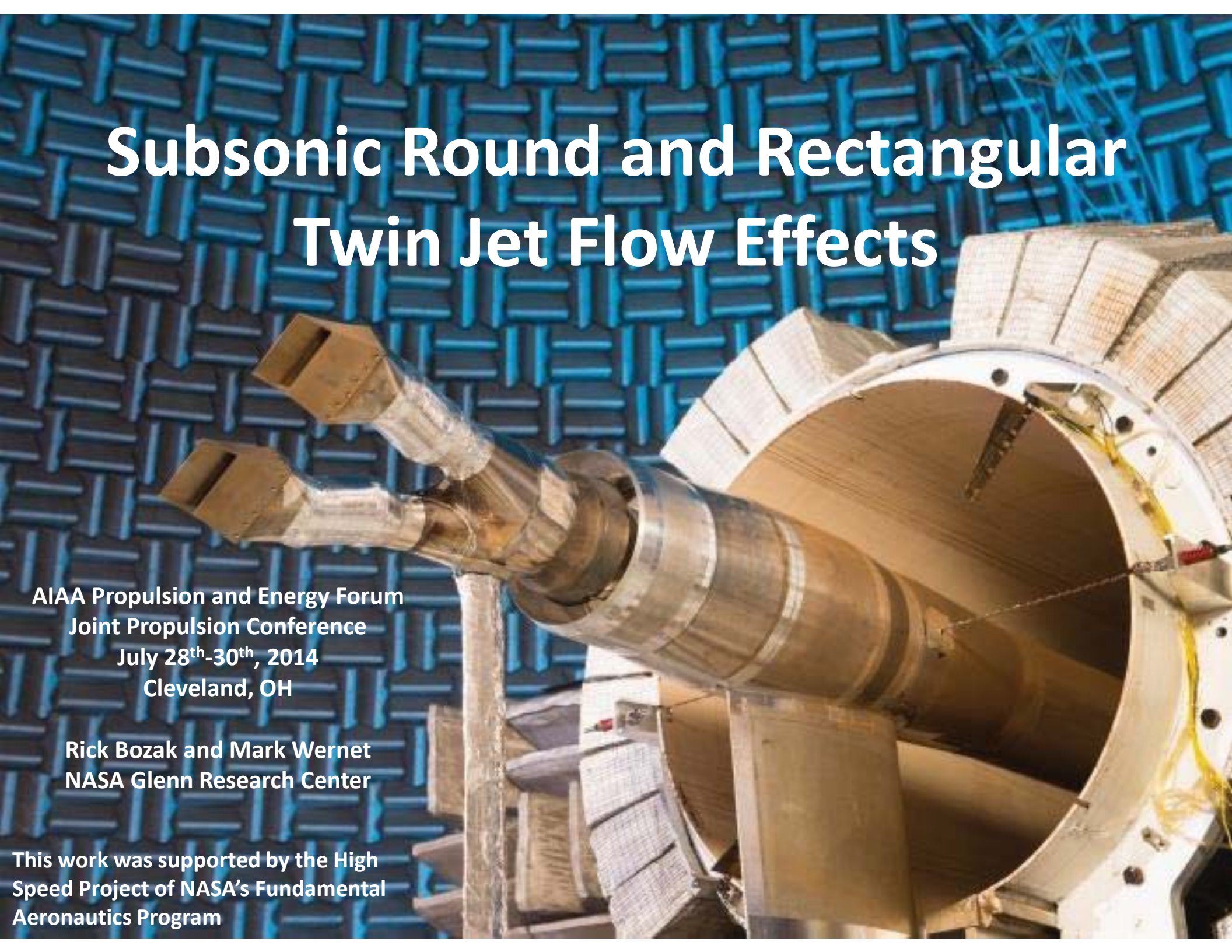
Subsonic Round and Rectangular Twin Jet Flow Effects

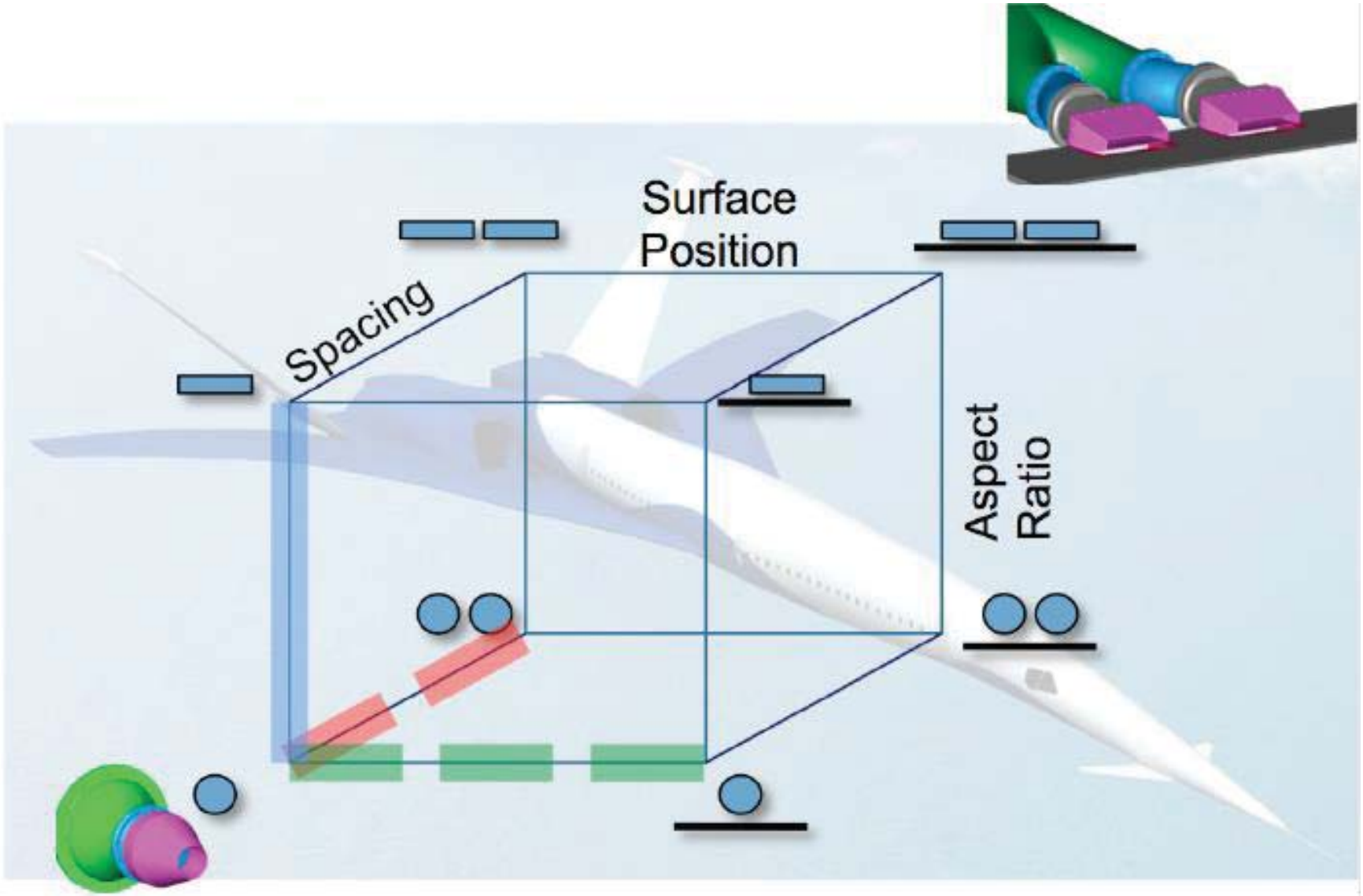


AIAA Propulsion and Energy Forum
Joint Propulsion Conference
July 28th-30th, 2014
Cleveland, OH

Rick Bozak and Mark Wernet
NASA Glenn Research Center

This work was supported by the High Speed Project of NASA's Fundamental Aeronautics Program

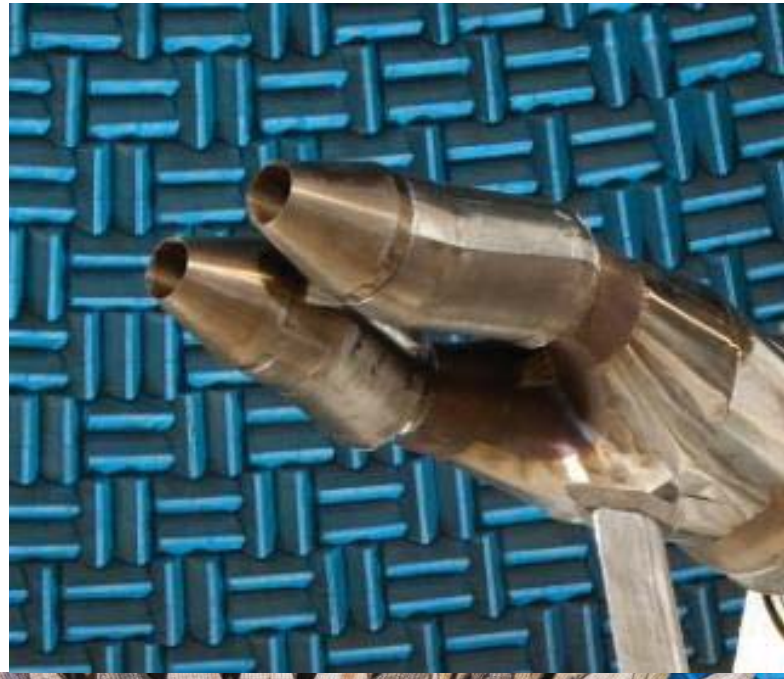
NASA Exhaust System Acoustic Experiments

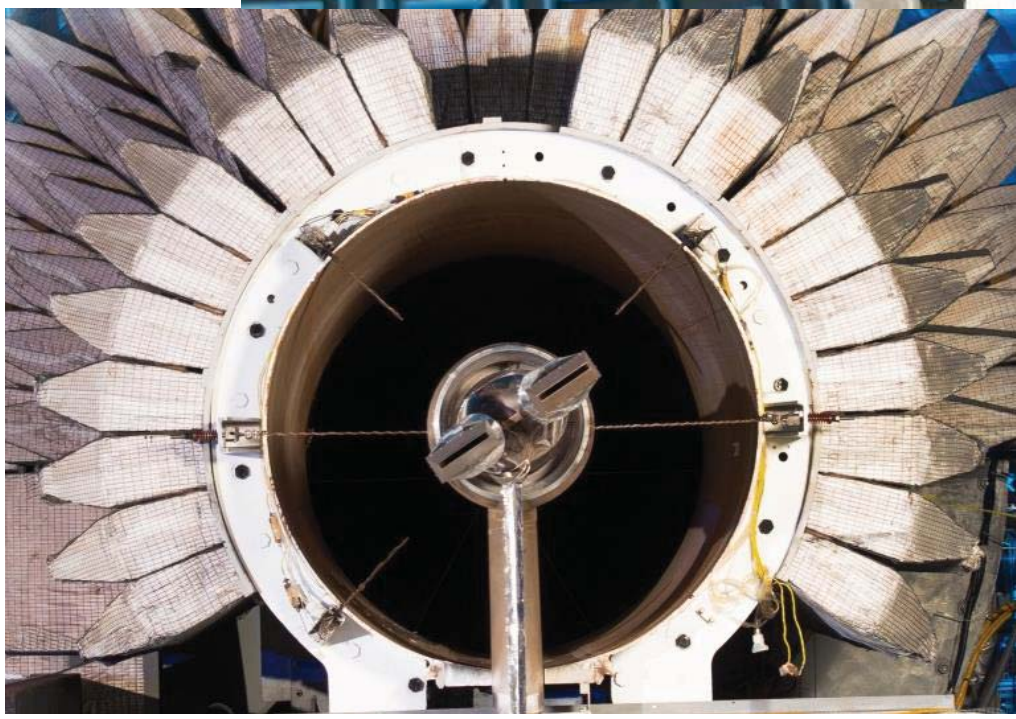


Bridges, J., Brown, C., and Bozak, R., "Experiments on Exhaust Noise of Tightly Integrated Propulsion Systems," NASA Glenn Research Center, AIAA-2014-2904, Atlanta, GA, Jun. 2014.

