Liquid Jets for Disruption Control

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Liquid Jets for Fast Plasma Termination

- P. B. Parks, M. N. Rosenbluth, S. V. Putvinski, and T. E. Evans, "High-Velocity Liquid Jet Injection into Tokamak Plasmas for Disruption Mitigation," *Fusion Technology* **35**, 267-279 (1999)
- Plasma disruptions are a critical issue for large next step tokamak devices (e.g. ITER) because they can affect the lifetime of plasma facing components and may cause serious damage to these structures
- Injecting impurity pellets can remove the plasma heat and stored magnetic energy by intense radiation cooling before the plasma comes in contact with the wall
- Killer pellets, however, can produce runaway electrons that can amplify into multi-mega-electron-volt runaway current that can also seriously damage in-vessel components
- Deuterium pellets could be used but ITER would require a 40-g (3 in diam.) 1km/s deuterium ball traveling >1 km/s or 500 1-cm diam. deuterium pellets delivered in <100 ms
- A single liquid deuterium jet 2.6 mm diam. 877 m/s acting for 15.6 ms was proposed for ITER

Parks' Helium Jet Device Concept

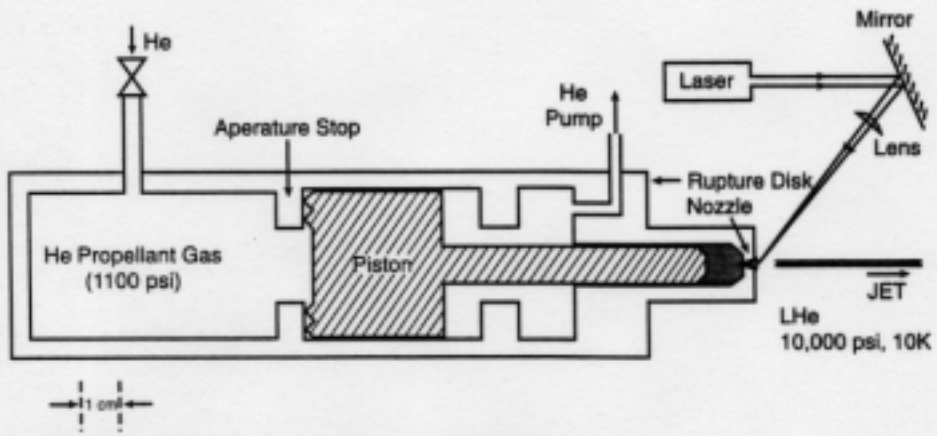

Fig. 9. Schematic of a conceptual pulsed liquid helium injector. Laser warming is used to burst open a rupture disk placed over the nozzle opening. This instantaneous valve opening technique allows a constant pressure pulse during the brief ~3-ms injection period. The jet velocity is 777 m/s for reference DIII-D plasma conditions.

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LJET Design Parameters for DIII-D

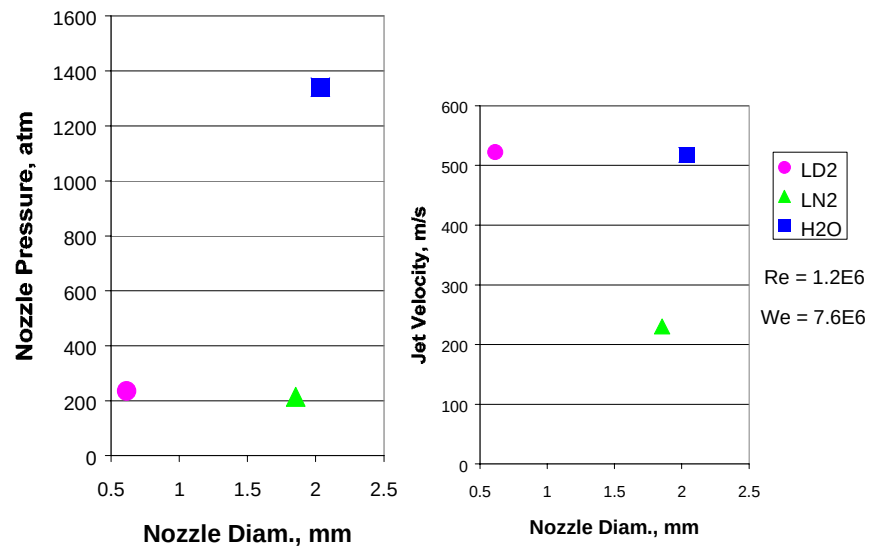
Parameter	Single Jet	Three Jets
Central electron temperature, T_0	4 keV	6 keV
Electron density, n_0	10^{14} /cc	10^{14} /cc
Δ_{ne}	20 n_0	40 n_0
Jet velocity	522.5 m/s	571 m/s
Jet diameter, D	0.61 mm	0.50 mm
Jet injection time	6.22 ms	5.69 ms
Jet volume	0.965 cc	0.643 cc
Distance to Plasma Center, L	1.3 m	1.3 m
L/D	2100	2600
Reynolds number, Re	1.2×10^6	1.1×10^6
Weber number, We	7.6×10^6	7.4×10^6
Pressure	236 atm	282 atm

$$Re = \rho\, v\, D / \mu$$
$$We = \rho\, v^2\, D / \sigma$$
$$P = \rho\, v^2/2$$

