FACULTY OF MECHANICAL ENGINEERING
UNIVERSITY OF WEST BOHEMIA

University of West Bohemia » Department of Power System Engineering

FINAL REPORT OF THE INTERNSHIP AT DRESDEN UNIVERSITY OF TECHNOLOGY

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evropský sociální fond v ČR
EVROPSKÁ UNIE
MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY
OP Vzdělávání pro konkurenceschopnost
INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

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1 ABOUT THE HOSTING INSTITUTION – UNIVERSITY

The TU Dresden is one of eleven German universities that were identified as an "excellence university". TUD has about 37.000 students, 4.400 publicly funded staff members – among them over 500 professors – and approximately 3.500 externally funded staff members, and, thus, is the largest university in Saxony, today.

The Technische Universität Dresden has its roots in the Royal Saxon Technical School that was founded in 1828. The Technical School is founded in Dresden and the Royal Saxon Commerce Deputation takes over the administration. Wilhelm Gotthelf Lohrmann (1796-1840), who did great scientific service as Inspector of the Saxon Cameral Survey, is the director. For the time being, the domicile of the institute is located very modestly in the Garden Pavilion on Brühlsche Terrasse and in a vault of the Kuffenhaus on Zeughaus Square. Outstanding teachers were convinced of the merits of working at the institute. Among them was Johann Andreas Schubert, designer of the first operational German steam locomotive "Saxonia."

Today it is a university that unites the natural and engineering sciences with the humanities and social sciences, as well as medicine. This wide range of disciplines, which is unique in Germany, brings with it the obligation for the university to promote interdisciplinarity and to contribute to the integration of science and society.

TU Dresden: synergy between people and technology, between society, science, and business: this is the goal of our research and our services for lifelong learning in all disciplines. Connected both internationally and among different disciplines, praxis-oriented and close to industry, technically competent and interculturally oriented. Reform-minded and with a clear understanding of service.

The TU Dresden is counted among the strongest research universities in Germany.

It cooperates closely with companies and other scientific institutions worldwide. As with research projects, its educational offerings are also praxis- and innovation-oriented. These achievements are based on a solid foundation: a spectrum of disciplines unparalleled in breadth and balance that promotes networking among the engineering, medical, natural, and social sciences and the humanities.

Companies gain TU Dresden graduates with a high degree of technical and social competence.

Foreign language education and general education are a fixture in every course of study – unique in Germany. Integrated internships assure that students and companies get to know each other early on. Consequently, many programmes are interculturally oriented and are part of an international network, with opportunities at partner universities on every continent. The distance learning programme in technical subjects – one-of-a-kind in Germany- and the continually growing selection of online courses provide a high level of flexibility and mesh first-time undergraduate education with continuing education.

THE SCHOOLS AND FACULTIES OF TU DRESDEN

More autonomy, synergies, interdisciplinarity, strategic and operative scope: Guided by this vision TUD's Faculties are on their way to organize themselves under the roofs of 5 Schools. Governed by the principle of subsidiarity, academic plurality shall be ensured and, simultaneously, the synergetic advantages in research, education, administration and infrastructure shall be supported. The restructuring of the 14 Faculties into 5 Schools implies fundamental changes for the University. In order to organize this in an optimal way, a defined transition process comprising 3 phases is envisaged: In May 2012 the Schools were established to bracket the respective Faculties. During the following transition (phase 2), the autonomy of the Faculties will be retained while they adjust their procedures gradually to the future School structure starting with implementing a School administration unit. The third phase of structural changes will start after a positive evaluation of phase 2 and shall be considered to transfer the remaining responsibilities of the Faculties to the School level.

TUD is divided to 5 schools and 14 Faculties

SCHOOL OF SCIENCE

- Faculty of Science, comprising the departments Biology, Chemistry, Mathematics, Physics and Psychology

SCHOOL OF HUMANITIES AND SOCIAL SCIENCES

- Faculty of Education
- Faculty of Law
- Faculty of Arts, Humanities and Social Science
- Faculty of Linguistics, Literature and Cultural Studies
- Faculty of Business and Economics

SCHOOL OF ENGINEERING SCIENCES

- Faculty of Electrical and Computer Engineering
- Faculty of Computer Science
- Faculty of Mechanical Science and Engineering

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

- Faculty of Architecture

- Faculty of Civil Engineering
- Faculty of Environmental Sciences
- Faculty of Transportation and Traffic Science

SCHOOL OF MEDICINE

- Faculty of Medicine Carl Gustav Carus

2 ABOUT THE HOSTING INSTITUTION – CHAIR OF THERMAL POWER MACHINERY AND PLANTS

Unlike virtually any other sector, power generation industry is in the focus of publicity and there are hot debates around all kinds of energy related questions.

