EUCASS 2009

July 6-9 th, Palais des Congrés, Versaille, France

REALISATION OF THE FUSEX HYBRID ENGINE: DEVELOPMENT, TESTS: THE FIRST SUCCESS IN FLIGHT.

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Keywords: hybrid propulsion, experimental set up, polyethylene – nitrous oxide

Nomenclature

Ax	= longitudinal acceleration (g)
Ay, Az	= lateral acceleration (g)
Isp	= Specific impulse (s)
0/F	= oxidizer to fuel ratio
N_2O	= Nitrous oxyde
PE	= Polyethylene
$\overset{0}{m}_{fuel}$	= mass flow rate fuel (kg/s)
$\overset{0}{m}_{ox}$	= mass flow rate oxidizer (kg/s)
m_{total}	= total mass flow rate (kg/s)
P_c	= chamber pressure (MPa)
P_{ing}	= igniter pressure (MPa)
P_{ox}	= Oxidizer pressure tank (Mpa)
r	= regression rate (m/s)
a	= regression rate coefficient
n	= regression rate exponent
G_{ox}	= average oxidizer mass flux rate (kg/m^{2}s)
A_{porti}	= initial area all cylindrical port (16)
$A_{port\ f}$	= final area cylindrical port

In the perspective of the replacement of the solid propellant rocket engine destined for "Planète Sciences", a juvenile space club, CNES has asked ONERA to design the prototype of a new motor capable of achieving similar performances, table 1. The engine, named FUSEX, has to have a mean thrust of 800 N and an impulsion of 1500 N.s.

	SOLID MOTOR	HYBRID MOTOR
Initial Thrust	850 N	850 N
Total Impulse	2060 Ns	1500 Ns
Diameter	90 mm	120 mm
Length	282 mm	600 mm
Mass	3,7 kg	~ 6 kg

Table 1: Specifiction FUSEX (Experimental Rocket)

Security objectives favoured the selection of a hybrid engine. On of the reasons is that hybrid engines are inert up until the tank filling oxidiser and hence do not forbid the presence of a team of youngsters from the moment the motor is inserted in the rocket body.

The choice of the propellant (fuel: PE polyethylene – oxidizer: N_2O nitrous oxide) was based on, both, its excellent performances as a function oxidizer to fuel ratio (O/F), variable during operation, and the auto-pressurisation of nitrous oxide, avoiding a pressurising system. A thermochemistry computer code (COPPELIA, ONERA code) provided the specific impulse (Isp) and the optimun O/F ratio based on our oxidizer, nitrous oxide (N_20) and fuel polyethylene (PE) Figure 1 shows the result of varying the ratios Vs Isp. We used this this graph to optain optimun O/F which would yield the highest possible Isp during the firing test

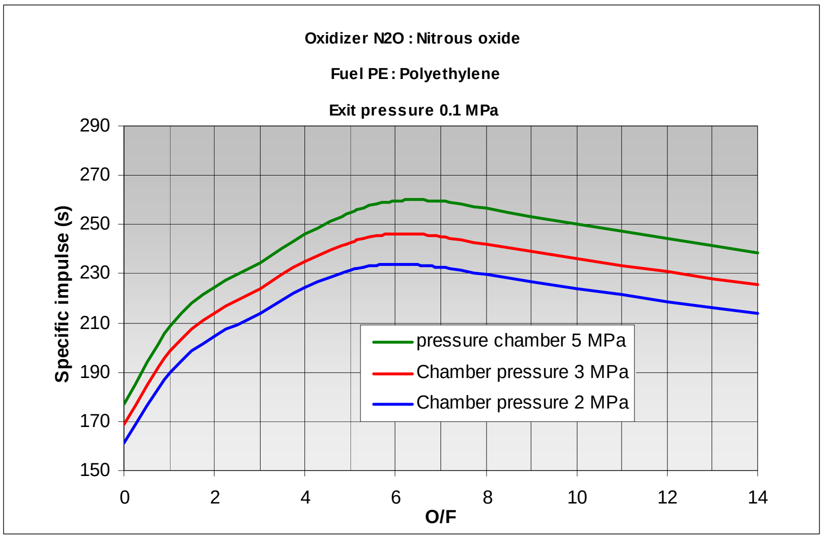


Figure 1: Specific impulse vs O/F

. The initial inner port diameter and the lenght was determined in fonction mass flux rate in each cylindrical port. We then used equation 1 to calculate $G_{ox\ avrg}$:

