COMMERCIALIZED ION PROPULSION FOR NORTH/SOUTH STATIONKEEPING OF COMMUNICATION SATELLITES

H. Bassner and K. Bohnhoff, Daimler-Benz Aerospace AG, Munich, Germany

A. Trivulzio, FIAR S.p.A., Space Division, Milano, Italy

Abstract

The Radiofrequency Ion Thruster Assembly RITA has been developed in Germany by Daimler-Benz Aerospace (formerly MBB) since many years. A first flight of RITA was performed in 1992 on EURECA with the demonstration of 244 operation hours at thrust levels up to 10 mN.

Currently the RITA with 15 mN thrust level is under qualification for its application to North-South-Stationkeeping of the ESA-ARTEMIS satellite. The flight hardware will be delivered in 1997 and the Artemis launch is planned for the year 2000 on the Japanese H- 2 launcher.

For a commercial application of RITA the thrust level has to be increased to decrease the operation time for its application on satellites with launch masses up to 4500 kg. Discharge chamber diameters up to 26 cm will be available to allow thrust levels up to 200 mN.

1. Introduction

Electric Propulsion for geostationary satellites offers advantages in launch mass and/or payload capacity and/or lifetime of the satellite.

A comparison of the advantages between Arcjets, SPT (Stationary Plasma Thruster) and RITA (RF-Ion Thruster Assembly) - as an example for the gridded ion thrusters - used for North-South-stationkeeping is shown in Fig. 1-1 and 1-2.

As shown in Fig. 1-1 the satellite launch mass based on a satellite dry mass of 2086 kg excluding the electric propulsion mass will be:

- 4050 kg for the use of Arcjets
- 3900 kg for the use of SPT
- 3670 kg for the use of RITA

This means that the launch mass of the satellite can be reduced by 380 kg using RITA instead of Arcjets or by 230 kg instead of SPT. The mass reduction can be used to decrease the launch cost.

Fig. 1-2 shows the satellite dry mass based on a satellite launch mass of 4050 kg. The satellite dry mass will be 2090 kg for Arcjets, 2170 kg for SPT and 2310 kg for RITA.

The payload in this case can be increased by the use of RITA by 220 kg with respect to Arcjets and by 140 kg with respect to SPT.

Both possibilities, the decrease of launch mass and the increase of payload mass, can be used to decrease the channel cost per year.

Electric Propulsion for North-South-stationkeeping

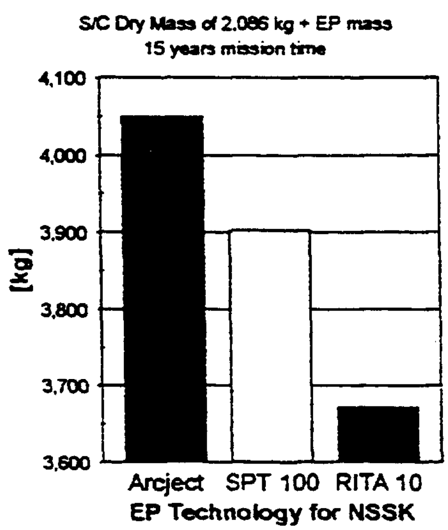

Fig. 1-1:Improvement of Launch Mass

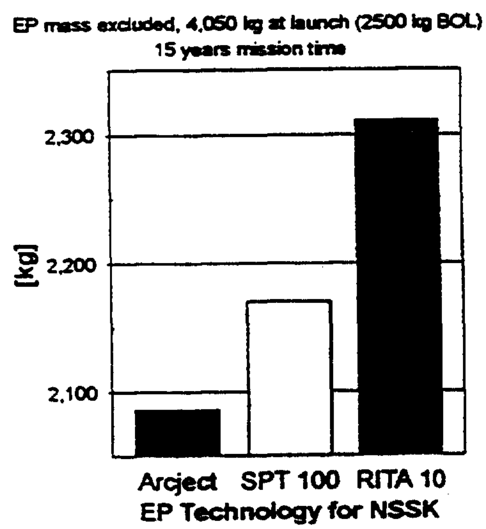

Fig. 1-2:Improvement of Dry Mass

has been used first by Lockheed-Martin. Resitojets and later on Arcjets did improve the performance of their geostationary satellites.

