AN ECOSIMPRO MODEL OF HERSCHEL AND PLANCK PROPULSION SYSTEMS

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ABSTRACT

The development of a new Reaction Control System (RCS) is a complex process. In this frame an accurate performance model is essential in evaluating system performance, predicting RCS operating for nominal and off-nominal hardware conditions, and anomaly investigations.

This paper presents the models built for the propulsion systems of Herschel and Planck at Thales Alenia Space France. Modeling of the RCS is performed by simultaneously solving a set of dependent (coupled) equations, using the EcosimPro software and the European Space Propulsion System Simulation (ESPSS) library.

Both Herschel and Planck propulsion models have been validated by comparison with actual flight data.

Herschel, Planck and the ESPSS library are programs of the European Space Agency (ESA).
EcosimPro is a simulation tool developed by Empresarios Agrupados International.

1. INTRODUCTION

The RCS used on Herschel and Planck are monopropellant hydrazine propulsion systems, operated in blow-down mode. They provide the necessary forces and torques to achieve spacecraft linear and angular momentum changes necessary for orbit transfer / insertion / maintenance and attitude control, during all phases of the mission.

The paper provides a description of the RCS models, their structure and interface. An assessment of the accuracy of the models is also given.

2. MODEL STRUCTURE

The performance models simulate the internal flow environment (pressure, temperature, flow rate) of the RCS. They accurately predict the performance characteristics of individual components.

System modeling provides a determination of propellant consumption and distribution by simulating each of the maneuvers. During mission operations, the models provide predictions on propellant tank blowdown pressures and thruster inlet conditions.

Flow test data for the components and the actual RCS geometry have been entered to allow for calculation of the pressure drops.
Subsystem components are modeled independently, then integrated into the model.

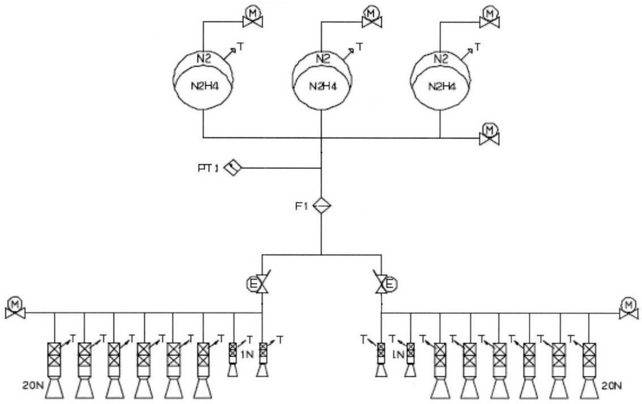

Figure 1: Planck RCS schematic

The user inputs initial conditions (tank temperatures, tank loading conditions) and, by using simple flag switches, can turn an engine or a valve On or Off to allow for modeling of various scenarios without having to modify the flow model.

The software will then run to completion and output the results graphically. Raw data is also available for in-depth analysis.

2.1 Component modeling

Hydrazine thrusters
Two types of thrusters are used on Herschel and Planck: 1N and 20N thrusters.
The thruster performances (thrust, flow rate and impulse bit) are expressed as a function of the inlet pressure, thruster ON and OFF times.
As the thruster is mainly used in pulse mode, the flow rate is computed as an average flow rate over a pulse train. The model does not take into account any modulation of the flow rate during the thruster actuation.

Other discrete components (propellant tanks, latch valves, filters) are based on standard components of the Ecosim ESPSS library.

The whole pipe geometry is imported from the actual RCS CAD model. It is converted into standard pipe, junction and tee components of the ESPSS library. Specific discrete elements (eg. miter bend) are also used.

Components which are not part of the ESPSS library have been validated before integration into the RCS model.

2.2 System

The Propulsion system model is created by simply connecting the components together.
A schematic view of the Planck model is presented Figure 2.

2.3 Mission data

The tank loading pressures and temperatures, as well as loaded propellant mass must be initialized.

The propellant tank temperature is considered as an input for the simulation.
The data entered corresponds to a tank wall temperature, and therefore the propellant and pressurant will reach the requested value after a certain delay.

The thruster and latch valve actuation profiles are considered as an input for the simulation.

