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

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Plan:

1. Review of previous work
   - Propulsion checks
   - These are the optimization results for a 11 ton - 400 km mission
2. Key points discussed
   - Models to be used from LAST
3. Future actions

This is how I'm modeling the propulsion module. Given O/F, P_c, P_e, P_a and T at vacuum compute:

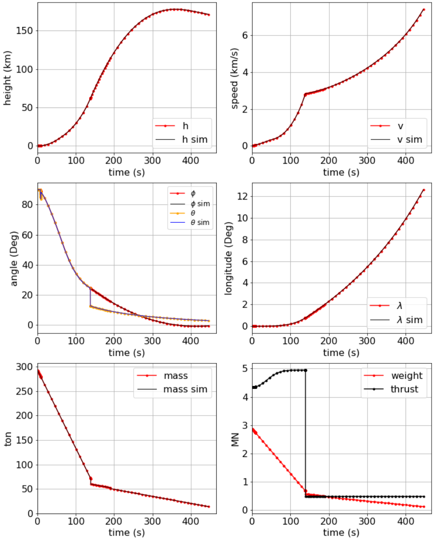
1. From O/F and P_c: Use Rocket CEA to obtain γ_t, T_c and M_c
2. From γ_t, T_c and M_c: $c^\star = \eta_{c^\star} * \frac{\sqrt{\gamma_t R T_c}}{\gamma_t (\frac{2}{\gamma_t+1})^{\frac{\gamma_t+1}{(\gamma_t-1)2}}}$
3. From P_c, P_e and γ_t: $\epsilon = \frac{(\frac{2}{\gamma_t+1})^{\frac{1}{\gamma_t-1}} (\frac{P_c}{P_e})^{\frac{1}{\gamma_t}}}{\sqrt{(\frac{\gamma_t+1}{\gamma_t-1})(1-(\frac{P_e}{P_c})^{\frac{\gamma_t-1}{\gamma_t}})}}$
4. From γ_t, ϵ, P_c, P_e and $P_a = 0$:

$$C_f = \eta_{c_f} \sqrt{\frac{2\gamma_t^2}{\gamma_t - 1} * \frac{2}{\gamma_t+1}^{\frac{\gamma_t+1}{\gamma_t-1}} * \left(1 - \left(\frac{P_e}{P_c}\right)^{\frac{\gamma_t-1}{\gamma_t}}\right)} + \frac{\eta_{c_f}\epsilon}{P_c} * (P_e - P_a)$$

5. From $c^\star$ and C_f: $I_{sp} = \frac{c^\star}{g_0}$
6. From I_{sp} and T: $\dot{m} = \frac{T}{I_{sp} g_0}$
7. From $\dot{m}$, P_c and $c^\star$: $A_t = \frac{c^\star \dot{m}}{P_c}$
8. From A_t and ϵ: $A_e = A_t \epsilon$

Review of previous work

These are the optimization results for a 11 ton - 400 km mission



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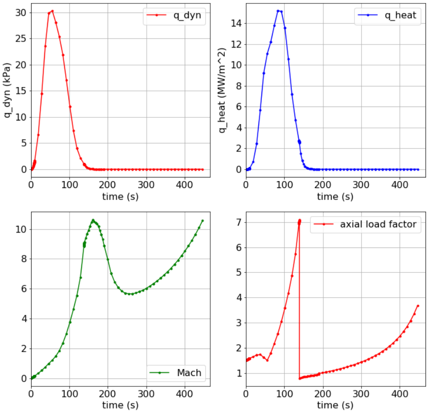

Review of previous work

These are the optimization results for a 11 ton - 400 km mission

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===============================================================================
========================== Optimization Report ===========================
===============================================================================

Design parameters:
Design parameters marked with (***) are close to their bounds or violate them
Name                                        lower          value          upper
--------------------------------------------------------------------------------
lift_off.t_duration                         1.0            7.5705         100.0
pitch_over_linear.t_duration (***)          1.0            1.0            100.0
pitch_over_exponential.t_duration (***)     1.0            1.0            100.0
gravity_turn.t_duration                     1.0            128.36         200.0
xi                                          -1.0           -0.2148        1.0
delta_theta_pitch_over                      0.0175         0.0905         0.1396
delta_theta_exoatmos                        -1.0472        -0.2116        1.0472
theta_f                                     -1.0472        0.0492         1.0472
phase_duration_a_dp (***)                   1.0            1.0            500.0
phase_duration_b_dp                         1.0            51.5159        500.0
phase_duration_c_dp                         1.0            256.4655       500.0
P_c_stage_2 (***)                           6000000.0      10000000.0     10000000.0
P_e_stage_2                                 0.0            1303.9381      10000.0
o_f_stage_2                                 1.2            2.3589         5.4
TW_b                                        0.1            0.834          2.0
mp_2                                        10000.0        44619.5343     200000.0
max_n_f_2                                   1.0            7.0864         10.0
P_c_stage_1 (***)                           6000000.0      10000000.0     10000000.0
P_e_stage_1                                 40530.0        43018.1172     200000.0
o_f_stage_1                                 1.2            2.3017         5.4
TW_a                                        0.1            1.7209         2.0
mp_1                                        100000.0       222362.894     600000.0
max_n_f_1                                   1.0            7.0864         10.0
```

Review of previous work

These are the optimization results for a 11 ton - 400 km mission

Constraints:

Name	lower	value	upper
lift_off.final_value:r	6378285.0	6378285.0	6380135.0
gravity_turn.final_value:q_dyn	-1e+21	1000.0	1000.0
exoatmos_b.final_value:q_heat	-1e+21	1135.0	1135.0
exoatmos_c.final_value:ra	6778135.0	6778135.0	6798135.0
exoatmos_c.final_value:rp	6523135.0	6523135.0	1e+21
propulsion_stage_2.nozzleExitArea.Ae	0.1	8.5	8.5
nozzleExitArea.Ae	0.01	0.67	0.67
Jettison.residual_ms_1	0.0	-0.0	1e+30
Jettison.residual_mplf	0.0	0.0	1e+30
Jettison.residual_m_final	0.0	-0.0	1e+30
Propellants.residual_mp_1	0.0	-0.0	1e+30
Propellants.residual_mp_2	0.0	-0.0	1e+30
LoadFactor.residual_max_n_f_1	0.0	-0.0	1e+30
LoadFactor.residual_max_n_f_2	0.0	-0.0	1e+30

Review of previous work

These are the optimization results for a 11 ton - 400 km mission