Electrostatic Ion Thruster technology has reached an advanced stage of development and is now on the threshold for commercial applications:

- SPT's from Russia have been flown to compensate air drag of LEO-satellites since more than 20 years and are operational for North-South-stationkeeping on the GEO-satellite GALS launched in 1994.
- The Melco 25 mN Kaufmann thruster system has been launched on ETS VI experimental satellite. It has been operated in the geo-transfer orbit for some hundred hours.
- Hughes has already sold several GEO commercial satellites with their 13 cm XIPS and 18 mN thrust, that will be launched this year.

  The new 702-platform will be equipped with a 25 cm thruster with higher thrust level for North/South stationkeeping and assistance in orbit raising.
- Dasa has a long heritage in the development of ion thrusters based on the RF-ionization principle
  - RITA with 10 cm ionizer diameter has been flown on EURECA with 10 mN thrust and is now under qualification with 15 mN for its application on the ESA-experimental communication satellite Artemis, launch in year 2000 by a Japanese H-2 launcher.

    A commercial version of this thruster would be able to generate a thrust level of 25 mN.
  - RITA with 15 cm ionizer diameter, thrust level up to 50 mN, is currently under test at the University of Giessen.
  - ESA-XX (RITA with 26 cm ionizer diameter), with a thrust level up to 200 mN, is under development at Dasa/AEA Technology for primary propulsion.
  - RITA with 35 cm ionizer diameter has been designed and manufactured by Dasa and extensively tested by University Giessen with a dished carbon acceleration electrode.

Based on this situation the paper will discuss the possibilities for the commercial application of the RITA thrusters.

2. Application of Electric Propulsion

The main tasks of propulsion and its necessary propulsion requirements on geostationary satellites are:

- Orbit raising	1500 m/s mission
- N/S - stationkeeping	47 m/s year
- E/W - stationkeeping	< 5 m/s year
- Attitude control	< 5 m/s year
- Deorbiting	5 m/s

There are two attractive tasks to be performed by electric propulsion, characterized by high velocity increments:

- Orbit raising

  Chemical propulsion needs about 40 % of the launch mass of the satellite. 10 days will be necessary to move the satellite from the transfer orbit to the GEO.

  In case of electric propulsion the thrust level will be selected to allow the performance of this task within 3 months or less. This leeds to thrust levels of 400 mN or more, which can be generated by one or more thrusters.

  The solar array power of 10 to 15 kW will limit the available thrust level. Injection of the spacecraft into a higher transfer orbit than GTO will reduce the delta v-requirements
- N/S stationkeeping

  An average velocity increment of 47 m/s per year leads to a total delta v of 705 m/s for 15 years mission time.

  The thrust level shall be adaquate to perform the task in less than 3 hours per node and day. In addition the duration of lifetime demonstration of the thrusters shall be low enough to keep the qualification cost in a reasonable range. This leeds to thrust levels of 25 mN or more.

Under consideration of the current status of the RITA development the implementation on commercial geostationary satellites could be conceived in the following steps:

- Use of commercialized gridded ion thrusters of thrust levels in the range of 25 mN based on the current qualified developments for N/S stationkeeping. Other tasks are performed by chemical propulsion as before.

Satellite structures will be used as they exist. The additional development effort is moderate.

- The use of electric propulsion for orbit raising will need thrusters with higher thrust level and will have more impact on the satellite structure. Therefore this application is seen as a second step which will need a redesign of the complete satellite structure and additional effort in ion thruster development.
- The final goal could be an "All Electric Satellite", where all propulsion tasks are performed by ion thrusters, in combination with flywheels and gimbal mechanisms. This would have a major impact on the satellite design, could be performed together with step two but will need a higher effort for redesign of the satellite bus.

3. RITA for Commercial Application

RITA thrusters systems are under development in Germany since many years. Discharge vessel diameters from 10 cm to 35 cm have been investigated.

TABLE 3-1 shows the main data of the RITA thrusters being under investigation in Germany.

The most advanced thruster is the RIT 10 which allows a thrust level up to 25 mN. The thruster system for Artemis with 15 mN thrust level is under qualification this year for Artemis. The flight hardware will be delivered before the end of this year.

For commercial application the thrust level of the 10 cm discharge chamber thruster must be increased to 25 mN. The design may be further improved with respect to serial fabrication in order to decrease the recurring cost to a price which is in correspondence with the market requirements.

Higher thrust levels can be achieved by the increase of the discharge chamber diameter which allows an increase of the beam diameter.

At the University of Giessen a RIT 15 thruster is under test which is able to generate a thrust level of 50 mN.

80 mN can be generated using a discharge chamber diameter of 18 cm.

