Appendix N

N92-10053

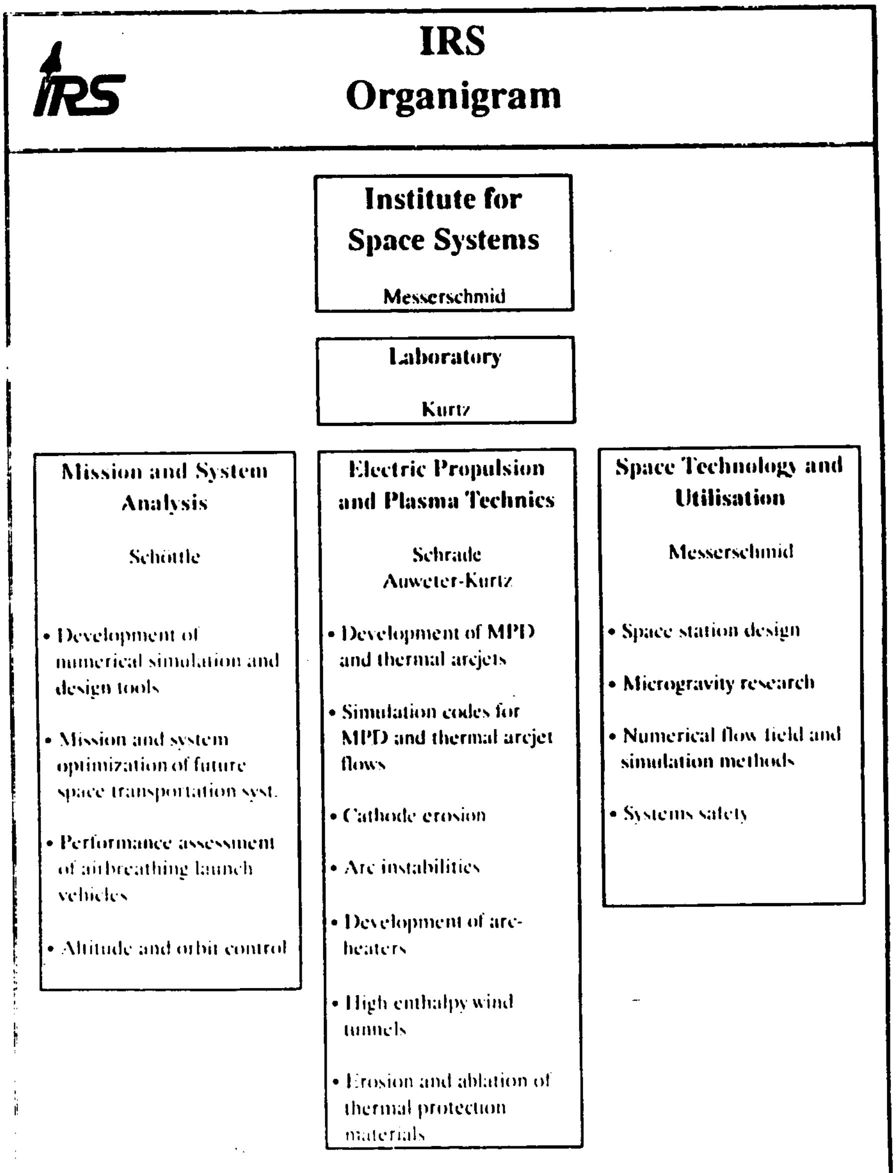
MPD Thruster Technology Workshop

NASA H.Q., Washington D.C.

