Applications of Micro System Technology (MST) in propulsion, activities at the TNO Prins Maurits Laboratory

Sanders, H.M., Rijkeboer, M., Hogedoorn, A.T., van Vliet, L.D., Weterings F.P., Keizers, H.L.J.
TNO Prins Maurits Laboratory, P.O. Box 45, 2280 AA, Rijswijk, The Netherlands

Abstract

MST offers the opportunity to make propulsion systems smaller, more effective and at lower costs. At the TNO Prins Maurits Laboratory (TNO-PML) several activities are underway to apply MST in both macro and micro propulsion systems.

TNO-PML is active in three areas. It has developed software for analyses of injection, mixing, combustion and heat transfer and has established the conditions under which these tools can be used for micro rocket motors. At present, TNO-PML is part of a European Consortium that aims to develop a micro bi-propellant rocket motor.
Secondly TNO-PML is working on micro solid propellant cool gas generators. These generators produce pure nitrogen, oxygen, hydrogen or methane that can be used among other applications as propellants for propulsion systems. A demonstration system has been developed and has shown that these generators can be miniaturized to a volume of 1 cm^3 for use in small propulsion systems.
Thirdly, together with other TNO institutes TNO-PML is developing a demonstration micro sensor system. In this system, different sensors, intelligence and wireless communication and power supply are integrated in a volume of 1 cm^3. Applications in the space field are performance, and health monitoring sensors in both solid and liquid propulsion systems. Space applications of these sensors will be further studied within the Dutch MicroNed program.

Nomenclature

CFD	Computer Fluid Dynamics
ESA	European Space Agency
MST	Micro Systems Technology
NIVR	Nationaal Instituut Voor Ruimtevaart (Dutch National Space Agency)
PML	Prins Maurits Laboratory
TNO	Netherlands Organisation for Applied Scientific Research
TPD	Technisch Physische Dienst (Technical Physical Services)

1 Introduction

The Prins Maurits Laboratory is part of TNO (organisation for applied scientific research) in the Netherlands. Its space activities are centred around the development of new propellants, gas generators, igniters, hot structures and small propulsion systems. The application MST in propulsion is part of the last group. PML focuses on improving systems by applying MEMS and does this in co-operation with different partners.

The main areas of MST work at TNO-PML are the analysis of micro combustion and heat transfer, the development of micro gas generators and the use of microsensors in health and lifetime monitoring. These topics will be discussed in the remainder of this paper.

2 Analysis of micro combustion and heat transfer

TNO-PML has performed combustion and heat transfer analyses for different national and ESA programmes, among which are the Vinci igniter program and small hydrogen and oxygen thrusters.

In the framework of the small thruster program, these models have been validated using a combination of CFD (in cooperation with TNO-TPD) and actual test data. These yielded good results for combustion chambers with a diameter of a few centimetres.

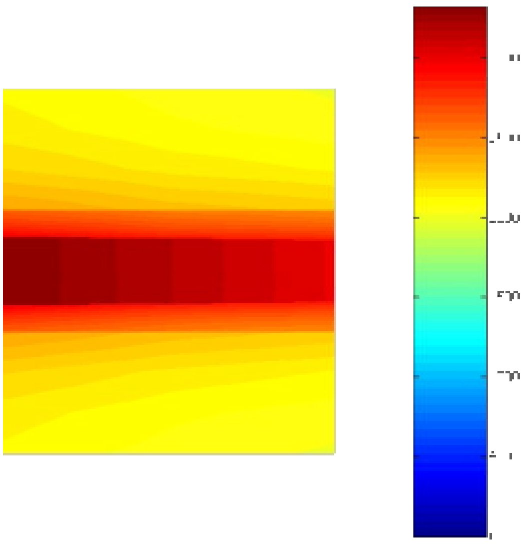

Figure 1: Temperature profile for H_2 - O_2 micro thruster after 2 seconds with a mixing ratio of 8. The chamber wall was assumed to be of SiC.

