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A survey of drag and heat reduction in supersonic flows by a counterflowing jet and its combinations

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2. Counterflowing jet
3. Combination of counterflowing jet and other techniques
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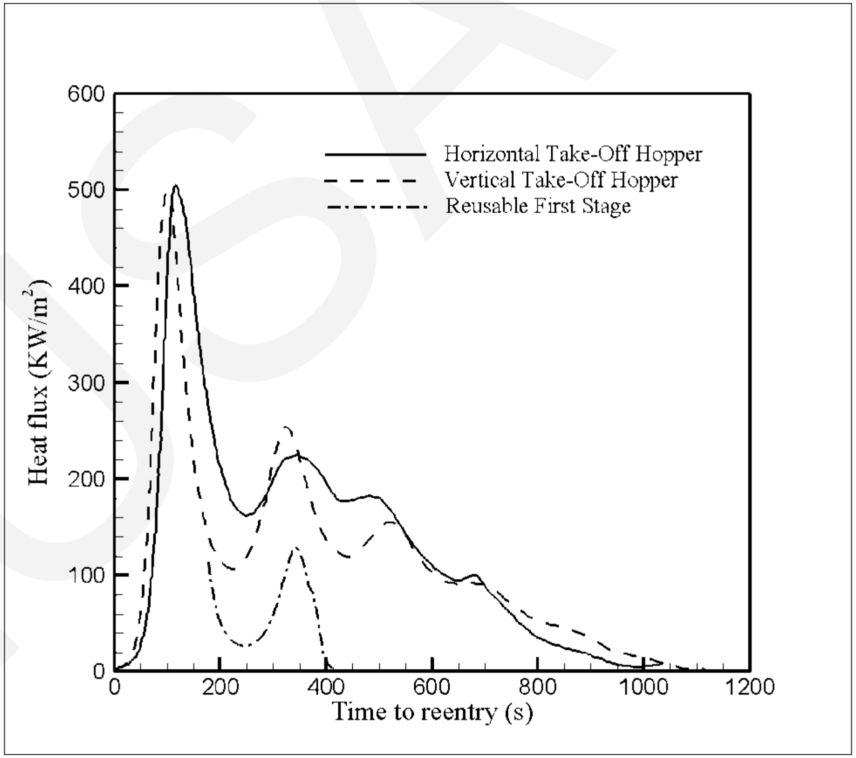
1. Introduction

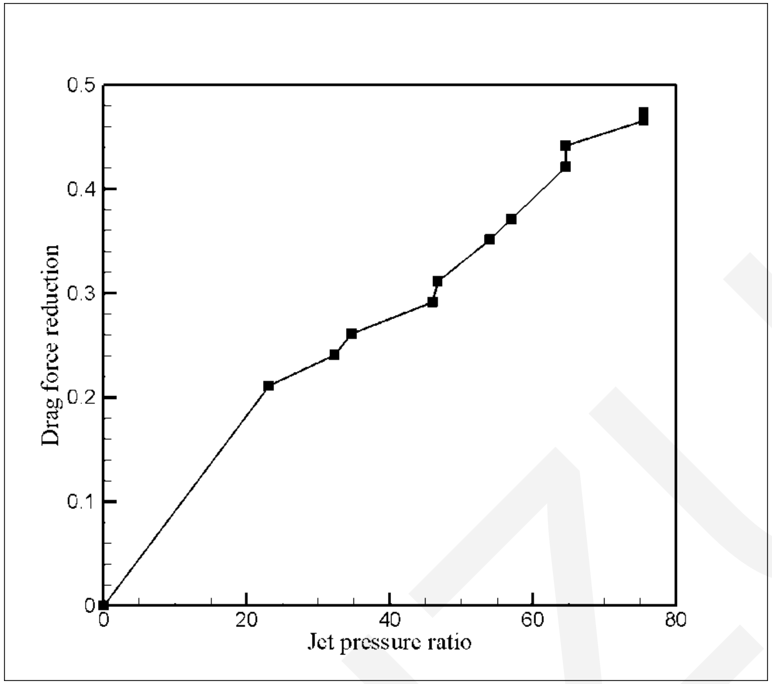
- Drag reduction and thermal protection on the surface of a hypersonic vehicle become especially important when the vehicle enters the atmosphere at high speed.
- Damage on the nose of the vehicle induced by high temperature and high pressure must be prevented.
- Many techniques, i.e. concentrated energy deposition along the stagnation streamline, a retractable aerospike ahead of the blunt body and a counterflowing jet in the stagnation zone of the blunt body, have been proposed.



