



Investigation of Physical Mechanisms for Jet Noise Reduction by Plug Nozzle Porosity

Supported by: Commercial Supersonics Project

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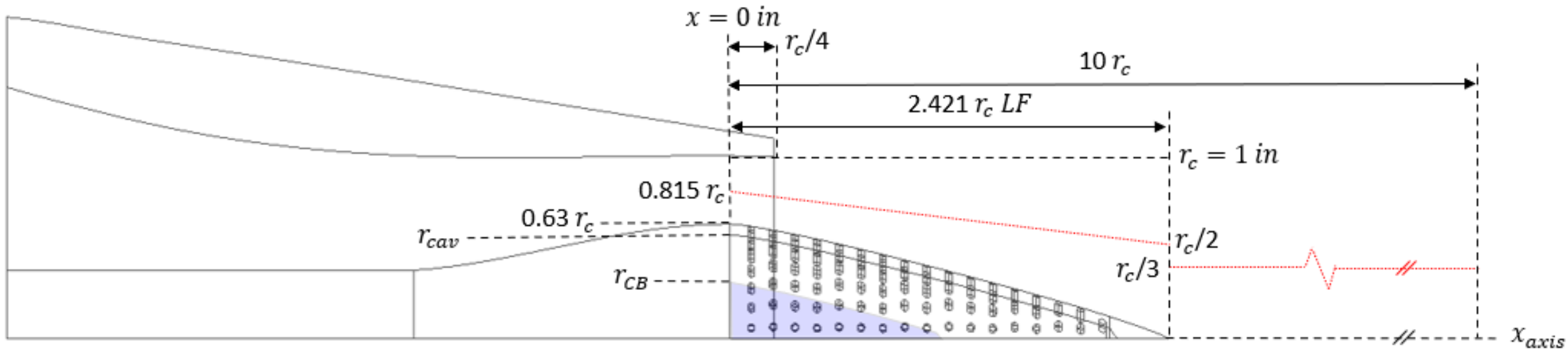
NASA Glenn Research Center, Inlets and Nozzles

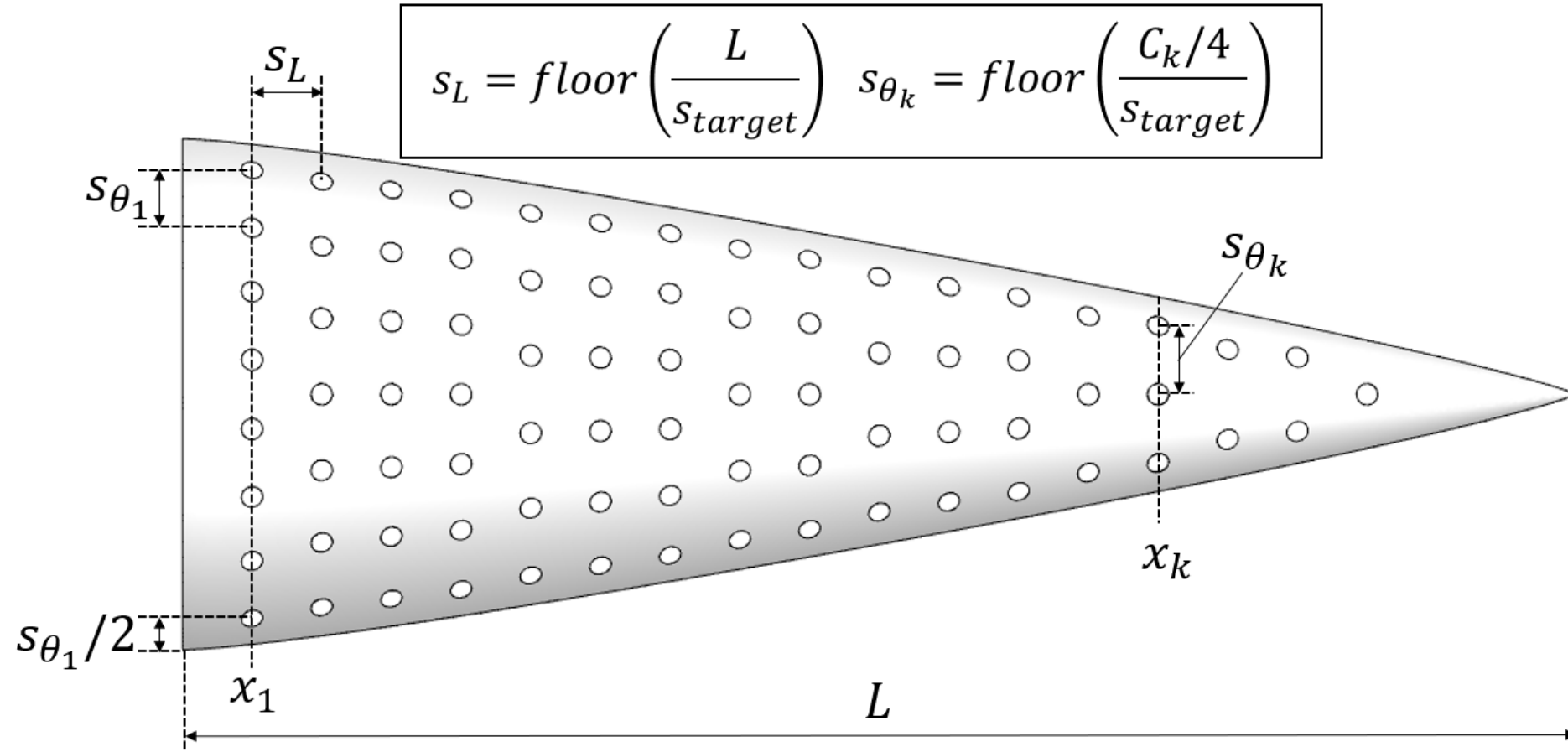
SciTech Conference 2025, Orlando FL

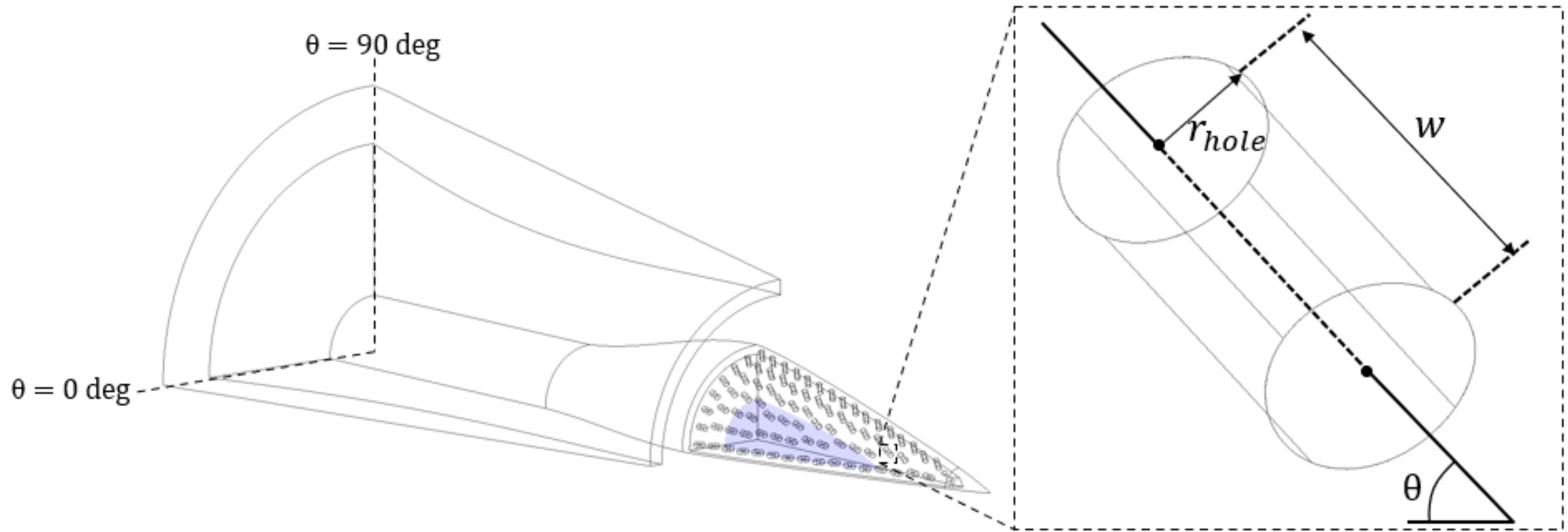


- **Airport Noise Challenge:** Jet noise from low bypass ratio engines at takeoff is a major obstacle for supersonic commercial vehicles, limiting regulatory compliance and public acceptance.
- **Porous Plug Nozzles:** Passive circulation reduces shock strength and broad-band shock noise (BBSN), showing promise in recent experimental studies.
- **Geometric Sensitivities:** Effectiveness strongly depends on plug shape, jet Mach number, and cowl geometry, requiring further investigation.
- **Study Goals:** Use RANS simulations to explore design sensitivities and mechanisms behind BBSN reduction, advancing quieter nozzle designs.

