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Swedish Aerospace Technology in a Globalised World

The Conceptual Design of a Horizontal Take-off and Landing, Reusable Satellite Launcher

CONDAX TECNOLOGIA
Brazil
UFMG

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The Conceptual Design of a Horizontal Take-off and Landing, Reusable Satellite Launcher

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The Conceptual Design of a Horizontal Take-off and Landing, Reusable Satellite Launcher

Topics:

- Concepts and Assumptions
- General Methodology
- Mission
- First definition of the vehicle
- Adopted configuration
- Second definition of the vehicle

Who we are:

A group of aerospace engineers and students, linked to the University, interested in high-speed research

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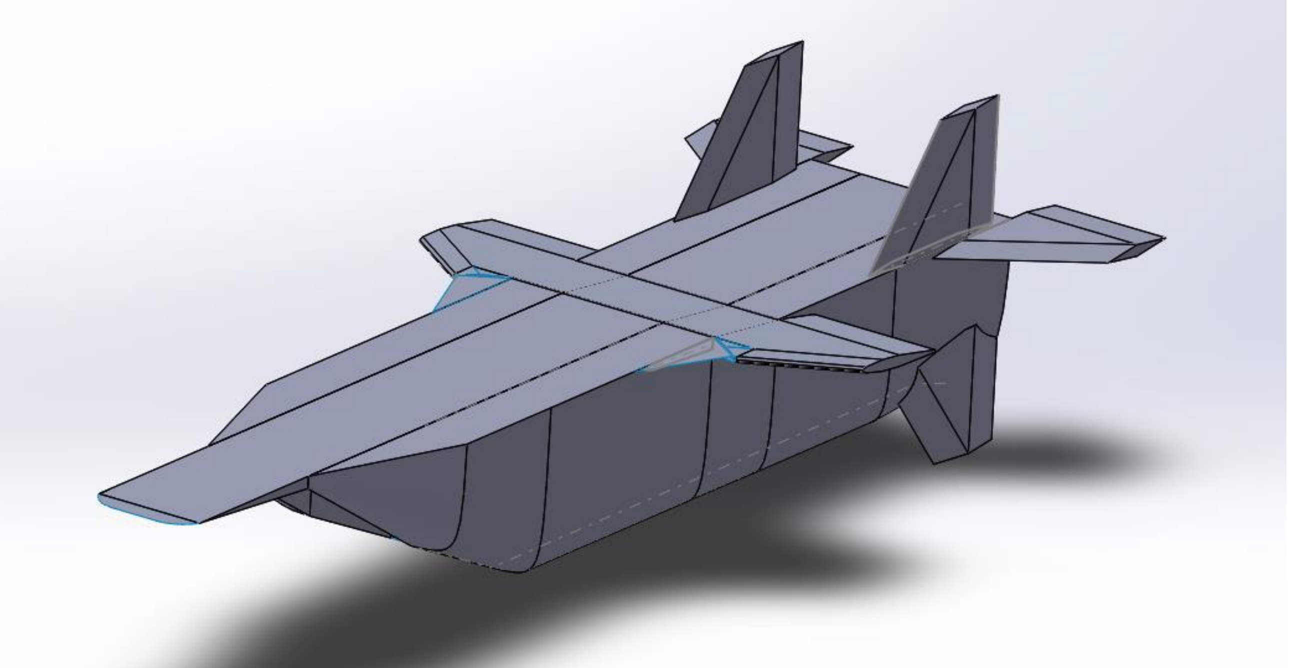
Previous work: The conceptual design of small aircraft to use a scramjet engine



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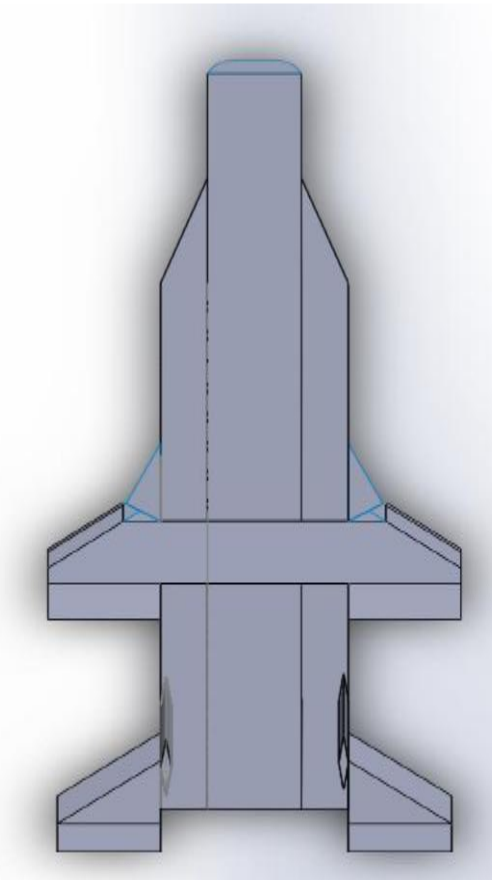

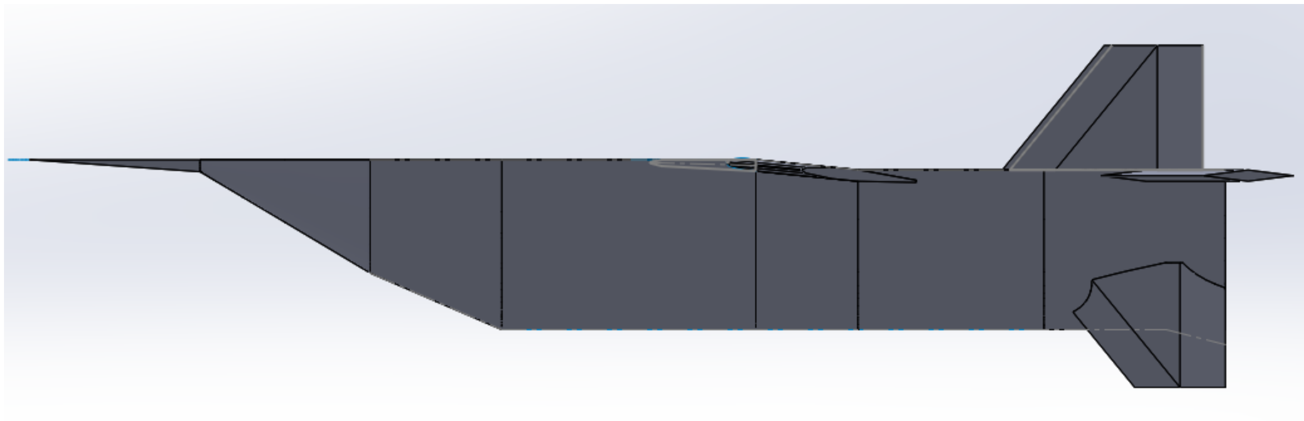

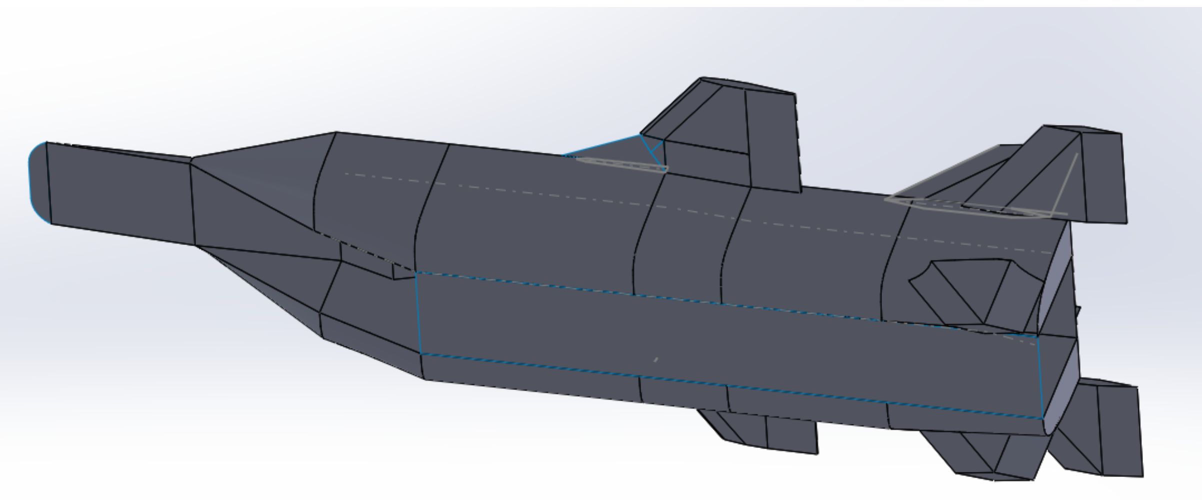

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Concepts: Airplane vs Rocket

Atmospheric flight vs flight-to-orbit

Breguet's Law vs Tsiolkovski's Law
distance vs speed per burned fuel

Atmospheric flight:

* needs less thrust
* requires longer 'burning times'
* less weight per distance & payload (no oxidizer)... but
* speeds up to Mach 3 (Ramjet) or 7 (Scramjet)

Flight to orbit: speeds up to (the equivalent of) Mach 25

Concepts:

Engine &Airframe Design:

For high thrust ratio,
engine and airframe shall be designed together
in a iterative approach.

(For Scramjets, this is particularly true:
almost all the fuselage can be considered as part of the engine; strong interaction between wing and fuselage)

Assumptions:

* Engine performance and mass values adopted considering already-flown engines, aircraft and rockets.

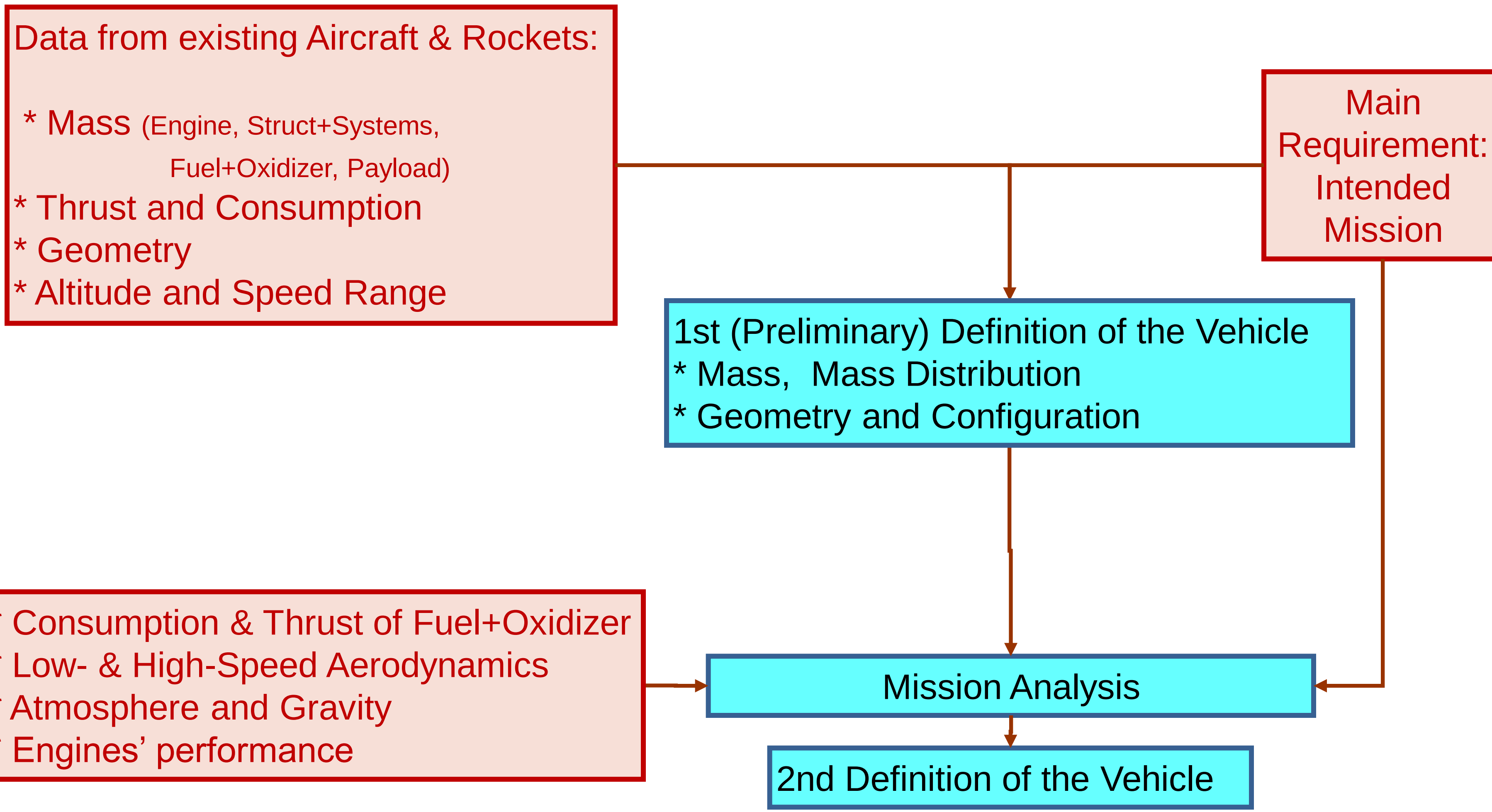
* Standard Atmosphere

* Compressibility effects on the aerodynamic coefficients

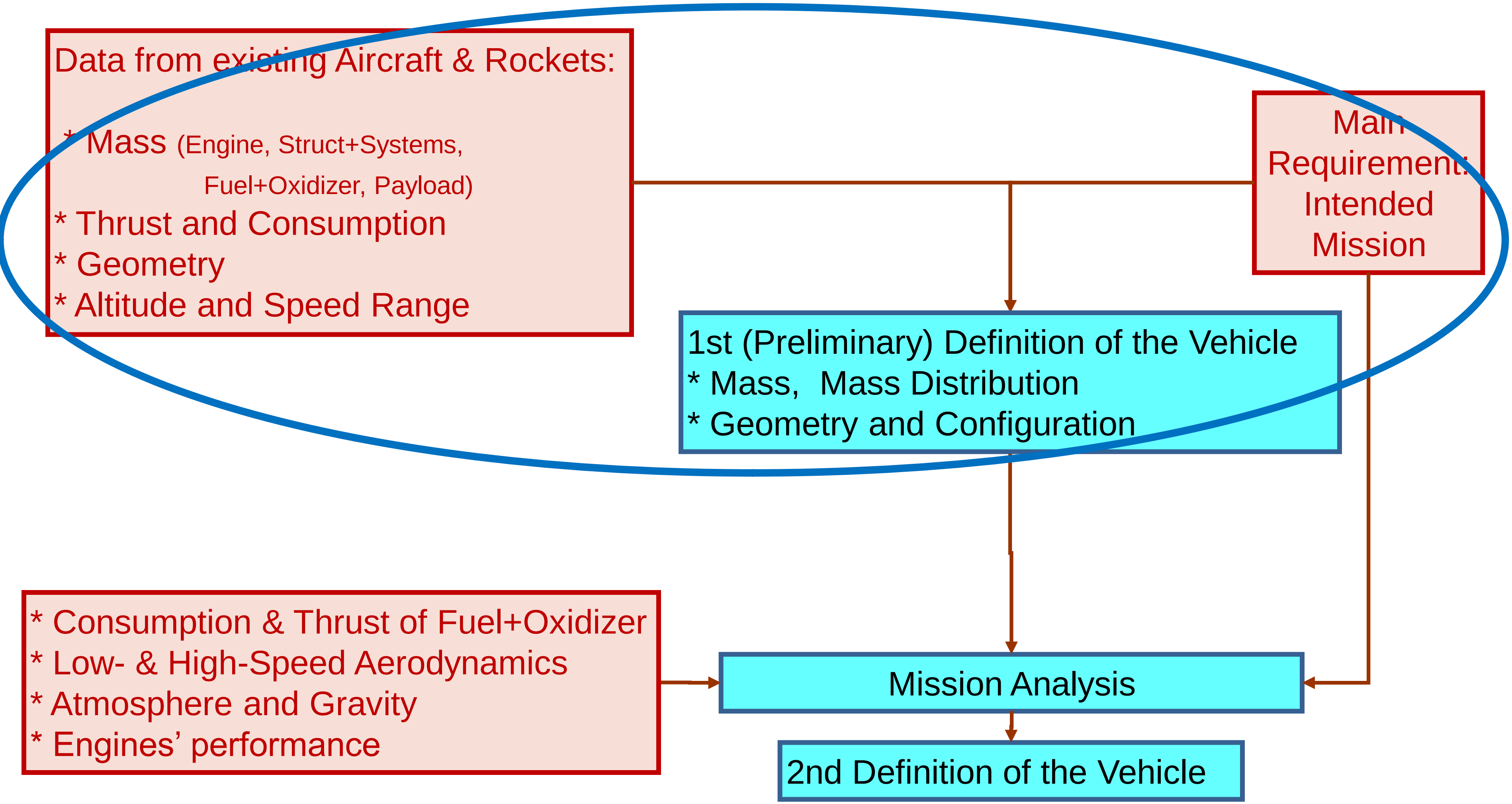
* Reynolds number effects not considered

* Quasi-static approach

Methodology:



First Definition of the Vehicle:



Desired Mission and main requirements:

The vehicle shall

* be composed of no more than two stages.