Energy is a hot issue for the Chair of Thermal Power Machinery and Plants as well but from an engineering point of view. Processes and system components of high-temperature power plant technology dominate the scientific profile of the Chair, which has also been member of the Rolls-Royce University Technology Centre (UTC) "Lightweight Structures and Materials" of TU Dresden since 2006.

Research is focused on system integration of thermal power machinery and plants with following research areas:

- Energy conversion processes – Process layout, static and dynamic behaviour, process control and monitoring
- Turbo machinery, apparatus engineering, energy storage – Design and operational behavior, thermo-mechanical behavior, stressing and service life
- Static and dynamic analysis of system behavior

Mathematical-physical modelling and simulation

- Modelling: Fluid flow, heat transfer, system component
- Fluid dynamical, thermo dynamical and structural mechanical simulation
- Advancement of material and lifing models
- Simulation of static and dynamic system behavior

Experimental simulation and measurements

- Investigation of laboratory components with features of real system components with/ without inner cooling under static, low/high cyclic mechanical and thermal cyclic loading up to 1250 °C in hot gas flow atmosphere
- Testing of small-scale specimens
- Experimental investigation of the steam injected gas turbine process with water recovery for heat load tolerant CHP systems (gas turbine research plant)
- Experimental investigation of heat transfer in turbine components

2.1 CONTACTING THE INSTITUTION

At the following chapter will be briefly described "how to arrange internship" at The Dresden University of Technology at the Chair of Thermal Power Machinery and Plants.

- Must choose the topic. Main fields of research and courses are described at the chair's web page (https://tu-dresden.de/die_tu_dresden/fakultaeten/fakultaet_maschinenwesen/iet/tea/index_html).
- Contact one of the persons with describtion of your interest. I personally met Dr. Guntram Buchheim at Turbomachinery Workshop at Poland. The contacts to the entire staff of the chair is also at the chairs's web page.

- After the meeting we change several emails about the subject and date of my internship he followed me to the international office of TUD.
- Contacting person at the international office is Mrs Katharina Gabel-Stransky:

Katharina Gabel-Stransky
Director
LEONARDO-OFFICE SAXONY
Contact Point University - Industry
Saxon Internship Office
Technische Universität Dresden
01062 Dresden
Phone.: +49 (0)351/463-32219
Fax: +49 (0)351/463-37156
www.leo.tu-dresden.de

Address of the international office

Nürnberger Straße 31A
01187 Dresden
2nd Floor, Room 110

- She arranged the accommodation. Personally I have been accommodated at this apartment: http://dresden-zimmerservice.de/objektdetails/dresden-freiberger

+ Quiet place
+ Good connection to the train station, shopping, city center and university.
+ Bus and tram stops are in the radius 100 m
- No internet connection

- During absence of Mrs. Gabel-Stransky, my contact was person Mrs. Claudia Schönherr During my first day, we met at the international office to arrange papers of the internship agreement. After that she came with me to arrange papers at the foreign office, to arrange transportation card at Dresden transportation services and to arrange a card necessary to canteen. Afternoon a have been already at the chair and started the work.

Contact to Mrs. Claudia Schönherr:

Project coordination staff mobility

Incoming internships at TU Dresden

placement@leo.tu-dresden.de

Tel .: +49 351463-42444

Fax: +49 351463-37156

3 INTRODUCTION TO THE PRACTICAL WORK AT HOST INSTITUTION

The work at the host institution was connected with the integrated gas turbine with recycling process. This facility was supervised by the Chair of Thermal Power Machinery and Plants. Besides my investigation at that facility there were several investigation:

- Performance of power plant process
- Steam injection for high steam mass flow (optimal position, optimum steam parameters, mix with flue gases)
- Impact on flow, cooling, performance and life of the turbine
- Affect behavior and performance of the compressor
- Water treatment (procedures, operating at elevated temperatures)

My investigation was connected with the CFD (Computational Fluid Dynamics) investigation of The Inlet Guide Vane (IGV) System integrated into the gas turbine. This report describes the process of the IGV system numerical simulation and describes my work step by step. The work started with geometry generation and follows by generating mesh and setting up calculation. Last part includes important results and conclusions. Also includes description of the position of the important files, which were forwarded to the host institution.

