

The Electric Propulsion Library of ESPSS for System Simulation

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Abstract: The paper describes the phase three of the work performed for the implementation and validation of an electric propulsion system modelling library of ESPSS (European Space Propulsion System Simulation) within the existing tool EcosimPro®. EcosimPro® is a Physical Simulation Modelling tool developed in an object-oriented visual simulation environment capable of solving dynamic systems written by equations and discrete events. It solve both transients and steady states. This tool, with the propulsion library ESPSS for example, allows the user to design (and to draw at the same time) the propulsion system with components like tanks, lines, orifices, valves, thrusters, etc. The design capabilities are enhanced by components from the thermal library (heaters, thermal conductance, radiators), from the control library (analogue/digital devices), from the electrical library, etc. The paper presents several new components added to the propulsion library. These improvements of ESPSS are updating and extending multiple libraries to represent a functional propulsion system, e.g. fluid properties, pipe networking including multi-phase fluid flow, two-phase two fluids tanks with gravity or accelerations effects, non-adiabatic combustion chambers, chemistry, turbo-machinery, etc. The paper presents the modelling of electric propulsion systems performed in order to check the implementation of the new components especially the thruster, the PPU (or PSCU), the xenon flow control XFC (or XFCU), etc. The Electric Propulsion (EP) library allows the user to simulate the operations necessary for the activation of the electric propulsion on-board of a satellite and to simulate the outputs of the several telemetries and functional characteristics. In addition, this library includes a port so called "RAMS" for simulating some predetermined failures cases for each component.

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Nomenclature

η_F	parameter of model, thrust efficiency
η_e	parameter of model, electrical efficiency
$g_0 I_{sp_{loss}}$	parameter of model, losses (m/s)
F	Thrust force (N)
P_e	Electrical input power (W)
\dot{m}_{prop}	total mass flow rate (kg/s)
$g_0 I_{sp}$	specific impulse (m/s)
I_d	discharge current or beam current (A)
U_d	discharge voltage (V)
k_I	parameter of model, proportion between current and mass flow
U_{dSet}	wanted discharge voltage in operation (V)
$I_{max Op}$	discharge current maximum at constant voltage (A)
a	negative resistance of the voltage current characteristic (Ω^{-1})
I_{short}	short circuit current (A)
K_p, K_i, K_d	gains

I. Introduction

THE paper presents first a simulation concept that is a system engineering tool dedicated for complex systems, the European Space Propulsion System Simulation (ESPSS) libraries, and in a second part a specific Electric Propulsion (EP) library dedicated first for the operations of any EP system.

II. European Space Propulsion System Simulation (ESPSS) background

EcosimPro® is a Physical Simulation Modelling tool developed for ESA by Empresarios Agrupados Internacional (Spain) since 1989. EcosimPro® was a precursor and now with its 24 years of careful growing it belongs to the last generation of the common engineering tools after computer aided design (CAD) and integrated engineering analysis tools available on classical laptops. The kernel of EcosimPro® is an expert solver of all the equations set in the different components of a system. Solving all the equations together has been found extremely efficient and this justify the main feature of the tool which is to describe every component in terms of symbolic equations. Thanks to such expert solver, the tool allows to manipulate components like objects that can be independently further developed with more sophisticated equations. EcosimPro® is based on a visual simulation tool for solving simple and complex physical processes that can be expressed in terms of equations (including ordinary differential and differential-algebraic) and discrete events (especially for the commands or triggering events).

Practically, the modelling of physical components is based on a basic “EcosimPro language” (EL), an object-oriented programming language which is very similar to other conventional programming languages (Basic) but is very powerful to write any equations and differential equations for modelling continuous and discrete processes. EcosimPro employs a set of libraries containing various types of components (mechanical, electrical, pneumatic, hydraulic, etc...) which can be interconnected to model complex multi-domain dynamic systems. The ESA ESPSS is a set of EcosimPro® libraries written to model all aspects of a functional propulsion system. For example, as a tool ESPSS is relying on 1D flow equations, thermodynamic relationships and real fluid properties, there is no need for fudge factors, therefore the results of the simulations could be considered as general as long as the flow is one-dimensional and homogeneous (either as mono-phase, or two-phase state or as a mixture).

III. European Space Propulsion System Simulation (ESPSS) Libraries

The following libraries have been developed in the phases 1&2 of the project ESPSS: “Fluid Properties”, “1-D Fluid Flow”, “Tanks”, “Combustion Chambers” and “Turbomachinery” libraries. An overview of these propulsion libraries with some validation cases is presented in ref. ¹.

As the third phase of the project ESPSS started few years ago, only the new improvements are discussed in the following chapters. One among them is the new Steady-State library compatible with other parts of ESPSS along

with two new libraries for satellites: the SATELLITE library and the Electric propulsion library (EP library). Those improvements will be added for the next release of ESPSS to its users ².

