# THRUSTER ORIENTATION MECHANISM

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## ABSTRACT

The French national space agency (CNES) initiated a project called STENTOR to develop a French technological satellite. ALCATEL is in charge of the development, qualification and delivery of two flight models of a Thruster Orientation Mechanism (TOM). The function of the TOM is to allow the in-orbit positioning of the plasmic motor thrust vector by ± 8 degrees rotation around two perpendicular axes. This mechanism is already used on the TELECOM satellite ASTRA 1K.

The main challenging design driver was to develop a mechanism structure allowing to fulfil the very stringent requirement associated to the plasmic motor strength : the TOM mechanical transfer function has to be lower than 1 between 200 Hz and 2000 Hz.

The paper will present the design of the TOM, its vibration test results, and its performances. The novelty feature of the mechanism will be highlighted : the sizing w.r.t. transfer function by tuning of eigenfrequencies associated with damping factor adjustment.

## 1. PURPOSE

At the opposite of the classical thruster, the plasmic motor thrust vector needs a bi-directional adjusting device mounted between the spacecraft structure and the plasmic motors.

For this reason, the TOM mobile plate, which supports the two plasmic motors (one being nominal, the other one being redundant), is fixed on a gimbals system which allows the mobile plate rotations around two perpendicular axes.

## MAIN SPECIFICATIONS

The main specifications which were the basis of the TOM design are detailed therein under :

### Thermal specification

The mobile plate shall have a surface greater than 8 dm² allowing the mounting of OSR.

### Angular range

Two different ranges of rotation are defined as follow:

- the « operational rotation range » is defined by a maximum angle of ± 7 degrees around the 2 perpendicular axes
- the « maximum rotation range » is defined by a maximum angle of ± 8 degrees around the 2 perpendicular axes

Mechanical stops shall limit the motion of the mechanism at ± 8 degrees around these two perpendicular axes.

### Rotation accuracy, stability and reproducibility

When a relative rotation command $\Delta\Theta c$ is applied, the effective relative motion $\Delta\Theta$ shall be such that ($\Delta\Theta$ - $\Delta\Theta c$) < Max. (resolution x 1/3; 0,02 x $\Delta\Theta c$) on each axis.

At the end of the command pulse, the power is removed, and the mechanism shall provide a holding torque such that the mechanism remains in its new steady-state position. The stability of the mechanism submitted to thermoelastic effects shall be better than 0,1 degree over 1 hour and 0.2 degree over the full orbit life.

### Position indicator

Each rotation axis shall be equipped with a redundant reference position indicator which shall be used as part of a mean of measurement for the 2 axes angular position of the mobile plate. The 0° indication shall be located at the reference position with a precision of ± 0,1 degree.

The position of the mobile plate w.r.t. the reference position shall be indicated by a status bilevel corresponding to the positive or negative rotation over the full operational range on each axis.

**Reference position**

In locked configuration, the TOM shall be in its reference position (0°).

By reference to this position, the mechanism shall be able to rotate the mobile plate in the whole specified angular range for the two orthogonal gimbal axes.

**Frequency**

In launch configuration, the first frequencies of each of the 6 degrees of freedom of the mechanism loaded with a representative thruster mass and fixed on rigid interface shall be discoupled from thruster eigenfrequencies in order to minimize the vibration loads on thruster elements. This specification is derived in maximum allowable sine and random levels at TOM/motor interface.

In orbital configuration, the first frequency of the mechanism loaded with a representative thrusters mass and fixed on a rigid interface shall be higher than 3 Hz.

These specifications are very stringent for the design of the structure, mobile plate, gimbal and hold-down mechanism.

## 2. CONCEPT DESCRIPTION

The drawing thereafter shows the overall architecture of the TOM.

