

# **ELECTRIC PROPULSION ON @BUS PLATFORM**

## **IEPC 03-170**

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### **SUMMARY**

Alphabus (@Bus), an ESA – CNES initiative, is a new European Advanced Platform under development for future High capacity Geostationary Telecommunication Spacecraft.

@Bus satellite propulsion is implemented mainly for satellite positioning to its orbital slots after injection to Space by launch vehicle as well as for station keeping during its operational life. Additional sub-functions as repositioning, post mission disposal are also addressed.

@Bus satellite propulsion is performed with both chemical and electrical technology. The aim of this paper is to study the electrical technology application

Chemical propulsion can be implemented in case of quick satellite positioning .

Chemical propulsion configuration study is derived from existing in use satellite platform ( Eurostar and Spacebus heritage) and include particular enhanced components.

High Power Electrical Propulsion implementation for Station Keeping mission and for partial or total orbit raising phase is considered.

System analyses on propulsion means according to a set of mission profiles and launch scenarios provide preliminary results showing that for electrical propulsion, high power thrusters either gridded ion engines or plasma Hall effect thrusters are good candidates to optimally answered to a predefined set of programmatic and economical constraints .

Therefore pre developments activities on these two technologies are started in order to prepare the future optimised propulsion scheme of the @Bus platform.

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## INTRODUCTION

Over the last decades, European industry has acquired a credible and viable position in the communication satellite activities. To maintain the European technology and products position in the evolving environment, it is necessary to pursue these efforts and prepare the future .

The evolution of communication satellite is driven by several factors :

- Launcher evolution : the next generation of launch vehicles (Ariane 5 evolution, Atlas V, Delta IV) will permit not only to increase the separation mass but also to deliver their payload on higher orbits, offering opportunities to reduce satellite propulsion needs .
- Satellite technologies: Benefits must be taken from the availability of high performance electric propulsion systems, improved payload technologies, high performance solar generators and batteries etc...
- Operator requirements: permanently asking for in orbit transponder price reduction, pushing for higher capacity satellite with significant in orbit flexibility .

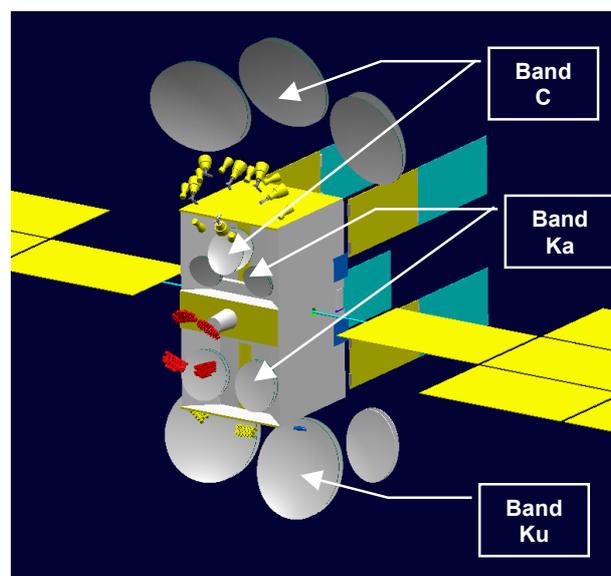
All these facts are pushing for bigger, higher power and more complex geostationary communication satellites.

European industry must be in a position to answer to this evolving environment and start now the development of the next generation of communication satellite .

A first assessment permitted to identify that these satellites must be able to operate simultaneously 100 to 150 channels , leading to satellite power as high as 30 kW for the top of the range (25 kW Payload).

In order to face this challenge , ALCATEL and ASTRIUM have agreed to investigate the possibility to develop a common high power bus @Bus (AlphaBus) that will complement their current product line in the upper range . A joint project team (JPT @Bus) has been set up in Toulouse with people from both companies. They have also agreed to propose this bus as the basis for the next communication satellite technology demonstrator of ESA : @Sat .

Preliminary study of @Bus with multi spectra C/Ku/Ka bands application



## 1. TELECOMMUNICATION MARKET

The satellite services evolution trends are to be assessed in the context of the telecommunications services market trends. Satellite Industry prospects can be seen as taking benefit of the growth of the telecommunication service demand , boosted by the data and internet transfer rates.

The telecommunication market is an expanding market where the satellite has a strategic role to play because of its inherent ability to bypass congestion, to reach regions without alternatives and to meet multicasting requirements , with unrivalled efficiency.

The GEO satellite market will require within the next five years a new generation of bigger and high power satellites , able to accommodate large payloads with power in excess of 20 kW and mass of more than 2 tons.

The GEO satellite market over the coming 10 years will be mainly driven by :

- The need of operators to replace their ageing fleets and to address the growing transponder demand with more cost effective and more flexible satellites ; this aims to serve quickly emerging service market opportunities and to allow for capacity instantaneous retail instead of longstanding wholesale.
- The recovery and long-term growth in emerging economies, primarily in the Asia Pacific area and to a lower extent in Latin America .

The need is therefore for a next generation of high power satellites within 5 years .