Furthermore, a tool has been developed to simulate the transient heating of a structure heated by hot gas. The effects of a cooling gas flow can also be simulated. This tool has been verified using experiments with a solid propellant rocket motor.
A study proposed to the Dutch National Space Agency (NIVR) explored the possibilities to use these CFD and thermal analyses tools for rocket motors with chamber diameters of a few millimetres. It was determined that, when used in the appropriate way and under certain conditions the analysis tools can also be used for micro engines. The physical processes remain the same, however, the ratio between the effects of the different processes changes. The performed analyses consist of analytical injection and mixing models, CFD combustion analyses and transient thermal analysis of a thruster with cooling.

These tools are applicable for combustion chamber analysis and for mono and bi-propellant micro engines design.

Figure 1 shows the results of the thermal analysis tool. This simulation has been performed within the NIVR study, were the micro combustion chamber shown in Figure 2 has been used with H_2 and O_2 gas and a H_2 cooling flow. The combustion chamber material is assumed to be SiC.

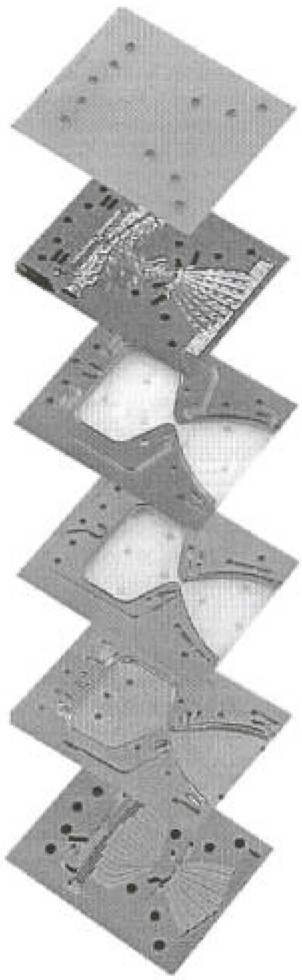

Figure 2: micro combustion chamber developed by MIT. Such chamber was used for the thermal calculations.

Figure 1 shows the temperature profile of a micro thrust chamber after 2 seconds of burning time. The propellant is H2-O2 gas, burned with a mixing ratio (oxidizer/fuel) of 8. In this case, no cooling was applied, therefore, very high temperatures of the surrounding material can be seen.

Ongoing projects

Among the projects currently carried out at TNO-PML is the bipropellant micro turbine engine development for ESA. This project is characterised by its staged approach, were first the technology is developed. After which a mono propellant engine and than a bipropellant turbo pump fed engine are developed.

This project is run together with Qinetiq (prime), SSTL and University of Upsala. TNO-PML performs combustion and heat transfer analysis, turbine analysis and support in system design.

Another project has been started together with MicroNed. This is a Dutch research programme were a micro satellite propulsion system will be designed.

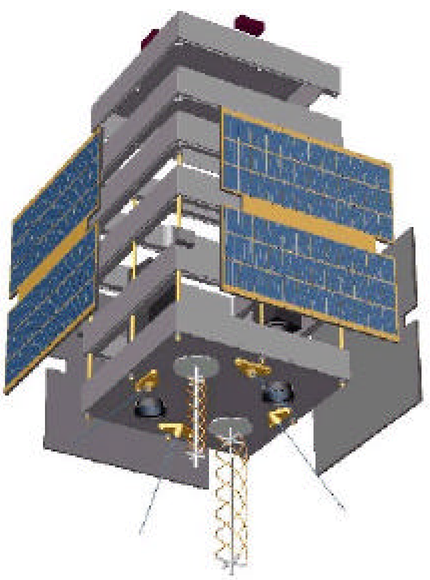

Figure 3: Potential application: the ALMASAT of Mechatronics (Austria) and the University of Bolonga

3 Micro Gas Generators

The gas generator activities have a long history at TNO-PML. In the eighties, the Vulcain Turbo Pump Starter (TPS) was developed. In this TPS a new propellant was used which produced relative cold gas. At the end of the nineties TNO-PML started the evaluation and development of the cool gas technology which is now the main development area.