Before the final calculation described in this report was done several calculations was done to improve accuracy of the calculation. First step was a mesh study. Different mesh sizes was tested to investigate sensibility of the calculation (Fig. 1). Meshes described in this report are generated according the mesh, which have 1,737 million of elements. These meshes starts with first boundary layer height 0,0001 [m] and the maximum length of the elements is around 0,0015 [m] in the volumes between blades. This setting represents a good balance between the accuracy and mesh size.

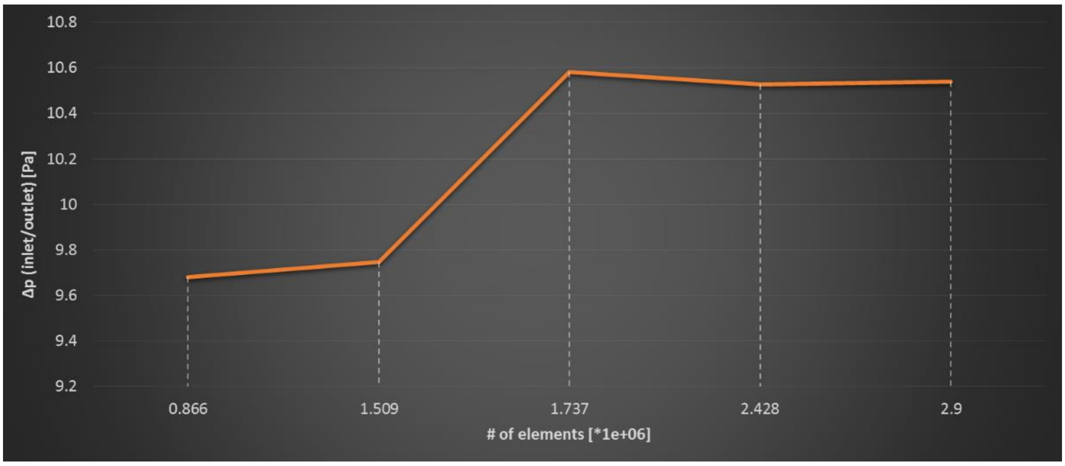

Fig. 1 Results of mesh sensibility study

During the calculation of the entire IGV with inlet was observed a large separation of the flow at one side of the inlet part. The first geometry was generated with sharp edges. These sharp edges at inlet part was blended with constant radius 5 [mm] to prevent huge separation at inlet. The effect of this modification are obvious from Fig. 2. All geometry mentioned below was generated as blended.

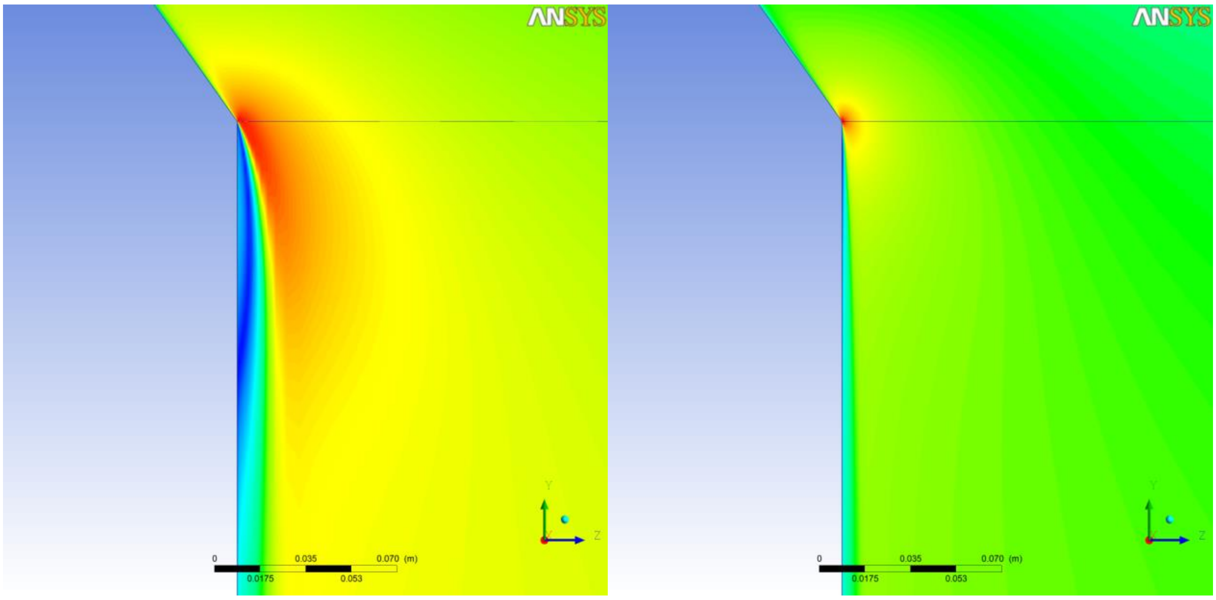

Fig. 2 Flow separation – Sharp edge (left) – Blended Edge (right)

4 GEOMETRY

4.1 SOLVER AND ARRANGEMENT OF THE FILES

Geometry dimensions was measured at the real IGV system and were implemented into CAD model. IGV CAD model have been generated at ANSYS Design Modeler ver. 14.0. This software with a source files is able to generate the IGV geometry with different angles of the guide vanes. Source files are located at IGV/GEOMETRY/GEOMETRY_GENERATOR.