Scaling for Equal Re and We

$$v_1 / v_2 = \mu_2\, \sigma_1 / \mu_1\, \sigma_2$$

$$D_1 / D_2 = \rho_2\, \mu_1^2\, \sigma_2 / \rho_1\, \mu_2^2\, \sigma_1$$



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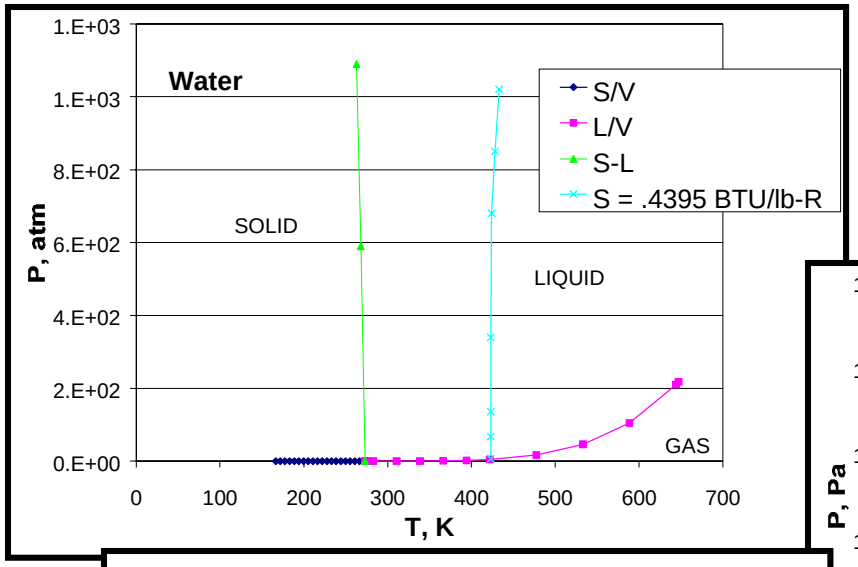
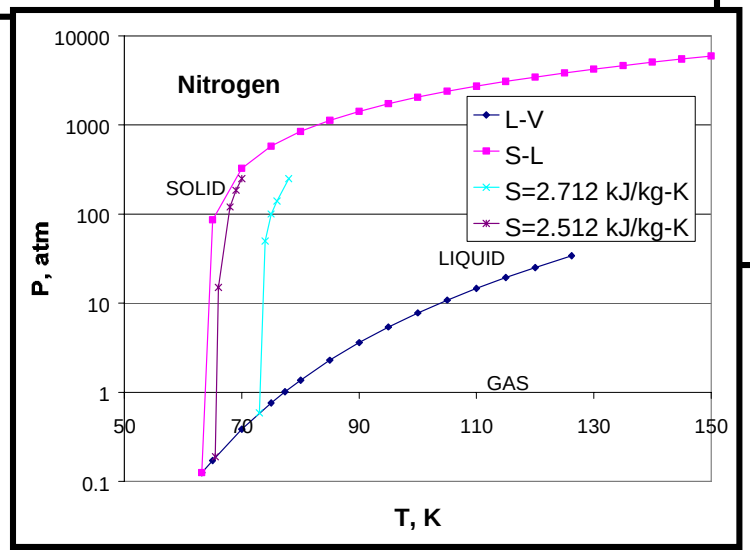
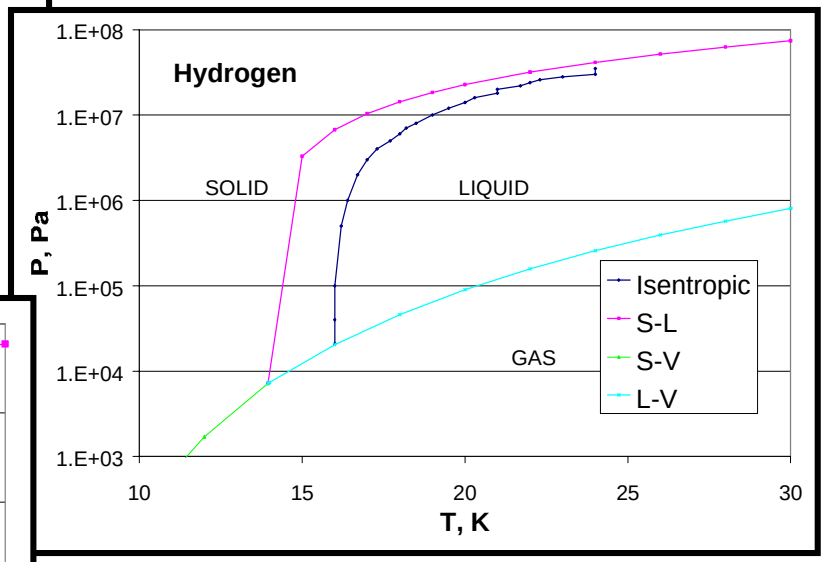
Ideal Nozzle Flow is Isentropic







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General Liquid Jet Performance

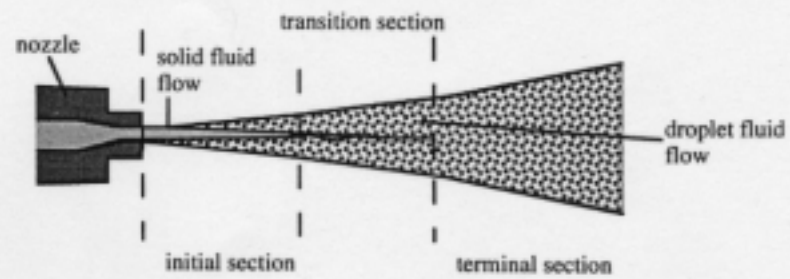

Figure 11.3 Change in jet structure with distance from the nozzle [11.4].

Turbulent Jet

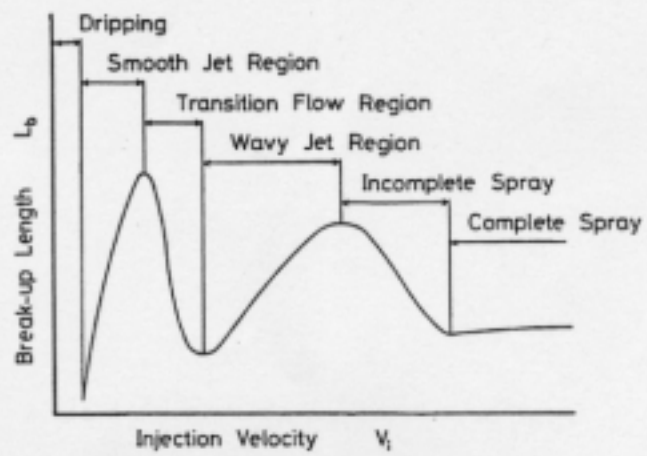

Fig. 1 Breakup behavior of a liquid jet.

