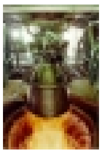

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Start up transient modelling of pressurised tank engine: AESTUS application

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INTRODUCTION

In the scope of V-142 recovery program, a simulation code for the Ariane 5 upper stage (EPS) with the AESTUS engine was performed at the CNES in order to study the start up transient. The aims of the model were to contribute to the comprehension of thermohydraulic and thermochemistry engine phenomena during the transient phase. The model is not able to predict high frequency instabilities appearance but it permit to better understand the implication and the interaction of the various physicals effects on the start up phase.

A storable propellant engine start-up transient is a complex phase who involves instationary hydraulic effect, two-phase flow, and the entire chamber phenomenon like injection, atomisation, vaporisation, mixing and chemical reaction.

MODEL

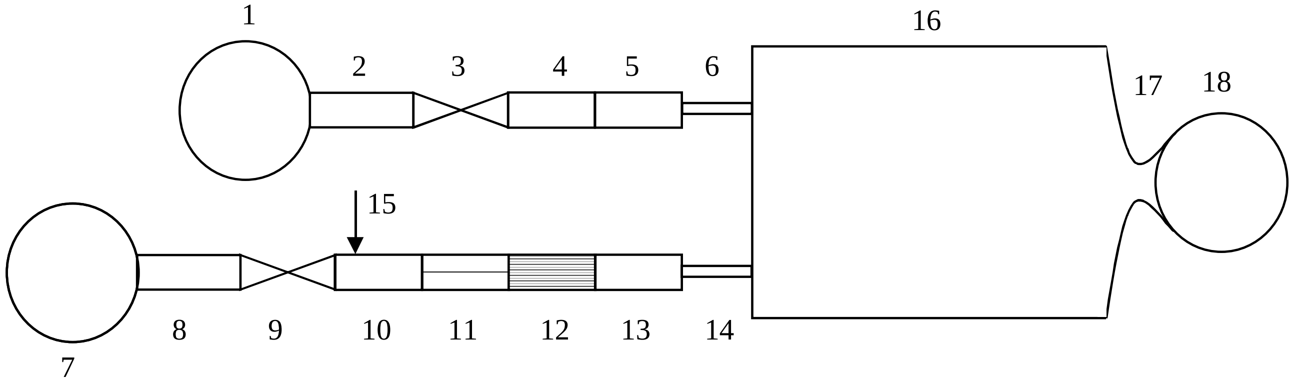
The simulator is a 0-D model who has been built by using complex process representation. It schematises the entire stage and test bench: from tanks to the exhaust nozzle and simulates all the transient phase from the valve opening until the quasi steady state condition in the combustion chamber. Each stage element that has a significant role in the process has been identified and separates (Figure 1). They have been regrouped in three subsystems:

- The oxidiser feed line
- The fuel feed line
- The combustion chamber

An elementary simulator represented by an ordinary differential equation system simulates each element. The various elements have been put together with respect to variable transported between two elementary simulators.

The simulator is initialised with both valves close. They isolate the fluids under pressure and the down stream vacuum. The opening sequence of the various valves (oxidiser, fuel, purge gas) is an entry of the simulator. The boundary conditions are:

- The tanks pressure and temperature
- The external pressure



N_2O_4 line

1. Tank
2. Line
3. Valve
4. Pipe
5. Dome
6. Injector

MMH line

7. Tank
8. Line
9. Valve
10. Pipe
11. Tore
12. Regenerative circuit
13. Dome
14. Injector
15. Purge gas injection

Combustion chamber

16. Chamber
17. Nozzle
18. Outside

Figure 1 : EPS simulator schematisation

The line between the tank and the valve is assumed to be continuously full of liquid and treat as a hydraulic line. We assume that acoustic effect does not take place in the line, so only inertia and resistance effect would be take into account. On the down stream part, the phenomena of the start up transient involve two phase fluids for example during the filing process of the feed lines. The feed line model does not simulate this two-phase flow. It considers the two phases but separately: a liquid column with a gaseous volume above (Figure 2):

- The liquid phase is treat as a hydraulic way, as already mention.
- The equation system of the gas phase is obtained by simplification of the mass, movement quantity and energy conservation, with perfect gas and constant specifics heats assumptions.

A mass transfer from liquid to gas is present to take into account the vaporisation. This process is assumed to take place until the vapour pressure is reached in the cavity.

The injectors are modelled by two different ways, it depend of the cavity up stream the injectors:

- If she is gaseous, they are treat as sonic nozzle with pressure drop
- If she is full of liquid, they are treat as a incompressible singular pressure drop

The mass flow trough the injectors can be compute in both way. The mass flow direction depends of the pressure difference between the dome and the chamber. This modelling permit to the simulator to take into accounts the entry of oxidiser in the fuel line during the transient du to the opening valve sequence.

