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EXPERIMENTAL STUDY OF THE FLOW IN A DUAL-STREAM SUPERSONIC JET

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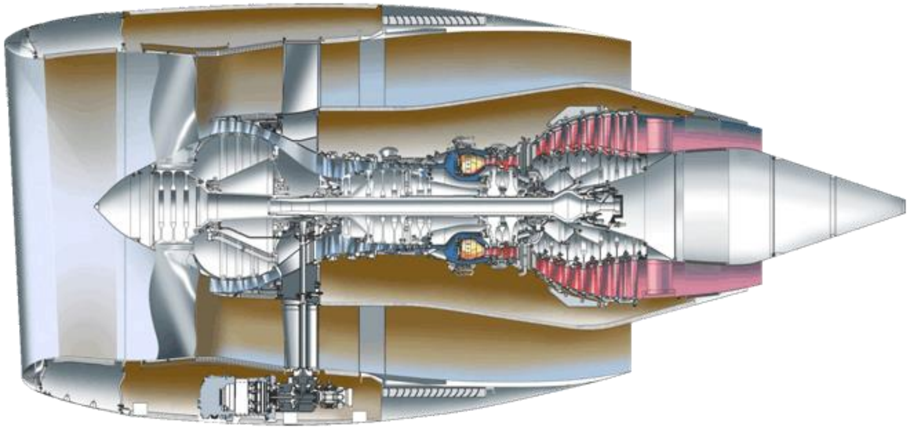
Motivation

The ability to simulate aerodynamic flows using CFD methods has progressed rapidly over the last decades and has given rise to a change in design processes in aeronautics already. But more improvement is necessary to overcome the existing lack in confidence in CFD usage, based on turbulence modelling.

There are necessary at complete reliable experimental data for verification of CFD results of flow parameters for dual-stream jet exhausted from model nozzle.

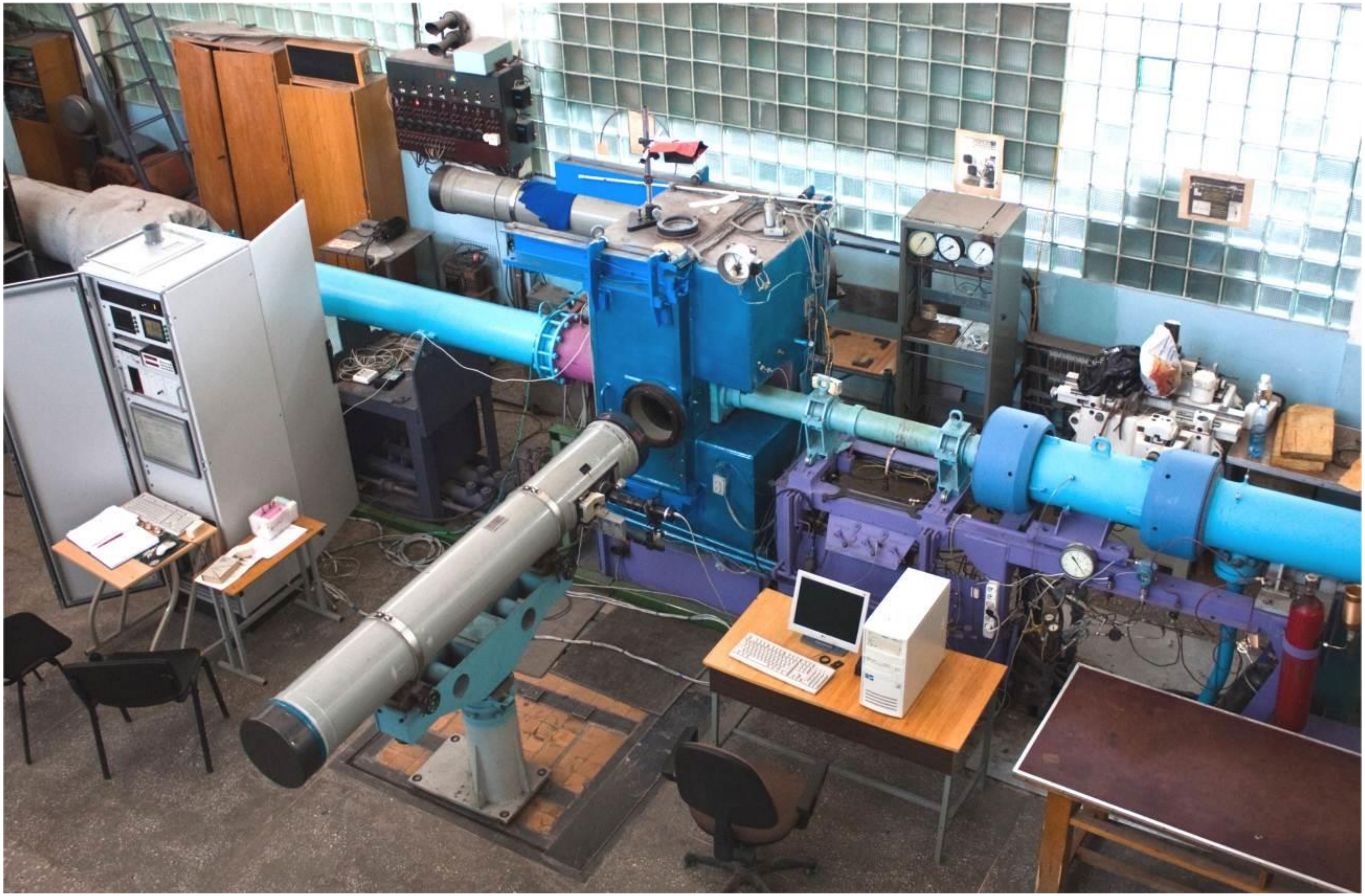


Scheme of the turbojet engine

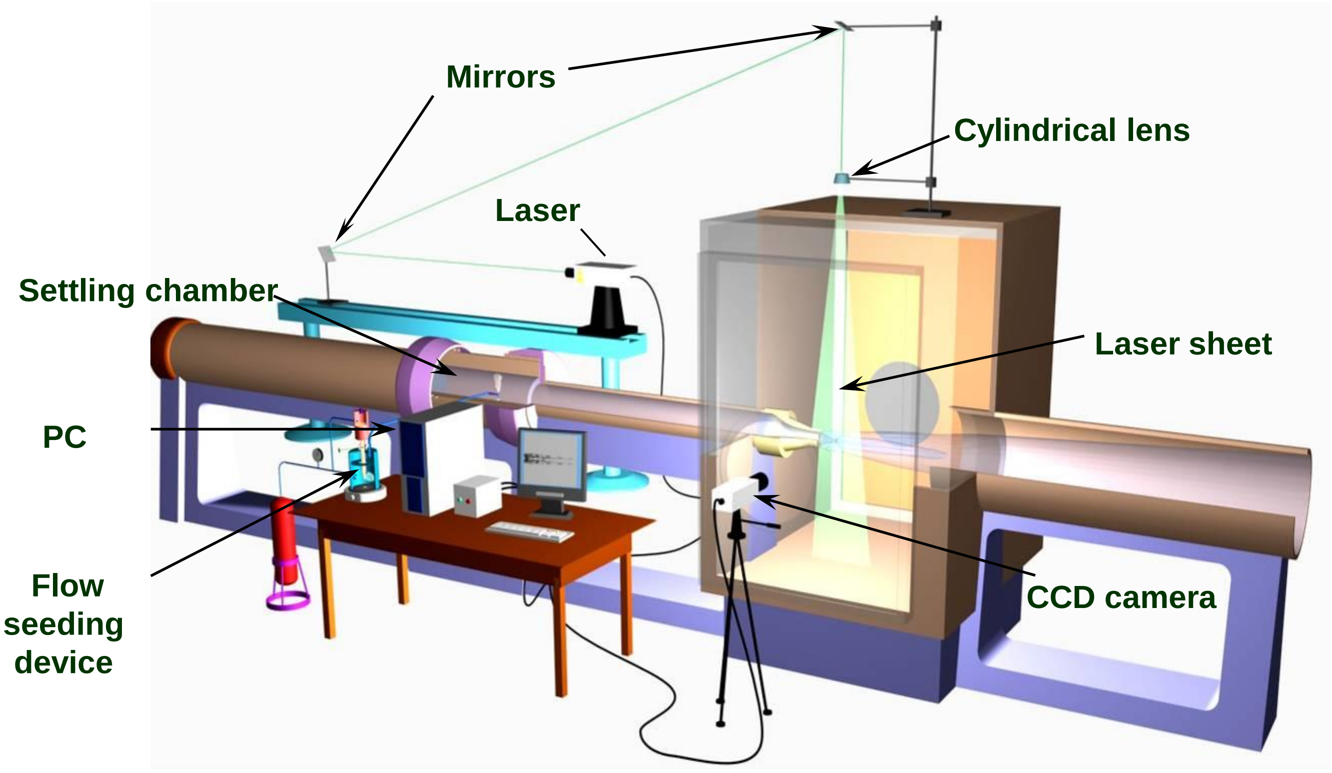
Contents

- *Brief description of equipment using for experimental investigations of gasdynamic flow structure of supersonic nonisobaric jets*
- *Description of experimental data necessary for creating of dual-stream jet test case*
- *The work is carried out within a project being executed by the Be-lotserkovskii Scientific-Educational Center for Computer Modeling and Security Technologies in collaboration with colleagues from TsAGI, team of Prof. S.M. Bosnyakov*