Outline

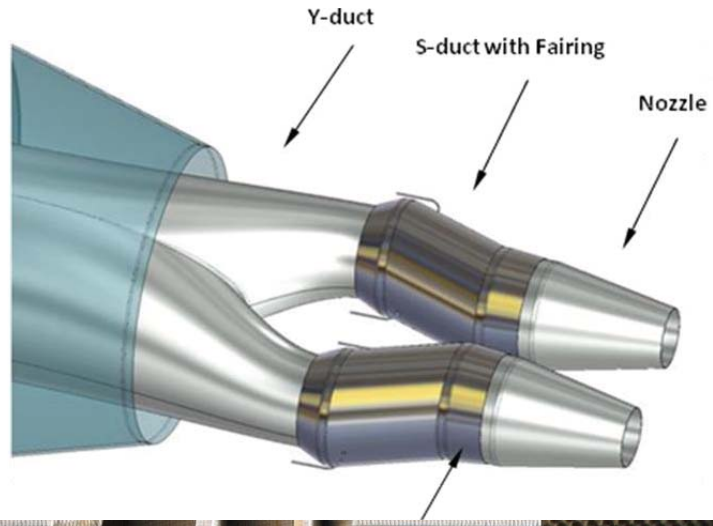
- Twin jet configurations
- Twin jet conditions
- PIV configurations
- Results
  - Single Jet Comparison
  - Twin Round Jets
  - Twin Rectangular Jets
- Summary

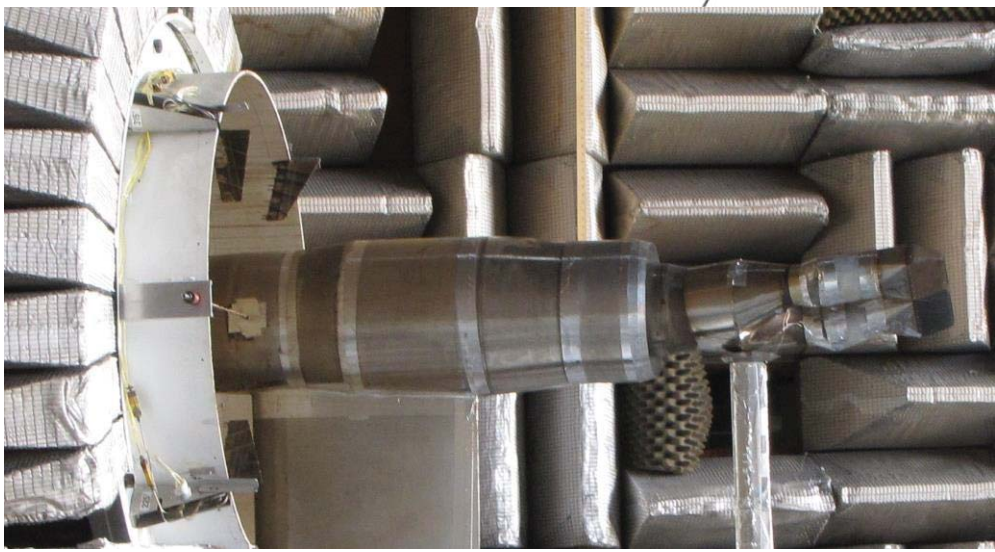




Twin Jet Configurations

- Jet spacing in center-to-center distance (*s*) over nozzle diameter (*D*)
- 2-inch diameter convergent round nozzles (TCON)
- 2.13-inch area equivalent diameter rectangular nozzles:
  - 2:1 aspect ratio (A2Z0)
  - 8:1 aspect ratio (A8Z0)





Twin Spacings	Round *s/D*	TCON	Rectangular *s/D*	A2Z0	A8Z0
Z1	2.63		2.45		
Z4	3.55		3.32		
Z9	5.63		5.26		

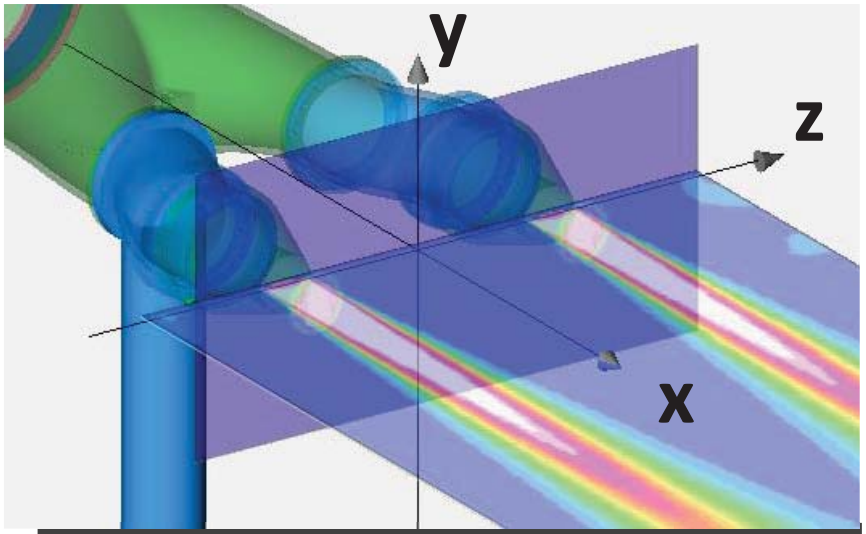
Twin Jet Conditions

- Jet Conditions
  - Acoustic Mach Number M_a from 0.7 to 1.33
  - Nozzle Static Temperature Ratio T_{sr} from 0.84 to 2.27
  - Forward Flight Mach Number M_f from0.05 to 0.25

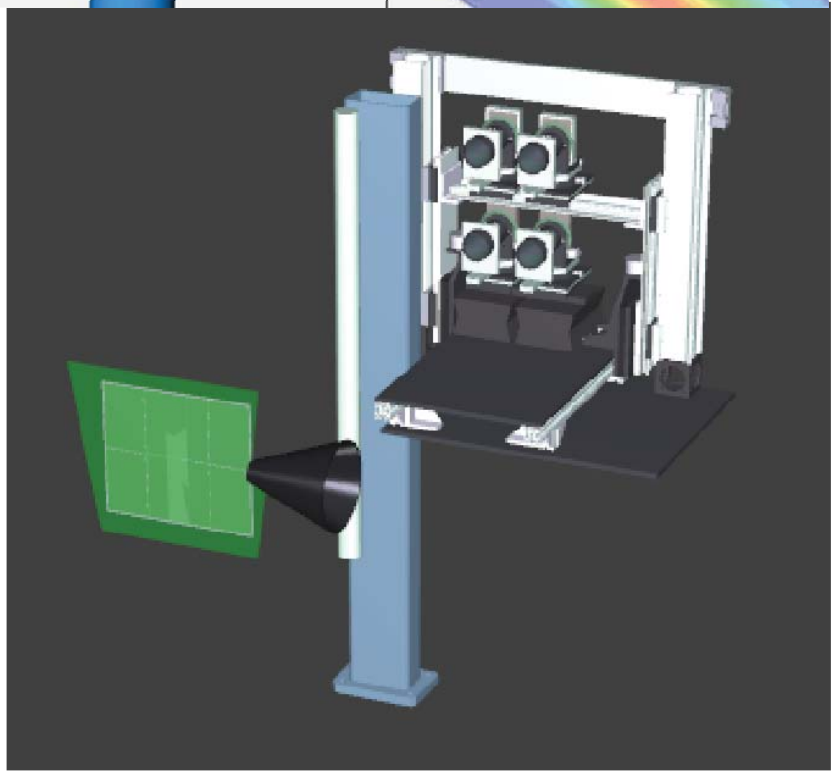
Jet Conditions			**TCON**				**A2Z0**	**A8Z0**			**Nozzles**
M_a	T_{sr}	M_f	**Single**	**Z1**	**Z4**	**Z9**	**Z1**	**Single**	**Z4**	**Z9**	**Spacings**
0.90	0.84	0.05	☑	☑	☑	☑	☑	☑	☑	☑	
1.33	2.27	0.05		☑	☑	☑	☑			☑	
1.33	1.76	0.05	☑	☑	☑	☑	☑	☑	☑	☑	
1.33	1.76	0.10	☑	☑							
1.33	1.76	0.20	☑	☑							
1.33	1.76	0.25	☑	☑	☑	☑	☑	☑	☑	☑	