* take-off horizontally, in a conventional, paved runway, without external devices (e.g. no catapult, no RATO/JATO units)

* use aspirated engines (turbo-jets, ram-jets) up to altitudes higher than 20 km

* deliver a payload of at least 70 kg, in orbital conditions, at least at 160 km of altitude.

Desired Mission and main requirements:

The take-off shall occur at sea level and equatorial latitude, initial flight path in same direction and sense of Earth Revolution (West-to-East flight)

After the ignition and separation of the 2nd stage, the remaining part of the 1st stage (engine, structure and systems) shall return safely to ground in order to be used for the same mission with a minimum of maintenance.

Desired Mission and main requirements:

If the runway is not the same from the one used for take-off, the 1st stage shall be transported as easily as possible to the original runway.

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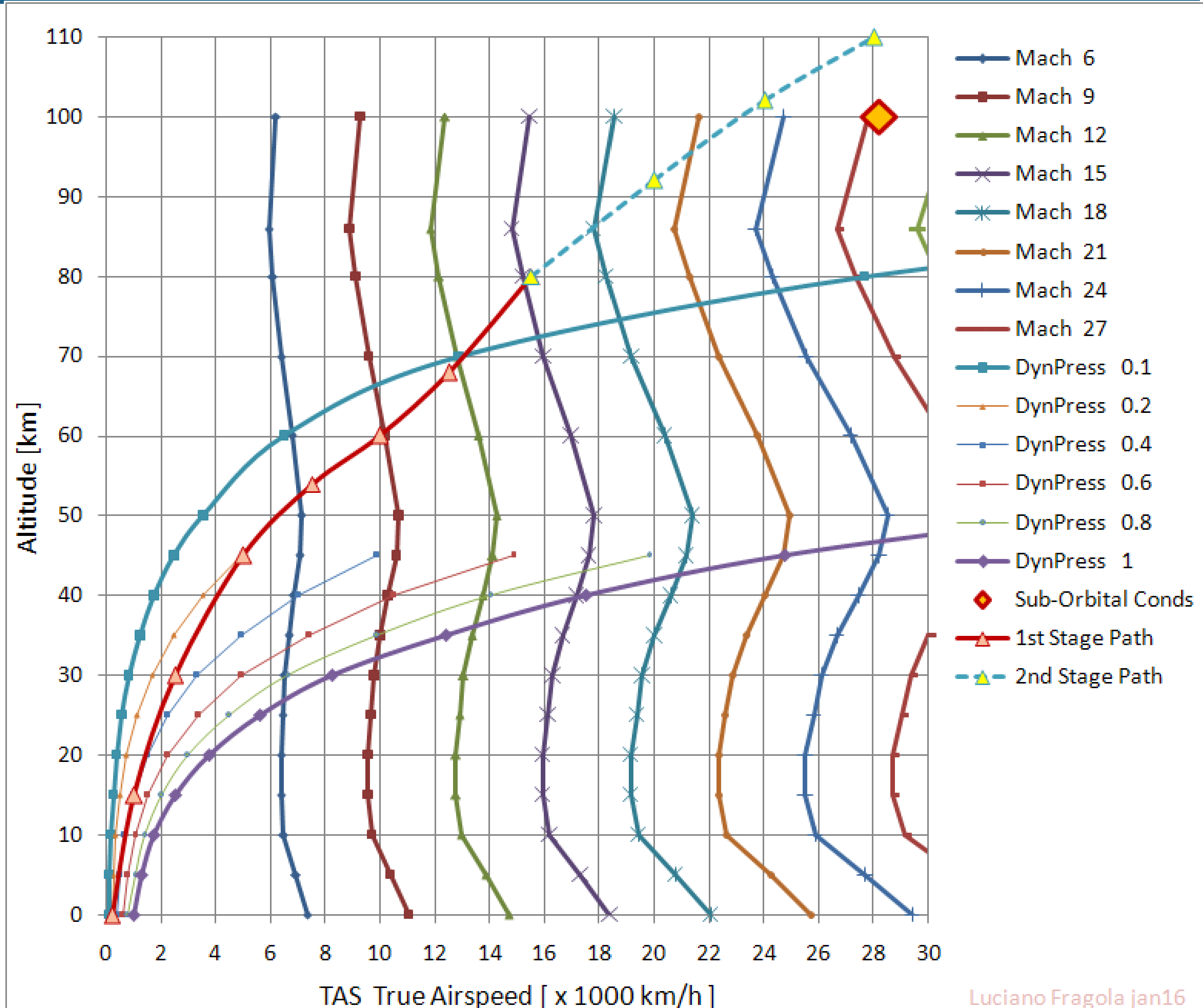
Initially Intended Mission



Engine definitions

The Engine of the 1st stage is considered as being capable to operate at three different regimes:

- Low speed, up to Mach 1.6 and 18 km, as a turbo-jet
- From Mach 1.5 up to Mach 2.5 and 28 km, as a ram-jet
- Above Mach 2.4 and 15 km as a pure Rocket

The Engine of the 2nd Stage is a conventional, liquid- or solid-propelled rocket.

First Definition of the Vehicle:

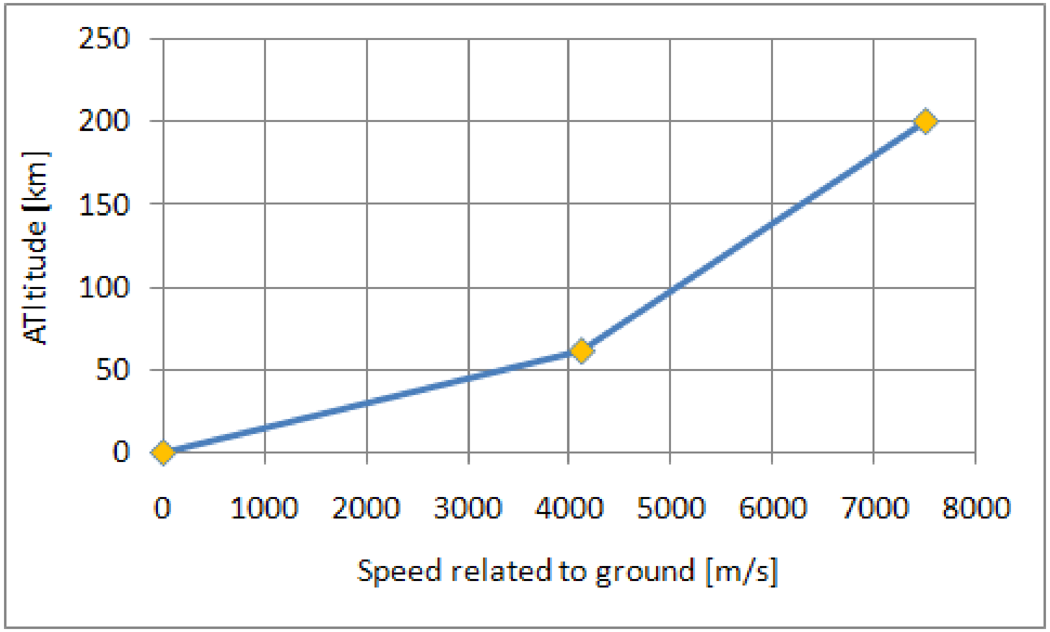
* Tsiolkovsky law

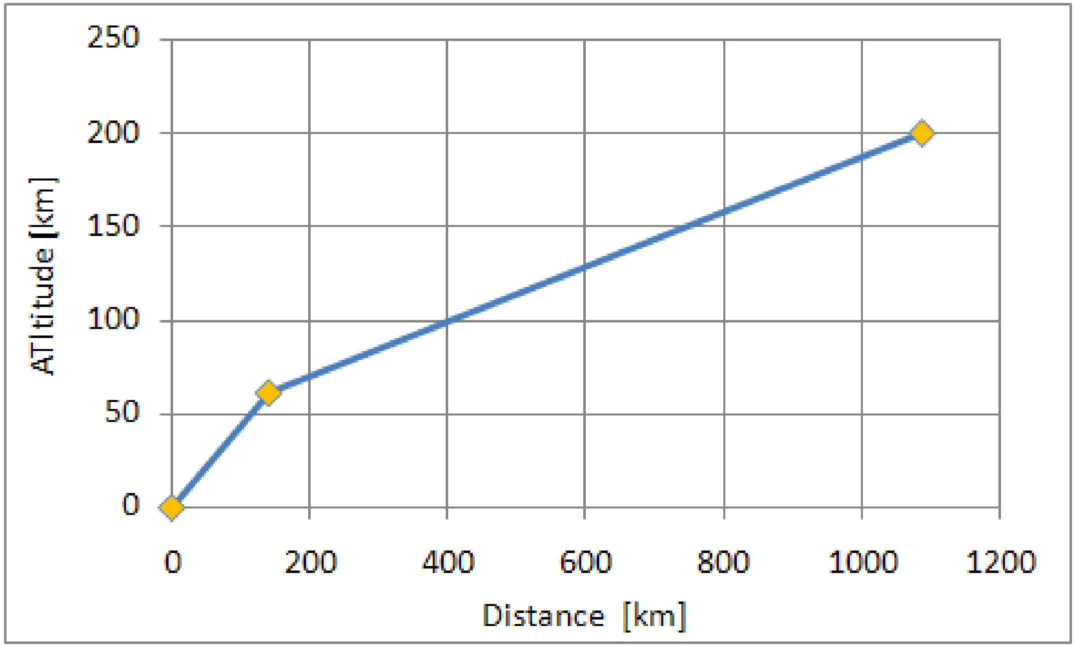
* Data from already-used orbital or sub-orbital rockets

* Data from already-flown high-speed aircraft

First Definition of the Vehicle:

* Simplified Analysis for a Launcher





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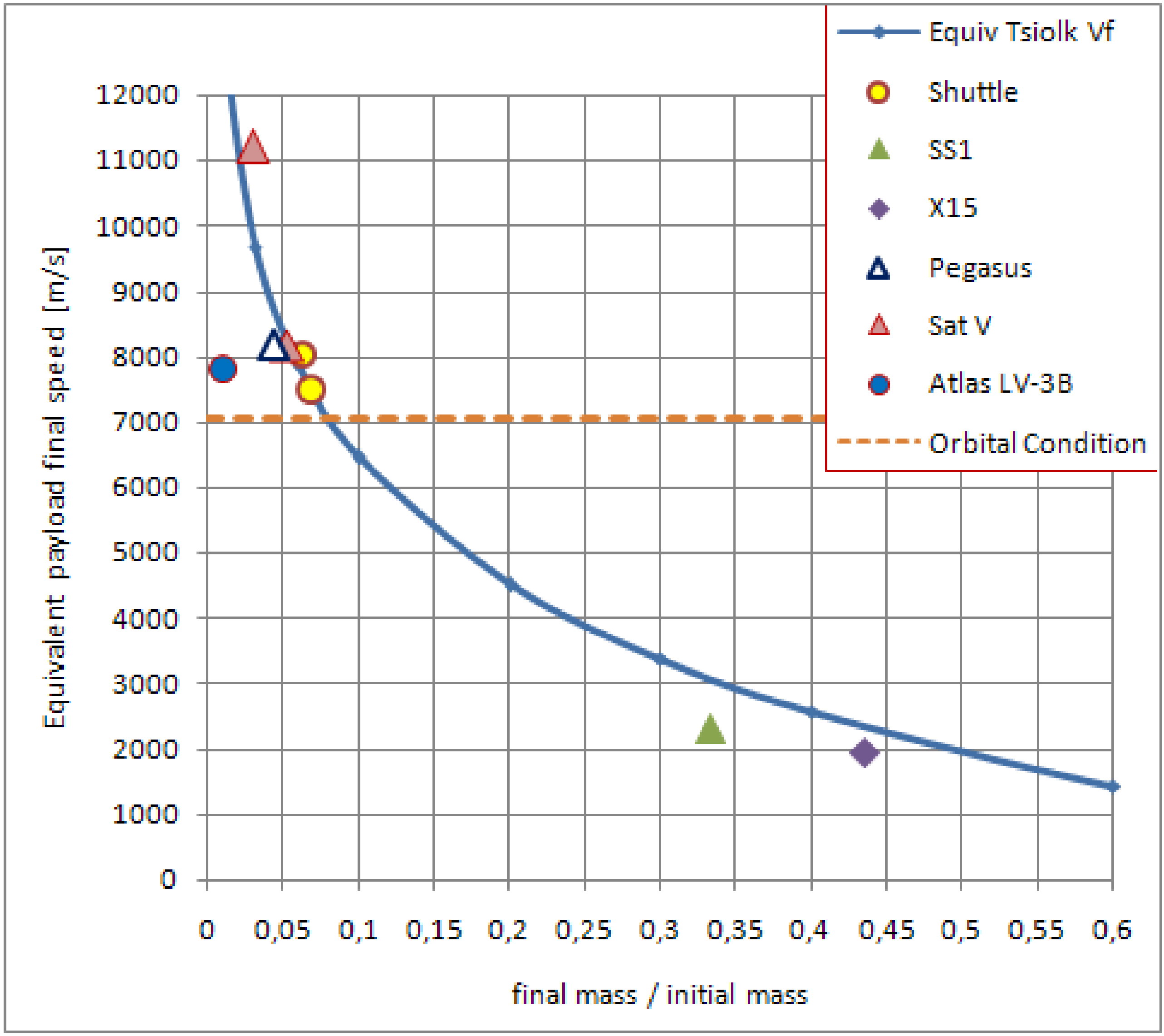
First Definition of the Vehicle:

* Tsiolkovsky Law and some already-flown rocket vehicles



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First Definition of the Vehicle:

* Data from already-flown high-speed aircraft
  - Concorde
  - Valkyrie
  - SR-71
  - X-15