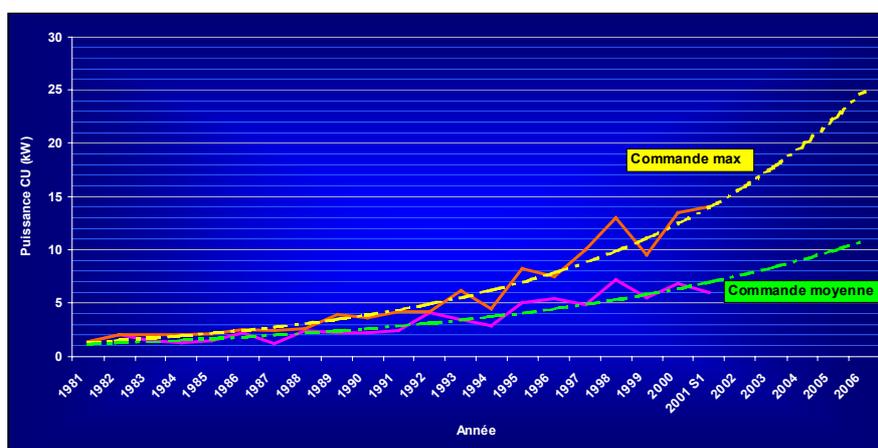
The global operators look for improving competitiveness and they will focus on large and powerful satellites to reach lower cost per transponder and lower terminal cost , and to carry at the same time complex and flexible payloads. They will thus fuel the trend for ever bigger and powerful satellites which has already been a constant evolution of the GEO communication satellite market over the past.

This trend towards higher power spacecraft continues, and there is a real need for a next generation of high power satellites , able to accommodate large payloads with power in excess of 20 kW and of more than 2 tons of mass .

In order to optimise the use of C band and Ku band spectrum at a single orbital slot , the global operators will shortly look for up to 25 kW payload missions. In addition , they also look for progressively implementing large Ka band payloads .

This new generation of bigger and more powerful satellites (above 14 kW) is anticipated to build a substantial segment with typical 30% of the market in value, starting with 2 to 3 satellites contracted each year after 2007 to grow up to 6 satellites per year beyond 2010 .

The past evolution towards high power is shown in the following figure.



## 2. @BUS PRODUCT

There is a number of significant advantages for the satellite operators to consider large and modern satellites , in spite of a larger upfront investment :

- To benefit from a lower cost per transponder through a scale effect at satellite level.
- To increase the communication mission performance of their satellites ( larger fairing , larger antennas ...)
- To provide interconnectivity within several payloads ( multi beams multi spectra C/Ku/Ka)
- To improve flexibility of on board resources ( MUXes switchings, channel routing, multiport amplifiers , etc...)

### LAUNCHERS

By 2004, satellite manufacturers will be offered five meter fairing multi launchers, high perigee injection capability in addition to mass in excess of ten tons GTO equivalent.

Launch vehicle offer for the next ten years is characterised by three evolutions :

- Increased performance both to Geostationary Orbit (GTO), which will exceed ten tons for at least two launchers .
- Increase in volume availability for the payload with introduction of "five meter" fairing.
- High perigee injection orbit capability will be offered by re-ignitable upper stages, reducing the constrains on satellite propulsion system capability .

An overview of the development and commercial availability of enhanced launch vehicles is summarised in the following table ( all performances in equivalent Ariane GTO  $i=7^\circ$ )

Launcher	Typical GTO perfo	Highest perfo inclination	Dual launch capability	Re-ignition capability	Cryogenic upperstage
Ariane 5 ESV	7.5 tons	7°	Yes	Yes	No
Ariane 5 ECA	10.4 tons	7°	Yes	No	Yes
Ariane 5 ECB (*)	11.2 tons	7°	Yes	Yes	Yes
Sea Launch (extension +13%)	5.6 tons	0°	No	Yes	No
Delta 4 M+ (5.4)	6.5 tons	28.5°	No	Yes	Yes
Delta 4 Heavy	11.8 tons	28.5°	Yes	Yes	Yes
Atlas 5 (531 to 551 versions)	6.9 to 8.3 tons	28.5°	No	Yes	Yes
Proton M/Breeze M	5.4 tons	51.6°	No	Yes	No

(\*) date of introduction delayed

Increased performance in launchers environment from 5.4 tons class (equivalent 200 km/7° GTO) in single/dual launch to :

- 7.5 tons after 2004 (Ariane 5 ESV, Atlas 551)
- 10.4 tons after 2005 assuming Ariane 5 ECA, Delta 4 , Atlas 5 heavy versions
- 11.2 tons after 2007 assuming Ariane 5 ECB(\*), Delta 4 , Atlas 5 Heavy versions

### PLATFORM TREND

In order to respond to the evolution of the market environment, Alcatel and Astrium have identified the need for a new platform product that will complement their current EUROSTAR and SPACEBUS product family. This new platform will :

- Cover the 12 kW to 18 kW payload range with extension up to 25 kW , this will require significant enhancement of both power supply and heat rejection systems .
- Optimise the use of the new launcher parameters , such as large fairing or high energy orbit injection.
- Make the best use of the new technology available for such satellites such as enhanced electric propulsion systems, deployable radiators, etc ...
- Maintain an acceptable delivery schedule even with an increased payload complexity .