16 May 1991

IRS Presentation

E. Messerschmid



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Electric Propulsion and Plasma Wind Tunnel

IRS

Activities at the IRS

May 1991

Activity / Thruster	MPD (Selffield)	Arcjet			Reentry (Material-Tests)		Missions, Trajectories
Power Level Isp [km/s] Thrust [N] Propellant	100 kW-1 MW 10 - 20 5 - 20 Ar,N_2,H_2,NH_3	1 kW 5 - 6 0.1 NH_3, H_2,N_2-H_2	< 20 kW < 10 > 1 N_2-H_2, H_2	< 100 kW 10 - 15 > 10 NH_3, H_2	$h_0 < 10^8$ J/kg		
Theories	Flowfield Stability Arc-Attachment Erosion	Constrictor Flow Heat Transport					Traject. - Optimizat.
Diagnostics	Emission Spectroscopy, el. Probes, Fabry-Perot Interferometry, Mechan. Probes, Mass Spectroscopy, Optical Temparature Measurement						
Status	Water Cooled Laboratory Devices	Radiation Cooled Lab. Model	Water Cooled Devices	Water Cooled Devices	PWK1 - IRS Operat. since 1987	PWK2 - IRS Operative	in Work
Contractors	USAF DFG BMFT	DARA		NASA (IST)	ESA / CNES, AMD-BA, AS, SEP, DO, MBB, MAN, DLR	DARA SFB ESA, FGE	

IRS Facilities

High DC Power Supply:

Power: ≤ 6 MW
Current: ≤ 48 kA
Ripple: ≤ 1 %

Vacuum System:

Four Stage Pump System:

1) 3 MTP 50.000 m^3/h roots pumps
   1 Alcatel 120.000 m^3/h roots pump

2) 1 MTP 50.000 m^3/h roots pump

3) 1 multiple slide valve type pump RV 500

4) Rotary vane pump BA 600

Total suction power: >200.000 m^3/h at 10 Pa
Tank pressure can be set

Vacuum tanks:

8 tanks connected to vacuum system

6 for plasma accelerator development
2 plasma wind tunnels

2 independent test stands for smaller thrusters or basic experiments

History of MPD Activities at IRS

1976	Begin of Building-Up of IRS Propulsion Laboratory
1982-1991	Cooperation Grants "Basic Processes of Plasma Propulsion" from AFOSR (analytical and numerical).
1982-1991	Cooperation Grants with interruptions "MPD Thruster Development" from AFRPL, AFOSR. 1987-1988 financed by the SDIO over ONR (experimental and numerical).
1989-1991	"MPD Thruster Instabilities", contract by the German Research Organisation DFG (theoretical studies).
1990-1993	"Plasma Instabilities in MPD Thrusters", contract by the German Ministry of Research BMFT (numerical and experimental; together with MAN).

History of Thermal Arcjet Activities at IRS

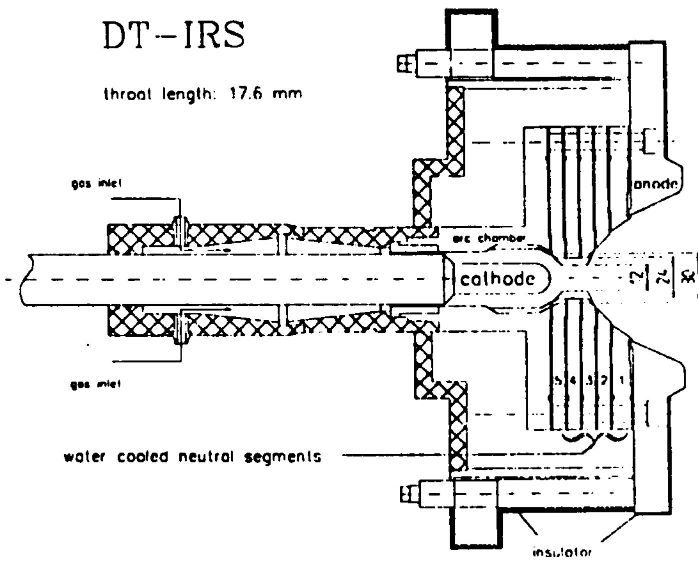
1986-1990 "Arcjet Flow Analysis", contract by ESA/ESTEC (analytical and numerical).