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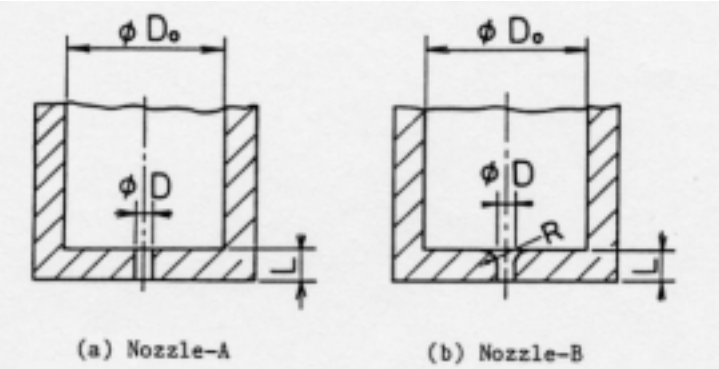
Arai Jet Data



(a) Nozzle-A (b) Nozzle-B

Fig. 2 Specification of nozzles

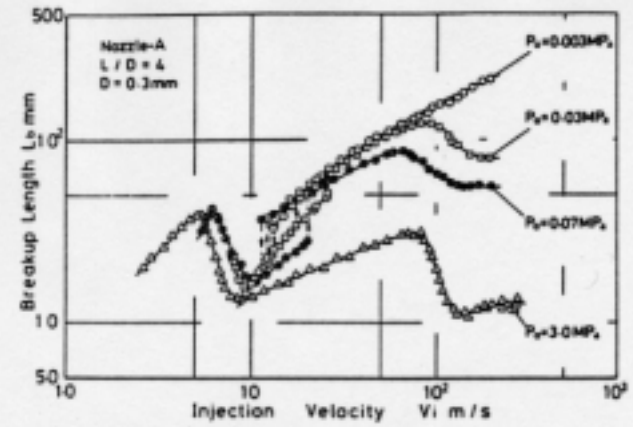


Fig. 7 Effects of ambient pressure for Nozzle-A, L/D=4 under D=0.3mm

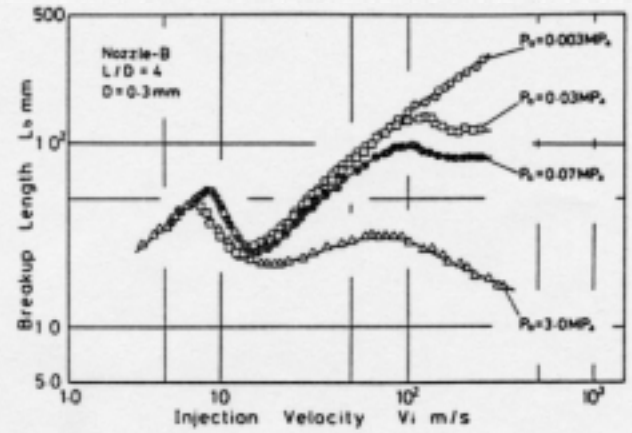


Fig. 8 Effects of ambient pressure for Nozzle-B, L/D=4 under D=0.3mm

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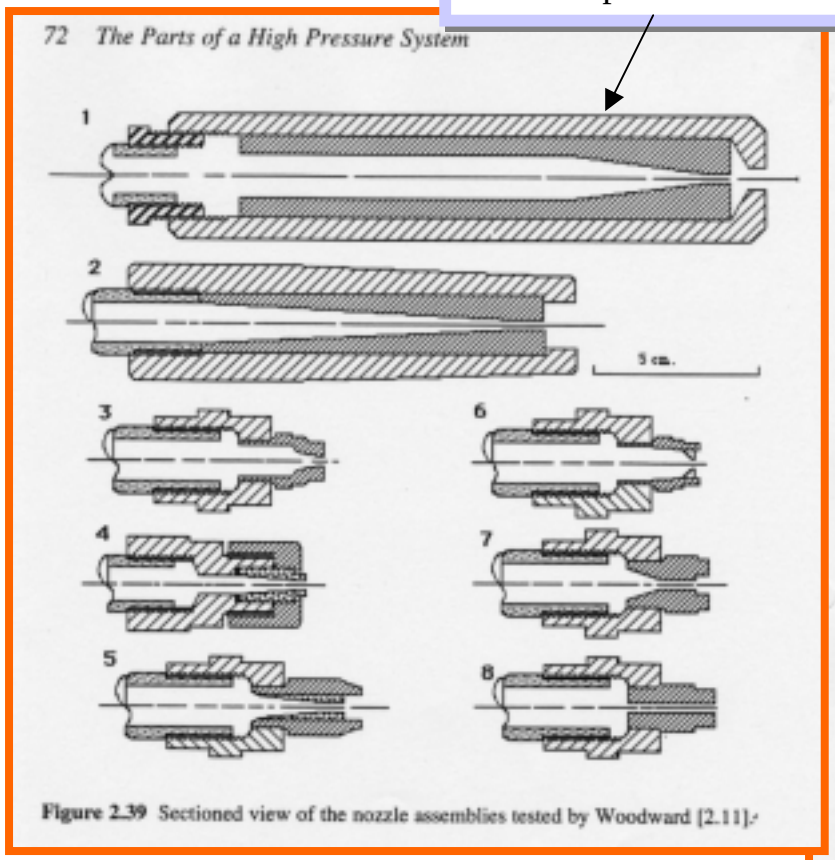
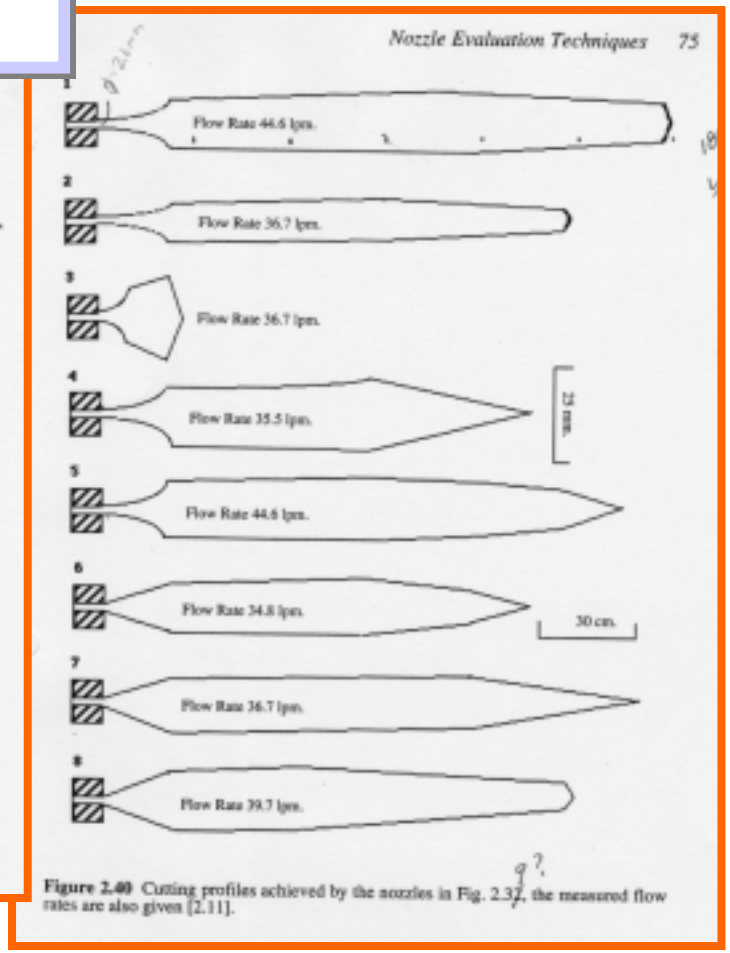
Comparison of Several Cutting Nozzles