It is mainly composed of:

- a mobile plate or radiative plate (1)
- a gimbal assembly (2)
- a structure made of five feet (3)
- 2 linear actuators (4)
- 2 switches giving the zero-reference position (5)
- a hold-down and release mechanism (6)
- structural damping devices

**Mobile plate (radiative plate)**

The mobile plate provides :

- structural functions
- a radiative function

The two structural functions are :

- to assure the plasmic motors fixation
- to fulfil the launch and on-orbit frequency specifications

The mobile plate is mainly constituted of two longitudinal rectangular section tubes made in Aluminium connected together with the help of four (4) transversal rectangular tubes. Four flexible blades supporting the thrusters are fixed on the transversal tubes. An Aluminium sheet is welded onto the top of this plate framework.

The mobile plate also provides the brackets interfacing with the hold-down and release mechanism.

**Gimbal assembly**

The gimbal assembly assures :

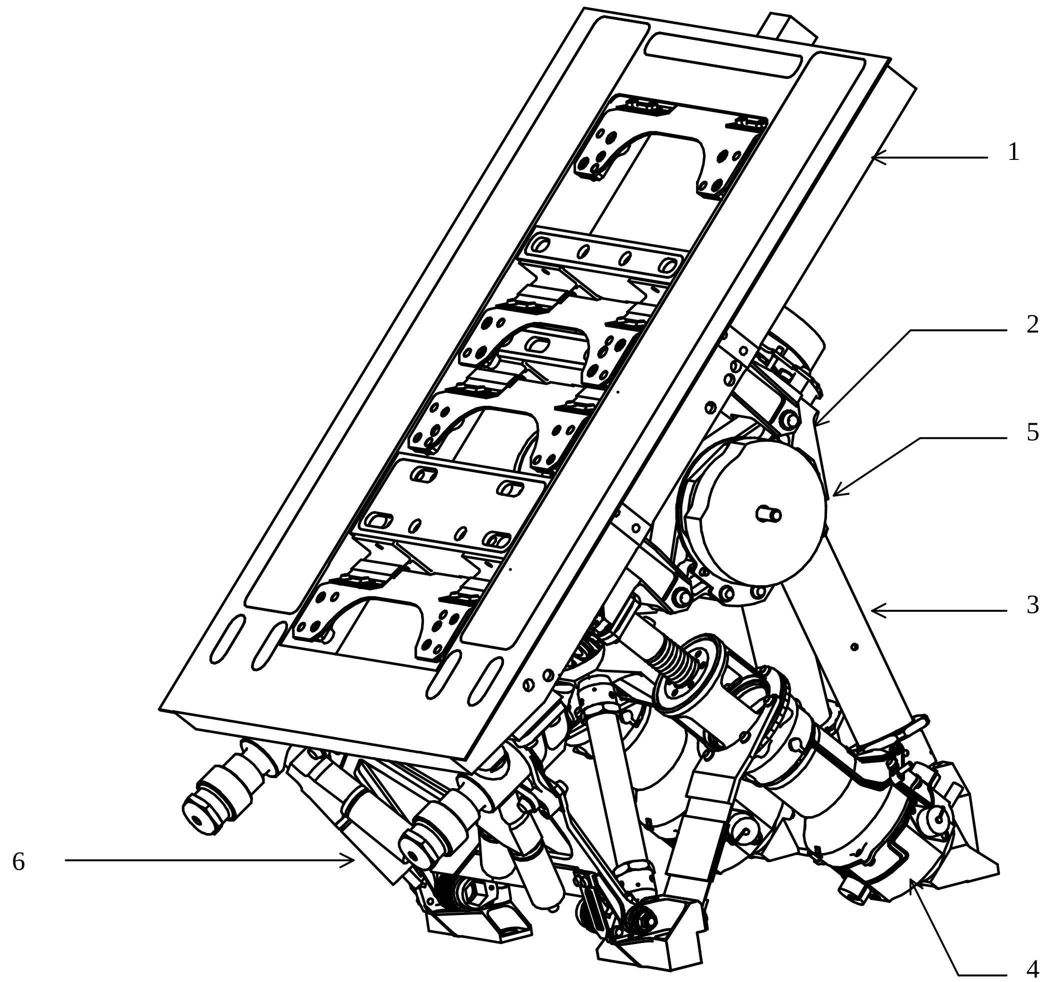
- the mobile plate guidance in the whole angular range specified about both orthogonal axes
- the launch frequencies of the TOM in locked configuration
- the on-orbit frequencies of the TOM in unlocked configuration

The gimbal assembly does also participate in the rotation accuracy, stability and reproducibility of the TOM.