- Hole Radii (r_{hole}): 0.015 in, 0.0225 in, 0.03 in
- Plug Length Factors (LF): 0.7, 1.0, 1.3
- Plug Porosity (ϕ): 0% (solid), 5%, 10%, 15%
- Mach: 1.1, 1.2, 1.3, 1.4, 1.5



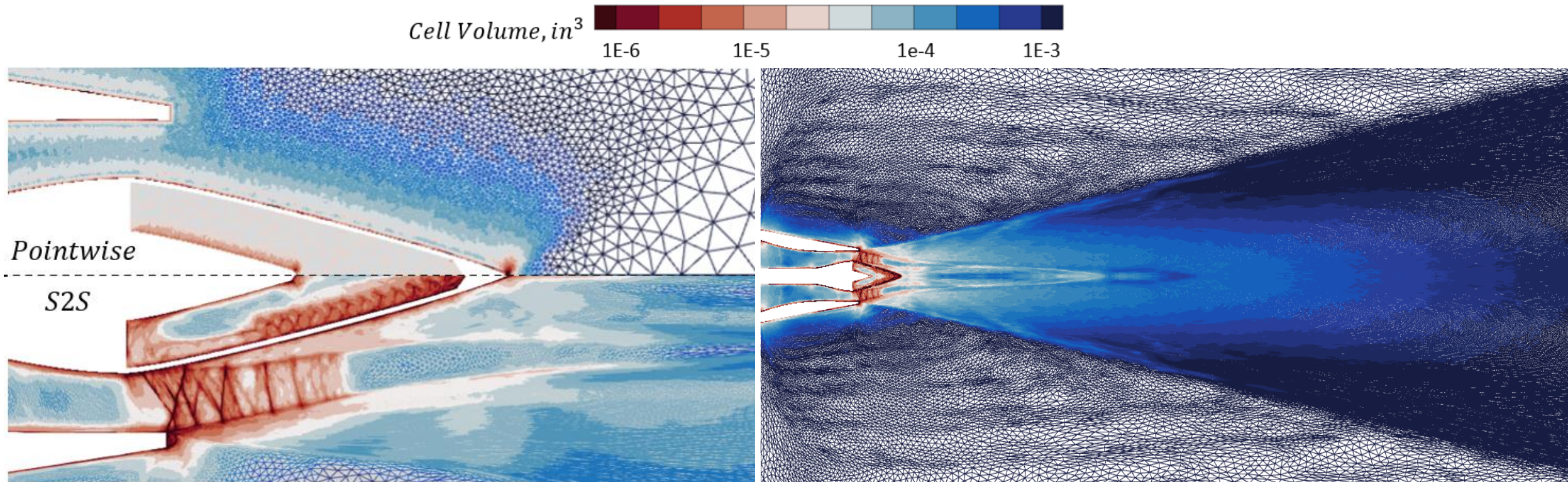




Simulation Methodology



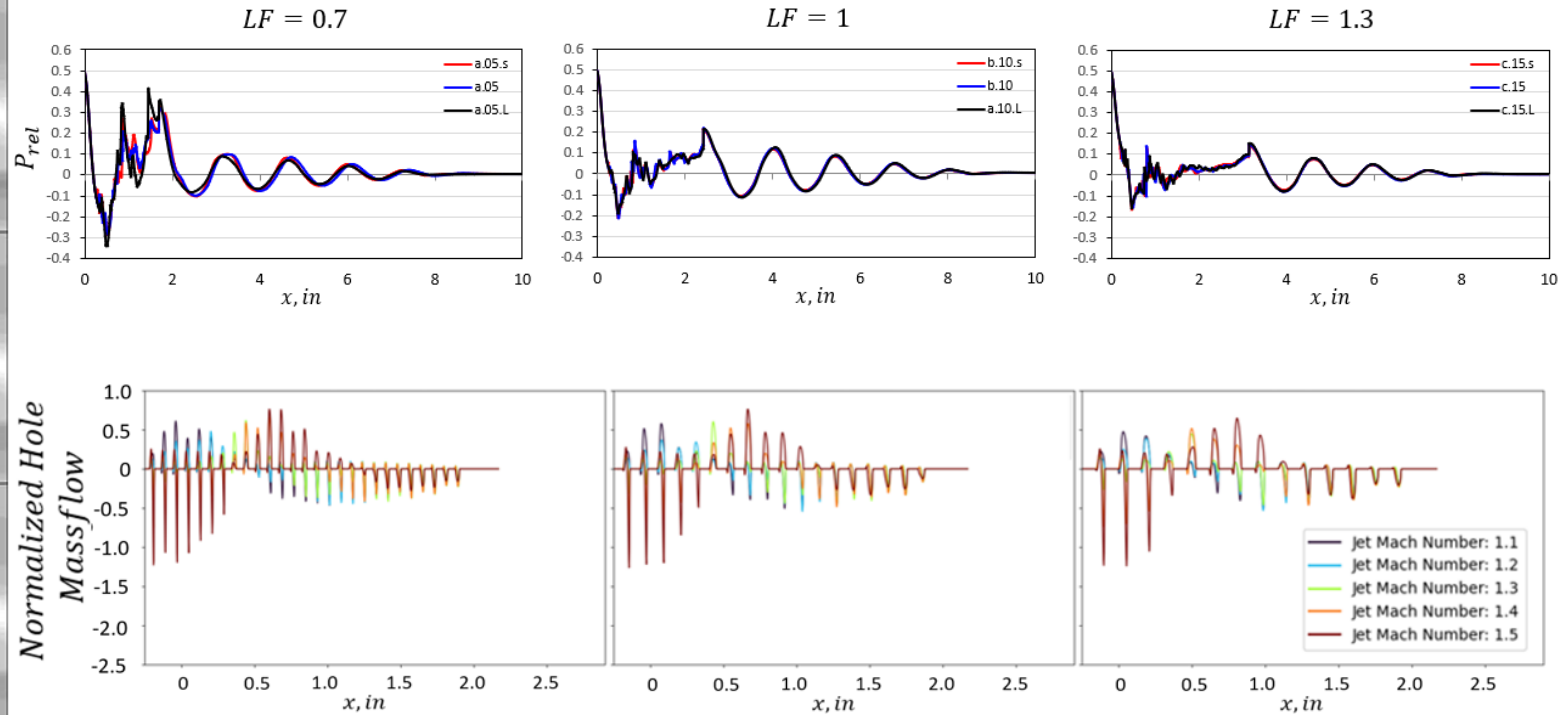
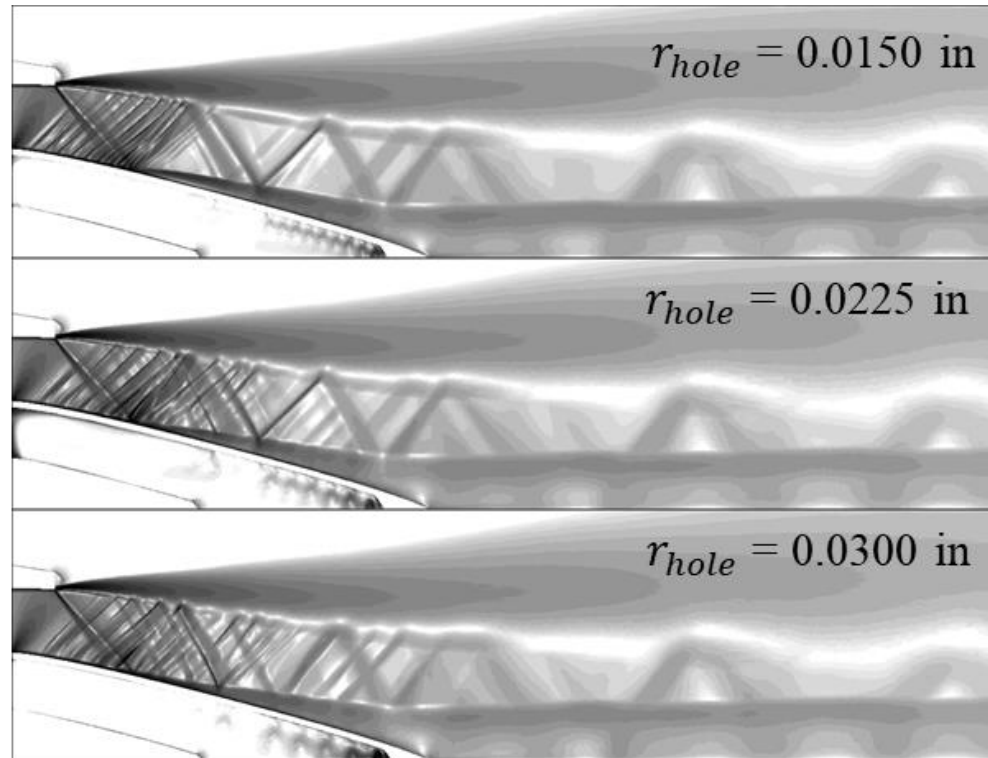
- Farfield Parameters: $M_{farfield} = 0.1$, $Re = 53.4k/in$, $T = 72.9^{\circ}F$, $D_{cowl} = 50.8in$
- Turbulence and Solvers: SA-neg with ldfss, H-Van Leer flux limiter and HANIM
- Mesh Refinement: Initial 3M cells refined via 22 adaptations to 372M cells, $AM = \nabla \nabla M$