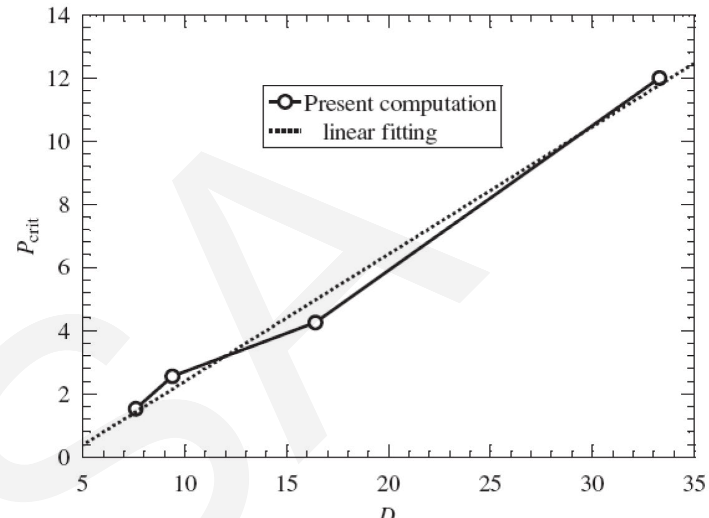
Heat flux comparison for three typical reentry loading environments (Pezzella, 2012)

Pezzella G. Aerospace Science and Technology, 2012, 23: 233-249

2. Counterflowing jet



Drag force reduction for different jet pressure ratios of the Mach 8 test flow (Venukumar et al., 2006)

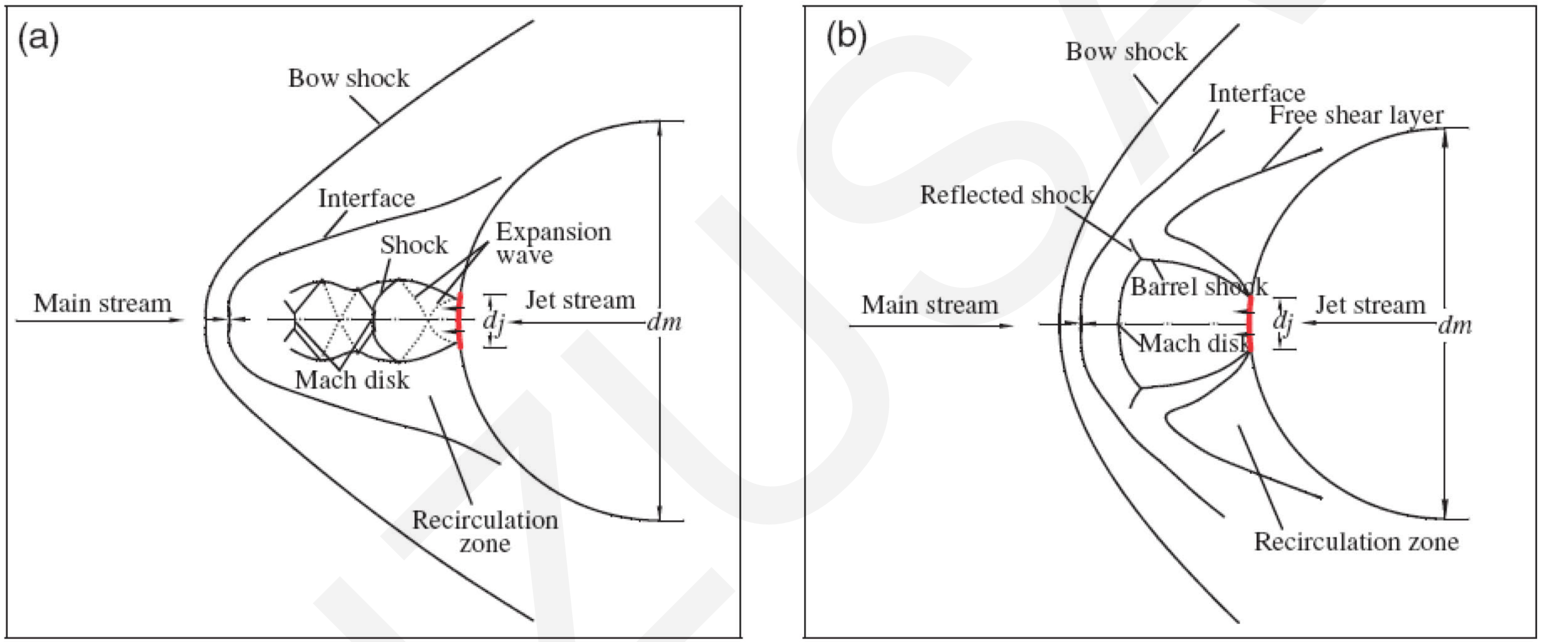


Variation of critical jet pressure ratio with the jet nozzle exit size (Zhou and Ji, 2014)

- Jet pressure ratio has a large impact on the drag force reduction.
- A reduction of about 45% was possible for larger values of the jet pressure ratio.
- Only the steady flow fields have been considered, and the jet pressure ratios are larger than the critical value.