The gimbal assembly is made of :

- a structural housing made of Titanium (TA 6 V) which is composed of two coaxial rings connected together by four axes disposed at 90° which form the two orthogonal axes of the gimbal joint
- two pairs of face-to-face ball bearings on each perpendicular axis. They are « X » mounted with a rigid preload and MAPLUB wet lubricated

In order not to stress the gimbal joint ball bearings under thermo-elastic effects, three of the four brackets interfacing with the mobile plate provide an axial flexibility. This flexibility is performed with the help of two pairs of thin blades which are flexible along their normal direction but rigid in their plane.




***TOM overall architecture***

**Structure**

The structure provides :

- the launch frequencies of the TOM in locked configuration
- the on-orbit frequencies of the TOM in unlocked configuration

The structure is mostly constituted of five feet (one bipod and one tripod) made of Aluminium that support the gimbal assembly. Both bipod and tripod designs guarantee a pure traction / compression in the five feet.

Four brackets support the base of the bipod and tripod and constitute the four only mechanical interfaces of the TOM with the satellite structure. Two of these brackets provide the rotating interfaces of the hold-down and release mechanism mobile arm.

Two brackets are connected to the bipod and tripod tops. These brackets are providing the first rotation axis of the gimbal joint.

The tubular structure allows to adjust the first eigenfrequencies of the mechanism.

### Actuators

The two similar actuators allow to fulfil :

- the specifications of rotation accuracy, stability and reproducibility
- the actuation of the mobile plate in the whole specified angular range
- the discoupling of the sensitive parts of the actuator during the launch phase

One must distinguish two sub-assemblies in the actuators composition :

- the actuation device
- the transmission device

The actuation device is mainly composed of :

- an external housing made of Titanium (TA 6 V) equipped of an active thermal control (electrical heaters) which guarantees the motorization margins in cold case
- a 200 steps per revolution pan cake stepper motor (redounded bipolar bi-phase)
- a pair of face-to-face ball bearings associated to a single ball bearing. All of them are wet lubricated with MAPLUB
- a 0.8 mm pitch and 48 mm stroke MAPLUB wet lubricated roller screw with an elastic preload
- a shaft made of Titanium (TA 6 V) providing the actuators mechanical stops
- a bellow

Thanks to the bellow that is locking the spindle screw rotation, the association of the motor with the spindle leads to perform 200 motor steps per revolution which corresponds to 0,8 mm linear displacement of the screw. The combined displacements of the two actuation devices permit to rotate at any time the mobile plate in the whole angular range about the two rotation axes of the gimbal joint.

Flexible transmission device : the rotations of the mobile plate around the two gimbal axes induce displacements and rotations which can't be supported by the actuators axis without intermediate flexibility. This flexibility consists of :

- a compression spring
- a cable located at the spring axis

This device is designed flexible not to overstress the actuators sensitive elements during the launch but in on-orbit configuration, the stiffness of the cable under the spring tension is enough to displace the mobile plate of the same quantity than the actuator translation.

### Optical switch

An optical switch is implemented on each gimbal joint axis. It indicates the TOM reference position, the TOM position side with regard to the reference position and with regard to the specified operational range.Both optical switches are identical. They are mainly composed of two parallel printed circuits boards (one transmitter and one receiver) inside of which rotates an engraved disc made of glass.

