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ONERA
THE FRENCH AEROSPACE LAB

Description of launch vehicle design test case

Specifications

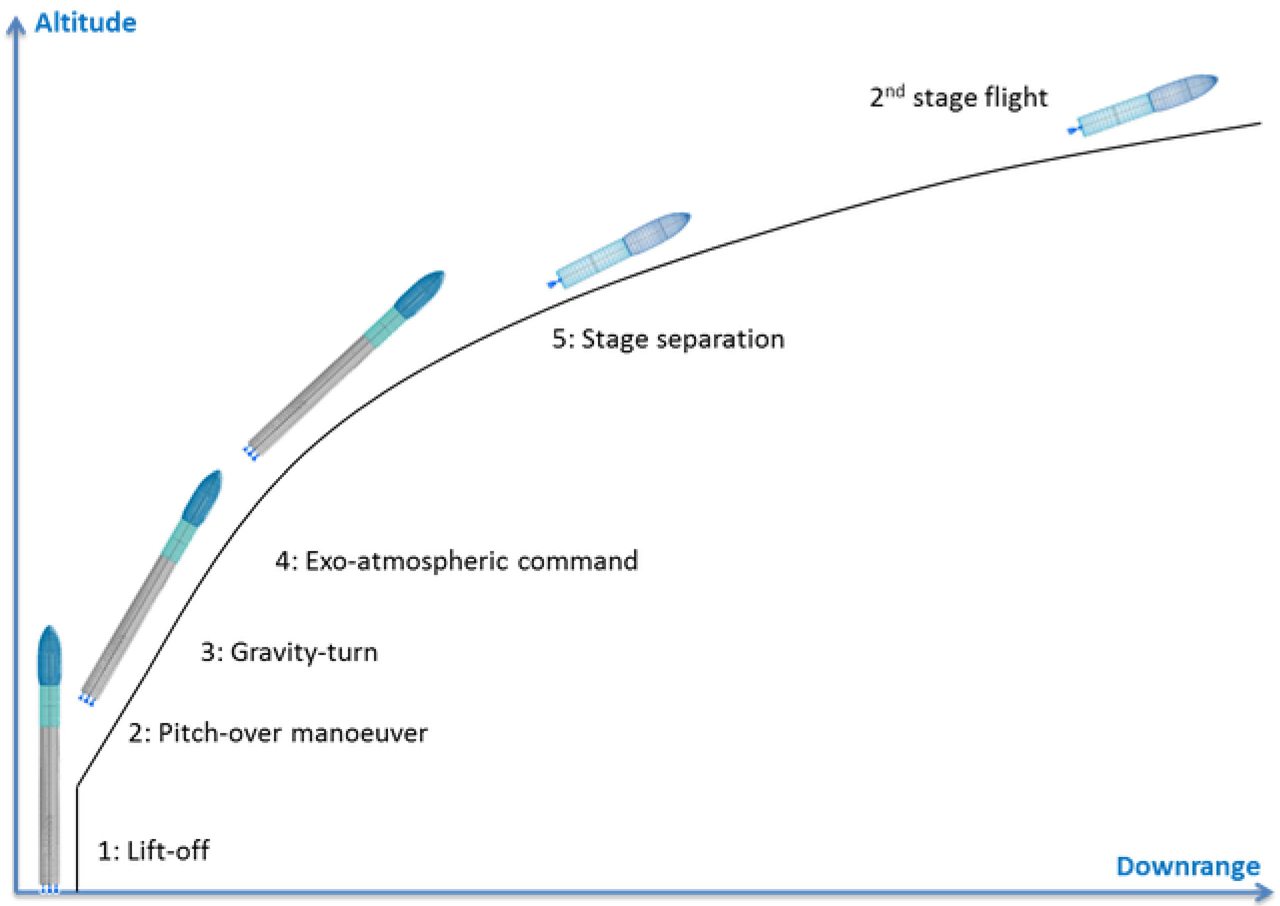
- We aim at designing a two stage to orbit launch vehicle to inject a 5 tons payload into 700 x 700 km equatorial orbit.