IV. European Space Propulsion System Simulation (ESPSS) Improvements

The improvement of ESPSS are numerous, here are reported only some significant points for the ESPSS libraries FLUID_FLOW_1D, TURBO_MACHINERY, COMB_CHAMBERS and TANKS:

- In the Junction components the supersonic conditions are allowed as option, and can be detected automatically.
- The heat Exchanger have been upgraded for cross flow dispositions accounting for several baffles and tube passes.
- A more robust version of the Cold Thruster component using supersonic junctions (non adapted conditions can be calculated included the shock inside the nozzle).
- Valves have been upgraded to consider EqualPercentage, Linear, QuickOpening or user-defined laws.
- Fluid Cavities (not the simple Volumes) and Tank models account for the volume expansion due to wall compressibility.
- Added new input data and options for right, "Y" and User defined Tee component.
- Nozzle & chamber diameters reconstruction is included in the continuous block allowing geometry redefinition during a simulation.
- New components are available for imposed static boundary conditions (intakes).
- N₂, He, O₂, H₂, CH₄ real properties files are rebuilt with more points in pressure & temperature. Moreover, extrapolating in real properties at $P > P_{max}$, $T < T_{min}$ or under two-phase flow is better detected and treated.
- 1D Tanks include film boiling bubbles formulation (as a new option) and better simulation of the generalized boiling process.
- Condensation (raining) flow is now optional: Droplets can remain as a fog in the ullage volume or can drop to the liquid volume at a given speed.
- Pumps model: Table of loss of head vs. net positive suction head (NPSH) and compressibility effects due to pump cavitations have been included.
- Combustor models are more robust simulating start-ups and shutdown sequences.
- New components are available to compute the delay in the transport of the combustion products also permitting the simulation of a mixture of combusted gases and pure fluids (chamber with more than 2 injectors).

In addition a new library called STEADY has been added to ESPSS for simplified cases of Steady states. The STEADY library contains a complete set of components (combustors, cooling-circuits, nozzles, turbines, pumps and valves) able to calculate the performances of any rocket engine cycle type under design and off-design conditions.

A new "SATELLITE" library deals with interactions of the Satellite Attitude and Orbit Control System (AOCS) with its propulsion subsystem. This library includes an orbit propagator as well as management of variable inertia and dynamic evolution of center of mass due to propellant consumption and inertial acceleration due to the thrusts or to the perturbing forces.

The satellite library contains the main components, shown in Fig. 1, needed to build a satellite AOCS with the major interactions and perturbations that occurs in flight^{3,4,5}.

- Moon and Sun perturbations, mainly corrected by the use of thrusters for the North-South station keeping of a GEO satellite,
- Earth flatness or so called "J2" perturbations to be used for the helio-synchronous satellites,
- Sun pressure interaction with the solar arrays of the satellite.

In addition, a control of the satellite attitude can be added (using the existing components of the existing CONTROL library) for performing an Earth Pointing

with a set of actions on the reaction wheels or on a set of thrusters or Electric thrusters.

Finally the Electric Propulsion "EP" library allows the user to simulate the operations needed to activate the electric propulsion aboard a satellite and to simulate the outputs of the several telemetries and functional characteristics. In

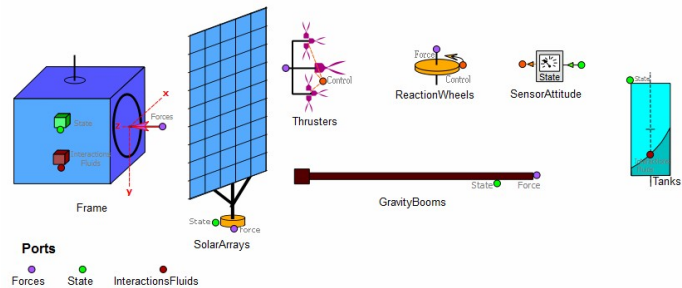


Fig. 1 Palette of components for the SATELLITE library of ESPSS

addition this library includes a port so called "RAMS" for simulating some predetermined failures cases for each component. This EP library is described in more detail below.

V. The Electric Propulsion "EP" Library

EP is an EcosimPro® library for the transient simulation of electric propulsion systems. Because the numerous possible systems, this library is more oriented as an example design for building such system. The most important features are the following:

- Thrusters model provided with tabulated example of characteristic adapted to Hall effect thrusters (PPS1350⁶), Gridded Ion Engines (T6, EsaXX⁷) and for UserDefined models.
- Xenon Flow Contoller (XFC⁸) based on the use of a thermothottle for the control of the mass flow rate and Filter Units (FU) components are more oriented for Hall effect thrusters (PPS1350), but can be used without difficulties with Gridded Ion Engines (T6, EsaXX).
- The Power Processing Unit (PPU^{9,10}) component allows receiving simple Tele-command list in the experiment to successively perform the operations.

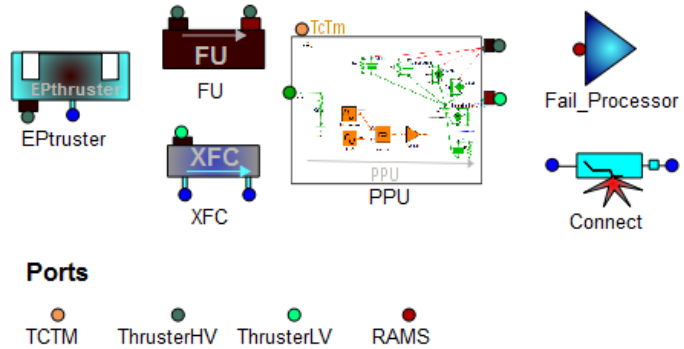


Fig. 2 Palette of components for the EP library of ESPSS

The general design of the components of EP

LIBRARY is coming from open bibliography references. The users are encouraged to modify the design in order to match with their own performances and characteristics.