* Data from already-used orbital or sub-orbital rockets
  - Pegasus
  - Saturn V

Valkyrie

http://www.aircraftinformation.info/art_xb-70.htm

X-15

NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/gallery/photo/index.html

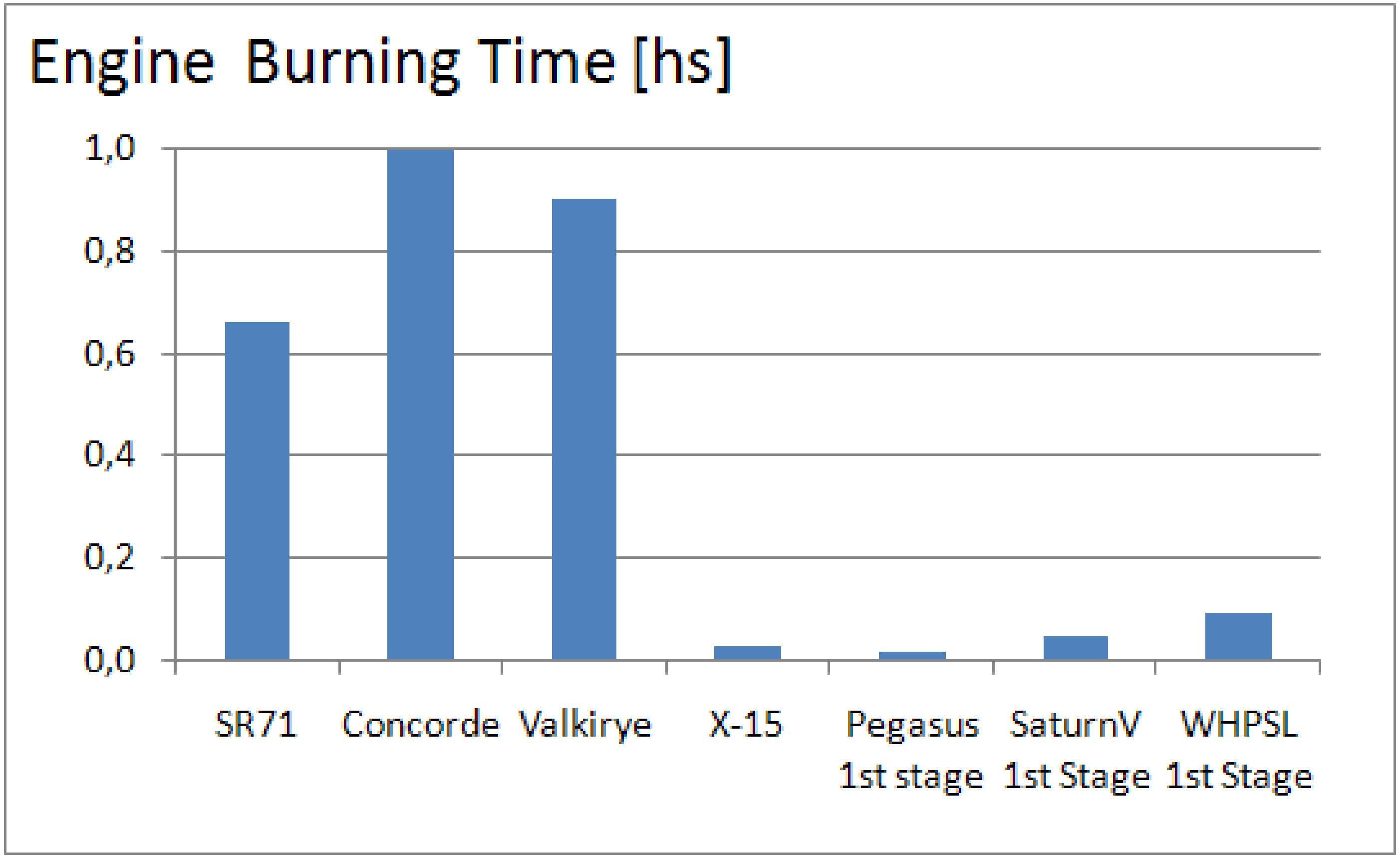
SR-71

http://lloydspost.com/2015/06/5-american-airplanes-that-changed-aviation/

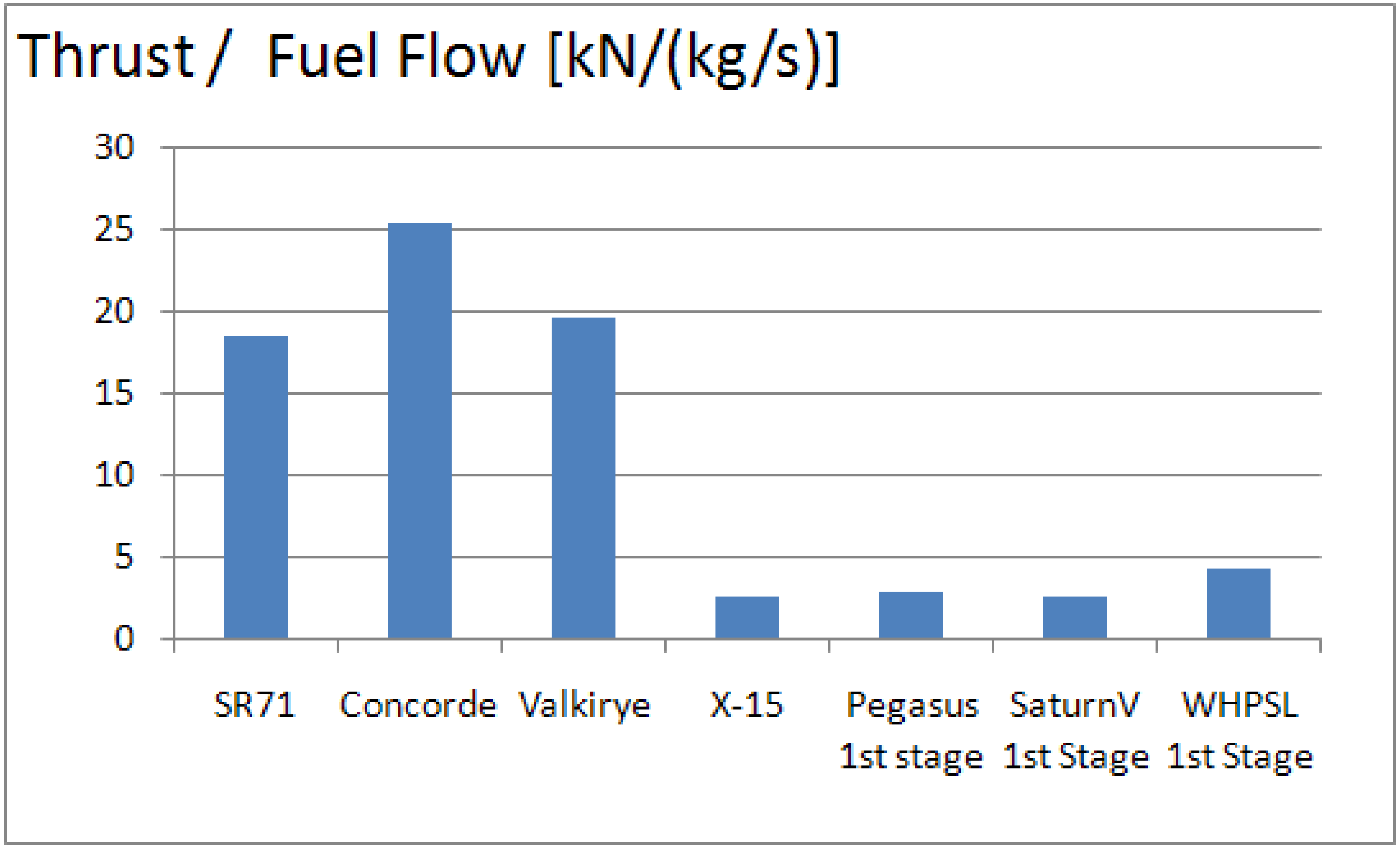
Pegasus

http://www.orbitalatk.com/flight-systems/space-launch-vehicles/pegasus/

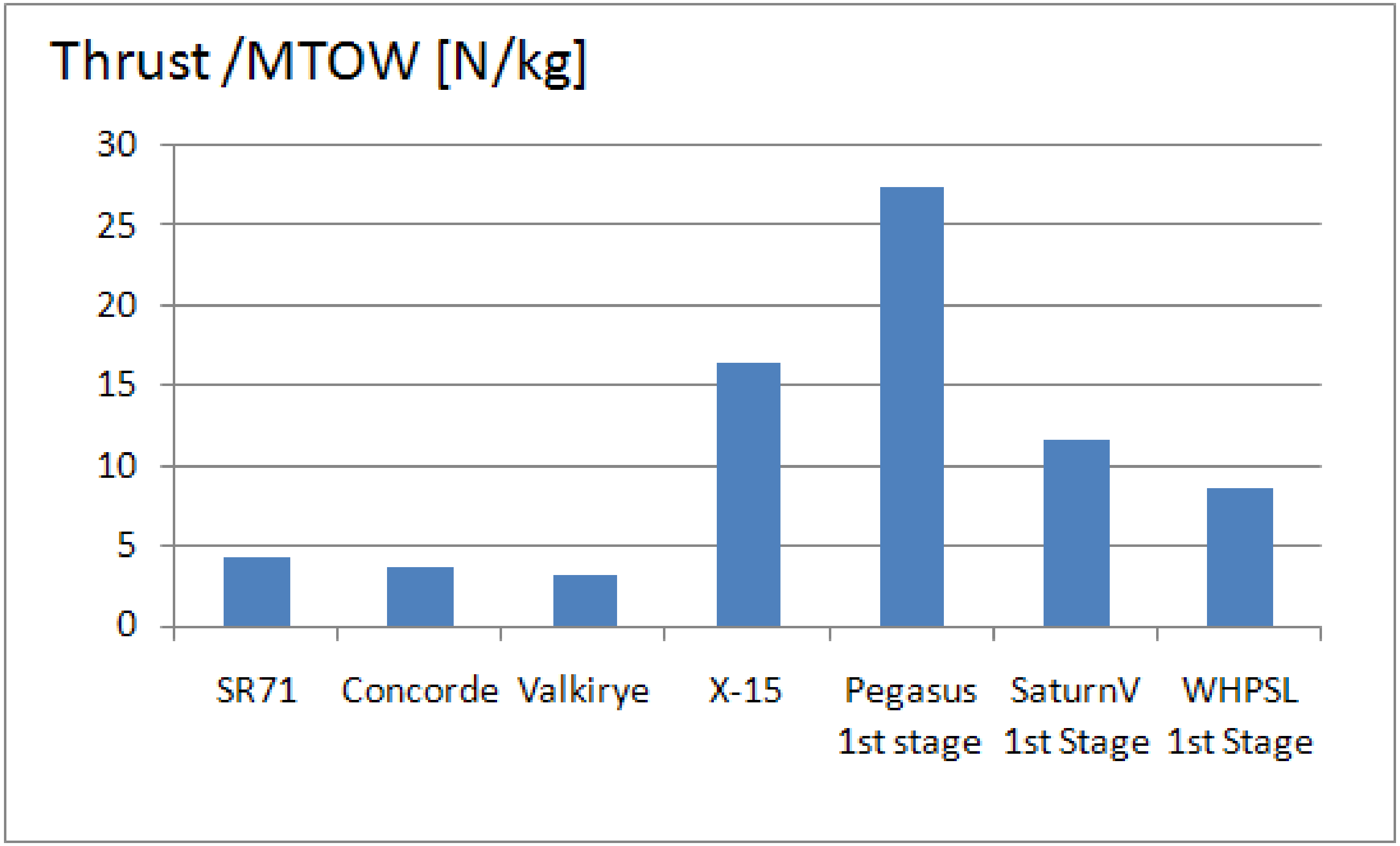
Comparison between vehicle characteristics



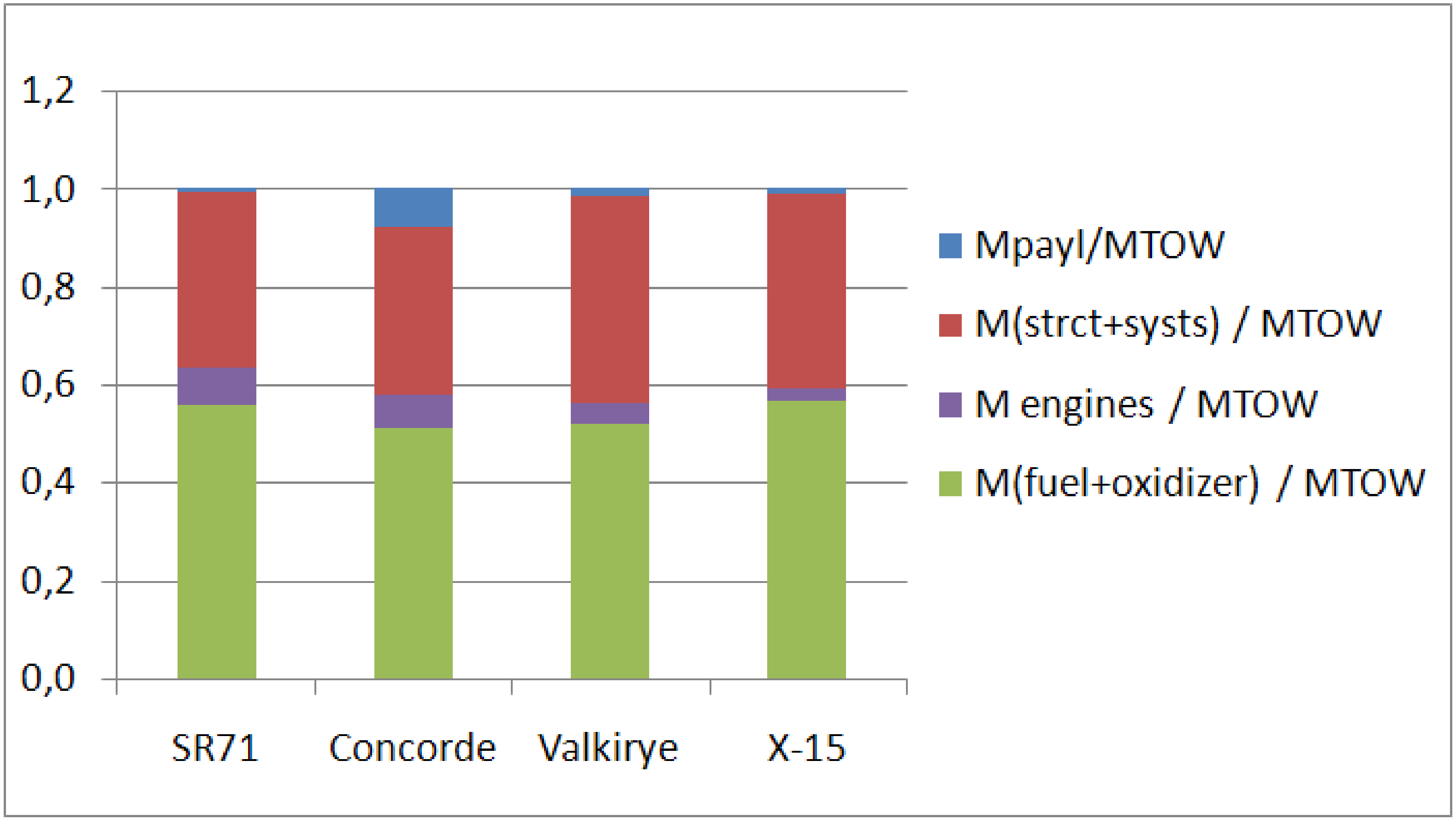
Comparison between vehicle characteristics