Leach and Walker 13° nozzle will be used in initial experiments





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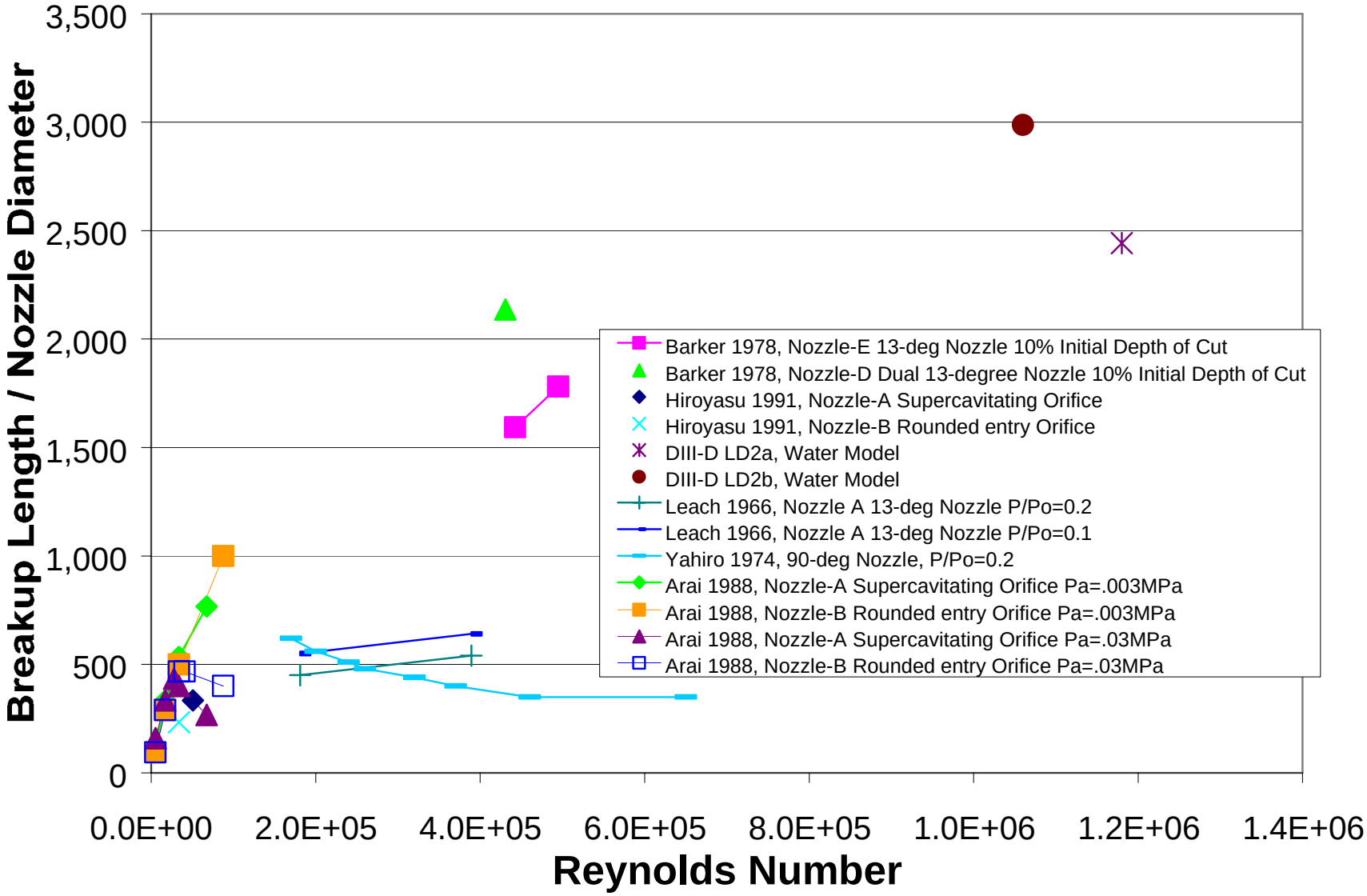
Nozzle Data from Literature