The Effects of Hole Size



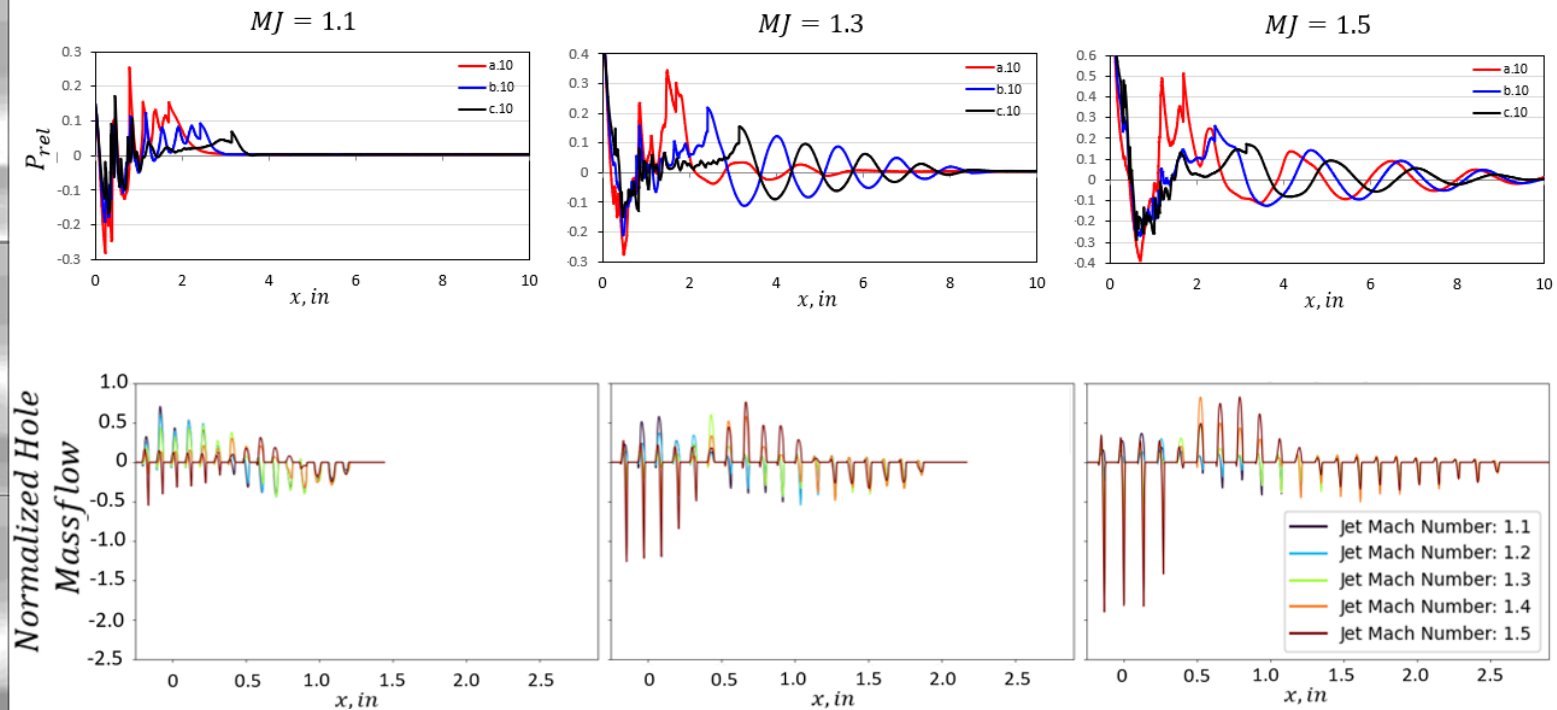
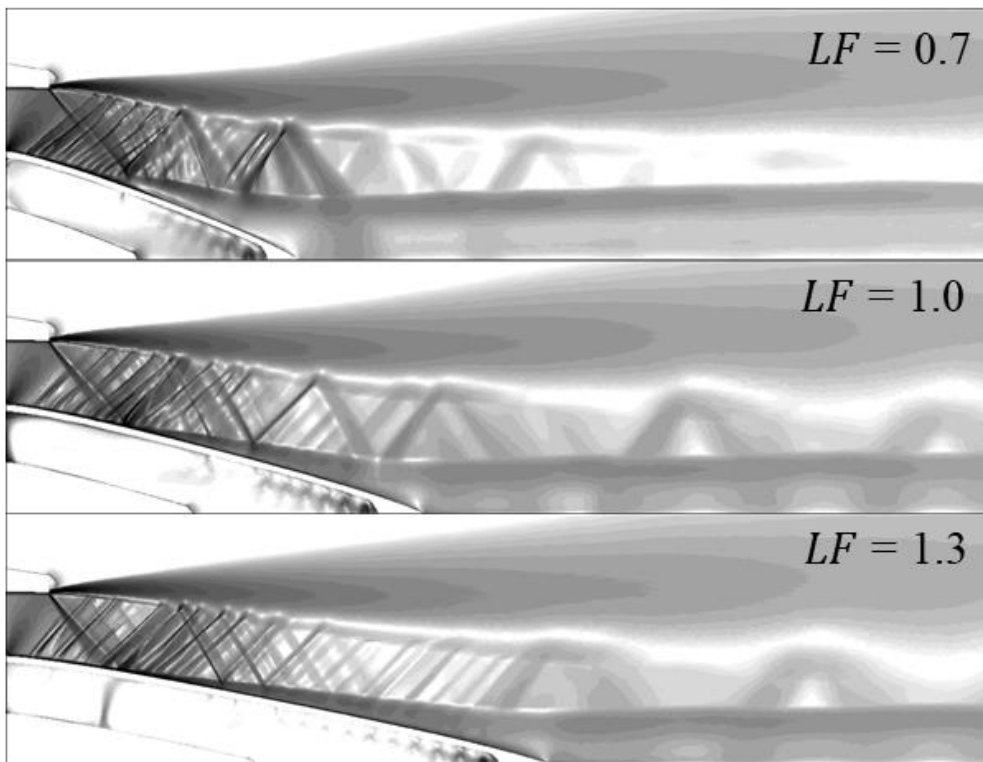
- Minimal qualitative differences in flow structures with varying hole radii; smoother schlieren contours, pressure signals, or normalized radial massflow patterns