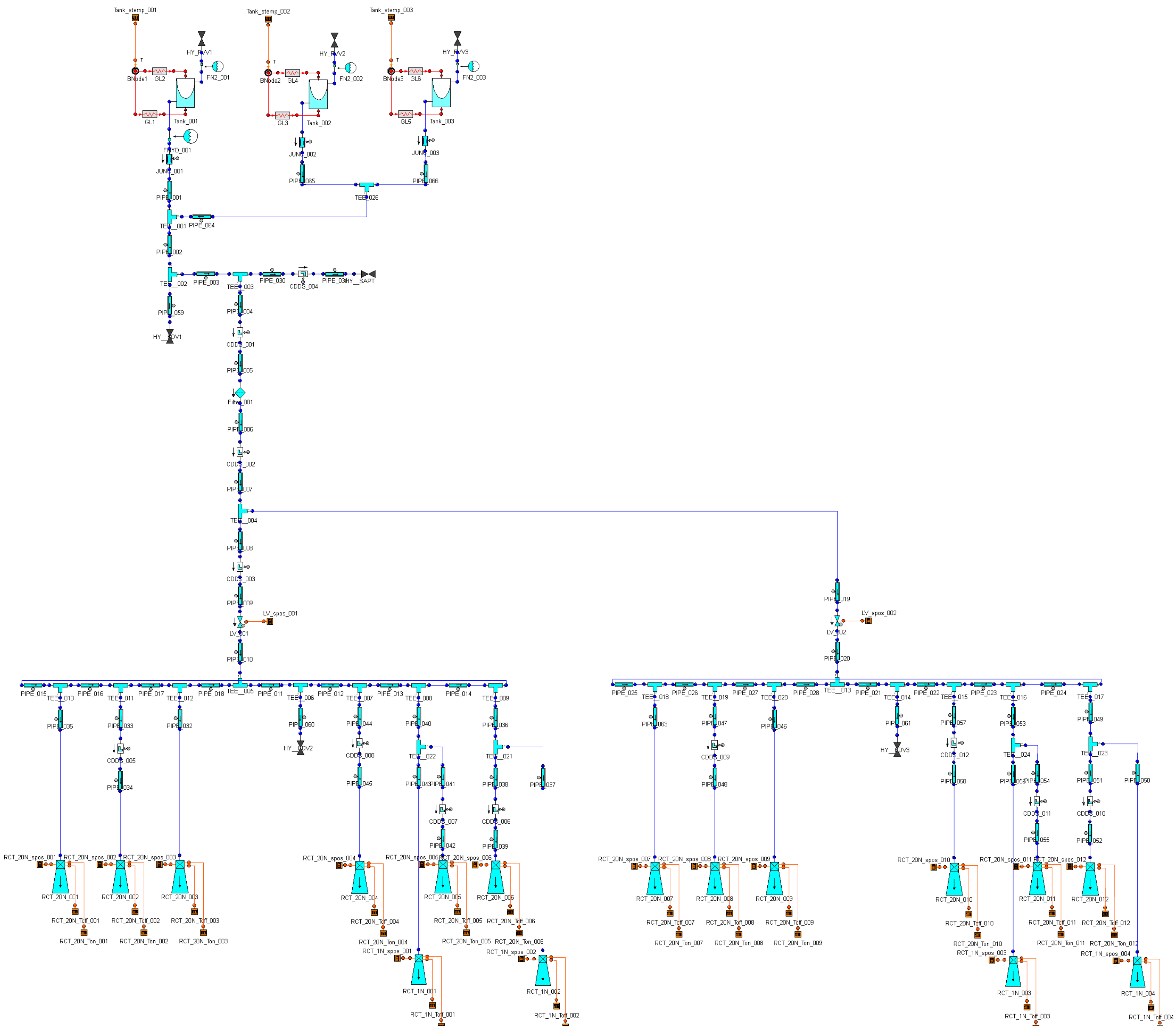

Figure 2: Planck model schematic

2.4 Model interface

Two standalone executable versions of the models have been created. They run under the Microsoft™ Excel environment.

From the Excel sheet (Figure 3), the user may:

- modify the data files (propellant tank temperatures, thruster and latch valve actuation profiles),
- initialize the hydrazine and nitrogen masses,
- start or stop the simulation.

The main results of the simulation are presented graphically.