The EP components can be connected to other ESPSS libraries (FLUID_FLOW_1D components and to ELECTRICAL components) in order to simulate a complete Electric propulsion system.

The palette of objects designed for this library) is shown in **Fig. 2**, it comprises EPthruster, FU (filter unit), XFC (xenon flow controller), PPU (power processing unit), and a Fail_Processor and Connect (a fluid connection enabling on command a leakage).

VI. Simplified General model of EP thruster

As sketched in **Fig. 2**, the component EPthruster is equipped with 2 ports. Ports are fundamental communication interface between components in Ecosimpro®, comprising the variables needed as in the real system. For the EPthruster, one port is dealing with high voltage (and high current, and other parameters) the other is a fluid port for the input of propellant (i.e. xenon coming from an existing ESPSS library FLUID_FLOW_1D fluid port). That means that the system build with the EP library will be compatible with the numerous existing components for all what concern the propellant sub-system.

Regarding the thruster itself, the model used for the relation "Thrust, Power and Isp" is already developed¹¹. This is a simplified model based on 2 parameters (η_F and $g_0 I_{sp_{loss}}$), but valid for Hall and Ion thrusters (with F in N, P_e in W and $g_0 I_{sp}$ in m/s).

$$F = \frac{\eta_F \cdot P_e}{\frac{1}{2}(g_0 I_{sp})^2 + (g_0 I_{sp_{Loss}})^2} \cdot g_0 I_{sp} \quad (1)$$

With a given total mass flow rate \dot{m}_{prop} (kg/s) and the thrust force F , the $g_0 I_{sp}$ (m/s) can be deduced:

$$g_0 I_{sp} = F / \dot{m}_{prop} \quad (2)$$

Thus the two equations (1) and (2) make the variable $g_0 I_{sp}$ as algebraic and thus those equations are to be solved together in a so-called "box" of EcosimPro®. It is to be highlighted that this process is automatic in EcosimPro®

because the model is only written in terms of symbolic equations, the expert solver of EcosimPro[®] will recognize the need for such algebraic loop. In addition the current I_d (discharge current or beam current) is derived from the total mass flow rate by a relation with one coefficient k_I (theoretically one electron for one ion) which is actually also linked to the fraction of propellant feeding the anode with respect to the total mass flow rate:

$$I_d = \dot{m}_{prop} / k_I \quad \text{with } I_d \text{ in A} \quad (3)$$

And the total input power P_e is derived from the voltage U_d (discharge voltage or beam voltage) and current by a relation with one coefficient η_e :

$$U_d = \eta_e \cdot P_e / I_d \quad \text{with } U_d \text{ in V} \quad (4)$$

Two last equations are coming from the fluid port that impose the mass flow rate and from the PPU that impose the voltage

$$\dot{m}_{prop} = \text{given_by_the_XFC} \quad \text{and} \quad U_d = \text{given_by_the_PPU} \quad (5,6)$$

Every model is based from correlations formulae, but those formulae are customizable: users who want to use other thrusters have to adjust the parameters available in order to fit with the integrated formulations.

VII. Simplified General model of PPU

The model of the PPU has two parts: Hardware and Software.

- The hardware part contains all the devices that are used in the PPU based internally on several already existing components of the ESPSS libraries.
- The software part is dealing with the specific logic of operations managed into the PPU.

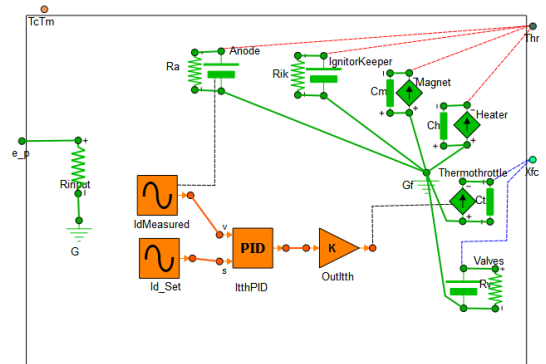
A. PPU hardware

From the block diagrams found in the bibliography^{12,13,14}, the PPU (or PSCU) component shall include 5 power supplies.

The PPU hardware comprises components from other ESPSS libraries as sketched in **Fig. 3**: components from ELECTRICAL library (green color) and CONTROL library (orange color). In addition some simple equations are added (symbolized by dashed lines in the sketch) for linking appropriately some components inside the object PPU :

the characteristic of the Anode power supply current (I_d) is linked to the input of the PID. Also the output of the PID is linked to the current of the Thermo-throttle current source. All the voltage and current sources inside the PPU are linked to two ports (multi-variable ports) for feeding the thruster system: "Thr" for the high voltage port and "Xfc" for the lower voltage port. Two other ports are implemented for the inputs: the bus voltage and the TcTm port for the direct and digital telecommands&telemetries .