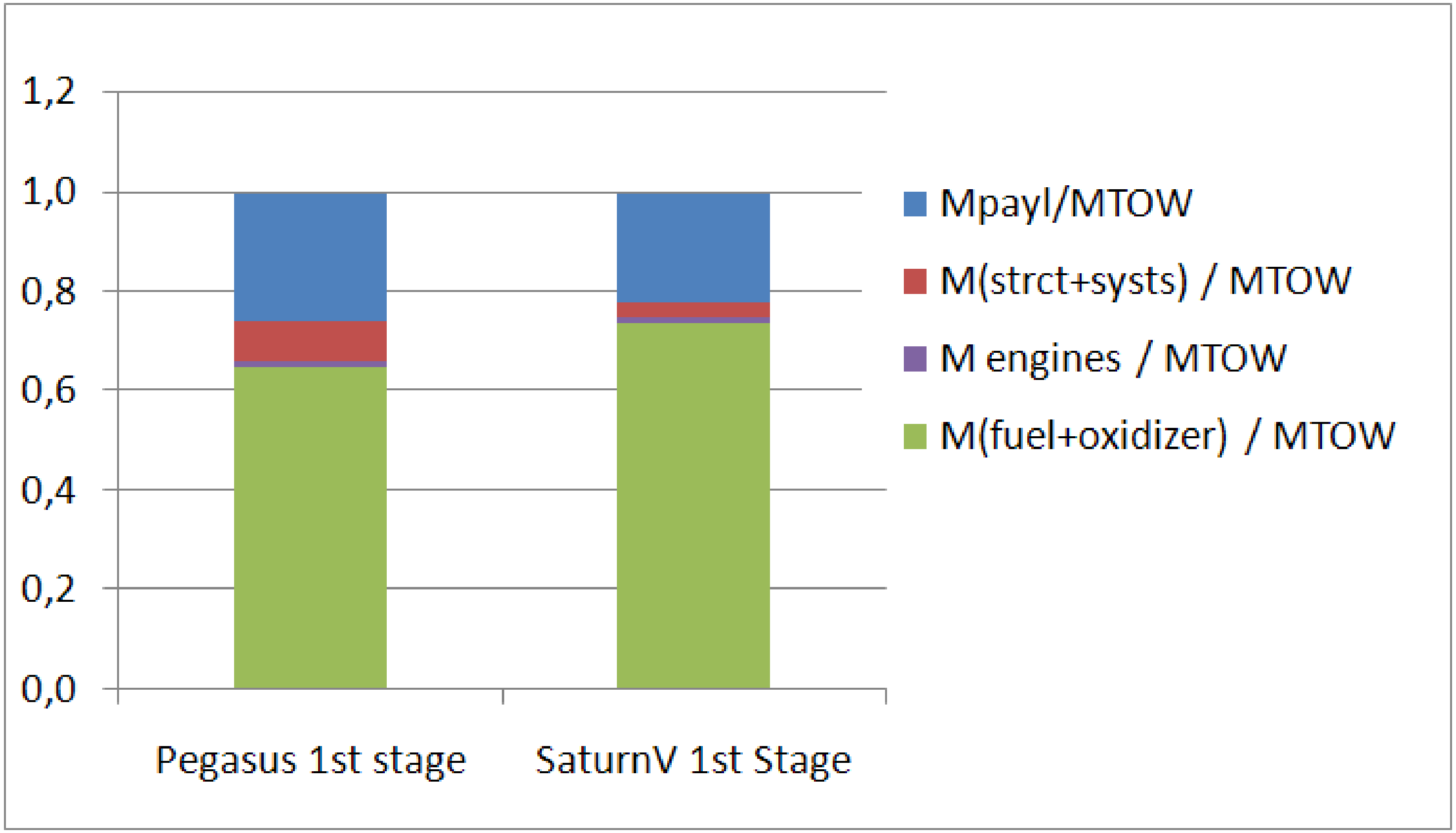
Comparison between vehicle characteristics



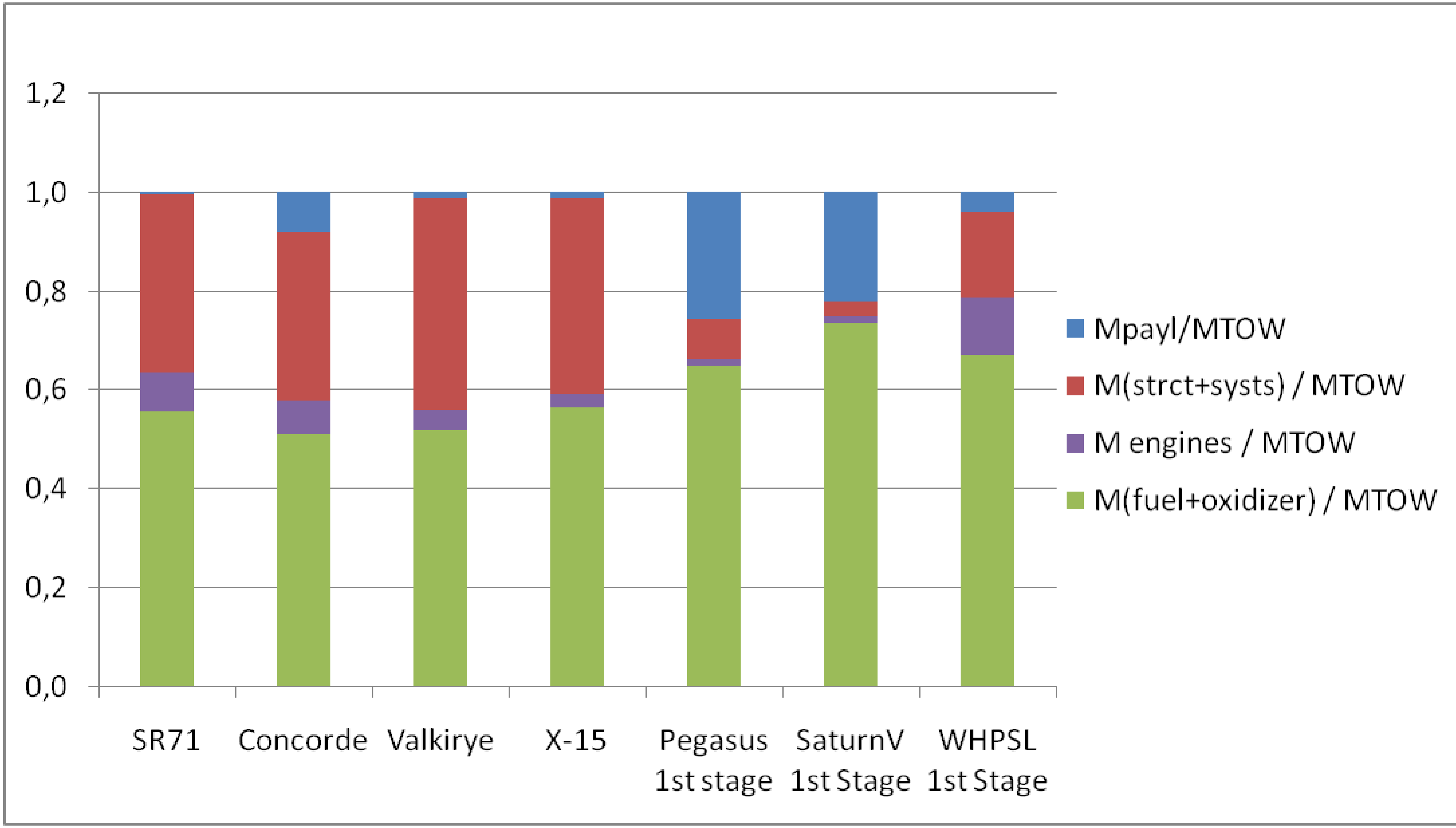
Data from already-flown high-speed aircraft: Mass breakdown



Data from already-used orbital rockets: Mass breakdown



Mass breakdown overall comparison



First Definition of the Vehicle:

From the comparison with the high-speed aircraft and orbital rockets, important ratios are adopted:

1st Stage:

Payload Mass*/ MTOW	= 0.042
Engine Mass / MTOW	= 0.115
M(fuel+oxid) / MTOW	= 0.671
M(struct+systems) / MTOW	= 0.172

* Includes 2nd Stage

First Definition of the Vehicle:

Defining the 2nd Stage at first…

Considered mission:

Starting from Mach 5 at 80km, to achieve orbital speed

Initial Speed = 1400 m/s Equivalent Final Speed ~7500m/s

Delta Speed 2nd Stage = 6100 m/s

Combustion Gases Speed = 2800 m/s (data)

Initial Mass / Final Mass = 8.85

Assuming:

Payload Mass / Final Mass = 0.6 Payload Mass = 80 kg

Final Mass = 133

Initial Mass 2nd Stage = 1180 kg M(fuel+oxid) = 1047 kg

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Defining the 2nd Stage at first…

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Payload Mass / Final Mass = 0.6   Payload Mass = 80 kg

Final Mass = 133

Initial Mass 2nd Stage = 1180 kg   M(fuel+oxid) = 1047 kg

First Definition of the Vehicle:

Now defining the 1st Stage...

Through the ratios obtained from comparison:

Payload Mass / MTOW = 0.042 => MTOW = 28100 Kg
Engine Mass / MTOW = 0.115 => Engine Mass = 3230 kg
M(fuel+oxid) / MTOW = 0.671 => M(fuel+oxid) = 18850 kg
M(struct+systems) / MTOW = 0.172 => M(struct+systems) = 4830 kg

Equiped Empty Mass 'EEM' = EngMass+M(s+s) = 8060 kg
EEM + Payload Mass = 9240 kg

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Now defining the 1st Stage…

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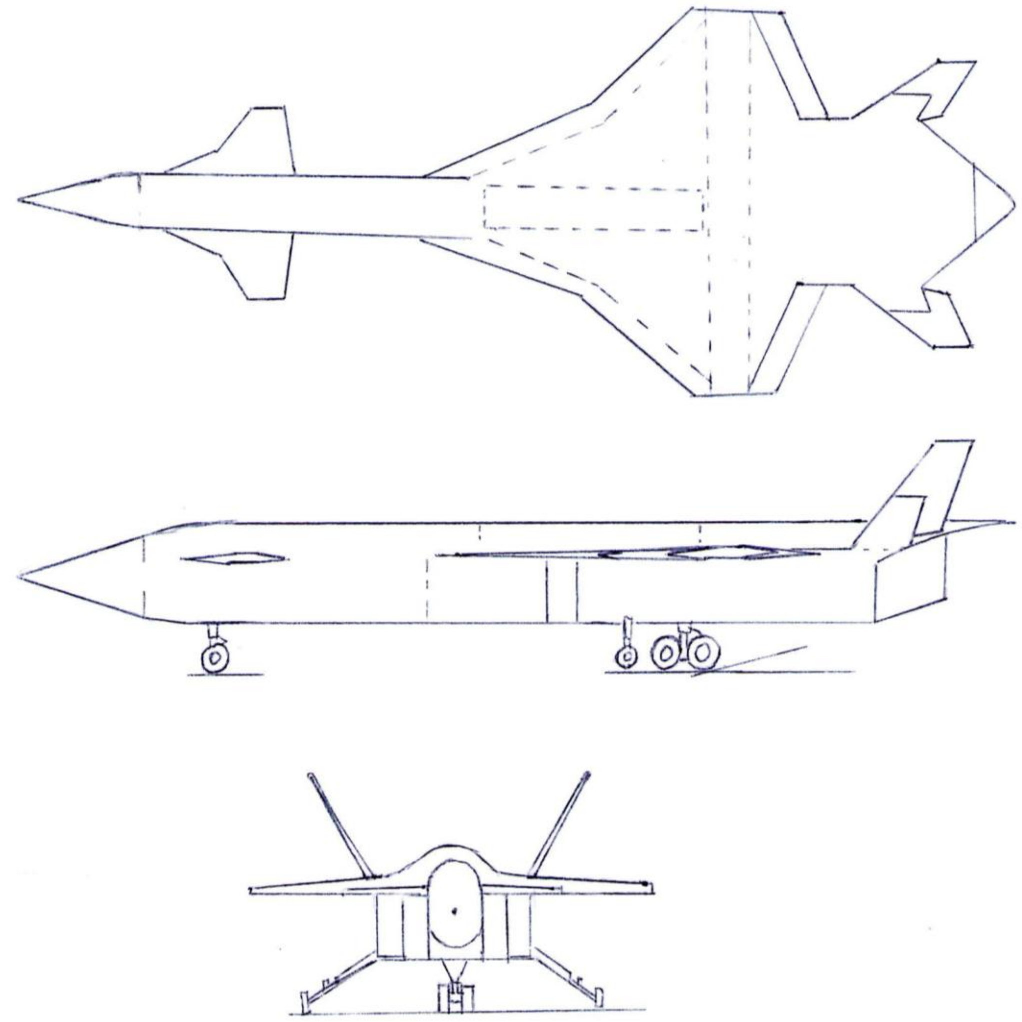
Adopted Configuration

Vehicle 3-View



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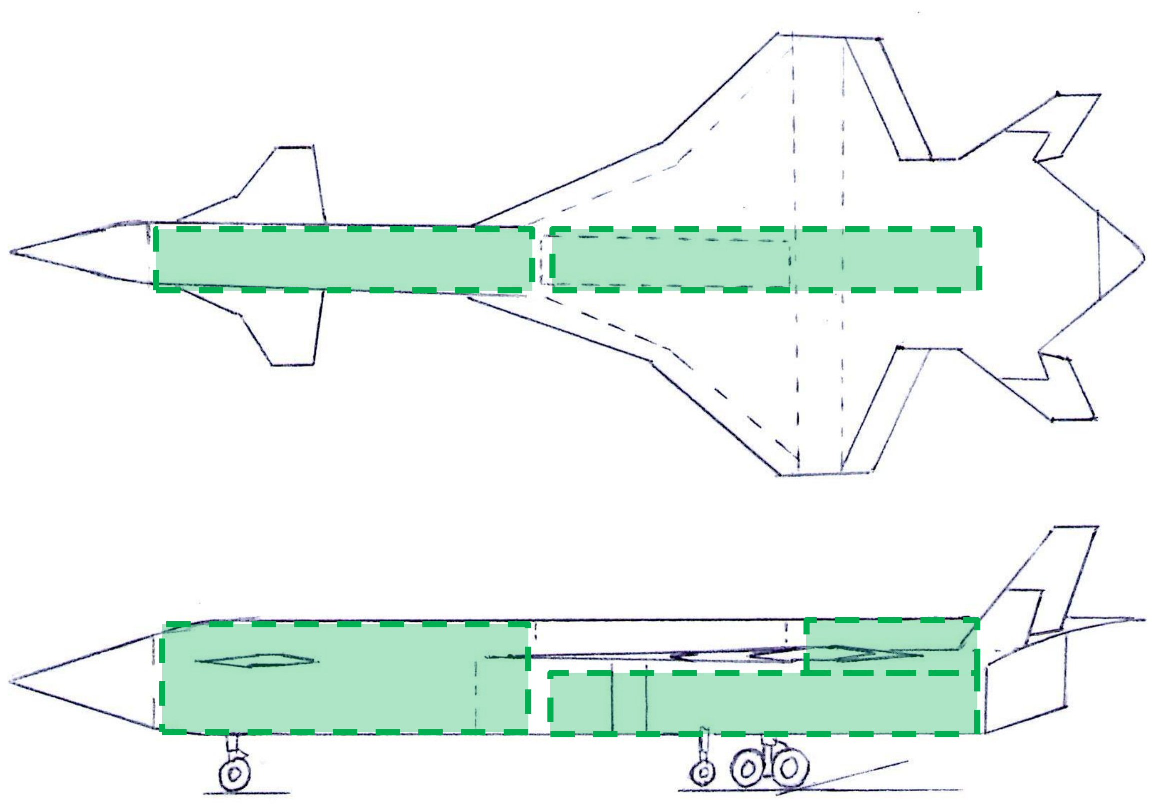
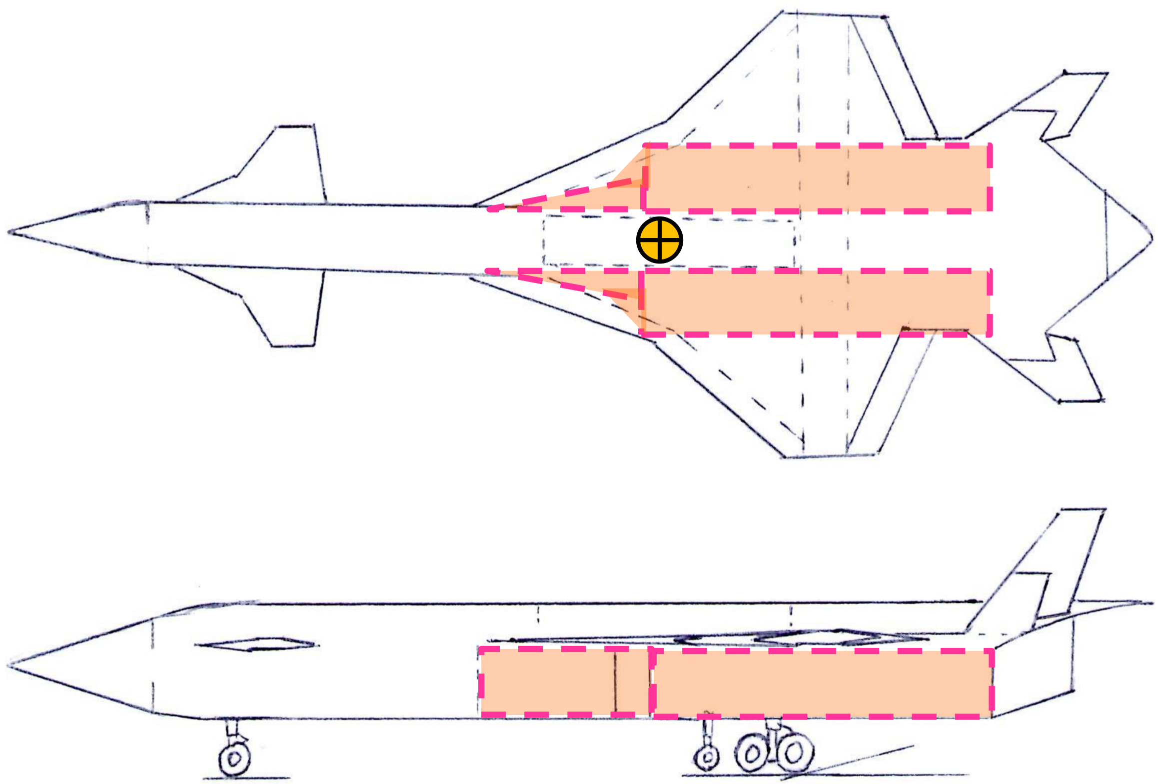
Adopted Configuration