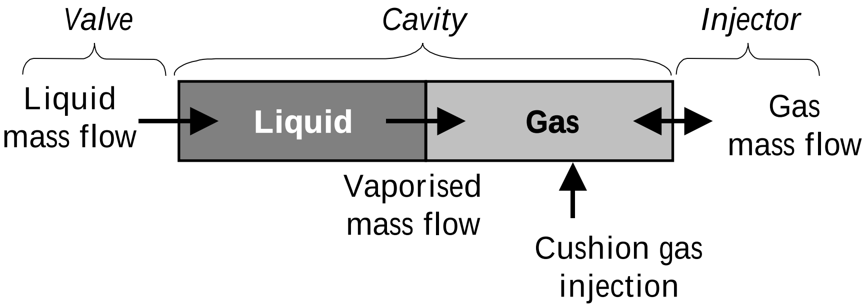


Figure 2 : Cavity model representation

To have more accuracy on ignition phenomena, a special attention on the combustion chamber modelling have been done with respect to the 0-D representation made for the simulator. The main drivers for ignition behaviour seem to be :

a) The propellant mass flows during pre-ignition and at ignition
b) The liquid atomisation, vaporisation and the finite rate kinetics
c) The accumulation of unburned propellant

To take into account these different points, the combustion chamber has been represented as show on the Figure 3. The two phases are treat separately in the combustion chamber. The propellant is injected in gas phase until the dome is full of liquid, afterwards is injected in liquid phase. Nevertheless, if the pressure in the combustion chamber is lower than the vapour pressure of the injected propellant, a part of liquid is injected in gas phase in order to represent the flash atomisation and the increase vaporisation associated [1]. This injection law is suppressed when the chamber pressure increase.

The liquid can accumulate in the chamber. If the temperature is low (not ignited), we assume that the residence time of droplet in the chamber is longer than the vaporisation time, so some droplets are ejected trough the exhaust nozzle, with the assumption that the droplets are homogeneously distribute in the chamber. A vaporisation law depending of the chamber temperature realises the transfer from liquid to gas phase. The law constants are parameter of the model but the ratio of theme has been deduced from [2].

The combustion chamber is considered as a homogeneous volume where a gas phase two-reaction Arrhenius model represents the combustion. The very simple scheme has been deduced from the global chemical scheme [3] with having regard to ignition delay and final pressure obtained.

The mass flow trough the exhaust nozzle is calculated with a sonic nozzle law without pressure drop.

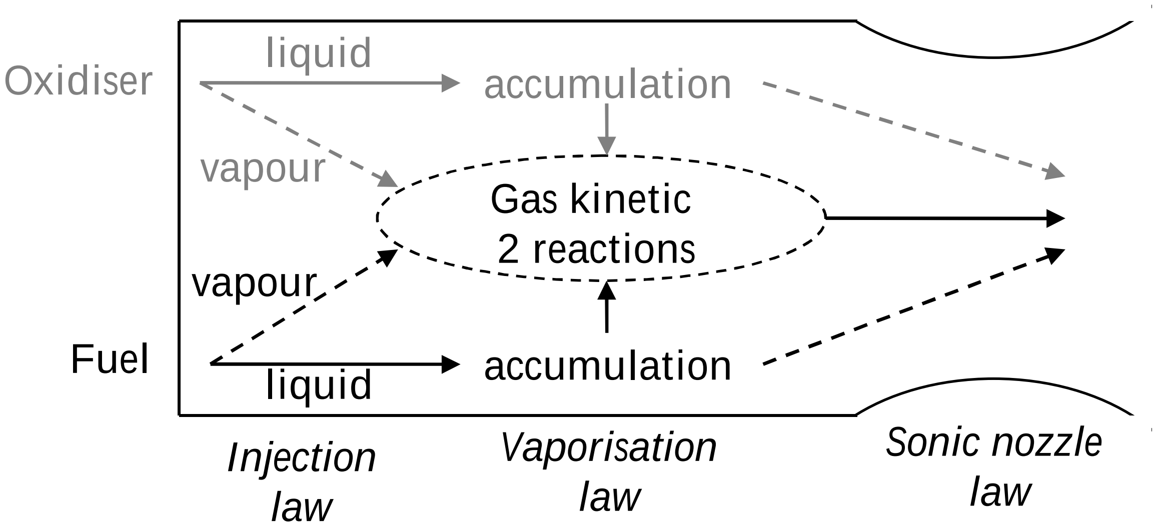


Figure 3 : AESTUS chamber model representation

(The arrows in dash line are ways who are suppressed when the pressure and temperature increase in the combustion chamber)

SOLVER

The simulator is partially composed of an ordinary differential equations system. This system is solved with LSODA or LSODES developed in Livermore [4]. Nevertheless the modelling performed generates discontinuities. They are mainly imposed by the passage from gas to liquid modelling. In order to treat this kind of event, an integration strategy independent from the solver as been applied. This strategy was earlier developed for the software SIMPA [5], [6]. The solver manages alone the time step and using the integration strategy, it permits to perform a simulation of a transient (0.5-second) in less than one minute on a classical workstation.