An advanced Breadboard Model of the ESA-XX ion thruster with 200 mN is ready for testing. This thruster uses the RF-ionization principle and a molybdenum grid system from a Kaufmann-thruster of AEA Culham. Details of this thruster are presented in a special paper within this conference.

4. Use of RITA for N/S-Stationkeeping

4.1 General Arrangement

North-South stationkeeping on geostationary satellites needs a resulting force along the North-South axis of the satellite in or around one or both nodes. Figure 4-1 shows the two possibilities which can be used.

Table 3-1: RITA Thrusters and their Applications

	RITA 10	RITA 10	RITA 15	RITA 18	RITA 26
	Artemis	Commercial			(ESA-XX)
Thruster Data:					
Ionizer diameter	10 cm	10 cm	15 cm	18 cm	26 cm
Thrust level	15 mN	25 mN	50 mN	80 mN	200 mN
Beam voltage	1500 V	1200 V	1200 V	1200 V	1200 V
Specific Impulse	3300 s	3300 s	3300 s	3300 s	3500 s
Total Power Input	530 W	780 W	1516 W	2407 W	5537 W
Development Status	Qual. in 1997	Delta qual.	BB in test	Concept	BB/EM in test
Application to:					
Micro-Gravity	X	X			
Stationkeeping	X	X	X	X	X
Orbit raising			X	X	X
Interplanetary Missions			X	X	X

- Anti-Earth arrangement

4 thrusters are installed on the satellite, 2 in North- and 2 in South direction, thrusting through the center of mass of the satellite. The inclination angle versus the N/S-axis is about 45°.

Thrusting is necessary around both nodes to compensate the in-plane disturbance of the thrust vector. This arrangement is used for Artemis.

- East-West arrangement

In this arrangement two thrusters are operating in parallel. The thrust vectors do not meet the center of mass of the satellite, therefore the thrusters can be mounted at a lower angle of incidence with respect to the N/S-axis (e.g. 35°) and therefore will work with higher efficiency.

The thrusters generate a resulting thrust vector in the required axis. In-plane disturbances are automatically compensated.

This allows the performance of N/S stationkeeping in one or in both nodes.

4.2 Lifetime Considerations

The necessary operation time for a thruster to perform N/S stationkeeping versus the satellite mass at begin of life (BOL) in orbit for the RIT thrusters is shown in Fig. 4-2 for the Anti-Earth configuration. For qualification purposes the necessary demonstration of lifetime has to be increased by a factor of 1.2 to 1.5. Lifetime demonstatration might become an important factor for the selection of the thrust level because it is expensive and takes time. We estimate that within one year (8760 h) the demonstration of about 6600 h (75 % efficiency) will be possible considering a cyclic operation and some time to refurbish the vacuum testfacility. Demonstration of 20,000 h would then take about 3 years.

Accelerated lifetime tests are cetainly possible by changing the operation parameters and/or changing the environmental conditions, but the relation between the erosions in both conditions are not easy to compare.

With respect to the RITA thrusters for a satellite of 2500 kg at BOL in orbit the operation time for 15 years mission time is as follows:

- RITA 10, 15 mN	23,000 h
- RITA 10, 25 mN	14,000 h
- RITA 15, 50 mN	7,000 h
- RITA 18, 80 mN	4,500 h
- RITA 26, 200 mN	1,750 h

The lifetime expectancy for RITA has been assessed according to a 2500 h preliminary lifetime test and to calculations by a special computer program to be more than 25.000 h.

A lifetime test on a RITA thruster qualification model with 15 mN will start soon for a real-time demonstration of 15.000 h.