Venukumar B., et al. Physics of Fluids, 2006, 18: 118104
Zhou C. Y., Ji W. Y. Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, 2014, 228(2): 163-177

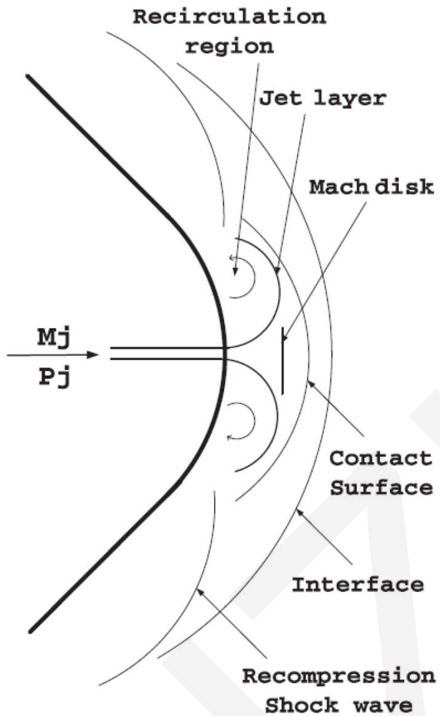
2. Counterflowing jet



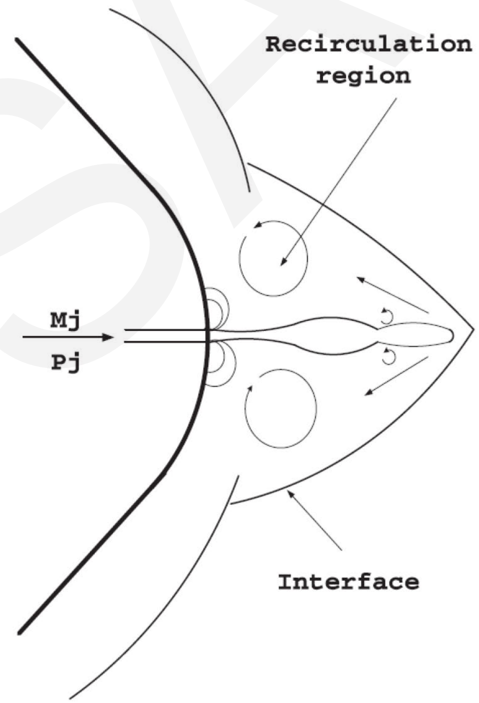
Flow field properties around the spherical body with counterflowing jet: (a) unsteady state mode with regular reflection and (b) steady-state mode with Mach reflection (Zhou and Ji, 2014)

Zhou C. Y., Ji W. Y. Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, 2014, 228(2): 163-177