## PROPULSION TREND

Two factors will drive the evolutions of satcoms bus :

- On the launcher side , delivery at high perigee orbit can be achieved with re-ignitable upper stages already available on US launchers and soon available on Ariane with ECB evolution.
- On the spacecraft side, the high power available on board can be used to extend the electric propulsion to final circularisation in GEO.

From those two factors , we can expect that the long term prospective is leading to the removal of the high thrust chemical propulsion on board the satellite. In such an attractive concept , the first velocity increment from GTO can be performed with the launcher upper stage firing at apogee and the second phase to GEO is performed with electric propulsion system implemented on the satellite. However, we still have to manage a transient phase during which there will be some launchers (including Ariane) that do not have high perigee injection capability .

For commercial satellites we need also to manage customer's conservatism and this is specially detrimental for electric propulsion as they require a 3 years minimum chemical propulsion back-up for the on station mission and thus this lead to a strong degradation of the competitiveness . Electric propulsion must therefore be very cheap in order to "pay it seat " on board the present satellites . This last aspect will become less heavy as soon as we will obtain in flight experience data with electric propulsion.

## 3. PROPULSION MISSION

### TRANSFER MISSION

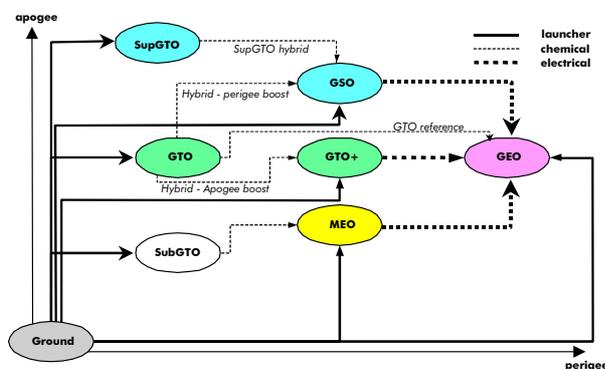
Recent studies performed by different authors had shown that due to the low thrust level when using electric propulsion for transfer, there are lot of different injection strategies possible and the optimisation of this mission lead to a classification into 3 families today almost standardised :

- GTO with «Sub GTO» or «Super GTO»
- «GTO+» : perigee altitude between 10000 and 36000 km
- «MEO» : actually, circular orbit of less than 36000 km altitude

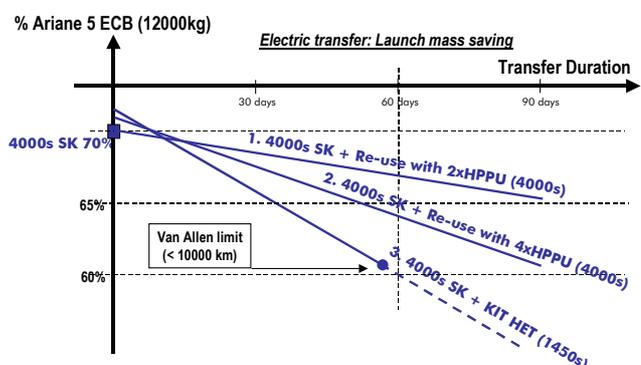
Among the different electrical propulsion technologies available ( SPT, TAL, Ion, PPT, FEPP, MPD, Arcjet, MHD, etc...) a quite obvious trade-off analysis show that for geo stationary telecommunication satellite two attractive technologies remains as the most promising candidates :

- Plasma Thrusters mainly SPT type or TAL
- Ion Thrusters with DC or RF ionisation discharge

On the other hand, higher on-board power for payload become fully available in transfer leading to electrical transfer phase duration limited to 2 or 3 months



Three families of transfer strategy



Typical launch mass saving versus electric transfer duration ( combined propulsion transfer and 3 cases : 1. Re-use of SK sub system  $I_{sp}=4000s$ , 2. Re-use of SK sub system with 4 PPU's  $I_{sp}=4000s$  ;3. SK sub system and dedicated kit for transfer  $I_{sp}=1450s$  )

As we can see large mass saving can be gained with the use of electric propulsion for transfer ; nevertheless if we consider the competitiveness of this operation , we obtain a more questionable interest since we need to compare mass savings in term of equivalent cost saving (with appropriate launcher price) balanced with dedicated propulsion sub system over costing and satellite immobilisation cost (ground station cost , financial cost etc ) . The associated trade off give a result which show the strong influence of sub system recurring cost .

**Thus requirements on electric propulsion for LEOP orbit raising can be summarised as follow :**

Power available for electric propulsion during LEOP is in the range 13 to 26 kW (75% of the sat power)

Total impulse needed : from 2600 kNs to 12000 kNs (transfer duration up to 3 month~2200h)

Total thrust and Isp :from 0.5N to 1.5N if Isp is 1600sec, from 0.3N to 1N if Isp is 3000sec

As transfer duration is a key driver (customer sensitivity): 1500<Isp< 2500 is preferred

Maximum efficiency : Thrust level / Electrical power

Assembly of thrusters adapted to the range of available power : from 10 to 20 kW

Thrusters for transfer likely to be dedicated ones. Additional thruster expected for N/S control

Thrust direction management has to be defined: Thrust level control with a set of > 4 Thrusters, Thrust direction control at thruster level or mechanism.