Hypersonic wind tunnel T-326 ITAM SB RAS with jet module

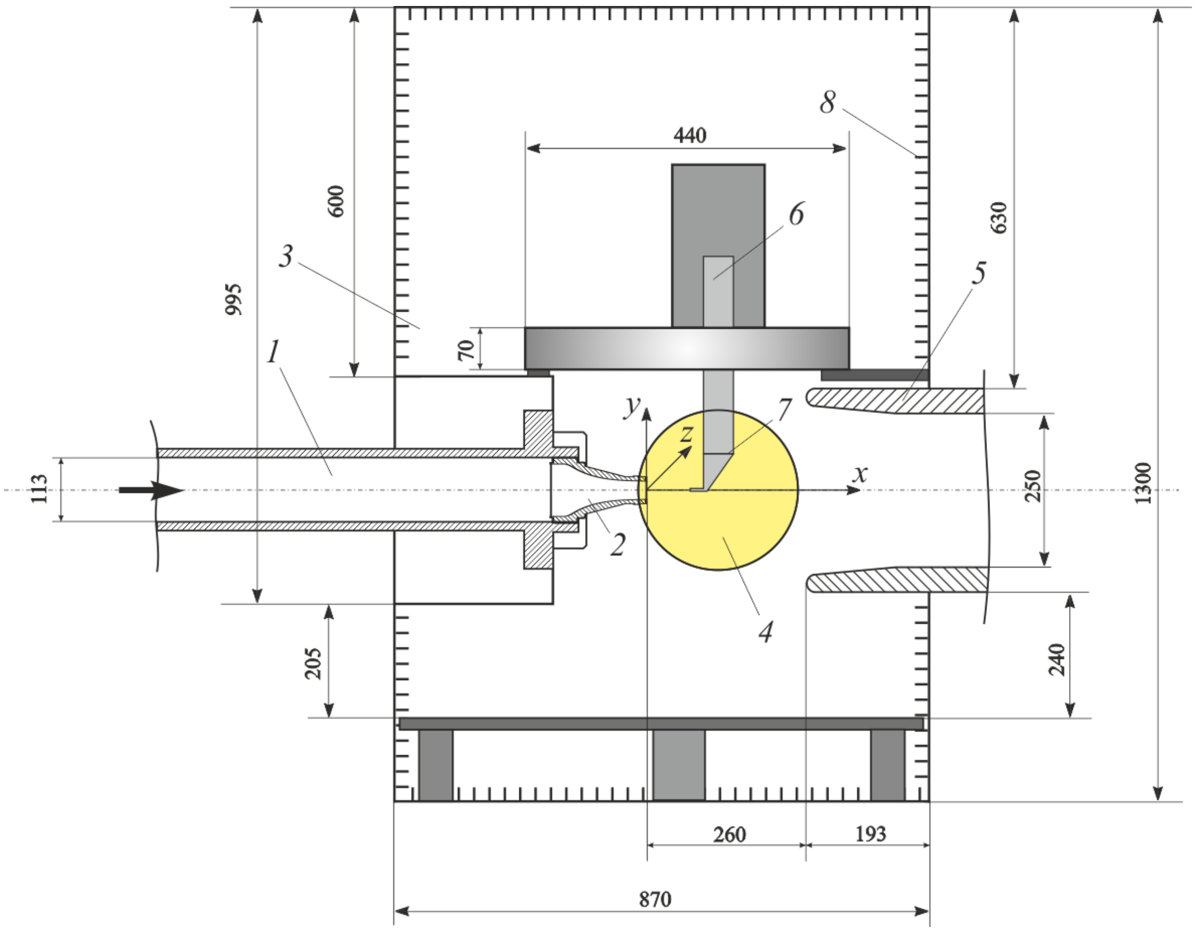


Equipment for PIV method on T-326 ITAM SB RAS



CCD camera «SENSI CAM», double impulse laser ND-YAG, synchronization module

Jet module of Hypersonic wind tunnel T-326 ITAM SB RAS



1 –plenum chamber of jet module ; 2 - nozzle; 3 - test section (Eifel chamber); 4 – optic window; 5 – exhaust channel; 6 – 3D traverse gear, 7 – Pitot tube, 8 – beams

Test section 1.3 X 0.87 X 0.9 m^3

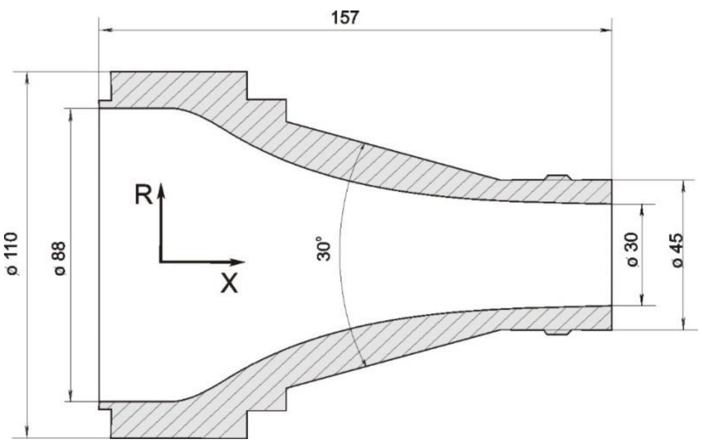
Equipment using for experimental investigations of gasdynamic flow structure of supersonic nonisobaric jets

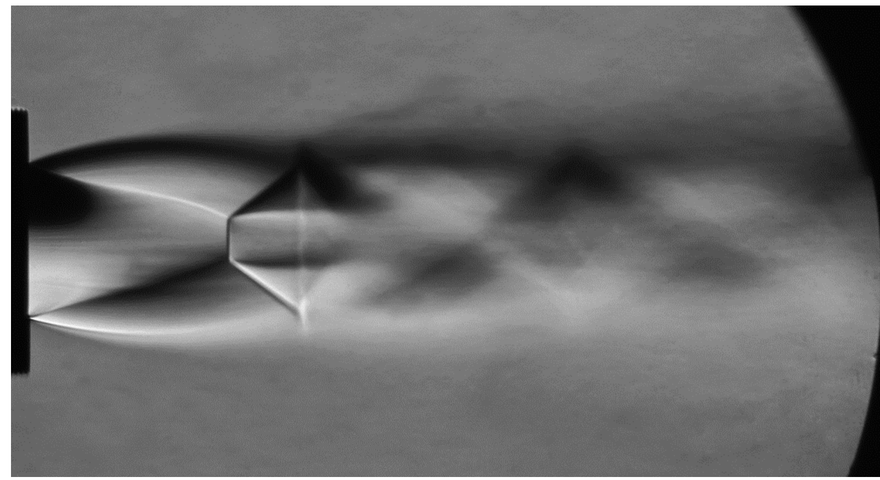
- Hypersonic wind tunnel T-326 ITAM SB RAS with jet module;
- Model nozzle;
- Automated data acquisition system T-326 with using of multimeter HP-34970A;
- 3D precise traverse gear with position accuracy ± 0.02 mm;
- Hot wire anemometer constant temperature AN-1003;
- Microprobe Pitot pressure (Pitot tube) d = 0.6 mm;
- Optic device IAB-451 (window D=230 mm) and CCD Camera;
- PIV-system "Oxford Lasers".

Transducers:

- Piezoresistive pressure gage at settle chamber 1 MPa, P_0;
- Piezoresistive pressure gages for measured stagnation pressure at inner and outer nozzle flow contour (P_{01}, P_{02}), at Eifel chamber (Pc), Pitot pressure (Pt) - TDM-A (0.1-0.6) MPa;
- Thermocouples for measured stagnation temperature at settle chamber and ambient space temperature at Eifel chamber (T_0, Tc);
- Hot wire anemometer sensor of flow rate (wolfram wire diameter 0.01 mm) .