All the current sources or voltage sources are simulated by standard components of ESPSS except the main power source (Anode power source) which includes a particular important feature (needed for some Hall Effect thrusters) with a limited power discharge voltage-current characteristic. Moreover, the control loop of the discharge current is active only in **Fig. 3 PPU Hardware model build from existing libraries**



The simple equation to model this Anode power source used is

$$U_d = U_{dSet} + a \cdot \max(0, I_d - I_{maxOp}) \quad (7)$$

where the coefficient a represent a negative resistance (in ohm), a being negative infinite for GIE and simply negative for HET ($a < 0$). For $U_d=0$, the current is defined by I_{short} which is a data of the model.

The other power supplies for feeding the devices included in the thruster system are:

- Magnet power supply,
- Igniter/ Keeper power supply,
- Heater power supply,
- Acceleration grid power supply.

A last power supply deals with the control loop for the mass flow rate

- In the case of Hall Effect thrusters (or thruster using thermal flow controller), this is a current source where the current level is given by the error between the actual discharge current and the goal I_{dSet} given in the data of the component or set by telecommand.
- For initialization purpose, when the thruster is still off ($I_d=0$) the current level of the current source shall be set to an initial current I_{itSet} (sometime called warm-up current).
- The control loop may use according to the gains K_p , K_i , K_d a proportional (P) loop control, or a proportional integral (PI) loop control or full proportional integral derivative (PID) loop control.
- The PID implemented in the PPU component of the EP library is a standard PID coming from the CONTROL Library with most of the default settings. The current position corresponds to the I_d measured while the wanted position of I_d is I_{dSet} . The output toward the thermothrottle is the current I_{tth} as sketched in Fig. 5.

Because the increase of I_{tth} decreases the mass

flow rate and thus decreases the current I_d , the gain of the controller shall be negative (-1). The time constant of integration has been set appropriately in order to follow the expected behavior of the device. The range of output for I_{tth} is defined in the data. In the case of Ion engine, if the flow controller is different from above, the user shall use the available components of the ESPSS library (heaters, proportional valves) to build the relevant control loop because up to now, the details of the control for those thrusters are not disclosed. But it must be highlighted that the HET XFC can be used also with Ion engines.

B. PPU software

For Hall Effect thrusters the following accurate description available in the bibliography¹⁰ is taken into account: The PPUs exchange data with the on-board computer. According to the received command, the PPU enters into one of its six possible modes: OFF, STAND-BY, CONFIGURATION, VENTING, AUTOMATIC and REMOTE. These transitions are sketched in Fig. 6 . Their description is as follows:

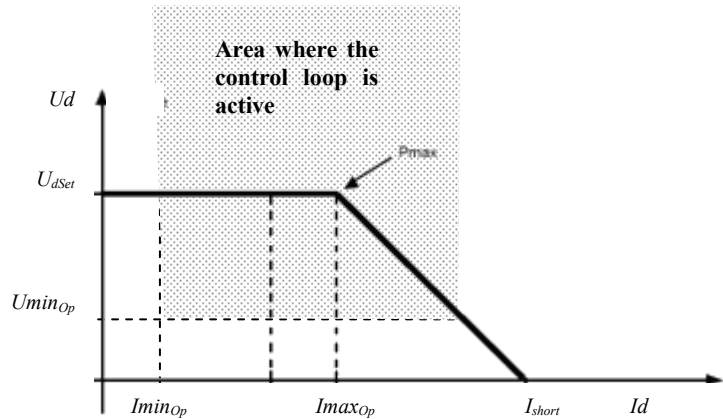
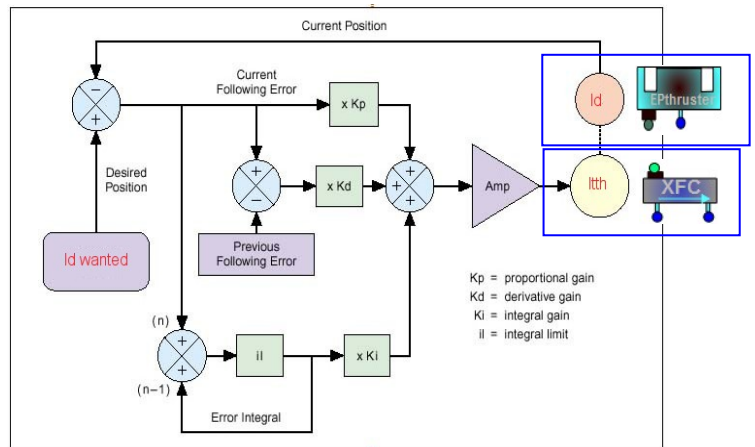


Fig. 4 Example PPU voltage-current characteristic ⁹



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Fig. 5 Control loop of the thruster discharge current I_d by the thermothottle current I_{tth} courtesy www.newport.com

1. After the power bus of the satellite is connected to the PPU (switch closed for example) the PPU is OFF and can receive only direct telecommand and act accordingly.
2. Then the user send the DTC (direct telecommand) “PPU ON” to turn ON the PPU DC/DC, the sequencer enters into an initialization phase before being put in STAND-BY mode.

During this initialization, the checksum of the ROM memory is performed. If a failure is injected for this check, the PPU does not start.