### Hold-down and release mechanism (HRM)

The hold-down and release mechanism main functions are :

- to position the mobile plate at the reference position during the launch
- to participate in the stiffness required in locked configuration
- to allow the rotation of the mobile plate in the whole angular range specified for on-orbit operations

During the launch phase, the mobile plate in the reference position is stowed to the satellite structure and kept tightly in this position by the HRM in association with the TOM structure + gimbal assembly.

Once in orbit, the HRM is activated by the firing of the pyrotechnical cutters, letting the mobile plate connected by the only gimbal assembly. A part of the HRM remains attached to the mobile plate while the other part shall move away from the mobile plate operating range by rotating towards the TOM structure; this motion is powered by 2 torsion springs and starts as soon as the tie-rods are freed. The torsion springs also ensure that the moving part of the HRM remains locked in its final position during the whole satellite operating lifetime, thereby avoiding any mechanical interference between the HRM and the mobile plate. The guidance is assured with the help of two ball joints $\phi$8 mm ($MoS_2$ lubricated).

### Damping devices

Damping devices, using visco-elastic material properties, are used on the flexible blades of the mobile plate, between the actuators and gimbal joint and on the mobile arm of the HRM. Their function is to reduce the amplification factor at resonance of the element on which they are installed.

## 3. KEY TOM PREFORMANCE DATA

- resolution : 0.002°
- Maximal pointing error : $0.0045° + 0.015° \times \theta c / 7°$ ($\theta c$ : commanded angle in degre)
- Maximal depointing in hot case : 0.121°
- Maximal depointing in cold case : 0.068°
- TOM mass : 9.8 kg
- Worst TOM electrical consumption : 10 Watts

## 4. TOM DEVELOPMENT PHILOSOPHY

The main interesting points which had to be treated during the development of the TOM were the qualification of the used wet lubrication, and the dimensioning of the structure in order to minimise the shocks and the vibration levels induced on the thrusters.

MAPLUB wet lubrication based on PENZANNE is used in the gimbal ball bearings and in the actuators in order to reduce the prices and to avoid the difficulties linked to dry lubrication.

The low qualification level of the plasmic motor w.r.t. shocks and vibration leads to develop a damped structure with well positioned eigen frequencies. The tubular structure associated with flexible blades supporting the motors allow the tuning of the eigen frequencies whereas viscoelastic dampers were introduced to reduce the corresponding dynamic amplification.

In order to verify these two critical points before qualification, two development models have been manufactured and tested :

- a Bread Board Model (BBM)
- a Structural Test Model (STM)

### Bread Board Model (BBM)

The aim of the Bread Board Model is to verify the good behaviour of the sensitive elements of the TOM regarding lifetime.

The BBM is representative of the TOM Flight Model for :

- the gimbal ball bearing
- the actuator roller screw

Both of them are impregnated with MAPLUB wet lubrication.

This model has been tested under ultra-vacuum (lower than 10-7 torr) for the whole specified qualification lifetime profile ie 35 million motor steps distributed in such a way that 350000 actuations are performed on 100 different angular range of 0.1°

The results were satisfactory :

- the resistive torque of the whole model, performed before, during and at the end of the lifetime test, remained unchanged
- the final expertise of the gimbal ball bearing and roller screw, performed by their respective manufacturer, has been passed successfully.

### Structural Test Model (STM)

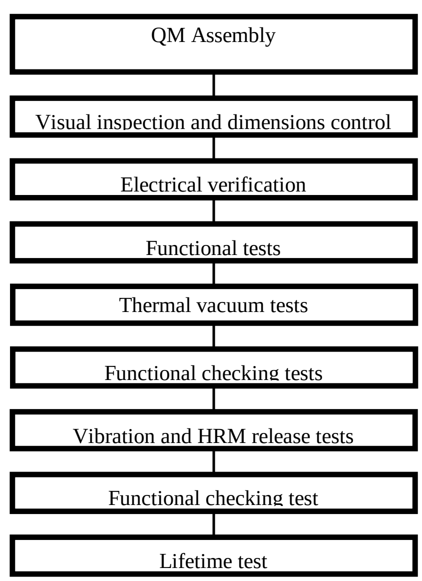
The most critical specification to be verified was the mechanical transfer function of the TOM : qualification level of the plasmic motor w.r.t. shocks and vibration being low. The aim of the Structural Test Model was to verify that the acceleration spectrum injected by the TOM to the plasmic motors during the launch phase is compliant with their qualification status.