Particle Image Velocimetry (PIV) Configurations

- Coordinate system

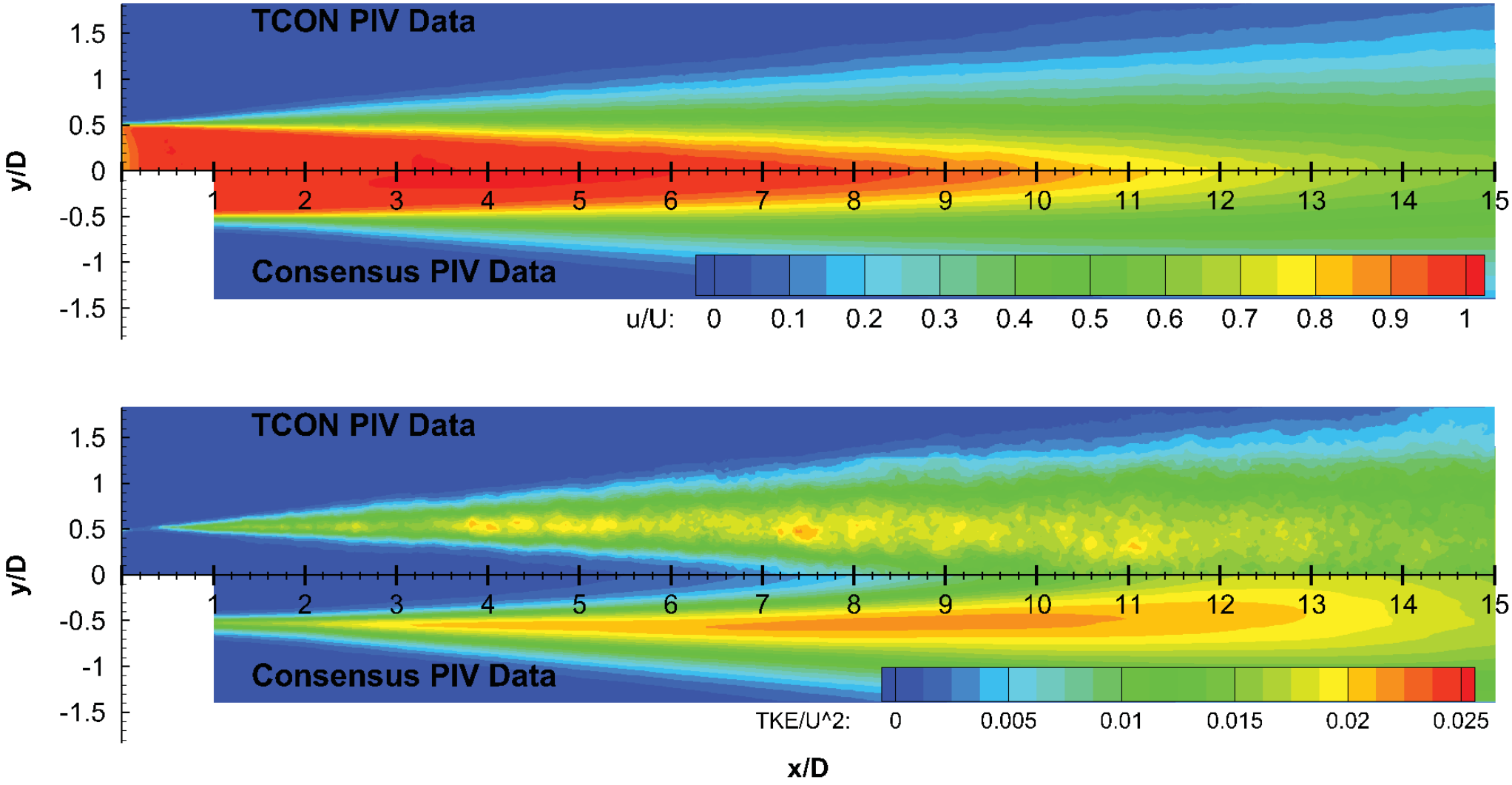


- Streamwise (x-z plane)
  - 22” x 14” field of view
  - *x/D* of 0 to 30
- Cross-stream (y-z plane)
  - 10.5” x 22” field of view
  - *x/D* of 1, 2, 5, 10, 15, and 20



Single Jet Comparison

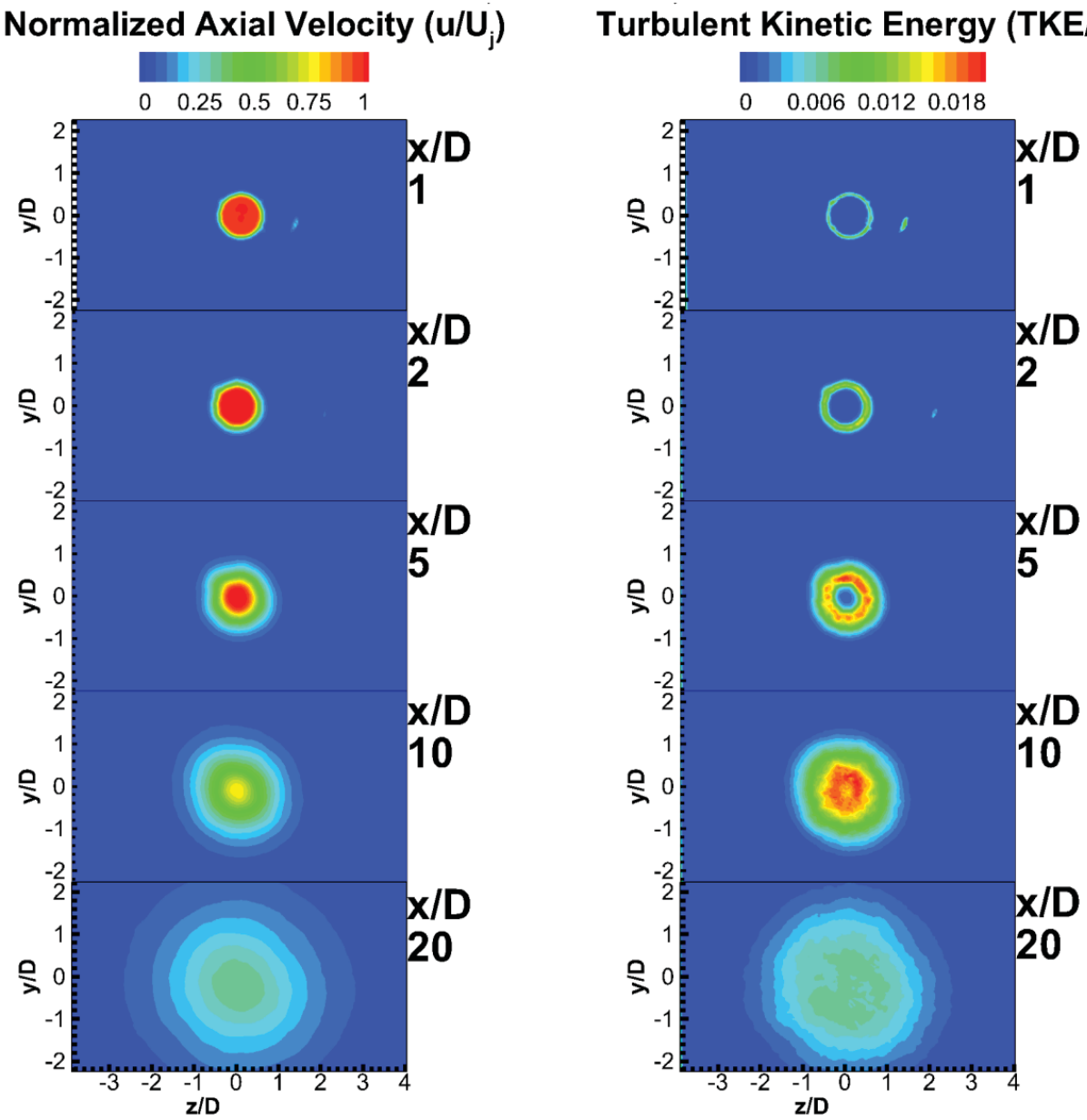
M_a = 0.9, Unheated

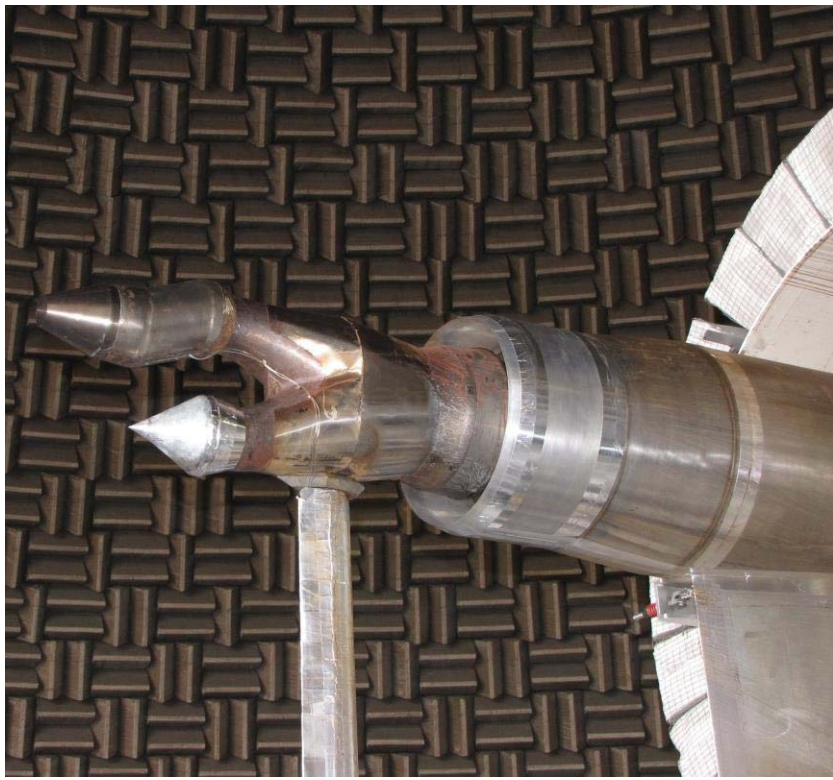


Bridges, J., and Wernet, M., "The NASA Subsonic Jet Particle Image Velocimetry (PIV) Dataset," NASA Glenn Research Center, NASA/TM—2011-216807.

