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# Computer Codes for MDO: Application to the Evaluation of the Interest of a New Propulsion Concept for an Upper Stage of Future Launchers

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## ABSTRACT

The Inner Arch developed several softwares:

- One dedicated to solid propulsion project : APSOL
- One dedicated to liquid propulsion projects ELIS

A third one, PERFOL, is used to optimize the trajectory and the propulsion parameters

The paper will describe the main software used for this study and illustrate the interest of these tools to make the first design of a new version of a launch vehicle with optimisation both of intrinsic propulsion parameters and of the trajectory

## INTRODUCTION

The project, illustrating a fast approach of launcher design, will be to replace the 3rd and the 4th stage of the European Launcher VEGA (replacement of Z9 and Avum) by an unique re-ignitable LOX/Methane Upper Stage

A pressure-fed system is leading to a stage easy to operate, reliable, needing no costly solutions (Expander engine, Boost pumps)

On another hand, many R&D programs are going on all ceramic liquid engines, engines cooled by "effusion" (DLR), Transpiration (PTAH-SOCAR from MBDA), Film or Trim (Astrium, Snecma), so very light engine may be offered on the market in a close future

Operating to relatively low pressure the specific impulse is slightly lower than a conventional one with a turbomachine (expander type or other) and the structural index lightly less interesting: a concept with the LOX tank nested inside the fuel tank with a scrolling common bulkhead appears easily usable for LOX Methane stage due to the fact that the 2 propellants are liquids in the same range of temperature and may lead to an interesting mass saving.

## ELIS: Liquid Stage Modelling

This light software is written under excel; taking as data the technological (mentioned above) and dimensioning hypothesis made so to give trends:

- Comparing architecture option
- On the influence of operating parameters
- The effects of technological options

The advantage of Excel, in this case is, the possibility to directly look at the effect on the design changing a parameter .To be effective, they have to be calibrated on detailed projects and for that excel is with its specific functionality (solver, target function)

## PERFOL: Trajectory Optimisation code

This software optimises the trajectory and the flight sequence but with the following requirements:

- Robustness and easiness: anybody without any skill in performances computation ,may use it an obtain an accurate result, from different launch pad , for different missions: the input is simplified as much as possible
- Computation time short enough to be used in a MDO software/platform
- Microsoft environment
- Excel interface
- 

The optimization problem is classically formulated with:

- A parametric optimization of the command and trajectory segmentation
- Parametric optimization with non linear constraints
- Reduce gradient method

The originality is an analytical computation procedure, the initialization process, and a gradual approach in term of complexity of the solution, for the initialization and the analysis of the optimality of the result, expert systems are implemented

The thrust law can be a real one or tailored The out-put is an **optimal trajectory and sequence** with**:**

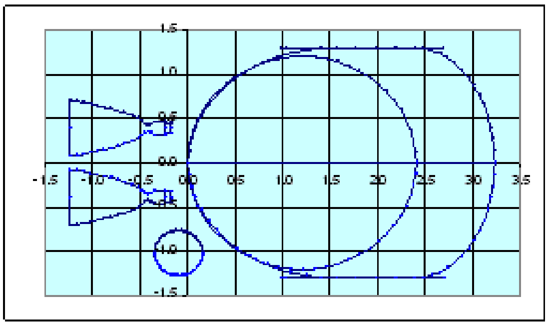
- A synthetic table of the result
- a listing with dimensioning events and parameters of the trajectory for mechanical dimensioning) and synthetic tables
- graphical display of the major parameters: some are shown hereunder, with the altitude versus range , the Pdyn, the shroud is jettisoned under flux constraints, the last one is the trajectory with the fall-out point of the stages