2. Counterflowing jet



Short penetration mode (SPM) jet

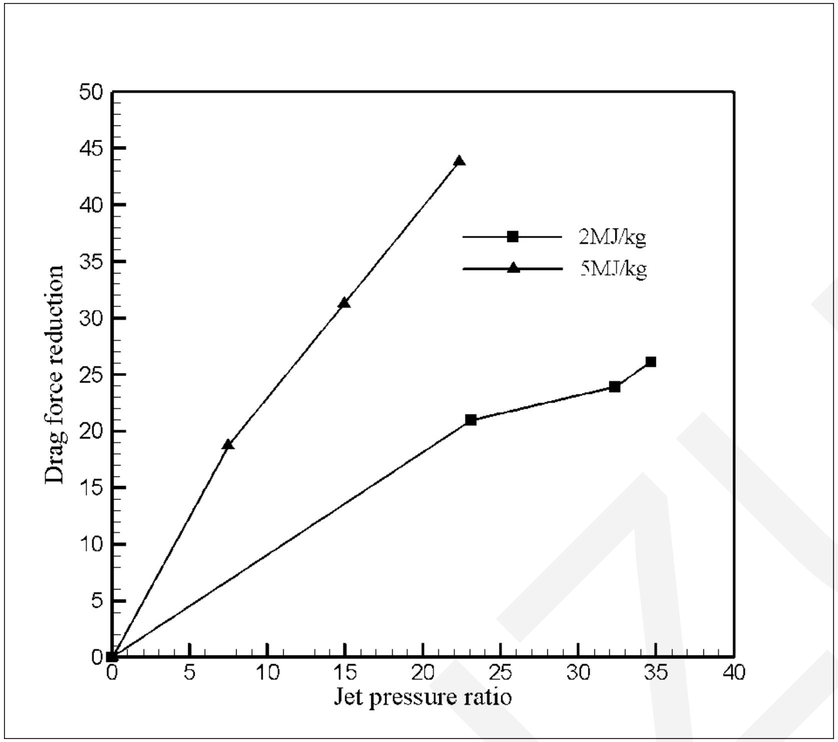


Long penetration mode (LPM) jet

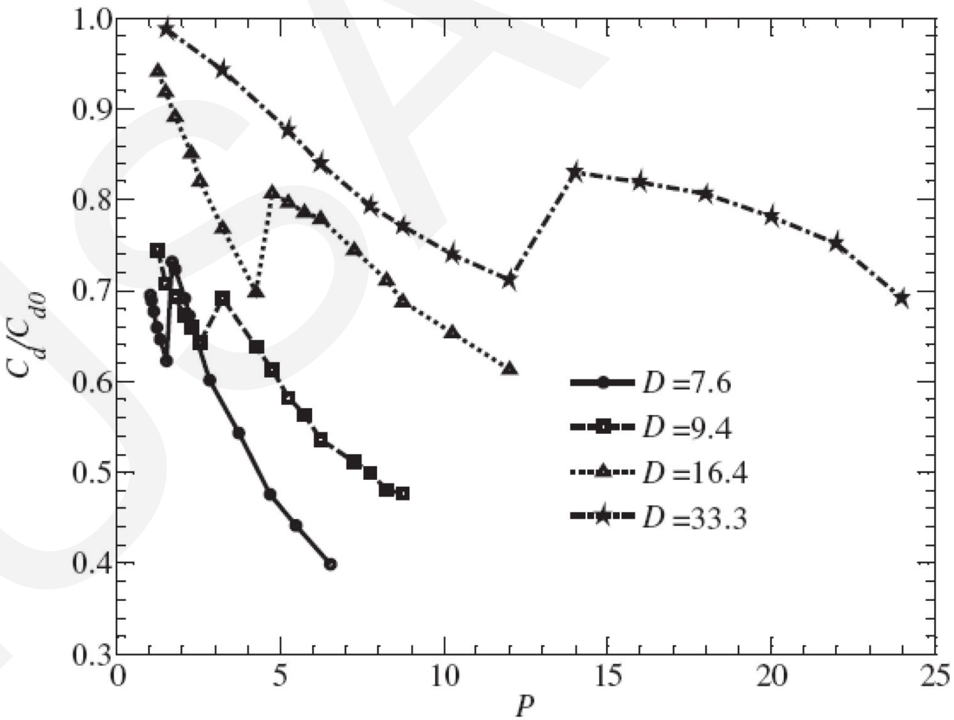
Comparison of flow field properties around the blunt body with a counterflowing jet: (a) short penetration mode (SPM) jet and (b) long penetration mode (LPM) jet (Gerdroodbary et al., 2012)

Gerdroodbary M. B., et al. Acta Astronautica, 2012, 73: 38-48

2. Counterflowing jet



Comparison of drag force reduction for Mach 8 flow with different freestream enthalpies (Kulkarni and Reddy, 2008)

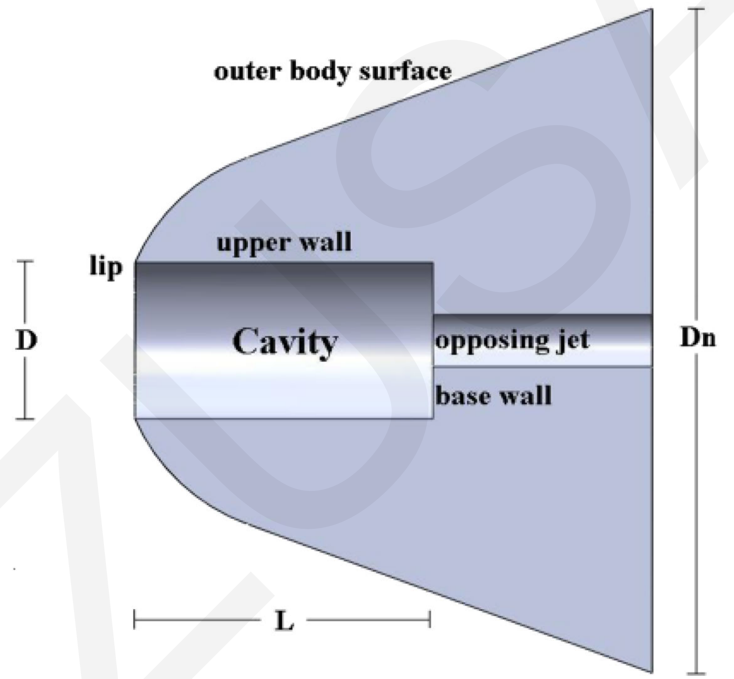


Variation of drag coefficient ratio with jet pressure ratio under different jet nozzle exit sizes (Zhou and Ji, 2014)