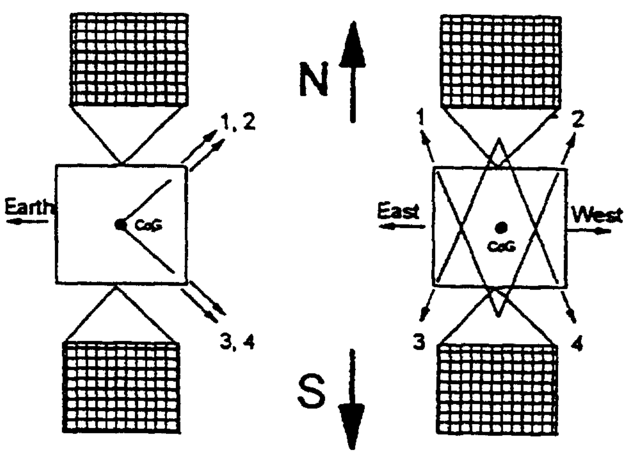

Fig. 4-1: Thruster Arrangements for NSSK

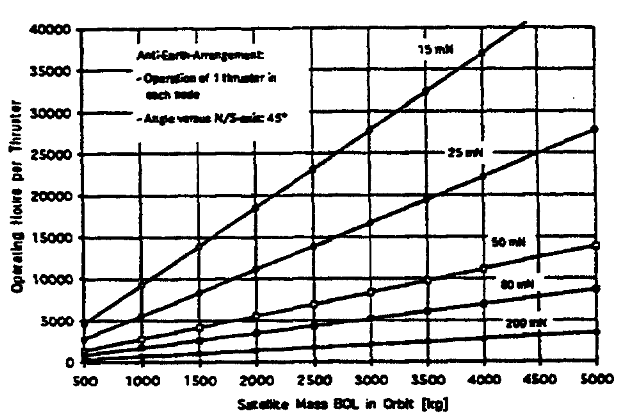

Fig. 4-2: Lifetime of thrusters

4.3 RITA Blockdiagrams

Depending on the arrangement of the thrusters on the satellite for N/S stationkeeping different requirements can occur on the units of the electric propulsion system.

To simplify the system and to decrease mass and cost for commercial application the reduction of the number of power supplies will be necessary.

Fig. 4-3 shows the electric propulsion system blockdiagram for the Anti-Earth configuration. In this case one thruster will be operated at a time and in each node. For this arrangement it would be useful to use one electronic box (PSCU) with a switching matrix which allows to operate one thruster out of two for redundancy.

One Flow Control Unit (FCU) will be able to supply one of the two thrusters as well. The FCU is designed to operate directly from the tank pressure. A separate additional pressure reduction unit is not necessary.

Each thruster will have its own RF-Generator.

Fig. 4-4 shows the correspondent blockdiagram for the East-West arrangement. In this case two thrusters will be operated in parallel. Therefore the electronic box should be designed to be able to operate 2 thrusters in parallel. The other units will be arranged in the same way as in Fig. 4-3.

5. RITA Application Aspects

5.1 RITA 10 for N/S-Stationkeeping

Based on the long experience with the 10 cm ionizer diameter thruster with the testflight on EURECA in 1992 (10 mN) and the development and qualification for Artemis (15 mN) the qualification of a commercialized thruster system with 25 mN thrust level will be possible with a low effort. An improved grid geometry for optimum ion beam current extraction and a redesign of the electronics for serial fabrication will be necessary.

First estimates did show that the recurring price of a four-thruster system will be competitive with respect to the currently expected market prices.

The time necessary for the technical changes, for the delta-qualification of the units and for the subsystem will take about 2 years. In this case the system would be available on the market in the year 2000.

To keep the time for lifetime demonstration as short as possible the results of the lifetime test for Artemis (15,000 h of cyclic operation, 3 h on 1 h off) will be used to develop an accelerated lifetime demonstration by comparison of the testdata with accelerated testresults supported by a computer programme which allows the calculation of the erosion in the grid system.