High Xenon capacity tanks is needed : more than 1500 kg pending Specific impulse.

**ON STATION MISSION**

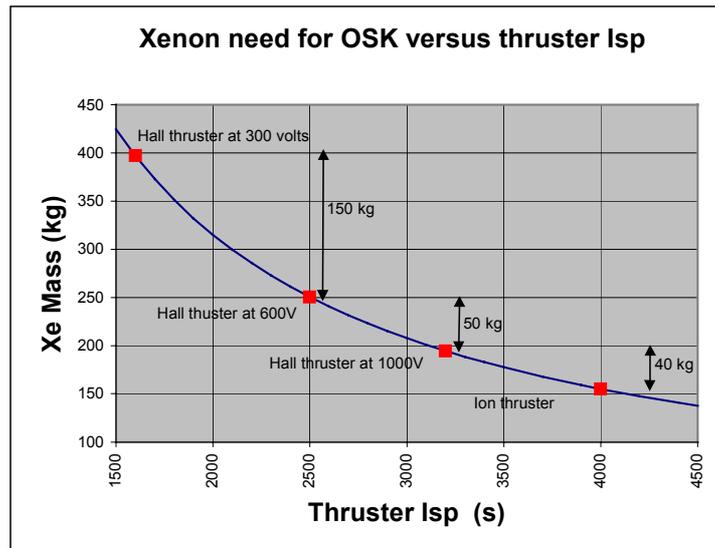
The different missions that is requested for propulsion during satellite service over up to 15 years is mainly :

- North South Inclination control
- East West Drift control
- Eccentricity control
- 3 axis wheels off loading
- Attitude control during Station Keeping manoeuvres

Once again here we can find lot of possible strategy of propulsion use specially if we take into account the requirement of additional 3 years of full chemical propulsion backup ; therefore the on station mission can be fulfilled by the two propulsion systems ie chemical and electrical through different combinations .

The consequent additional mass saving versus specific impulse of electric propulsion used for station keeping is illustrated hereafter and we can see that the highest the specific impulse is, the larger the mass saving we get; of course there is an upper bound for this growth . Besides the complexity of the electrical propulsion technology itself, we need not to oversize the solar arrays panels, the batteries and the firing duration for each manoeuvre.

Finally taking these constrains into account we can define a practical upper bound for the specific impulse around 4500 - 5000 s where complexity of propulsion system together with oversizing of batteries, solar array and total impulse need give a zero competitiveness for additional Xenon mass saving .



Mid range @Bus mission example calculation

**From the different studies we can derive the general requirements for electric propulsion:**

- Total impulse from 4000 kNs to 11 000 kNs (all thrusters)
- Needed Thrust : from 80mN to ~245mN
- Unitary thruster power : 2 to 6 kW
- Isp > 2500s and 4000s as a target for OSK mission
- 1500s < Isp < 2500s for transfer mission
- Minimum flow divergence

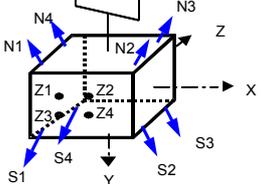
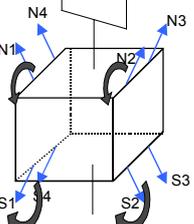
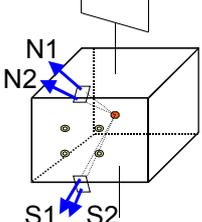
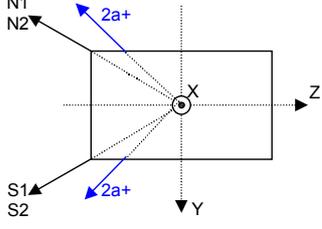
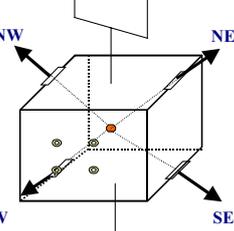
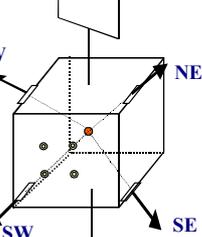
**Validation key points for electric propulsion:**

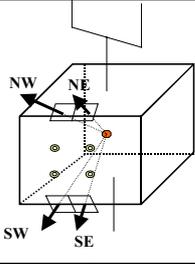
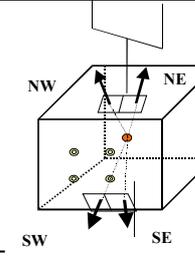
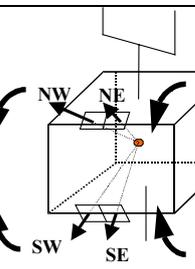
- Lifetime qualification of thrusters, especially if LEOP and GEO thrusters are common.
- Qualification of the thrusters at various reference points (discharge current, force, Isp).
- Potentially new architecture and new operation (potentially two or more thrusters simultaneously).
- New PPU with additional capability (operation of thrusters at different points) have to be optimised together with power chain and Corona effect robustness.
- Interaction with appendages (SA, radiators, Antennas, RF beam).
- Contamination by PPS, especially due to long LEOP duration.
- New mechanism if any.