Single Jet: Cross-stream PIV

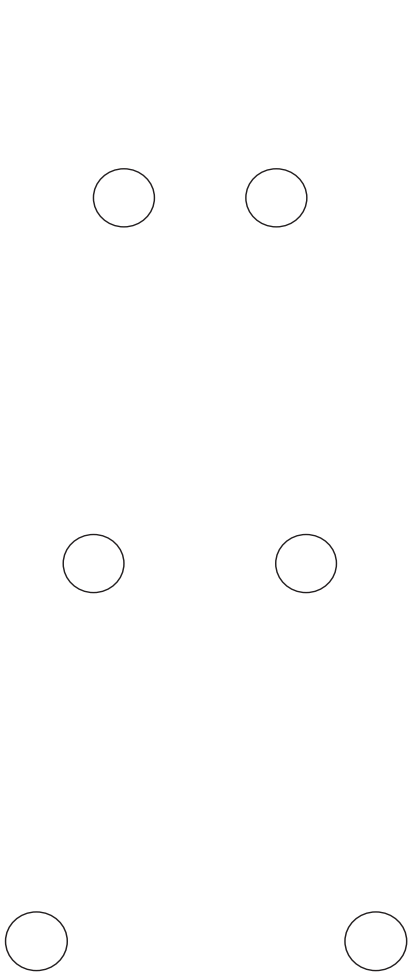
M_a = 0.9, Unheated

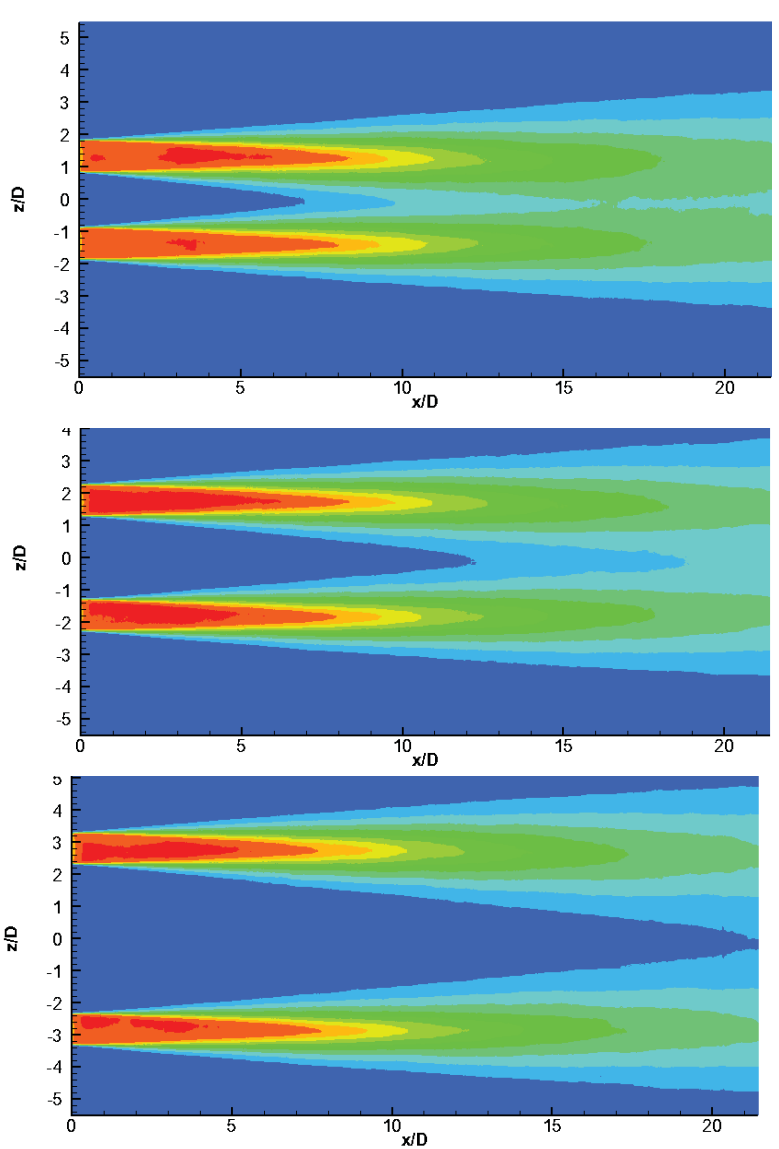


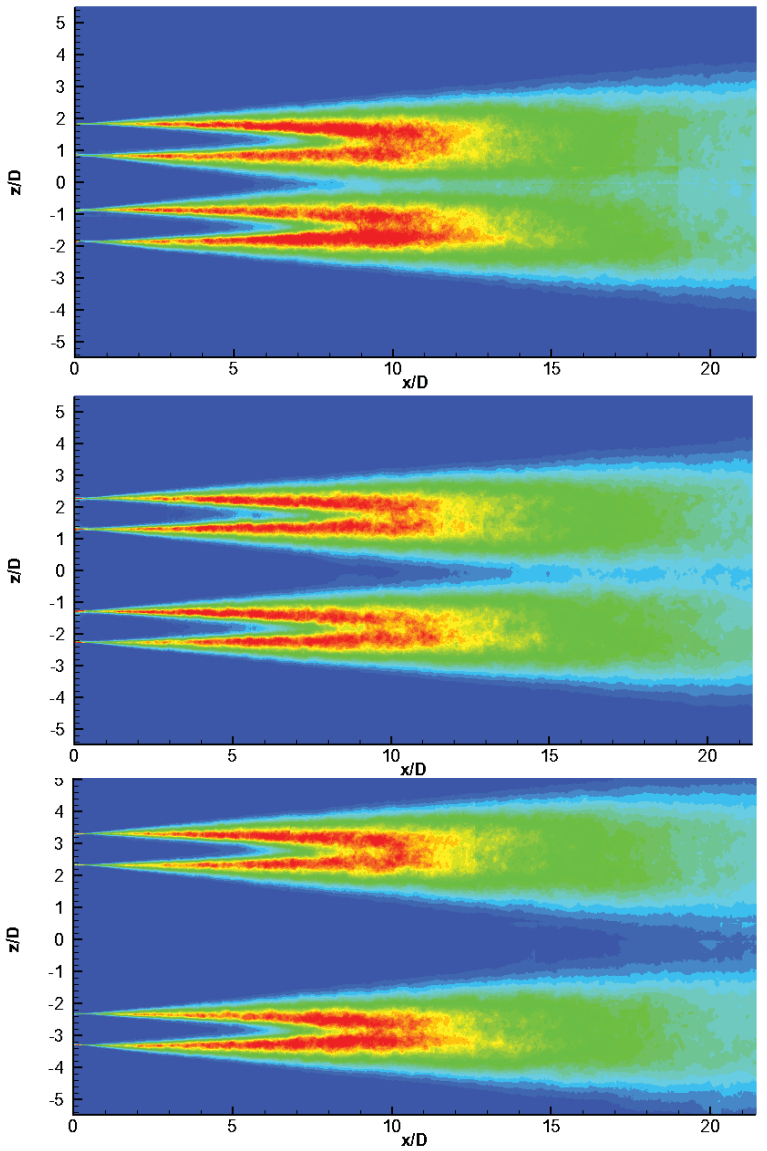


Twin Round Jets: Streamwise PIV

$M_a = 1.33$, $T_{sr} = 1.76$, $M_f = 0.05$

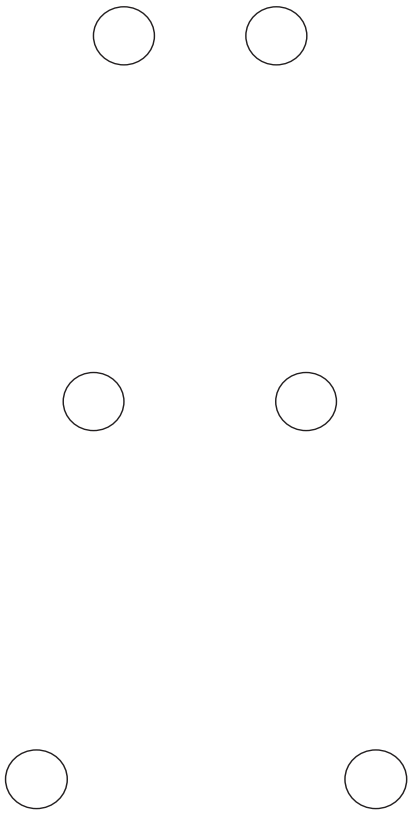


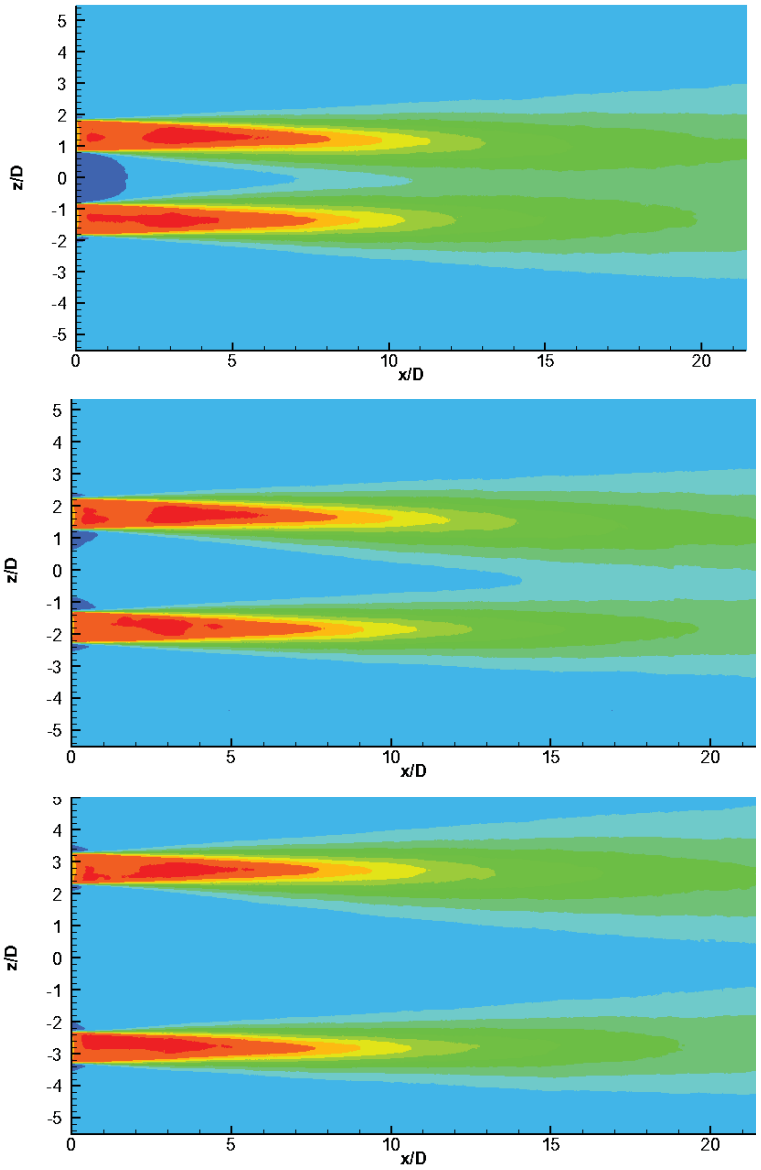


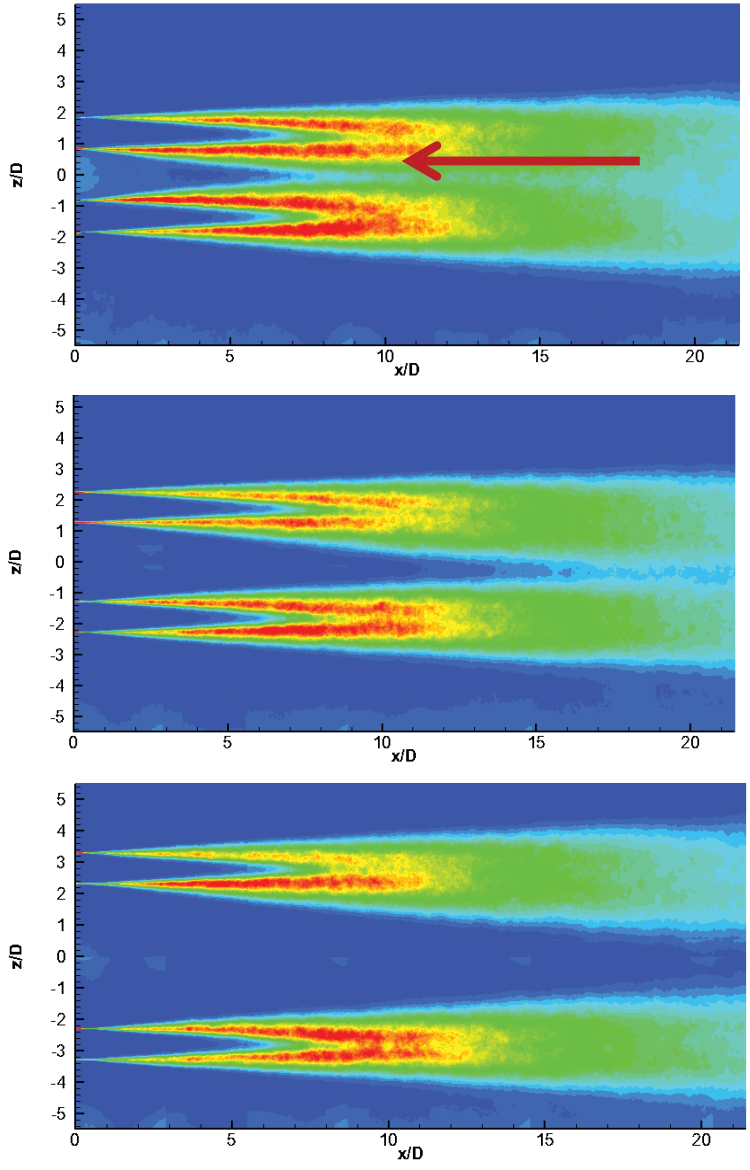


Twin Round Jets: Streamwise PIV

