future actions

Review of previous work

Updates on the use of Rocket CEA

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Rocket CEA

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- Low values of mass ratio and high values of chamber pressure were creating discontinuities in the Rocket CEA output. I fixed it and now derivatives are not noisy.

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- I decomposed the calculation of I_{sp} to have access to values of characteristic velocity ($c^\star$), thrust coefficient (C_f), etc...
- All values in the propulsion model are now calculated at the optimal point, i.e. $P_e = P_a$.

Theoretical Chamber Performance of RP-1 / LOx

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- Nozzle exit pressure: 14.7 psia
- Mixture mass ratio: 2.24
- Optimum expansion. Frozen equilibrium.

	Sutton	Propulsion model	Error
$I_{sp}(s)$	285.4	285.97	0.2 %
$c^{\star}(m/s)$	1774	1769.95	0.2 %
$T_c(K)$	3571	3539.13	0.9 %
$\gamma_t()$	1.24	1.2217	1.5 %
$m_c(g/mol)$	21.9	22.047	0.7 %

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Review of previous work

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- The combustion chamber pressure reaches its upper bound always. How can we constrain it?
  - Maximum value of response surface: 17 (MPa)
  - Merlin 1D engine value: 10 (MPa)

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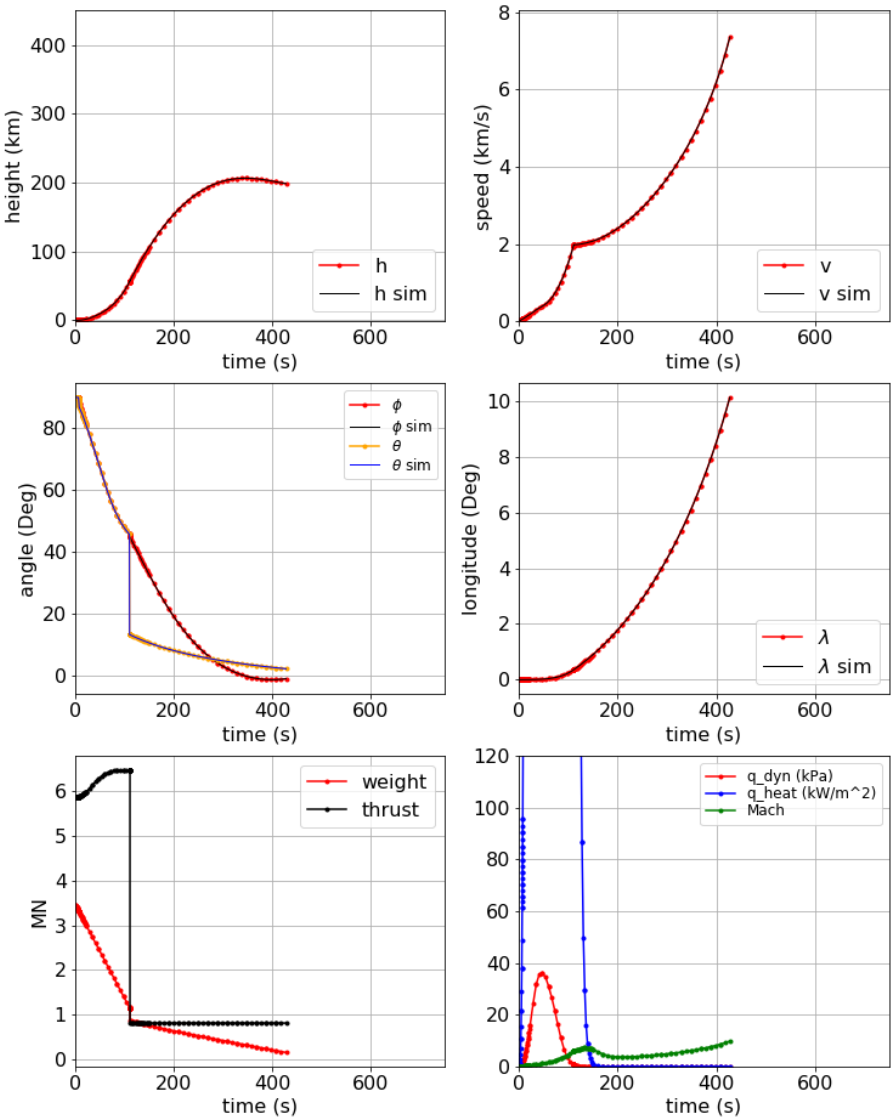
- Results in following slides are for payload mass of 11 Tons

Review of previous work

Overall optimization results



Review of previous work

Overall optimization results

	Merlin 1D	Opt results	Opt results- limited
P_c(MPa)	9.7	17	10
I_{sp}(s)	348	355.9	347.2
Ae(m^2)	8.5 ?	8.5	8.5
$\dot{m}$(kg/s)	287.3?	226.3	233.6
ϵ	165	357.9	204.9
Thrust(kN)	981	790.1	795.9

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- From the same initial guess used before (11ton - 400 km x 400 km)
- Limiting P_c and thrust to the values of Falcon 9
- Using its maximum GTO payload, 8.3 ton