The Effects of Plug Length



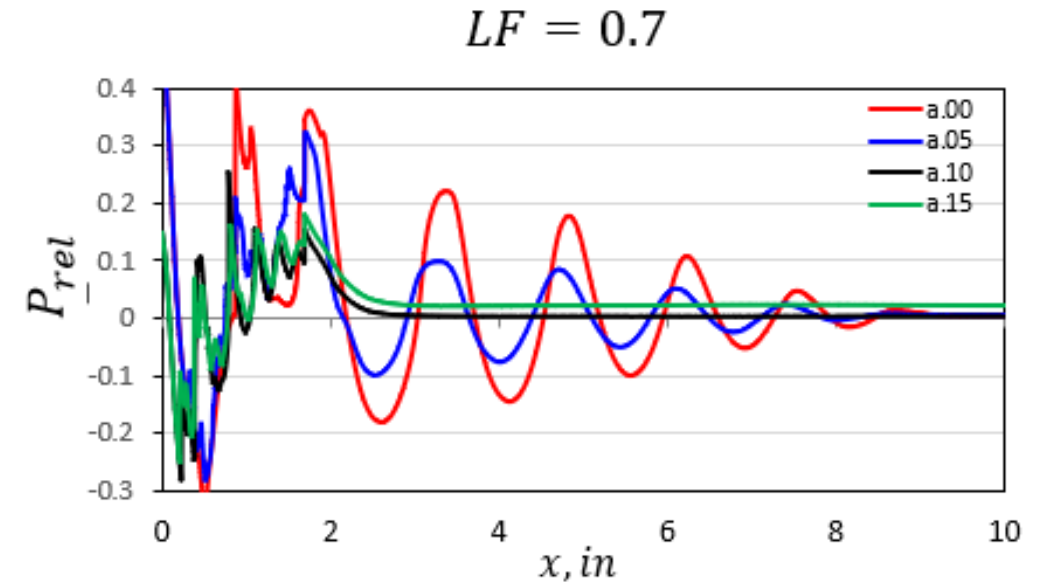
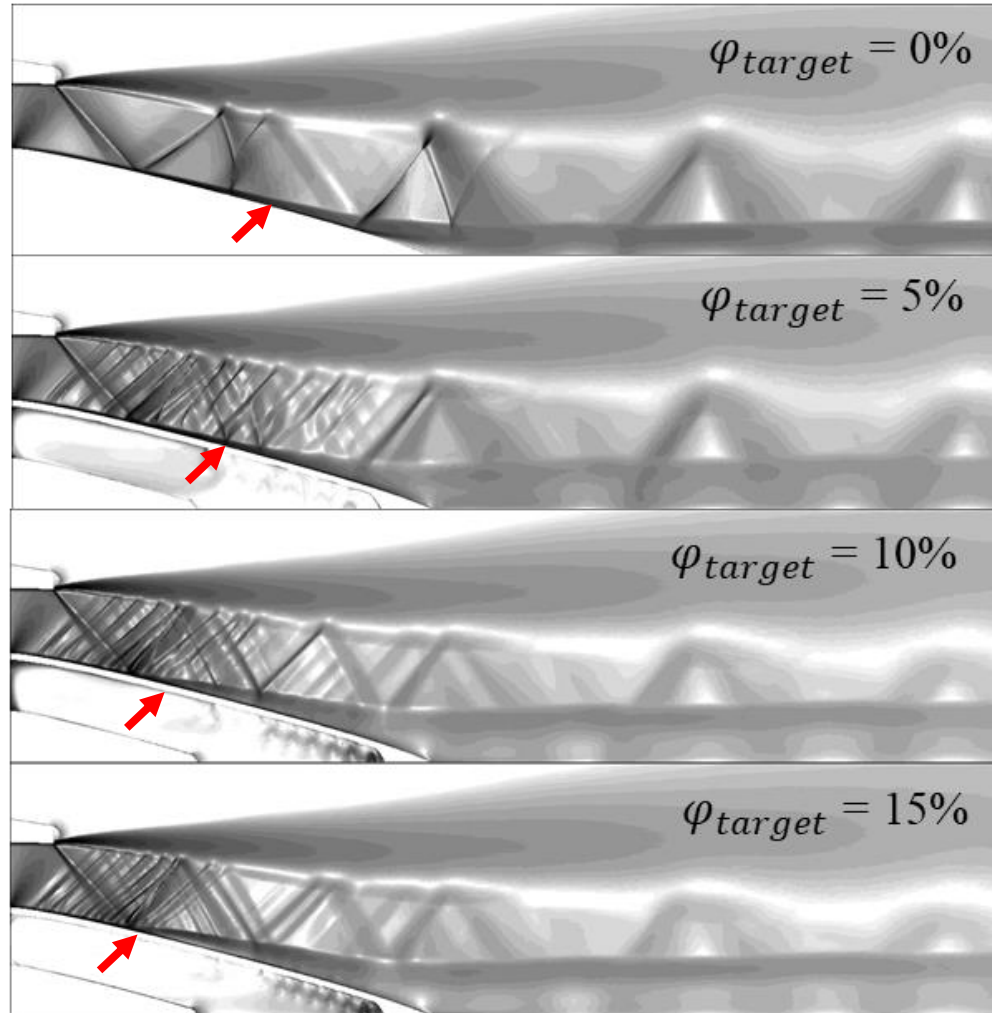
- Increasing LF shifts the internal jet shear layer downstream and toward the jet axis, narrowing the subsonic region and altering reflected shock patterns and phase differences in pressure oscillations