1987-1990 "1 N Arcjet", sub-contract by ESA/ESTEC (experimental), main-contractor BPD, Italy.

1989-1991 "High Power Arcjet", Cooperation Grant by NASA (IST) (experimental and numerical studies).

1990-1993 "A 1 kW Hydrazine Arcjet", contract by the German Aerospace Agency DARA (together with MBB).

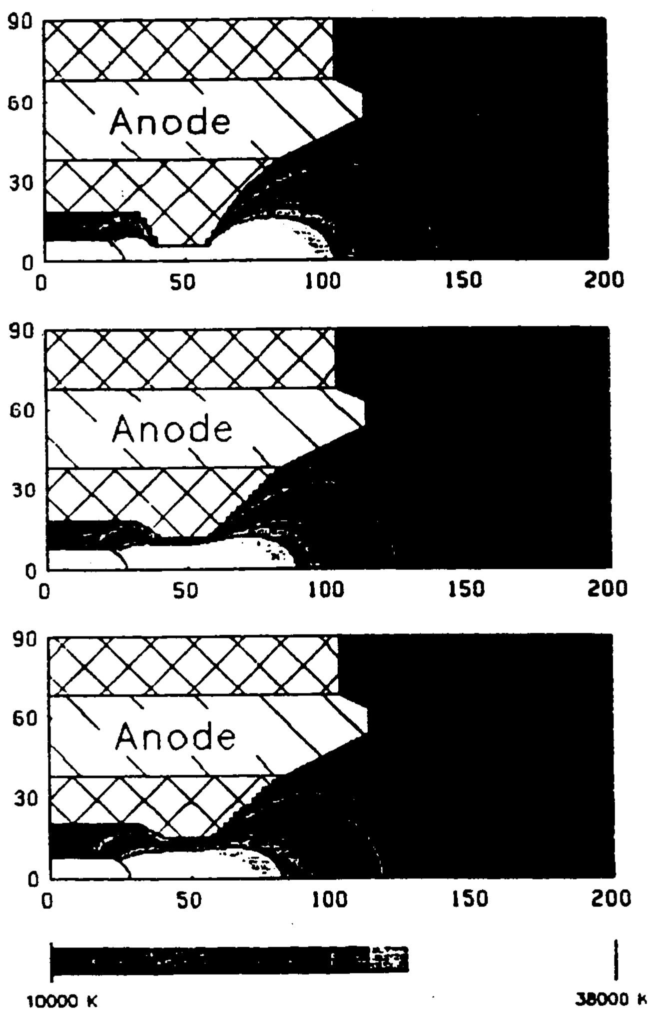
IRS Nozzle Type Thruster DT-IRS



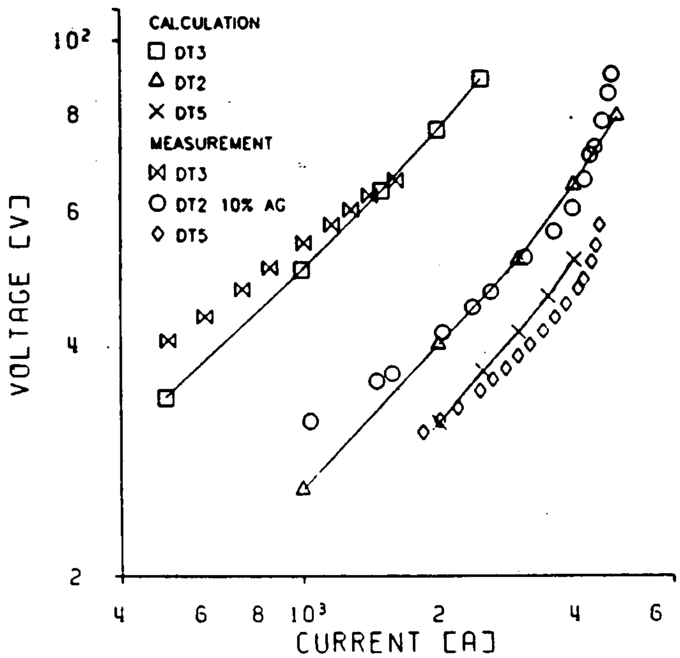
Configuration of the DT-Thrusters with different throat diameters