These cool gas generators can deliver gas at room temperature. The gases which can be delivered are pure nitrogen gas (operational), oxygen, methane and hydrogen gas (development). Besides generation of cool and pure gas, the main advantages are the capability of long storage times due to the fact that gas generators are not pressurized. Furthermore, a wide range of desired mass flows and pressure ranges can be produced. Due to these unique characteristics, cool gas generators are very interesting for various space applications (Figure 3).

Recently the cool gas generators have been studied for the use in space applications under an ESA contract together with Bradford Engineering. In this study a variety of applications have been identified and a cold gas propulsion system for a small satellite was selected as a demonstrator of technology.

Description of the system

The application which was selected for demonstration of the cool gas generator technology was a cold nitrogen propellant tank refill system for Nanosat.

In this system 12 cool gas generators are attached to a single propellant tank. The system is shown in Figure 4, were the gas generators can be seen at the top and bottom of the system. The gas generators will be operated in sequence. The first gas generator fills the tank volume, when the gas has been used the next generator will be operated.

The benefit of this system is that within the available volume, 70 x 120 x 20 mm, and 10 bar pressure limit, about 3.5 times more gas can be stored compared to conventional storage. The system mass is only about 150 gram.

Figure 4: micro cool gas generator tank refill system

In Figure 5 the pressure inside the tank for a test with 4 cool gas generators is presented. After each test the gas is released through a solenoid valve. The small peaks directly after filling of the tank are related to compression of the gas inside the tank.

In the summer of 2003 a successful series of tests were conducted with this demonstrator, and the technology is now ready for application in small satellites. Other applications may be: inflatable structures, bi-prop systems, fuel cells etc.

