Formulation of a mechanically improved paraffin fuel

Sounding rocket application

Due to the high development costs of conventional propulsion systems and launchers, space access was limited to multinational companies and state institutions.

Since numerous private and academic initiatives (see below) have recently appeared on suborbital flights or on the nanosatellite launch market, hybrid propulsion is seriously considered as a safe and low cost operability solution.

(<u>Private works</u>: SpaceX, SpaceDev, Scaled Composites, Armadillo Aerospace, Xcor Aerospace … <u>Academic works</u>: Stanford, Purdue, Kyushu …).

However this propulsion concept still needs to overcome a few problems, such as low frequency instabilities and poor combustion efficiency.

At the time of writing, a lot of work has already proved that the increasing regression rate of the fuel is the key to stable and efficient rocket motor designs. This can be achieved by using liquefying fuel.

During combustion, a thin and hydrodynamically unstable liquid layer is formed above a solid fuel surface and small droplets are entrained in an oxidized flow, increasing effective heat-exchange surface and mass transfer.

However, liquefying fuels, such as paraffin wax, do not have proper mechanical properties allowing the grain to withstand the stress loads of a launch (acceleration combined to pressurization and radial expansion of the combustion chamber).

Moreover, unlike cross-linking materials (like solid propellant) such thermoplastic materials exhibit a strong variation of density between the liquid and solid phase. This makes the fabrication process a real challenge.

This paper presents efforts to formulate and cast heterogeneous fuels that are composed of micrometric aluminium powder and mechanical improved paraffin wax.

Because no mechanical requirement exists to ensure the grain mechanical integrity during the launch, finite element calculations are used to produced them: considering linear elasticity and incompressible response of the fuel (small deformations, no plasticity and no damage) and considering that the launch is well represented by acceleration and pressure loads, the maximum stress obtained in the mesh gives us the yield strength that the paraffin wax needs in order not to break.

Then, new formulations of aluminized paraffin wax are tested to satisfy this mechanical criterion.

Uniaxial tensile tests are conduced on each formulation to obtain typical mechanical parameters (Young modulus, Poisson ratio, yield strength).

Four additive families are explored separately: synthetic and metallic fibers, polyethylene waxes, microcrystalline waxes, and carboxylic acids (stearin). All trying to enhance the mechanical network without affecting the ballistical performances.

Casting equally plays a fundamental role in the fuel grain mechanical integrity and is now responsible for strong geometrical defects (dissymmetry, holes and cracks).

Our detailed investigations clearly show two major parameters to control the process: the casting temperature and the thermal exchange between the mould and its environment.

An affordable and repeatable way to cast any kind of largescale aluminized paraffin wax grain is now developed.

Finally, several labscale grains (150 mm in external diameter, 40 mm for the internal diameter, 500 mm in length) made from original and improved paraffin waxes are produced and put into launch conditions in order to observe the benefits our new formulations.

All this work, including simulation, formulation and casting, is conducted by students from the aerospace engineering school ELISA (Saint-Quentin, France) for the PERSEUS project, with financial and technical supports from CNES, ONERA, AJSEP and Planete Sciences.