3. In the “STAND-BY” mode, only low level electronics are active. But it is also possible to modify the setting of firing parameters (mode independent parameters).

From the “STAND-BY” mode, the PPU accepts any transition to another mode and the entire mode independent telecommand (TC).

If a wrong TC is commanded from this mode, the PPU output a flag “TCforbidden”.

4. In the “CONFIGURATION” mode the PPU accepts telecommand for example to turn on the XFC valves. The user shall send “TCStandBy” to exit that mode.
5. The “VENTING” mode is only used at the mission beginning to allow venting of the Xenon lines before the first thruster firing. In this mode the PPU opens all the XFCs valves on the selected thrusters for the predetermined duration defined in the data by “Tventing”.
6. In the “REMOTE” mode the PPU accepts dedicated telecommand. The on-board computer allows “step-by-step” management of the thrusters in order to provide flexibility to the ground operators if necessary: to turn on or off individually every power supplies and to perform the ignition pulses and to turn on or off the loop control.
7. The “AUTOMATIC” mode is the nominal mode of the PPU when the PPU drives the firing of the thruster in closed-loop. The power supplies of the PPU are active. The firing is driven with the set of parameters defined in the configuration mode. The logic of the “AUTOMATIC” mode is as follows:
 - o During the starting phase, the PPU sequences as follows:
 - Heat the selected cathode and thermothrottle up to the corresponding stabilized thrust level for the thruster
 - Open the XFC valves
 - Supply the cathode with ignition pulses once the cathode is enough heated (according to a timer > Theating)
 - o The thruster has to be started within a given delay period from the start of this sequence. In case of failure the PPU act accordingly.
 - o During the stabilized phase (after the thruster starting sequence), the initiator electrode is no longer supplied and the closed control loop becomes operational. In stabilized mode the discharge current control is made by adjusting the Xenon flow rate through the thermothrottle in the XFC

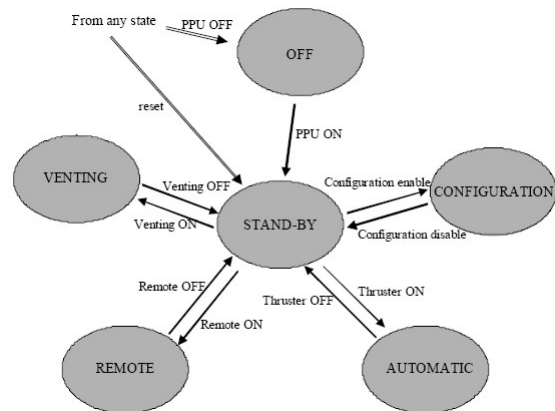


Fig. 6 PPU Modes and transitions for HET¹⁰

The implementation of all those features (that are mainly logic events) into the EP library has been performed thanks to the capability to model discrete events within the tool EcosimPro® .

VIII. Simplified General model of XFC

This component (also called Flow Control Unit FCU) can be explicitly developed with a real thermothrottle component (to be derived from a tube and its envelope), but such design requires too many input data, moreover such data are generally only available in house of the thruster manufacturer. Hence, as for the thruster model, the XFC model has been derived from correlations. A general XFC characteristic is given from the bibliography⁸. From this example, in order to be less specific to one thruster design but for a more general use, non-dimensional reduced characteristics have been set-up in Fig. 7. For this non-dimensional characteristics, the unit mass flow rate ratio and the unit thermothrottle current ratio have been set according to the following logic: For allowing a full authority around the nominal mass flow rate, the mass flow rate ratio is set to 1 for the middle range of mass flow for the most constraining conditions i.e. for the hot case. The thermothrottle current ratio is set to 1 for the most usual conditions i.e. for the ambient case.

With such logic, the normal operation of the XFC control can start at ambient condition with the nominal mass flow rate, and in the event the temperature of the device increase, then the corresponding thermothrottle current have to decrease (automatically by the PID of the PPU) for maintaining the mass flow rate.

Such curves of mass flow rate ratio versus the thermothrottle current ratio are put in a Table 2D "mfr" (feature of EcosimPro®) as a function of the temperature condition case and the thermothrottle current ratio. When the current temperature of the XFC is specified, linear interpolation with the temperature case is performed. The effect of the pressure is taken into account by a pressure ratio along with an exponent (set by default to $n=2$). Finally the XFC model for the mass flow rate \dot{m}_{prop} versus the pressure P and the current I_{th} is described by the following equation where the pressure P_0 , the current I_{th0} and the mass flow rate mfr_0 are set in the data of the component:

$$\dot{m}_{prop} = (P/P_0)^n \cdot mfr(I_{th}/I_{th0}, T_K) \cdot mfr_0 \quad (8)$$

IX. Model Description of The Fail Processor Components

Regarding the fail processor function, two approaches seems possible

1. The creation of a new port for transferring the failure cases so called "RAMS events" to the components.
2. The management of all the RAMS events foreseen with a global variable

The first approach is in line with the concept of a simulation tool using objects connected each other with their ports. This is the most interesting aspect of this approach. However the drawback is that several links should be added to the objects for connecting those ports together to a main fail processor: this may add a complexity to the system design when the user wants to play with some RAMS events, and this is much less intuitive than for real functional links like fluid or electric links. The second approach however relies on events that are coming via a global variable (feature available within EcosimPro®). In this second case, the user does not see any links between the fail processor and any of its components. But the presence of a Fail processor component shall be added to the system design for enabling an also highlighting this feature. For the two cases considered, the designer of the component shall include into each component the actions relevant to a specific RAMS event. In this aspect the two approaches are similar. Because the system simulation is firstly intended to simulate the nominal behavior of the system and second it may also simulate some failure cases, the second approach has been preferred. In addition one shall mention that this approach was already followed in the simulation of the SMART-1 Electric Propulsion System¹⁵.