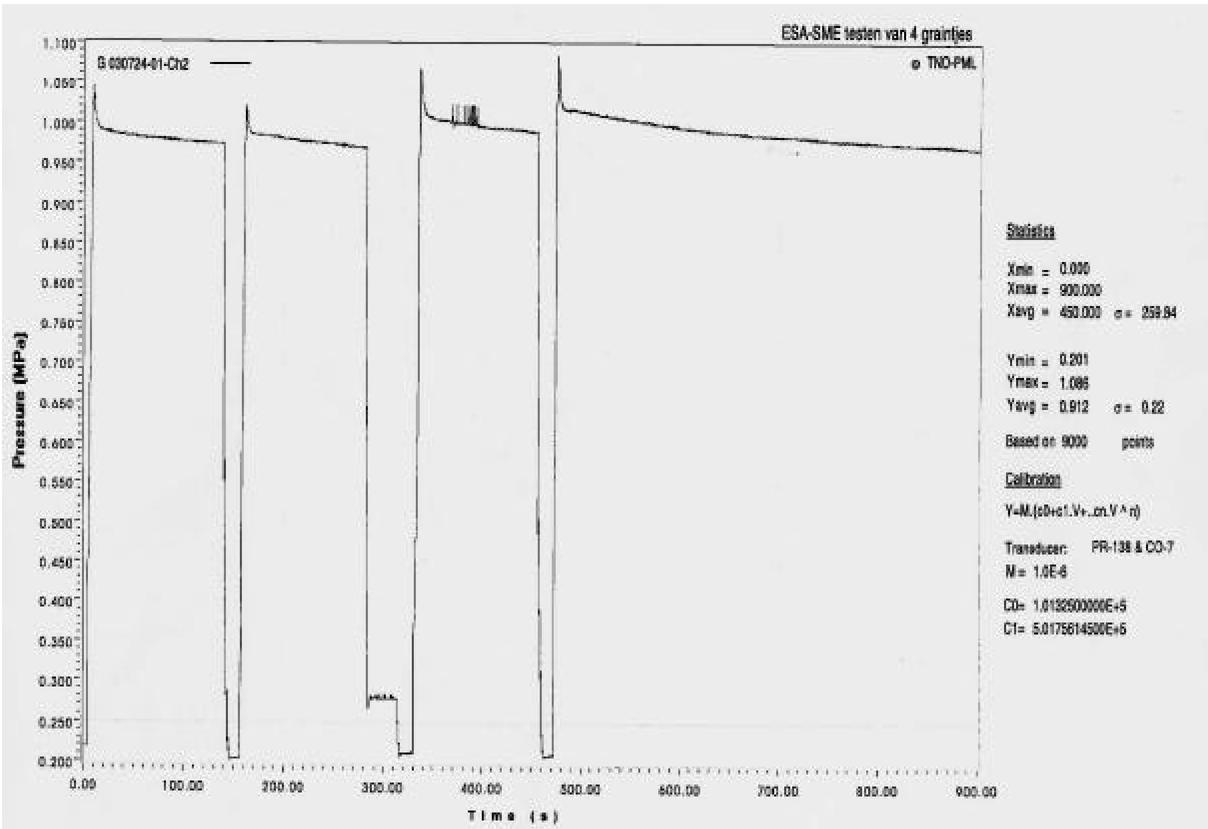

Figure 5: Pressure profile inside the tank of the cool gas generator refill system

4 <u>Microsensors</u>

In rocket propulsion, sensors are one of the applications which could benefit from miniaturizing. Sensors are necessary for the verification of the correct functioning of rocket motors. Miniaturization of these sensors can offer the following advantages:

- *Embedded sensors (in situ measurement)*: Microsensors can be placed inside a system, because of its small dimensions.
- *Distributed measurement*: Microsensors can form a more complete picture of the system than present day sensors by simultaneous measurement at different locations.
- *Wireless measurement*: Autonomous microsensors can be placed everywhere in the system, without wires.

The application areas where microsensors can offer advantages which are relevant for rocket technology:

- Lifetime monitoring of solid propellant rocket motors
- Health monitoring of igniters and thrusters (Figure 6).
- Measuring during testing (Figure 7)

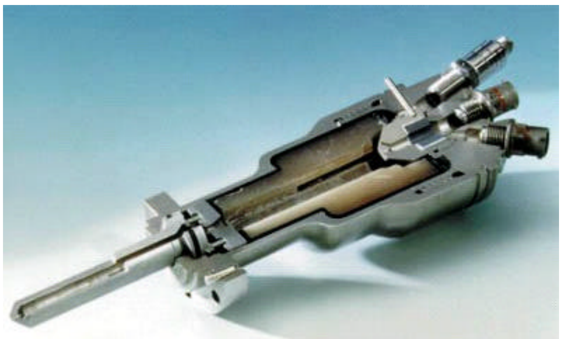

Figure 6: Vulcain igniter. For future igniters autonomous micro sensors can be used for health monitoring.

Figure 7: Rocket test stand, TNO-PML

TNO-PML has extensive experience with lifetime monitoring and prediction of solid propellant motors as well as testing small propulsion systems. In this framework TNO-PML is active on the development and testing of embedded sensor applications for health monitoring and life time prediction of missiles (Figure 8).

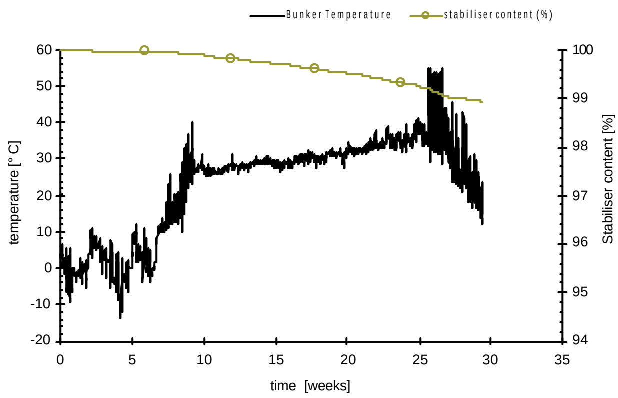

Figure 8: Example measured data

The graph shows the relation between the measured temperature of the missile and the amount of stabilizer in the propellant. The stabilizer is a good indication for the remaining life time of the missile. Furthermore, TNO-PML takes part in a broad TNO initiative for the development of autonomous sensor systems. The goal is to develop a MST sensor for lifetime monitoring of solid propellant rocket motors.