The Effects of Plug Porosity



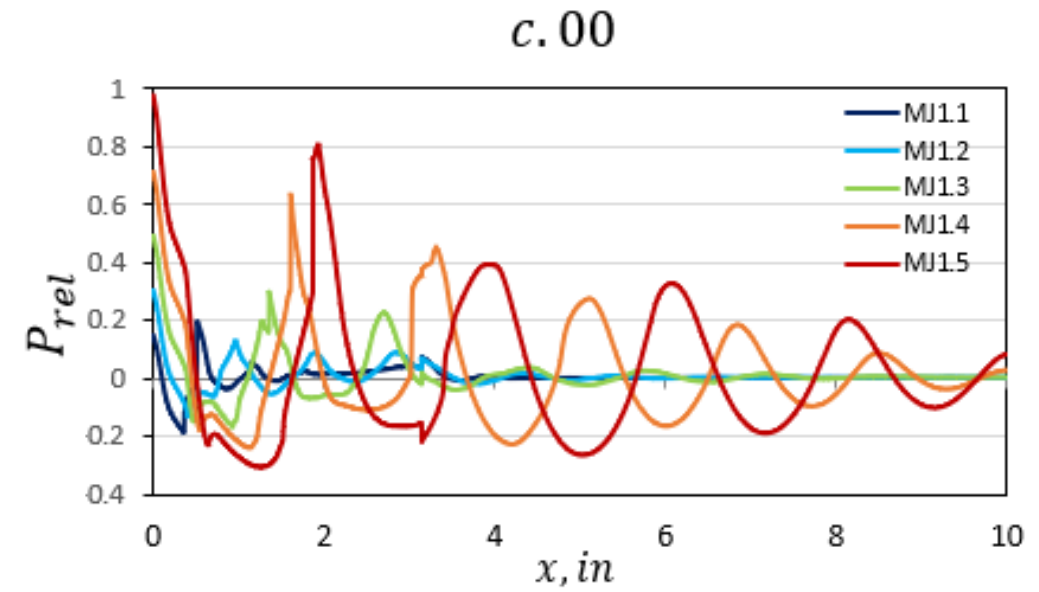
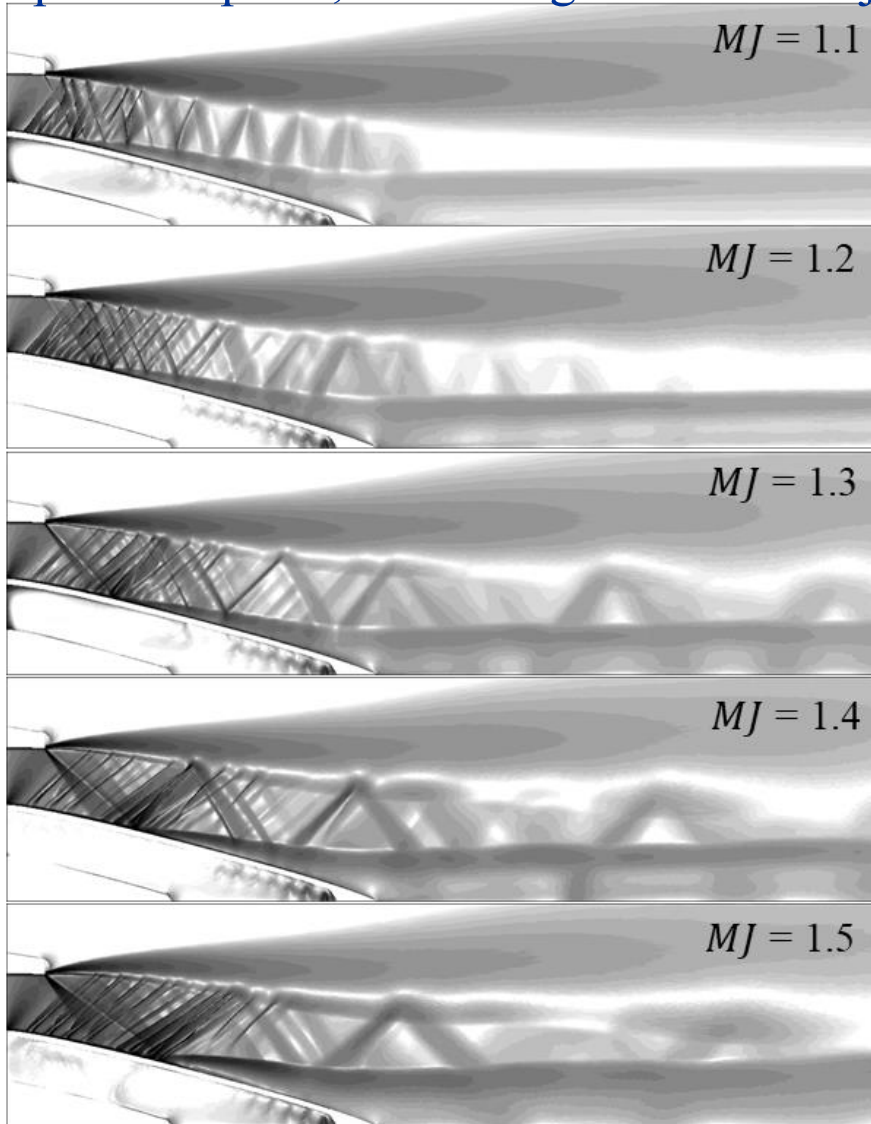
- Increasing porosity shifts the separation point upstream, weakens the Coanda effect, moves the interior shear layer radially outward, and reduces shock diamond strength downstream of the plug tip



The Effects of Jet Mach Number

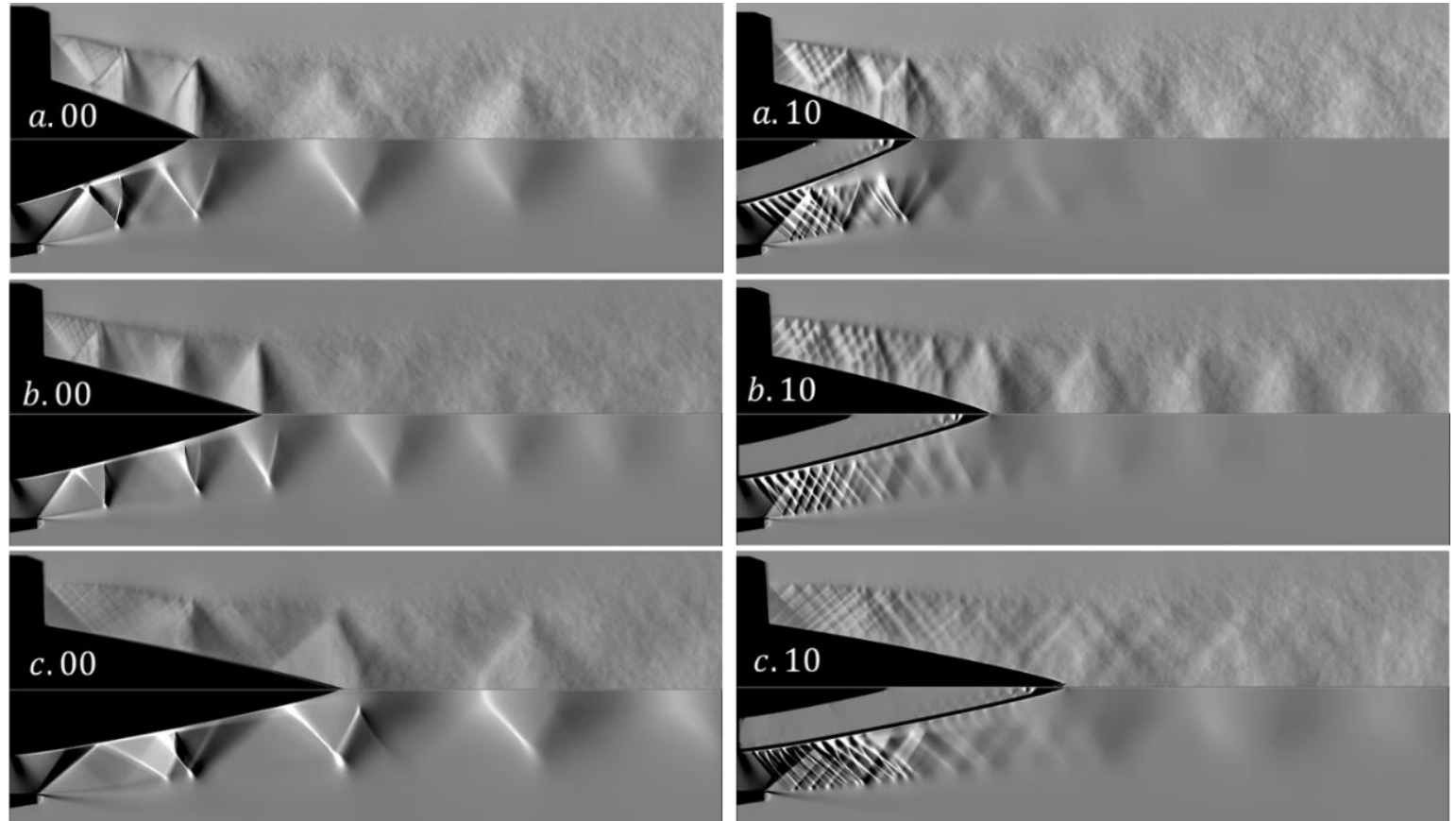


- Increasing MJ leads to steeper primary shocks, wider and stronger expansion fans, and aft movement of separation point, increasing downstream jet width and altering shock reflection phase and strength.