```
Vehicle paramaters
--------------------------------------------------------------------------------
Payload mass (kg):                      11000.0
Fairing mass (kg):                      1900.0
First stage:
    Structural mass (kg):               11159.87
    Propellants mass (kg):              222362.89
    Structural coef ():                 0.05
    Thrust (N):                         4950140.8
    Isp (opt) (s):                      315.38
    S (m^2):                            37.5
    Ae_t (m^2):                         6.03
Second stage:
    Structural mass (kg):               2272.7
    Propellants mass (kg):              44619.53
    Structural coef ():                 0.05
    Thrust (N):                         489000.48
    Isp (opt) (s):                      346.45
    S (m^2):                            37.5
    Ae_t (m^2):                         8.5
First stage flight with fairing:
    Tw_ratio ():                        1.72
Second stage flight with fairing:
    Tw_ratio ():                        0.83

Objective:                              value
Initial mass (ton):                     293.315

Initial guess:                          initial_guess/F9_11Ton_400km.db

Performance:
Message:                                Optimization terminated successfully.
Number of iterations:                   1
Number of gradient evaluations:         1
Number of function evaluations:         1
Optimization time (s):                  4.8
```

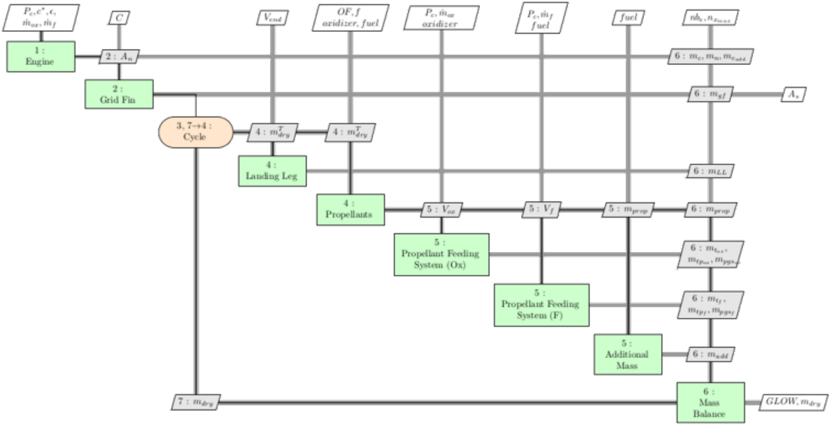
I did a comparison of the values of I_{sp} obtained with my propulsion module and Rocket CEA using the Frozen settings. I used $\eta_{c\star} = \eta_{C_f} = 1$

Inputs	
P_c(MPa)	10
P_e(kPa)	40.53
O/F	2.3069

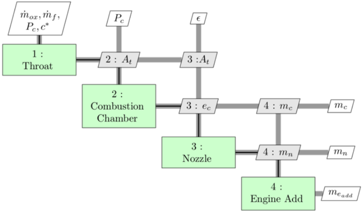
	Propulsion Model	Rocket CEA
γ_t	1.2182	1.2182
t_c(K)	3619.44	3619.42
m_c(g/mol)	22.435	22.434
$c^\star$(m/s)	1776.2	1776.9
ϵ	22.664	21.396
$I_{sp_{vac}}$(s)	329.15	326.39

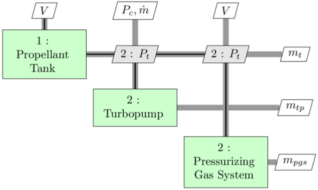
There's an error of around 1% on the value of I_{sp} and I think it comes from an error on the calculation of ϵ. For ϵ I double checked my equations and I don't know what could be causing this error.

This is the xdsm from LAST mass module. There's also a coded version for an expendable launcher, it ignores grid fins and landing legs.



I don't think is a good idea to plug the whole module because of the feedback loop. I would try an AAO approach instead. There's also a different approach to the definition of mass of propellants. I'm thinking on taking individual modules, implementing the "engine" , "propellants feeding systems" and "additional mass" first.





Future actions

Work more on the refinement of the structural module.