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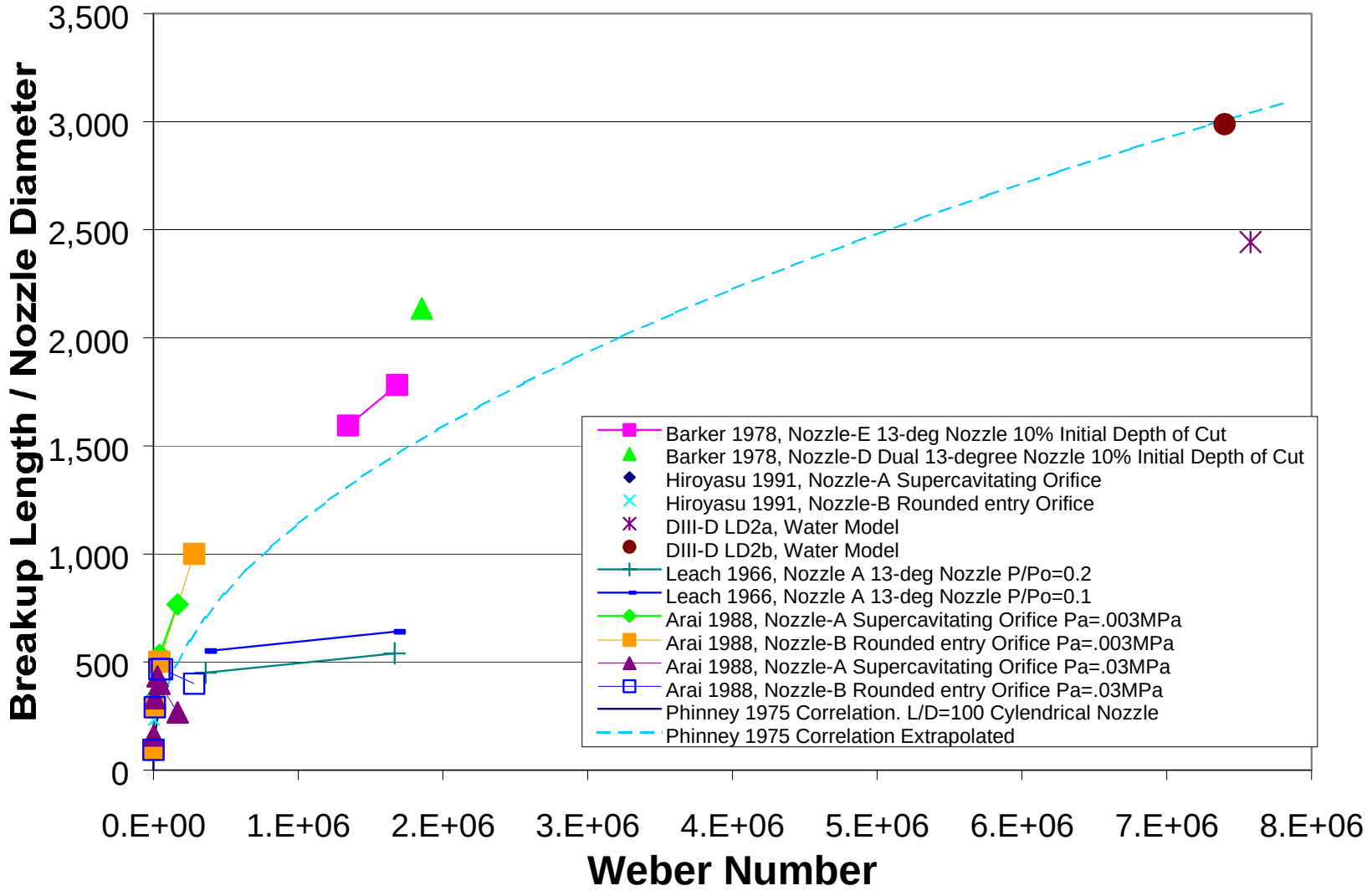
Nozzle Data from Literature



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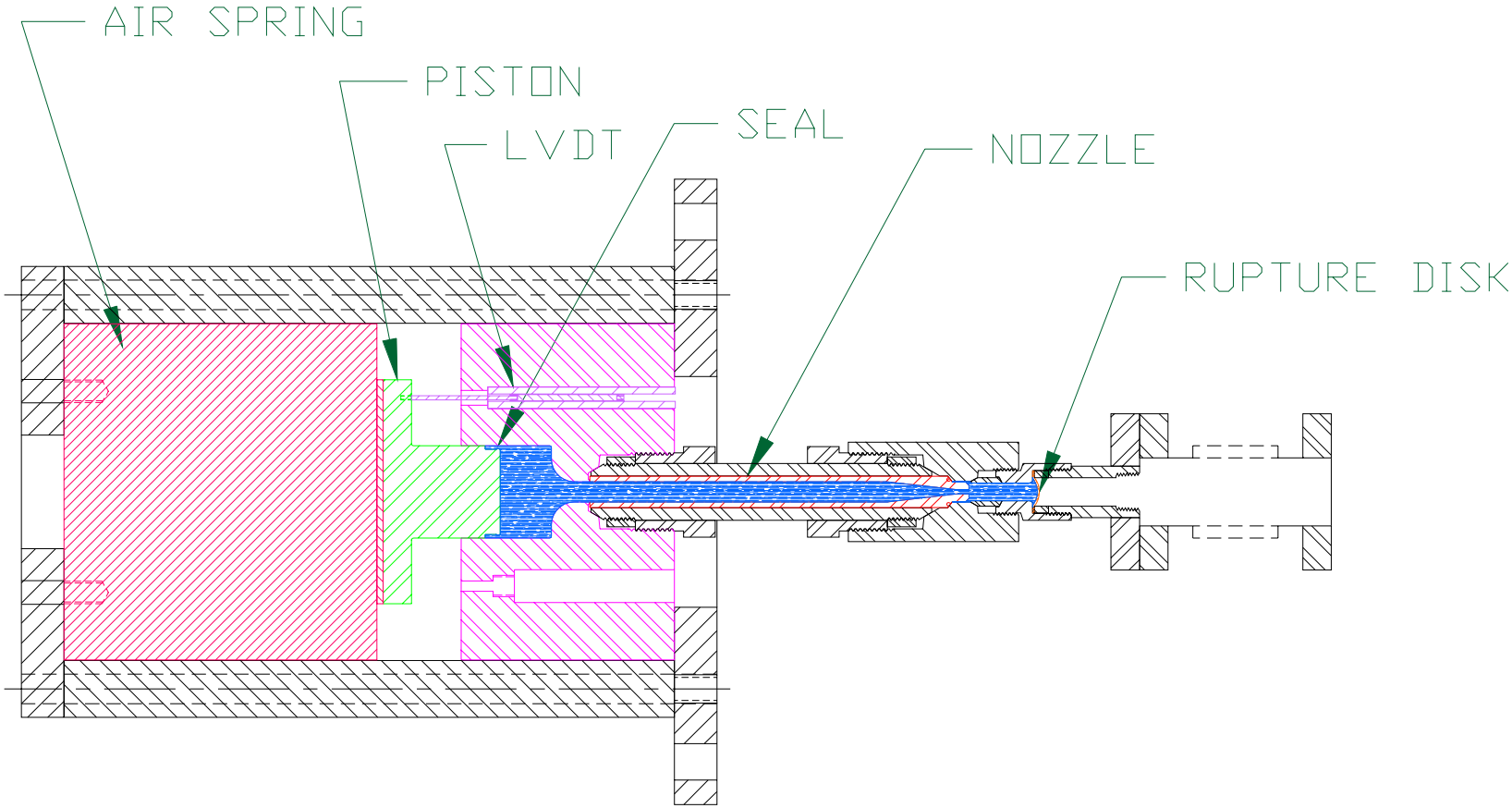
LJET Water Jet Device