Experimental Setup

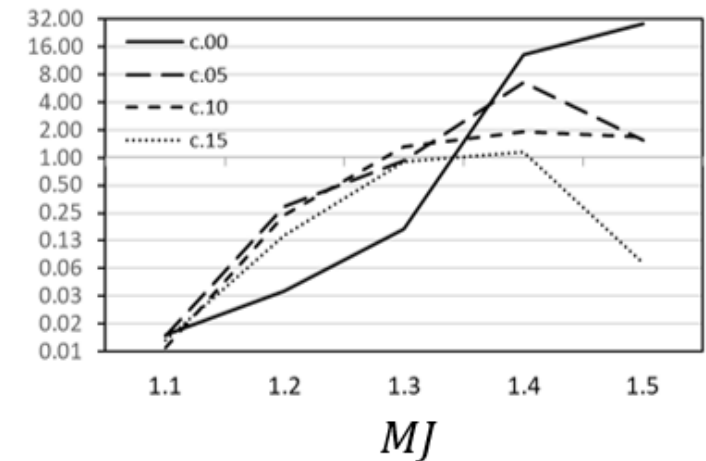
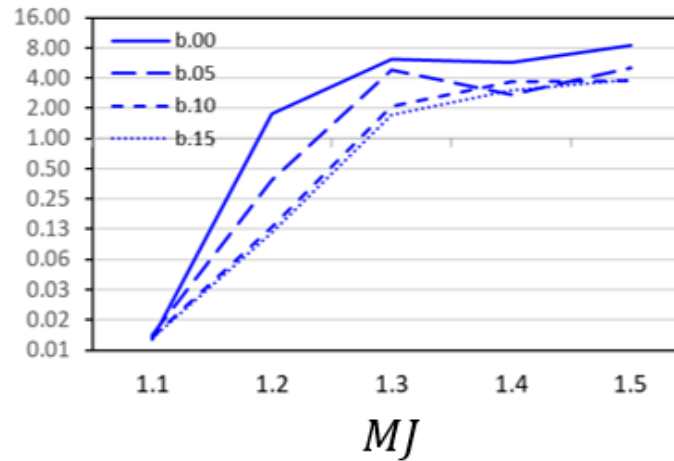
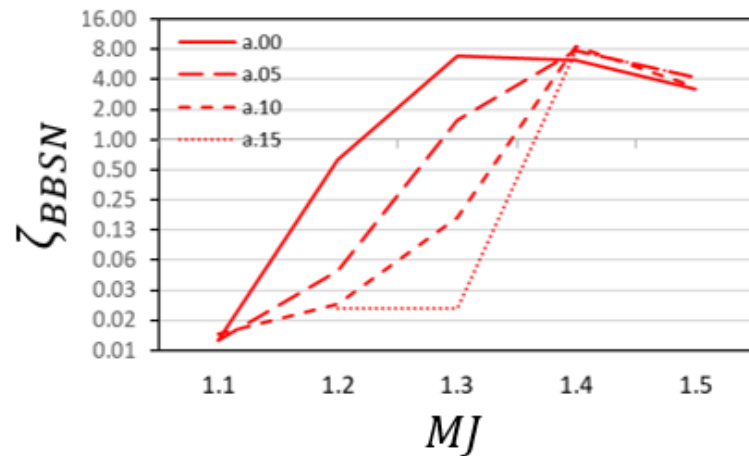
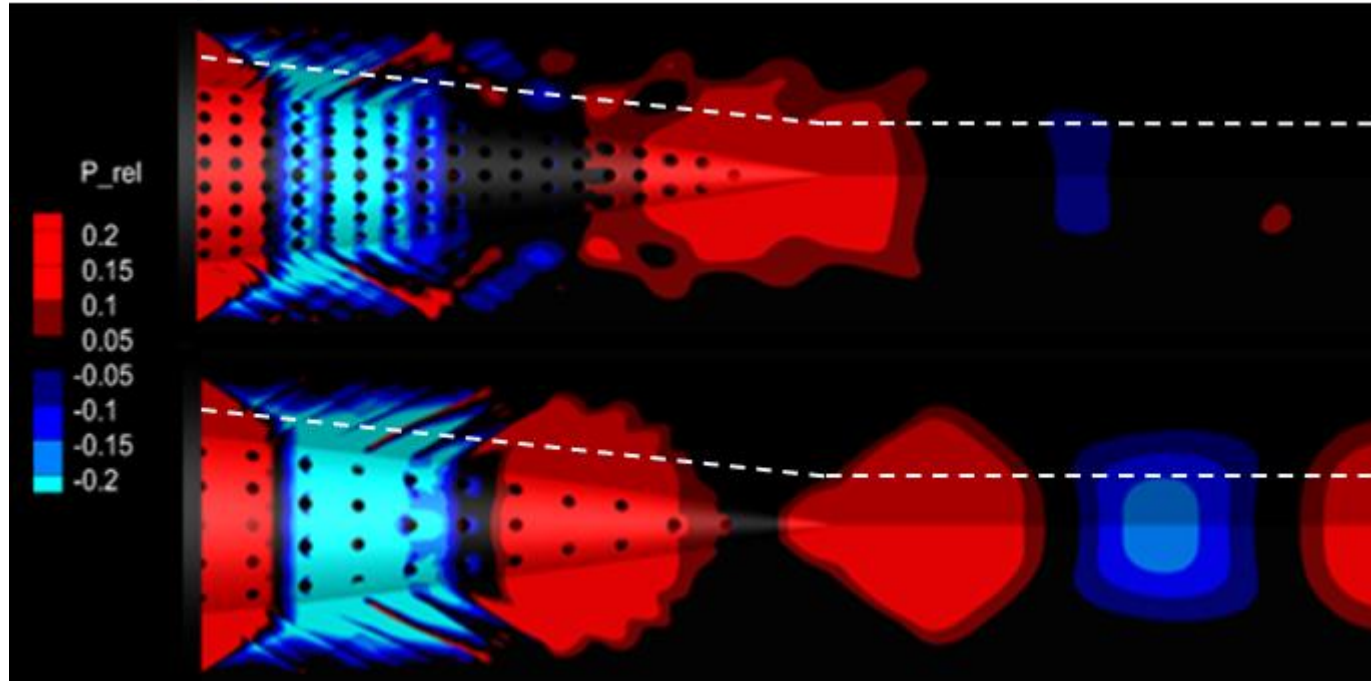
- Conducted experiments in NASA Glenn's CW-17 open-jet facility, measuring axial thrust and noise using a plug nozzle setup with interchangeable SLA 3d printed plugs.
- Acquired data with overhead microphones and a focusing schlieren system.
- Compared experimental schlieren images (time-averaged, ray-integrated) with CFD pseudo-schlieren (instantaneous, higher resolution); observed qualitative alignment.