RESULTS

The results of the simulator have been compared to test bench measurements. The figures of theses paragraph are related to high altitude simulation with nominal configuration.

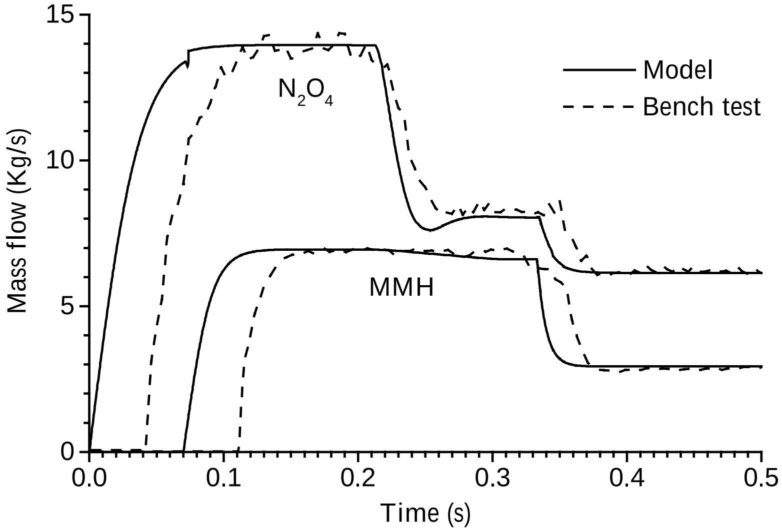


Figure 4 : Propellant mass flow evolution

The times shifts, observed between the simulator and the measurement on the beginning of the transient, are attributed to inertia of flow meter and the validity of the measurement during transient. Nevertheless, the mass flow during steady state are well represented by the simulator, these permit to suppose that the resistance effects are obtained. In the same way, increase and decrease of mass flow indicated that inertia effects are obtained.

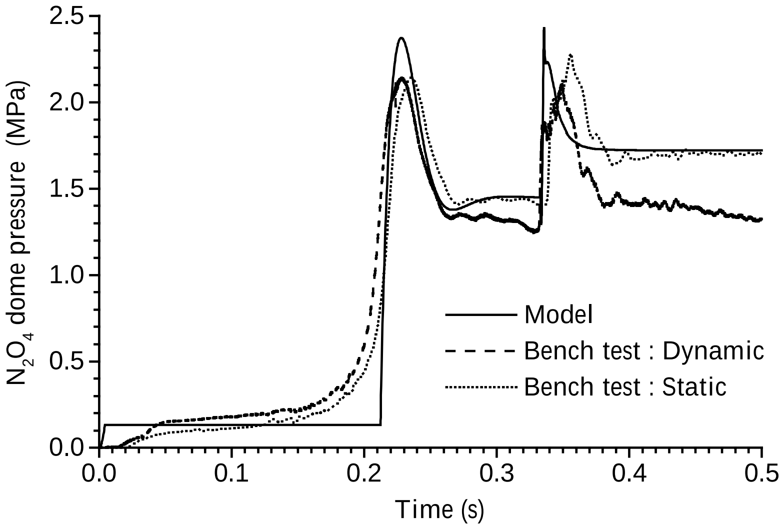


Figure 5 : Oxidiser dome pressure evolution

The pressure evolution in the oxidiser dome is well represented after it's filling. The first instants are not well represented. This is du to the too simple two phase modelling perform during this period. The missing of two phase mixing is prejudicial to this period simulation. The over pressure observe on the first spike is also probably du to the first phase modelling who induce a lower pressure just before the filling of the dome.