Gasdynamic flow structure of single supersonic axisymmetric underexpended jet

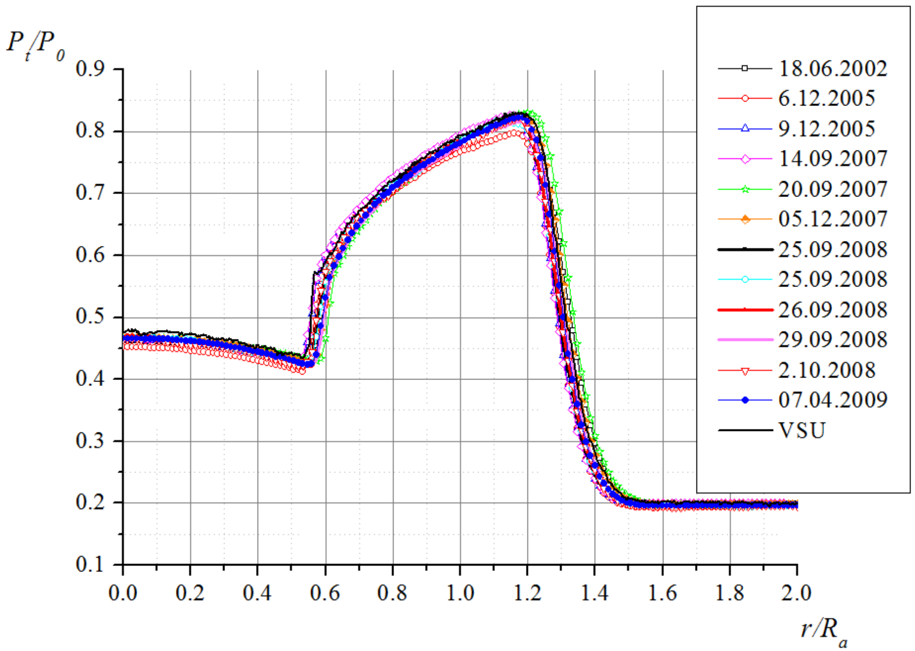


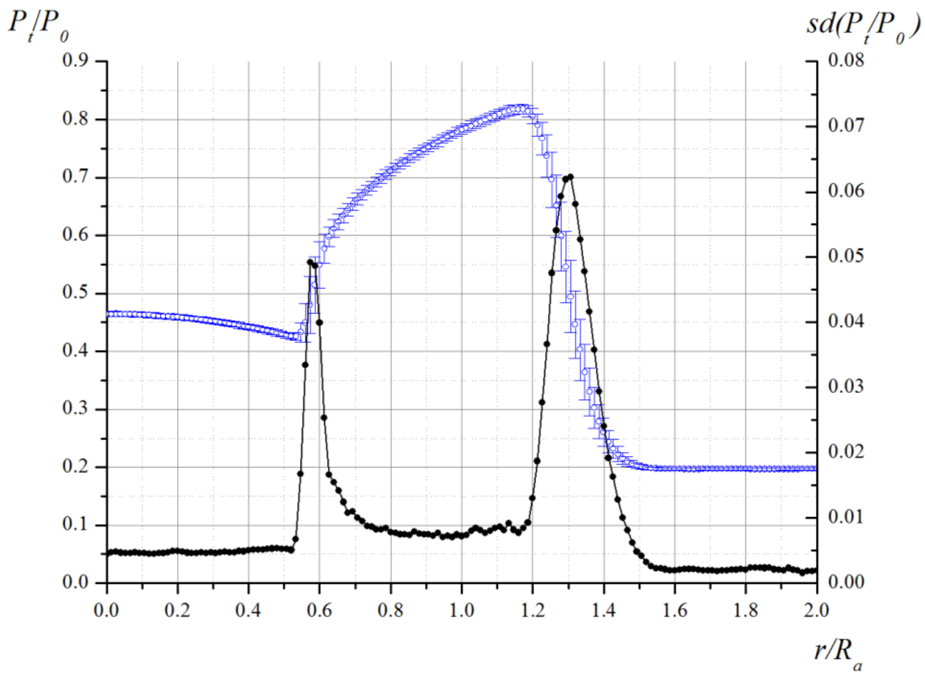


Convergent axisymmetric nozzle with Mach number at exit M_a= 1.0, D_a= 30 mm

Shlieren-visualization (horizontal knife) of axisymmetric supersonic uderexpanded jet Ma= 1.0, Npr= 5.0, exposure equal 0.01 sec

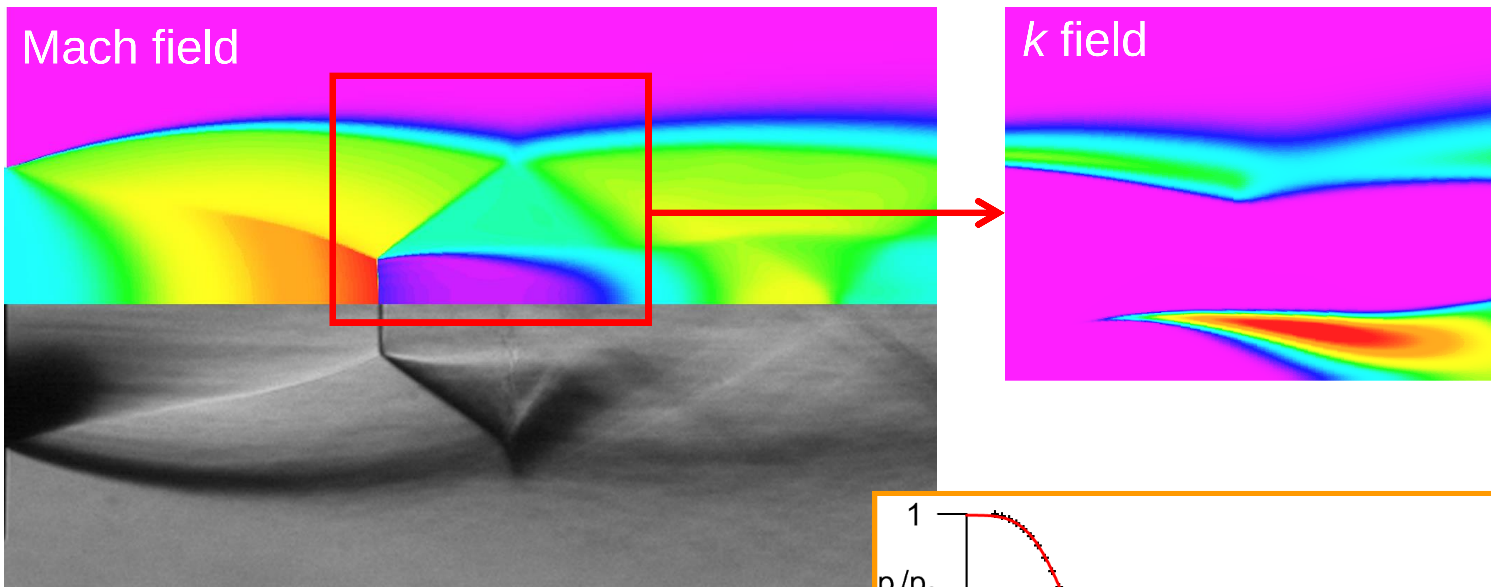
Radial pressure distributions (a) and r.m.s. deviation (b) in the jet cross-section x/Ra = 2.0; (a): (1) 2002; (2, 3) 2005; (4–6) 2007, (7–11) 2008; (12) 2009; and (13) vertical jet setup; (b): (1) mean pressure value and confidence interval and (2) r.m.s. pressure deviation.

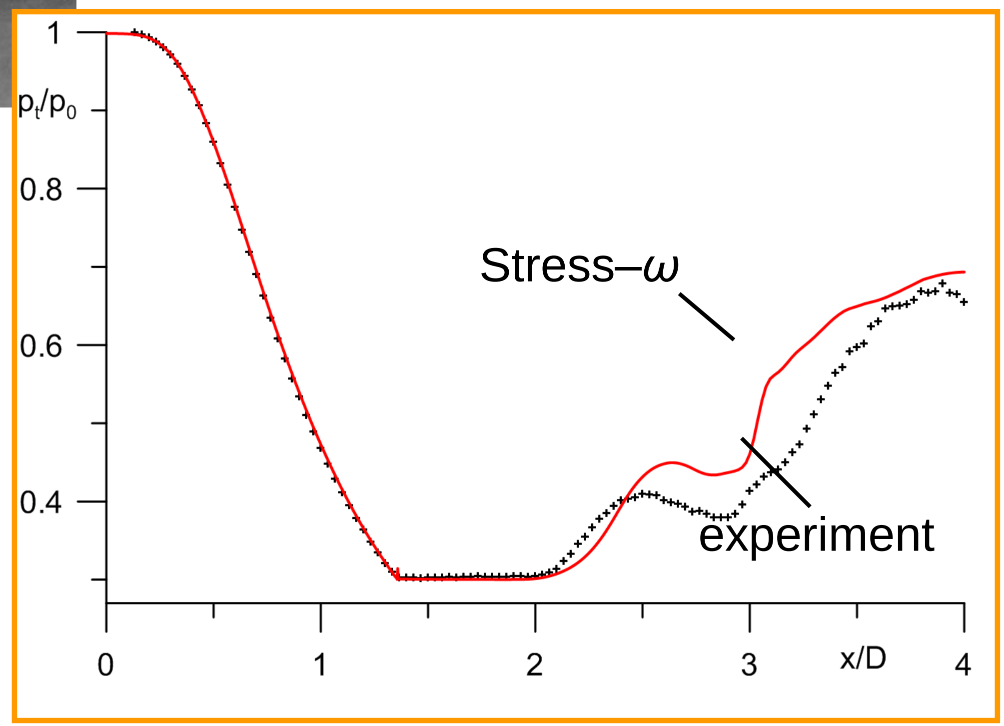




V. I. Zapryagaev, N. P. Kiselev, and A. A. Pivovarov. Gasdynamic Structure of an Axisymmetric Supersonic Underexpanded Jet // ISSN 0015-4628, Fluid Dynamics, 2015, Vol. 50, No. 1, pp. 87–97.