## Coupling PERFOL ELIS

Classically, influence coefficients (dpayload/dMp, dPayload/dIsp, etc) are determined using a trajectory code; these coefficients allowing optimising the intrinsic propulsion parameters. Using PERFOL, this intermediate step is no more useful, the optimisation being directly done by running PERFOL (decoupled or inside a MDO platform)

| **Mass Breakdown (kg)<br>Direct Injection** | |
|---|---|
| **Useful propellant** | 10000.0 |
| **Residual propellant** | 100.0 |
| **Gaseous Residual** | 16.7 |
| **Helium** | 26.6 |
| **Engines** | 62.6 |
| **Tank Insulation** | 31.6 |
| **Tanks & Skirts** | 468.3 |
| **Pressurisation** | 112.3 |
| **Stage components** | 172.0 |
| **Dry mass** | **815.1** |
| **Lift-off mass** | 10990.0 |
| **Mission End** | 958.4 |
| **Dry index** | 0.082 |
| **Mission End index** | 0.096 |
| | |
| **Loaded propellant** | 10116.7 |

Fig 1. Mass Breakdown generated by ELIS



## PERFORMANCES RESULTS AND CONCLUSION

The result of the study shown that a one may increase- using the best technologies under development in Europe- the payload of VEGA launcher from 1.4 tons to 2.7 tons on a Low Earth orbit (700/700km/90°)

Even if such an upper stage may lead to a dramatic increase of the performance of a small launch vehicle such as Vega, the aim of this presentation is mainly to show the interest of special tools to make the very first evaluation of the interest of a new solution

| **VEGA nominal** | | **POLAR ORBIT Circ 700km** | | |
|---|---|---|---|---|
| Mp | Mi | Tc | Isp_m | Q_m |
| 88 533 | 8616 | 108.8 | 269.6 | 813.7 |
| 24 027 | 2568 | 85.3 | 286.8 | 281.7 |
| 10 670 | 1425 | 124.5 | 294.9 | 85.7 |
| 396 | 826 | 500 | 315.5 | 0.8 |

| PdynSep1-2 (kPa) | Flux max (Kw/m2) | Accel max (m/s2) | Pdyn max (kPa) | |
|---|---|---|---|---|
| 2.8 | 83.5 | 61.2 | 49.9 | |
| Initial Mass (ton) | Payload (kg) | | | |
| 139 | 1403 | | | |
| **VEGAX with Ballistic Phase** | | | | |
| Mp | Mi | Tc | Isp_mean | Q_mean |
| 10 000 | 1480 | 450 | 360 | 22.2 |
| PdynSep1-2 (kPa) | Flux max (Kw/m2) | Accel max (m/s2) | Pdyn max (kPa) | |
| 1.1 | 81.4 | 42.3 | 55.6 | |
| Initial Mass (ton) | Payload (kg) | | | |
| 138.5 | 2724 | | | |

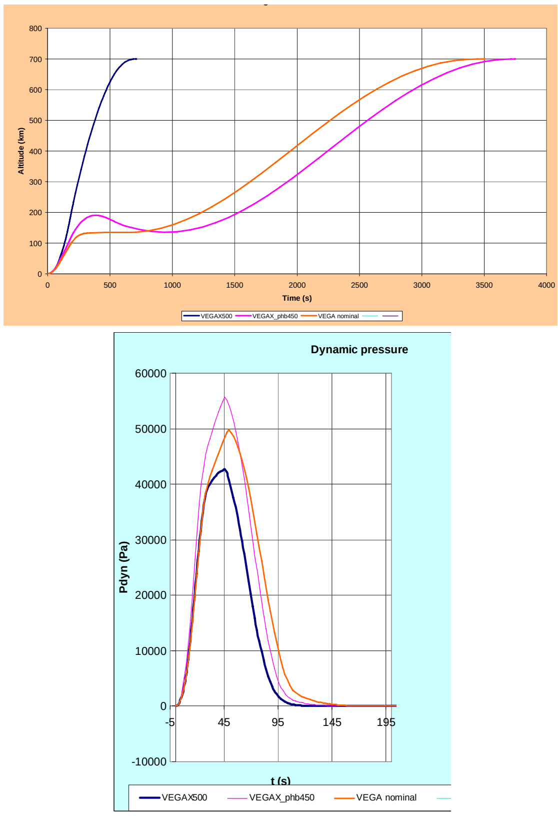



Fig 2. Altitude and Pdyn vs time

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