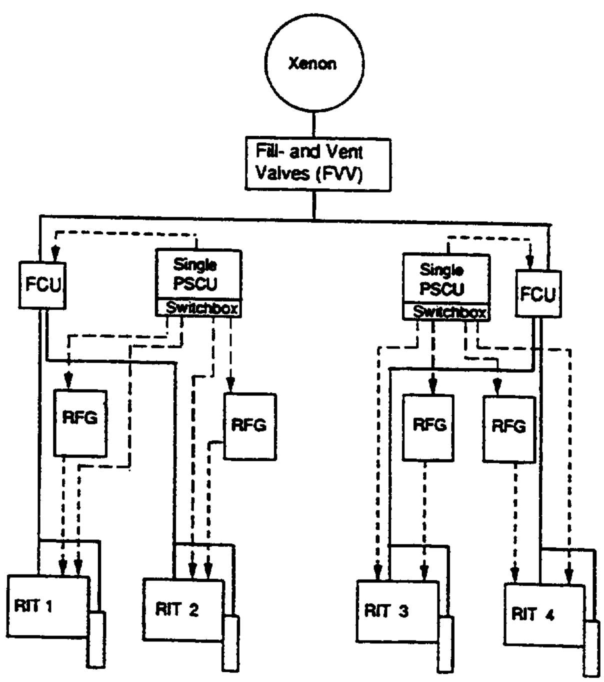

Fig. 4-3: Anti-Earth Arrangement

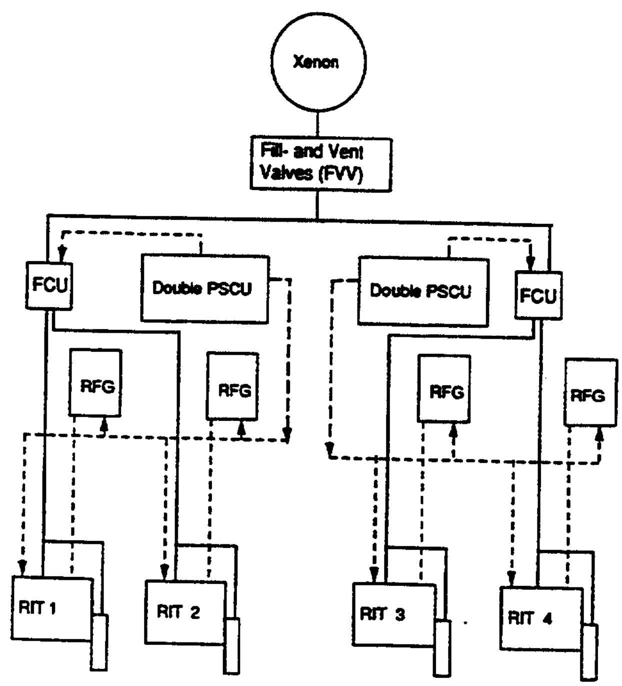

Fig. 4-4: East-West Arrangement

Demonstration of end-of-life operation parameters will help to asses the end-of-life operating conditions.

The mass breakdown of such a system is shown in Table 5-1.

Table 5-1: RITA 10 (25 mN) Masses incl. Margin [kg] for the Anti-Earth Configuration

	Unit	No.	Total
Thruster	1,78	4	7,10
FCU	2,75	2	5,50
RFG	1,20	4	4,80
PSCU	5,50	2	11,00
Gimbal Mech.	-	-	10,10
Tubing	1,00	1	1,00
Harness	1,00	1	1,00
Others	1,20	1	1,20
Total RITA			41,70

5.2 Bigger Ionizer Diameters

Dasa and the University of Giessen have experience with thrusters of discharge chamber diameters up to 35 cm.

Currently a RITA 15, 15 cm ionizer diameter, is operated at the University of Giessen at a maximum thrust level of 50 mN.

Years ago a thruster of 35 cm ionizer diameter has been fabricated at MBB and tested in Giessen. A combination of the RF-ion thruster principle from RIT 35 and the extraction grid system of the UK 25 led to the design of the ESA-XX thruster of 26 cm ionizer diameter, which is able to extract 200 mN of thrust.

This thruster has been built at a Breadboard/EM-Level for further testing, using alumina for the discharge vessel. With this improvement the thruster mass has been reduced to 7 kg.

Using the existing experience Dasa will be able to design, qualify and test a tailored thruster for a thrust level between 50 and 200 mN thrust level in an acceptable time. Ionizer diameters will be 15 cm for 50 mN, 20 cm for 80 mN and 26 cm for 200 mN.

50 to 80 mN could be used to decrease the necessary operation time for N/S stationkeeping and, consequently, the necessary time for the demonstration of lifetime.

The use of the 26 cm ionizer diameter thruster with 200 mN would allow orbit raising and, in combination with gimballed mounting, N/S stationkeeping, eventually with decreased thrust level, with the same equipments.

Table 5-2 shows the masses of 4-thruster systems for discharge chamber diameters 15 to 26 cm.

Table 5-2: RITA (15 to 26 cm ionizer diameter) Masses incl. Margin [kg] for the Anti-Earth Configuration

	No.	RITA 15	RITA 18	RITA 26
Thruster	4	12,00	16	32
FCU	2	5,50	5,5	5,5
RFG	4	6,00	7	10
PSCU	2	14,60	20,6	37
Gimbal Mech.		11,00	12	13
Tubing	1	1,00	1,00	1,00
Harness	1	1,00	1,00	1,00
Others	1	1,20	1,20	1,20
Total RITA		52,30	64,30	100,70

6. RITA General Advantages

RITA has the following advantages with respect to other thruster concepts:

- No electron emitter necessary

  The RF-ionization principle uses an RF-field in the range of 1 MHz for the ionization of the propellant in the discharge chamber. Electrons existing in the discharge chamber or drawn into it from the neutralizer plasma will be used to generate the necessary collosions with the neutral atoms.