Four graphs are displayed for the propellant tanks:

- tank pressures,
- tank temperatures (gas side),
- tank outlet flow rate,
- tank remaining propellant masses.

Four graphs are displayed for the thrusters:
- thruster inlet pressures,
- thruster impulse bits,
- thrusts,
- thruster flow rates.

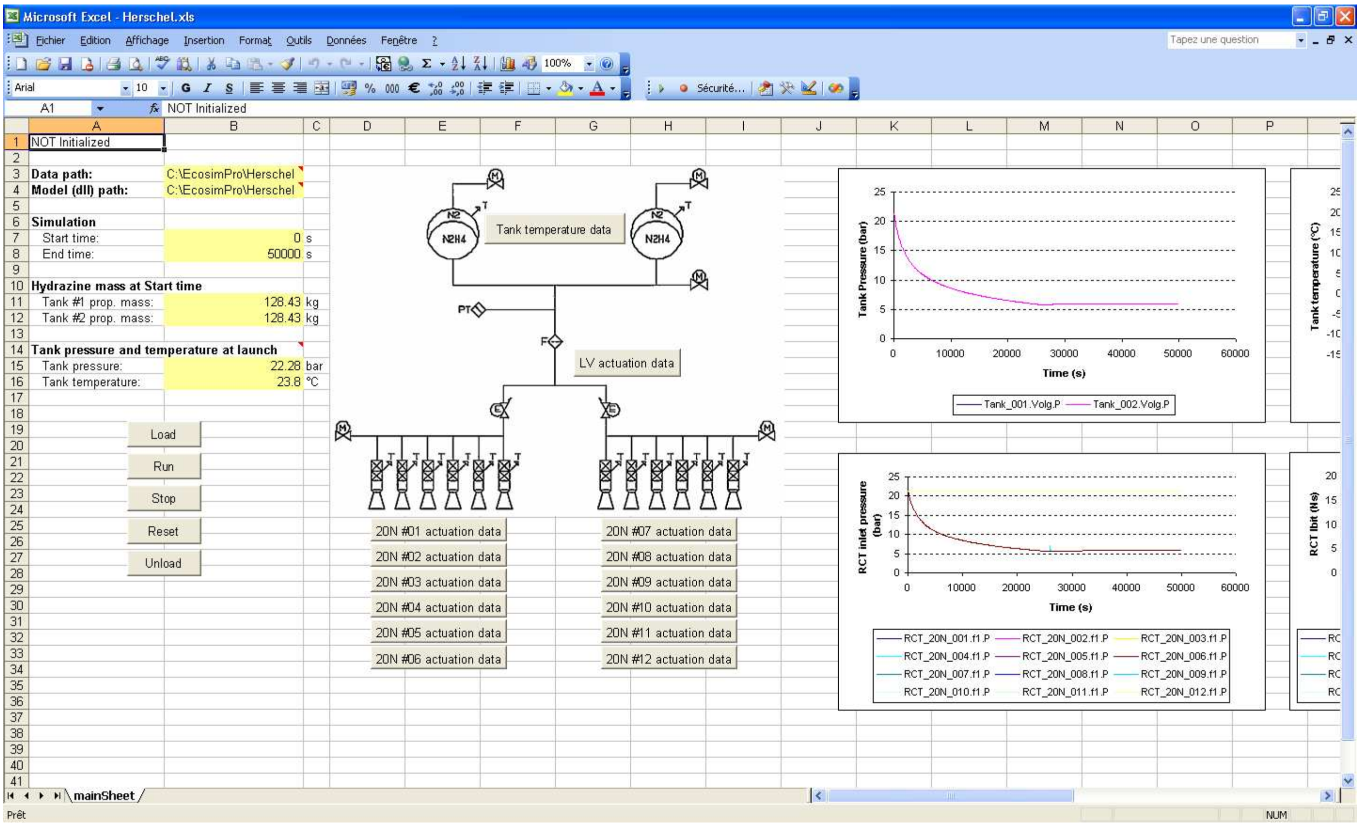

Figure 3: Herschel model interface

Raw data (value of model parameters at each step of the calculation) is also available for in-depth analysis.

3. MODEL VALIDATION

The validation of the model has been performed by comparing flight data and model data.