RANS Noise Marker



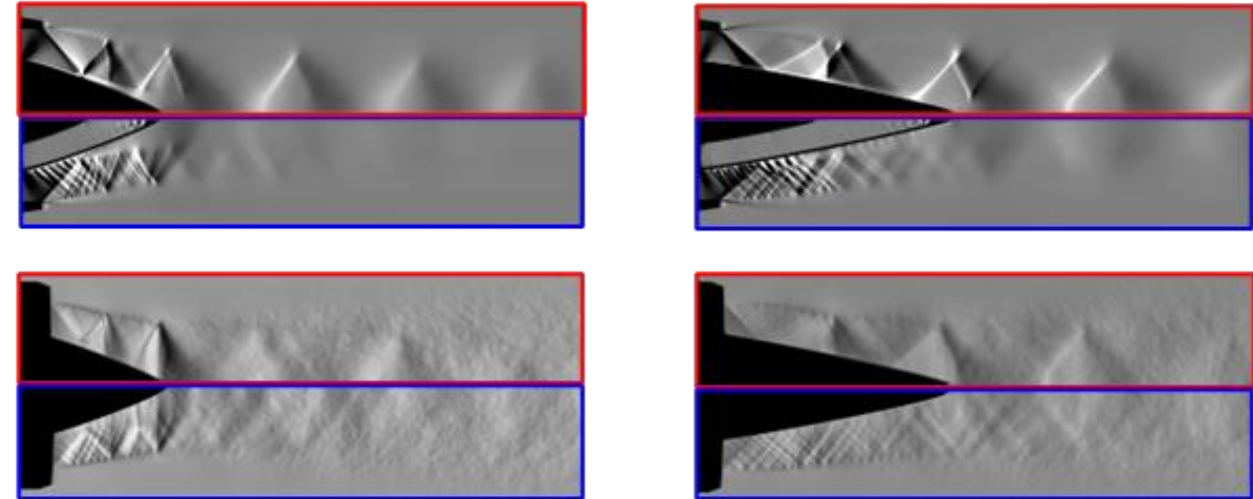
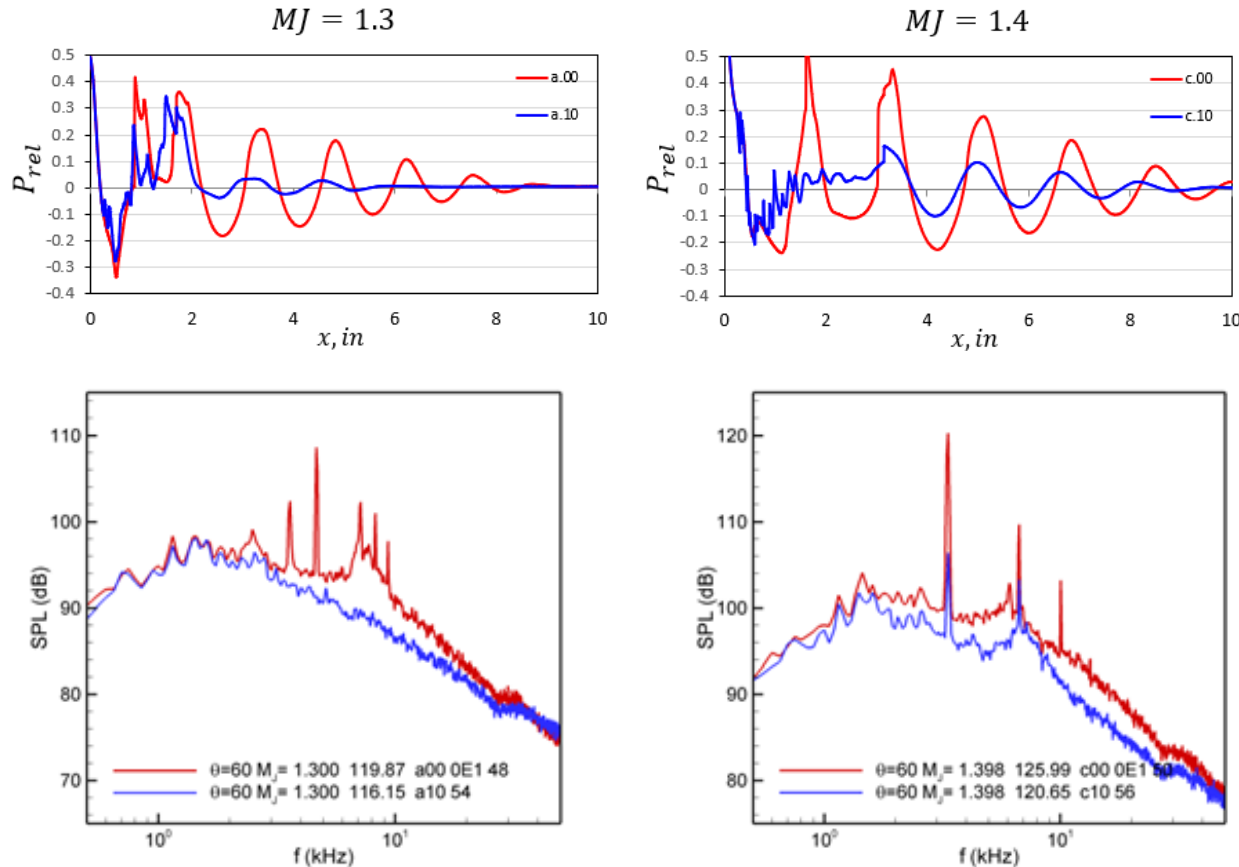
- Integrating relative pressure across “combined” extraction line can indicate shock diamond strength



Cases Of Interest I (Most Favorable)



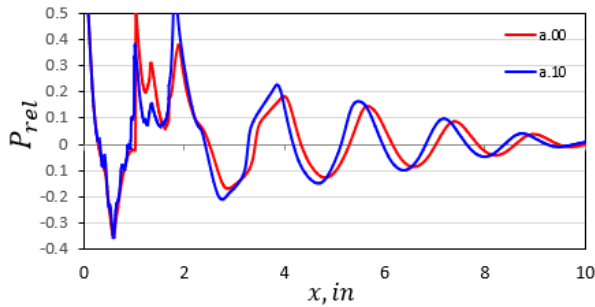
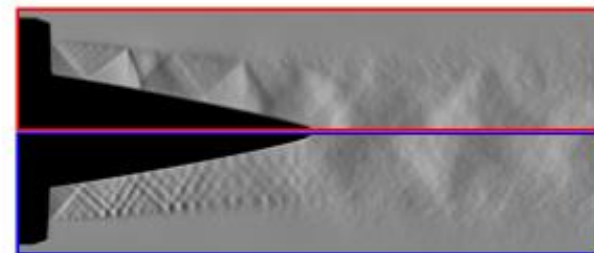
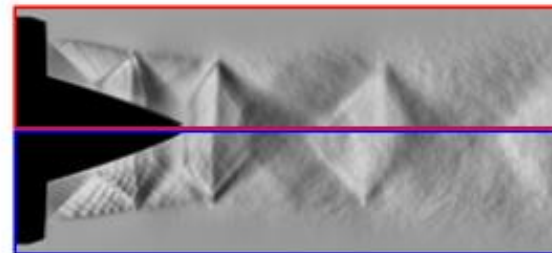
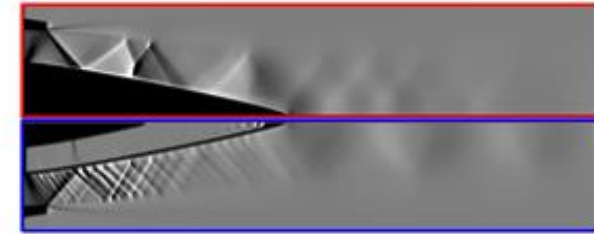
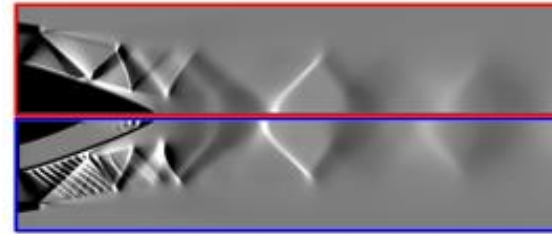
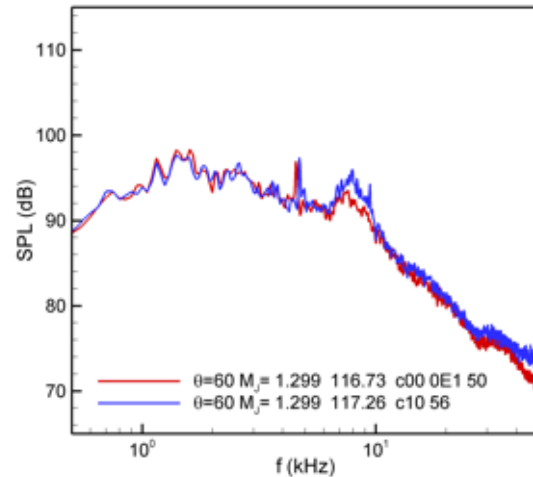
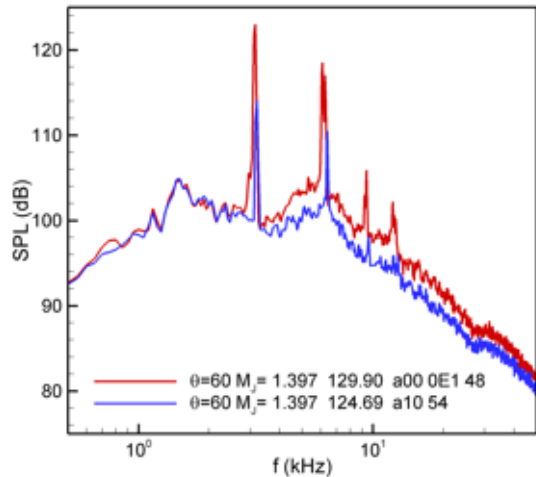
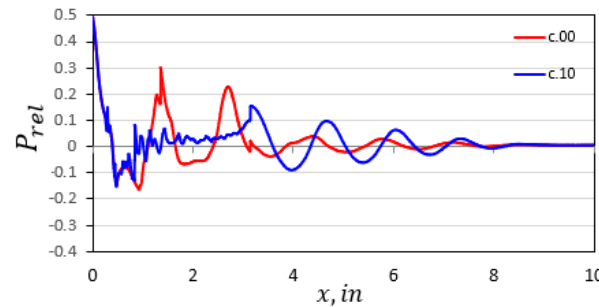
- Increasing plug porosity reduces shock diamond strength and persistence, significantly affecting BBSN; effects are highly dependent on jet Mach number and plug geometry.
- Porosity weakens or eliminates shock diamonds near the plug tip by reducing the effectiveness of the Coanda effect, promoting boundary layer separation and altering shear layer behavior.