## 4. CONFIGURATION ANALYSIS

Implementation of electric propulsion on board of @Bus platform is obviously strongly linked to the mission we want to ensure : full electric station keeping or north south only for OSK , partial or full electric transfer. Moreover the service module architecture itself will constrains the different possibilities of choice Therefore a trade off analysis is on going on these different options and we studied up to 14 different configurations .

We show here some of them with the associated advantages and drawbacks .

Candidate	Description	Comments
 <p>1A1</p>	<p>8+4 thrusters configuration; 4 N thrusters fired at a time ; Back-up 4 S thrusters fired at a time 4 Z- thrusters used for transfer</p>	<p>High NSSK efficiency, total impulse divided by 4 thrusters , no mechanism 4 PPU required on nominal and back-up, additional EP kit for transfer, plume effect, RF interactions</p>
 <p>1A2</p>	<p>8 thrusters configuration; 4 N thrusters fired at a time ; Back-up 4 S thrusters fired at a time 4 thrusters re-use for transfer</p>	<p>High NSSK efficiency, total impulse divided by 4 thrusters , no mechanism 4 PPU required on nominal and back-up, no kit for transfer, plume effect TBC, RF interactions, 4 large angle tilt mechanisms</p>
 <p>2A</p>	<p>4+4 thrusters configuration 1 thruster fired at a time Back-up: redundant thruster 4 Z- thrusters used for transfer</p>	<p>High heritage: 2 PPU only ; 2 mechanisms; good SK thrusters re-use; EW with chemical; low NSSK efficiency, poor back-up</p>
 <p>2A+</p>	<p>4+4 thrusters configuration 1 thruster fired at a time Back-up: redundant thruster 4 Z- thrusters used for transfer</p>	<p>High heritage: 2 PPU only ; 2 mechanisms; correct SK thrusters re-use; EW with chemical; better NSSK efficiency, poor back-up</p>
 <p>2B</p>	<p>4+4 thrusters configuration 2 thrusters fired at a time Back-up : 2 S thrusters for NSSK Altered efficiency for EWSK 4 Z- thrusters used for transfer</p>	<p>Full electric propulsion orbit control Good NNSK efficiency ; no efficient SK thrusters re-use capacity, 2 PPU required for nominal and back-up ( +1 for redundancy), 4 mechanisms</p>
 <p>2C</p>	<p>4+4 thrusters configuration 2 complementary dual firing for EWSK ans NSSK combined Back-up: 2 split single firing maneuvers; altered efficiency for EWSK 4 Z- thrusters used for transfer</p>	<p>Full electric propulsion orbit control Good back-up efficiency ; robust to 1 failure with only 2 PPU, no efficient SK thrusters re-use capacity, 4 mechanisms</p>

Candidate	Description	Comments
 <p><b>3A</b></p>	<p>4+4 thrusters configuration  4 single firing maneuvers combining NSSK and EWSK  Back-up : 2 split firing for NSSK + third dual maneuver for EWSK  4 Z- thrusters used for transfer</p>	<p>Full electric propulsion orbit control ; robust to 1 failure with only 2 PPU, good SK thrusters re-use capacity, 4 or 2 mechanisms</p>
 <p><b>3A+</b></p>	<p>4+4 thrusters configuration  4 single firing maneuvers combining NSSK and EWSK  Back-up : 2 split firing for NSSK + third dual maneuver for EWSK  4 Z- thrusters used for transfer</p>	<p>Full electric propulsion orbit control  Good NSSK efficiency ; robust to 1 failure with only 2 PPU, SK thrusters re-use capacity, 4 or 2 mechanisms</p>
 <p><b>3B</b></p>	<p>4 thrusters configuration  4 single firing maneuvers combining NSSK and EWSK  Back-up : 2 split firing for NSSK + third dual maneuver for EWSK  4 thrusters re-used in transfer by large angle tilt mechanisms</p>	<p>Full electric propulsion orbit control  Optimised NSSK efficiency ; only 2 PPU, very good SK thrusters re-use capacity, 4 large angle tilt mechanisms</p>

