EXPERIMENTAL STUDY IN THE ANECHOIC CHAMBER DIFFERENCE IN DIAGRAMS OF SOUND RADIATION DIRECTIVITY FROM THE OPEN END OF THE AIR INLET WHEN MODELING STATIC AND FLIGHT CONDITIONS

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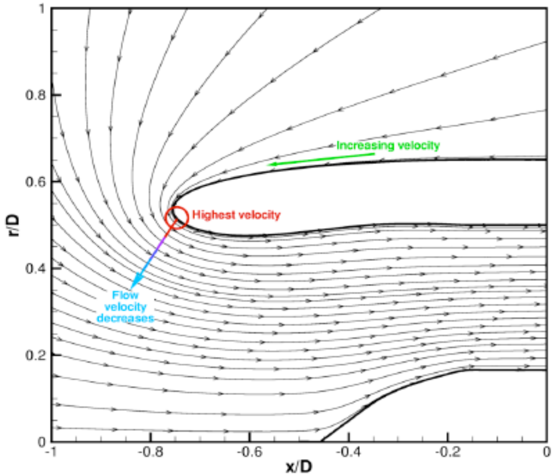
Outline

- Motivation
- Test rig
- Methodological investigations
- Far-field results
- Conclusions

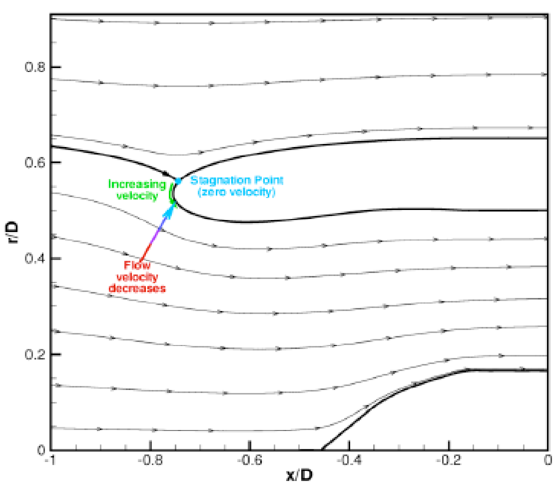
Motivation

C.K.W. Tam, S.A. Parrish, E. Envia, E.W. Chien. Physics of Acoustic Radiation from Jet Engine Inlets. AIAA Paper 2012-2243

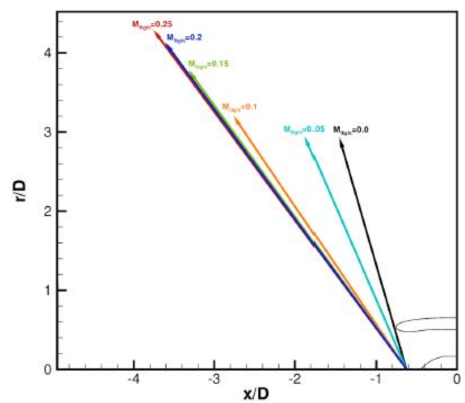
A significant difference in directivity for the radiation of the same duct mode from an engine inlet when operating in static condition versus in the forward flight

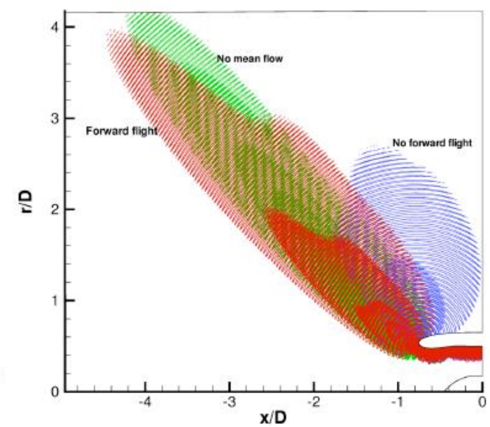


Static condition



Flight condition





The objective of present experimental investigation is the validation of this effect

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- **Test rig**
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- Far-field results
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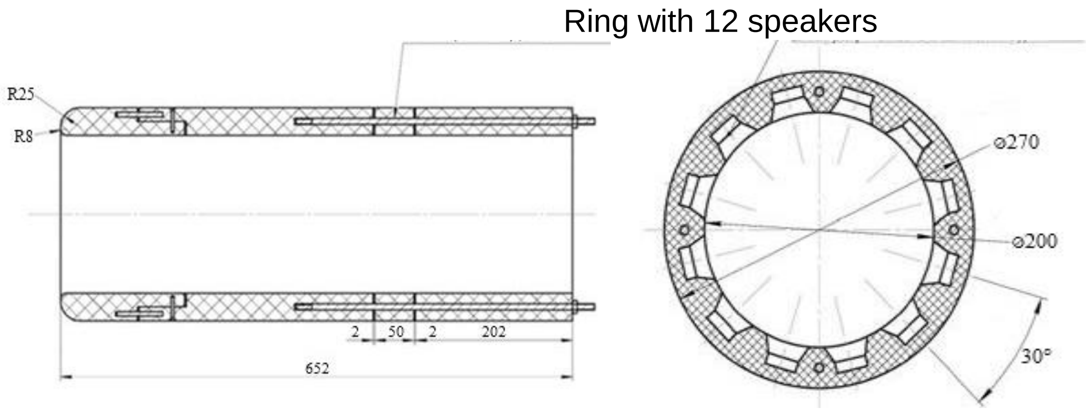
Test rig components