$M_a = 1.33$, $T_{sr} = 1.76$, $M_f = 0.25$

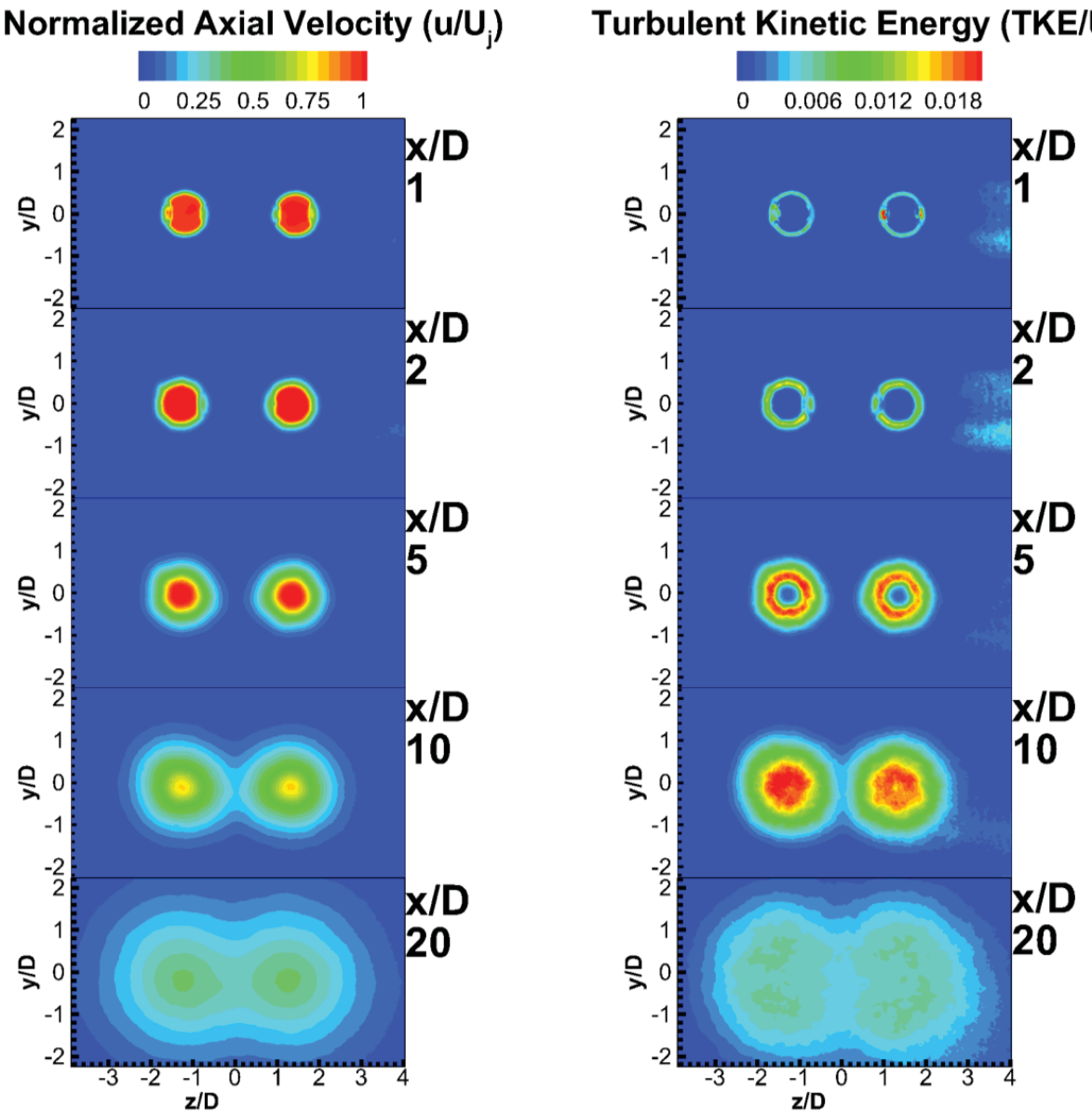






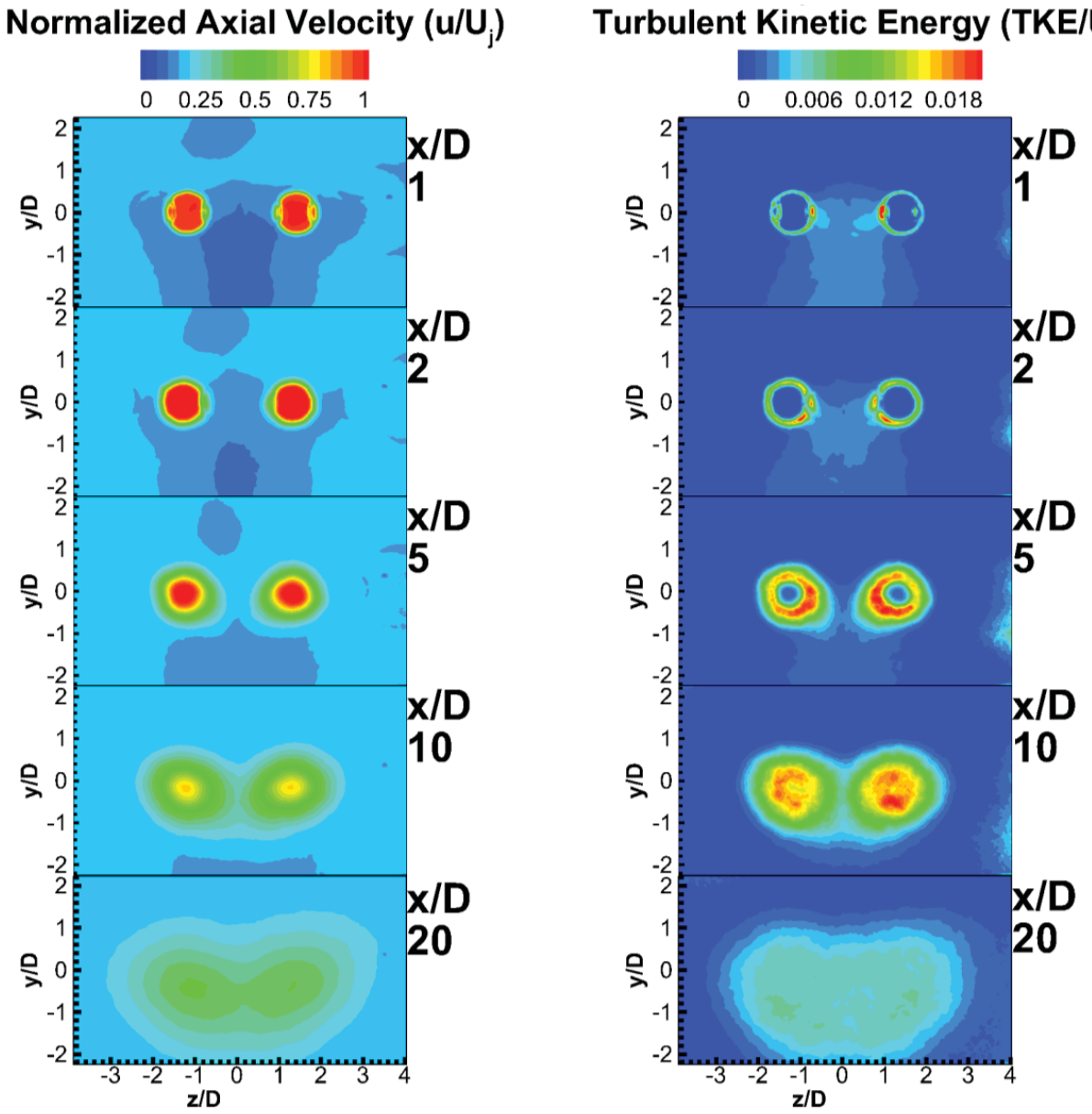
Twin Round Jets: Cross-stream PIV

$s/D = 2.63$, $M_a = 1.33$, $T_{sr} = 1.76$, $M_f = 0.05$



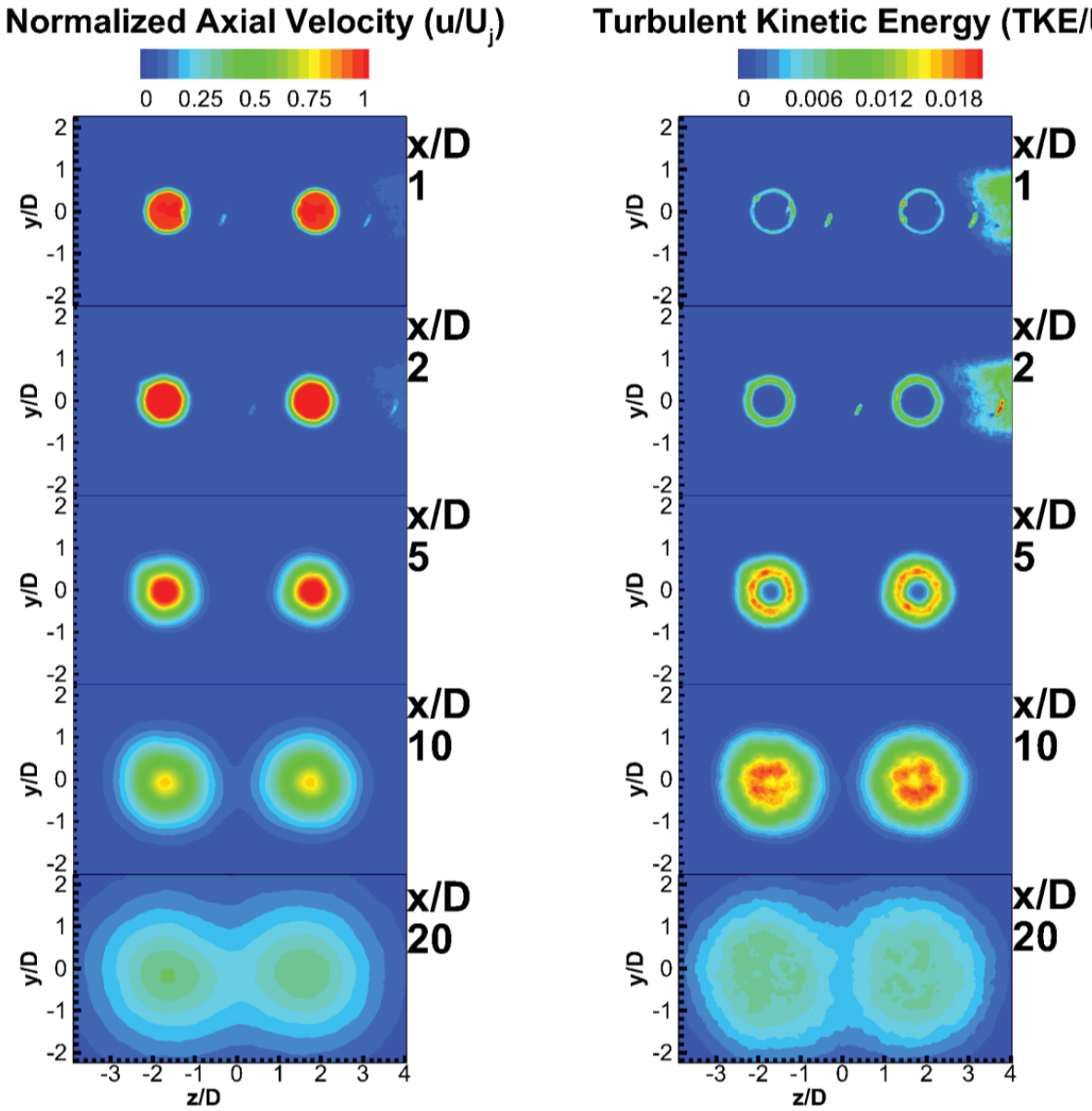
Twin Round Jets: Cross-stream PIV

$s/D = 2.63$, $M_a = 1.33$, $T_{sr} = 1.76$, $M_f = 0.25$



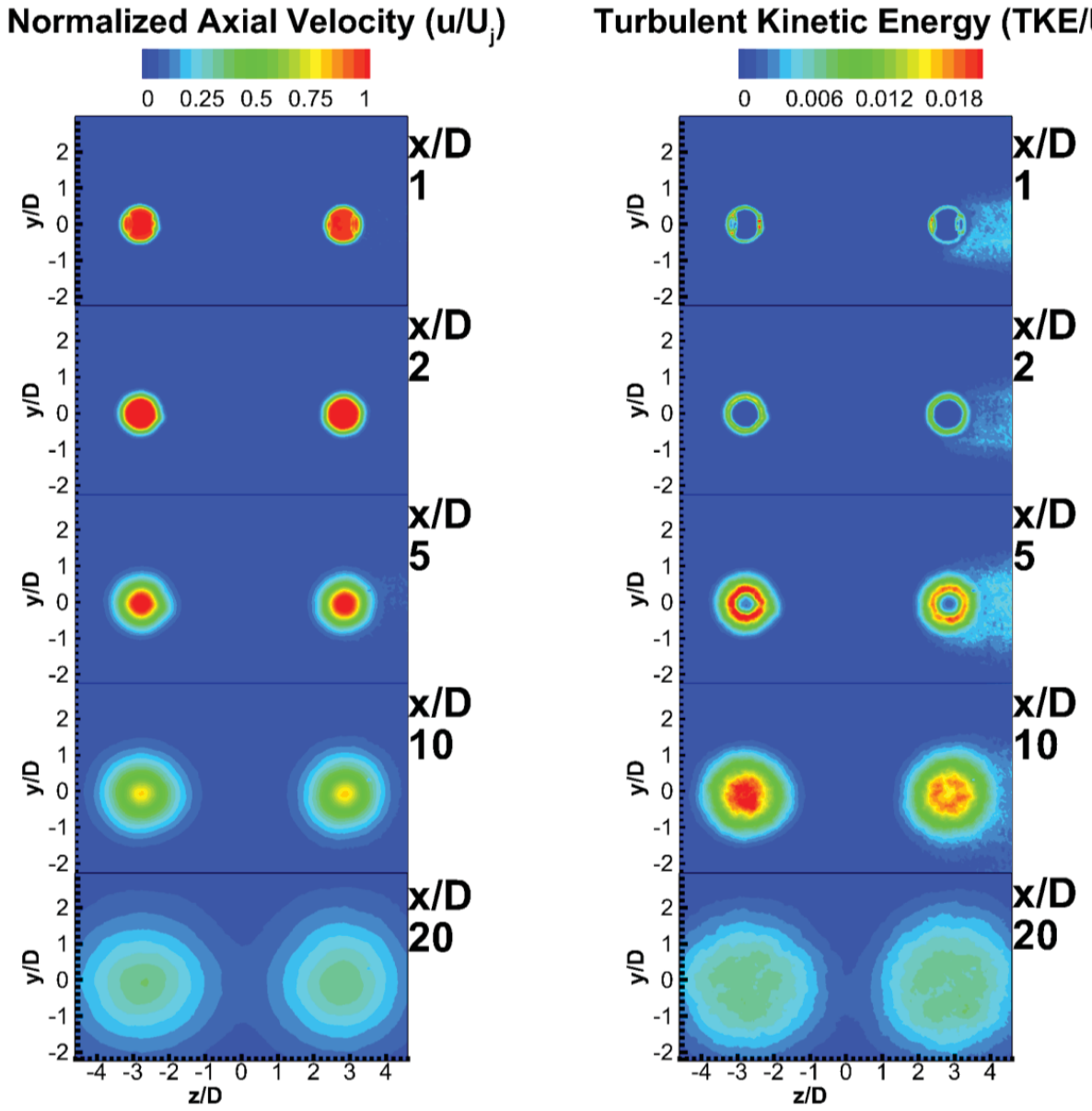
Twin Round Jets: Cross-stream PIV