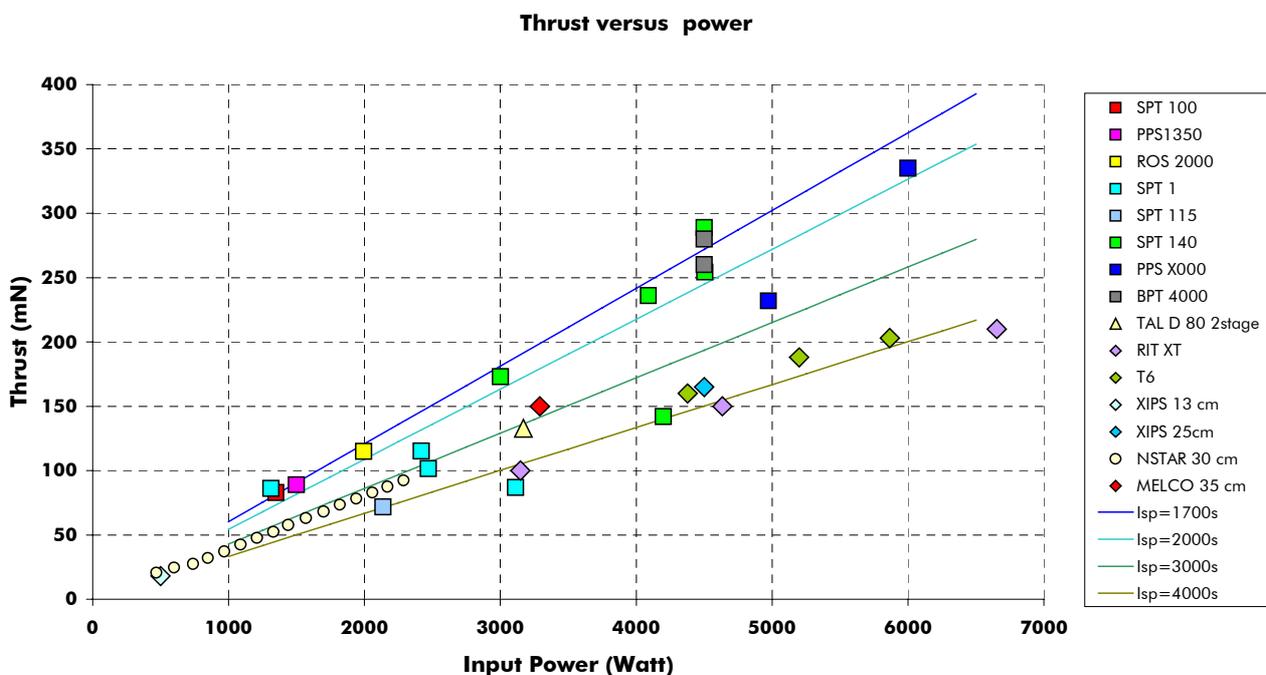
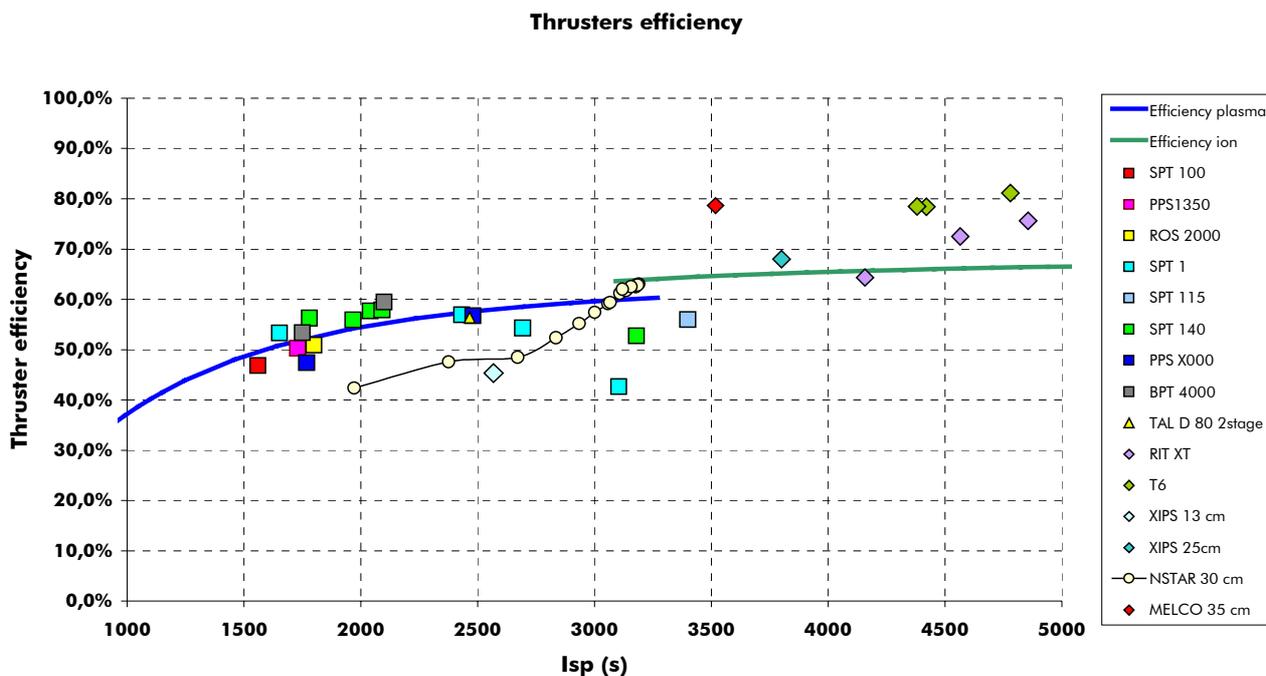
## 5. THRUSTER STATUS

Different thrusters are qualified , under qualification or under development; the table hereafter gives an overview of the present status that can be derived from published results .