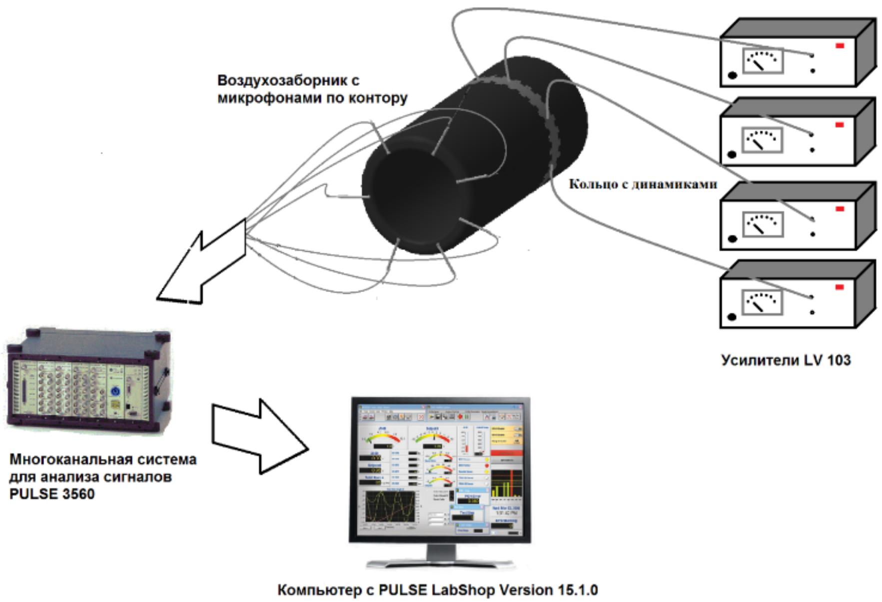
- Anechoic chamber with co-flow
- Model inlet with speakers
- System for creating suction flow within inlet

TsAGI’s anechoic chamber AC-2

Small scale TsAGI's model of inlet equipped by 12 speakers

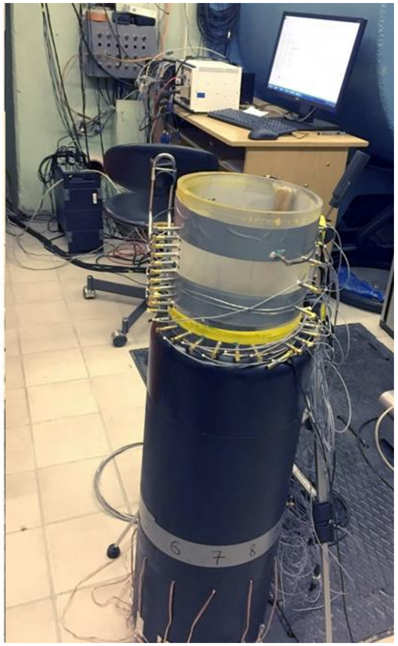


Spinning acoustic modes are generated by 12 speakers uniformly installed within the inlet duct and supplied by tonal harmonic signals with given phase shift



Microphone array for acoustic modes control

Azimuthal microphone array contained 13 microphones is used for extracting spinning azimuthal modes

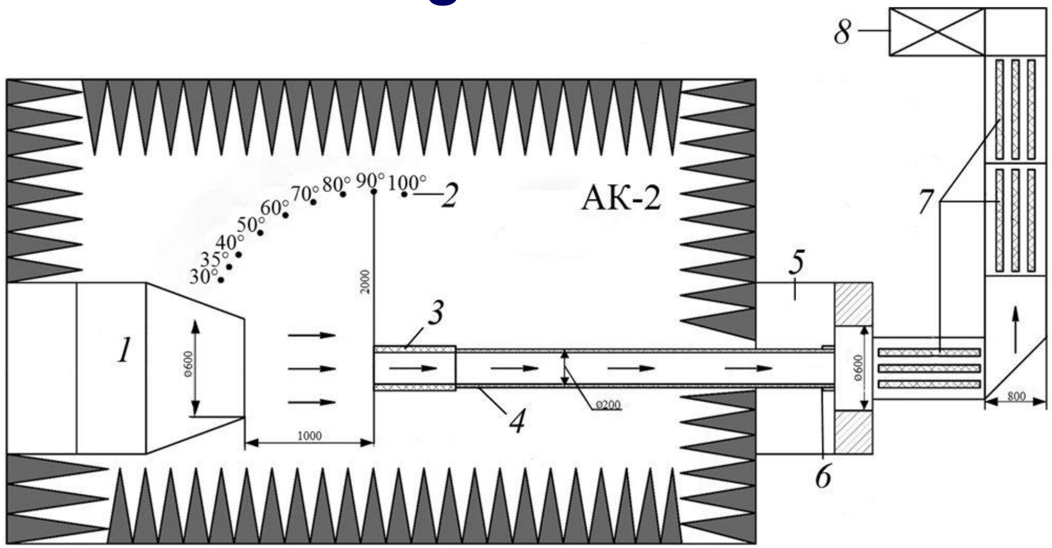


Microphone array contained 48 microphones containing 26 microphone in ring array is used for extracting modes structure with azimuthal numbers $-12 \le m \le 13$

	n=0	n=1	n=2	n=3	n=4	n=5
m=0	0	2080	3808	5523	7233	8941
m=1	999	2894	4634	6355	8069	9780
m=2	1658	3640	5412	7150	8874	
m=3	2280	4351	6159	7918	9657	
m=4	2886	5039	6884	8666		
m=5	3483	5711	7593	9399		
m=6	4072	6370	8289			
m=7	4656	7020	8973			
m=8	5237	7663	9649			
m=9	5815	8299				
m=10	6390	8929				
m=11	6963	9555				
m=12	7534					
m=13	8104					
m=14	8672					
m=15	9240					
m=16	9806					