Venukumar B., et al. Physics of Fluids, 2006, 18: 118104
Zhou C. Y., Ji W. Y. Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, 2014, 228(2): 163-177

3. Combination of counterflowing jet and other techniques

3.1 Combination of counterflowing jet and forward-facing cavity

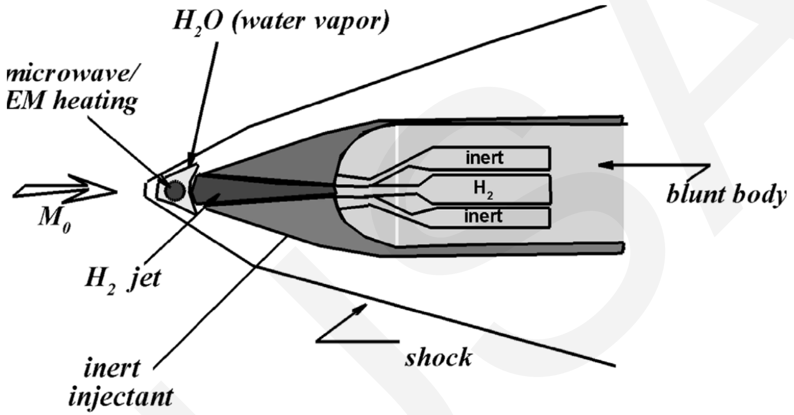


Schematic diagram of the combination of counterflowing jet and forward-facing cavity (Lu and Liu, 2014)

Lu H. B., Liu W. Q. Heat Mass Transfer, 2014, 50: 449-456

3. Combination of counterflowing jet and other techniques

3.2 Combination of counterflowing jet and energy deposition



Schematic diagram of the combination between counterflowing jet and energy deposition (Khamooshi et al., 2007)

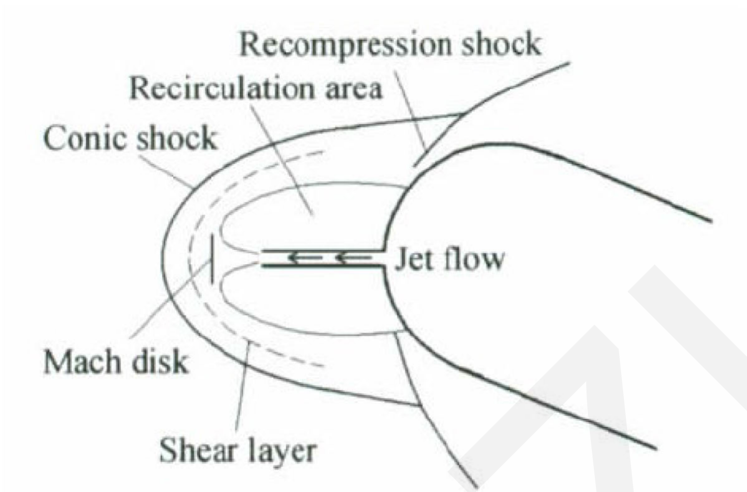
Performance summary of counterflowing jet and energy deposition (Khamooshi et al., 2007)

	Δ	*RD*	*RQ*
Baseline	0.16	1.00	1.00
Counterflowing jet	0.23	0.92	0.95
Energy deposition	0.48	0.60	1.10
Combinatorial configuration	1.10	0.34	0.37

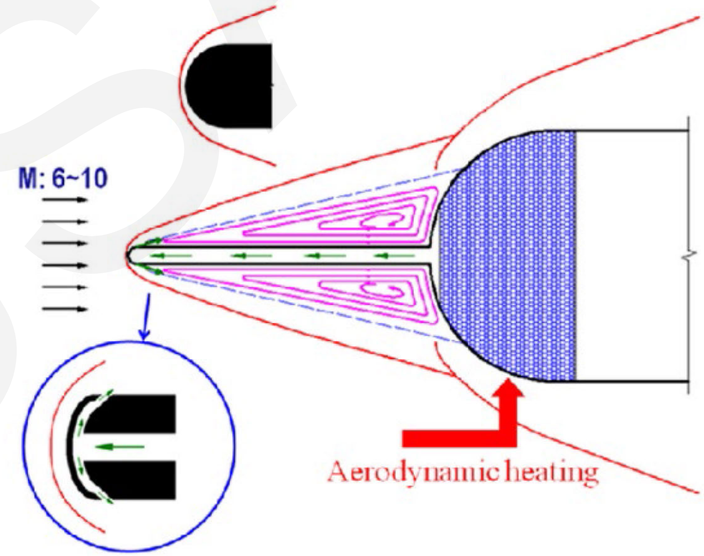
Khamooshi et al. AIAA Journal, 2007, 45(10): 2401-2413