Positioning of Fuel & Oxidizer Tanks



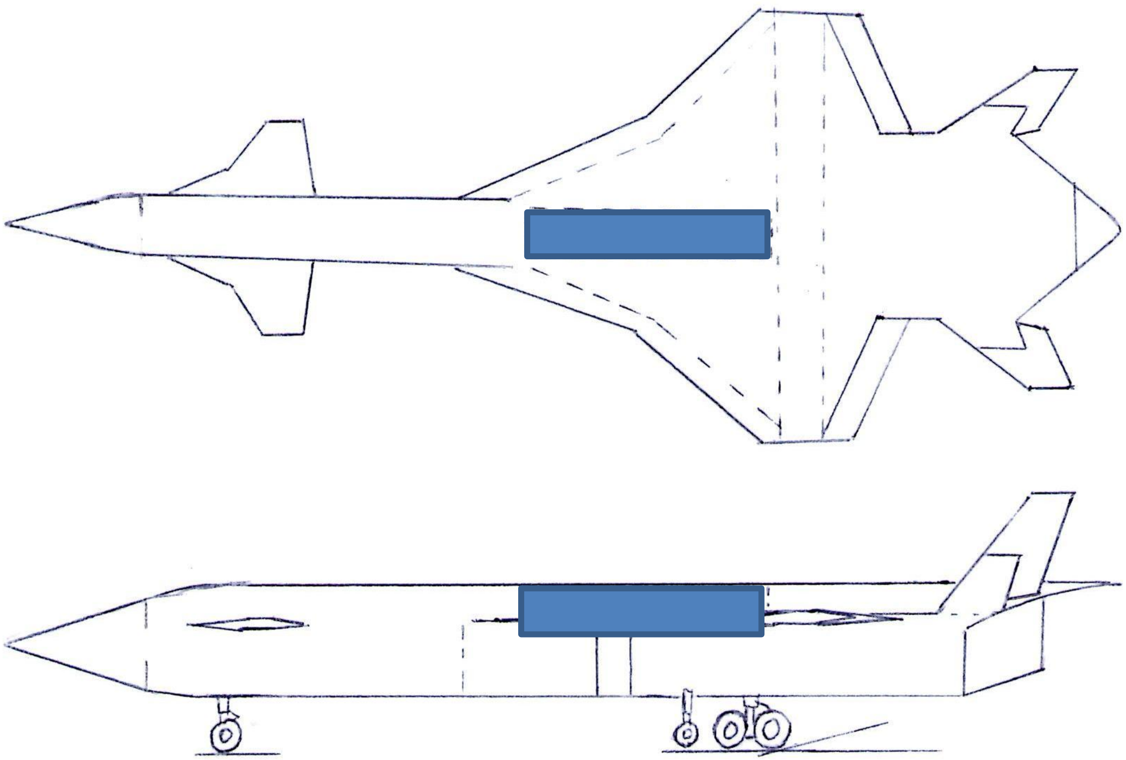
Adopted Configuration

Positioning of Engines & CG

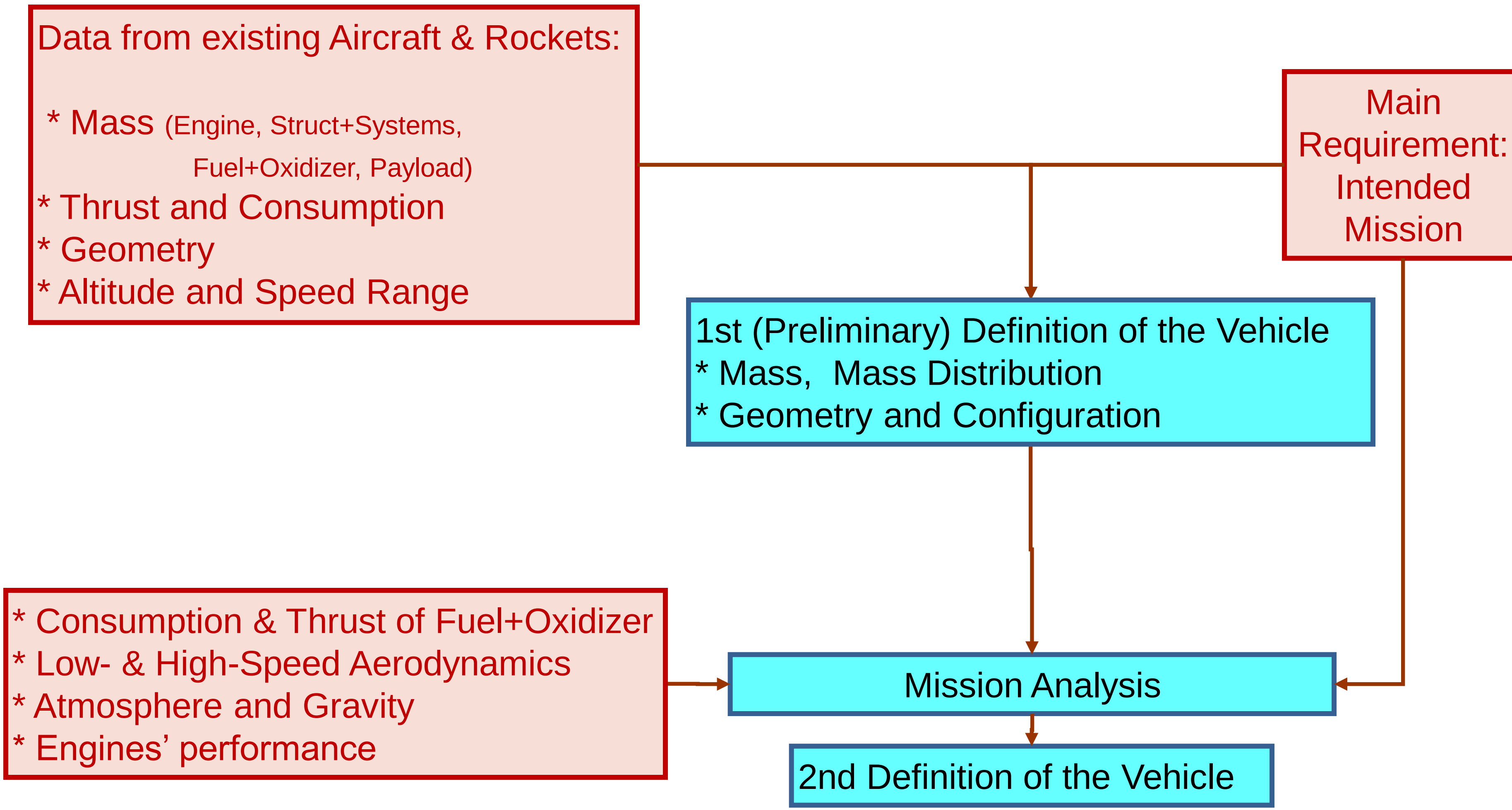


Adopted Configuration

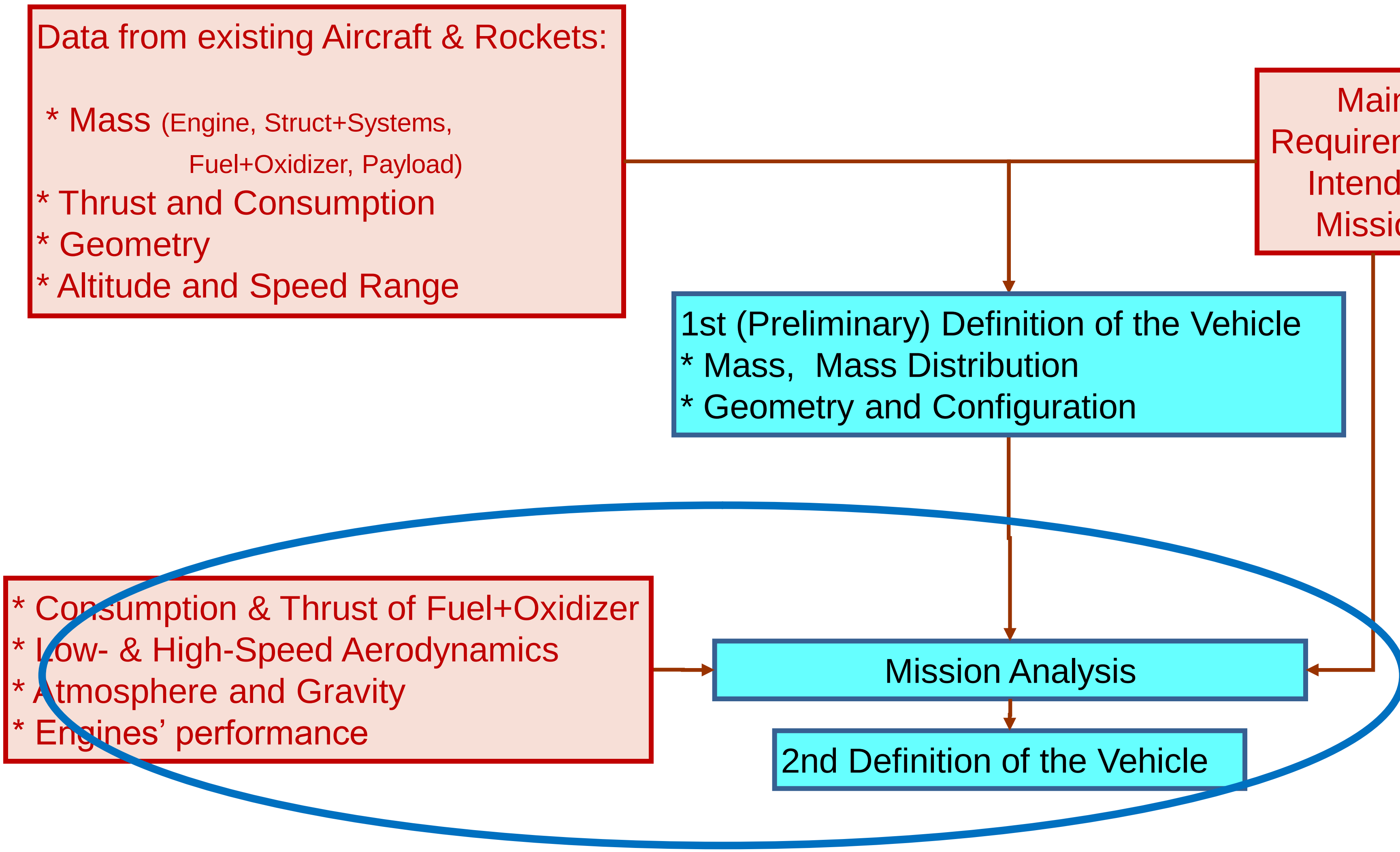
Positioning of ‘2nd Stage & Payload’ Bay



Methodology



Second Definition of the Vehicle



Second Definition of the Vehicle

Quasi-Static Simulation[1]

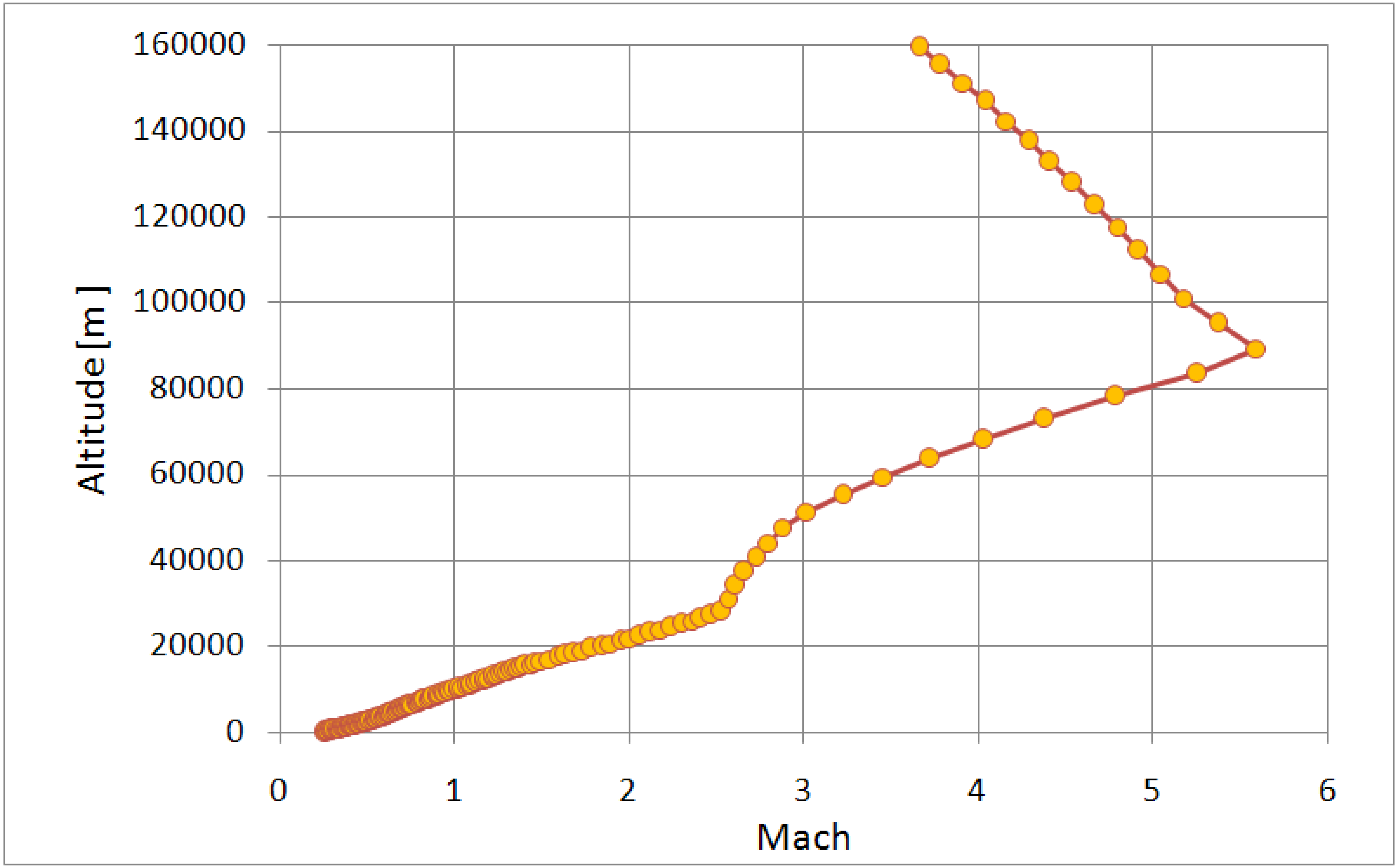
Analysis of 1st and 2nd Stage performed separately

Values related to 1st stage (thrust, fuel mass flow) adopted considering already-flown engines.