Cut-off frequencies for azimuthal mode radiated within model duct without flow

Test rig scheme

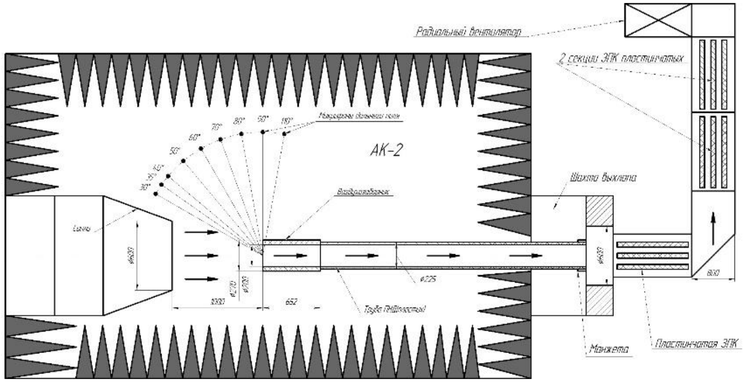


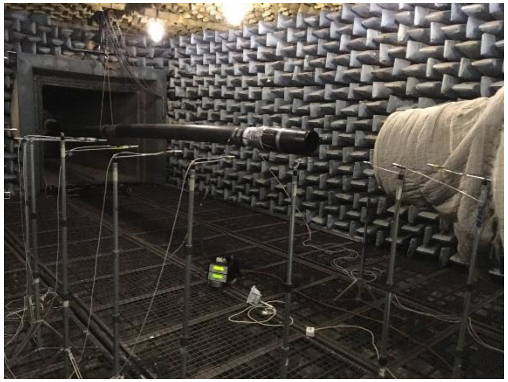
1 – co-flow nozzle; 2 – microphone array ; 3 – model inlet ; 4 – exhaust tube; 5 – exhaust shaft; 6 –collar ; 7 – mufflers; 8 – suction fan

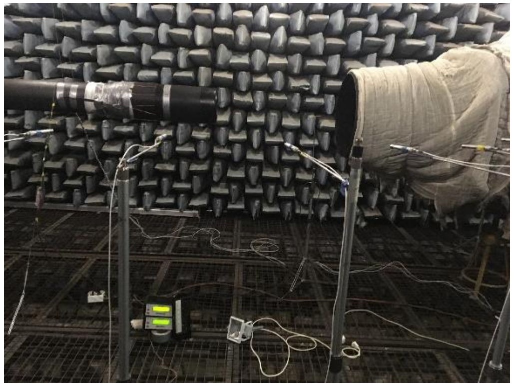
Suction fan obeys suction flow with velocity up to 40 m/s and co-flow velocities can be create up to 60 m/s.

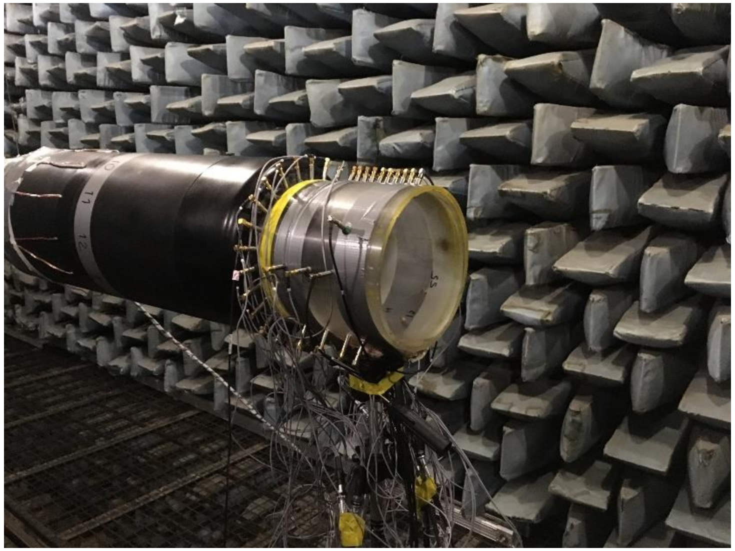
The purpose of experiments consists in study influence of co-flow and suction flow on far field directivity of spinning modes

Test rig photos





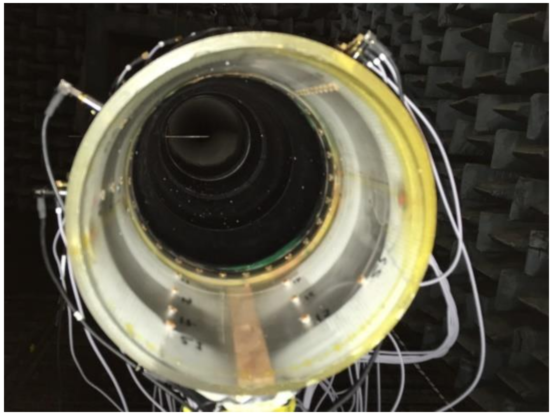




Additional measurements systems for co-flow and suction flow

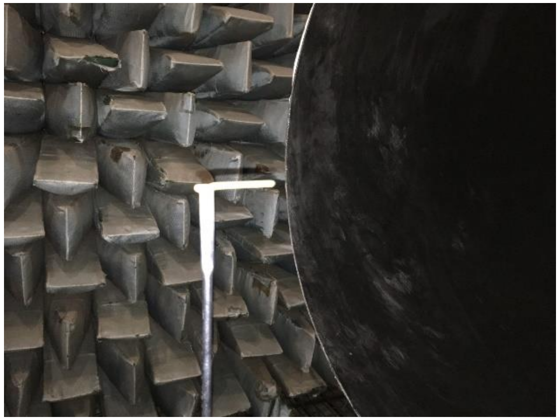
Pito tube in inlet duct

Outside view

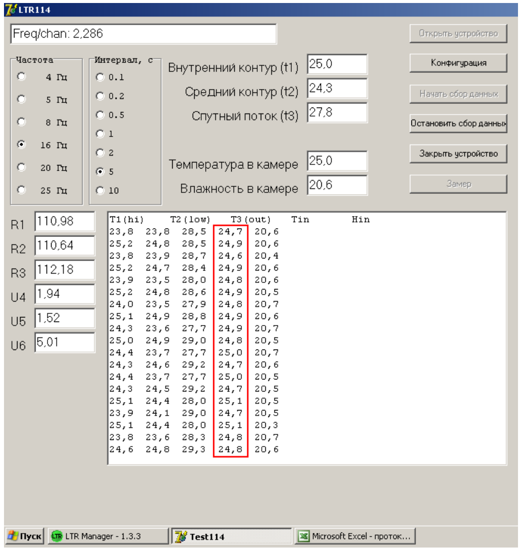


Inside view

Pito tube at the center of co-flow nozzle



Temperature control



Smoke machine for flow visualization

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Methodological investigations