The optimizer converges for:

- GTO mission (36 000 km x 145 km)
- Mass at lift-off near that of Falcon 9 (549 ton)

Some Falcon - 9 GTO missions are almost ”in-plane” missions

Review of previous work

Overall optimization results

```
Vehicle paramaters
-------------------------------------------------------------------------------
Payload mass (kg):                      8300.0
Fairing mass (kg):                      1900.0
First stage:
    Structural mass (kg):               28000.0
    Propellants mass (kg):              397650.23
    Structural coef ():                 0.07
    Thrust (N):                         8500000.0
    Isp (opt) (s):                      283.59
    S (m^2):                            37.5
    Ae_t (m^2):                         6.03
Second stage:
    Structural mass (kg):               4700.0
    Propellants mass (kg):              122597.11
    Structural coef ():                 0.04
    Thrust (N):                         1000000.0
    Isp (opt) (s):                      330.68
    S (m^2):                            37.5
    Ae_t (m^2):                         8.5
First stage flight with fairing:
    Tw_ratio ():                        1.54
Second stage flight with fairing:
    Tw_ratio ():                        0.74

Objective:                              value
Initial mass (ton):                     563.147

Initial guess:                          initial_guess/F9_11Ton_400km_prop_2.db

Performance:
Message:                                Optimization terminated successfully.
Number of iterations:                   244
Number of gradient evaluations:         244
Number of function evaluations:         480
Optimization time (s):                  259.88
```

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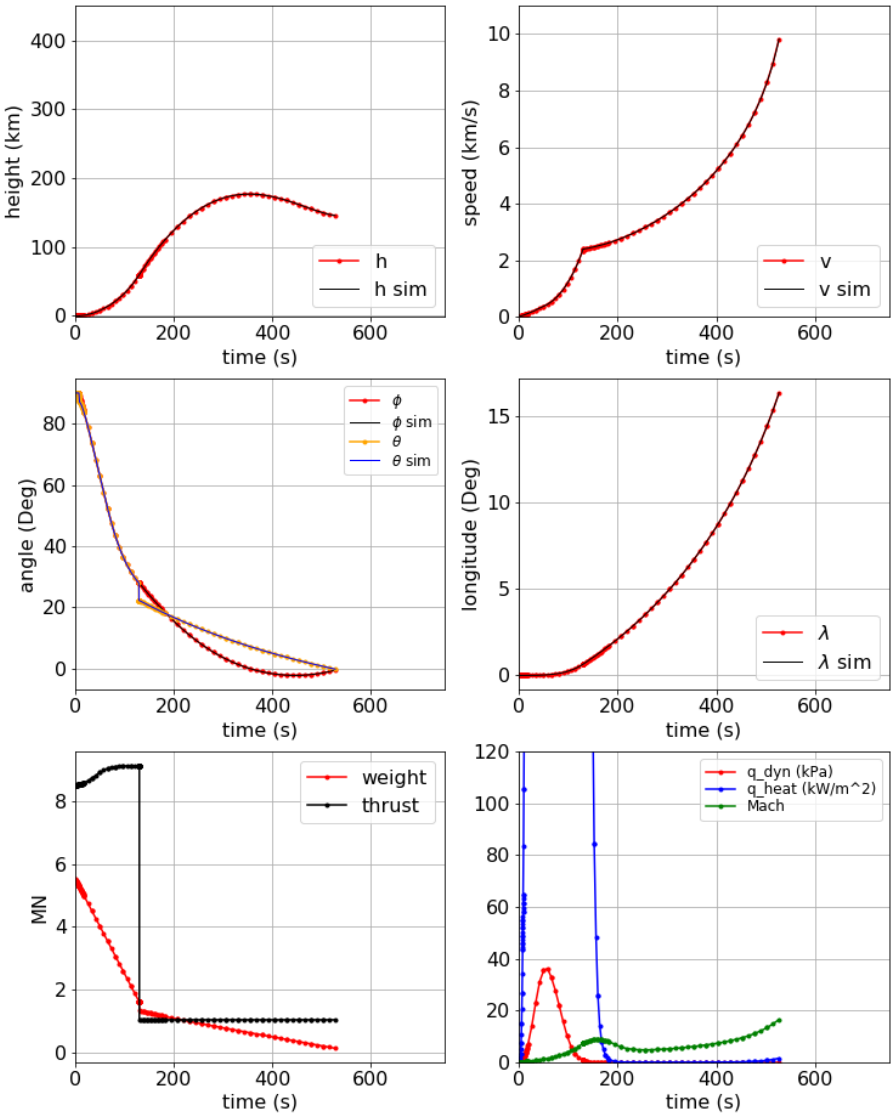

Key points discussed

- Calculation of propulsion parameters at optimal expansion leads to the design of the engine at that point. Design at vacuum is preferred.
- As all the variables are optimized at the same level, feedback loops should be managed with constraints. We will evaluate this in the N2 diagrams.

Future actions

- Try coupling for variables in charged of mass of propellants for the disciplines of trajectory and propulsion
- Correct propulsion module as discussed