- The launch site is the european space port (Kourou)

Configuration of launch vehicle

- Two-stage-to-orbit launch vehicle
- Propellant : LOx / LH2
- First stage with 8 engines
- Second stage with 1 engine

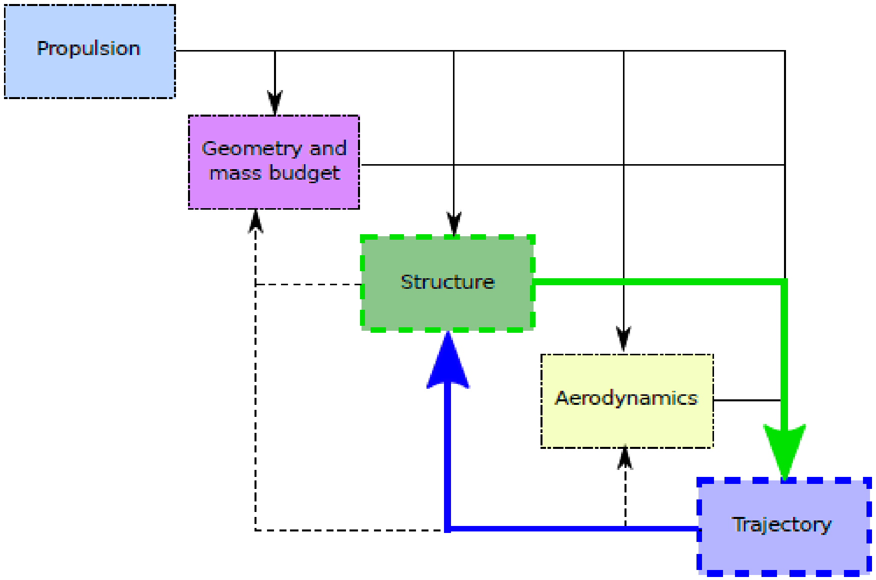
Flight phases



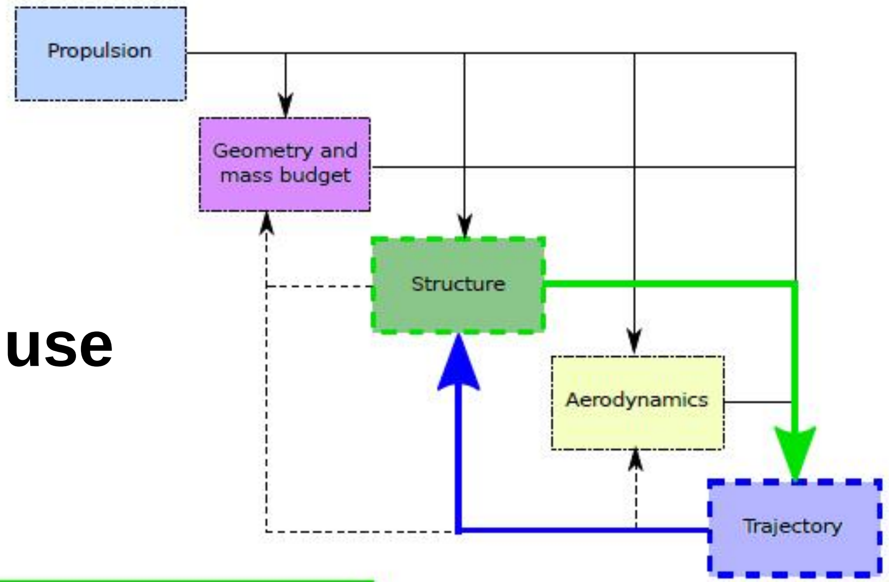
Launch vehicle design

- All the different disciplines have been modeled and coupled into openMDAO (NASA) using simplified models