Computation with Stress–ω model





- finite k amplification on shock waves which is independent of mesh spacing
- correct internal mixing layer growth rate

A. I. Troshin, TsAGI, MIPT

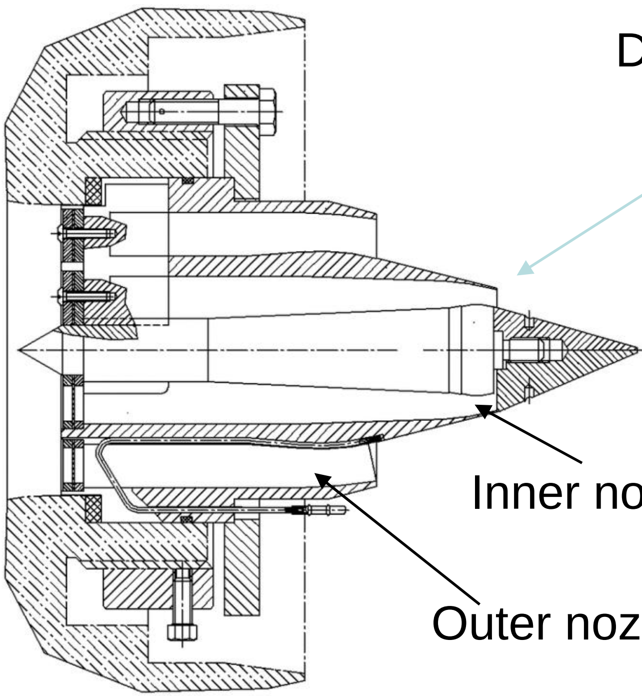
Application and modification of a Reynolds stress model in problems of jets outflow

Date for creating of dual-stream jet test case

Dual-stream jet nozzle

3D traverse gear

Dual-stream jet nozzle



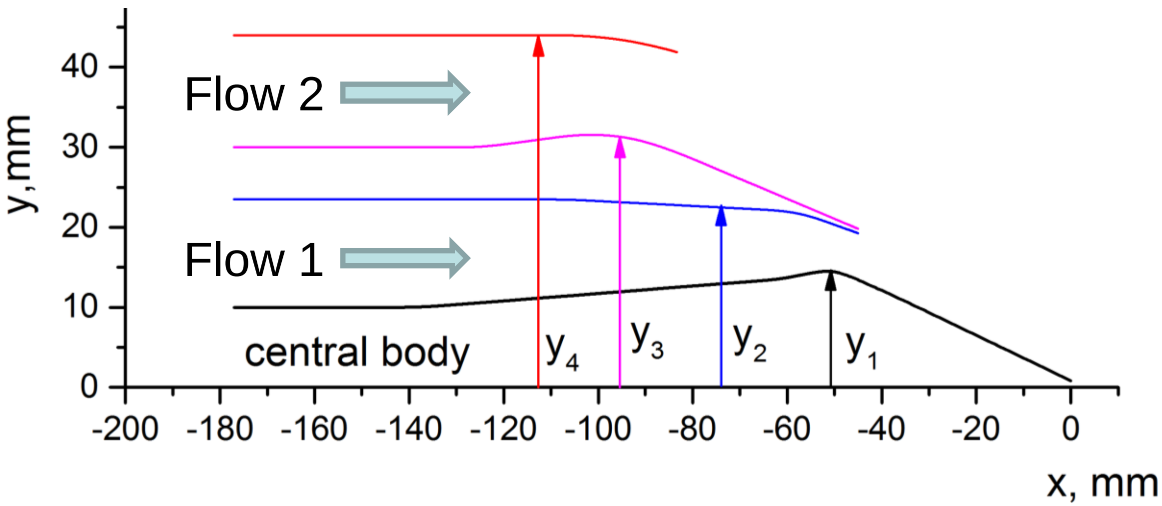
Inner nozzle contour (1)

Outer nozzle contour (2)

D_{a1}= 38.54 mm, D_{a2} = 83,74 mm

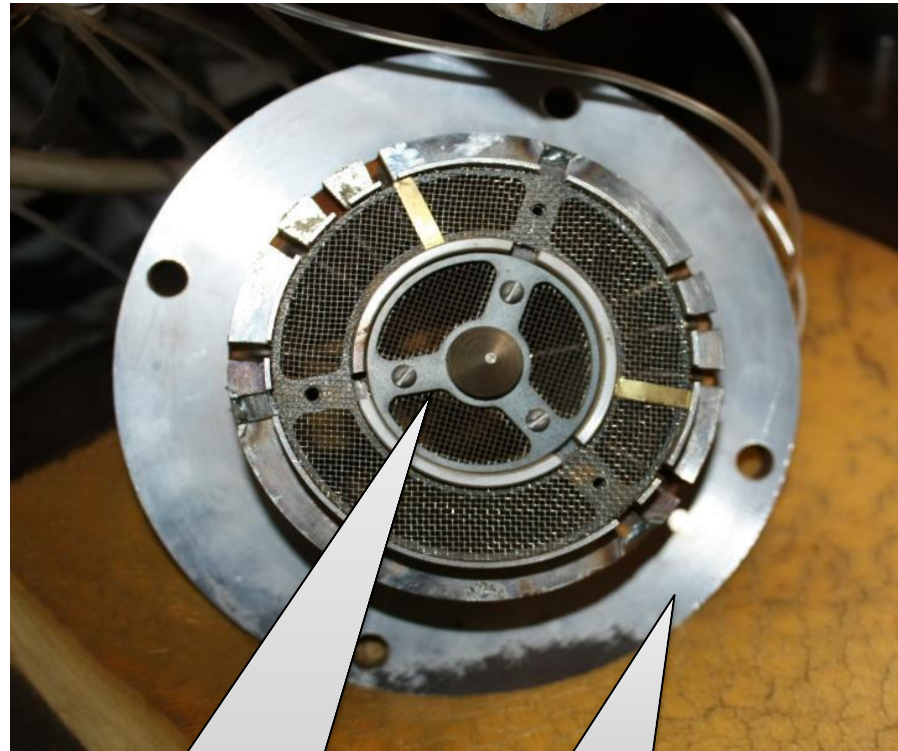
Profile of dual-stream jet nozzle,

D_{a1}= 38.54 mm, D_{a2} = 83,74 mm



x, mm	y_1, mm	y_2, mm	y_3, mm	y_4, mm
0	0.8	--	--	--
-46	13.96	19.48	20.07	--
-51	14.72	20.55	21.32	--
-56	14.19	21.56	22.56	--
-61	13.55	22.08	23.81	--
-66	13.3	22.24	25.06	--
-71	13.07	22.39	26.3	--
-76	12.84	22.54	27.55	--
-81	12.61	22.69	28.8	--
-86	12.38	22.85	29.95	42.32
-91	12.14	23	30.87	43
-96	11.91	23.15	31.4	43.52
-101	11.68	23.31	31.6	43.84
-106	11.44	23.46	31.46	43.99
-111	11.22	23.5	31.08	44
-116	10.98	23.5	30.68	44
-121	10.75	23.5	30.28	44
-126	10.52	23.5	30	44
-131	10.29	23.5	30	44
-136	10.06	23.5	30	44
-141	10	23.5	30	44
-177	10	23.5	30	44

Model of dual-stream jet nozzle



Front view

Back view

Wire grid for reduction of stagnation pressure at inner nozzle contour

Dual-stream jet flow parameters

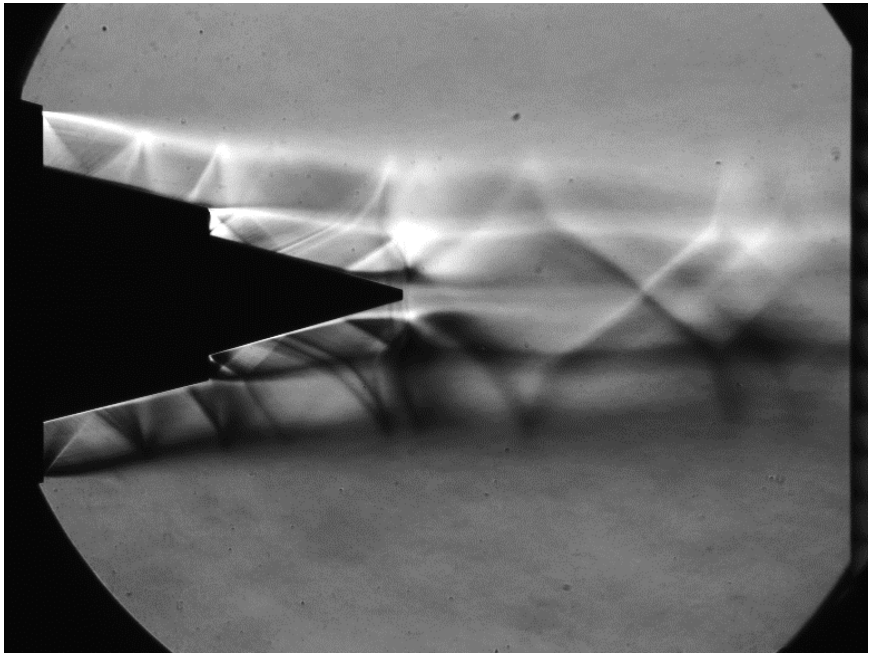
Npr1= 1.72, Mj1=0.915, $Re_{1D}=0.96*10^6$