Maximum values reached with the DT2-Thruster with argon as propellant:

electrical power:	$P_{el} \leq 800$ **kW**
specific impulse:	$I_{sp} \leq 1500$ **s**
thrust efficiency:	$\eta_t \leq 25\%$



Electron temperature distribution for three different throat geometries at 2 kA currant and a mass flow of 0.8 g/s.



Calculated and measured discharge voltage.

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Nozzle Type MPD Thrusters

1.) Specific impulse limited to 1500 s because of low $\frac{I^2}{\dot{m}}$ - values.
(Onset - Phenomenon)

2.) Efficiency : not more than 30% achieved with experiments.
Expectation with higher massflow rates and higher power:
above 30% .

3.) High power limitations: Heat load of nozzle throat.

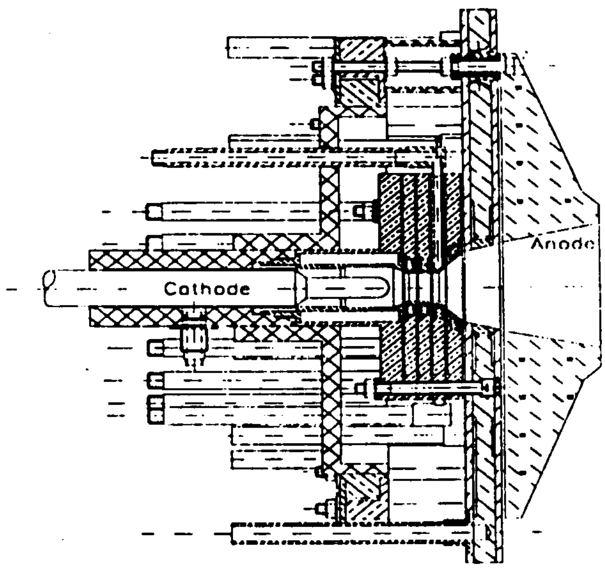
4.) Propellant: no significant difference in η and c_e with Ar, N_2, H_2,
lower $\frac{I^2}{\dot{m}}$ with H_2 and N_2 .

5.) High power limits:
vacuum system (high power ⇒ high mass flow rates)
(Influence of ambient pressure not so important with
selffield MPD's)

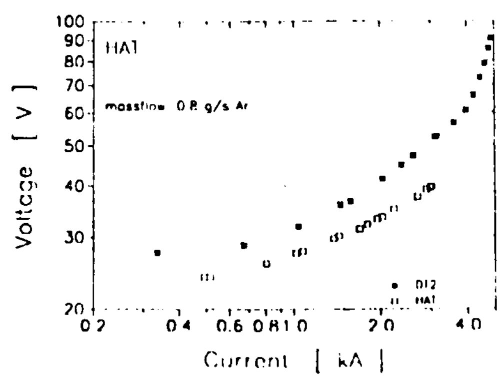
Research plans: Geometry optimization:

- Transition from nozzle to conical (flared) configurations.
- Radiation cooled anode.