$$G_{oxavrg} = \frac{\dot{m}_{ox}}{\left(A_{porti} + A_{portf}\right)^{1/2}} \qquad (1)$$

The fuel regression rate has been found to correlate with the mass fluix in the combustion port. In many cases one could relate the fuel regression rate to the oxidizer mass flux G_{ox} by an empirical correlation (2):

$$\dot{r} = aG_{ox}^{n} \qquad (2)$$

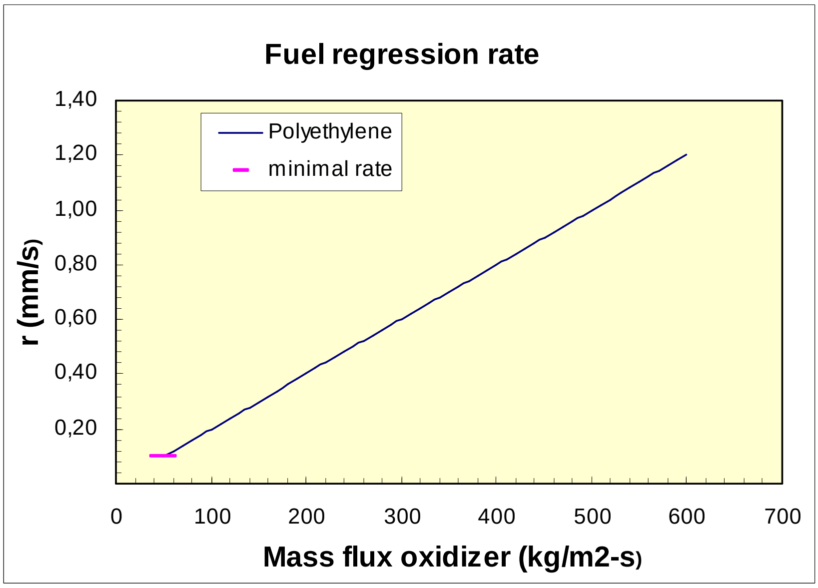


Figure 2: Polyethylene Regression rate vs. Oxidizer Port Mass Flux

A typical regression rate expression for an N_2O/PE system (3):

$$\overset{0}{r} = 2,0 * 10^{-6} G_{ox}^{0,8} \qquad (3)$$

where $\overset{0}{\mathbf{r}}$ is in m/s and Gox is in Kg/m^2 s is used in the calculation in OD Code simulation. The properties of N_2O:Fuel are presented in Table 2:

Fuel	PE	
ρ_{fuel} =	950	[kg/m3]
regression rate	a =	2,00E-06
r [m/s]	b =	0,80
Minimal rate =	0,0001	[m/s]

oxidizer	N_20	
ρ_{ox} =	950	[kg/m3]

Table 2 Fuel, oxidizer Properties

The launcher design, outlined since a couple of years by a group of ENSAE students in the framework of a research initiation project, was picked up by ONERA. The development and construction have been outsourced to COMAT, an aerospace R&D firm in Toulouse (cf. Figures 3 and 4)