$s/D = 3.55$, $M_a = 1.33$, $T_{sr} = 1.76$, $M_f = 0.05$



Twin Round Jets: Cross-stream PIV

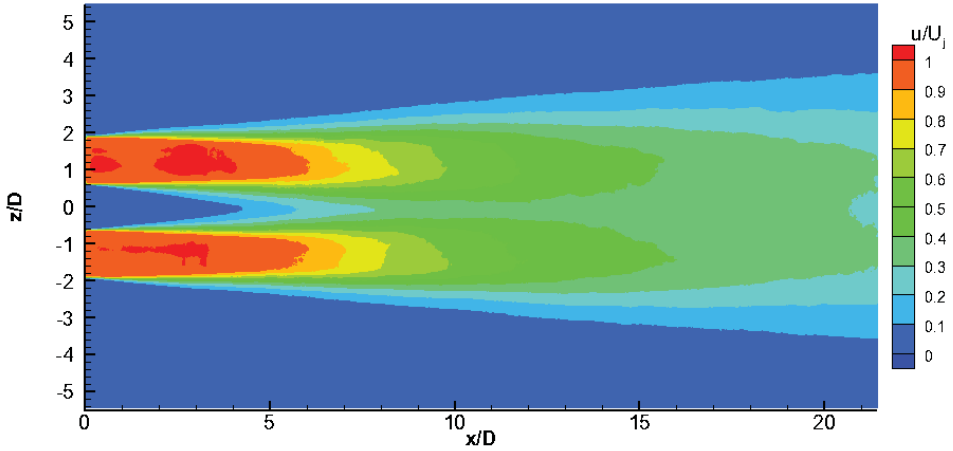
$s/D = 5.63$, $M_a = 1.33$, $T_{sr} = 1.76$, $M_f = 0.05$

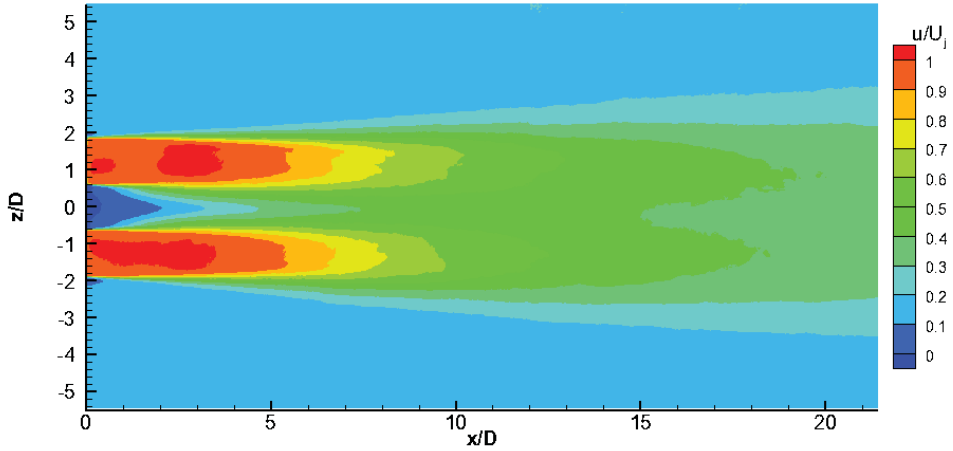


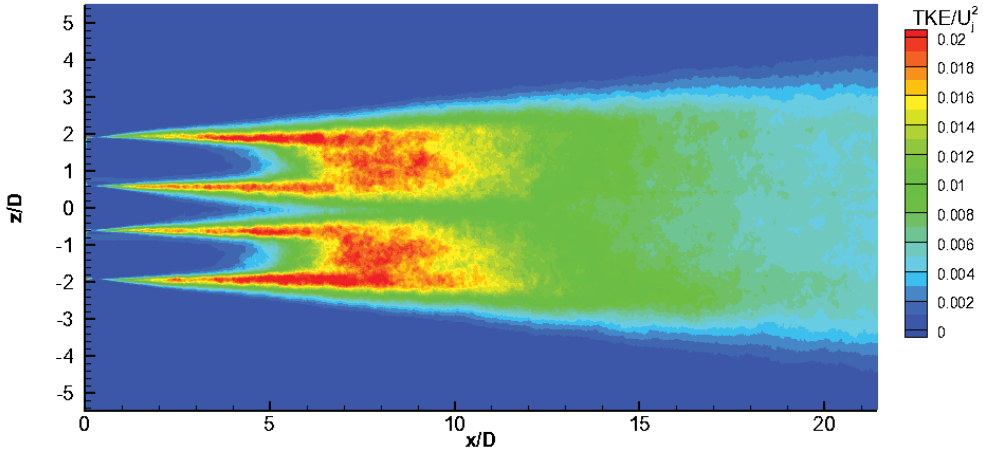
Twin 2:1 Rectangular Jets: Streamwise PIV

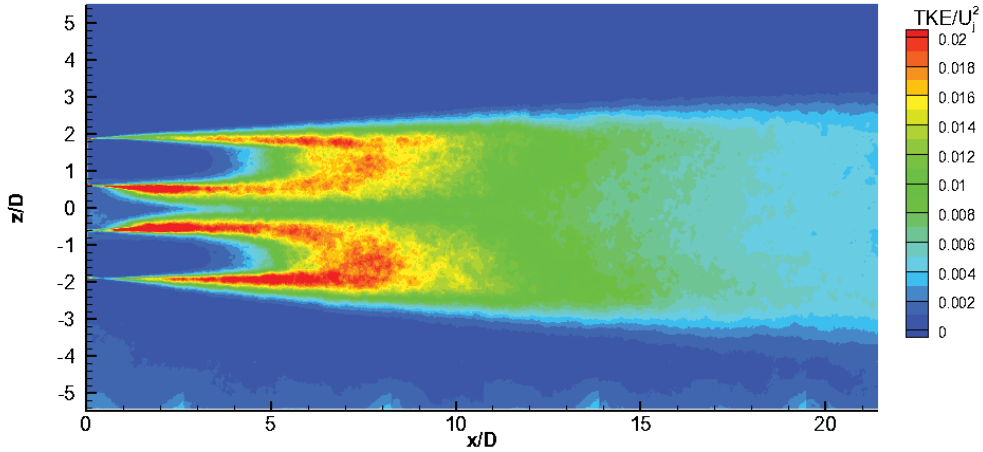
$s/D = 2.45$, $M_a = 1.33$, $T_{sr} = 1.76$