Npr2= 2.25, Mj2=1.141, $Re_{2D}=2.87*10^6$

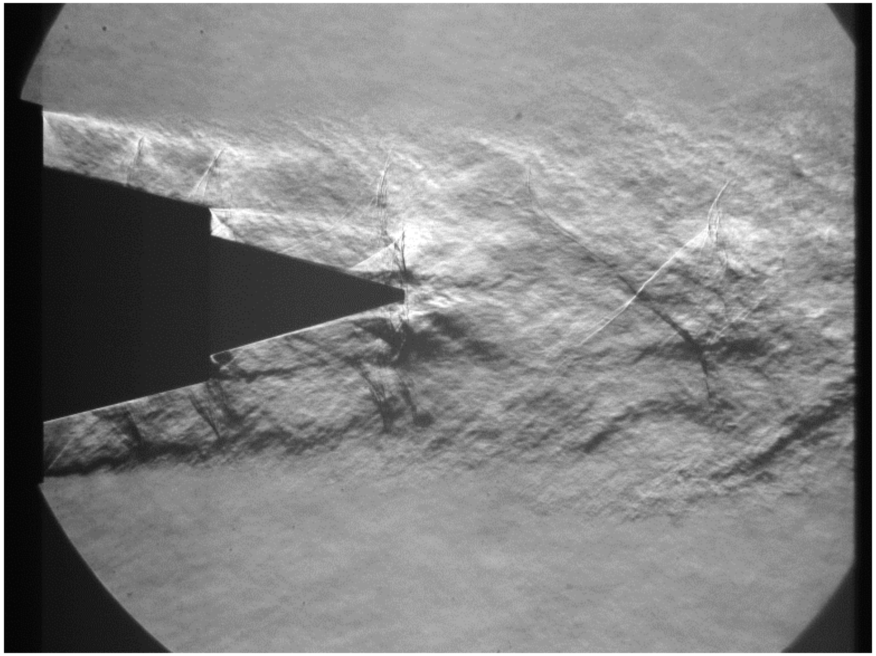
P0 – stagnation pressure at settle chamber,
Pc – pressure at Eifel chamber,
P01 – stagnation pressure at inner nozzle contour,
P02 – stagnation pressure at outer nozzle contour,
T0 – stagnation temperature at settle chamber (may be change for different runs),
Tc- temperature at Eifel chamber (may be change for different runs).

Shlieren-visualization of dual-stream jet. Supersonic uderexpanded jet on inner (1) and outer (2) stream jet

Flow regime - Npr1= 5.0, Npr2=2.8



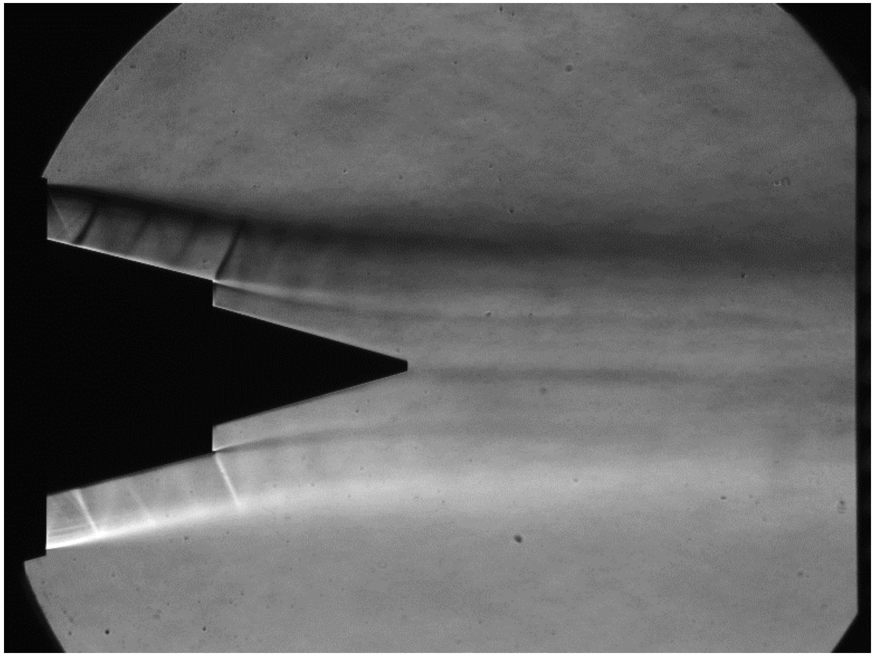
Exposure equal 0.01 sec



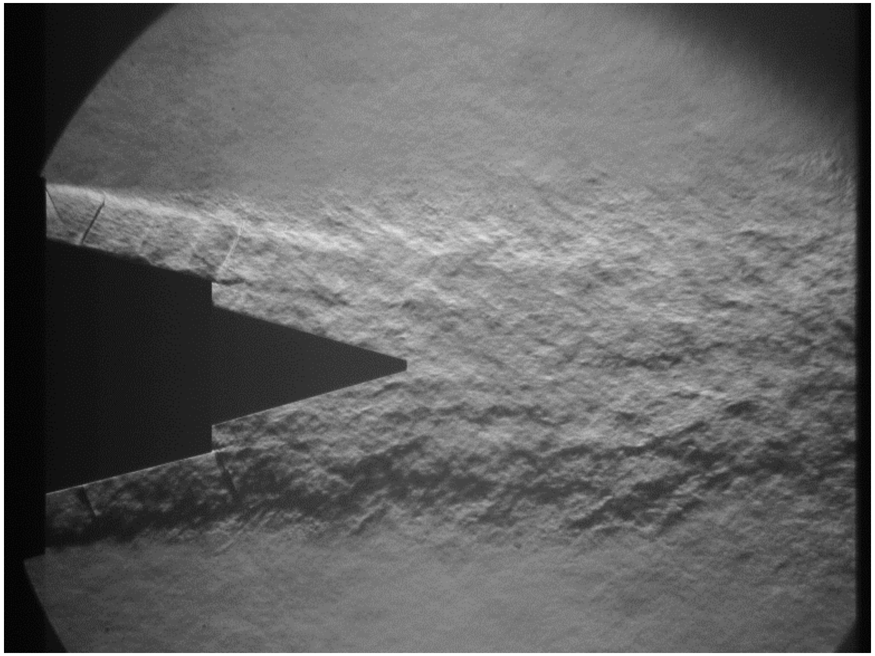
Exposure equal 3 microsec

Shlieren-visualization of dual-stream jet.
Subsonic inner jet (1) and supersonic underexpanded outer jet (2)

Main flow regime - Npr1= 1.72, Npr2= 2.25

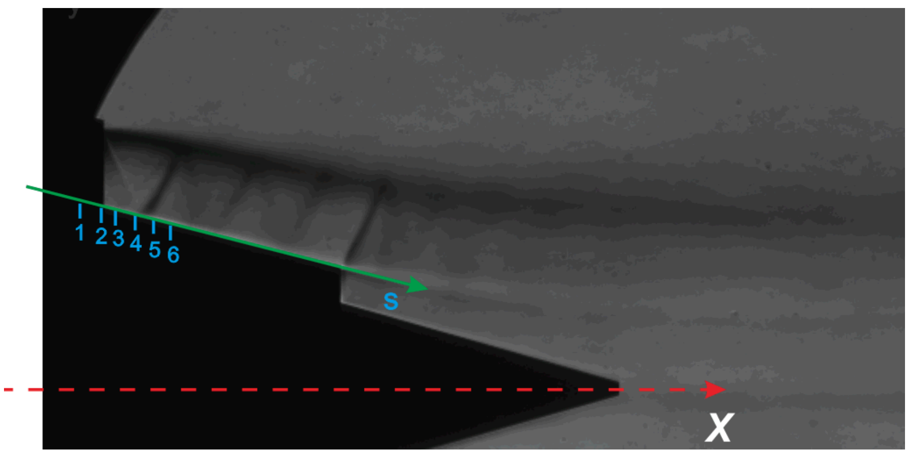


Exposure equal 0.01 sec

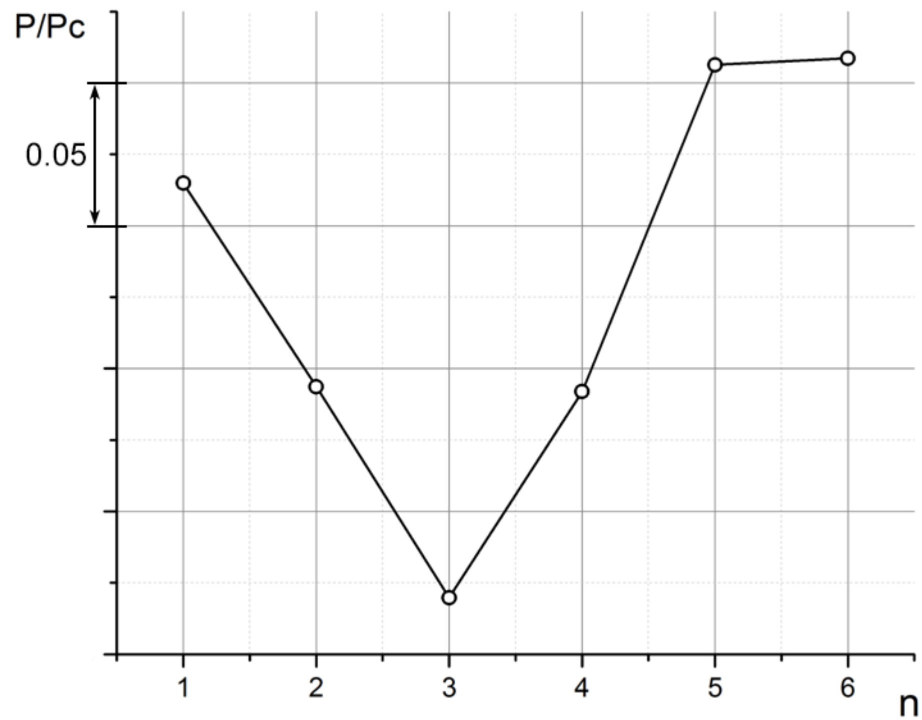


Exposure equal 3 microsec

Wall pressure (P) distribution at outer nozzle contour (symbols 1- 6 corresponding to number of pressure measurement point). **Npr1= 1.72, Npr2= 2.25**