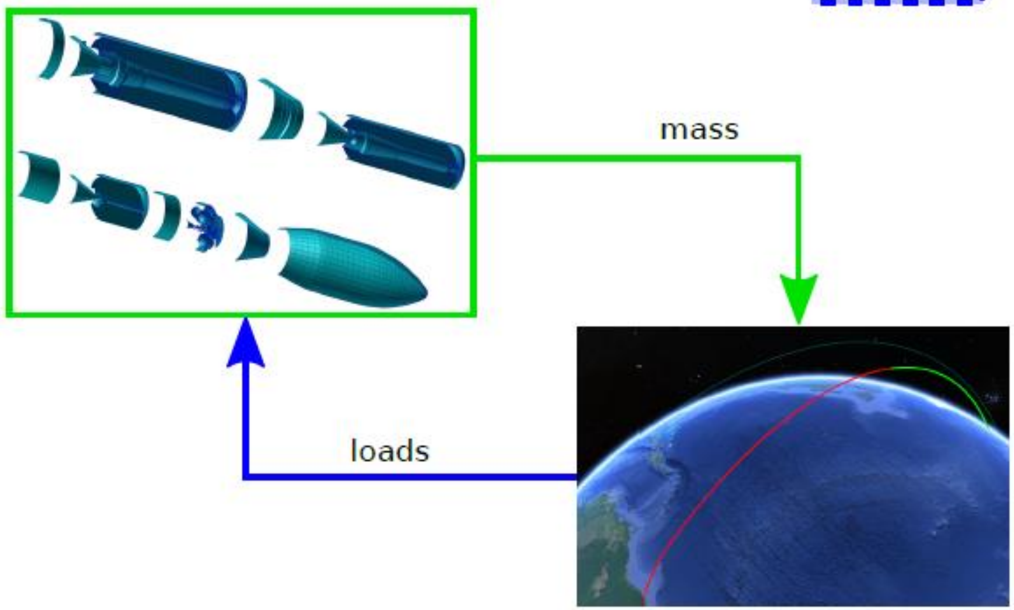
  - Trajectory
  - Propulsion
  - Structure
  - Aerodynamics