Hot Anode Thruster (HAT)



Configuration of the HAT-Thruster with radiation cooled anode



Voltage vs. current dependence for the HAT in comparison with the DT2-Thruster

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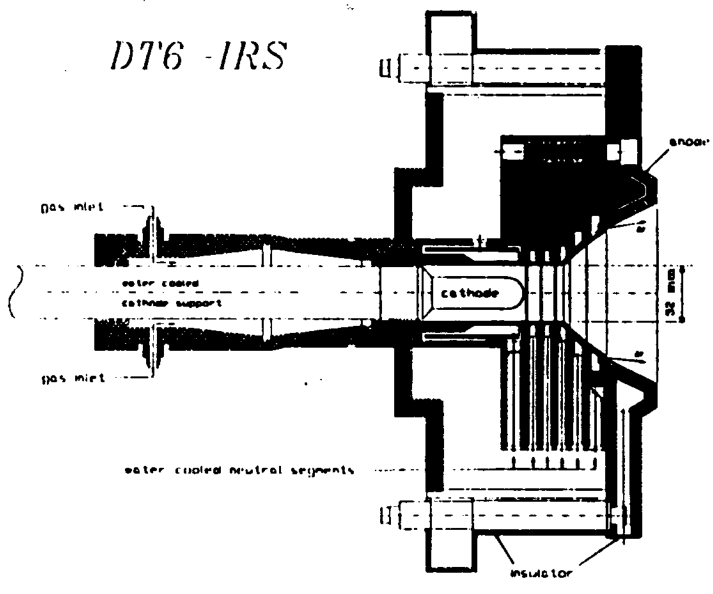
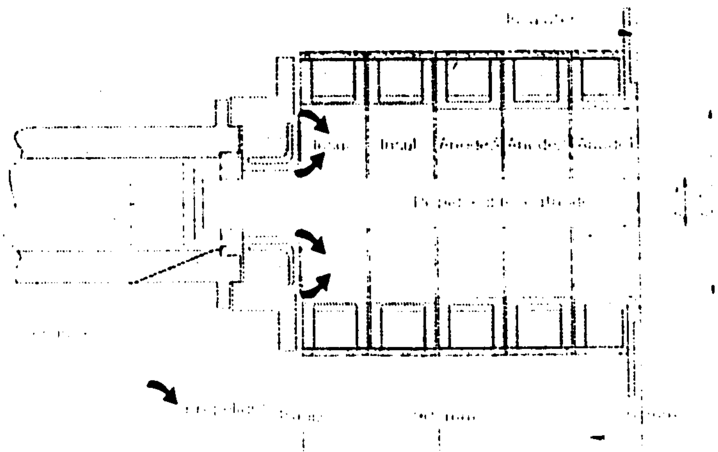
DT6-Thruster

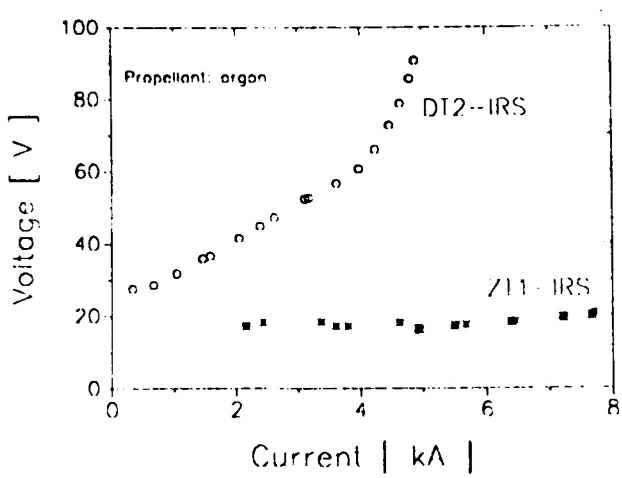


Configuration of the DT6-Thruster without throat constriction
(in construction)

ZT1-Thruster



Configuration of the cylindical ZT1-Thruster



Voltage vs. current dependence for the ZT1- respectively DT2-Thruster with argon as propellant

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Cylindrical MPD thruster

1.) Higher onset ($\frac{I^2}{\dot{m}}$) than with nozzle type thrusters .

⇒ higher specific impulse possible.