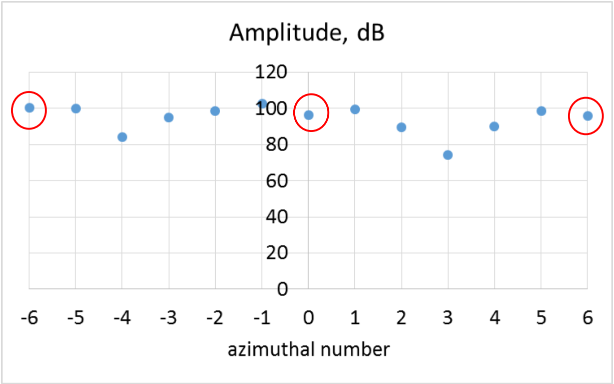
- Improvement of adjustment for generating of different azimuthal modes in inlet
- Effect of inlet wall thickness on directivity at flow absence
- Temperature effect on modes propagation
- Suction effect for co-flow shear layer
- Refraction effect on co-flow shear layer

The problem of adjustment of azimuthal mode generator

It is well known that if the acoustic drivers are *absolutely identical* and electric signals supplied each two adjacent drivers have the same amplitudes and the following the same phase shift $\Delta\phi=2\pi m_0/K$, where K – the number of acoustic drivers, then the azimuthal spinning modes with azimuthal numbers, m_0 – integer number, then the azimuthal spinning modes with azimuthal numbers $m=m_0+lK$ (here l is arbitrary integer) are generated in duct with the same amplitudes.

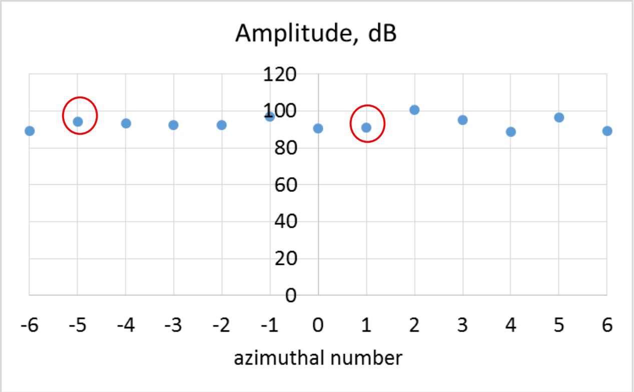
For example, if $K=6$ and $m_0=1$, then $m=\ldots,7,1,-5,-11,\ldots$, or if $m_0=0$, then $m=\ldots,6,0,-6,\ldots$

Reality for TsAGI's model inlet at frequency 4000 Hz



$\Delta\phi=0°$ $m_0=0$

Circle corresponds with expected modes numbers



$\Delta\phi=60°$ $m_0=1$

The assumption about absolutely identity of phase characteristics is failed for TsAGI's drivers

Advanced method of adjustment

Ostrikov N.N., Yakovets M.A., Ipatov M.S, The 24th International Congress on Sound and Vibration, 23 – 27 July 2017, London, UK.- Book of abstracts.

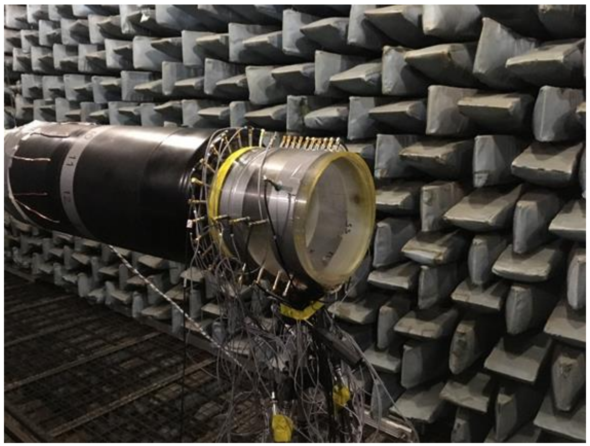
An analysis of drivers' system adjustment results described above shows that the influence of different loudspeakers on each other during their joint operation is insignificant under the conditions of the considered model inlet. Thus, the sound field generated by several drivers for given electrical signals is a superposition of the sound fields provided by these drivers operated under the same electrical signals separately. This feature allows us to propose a new method for adjusting modes generation system that can be implemented on a fully assembled test rig with microphone ring array installed at the inlet edge.

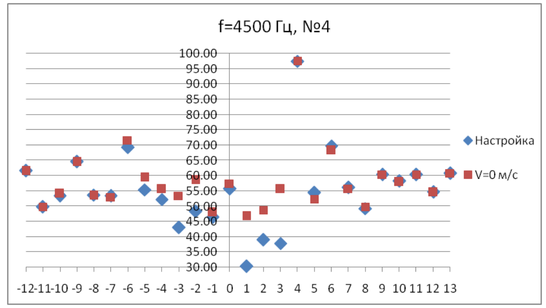
$$\tilde{C}_l = \frac{1}{M}\sum_{m=1}^{M} \hat{p}_m \cdot e^{-i\frac{2\pi l(m-1)}{M}}$$

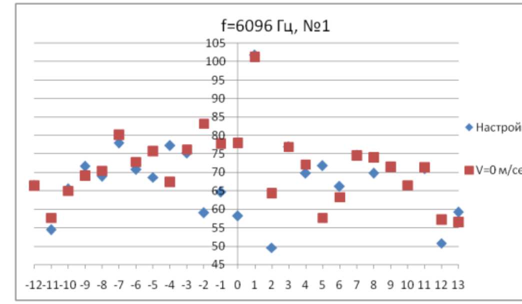
Complex amplitude of azimuthal mode with number l, where M - number of microphones in the ring array, p_m – complex acoustic signal on the microphone with the number m (phase of this value is obtained from cross correlation as phase shift between microphones with number m and number1).