Cases Of Interest II (Most Adverse)



- In some cases, plug porosity has less favorable or even adverse effects on shock diamond persistence, with stronger shock diamonds observed for porous plugs (e.g., a.00 vs. a.10 for $MJ = 1.4$).
- Cases with minimal or adverse effects on shock diamond strength are adjacent in the case matrix to cases with strong reductions, highlighting sensitivity to design conditions.

 $MJ = 1.4$  $MJ = 1.3$ 

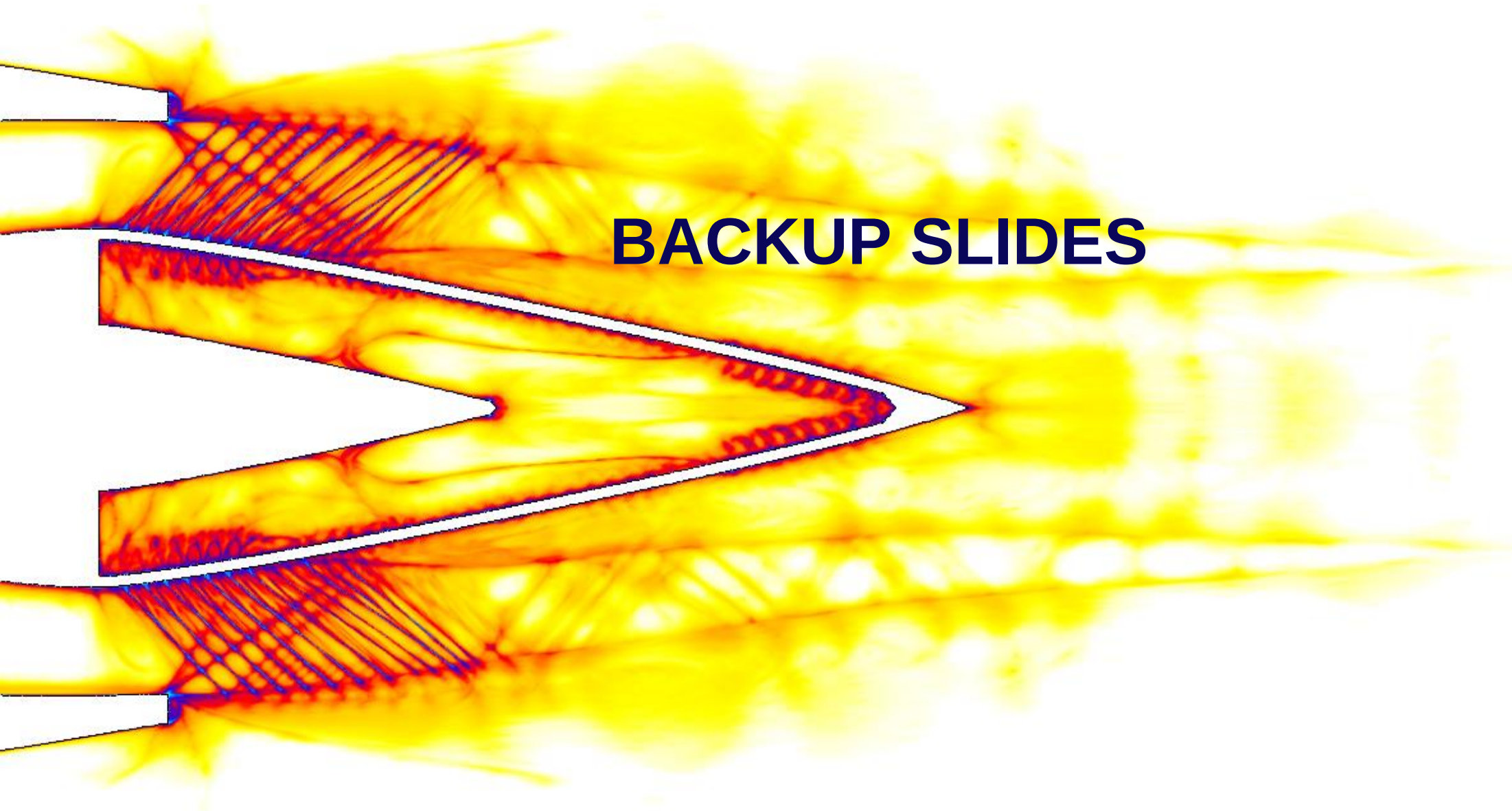
Conclusions



- Investigated noise reduction potential of porous plug nozzles for low-bypass turbofan engines during landing and takeoff conditions using RANS CFD for 31 designs and experiments on 15 subscale nozzles.
- Primary noise reduction mechanism at low Mach numbers seems to be the reduced effectiveness of the Coanda effect, effectively reduces overexpansion.
- Secondary mechanism porosity-induced destructive interference between shocklets and flow structures, altering jet core dynamics.
- Noise reduction effects diminish with increasing Mach numbers
- Lack of dependence on r_{hole}
- Future research should focus on flightweight designs, improving RANS-experiment correlations, and optimizing for more LTO Mach numbers. (truncated plugs, blowing, etc...)

QUESTIONS?

BACKUP SLIDES



Run Matrix



<i>Case</i>	<i>LF</i>	<i>r_{hole}, in.</i>	<i>Φ_{target}</i>	<i>Φ_{actual}</i>	<i>n</i>
a.00	0.7	0	0.00%	0.00%	0
b.00	1	0	0.00%	0.00%	0
c.00	1.3	0	0.00%	0.00%	0
b.10.m.c	1	0.0225	0.00%	0.00%	91
a.05.s	0.7	0.015	5.00%	5.19%	72
b.05.s	1	0.015	5.00%	5.05%	100
c.05.s	1.3	0.015	5.00%	5.09%	131
a.10.s	0.7	0.015	10.00%	10.10%	140
b.10.s	1	0.015	10.00%	10.20%	202
c.10.s	1.3	0.015	10.00%	10.14%	261
a.15.s	0.7	0.015	15.00%	15.58%	216
b.15.s	1	0.015	15.00%	15.50%	307
c.15.s	1.3	0.015	15.00%	15.38%	396
a.05	0.7	0.0225	5.00%	5.36%	33
b.05	1	0.0225	5.00%	5.00%	44
c.05	1.3	0.0225	5.00%	5.16%	59
a.10	0.7	0.0225	10.00%	10.55%	65
b.10	1	0.0225	10.00%	10.34%	91
c.10	1.3	0.0225	10.00%	10.40%	119
a.15	0.7	0.0225	15.00%	14.77%	91
b.15	1	0.0225	15.00%	14.77%	130
c.15	1.3	0.0225	15.00%	15.38%	176
a.05.L	0.7	0.03	5.00%	5.48%	19
b.05.L	1	0.03	5.00%	5.66%	28
c.05.L	1.3	0.03	5.00%	5.13%	33
a.10.L	0.7	0.03	10.00%	11.26%	39
b.10.L	1	0.03	10.00%	10.50%	52
c.10.L	1.3	0.03	10.00%	10.26%	66
a.15.L	0.7	0.03	15.00%	15.01%	52
b.15.L	1	0.03	15.00%	16.16%	80
c.15.L	1.3	0.03	15.00%	15.54%	100

<i>MJ</i>	<i>NPR</i>	<i>NTR</i>
1.1	2.135	1.68
1.2	2.425	1.68
1.3	2.771	1.68
1.4	3.182	1.68
1.5	3.671	1.68