The RAMS events have to be derived from the Failure Modes, Effects and Criticality Analysis (FMECA). Among them for example the list is the following:

- For thrusters: short between grids (in the case of GIE); swirl torque; thrust orientation,...
- For the PPU (or PSCU): sudden loss of the anode voltage due to a single event transient, higher power, ...
- For the propulsion system: leakage components using a specific valve to the vacuum.

The implementation of all those features (that are mainly conditional events) into the EP library has been performed thanks to the capability to model dynamically conditional equations within the tool EcosimPro®.

X. Reference Electric Propulsion System

The reference case of the use of the new components of the EP Library is a simple EP system with one PPU and one thruster. The fluid section for the xenon input is simulated by a constant source (as a perfect pressure regulator output). The sketch of the model is shown in Fig. 8.

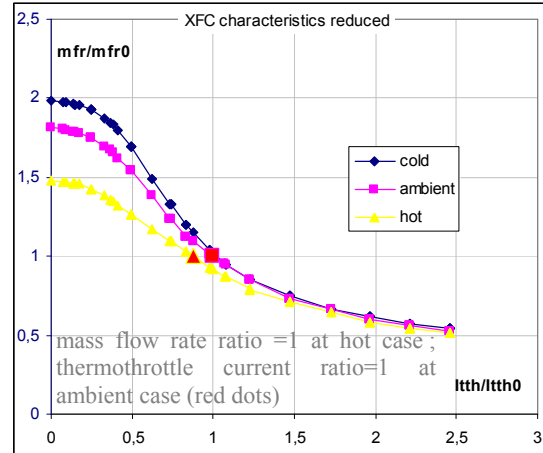


Fig. 7 XFC non-dimensional characteristics mass flow versus input current

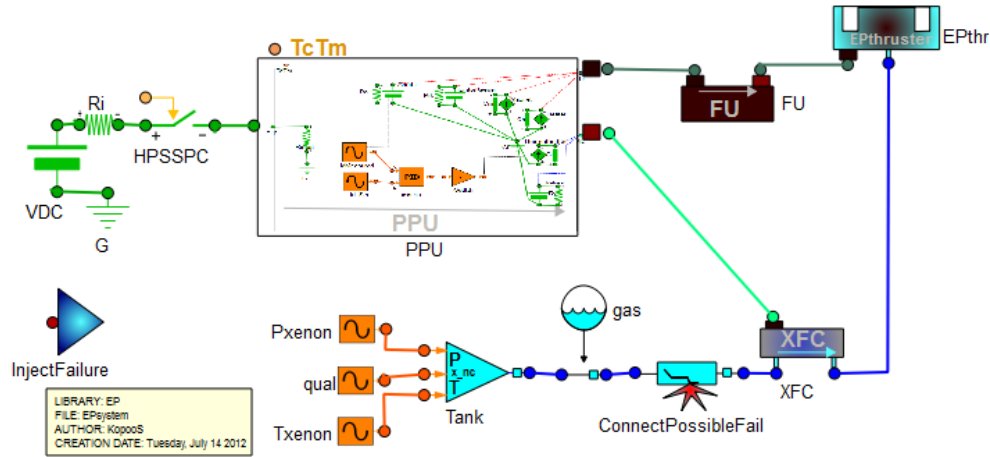


Fig. 8 Reference case of EP system model

A model by alone is not able to be used without any specific command. Thus in the EcosimPro® environment, one uses the experiment feature where all the commands to the model are specified in a chronological order. In addition one can also update some settings of the model and perform loops for parametric analysis. The experiment includes of course the command to EcosimPro® to run the simulation when wanted

For the reference case, the list of commands is the following (where the chronology of the command is given by the keyword AFTER in seconds):

Table 1: Example of a list of commands to run a simulation of the EP model in an EcosimPro® experiment

Actions	Experiment listing
1. Set the bus voltage	VDC.V=50
OPERATION and TC LIST	
2. Close the bus power switch	HPSSPC.b_fire.signal[1] = TRUE AFTER 0.5
3. Direct TC to turn ON the PPU	PPU.TcTm.DTC=1 AFTER 3
Sequence of digital TCs in the chronological order	
4. Switch to PPU automatic Mode sequence with default settings	PPU.TcTm.TC=TCAutomatic AFTER 8
5. Prepare a TC with a value	PPU.TcTm.TC_Value=4.125 AFTER 11
6. Send the TC to specify immediately IdSet the discharge current wanted at ignition (4.125 A)	PPU.TcTm.TC=TCIdSet AFTER 12
7. Prepare a TC with a value	PPU.TcTm.TC_Value=5.125 AFTER 409
8. Send the TC to change immediately IdSet the discharge current at time 410s (5.125 A)	PPU.TcTm.TC=TCIdSet AFTER 410
9. Finally, run the simulation for 750 s	INTEG_TO(750,10)

Hence a list of 9 commands is used to turn on the EP system with two different settings regarding the discharge current (and all other settings being set at their default value).