3. Combination of counterflowing jet and other techniques

3.3 Combination of counterflowing jet and aerospike



Schematic diagram of the Telescopic Self-aligning Jet-Spike (TSAJS) flow field structure (Geng et al., 2012)

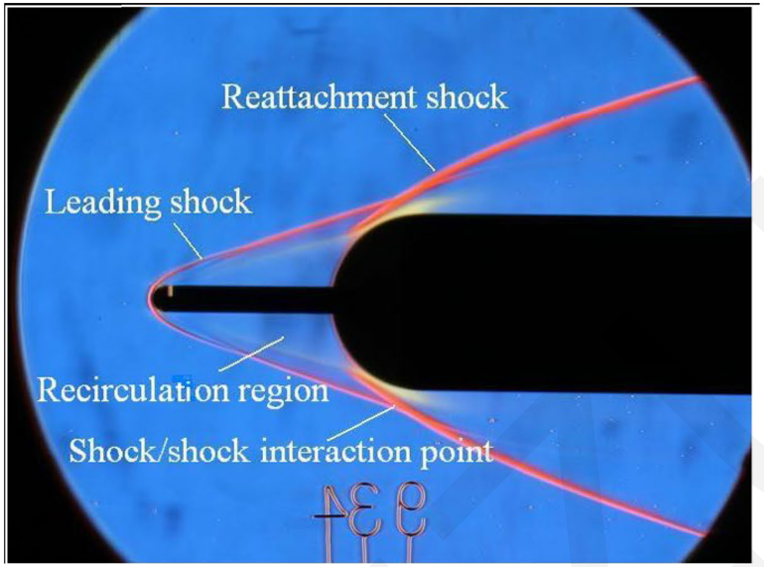


Operating principles of Non-ablative thermal protection system for aerodynamic force and heat load reduction (Liu and Jiang, 2013)

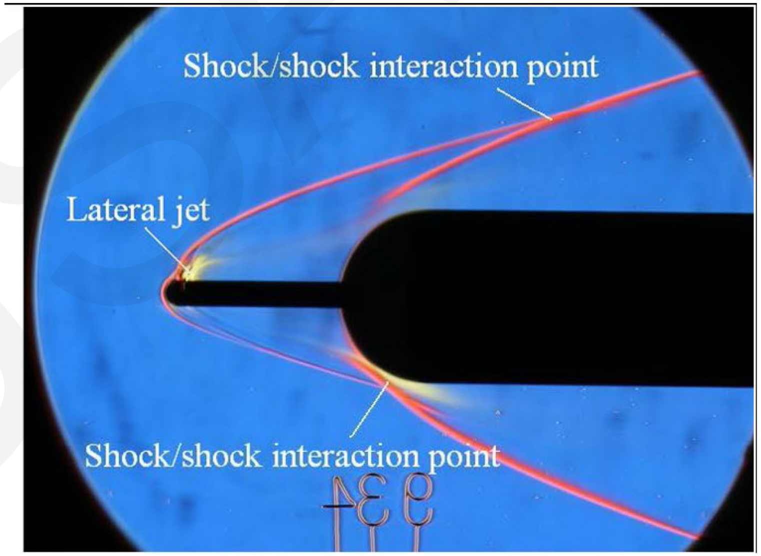
Geng Y. F., et al. Acta Aerodynamica Sinica, 2012, 30(4): 492-501, 545
Liu Y. F., Jiang Z. L. AIAA Journal, 2013, 51(3): 584-590