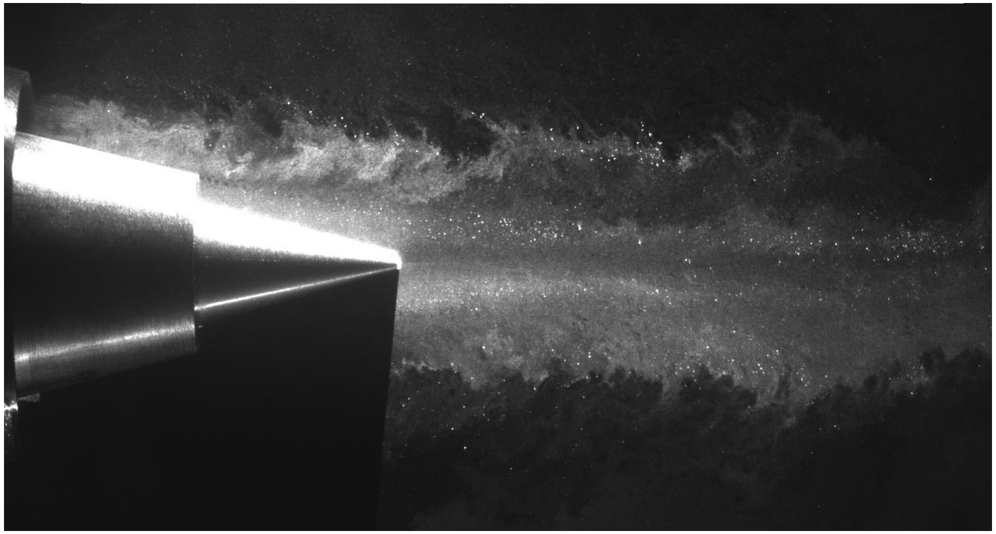


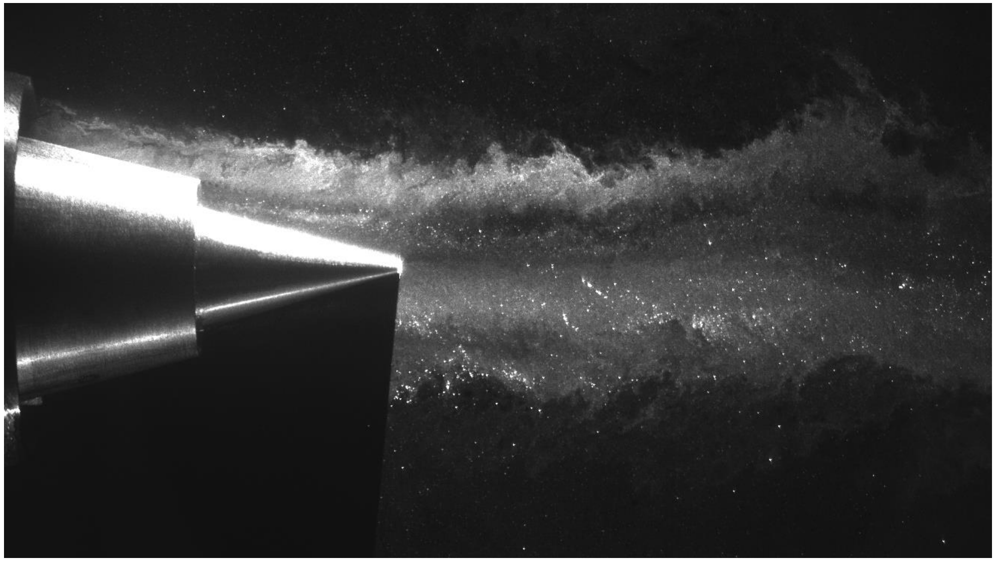
X_2=-83 mm, ΔS= 3 mm



Laser knife flow visualization of dual-stream jet

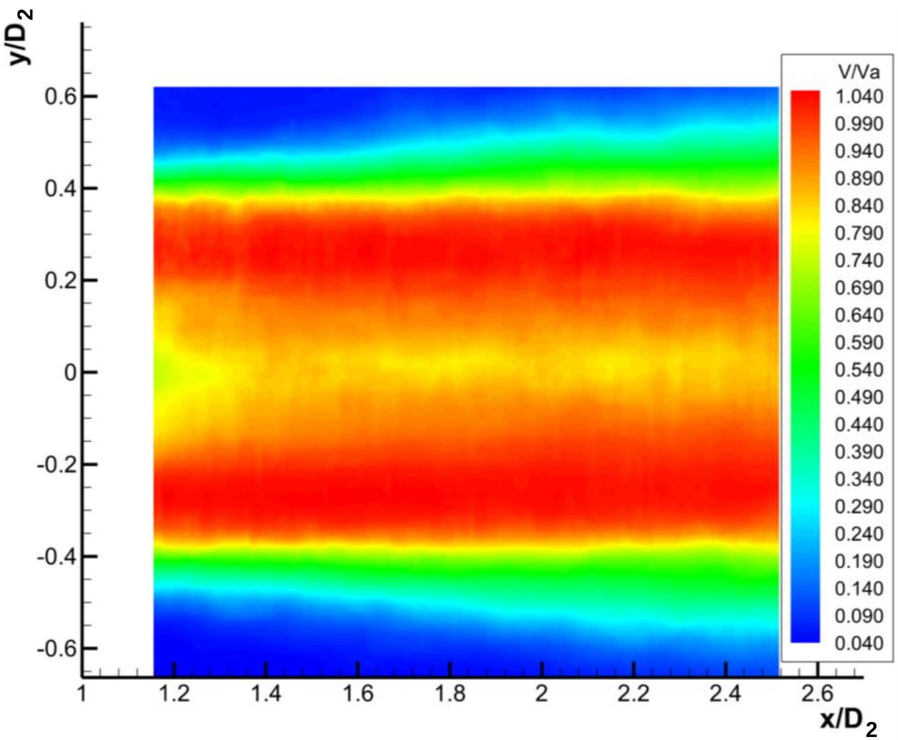
Flow regime - Npr1 = 1.72, Npr2 = 2.25

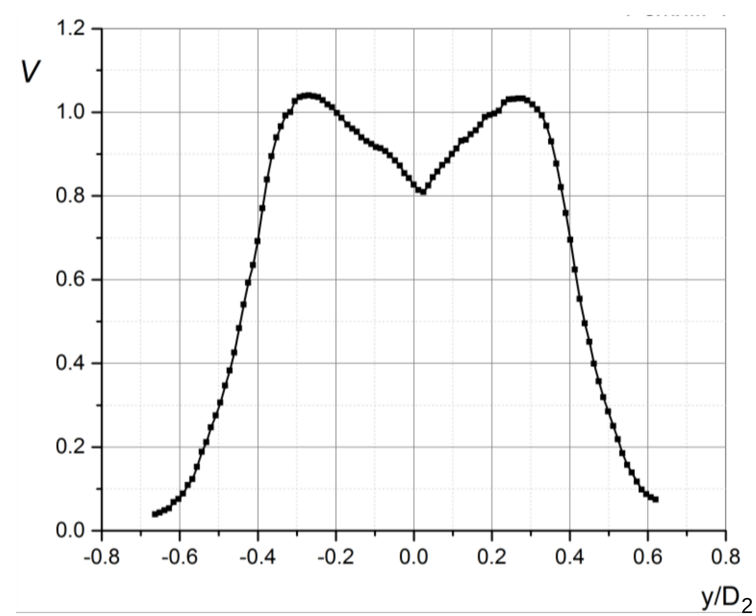




Averaged longitudinal velocity at the diametric axis cross section (PIV measurement)