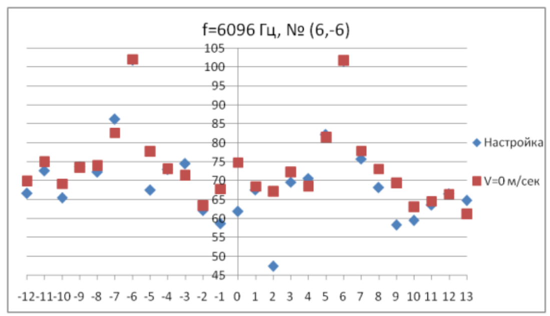
The results of speakers adjustment by 48 microphone array

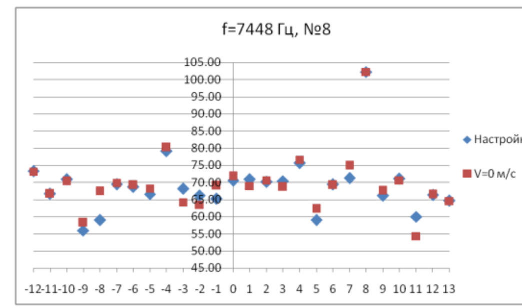
The case of suction flow absence

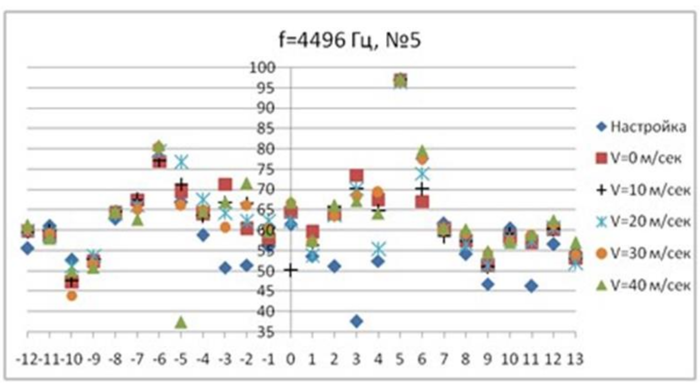








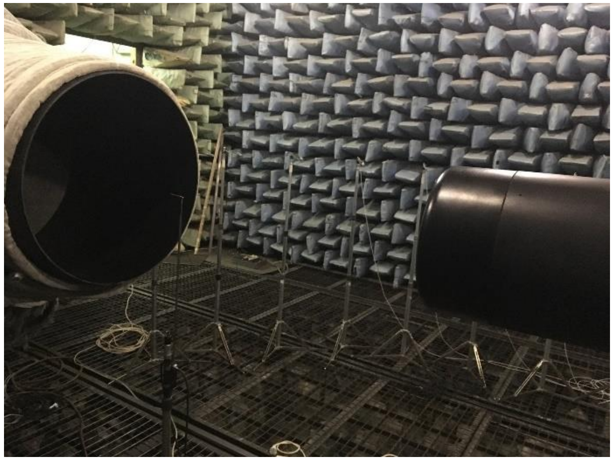


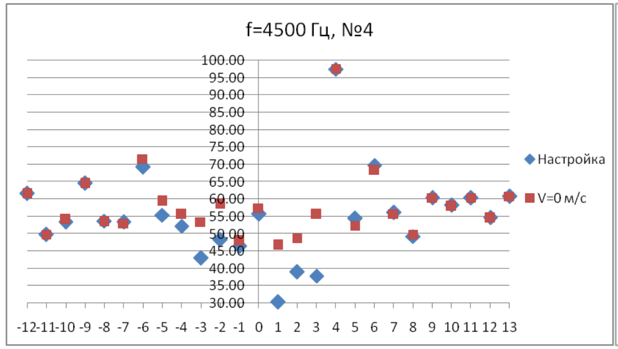


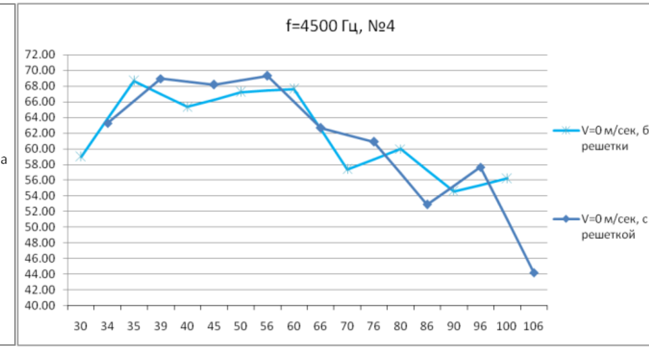
Confirmation of adjustment retention at suction flow arising

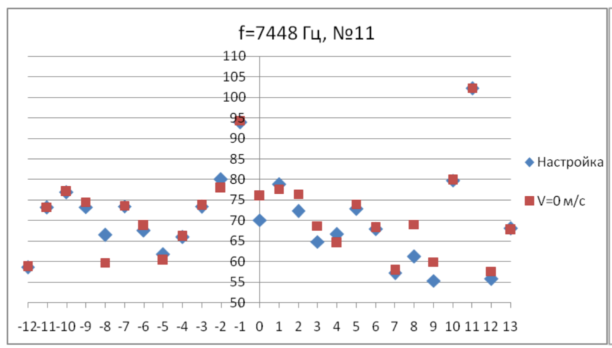
The adjustment method allows to retain azimuthal structure for suction flow case with divergence up to 1.5 dB