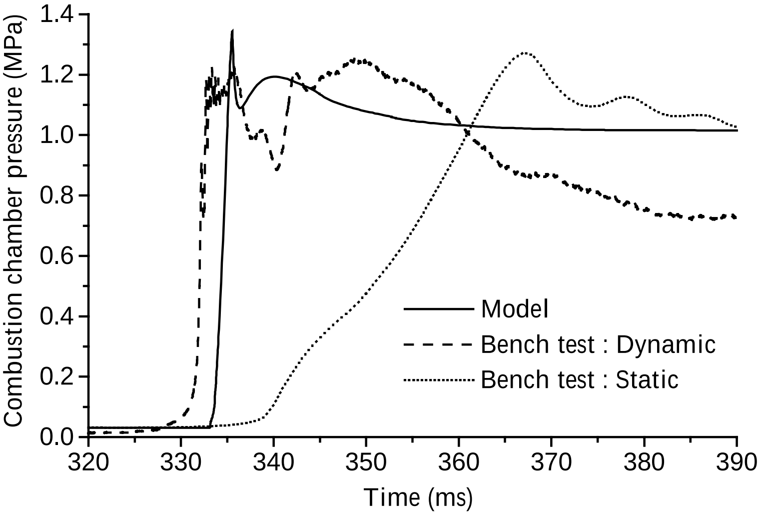


Figure 6 : Combustion chamber pressure evolution

The simulator permit to well represents the combustion chamber pressure evolution. The spike pressure value, the slope of the pressure during ignition and the pressure during steady state are obtained. Nevertheless some phenomena are not represented in this evolution. It is clear that all the complexity of the ignition transient can not be take into account in a global modelling. A more detail simulation of the combustion chamber should permit to obtain more accuracy on this evolution and a good representation of secondary order phenomena.

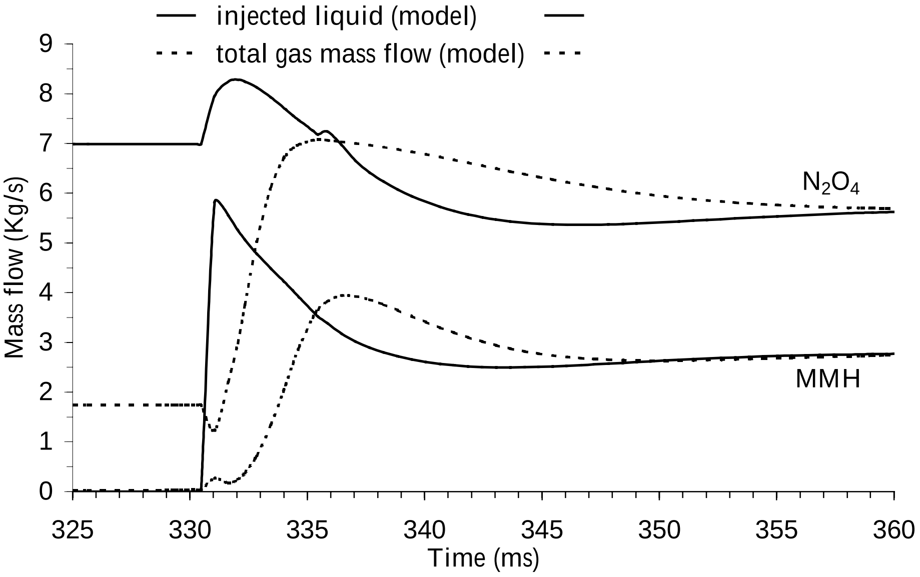


Figure 7 : Chamber mass flow evolution

The simulator permits to obtain complementary information with regard to test. For instance, the liquid mass accumulated in the combustion chamber that is a predominant parameter for the pressure spike observed during ignition. This accumulated mass can be calculated by made the difference between the liquid mass injected in the combustion chamber and the liquid mass vaporised.

Simulator tools have been developed in Scilab [7] in order to perform parametric studies. The parameter engine influences in regard to pressure peak and pressure slope have been obtained.

In order to obtain more accuracy on the simulator validation, it has been applied to a small altitude control engine ACS [8]. This engine operates with the same propellant and has a configuration that permit to only made minor modification in order to perform calculation. The engine transient sequences were also very close.

CONCLUSION

The simulator permit to represent the transient start up of liquid propellant and pressurised tank engine. It was mainly developed for AESTUS engine. Several hypotheses have been made in regard to observation of test result. To complete the validation is has been applied to an engine with similar architecture: ACS.

The modelling, who has been performed with a system approach, has represented with good agreement the measurement made during test of start up transient of those engine. It permits to better understanding of parameter influence on the start up characteristic.

Nevertheless it appears that the simple modelling of several processes do not permit to well represent all the phenomena. The two main physical process who modelling need to be improve, have been identified:
- the two phase flow in engine feed line and cavities
- the two phase liquid combustion in the chamber

Some modification could be introduced in the simulator on those points. For example, a two-phase flow modelling in the feed line and in cavities would permit to better represent the filling of the dome. In the same way, a combustion model with droplet tracking like Lagrangian approach would give better phenomena representation in the combustion chamber. Elementary specific test or more detail local modelling could sustain those improvements.

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