<b>Thruster</b>	<b>Thrust (mN)</b>	<b>Isp (s)</b>	<b>Power (Watts)</b>	<b>Efficiency (%)</b>	<b>Life Time (10<sup>6</sup> Ns)</b>	<b>Status</b>
<b>SPT 100</b>	83	1560	1350	46,8%	2,20	Qualified 7000h - 2.2 10 <sup>6</sup>
<b>PPS1350</b>	89	1730	1500	50,3%	2,90	Qualified 2250h - 0.7 10 <sup>6</sup> Under qualification for 2,90 10 <sup>6</sup>
<b>ROS 2000</b>	77 115 135	1800	1350 1995 2500	49,0% 50,9% 51,0%	3,30	Under qualification Under qualification Under qualification
<b>SPT 1</b>	86 115 102 87	1653 2432 2693 3105	1314 2418 2472 3113	53,3% 56,9% 54,3% 42,7%		Under development Under development Under development Under development
<b>SPT 115</b>	72	3400	2138	56,0%		Under development
<b>SPT 140</b>	289 173 236 254	1780 1967 2041 2091	4500 3001 4090 4505	56,2% 55,9% 57,7% 57,9%	5,80	Under qualification Developed Developed Developed
<b>BPT 4000</b>	280 260	1750 2100	4500 4500	53,4% 59,5%	7,00	Developed Developed
<b>PPS X000</b>	335 232	1769 2480	6000 4973	47,4% 55,6%	7,00	Under development Under development
<b>TAL D 55</b> <b>TAL D 80 2stage</b> <b>TAL D100 2stage</b> <b>TAL 110</b> <b>TAL D150</b>	133 200	2466 2070 3150	3170	56,4%		Qualified - 1 US flight techno Under development Under development Under development Under development
<b>RIT 10</b>	15	3300			0,81	Qualified 15000h - 0.81 10 <sup>6</sup>
<b>RIT XT</b>	210 150 100	4158 4560 4856	6653 4633 3147	64,4 (1)% 72,7% 75,7%		Under development Under development Under development
<b>UK 10</b>	15					Qualified
<b>T6</b>	203 188 160	4780 4420 4380	5866 5199 4378	81,1%(2) 78,4%(2) 78,5%(2)	>10.0	Under development Under development Under development
<b>XIPS 13 cm</b> <b>XIPS 25cm</b> <b>NSTAR 30 cm</b>	18 165 92	2568 3800 3120	500 4500 2290	45,3% 68,0% 62,0%	2,70	Qualified Qualified Qualified 8200 h - 2.7 10 <sup>6</sup>
<b>MELCO 35 cm</b>	150	3518	3290	78,6%		Under development

(1) Efficiency at high thrust levels > 180 mN is limited due to the available RF Generator limitation

(2) Efficiency without correction for beam divergence ; performance data are preliminary



Since all thrusters are using Xenon as propellant they have almost all the same general behaviour when looking specially at specific impulse and specific power ( thrust divided by input power) performance versus voltage .

The only thing coming out of the comparison (efficiency comparison) , is that ion engines are more efficient and this is primarily due to the lowest divergence of the Xenon ions output beam. Otherwise both technology exhibit same general trend of efficiency increase versus voltage since the first main losses mechanism is ionisation process which take an almost constant part ( for constant flow rate) of the input voltage.

Nevertheless, the associated power supplies are more complicated for ion engines than for Hall effect thrusters operating in single stage.

The following table give the main features of comparison of ion and Hall effect plasma thrusters.

<b>Gridded ion thruster</b>	<b>Hall effect plasma thruster</b>
Good specific impulse : from 3000 to 5000s High efficiency : from 0.62 to 0.70 Low divergence : from 6° to 25° half angle Good in flight experience : Nstar on Deep Space 1 , RIT10 and UK10 on Artemis...	Good in flight experience : Gals1, 2, Express3A, 6A, Sesat Ground qualification: Stentor, Astra, Intelsat, Inmarsat, Smart 1 Robust and reliable design Tunable specific impulse : from 1000 to 2500 s
<b>Drawbacks :</b> No Isp tuning capability : dual mode impossible Complicated design and power supply Sensitivity to shortening of grids	<b>Drawbacks:</b> Isp>3000s capability for OSK to be demonstrated Associated life time to be assessed Divergence difficult to reduce : from 45 to 35 ° half angle

### **SPT100**

The SPT 100 thruster is qualified and used on lot of spacecrafts ; but the use of this thruster for @Bus is limited by the life time .

### **SPT-1**

The SPT 1 is derived from the already qualified SPT 100 . It have been optimised for high voltage (around 1000 volts) operation and has been well characterised recently up to 1250 Volts with specific impulse up to 3400s ; the life time of this thruster shall be assessed .

### **PPS 1350**

The PPS 1350 has been qualified for Stentor application ; it will be used at low power on Smart 1. The qualification process in under progress to reach a lifetime of  $3 \cdot 10^6$  Ns . The application on @Bus is also - but less - limited by the life time capacity.

### **ROS 2000**

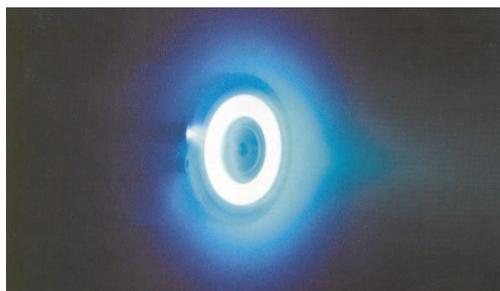
The ROS 2000 is under qualification process . The application on @Bus is also - but less - limited by the life time capacity.