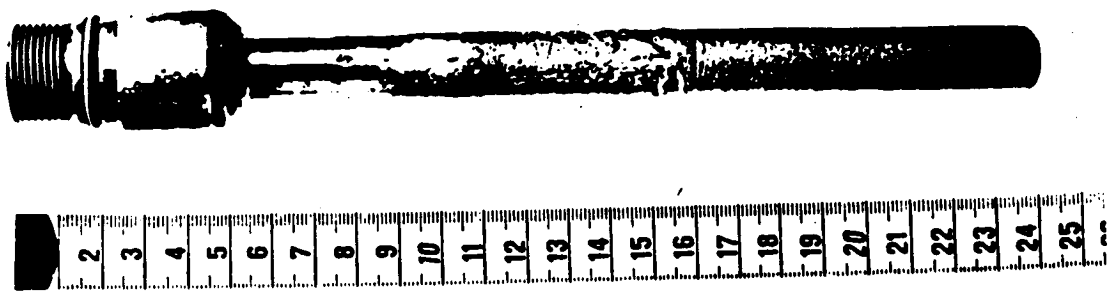
2.) Efficiency with continuous thruster not yet measured.
(Thrust balance in construction.)

3.) Lower voltage levels than with nozzle type thrusters.

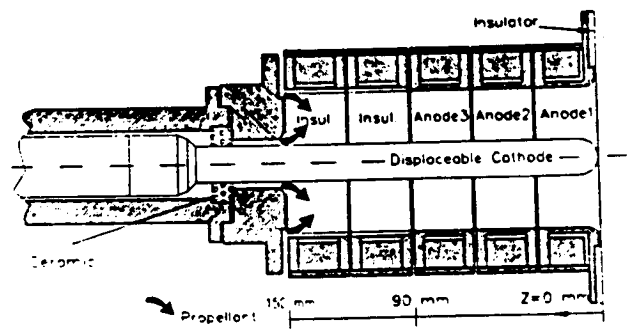
4.) High current issues:

- a) heat loads to anode (~ I)
- b) heat loads to cathode: can be solved by cathode geometrical configuration.

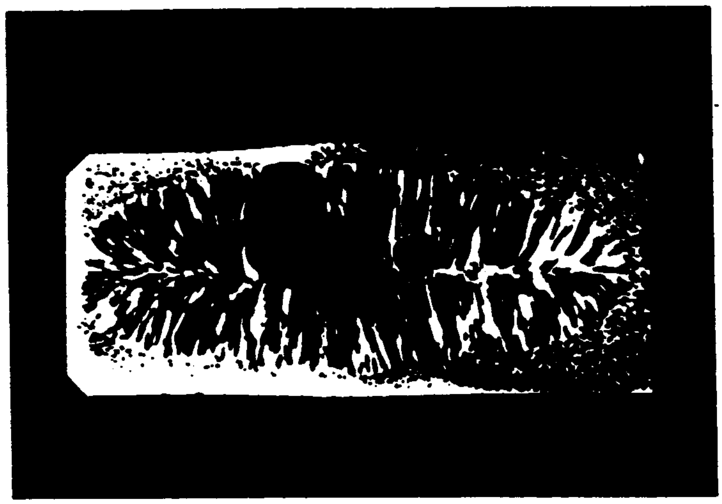
5.) High power limits:
vacuum system (high power ⇒ high massflow rates)
(Not so important with selffield MPD)



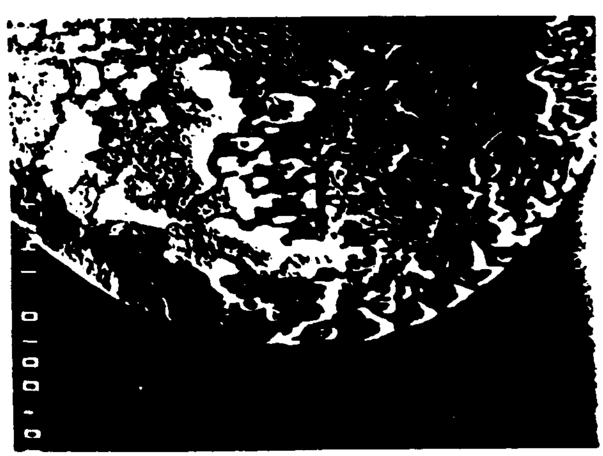
DAMAGED CATHODE OF THRUSTER ZT1



SCHEME OF THRUSTER ZT1



TYPICAL STRUCTURE OF AREA I (MELTED ZONE)