$M_f = 0.05$ $M_f = 0.25$



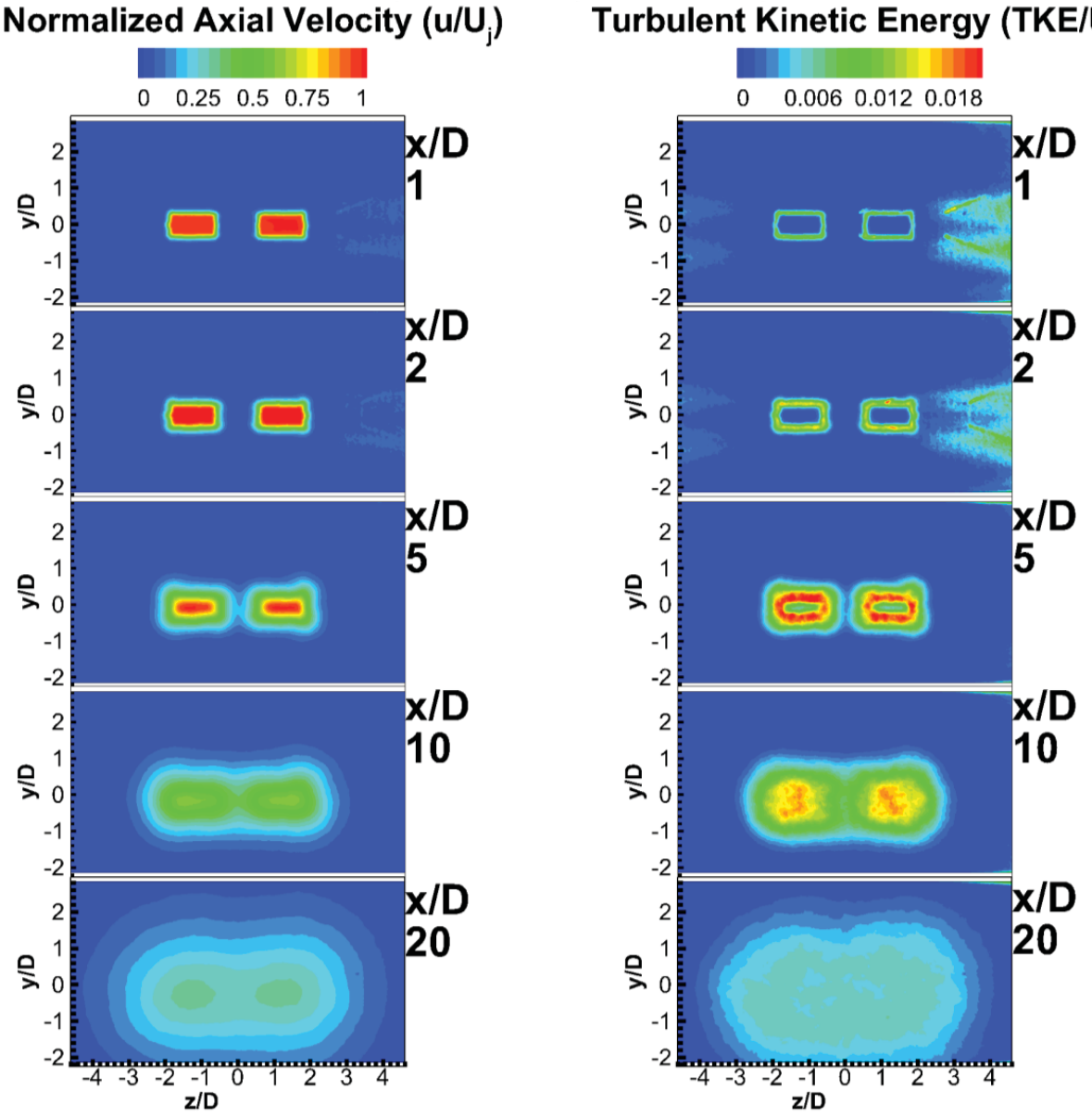






Twin 2:1 Rectangular Jets: Cross-stream PIV

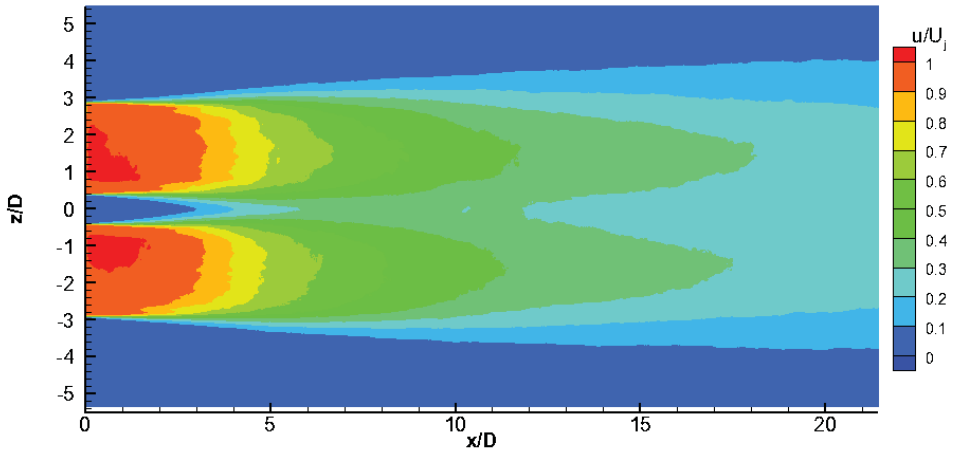
$s/D = 2.45$, $M_a = 1.33$, $T_{sr} = 1.76$, $M_f = 0.05$

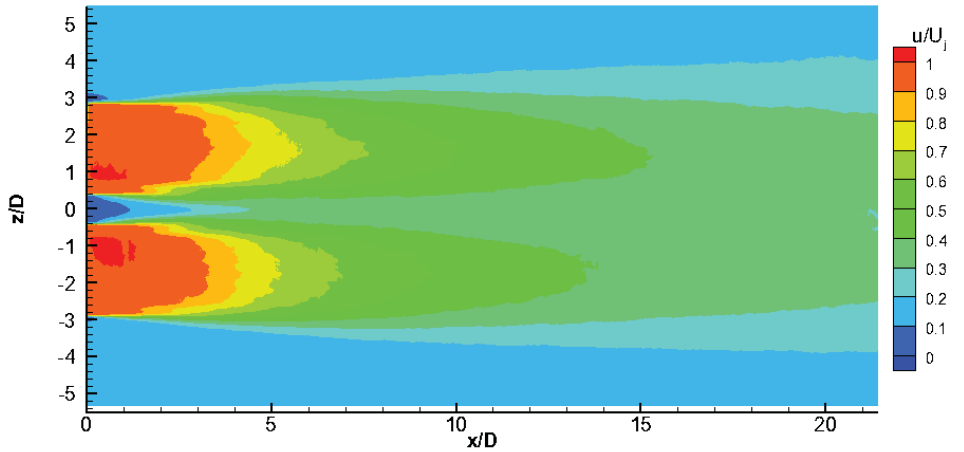


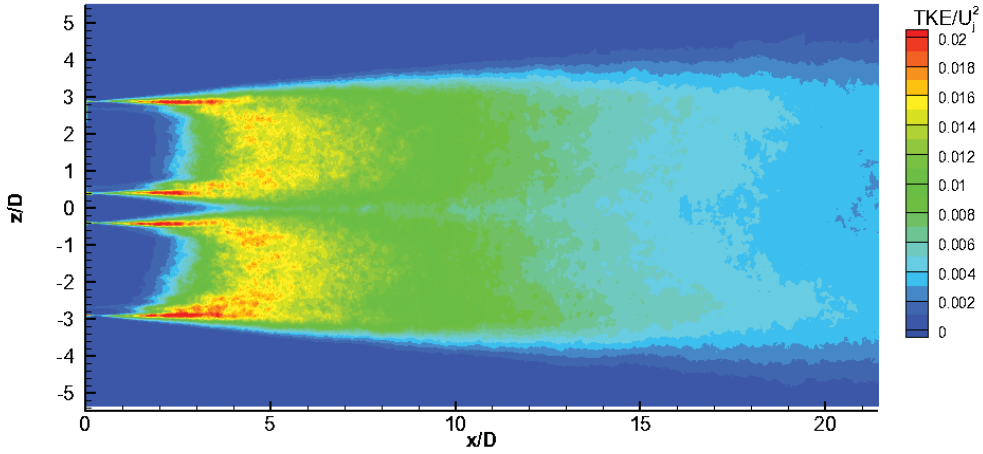
Twin 8:1 Rectangular Jets: Streamwise PIV

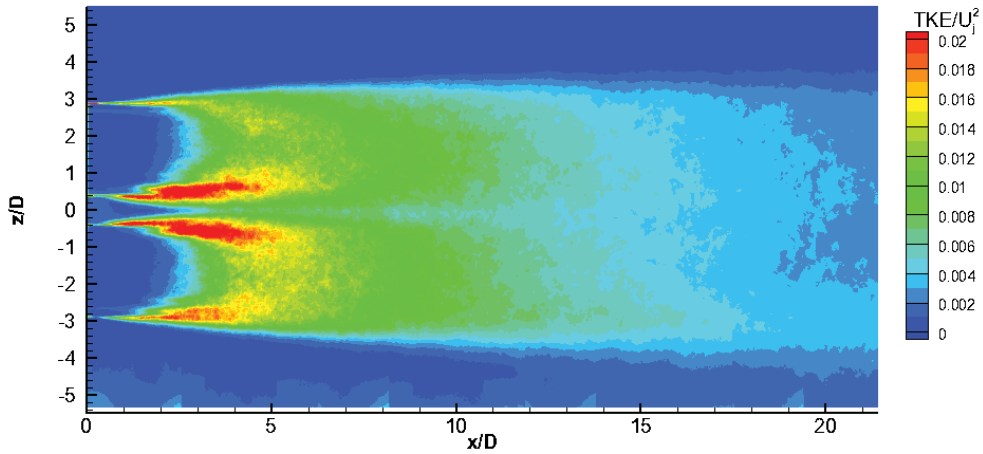
$s/D = 3.55$, $M_a = 1.33$, $T_{sr} = 1.76$