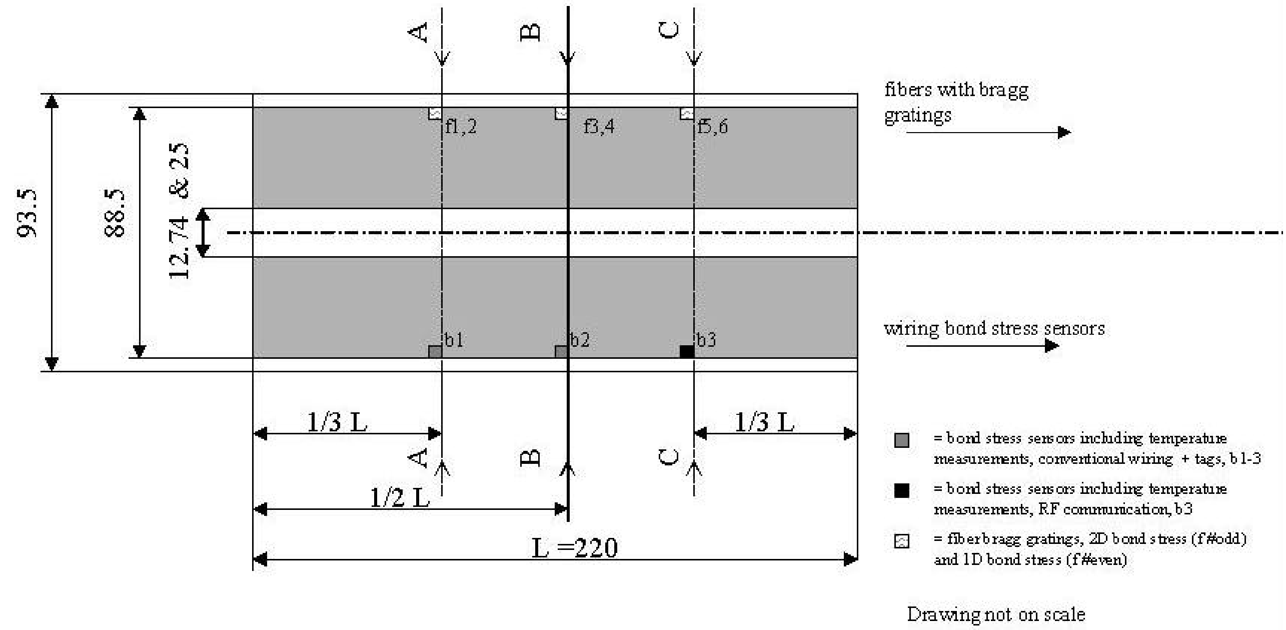

Figure 9: Schematic drawing of the demo (rocket motor) used for studying aging effects monitoring with various existing micro sensors

Present developments in embedded sensors

International developments are carried out into the use of embedded sensors for health monitoring of structures. Making use of data measured by embedded sensors, the quality of products can be monitored real time and the remaining lifetime of (complex) structures, including rocket motors, can be estimated.

In the framework of a TNO study, TNO-PML has performed material bond stress measurements, and measurements to determine alternations in the chemical composition of polymer materials.

A small solid rocket motor is used as a demonstrator (Figure 9 and Figure 10).
Used are commercial, of the shelf, embedded sensors which measure temperatures, internal mechanical stresses and chemical composition (stabilizer, decomposition products, O_2, RH, plasticizer level). The disadvantage of these sensors is that they still need wires that go through the casing.

Figure 10: Demo (rocket motor): stress sensor; O_2 sensor; RF-based temp sensor; Fibre Braggs (T, stress, strain)

The results from these tests are already very promising. The demonstrator rocket motor has been put through a cycling program, during which temperature and stress was measured. The first results show that by measuring stress and temperature inside the rocket motor, a life time prediction can be made.