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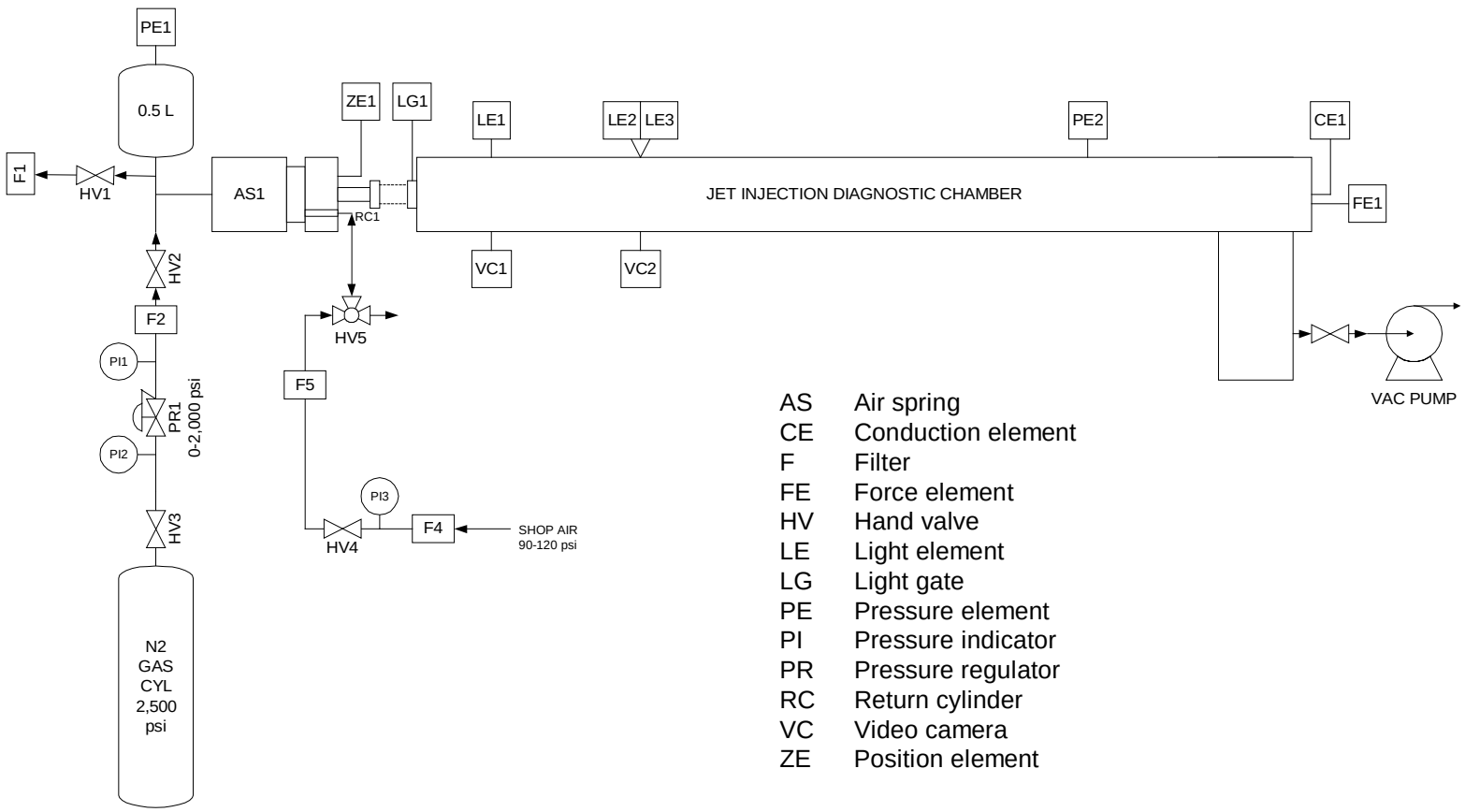
LJET P&ID



AS	Air spring
CE	Conduction element
F	Filter
FE	Force element
HV	Hand valve
LE	Light element
LG	Light gate
PE	Pressure element
PI	Pressure indicator
PR	Pressure regulator
RC	Return cylinder
VC	Video camera
ZE	Position element