The simulation provide the output as expected in **Fig. 9** where at time 410 s, one can see the change due to the new discharge current settings and successively in the **Fig. 9** the effects on the power (a) , the xenon mass flow rate and its pressure at XFC input (b), the discharge current and thermothrottle current (c), the Isp and thrust (d) and the discharge voltage (e) and the telecommand values (f).

Because the model is dynamic (includes differential equations), the change is not instantaneous, but some time is needed to reaches the steady state after the change has been requested.

Such simulation is very fast requiring only few seconds of computations on a standard laptop.

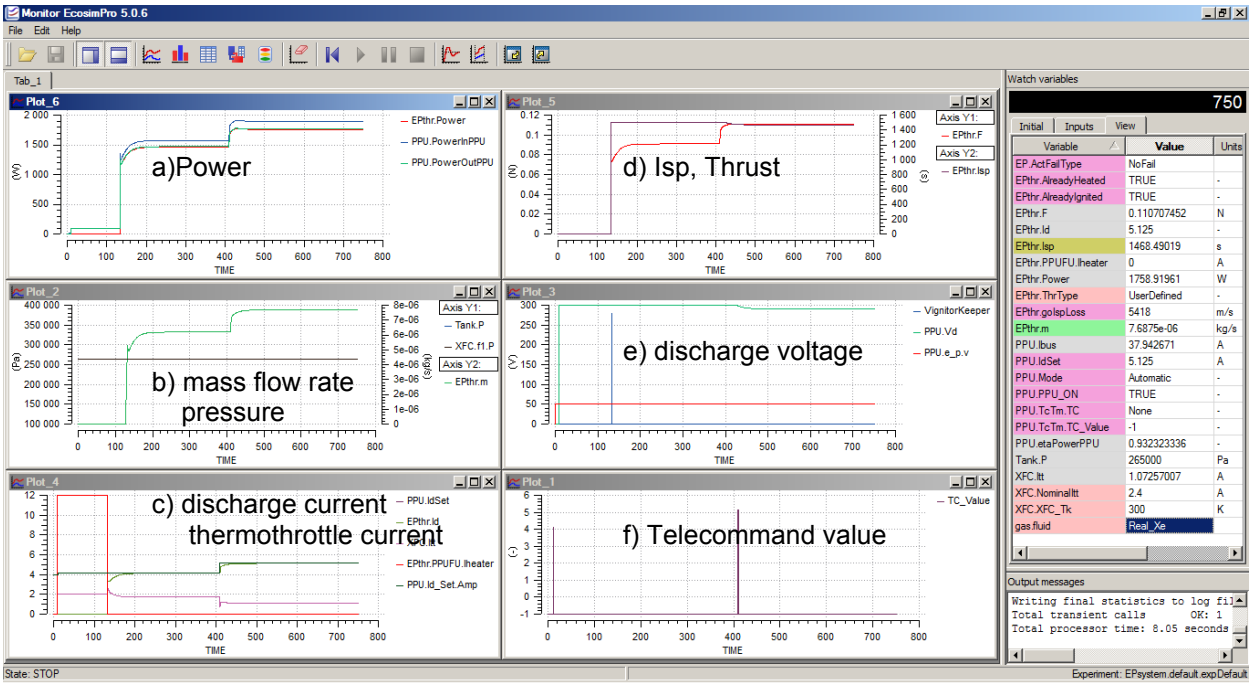


Fig. 9 Reference case of EP system: simulation results with change of thruster setting at time 410s

XI. Complete operational system of Electric Propulsion System

In order to show the capabilities of the ESPSS library with the features gained by the use of the EP Library, a complete operational system of EP system has been set up: the xenon system is simulated by a much more realistic system composed of two tanks (with thermal control) with tees, valves and pressure regulation and thermal control and with a final plenum volume before conducting the xenon to the two EP systems (EP1 and EP2).