For the Herschel model, the mission has been simulated over the period 14/05/2009 to 03/07/2009. The input data consists in:
- tank temperature telemetry,
- thruster actuation profiles.

The comparison is performed on tank pressure.

3.1 Tank temperature

The actual tank temperature profiles (one for each tank, see Figure 4) have been approximated by a few segments.

3.2 Thruster actuation profiles

The actual thruster actuation profiles have been approximated by a few segments representative of the accumulated ON time (Figure 5 and Figure 6).

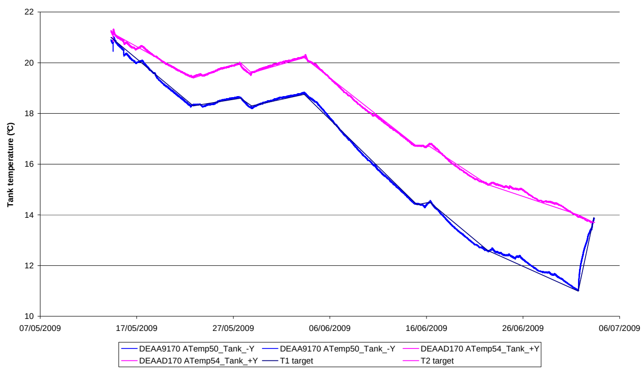

Figure 4: Approximation of tank temperature profiles

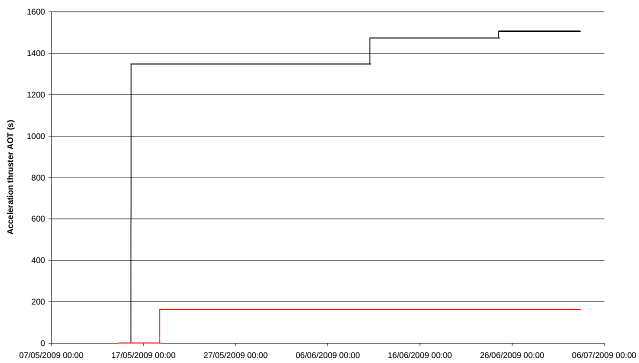

Figure 5: Thruster actuation profiles (Acceleration thrusters)

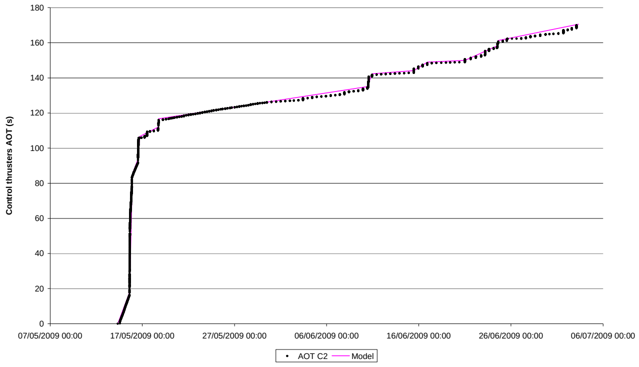

Figure 6: Approximation of thruster actuation profile (Control thruster)

3.3 Tank pressure

A comparison between the actual tank pressure (red curve) and the value computed by the model (black curve) is presented.
It shows a very good correlation: the discrepancy remains lower than 0.8%.

It is noticeable that this result was obtained during the first simulation attempt, thus reducing the validation phase to its minimum.