3. Combination of counterflowing jet and other techniques

3.3 Combination of counterflowing jet and aerospike



Without lateral jet



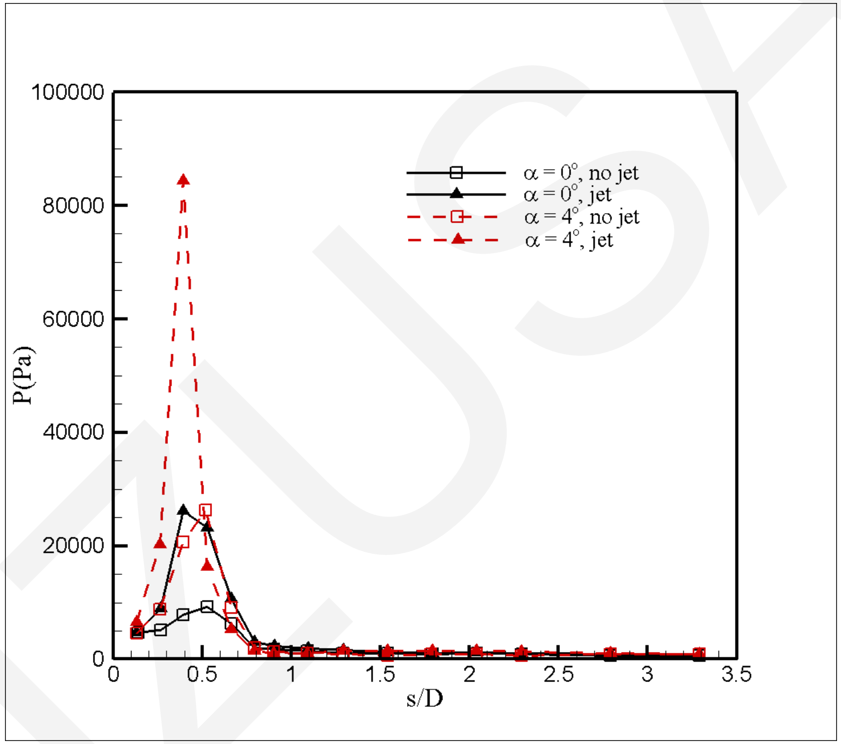
With lateral jet

Comparison of flow field properties around a Non-ablative thermal protection system test model with angle of attack being 0 degree, (a) without lateral jet and (b) with lateral jet (Liu and Jiang, 2013)

Liu Y. F., Jiang Z. L. AIAA Journal, 2013, 51(3): 584-590

3. Combination of counterflowing jet and other techniques

3.3 Combination of counterflowing jet and aerospike

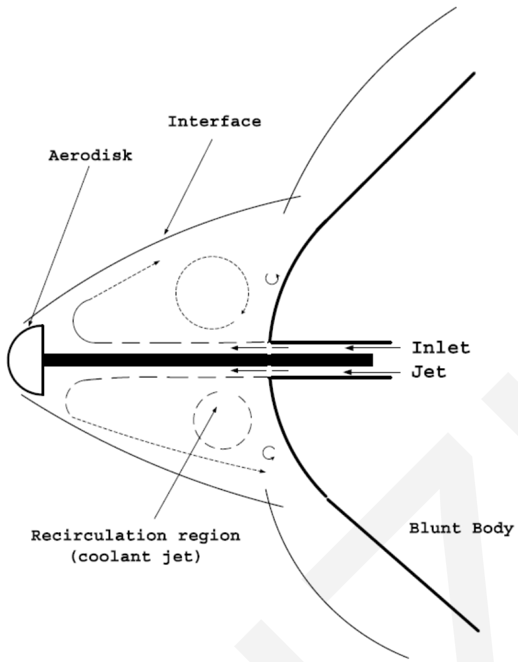


Wall pressure comparison along the generatrix of Non-ablative thermal protection system test model (Liu and Jiang, 2013)

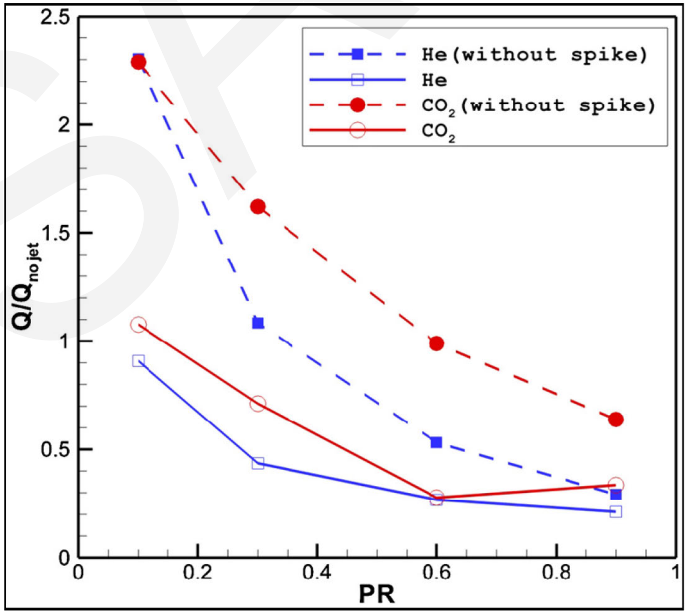
Liu Y. F., Jiang Z. L. AIAA Journal, 2013, 51(3): 584-590