$M_f = 0.05$ $M_f = 0.25$



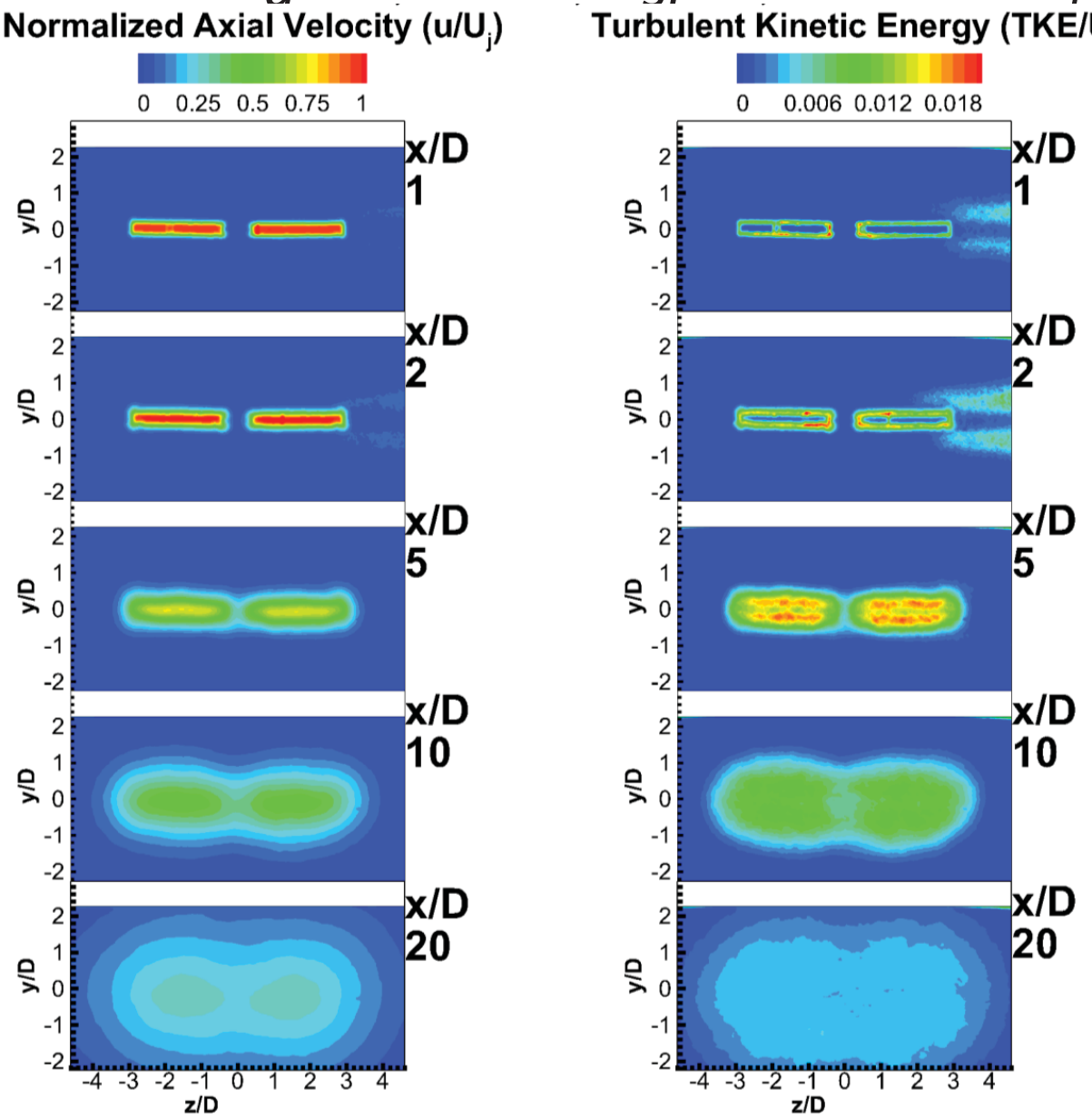






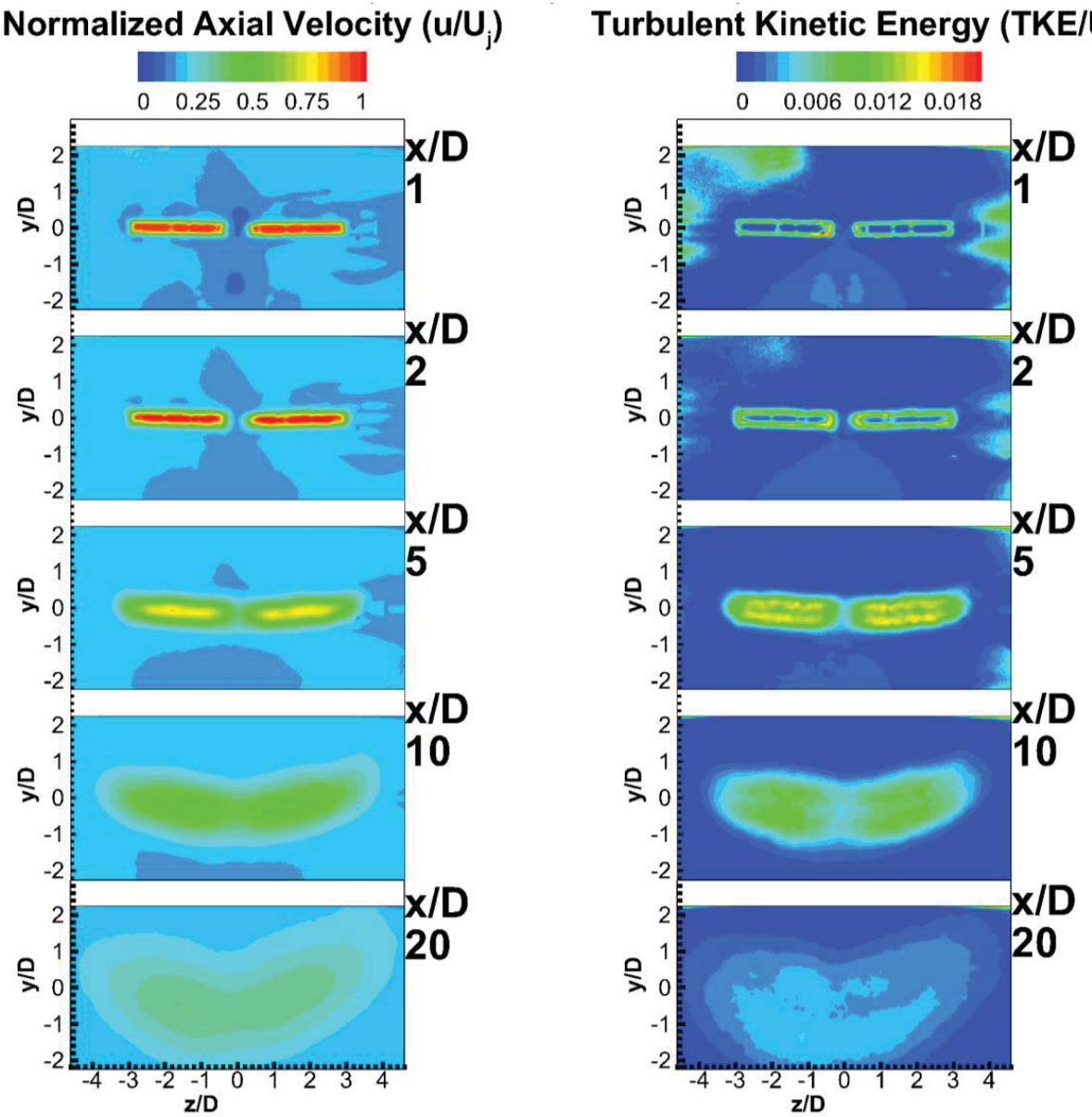
Twin 8:1 Rectangular Jets: Cross-stream PIV

$s/D = 3.55$, $M_a = 1.33$, $T_{sr} = 1.76$, $M_f = 0.05$

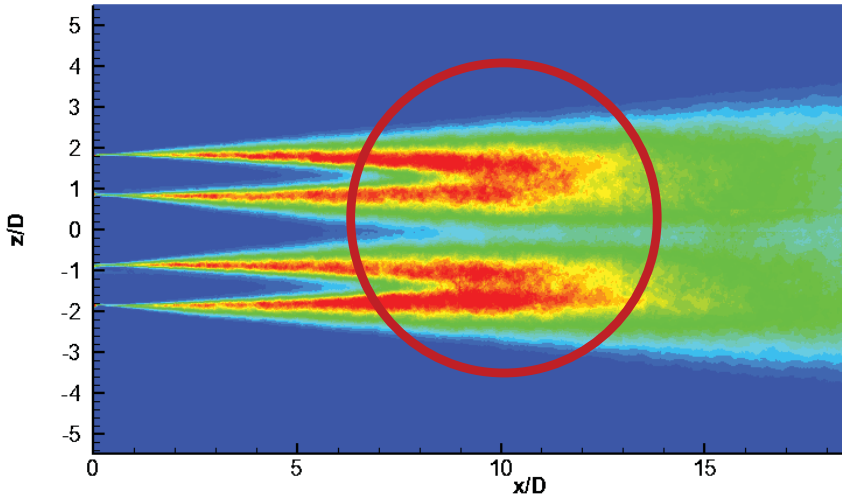


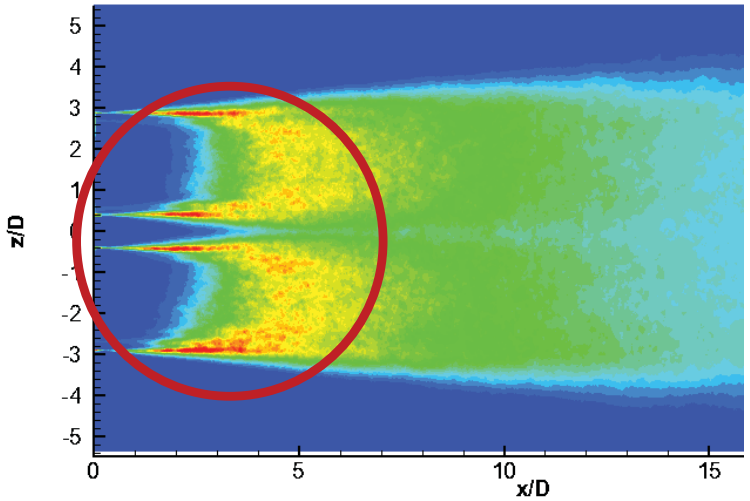
Twin 8:1 Rectangular Jets: Cross-stream PIV

$s/D = 3.55$, $M_a = 1.33$, $T_{sr} = 1.76$, $M_f = 0.25$



Streamwise PIV at M_a = 1.33, T_{sr} = 1.76, M_f = 0.05
Reductions in Peak Turbulence (TKE/U_j^2)





Twin Spacing	Round (*s/D*)	TCON	Rectangular (*s/D*)	A2Z0*	A8Z0*
Z1	2.63	13%	2.45	12%	X
Z4	3.55	0	3.32	X	10%
Z9	5.63	0	5.26	X	9%

*For the rectangular nozzles, the peak turbulence does not coincide with the streamwise measurement plane.

Summary

- Cross-stream and streamwise round and rectangular twin jet flow field PIV measurements were obtained at a few twin jet spacings and jet conditions.
- A decrease in turbulent kinetic energy levels relative to a single jet between the two jets at close spacings could be the result of enhanced mixing. This change in TKE levels is only evident in streamwise PIV measurements at the closest jet spacings obtained for each set of nozzles.
- When forward flight is increased, a velocity deficit between nozzles was measured. This appears to be due to the twin jet model blockage.
- The velocity deficit causes increased turbulence levels between the nozzles. The increased turbulence levels could be causing increased noise levels, relative to a single jet, found with far-field acoustic measurements.

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