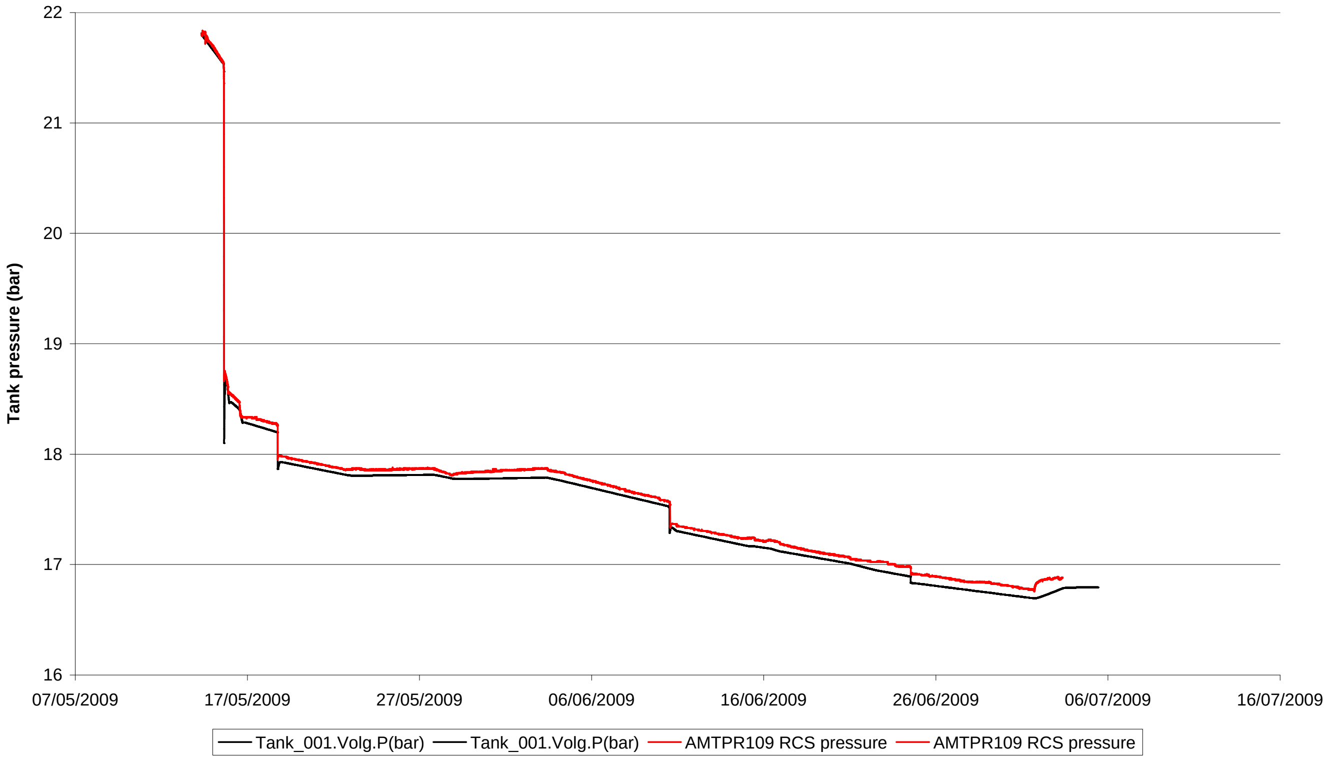

Figure 7: Comparison of actual and computed tank pressures

3.4 Transfer of mass between tanks

Figure 8 shows that a discrepancy of ~ 1 kg was created between the two tanks due to the difference in temperature. The heating of one tank on 01/07/2009 (see Figure 4) has cancelled this discrepancy by transfering the propellant from one tank to the other.

The ability of the model to cope with a transfer of mass between tanks was not initially requested and therefore can be considered as a bonus.

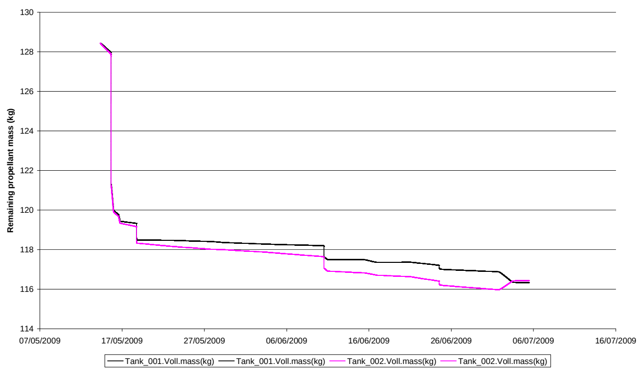

Figure 8: Remaining propellant mass

4. POTENTIAL EVOLUTIONS

Due to the modularity of the simulation tool, the model can be easily updated upon request to allow for modeling of various scenarios (eg anomaly investigations).

A thermal model of the tanks (their temperature is currently considered as an input) could also be introduced.

5. SUMMARY

An accurate model of the Herschel and Planck Propulsion systems was developped using the EcosimPro software and the ESPSS library.

The model is used as a tool for simulations and for support to spacecraft flight operation.

It was mostly built using the standard ESPSS components thus reducing the development cost of the model.