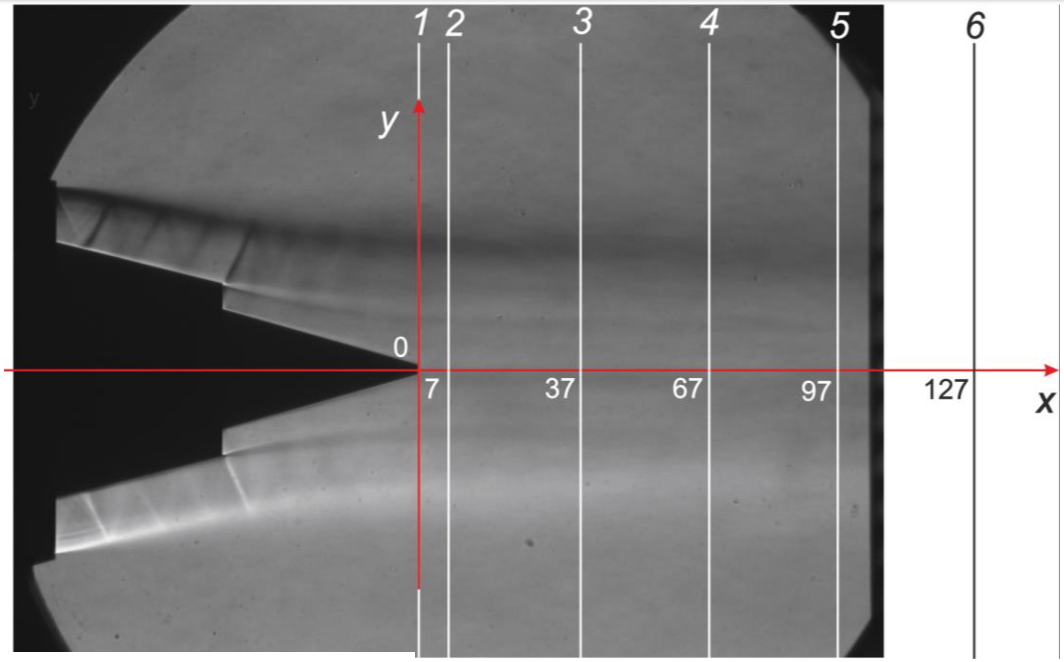
Flow regime – Npr1= 1.72, Npr2= 2.25

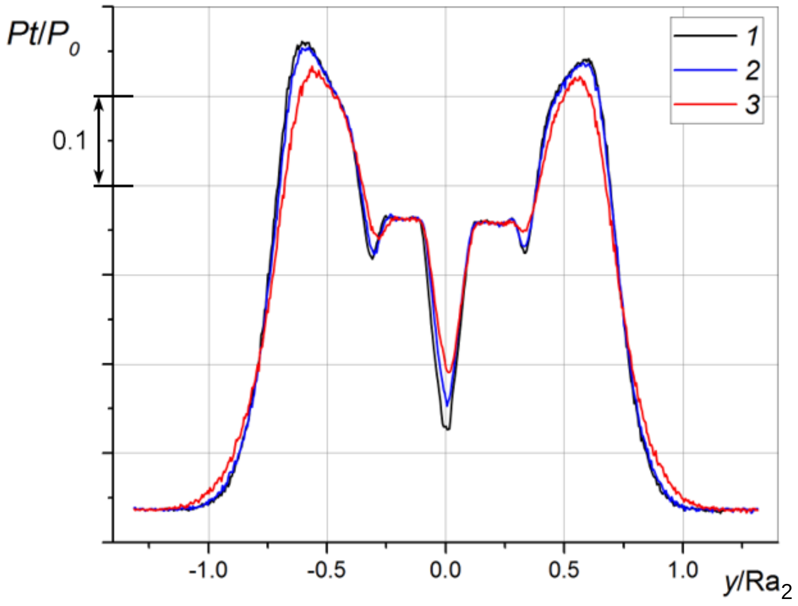


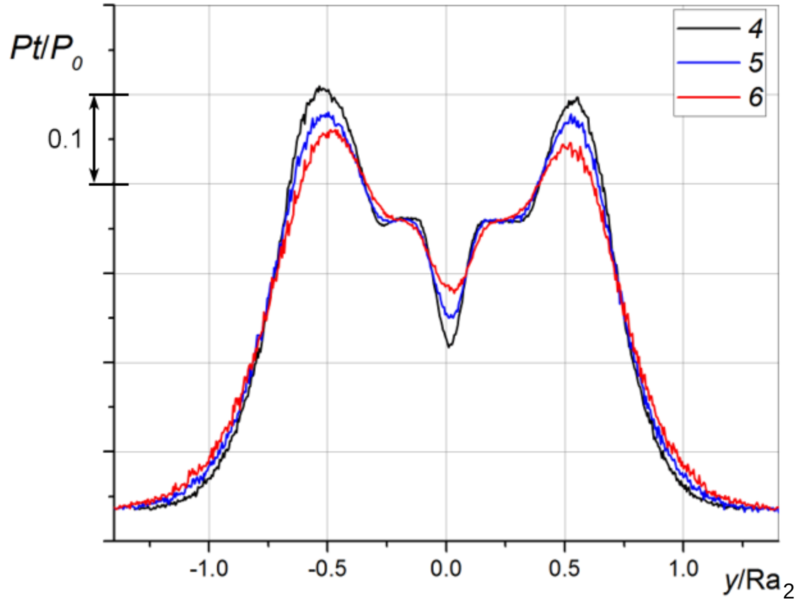


$x/Da_2 = 1.8$

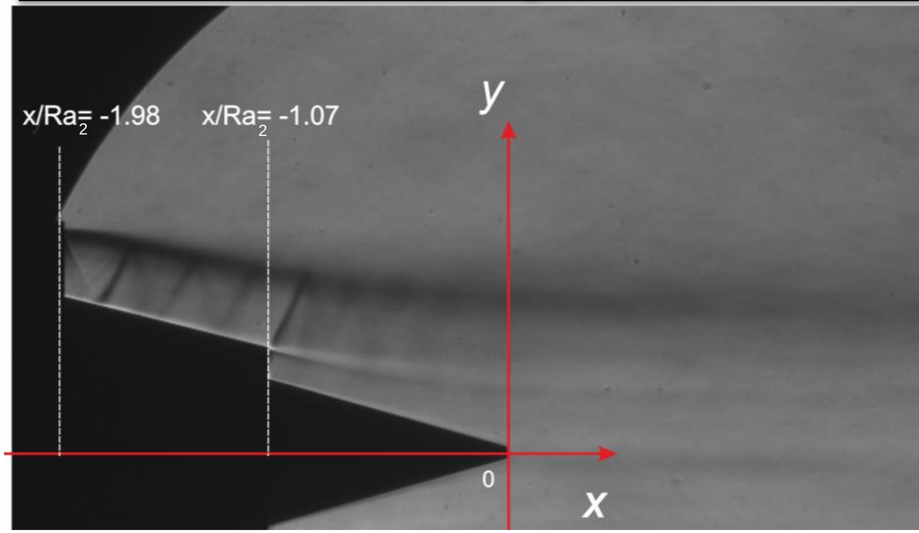
Radial Pitot pressure profiles measured at different cross section of dual-stream jet 1 – 6 (Da_2=83.7 mm)