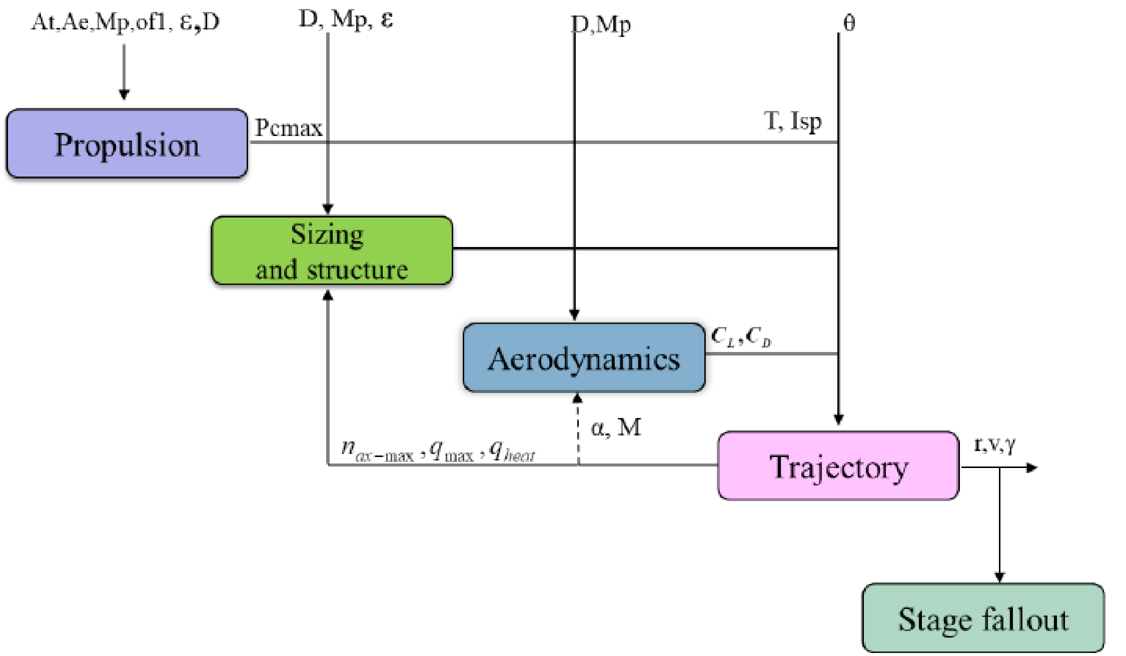


Interactions between the disciplines



→ **MDA by Gauss Seidel, use of MDF formulation**





Mp	Propellant mass	θ	Pitch angle
Ae	Nozzle area	C_D	Drag coefficient
At	Throat area	C_L	Lift coefficient
of1	Oxydizer to fuel ratio	α	Angle of attack
ϵ	Nozzle expansion ratio	r	Altitude
D	Stage diameter	v	Velocity
Pc	Combustion pressure	γ	Flight path angle
T	Thrust	n_x	Axial load factor
Isp	Specific impulse	q	Dynamic pressure

Optimization problem:
MDO problem

$$
\begin{aligned}
&\min \ \mathrm{GLOW}(\mathbf{z}) \\
&\text{w.r.t } \mathbf{z} = [\mathrm{M}_{prop1}, \mathrm{M}_{prop2}, \theta_i, \theta_f, \xi, \Delta_t, \Delta_\theta, t_{vertical}, \theta_{cmd}] \\
&\text{s.t. } \alpha_{ascent}(\mathbf{z}) \leq 15 \\
&\quad NX_{ascent}(\mathbf{z}) \leq 4.5 \\
&\quad Pdyn_{ascent}(\mathbf{z}) \leq 40. \\
&\quad HeatFlux_{ascent}(\mathbf{z}) \leq 100. \\
&\quad \mathrm{Apogee}(\mathbf{z}) = 700. \\
&\quad \mathrm{Perigee}_{Coast\,Phase}(\mathbf{z}) \geq 140. \\
&\quad M_{Circularization}(\mathbf{z}) \geq 0. \\
&\quad \mathbf{z}_{\min} \leq \mathbf{z} \leq \mathbf{z}_{\max}
\end{aligned}
$$

with:

- GLOW: Gross-Lift-Off Weight
- $\mathbf{z} \in \mathbb{R}^{10}$, in practice the input variables are normalized into $[0., 1.]^{10}$
- M_{prop1}: Prop_mass_stage_1
- M_{prop2}: Prop_mass_stage_2
- θ_i: thetacmd_i, pitch angle begining of bilinear phase
- θ_f: thetacmd_f, pitch angle end of bilinear phase
- ξ: ksi, shape parameter of bilinear phase
- Δ_t: Pitch_over_duration
- Δ_θ: Delta_theta_pitch_over
- $t_{vertical}$: Delta_vertical_phase
- θ_{cmd}: command_stage_1_exo (vector of dimension 2)

The constraints are defined in the specification.py file:

- α_{ascent}: angle of attack during the ascent phase that must be below 15 degrees
- NX_{ascent}: axial load factor during the ascent phase that must be below 4.5g
- $Pdyn_{ascent}$: dynamic pressure during the ascent phase that must be below 40kPa
- $HeatFlux_{ascent}$: heat flux during the ascent phase that must be below 100 W/m^2
- Apogee: Apogee altitude of the coast phase transition orbit must be equal to 700km
- $\mathrm{Perigee}_{Coast\,Phase}$: Perigee altitude of the coast phase transition orbit must be above 140km
- $M_{Circularization}$: remaining propellant mass before the circularization burn must be sufficient to circularize the final orbit 700 x 700km

→ Numerous optima : use of CMA – ES (see course 1) on top of MDA