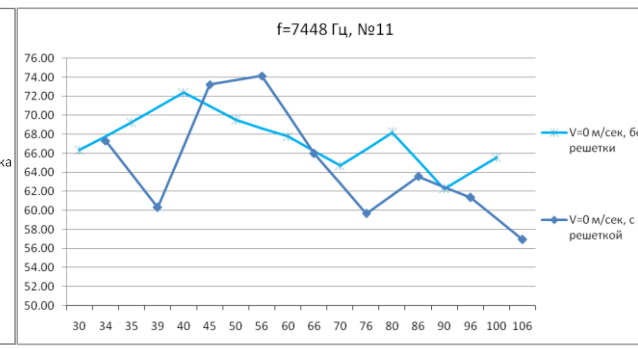
Effect of inlet wall thickness on directivity at flow absence





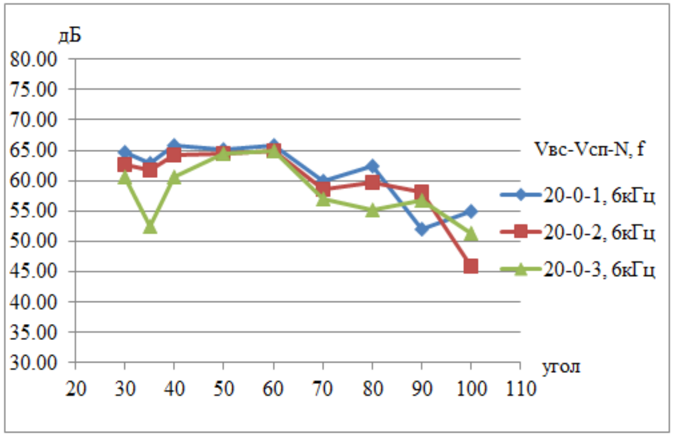




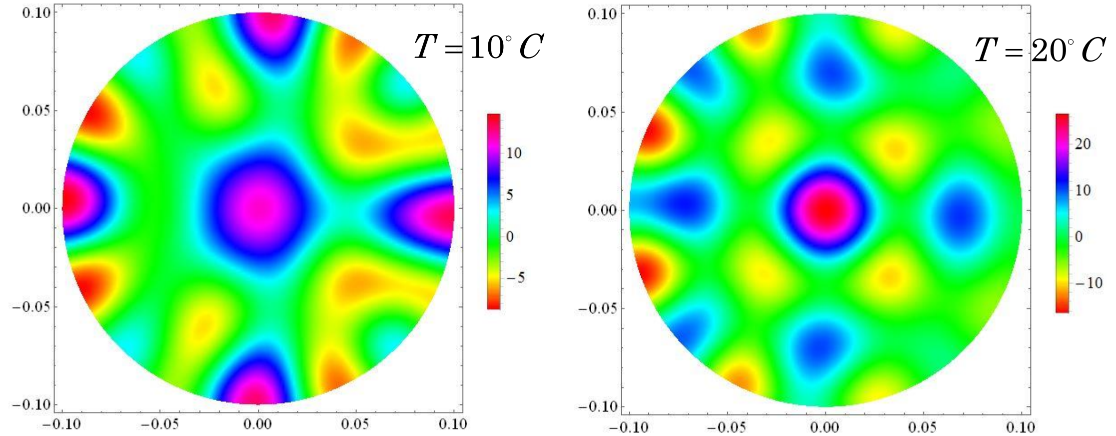


When wavelength is compatible with inlet wall thickness, directivity diverges from theoretical case

Temperature effect on modes propagation

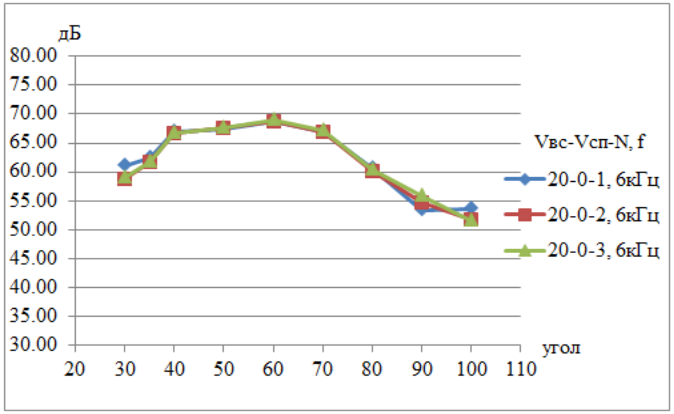


Directivity at frequency 6 kHz
without temperature control.
Repeatability is absent



Pressure distribution for duct section z=0.2 at frequency f=6 kHz

	T=10°C					T=20°C			
	n=0	n=1	n=2	n=3		n=0	n=1	n=2	n=3
m=0	1,704	4,501	7,279	16,249	m=0	1,734	4,591	7,492	18,094
m=1	0,142	0,196	0,329	–	m=1	0,145	0,200	0,343	–
m=2	0,285	0,333	0,682	–	m=2	0,291	0,342	0,746	–
m=3	0,715	0,806	–	–	m=3	0,730	0,836	–	–
m=4	8,931	10,890	–	–	m=4	9,134	11,535	–	–
m=5	1,882	3,247	–	–	m=5	1,931	3,843	–	–
m=6	1,500	–	–	–	m=6	1,549	–	–	–
m=7	2,200	–	–	–	m=7	2,297	–	–	–
m=8	11,265	–	–	–	m=8	12,088	–	–	–
m=9	5,397	–	–	–	m=9	6,925	–	–	–