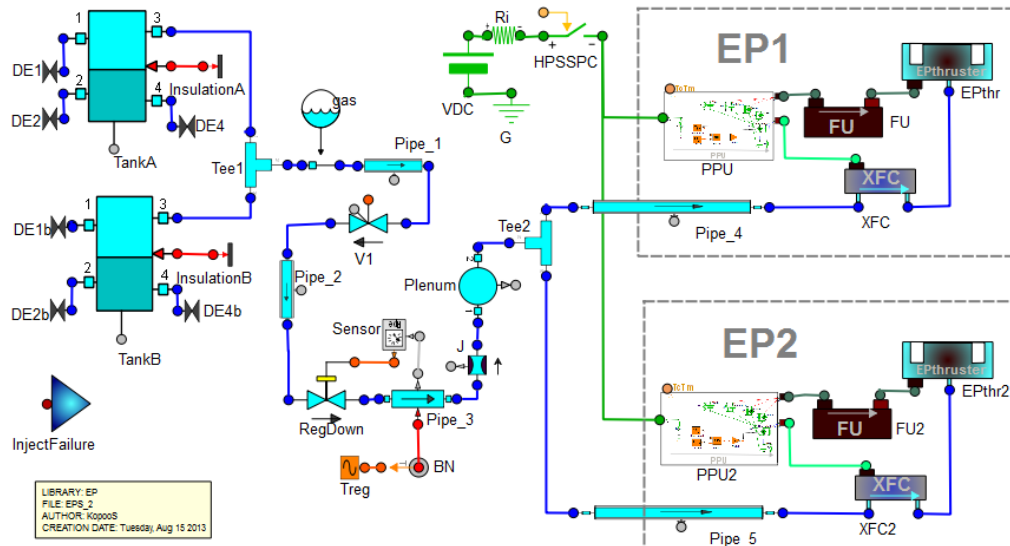


Fig. 10 Complete operational EP system

The same list of command as before is used, that is with a change of setting of the discharge current at time 410s. The simulation provide the output as expected in **Fig. 11** where at time 410 s, one can see the change of discharge current settings. As before, the change is not instantaneous, but some time is needed to reaches the steady state after the change has been requested, and because the model of pressure regulation is much more realistic than before, some tiny effects of the dynamic pressure regulation can be observed in the plot (b), but the overall picture is however quite similar to the previous reference case shown before.

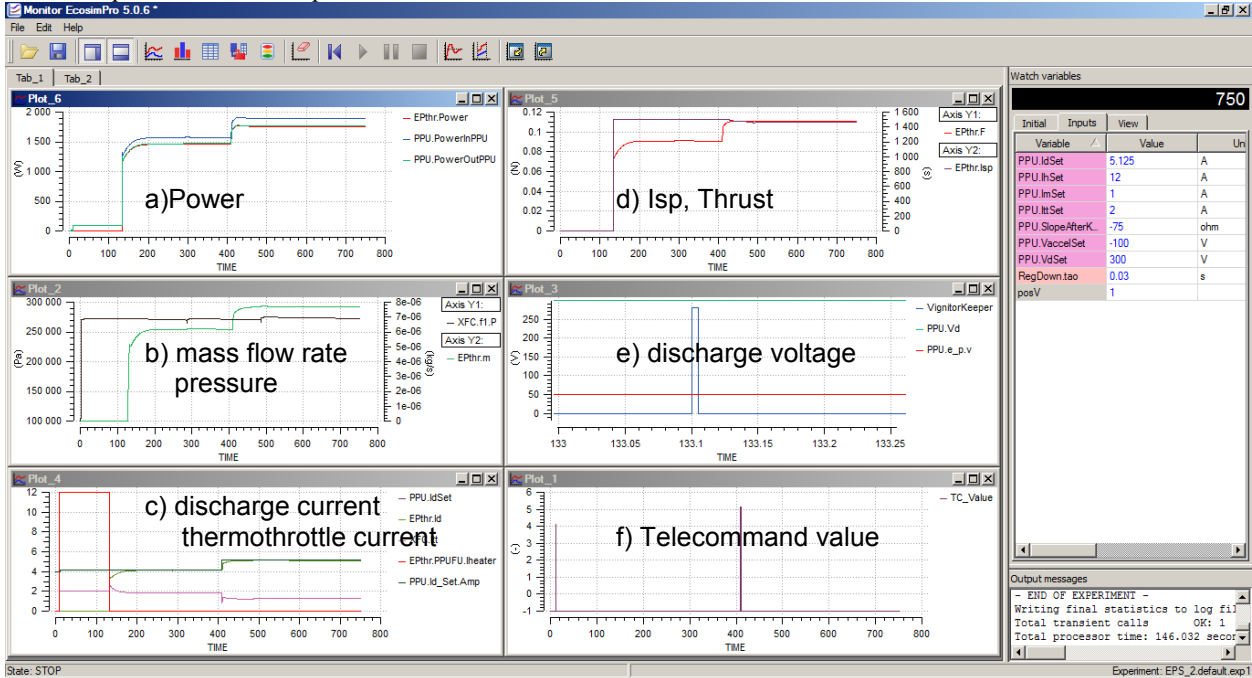


Fig. 11 Complete operational EP system: simulation results with change of thruster setting at time 410s

XII. Conclusion

Many features of the European Space Propulsion System Simulation (ESPSS) libraries with the new components of the Electric Propulsion (EP) library have been described in details.

The components of EP library allow simulating the operations needed to be performed for using the electric propulsion in space as well as in ground laboratories.

In addition two simulations models have been described in order to show the reference case simulation of an EP system and to show an extension of the system simulation to a complete EP system thanks to the features available included in the propulsion library ESPSS.

The users of ESPSS will be able to enhance the models included in the EP library to fit with their own characteristics of thruster or other devices in order to deliver to their customer operational models.

One shall add that the tool EcosimPro® provides in its environment a full capability for connections between the models and simulations developed within this software and other ones, from the generation of C++ code itself, reusable in other applications, to the interface with Microsoft environments (Microsoft Excel© and Microsoft Visual Basic©) and Matlab simulink©. This flexibility can be very appreciated for using operationally the models designed with ESPSS.

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