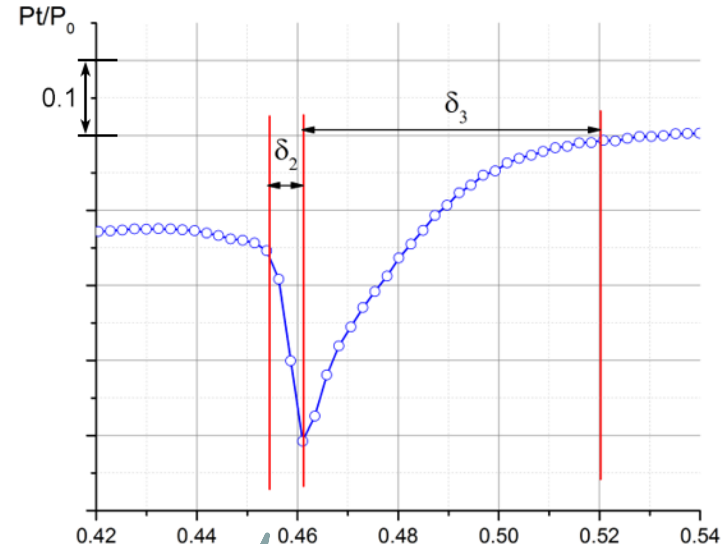


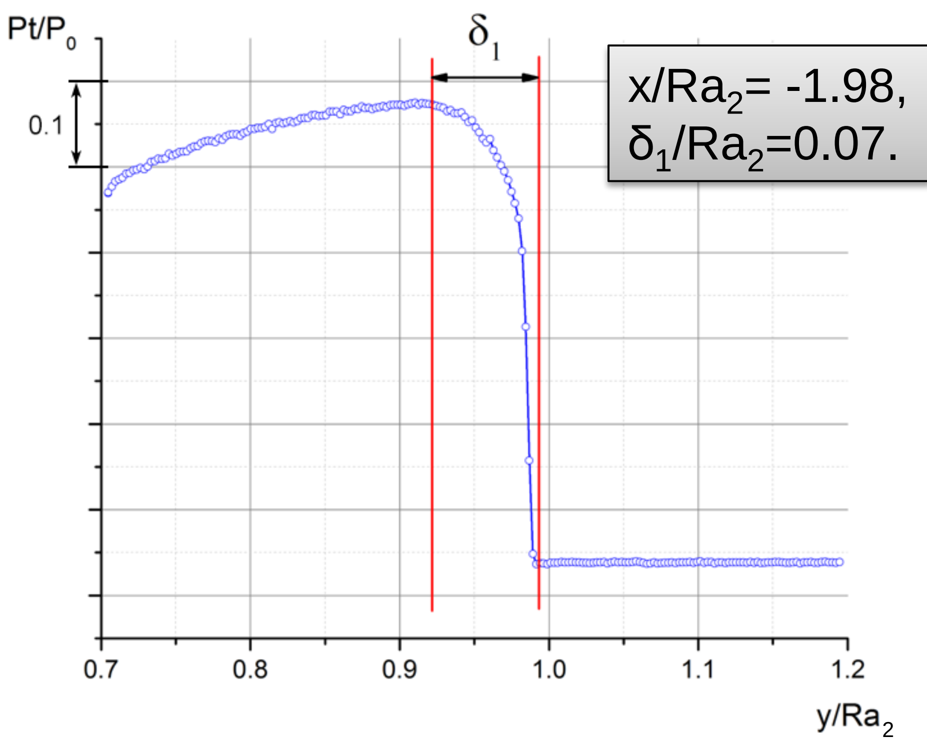


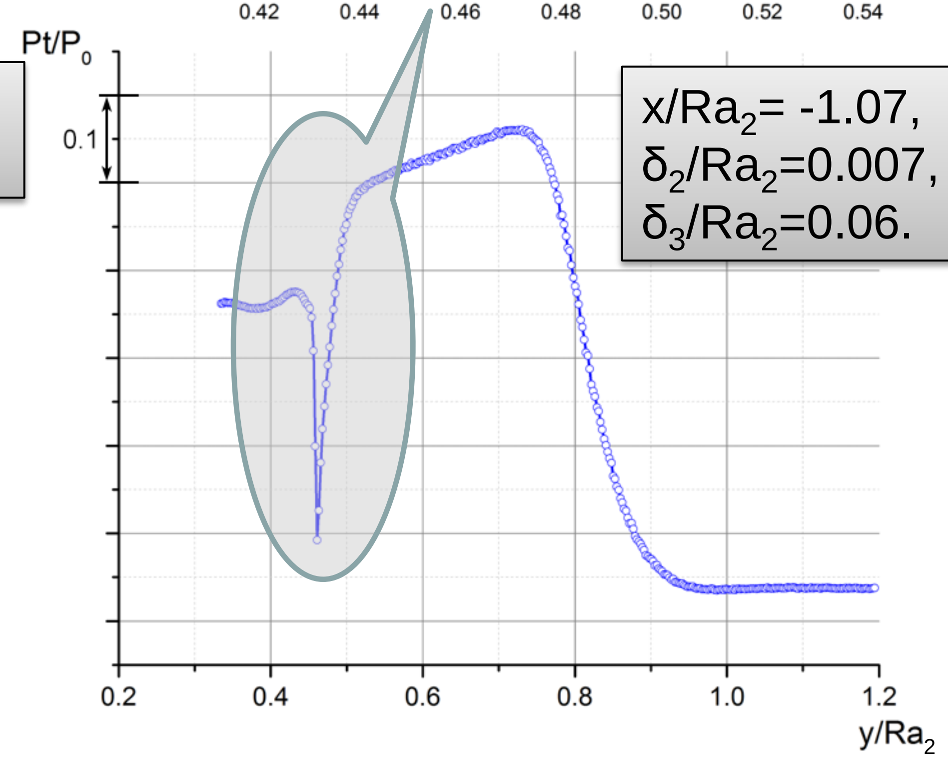


Boundary layer thickness estimation at x/Ra_2= -1.98 and -1.07 (Ra_2= 41.85 mm)

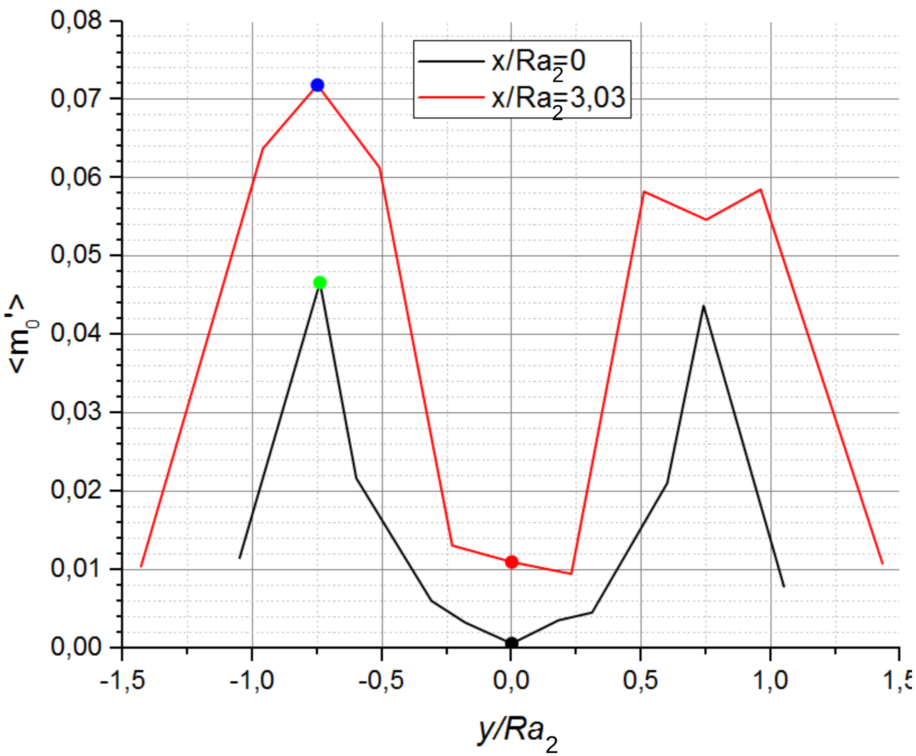


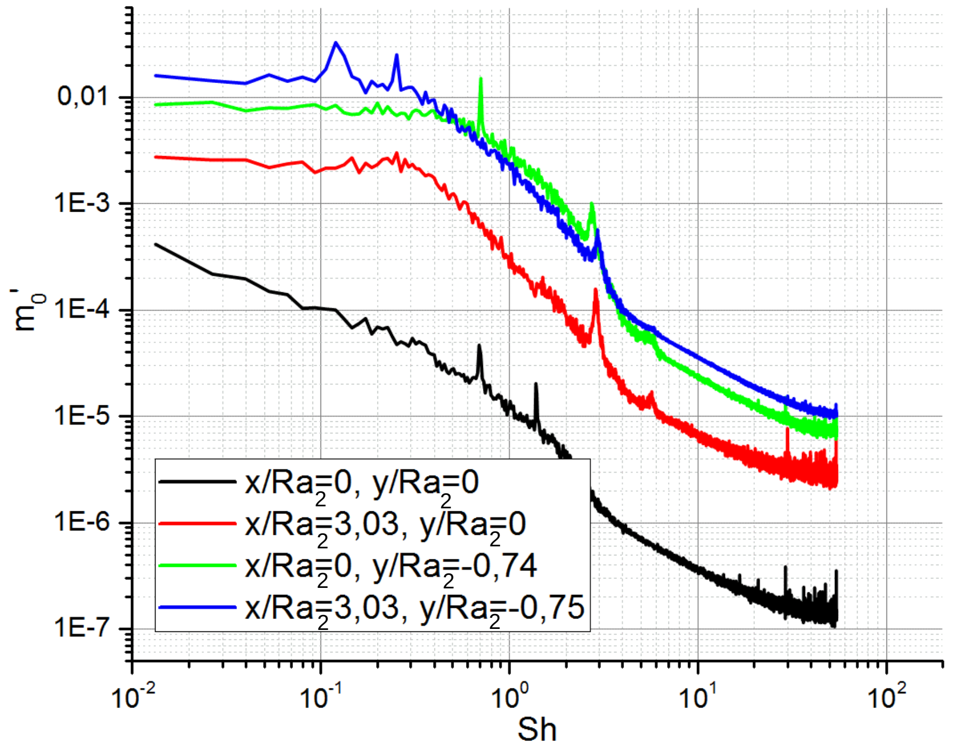






Mass flow rate pulsations measured by hot wire anemometer





Root mean square (RMS) mass flow rate pulsations at two jet cross sections

Frequency amplitude spectrum (Fast Fourier transform) for jet axis ($y/Ra_2 = 0$) and for two character positions at jet shear layer (y/Ra_2 = -0.74, -0.75); $Sh=(f^*R_{a2})/Uo$

Summary

Description of equipment and results of dual-stream jet experimental investigations are presented.
This data are proposed as the test case for verification of CFD results of gas-dynamic flow structure of the model dual-stream jet in frame of TILDA project (TsAGI).

This presentation was made with participation of my colleagues:

PhD Nikolay Kiselev

PhD Dmitry Gubanov

M.Phil. Sergey Kundasev

M.Phil. Andrey Pivovarov

Thank you for your attention!