For these vibration tests, the STM was fully representative of the Flight Model for all structural and damping parts. According to the flight configuration, two plasmic motors have been mounted on the STM.

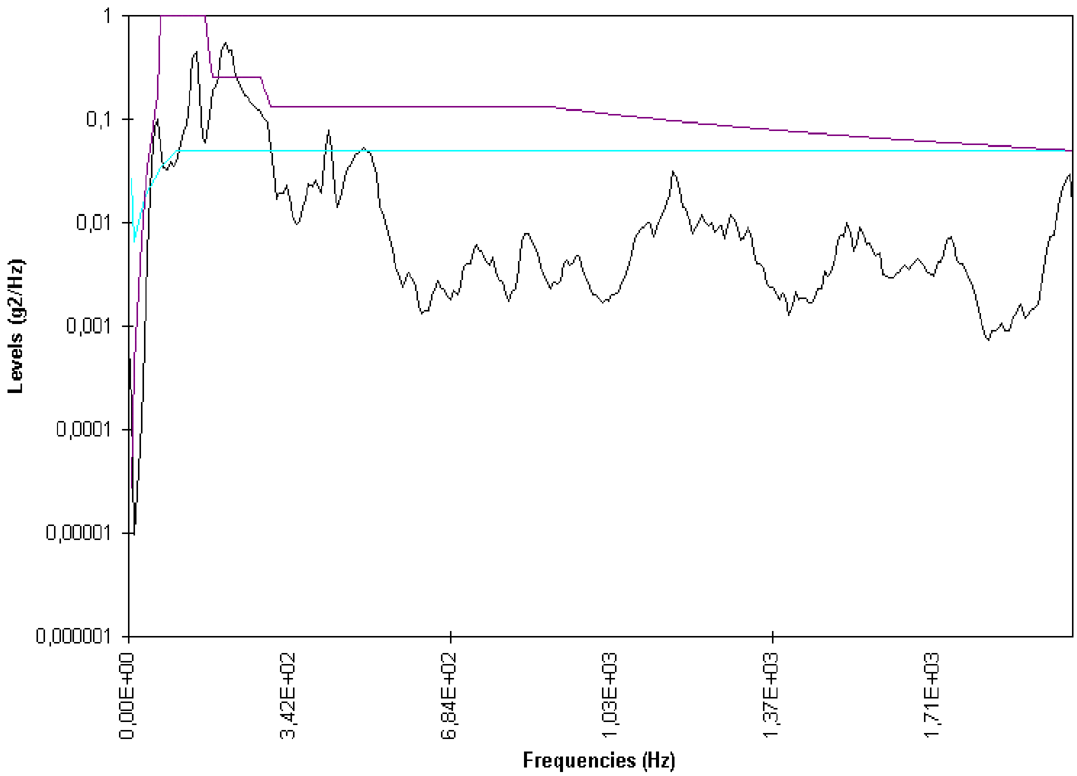
The random and sine vibrations have been performed successfully as described hereafter.

### Qualification Model (QM)

The below flow chart summarises the qualification test sequence.



The figure hereafter show a typical measured mechanical transfer function. The TOM input level, the actual measured and the allowable levels at thruster I/F are printed. The filtering effect of the first eigenfrequencies allow to induce low density on the motor above 200Hz




## CONCLUSION

The TOM specification are met. The selected wet lubrication has been successfully tested according the stringent lifetime profile. The eigenfrequencies of the damped structure have been tuned such that the strength of the breakable plasmic motors is insured.

The picture herebelow shows the TOM structural elements.