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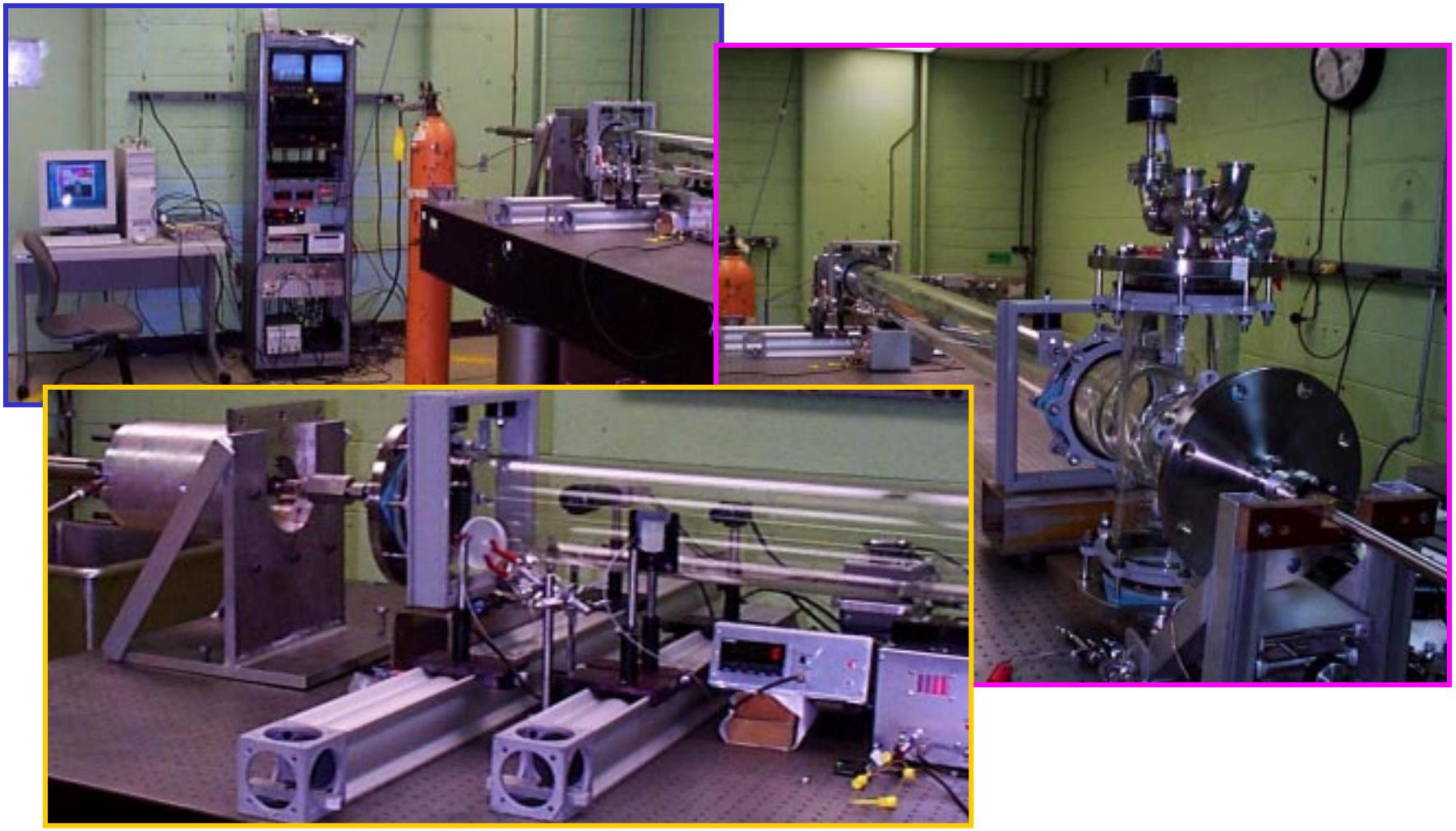
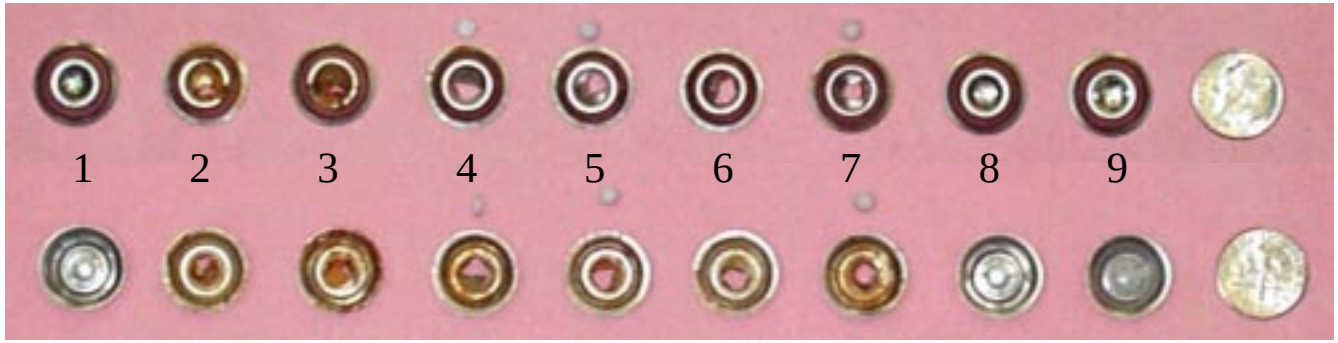
LJET Apparatus



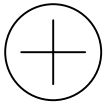
LJET Rupture Disks



Upstream Side

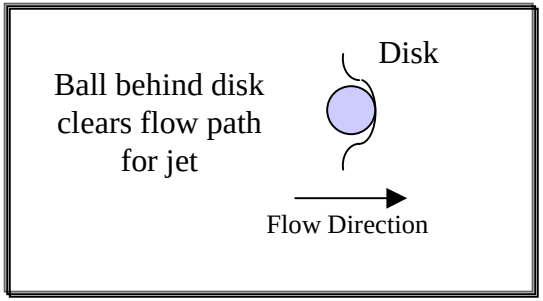
Downstream Side

Number	Type	Pressure, psi	Opening
1	Cross Scored		New disk
2	Cross Scored	5,000	One petal (1/4)
3	Cross Scored/Teflon Disk	10,000	One petal (1/4)
4	Cross Scored/Teflon Ball	5,000	Two petals (1/2)
5	Cross Scored/Teflon Ball	5,000	> One petal (1/3)
6	Circular Scored/Teflon Ball	5,000	> One petal (1/2)
7	Circular Scored/Teflon Ball	10,000	Circular scored area
8	Circular Scored		New disk
9	Larger Circular Scored		New disk