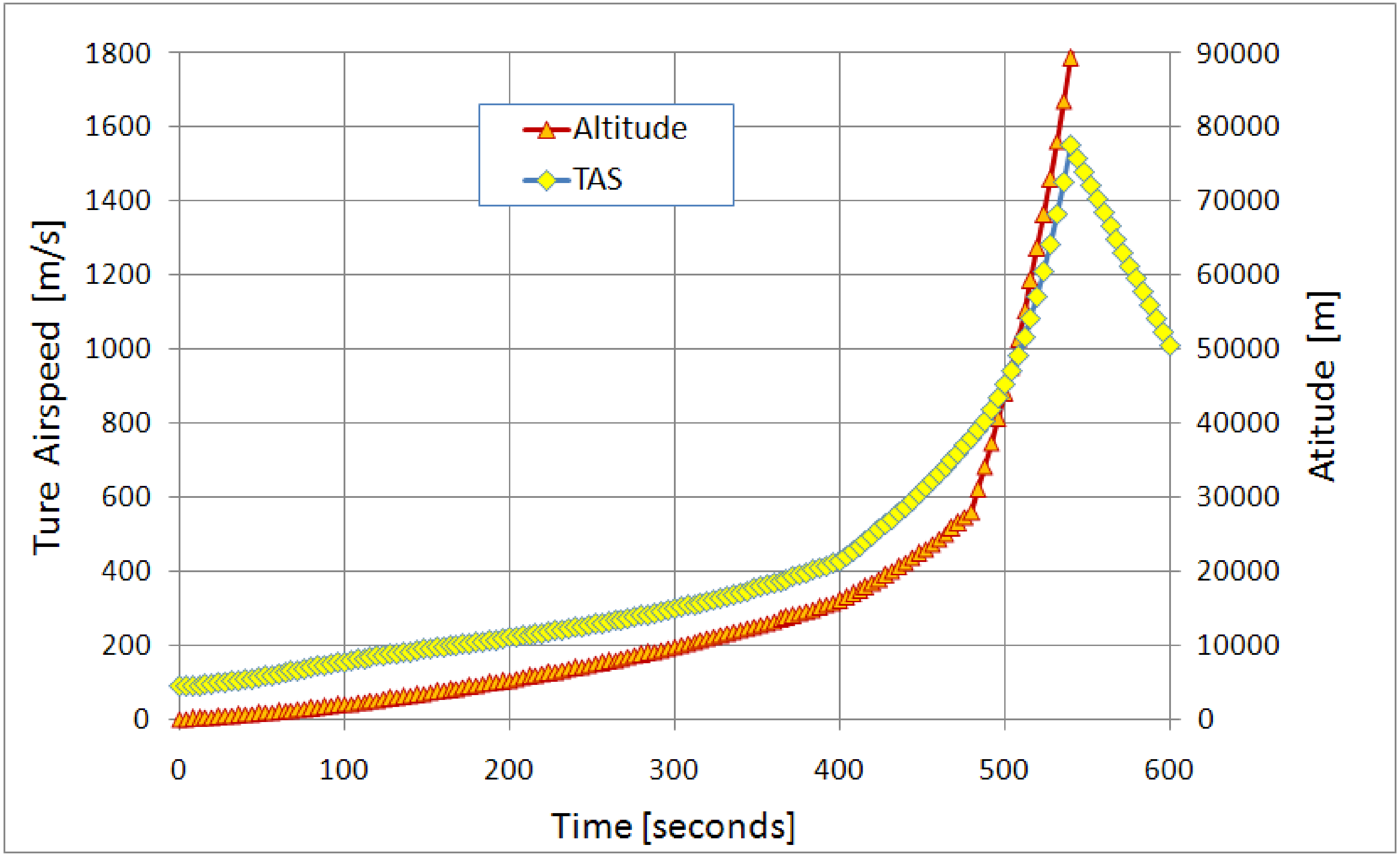
Fuel + Oxidizer mass values started from values of 1st analysis, and adjusted iteratively up to desired mission is achieved.

1 Small intervals of time in which mass, forces and accelerations are considered constant.

Results from the simulation, 1st Stage



Results from the simulation, 1st Stage



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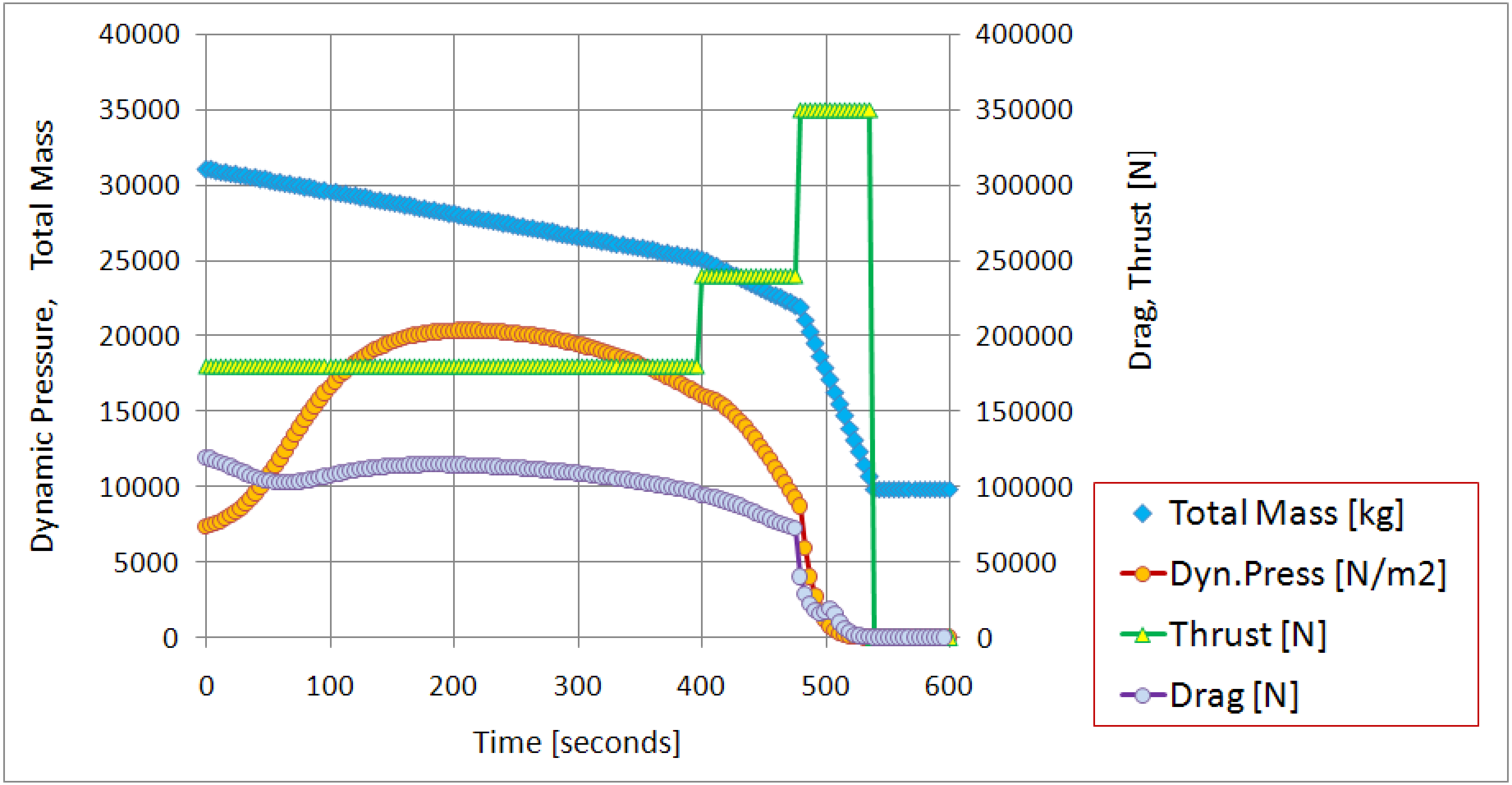
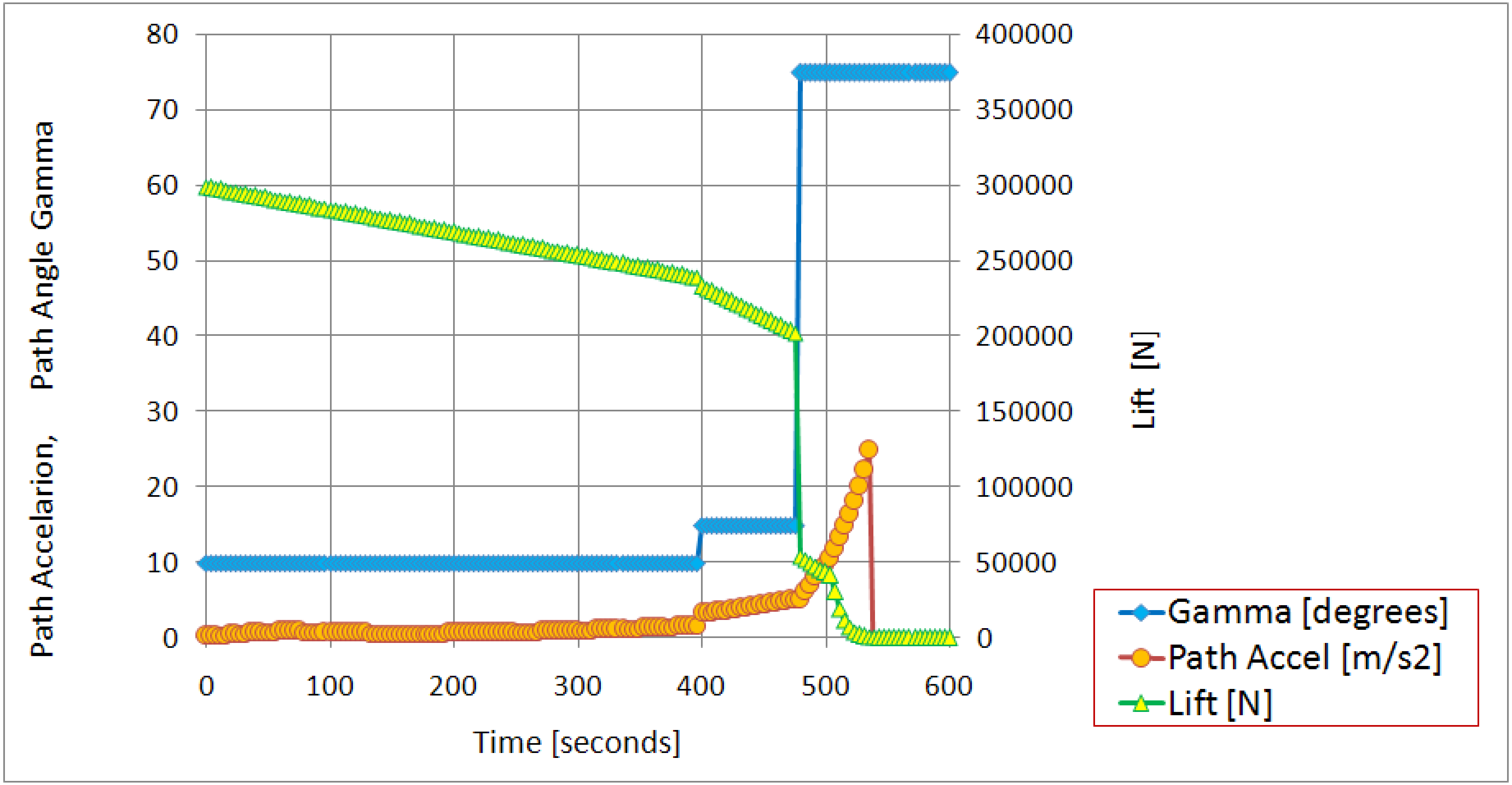


Results from the simulation, 1st Stage



Second Definition of the Vehicle

Results obtained from the simulation, 1st Stage

Engine Regime, 1st Stage	1	2	3	Value from 1st Definition
Thrust [kN]=	**180**	**240**	**350**	
Fuel (+ Oxidizer) Mass [kg] =	**6000**	**3095**	**11765**	
Fuel Mass Flow [kg/s]=	**15**	**40**	**200**	
Thrust/Mass Flow [kN/(kg/s)] =	12.0	6.0	1.8	
Burning Time [s]=	400	77	59	
Accumulated Fuel (+Oxdz) Mass [kg] =	6000	9095	**20860**	**18850**
Accumulated Time [s]=	400	477	536	

Second Definition of the Vehicle

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Second Definition of the Vehicle

Results from the simulation, 1st Stage

1st Stage	Climb Start	End of Regime 1	End of Regime 2	End of Regime 3
Altitude [km]=	0	16	27	84
Mach Number=	0.26	1.43	2.47	5.26
EAS [m/s]=	90.0	163	123	4
Air mass flow [kg/s]=	110	231	100	0
Aircraft Mass [kg]=	31100	25100	22005	10240