3. Combination of counterflowing jet and other techniques

3.3 Combination of counterflowing jet and aerospike



Schematic diagram of the flow field properties around the aerodisked blunt cone with counterflowing jets (Gerdroodbary et al., 2014)



Comparison of influences of various jet pressure ratios on the heat load reduction of the counterflowing jet with L/D = 1.0 (Gerdroodbary et al., 2014)

Gerdroodbary M. B., et al. Aerospace Science and Technology, in press, doi: 10.1016/j.ast.2014.07.005

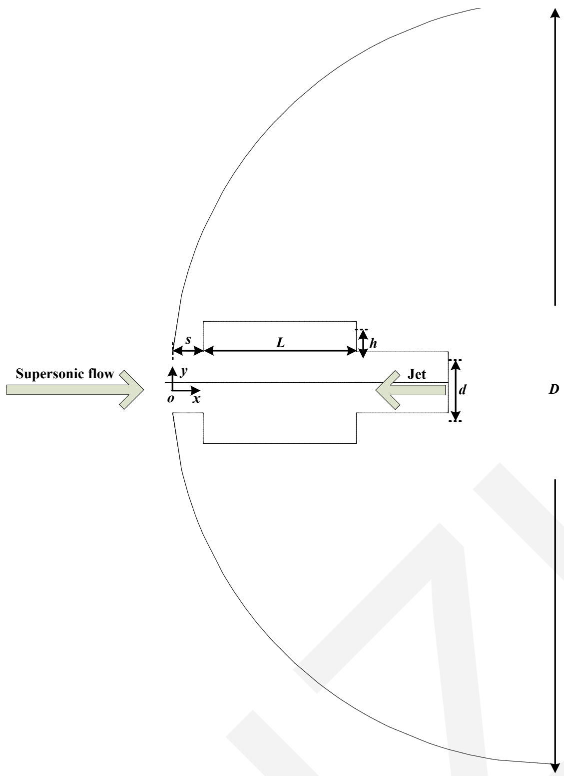
4. Remarks and recommendations

- The jet instability encountered in a counterflowing jet and its combinations is a critical problem for the variation of drag force, and it needs to be further investigated by using an unsteady numerical approach.
- Drag and heat release reductions on hypersonic vehicles are often conflicting, and they should be solved by using a multi-objective design optimization approach. The influences of the operational and geometric parameters on the drag and heat release reductions should be investigated comprehensively.
- The combinatorial configurations show better drag and heat release reduction performance than for a single counterflowing jet, and more attention should be paid to combinations of the counterflowing jet and other techniques.

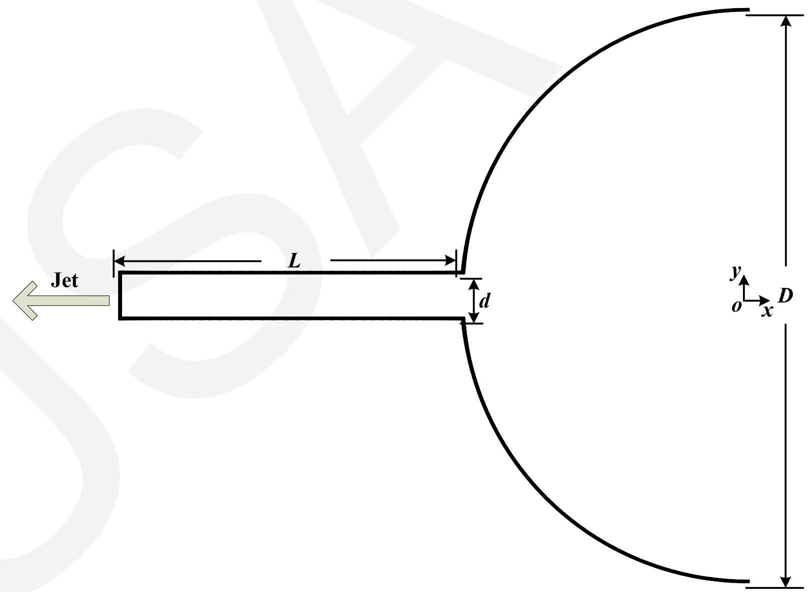
5. Acknowledgements

- Science Foundation of National University of Defense Technology (No. JC14-01-01).
- A fund for owner of outstanding doctorial dissertation from the Education Ministry of China (No.201460).

6. Further works



Sketch of the combinational opposing jet and acoustic cavity concept (Huang et al., 2015)



Sketch of a combinational opposing jet and spike concept (Huang *et al*., 2015)

Huang W., et al. Aerospace Science and Technology, 2015, 42: 407-414
Huang W., et al. Acta Astronautica, 2015, 115: 24-31