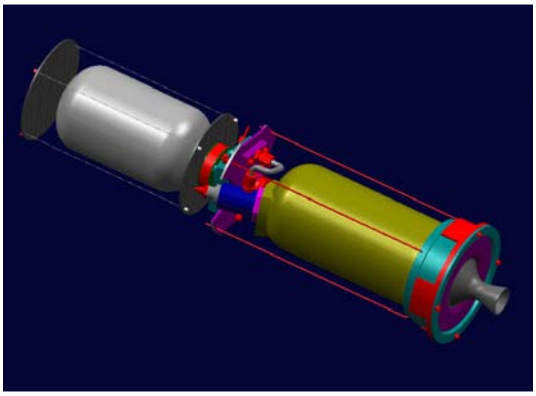


Figure 3: Overview of the FUSEX engine

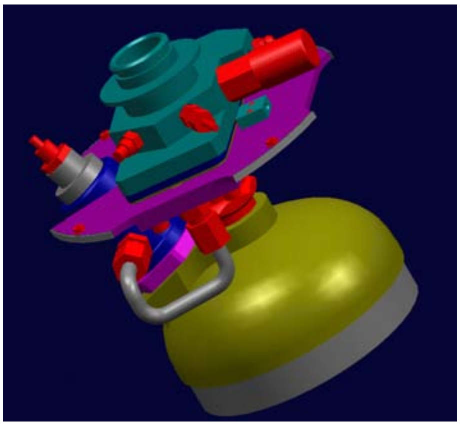
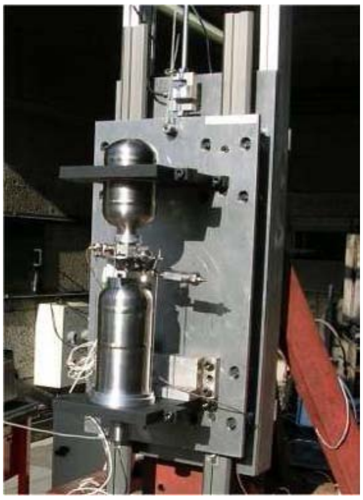


Figure 4: Overview of the Fusex - pyrotechnic valve

The main goal of this project was to improve the motor in general and the charge in particular in order to reduce the unburned leftovers. An innovative, revolver like, system to load the combustible also, eventually, allows for the reloading of the engine after a launch when the rocket has been recaptured.

In order to respect the mass criteria, imposed by CNES (empty mass inferior to 6 kg), the motor is essentially build from titanium (welded Ta6V). This has resulted in several delivery and manufacturing problems that all have been resolved. The engine has a final mass of 5.5 kg and can hold 0.6 to 0.7 kg of N_2O. The finished engine has been handed over to ONERA at the beginning june of 2007 (cf Figure 5).



The only pyrotechnical element of the motor is the fuse. It consists of 2 grams of solid propellant used to initiate the decomposition of the polyethylene and the opening of the valve that pilots the injection of the nitrous oxide. The valve/fuse coupled system has been designed and validated in order to assure a viable delay as to allow for the hot gasses to sufficiently degrade the polyethylene before the N_2O hits the surface. The operational envelope of the valve has been found to be limited by a minimal temperature of 15 °C at pressure tank of 70 bar.

Figure 5: The experimental set up before the firing

During the first test of the engine (figures 6 and 7), an over-consumption of the polyethylene, superior to prior estimations, has observed. Never the less, this test has permitted to verify the fuse-valve system, the engine ignition (found to be nominal) and overall functioning with a performance level in agreement with the specifications during the 1.2 seconds of operation. Thrust has been found to be around 120 DaN with a chamber pressure between 30 and 36 bar, suffering from instability amplitudes inferior to those observed in previous tests with similar configurations.