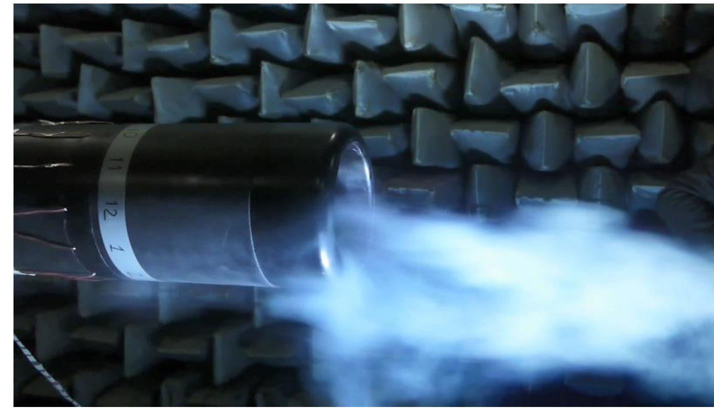


Directivity at frequency 6 kHz
with temperature control

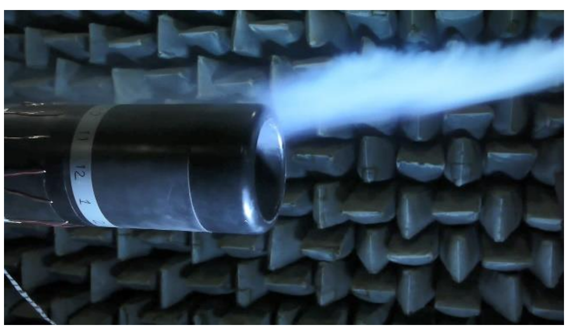
Amplitudes of cut-on modes generated by 12 monopoles in duct without flow

Smoke visualization for testing suction effect for co-flow shear layer

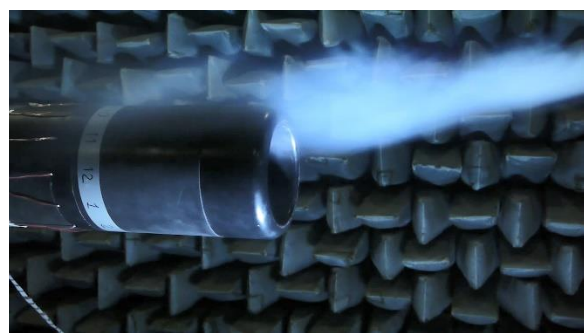
V_{suct}=40 m/s , V_{coflow}=0 m/s



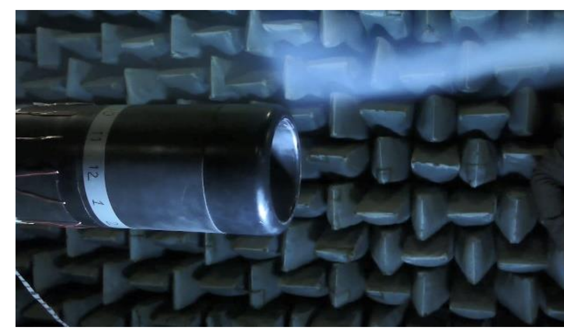
V_{suct}=40 m/s , V_{coflow}=10 m/s



V_{suct}=40 m/s , V_{coflow}=20 m/s

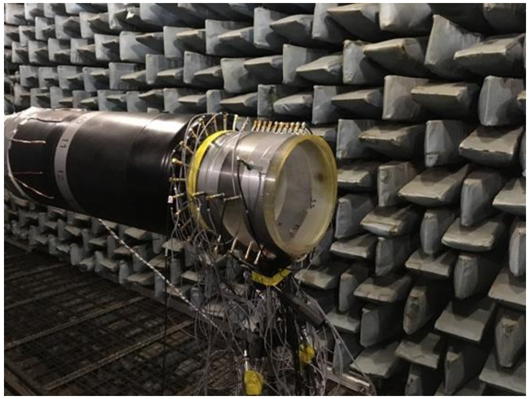


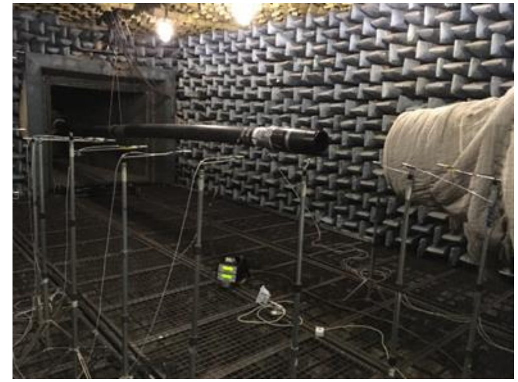
V_{suct}=40 m/s , V_{coflow}=30 m/s

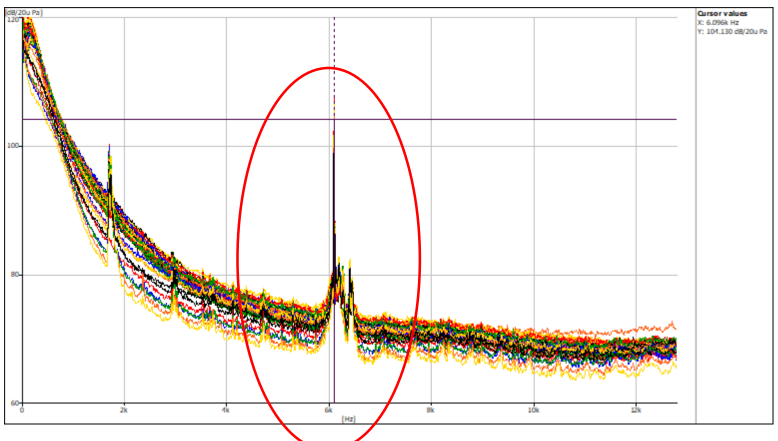


V_{suct}=40 m/s , V_{coflow}=40 m/s

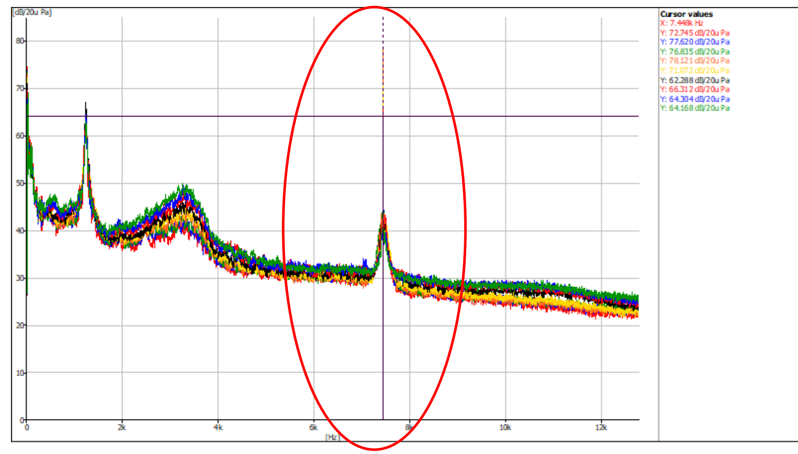
Refraction effect on co-flow shear layer