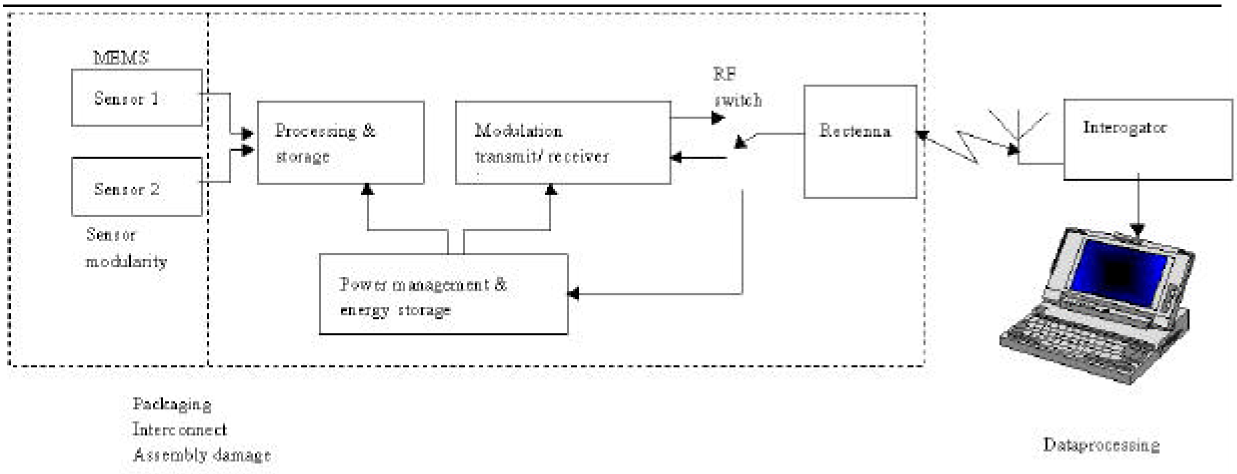

Figure 11: NIMST System concept of an autonomous wireless sensor which can be placed in a rocket motor for health monitoring

Autonomous sensor development (NIMST)

Together with other TNO institutes (Industrial Technology, Physics and Electronics Laboratory and Applied Physics laboratory) TNO-PML is developing demonstration micro sensor systems (NIMST). In one of these systems, different sensors, intelligence and wireless communication and power supply are integrated in a volume of 1 cm^3. The different sensors for the demonstrator are temperature and pressure (stress) sensors.

Applications in the space field are performance, health and life monitoring sensors in both solid and liquid propulsion systems. Space applications of these sensors will be further studied within the Dutch MicroNed program.

Testing of the 1 cubic cm system is planned for 2004. Within the NIMST project, PML is responsible for the application of the sensor in a rocket motor. To that end TNO-PML provides the specifications, supports the design and performs the testing of the micro sensor.

5 Conclusions

PML tries to develop new applications for MST in different areas of rocket technology where they can help to improve the performance of a system. This can be in the form of MST spin-off, where micro technology can improve an existing product (e.g. use of micro sensor systems for life and health monitoring) as well as spin-in where existing tools and procedures can be used for the design of MST components and systems (like thermal and CFD tools) or where technologies can be miniaturized to fit in a MST systems (e.g. the miniature gas generator).

When such an application has been identified and proven, PML tries to develop them further with existing and new partners.

Besides the ongoing developments that are reported here, a number of other future developments and possibilities are identified:

- Current sensor technology development for life monitoring of military missiles is directly applicable for solid rocket motors for space applications.
- Micro rocket motors using advanced HNF solid and mono propellants developed by PML. This would greatly increase the

performance of the micro propulsion system.

- Application of autonomous sensors in satellites. Wiring harnesses are becoming a limiting factor in small satellites. Wireless communication between subsystems in a small satellite might therefore lead to further integration.
- The use of miniature hot gas generators or cool gas generators that produce other gasses might be interesting for some small satellite applications.
- For future launchers health monitoring will be important in order to lower the operational costs. Autonomous microsensor systems may prove to be an enabling technology to create an efficient light weight and flexible health monitoring system

The developments listed above can start soon and it is certain that they will lead again to newer applications and developments. It is therefore expected that in due time MEMS will become an integral part of nearly all space systems.