### **SPT 140**

The SPT 140 thruster has been developed by Fakel under ISTI funding .

The present status of the thruster will allow to start the qualification test within a few weeks , at the early beginning of 2003 leading to give an available qualified thruster at low voltage by the end of 2004.

A derived version of this thruster will be qualified for the Russian application Phobos mission.

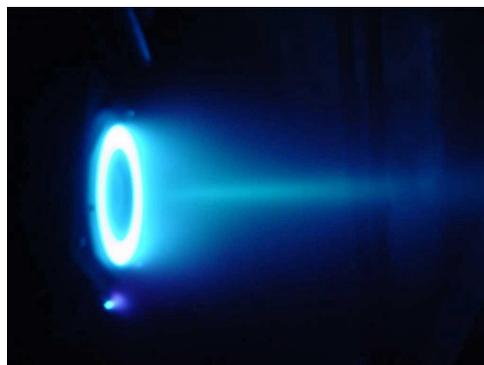
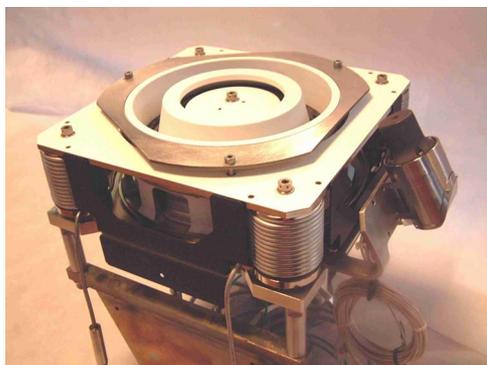


## PPS X000

Snecma Moteurs started in 1999 preparatory work for the development of a new high power Hall effect thruster with the support of CNES and in co-operation with the Russian company FAKEL. This effort led to the design of the so-called PPS X000, a prototype model of a high power (up to 6 kW) Hall Effect Thruster with dual-mode capability able to meet the propulsive needs of the next-generation geostationary satellites.

The goals of the PPS X000 technology demonstrator were twofold, namely :

- a) to demonstrate, as close as possible to full scale, the feasibility and effectiveness of the technologies required for high power Hall-effect thrusters, e.g., new coil wires, improved radial heat conduction within the internal coil, thermal drains to reduce inner coil temperature, and anode design adapted to high thermal loads; and
- b) to allow experimental parametric testing on magnetic configuration, axial position of the gas distributor and ceramic discharge channel, discharge voltage and impact of ceramic wall erosion on performance stability.



Extensive characterisation testing performed end of 2002 has demonstrated a considerable range of stable operating conditions for a given thruster configuration. In particular, a thrust level of 340mN (+/-10) was measured at 6kW and 300V, respectively, of discharge power and voltage, while a maximum total specific impulse of 2480s (+/-107) and total efficiency of 55.6% (+/-6.6) were measured under discharge conditions of 5kW and 585V.

The PPS X000 design is fully based on Snecma Moteurs patents, consistent with a totally independent European design and product. The effort pursued so far has paved the road for the successful development of a Hall effect thruster with performance consistent with the requirements of the Alphabus program.

## T6 thruster :

The T6 thruster is a development of the 10 cm diameter T5 and 25 cm diameter UK-25 Kaufman thrusters and was designed using well established and proven scaling laws. All of these thrusters have exhibited good performance, resulting principally from good ion optics and efficient discharge chamber designs.

Laboratory standard T6 thrusters have been operated between 90 and 210 mN, at 3500 and 4800 s SI respectively. The thruster is equipped with high total impulse graphite grid technology and the ion optics assembly is designed to exhibit exceptional thrust vector stability over the entire thrust range. A laboratory model T6 has been successfully vibration tested to 22 g rms. An engineering model T6 has also been vibration tested, followed by an acceptance firing test in the QinetiQ LEEP1 EP facility. During this test the beam divergence and functional characterisation across the thrust range was performed. The thruster was then subjected to a second vibration test, to simulate launch, returned to the facility and subsequently successfully operated for a period of 750 hours at 120 mN.

In March 2003, two T6 thrusters will be fired simultaneously at high thrust and high SI in the QinetiQ LEEP2 EP facility (3.8 m diameter x 10 m long) to verify successful tandem operation in close proximity. One of these thrusters will also be operated over an elevated temperature range to simulate operation at the near Mercury thermal environment as part of the European Space Agency BepiColombo Technology development activities.





## CONCLUSION

The development of the new European @bus platform is going on.

The different trade off analysis for both transfer mission and on station keeping mission will led to the final design of electric propulsion sub system for @Bus . The most important aspect is the recurring cost of the propulsion sub system which play a fundamental part in the final choice.

The activities set up on both ion and plasma Hall effect technologies will give us the needed technical data on the main identified issues (grid short recovery for ion thruster , high specific impulse capacity of Hall effect thruster) leading to the consolidated electric propulsion sub system for @Bus.

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