Maximum altitude: 188 km

Horizontal speed at maximum altitude: 376 m/s

Second Definition of the Vehicle

Results from the simulation, 1st Stage

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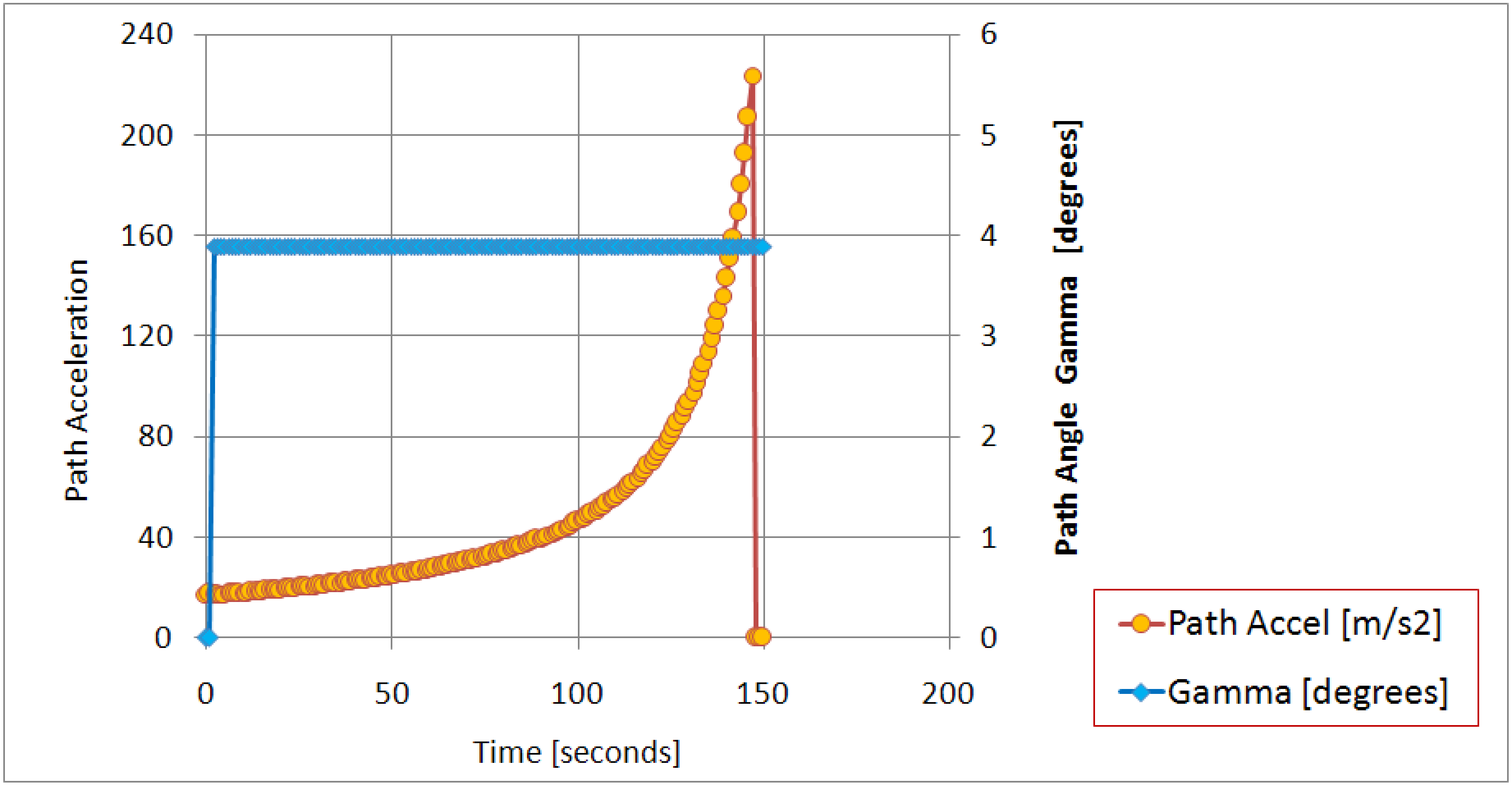
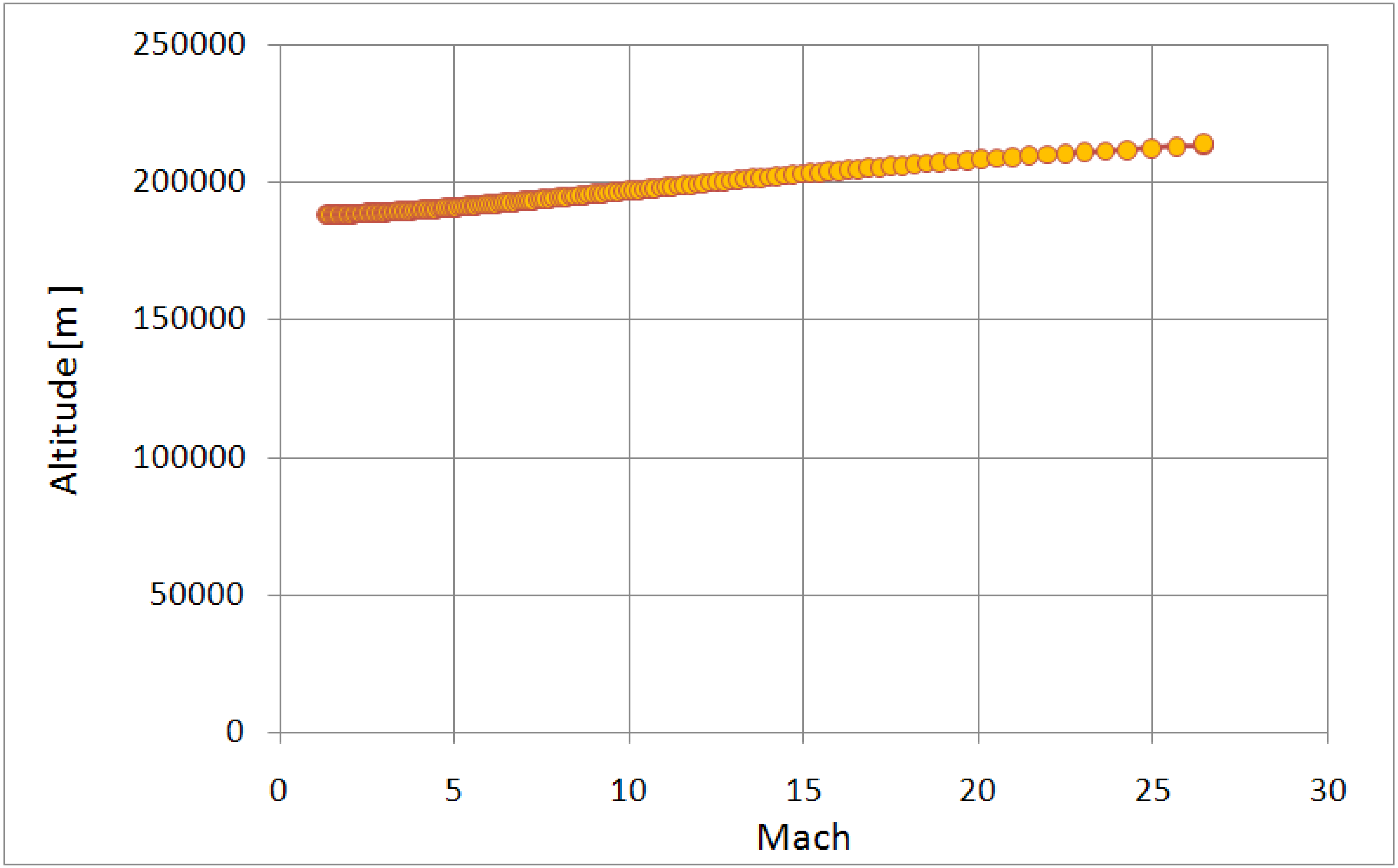
Horizontal speed at maximum altitude: 376 m/s

Results from the simulation, 2nd Stage:



Results from the simulation, 2nd Stage:



Second Definition of the Vehicle:

Results from the simulation, 2nd Stage:

Engine Regime, 2nd Stage	1	Value from 1st Definition
Thrust [kN]=	35	
Fuel (+ Oxidizer) Mass [kg] =	1838	1047
Fuel Mass Flow [kg/s]=	12.5	
Thrust/Mass Flow [kN/(kg/s)] =	2.8	
Burning Time [s]=	147.0	

Second Definition of the Vehicle:

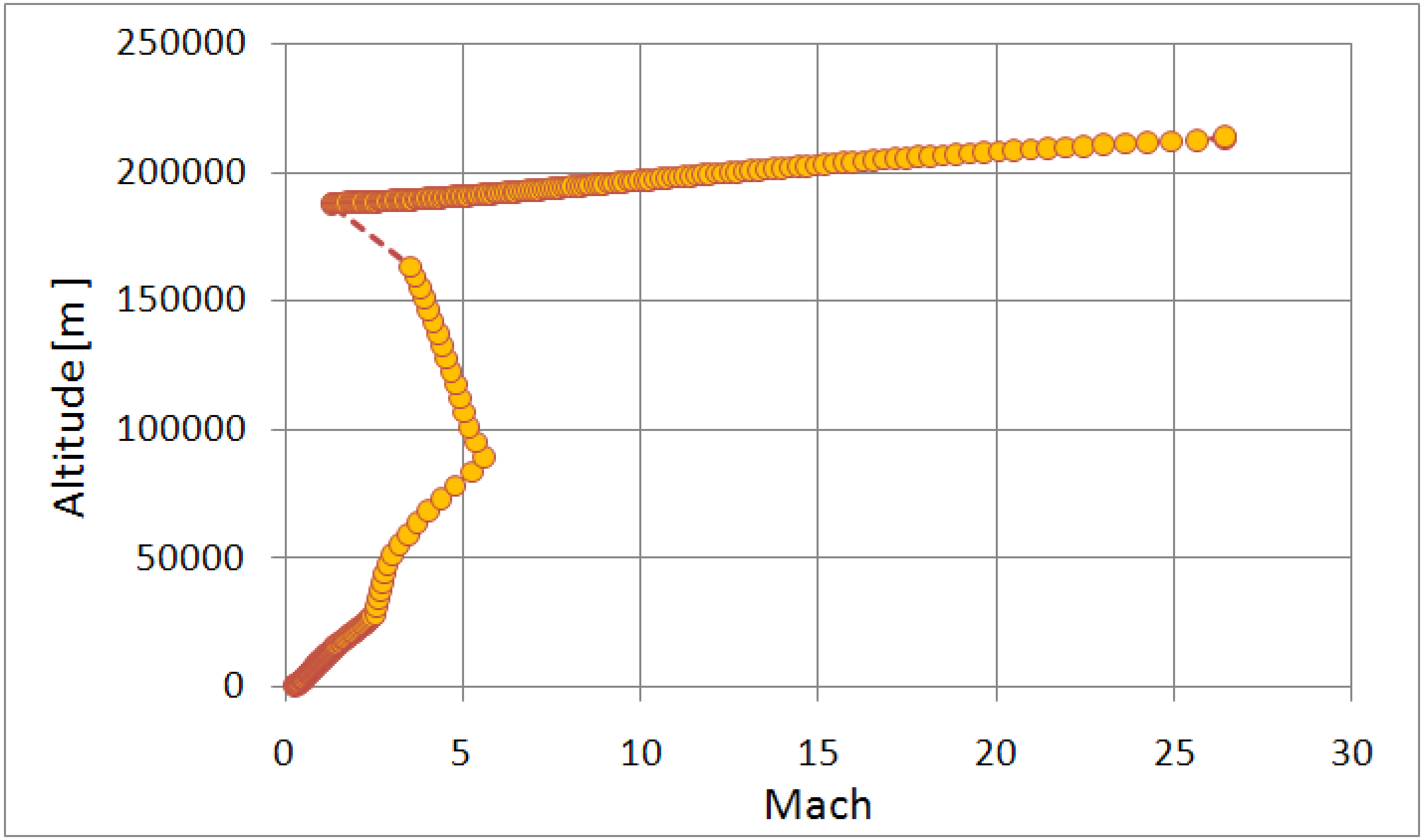
Results from the simulation, 2nd Stage:

1st Stage	Coast (no thrust phase) Start	Engine Start; end of Coast	End of Engine Burning
Altitude [km]=	84	188	212
Mach Number=	5.26	1.35 (equivalent)	25.6 (equivalent)
TAS [m/s]=	1453	376	7334
2nd Stage Mass [kg]=	2000	2000	162

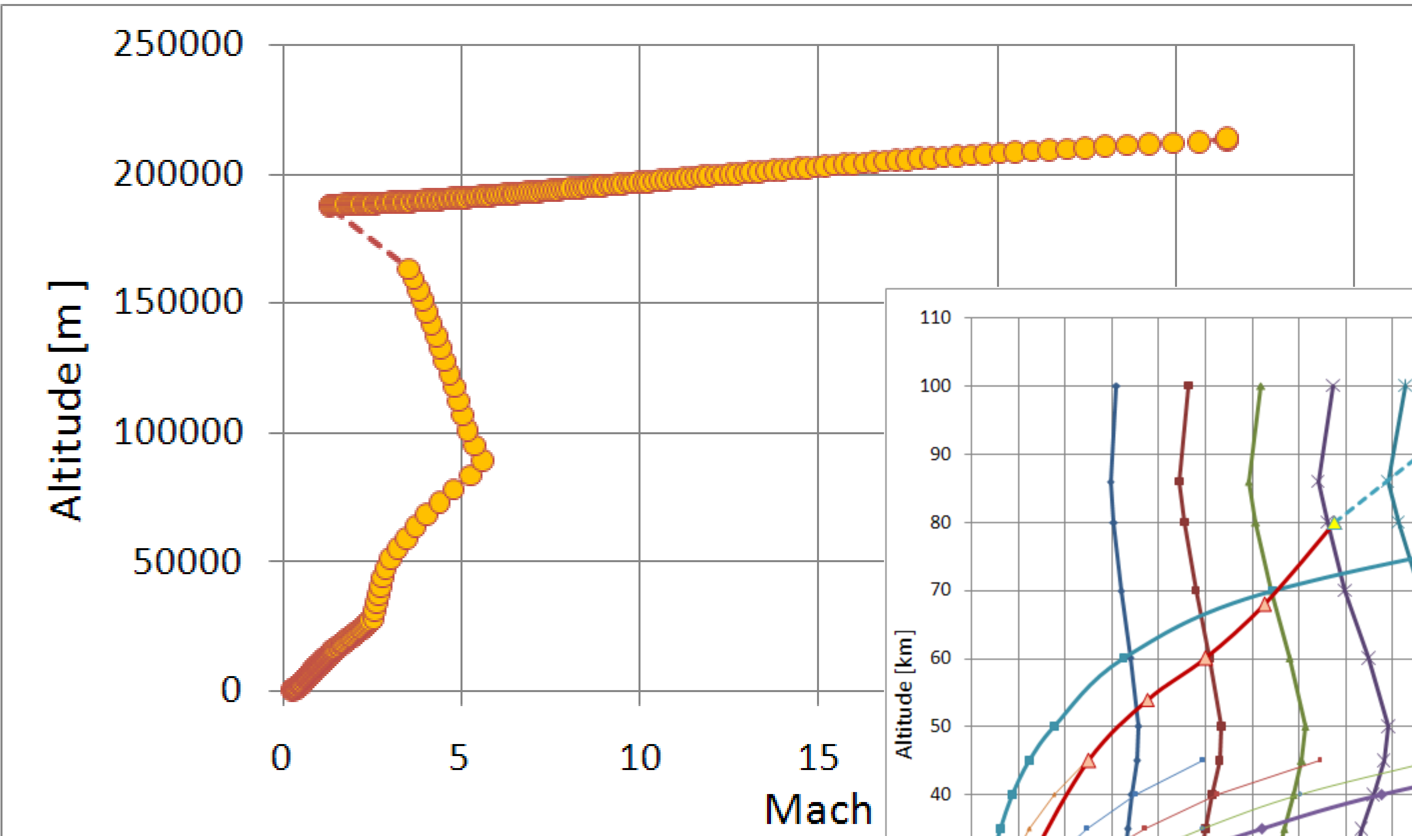
Orbital Payload Mass = 0.6 *162 = 97 kg

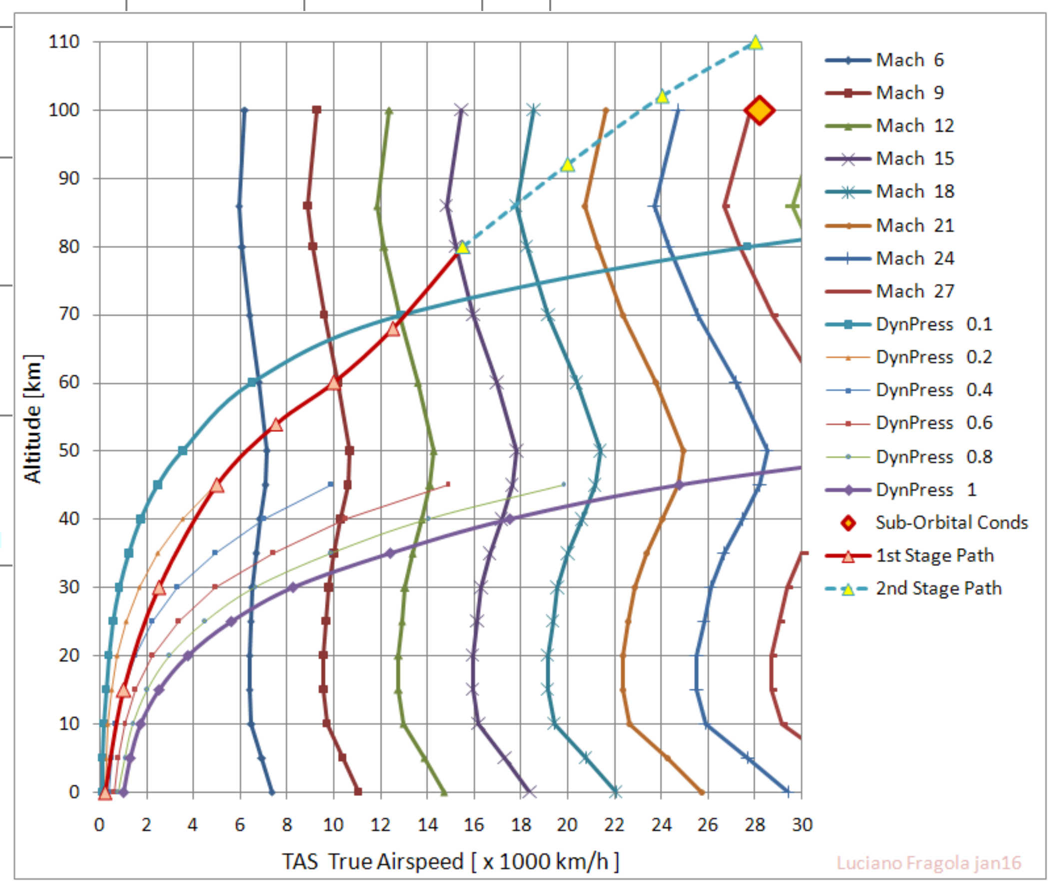
Mass of Structure+Systems+Engine = 65 kg