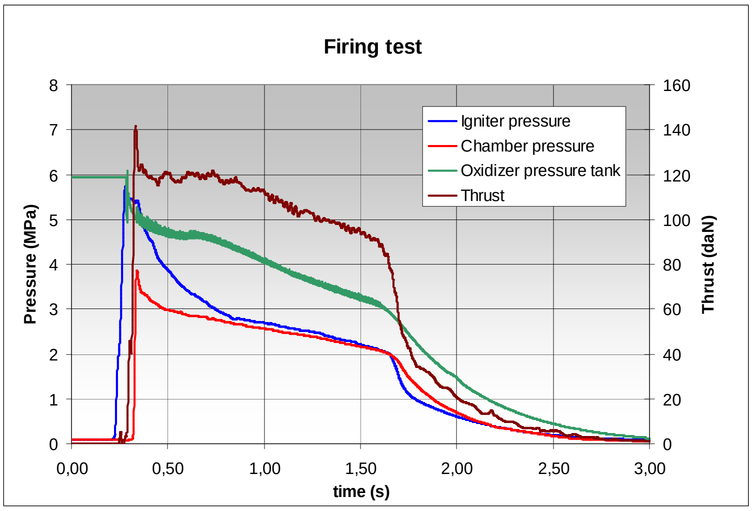


Figure6: Measurements on the engine during a firing test

Figure 7: The FUSEX engine ignited

Depending on CNES will to finalise, this project will proceed in order to be launched in 2007 either at "La Courtine" after the necessary modification having successfully been tested. This operation is part of the PERSEUS program [1]. PERSEUS has for a goal the realisation of a launcher capable of putting 10 kg satellites in a 250 km orbit Hybrid propulsion is planned to propel the first and second stage. FUSEX is the first demonstrator of such a propulsion system Fusex engine.

 Le fuel grain propellant has a diameter 94 mm and the length 155 mm. It has 16 cylindrical ports with the initial radius 2.4 mm at the head end and conical at the half end. The hope are on two circonferential diameter for incriseace the thick securities, figure 8.

Figure 8 : Fuel propelant grain before firing (head end and half end)

Figure 9: The first success in flight FH 01

In the 1st august 2007, at La Courtines, the Fusex engine was tested in flight with success (figure 9), the performances are in conformity with the test of qualification carried out in June 2007 at the Propulsion Laboratory of ONERA. The engine was integrated in FH 01 Rocket manufactured by Planete Sciences.

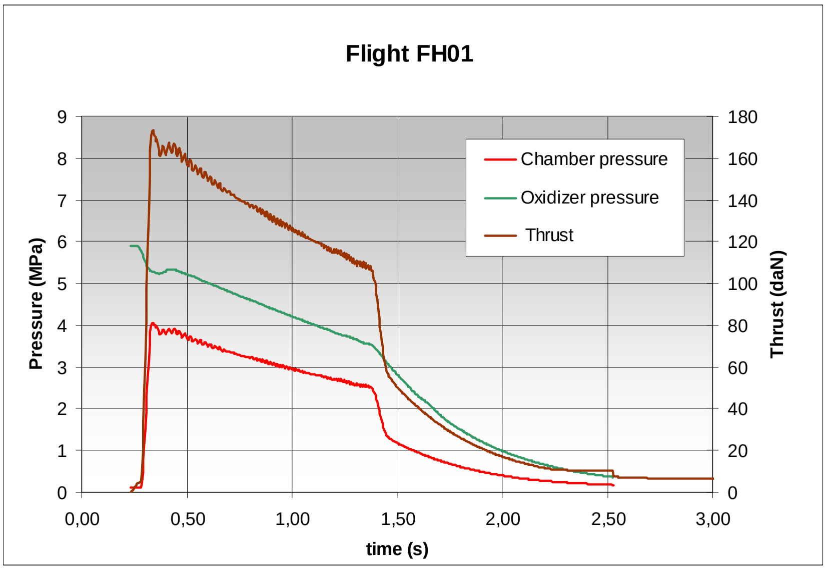


Figure 10: All parameters during the first flight

The operating time was 1,2 s with a thrust of 120 daN. The instrumentation of edge (pressure chamber, pressure tank oxidizer, temperature tank figure 8, and acceleration on the triaxial accelerometer axes ‘Ax, Ay, Az) (Figure 10) made it possible to restore the parameters of flight (Figure 11), during the flight of one of duration of 40 s, the rocket culminated at an altitude approximately 600 m, figure 12.