- Neutralizer extremly reliable

  The emitter in the hollow-cathode neutralizer has been developed for the Travelling Wave Tubes and has therefore a long heritage in performance and lifetime.

- 3-grid system used

  The acceleration of the ions in a 3-grid system results in a

  - constant exhaust velocity of the ions
  - accurate thrust vector direction
  - small beam divergency for high flexibility of the

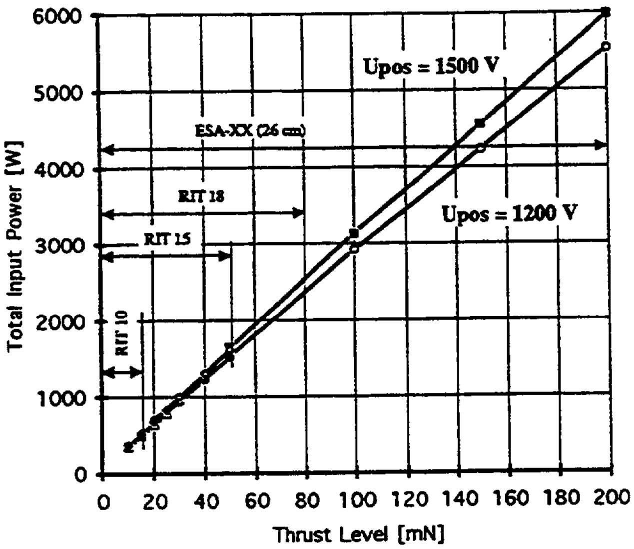

Fig. 6-1: Total Power Input for RITA Thrusters

thruster arrangement on the satellite

- low accel electrode erosion

• Simple thrust level regulation

The ion beam current can easily be adjusted by regulation of the RF-power to the thruster: Fig. 6-1 and 6-2 show the total power input and the specific impulse during throttling for the the 4 discharge chamber diameters.

• Step-wise switch-on of the thruster functions has lower impact on the satellite power subsystem

• Accel electrode made of graphite for long lifetime

• Simple flow controller, can operate directly from the tank pressure as a single stage pressure regulator.

• Most leightweight system mass. Can save 141 kg with respect to a comparable system of 4 SPT's for a 3500 kg launch mass satellite, 15 years mission time.

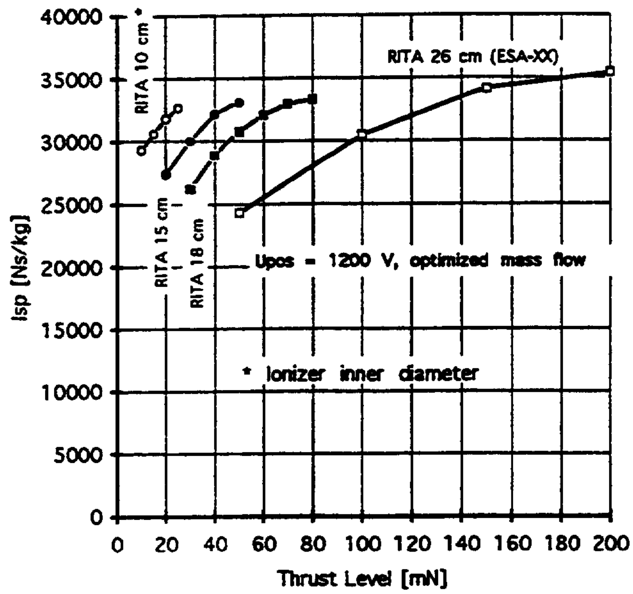

Fig. 6-2: Total Specific Impulse for RITA Thrusters

7. Summary

The RF-ion thrusters RITA have been under development in Germany for many years. The most advanced thruster with 10 cm ionizer diameter can be made available for commercial application with updated thrust (25 mN) and a redesign of the electronics for serial fabrication. This thruster system can be easily implemented on existing satellite busses and could be available on the market within 2 years.

If higher thrust levels are required to reduce the operation time of the thrusters and/or orbit raising has to be considered, thrusters with increased ionizer diameter have to be applied. Thrust levels up to 200 mN at a specific impulse of above 3000 s will then be available.

The RF-ion thruster principle has a number of advantages with respect to its competitors like the electron bombardement thrusters and the SPT's and will be therefore a candidate for commercial application.