DETAIL OF THE VOID

Comparison

IRS

continuous MPD ⇔ quasi-steady MPD

Biggest problem: different cathode modes:

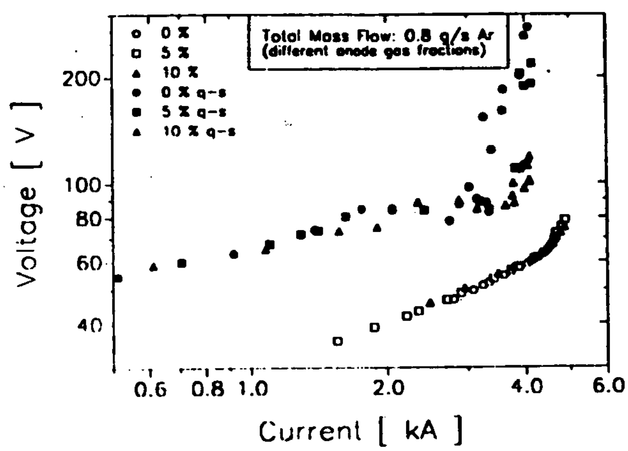
thermionic ⇔ cold

- ⇒ different arc attachments
- ⇒ different voltages
- ⇒ different current distributions

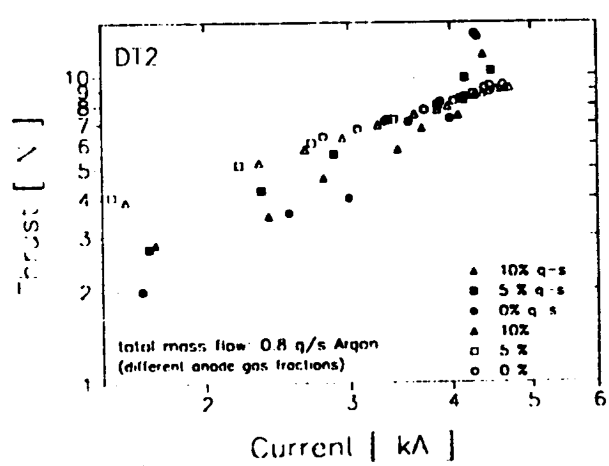
Comparison

IRS

continuous MPD ↔ quasi-steady MPD



Comparison of the voltage vs. current dependence for the continuous DT2-Thruster (open signs) and the quasi-steady MPD-Thruster (Closed signs)



Thrust vs. current curves for both thrusters

MPD-Thrusters

1.) Nozzle Type MPD-Thrusters (DT-IRS serie)

- Geometrical optimisation of the nozzle
  (experimental and numerical)

- Investigation of the plasma instabilities
  (experimental and numerical)

2.) Hot Anode Thruster (HAT)

- Reduction of the anode losses

3.) Cylindrical Thruster (ZT-IRS)

- Thrust measurments will hopefully resulting in

higher c_e !

IRS — MMW-Thrusters

MMW thruster have to be cooled actively (at least partly).

Cathode heat loads could be solved by geometrical configuration.

How to address these issues:

1.) Measure heat loads in cooled devices and surface temperatures.

2.) Establish thermal models (numerical).

3.) Numerical variation of geometries and configurations.

4.) Validate with new device.

IRS — Facility requirements

1.) Vacuum:

- for selffield MPD better 1 mbar
- for applied field MPD better 10^{-3} mbar

2.) Thrust balances for MMW-Thrusters are difficult to realize.