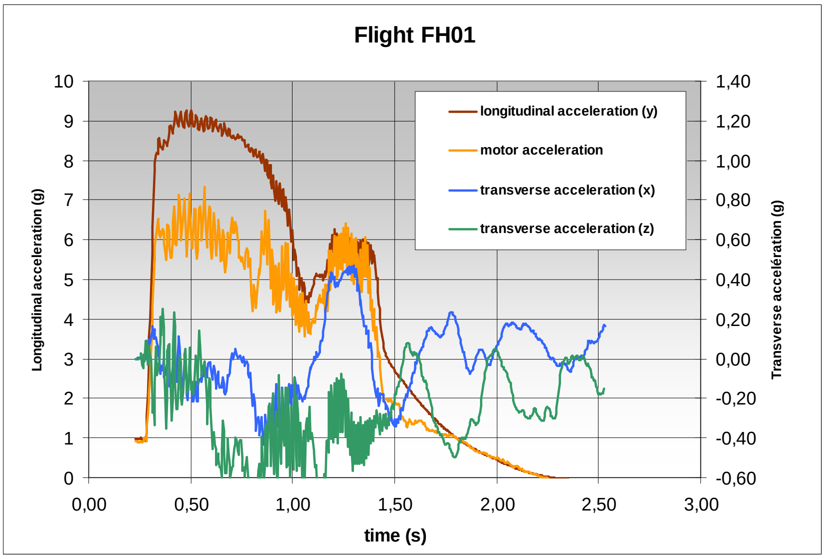


Figure 11: Accelerometers parameters during the first flight

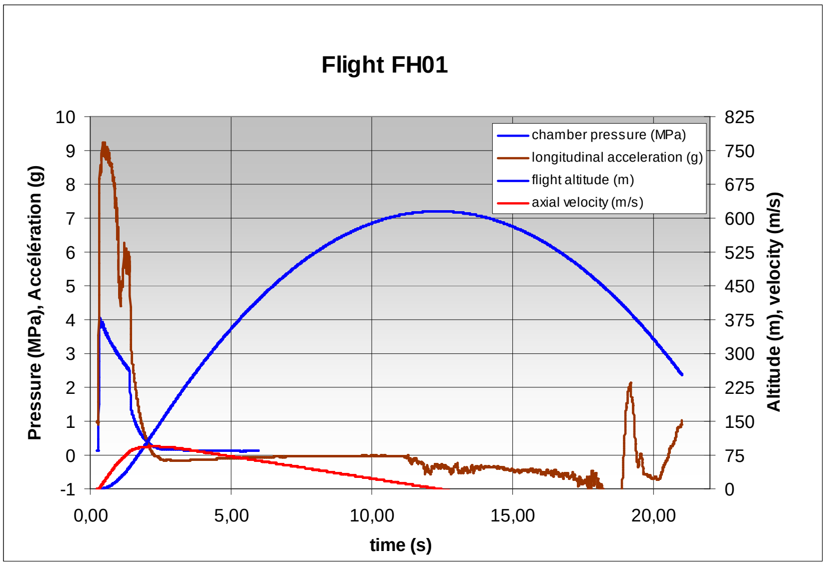


Figure 12: Flight parameters

All Performance can be viewed, compared by the initial Solid rocket Motor in table 3:

	Main Goal	Test firing	Flight FH01
Initial Thrust (N)	850	1 260	1650
Total impulse (N.s)	1 500	1 636	1609
Burning Time (s)	2	1,4	1,1
Oxidizer to fuel ratio		4,2	4
Specific impulse (s)		216	221

Table 3: performance flight FH01

In the 1st august 2009, at La Courtines, two Fusex engine was tested in flight with success (figure 9) : one with polyethylene, FH02, in the same configuration that FH01 and one with a new fuel more powerful : parrafins; FH02[2, 3].

Acknowlegments
This study has been supported by the french Space agency CNES and by ONERA. The authors are grateful to Franc Julien and Badr Rmil (Planete-Sciences) for their precious contribution.

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