Results from the simulation, 1st plus 2nd Stages:

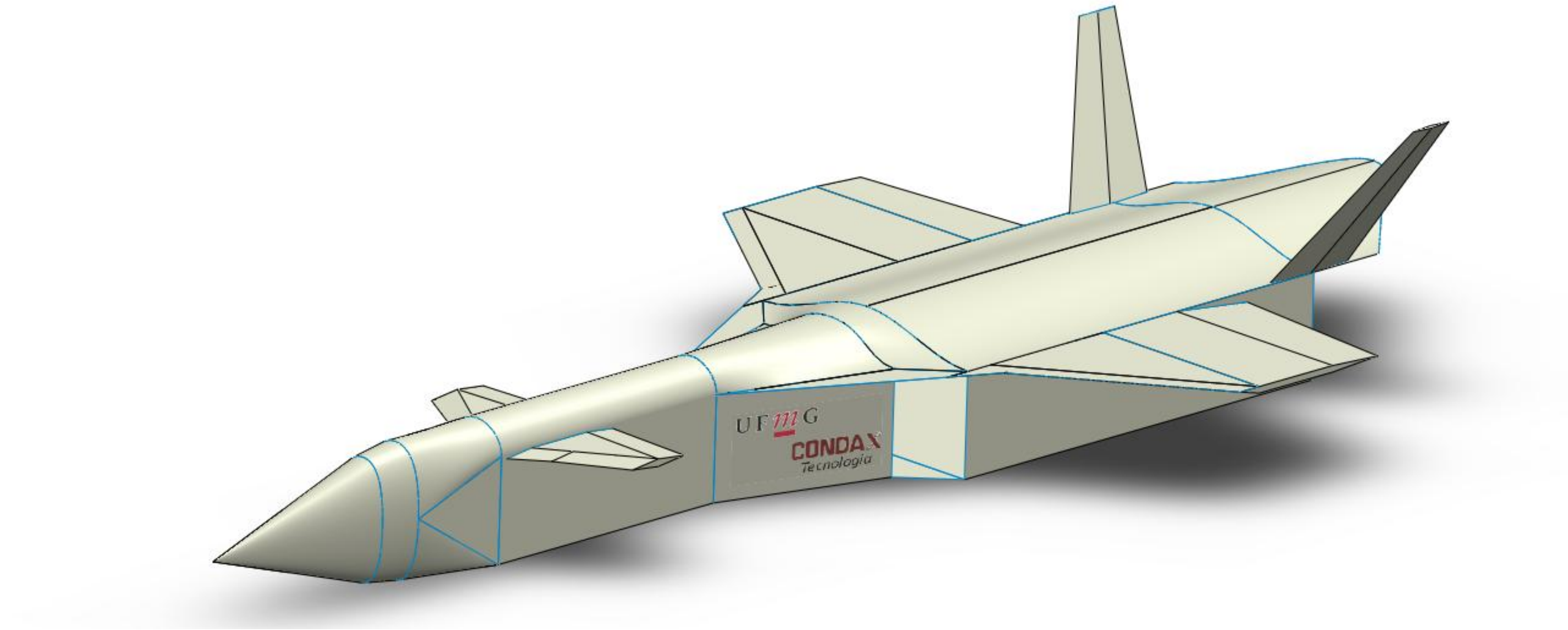


Comparison of results with the initially conceived mission





Adopted Configuration



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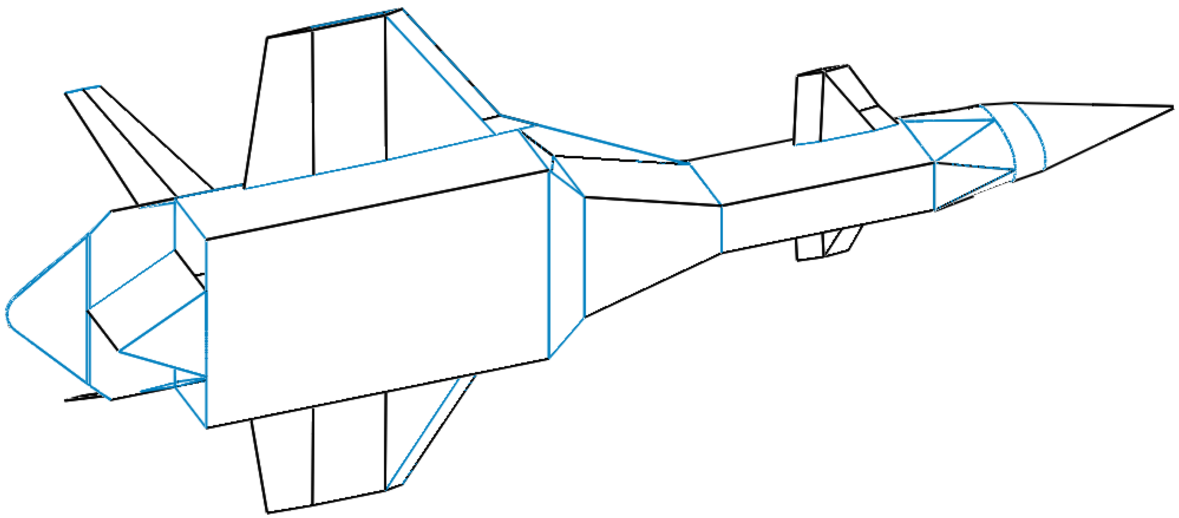
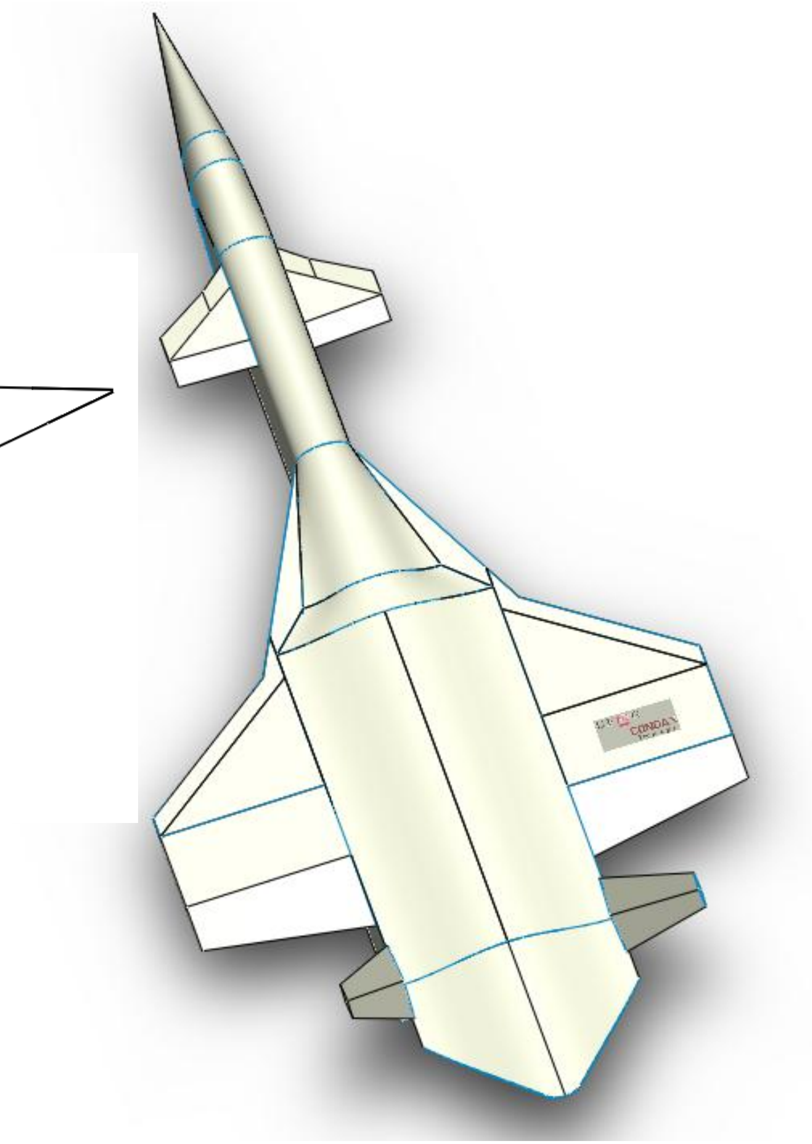
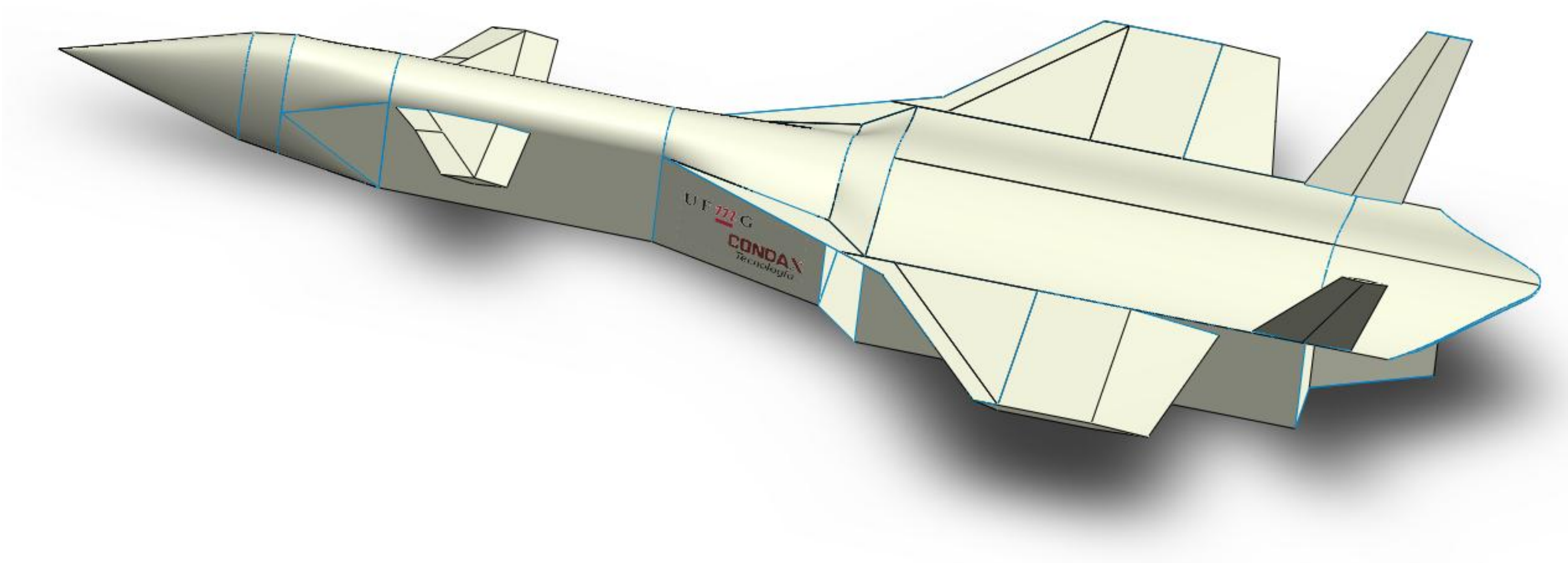
Adopted Configuration





Adopted Configuration



Other analyses performed:

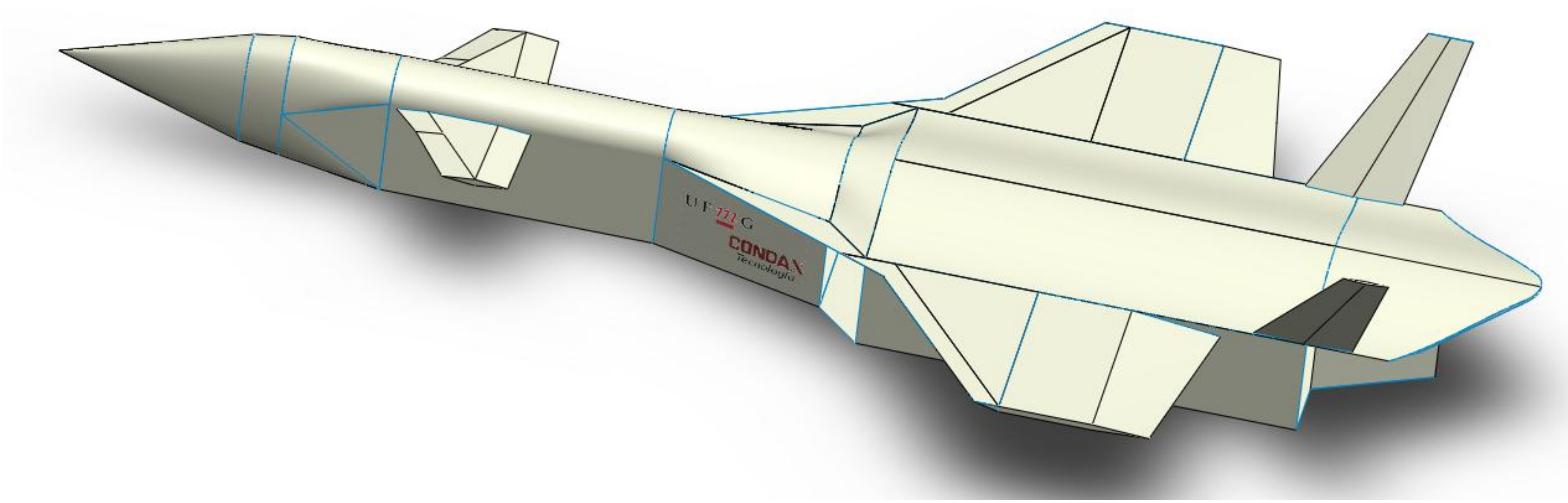
- Take-off
- Landing
- Glide after 2nd Stage separation
- Ferry-flight

These analyses also indicated that the concept can be feasible.

Conclusions:

Through a sequence of simplified conceptual approaches, the general parameters for a small, reusable, horizontal take-off and landing, satellite launcher, has been defined.

The results obtained indicated that overall concept can be feasible.



Doubts? Questions?

Thank you very much!

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