Spectrum on array microphone for Vsuct=40 m/s , Vcoflow=0 m/s. Haystacking effect is observed due to turbulent boundary layer or flow separation near inlet orifice



Spectrum on far field microphone for Vsuct=40 m/s , Vcoflow=40 m/s. Haystacking effect is observed due to turbulent boundary layer within inlet or turbulent shear layer of co-flow jet

Experimental method for effect investigation

- Adjustment of speakers for generating one dominate azimuthal mode in inlet duct by use of 48 microphone array installed on inlet orifice
- The frequencies are to be chosen so that cut-off frequencies does not cross these frequencies at suction flow velocity variations
- Remove 48 microphone array from inlet orifice
- Reproduction of adjustment parameters for sound generation system at temperature control within 1 C degree
- Far field measurements for different combination of co-flow and suction flow velocities
- Two or more times repetition of the same regime with temperature control

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- **Far-field results**
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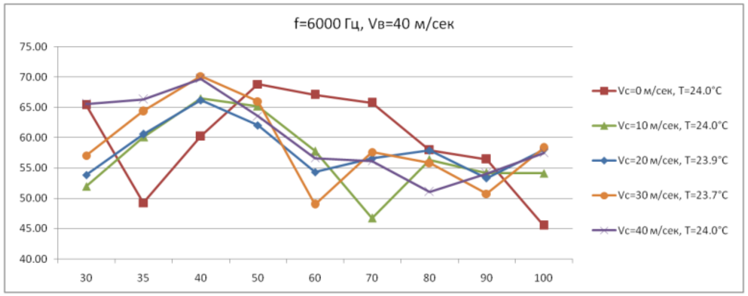
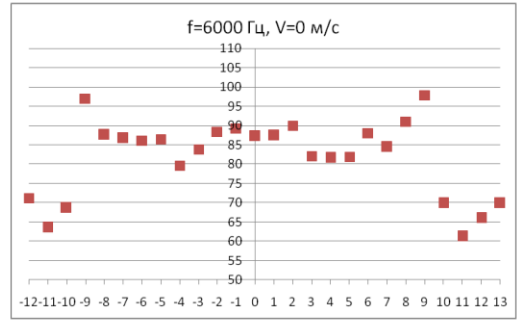
Comparison of directivities at modelling static and flight condition

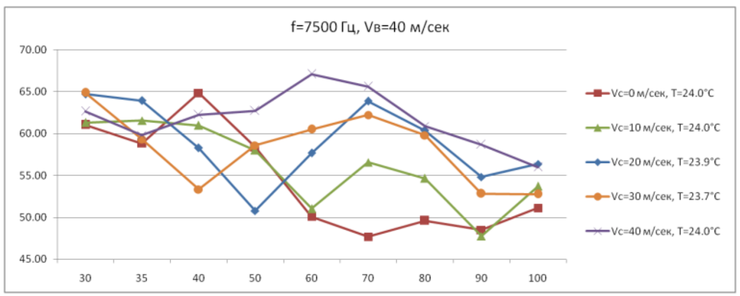
Generation of single dominate azimuthal modes

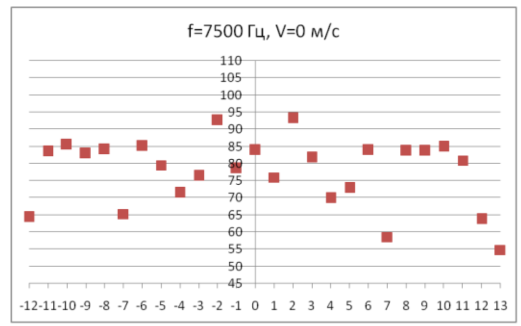
Comparison of directivities at modelling static and flight condition

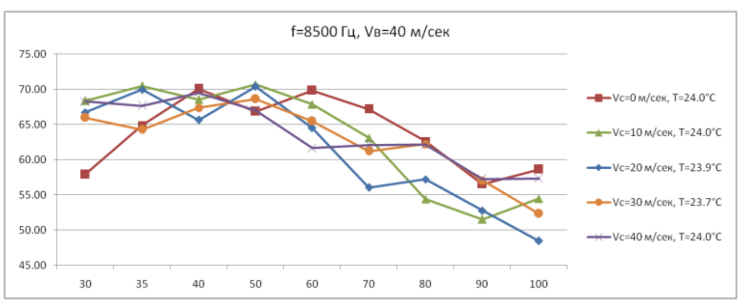
Multi modes generation











Azimuthal modes eduction is impossible for this frequency

Conclusions

- To validate the effect presented in AIAA Paper 2012-2243 on the basis of numerical simulation, it is need to overcome several methodical difficulties, such as adjustment of speakers array on generating one dominate azimuthal mode, hypersensitivity of the sound radiation pattern to temperature variations, the suction of co-flow shear layer in inlet etc
- Experiments have shown that this effect found for single-mode sound generation in the duct, in general, finds experimental confirmation: the analysis of the measured directivities shows their significant dependence on the selected test speed for the suction flow and co-flow.
- To obtain in anechoic chamber the directivity corresponded with flight condition, it is need to create a new method of accounting for the refraction effect for the case when spinning modes is emitted from duct open end and then passes through the jet shear layer
- The experimental investigation shows that this effect are to be taken into account at assessment of environmental impact if engine static condition data are used