Cross Scored

Circular Scored



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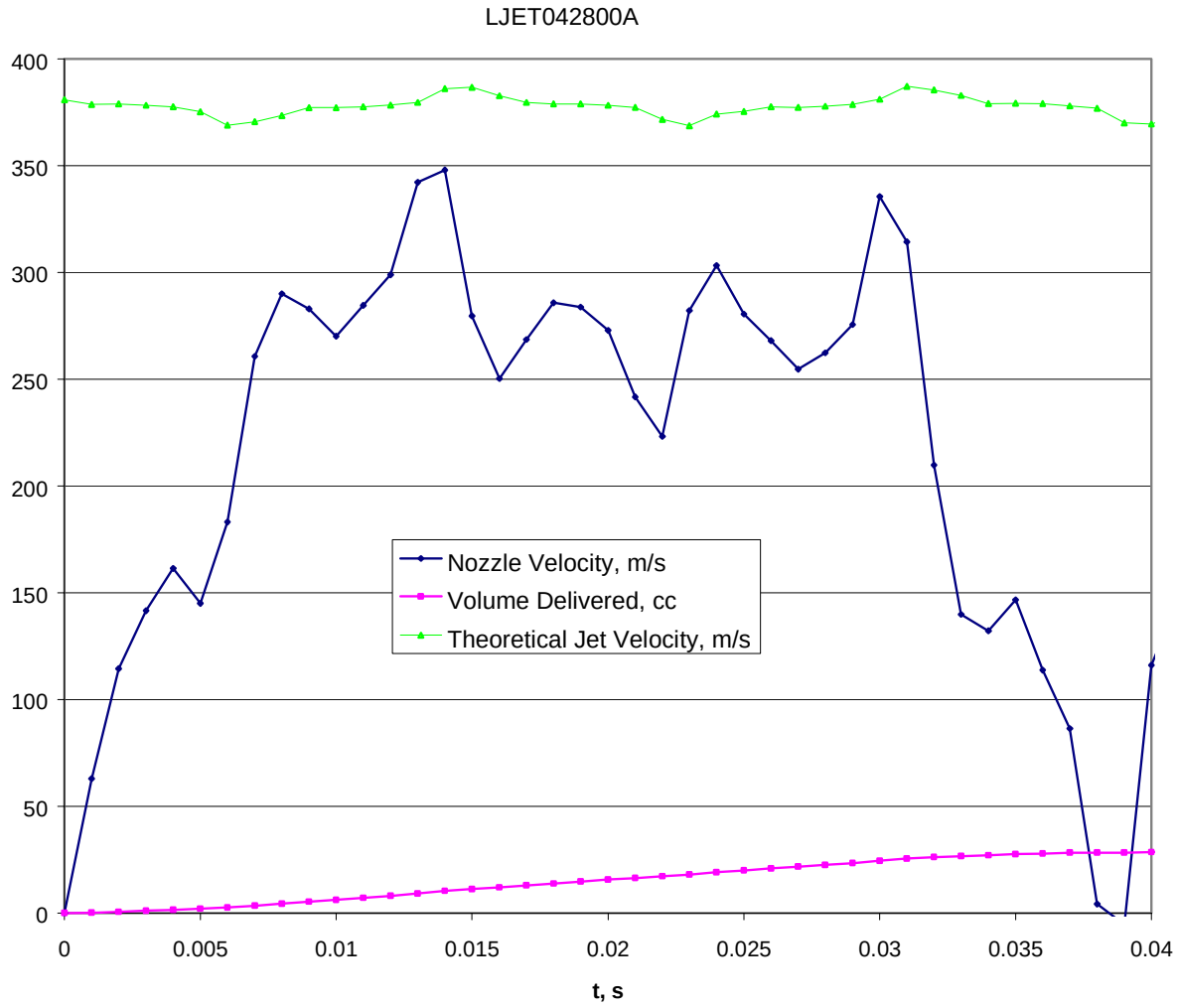
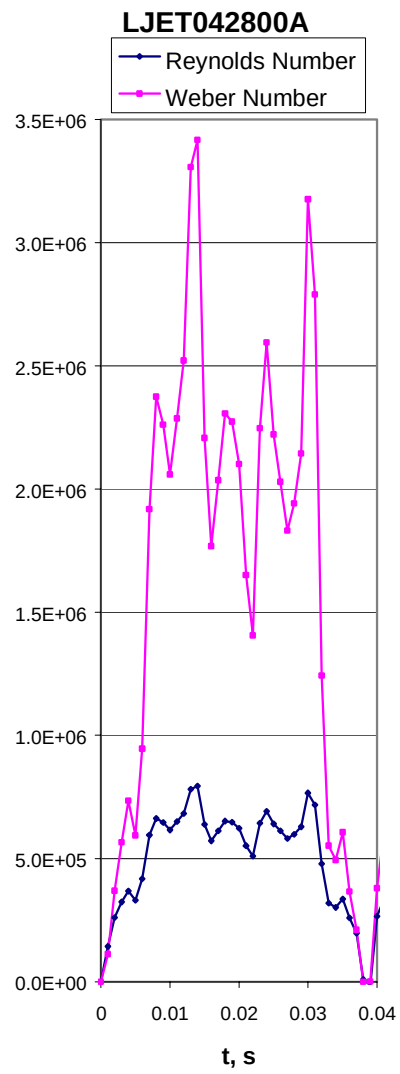
Typical Preliminary Results





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Liquid Jets for Disruption Control

- Experimental work at ORNL involves a staged approach using model systems for development of the liquid hydrogen jet system
- Water jets with the same Reynolds (~10^6) and Weber (~10^7) numbers as the LD_2 jets will be used for development of nozzles and injector concepts with a goal of reaching the required 2000-3000 jet diameters of useful jet
- Liquid nitrogen jets will be used to study the additional problem of flashing to vapor
- A prototype liquid jet device will be built and evaluated in experiments at DIII-D