4.2 FILE NAMING

IGV_0_NC_B

- IGV – indicates the IGV part was investigated
- 0 – indicates the angle of the blades
- NC – indicates that the computation is without the compressor part (**N**o **C**ompressor)
- B/S – indicates that the inlet channel is **B**lended or **S**harp

4.3 GOMETRY GENERATOR

The purpose of the source file "GEOMETRY GENERATOR.wbpj" is to generate IGV geometry model for further computation. Into the project are four particular projects generated (Fig. 3).

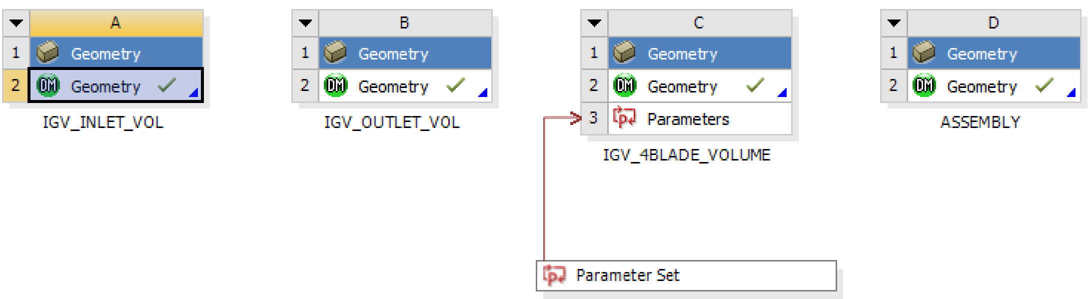

Fig. 3 First view to the "GEOMETRY GENERATOR" project

First two particular projects (IGV_INLET_VOL; IGV_OUTLET_VOL) generate the upper and the lower part of the IGV system (Fig. 4). The geometry is generated with sharp edges and there is a possibility of further work or modification.

The third project generates the part with the guide vanes (Fig. 5). There is one parameter which is adjustable. This parameter is the angle of rotation of the guide vanes (Fig. 6). There is enough to change a value into the “Parameter Set” (Fig. 3) and Refresh () and Generate (). The geometry on Fig. 5 will be generated automatically.

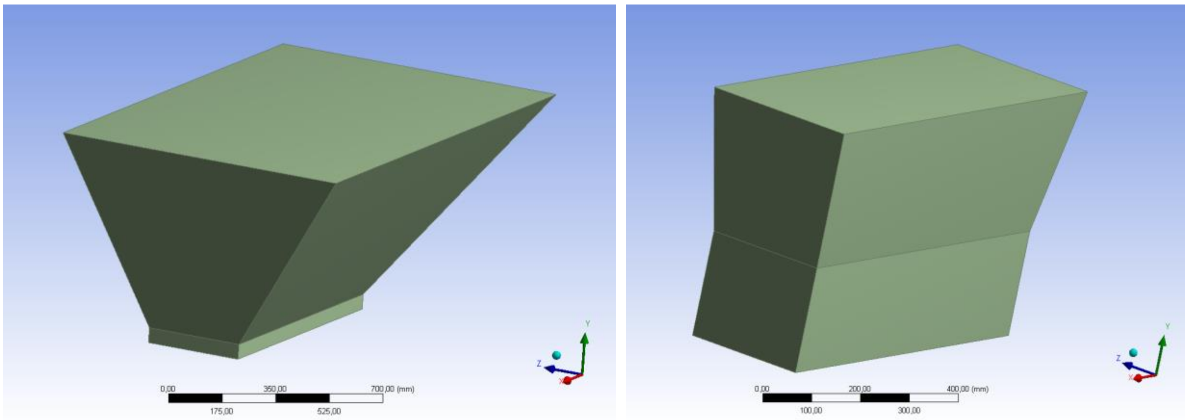

Fig. 4 Generated IGV_INLET_VOL (left) and IGV_OUTLET_VOL (right)

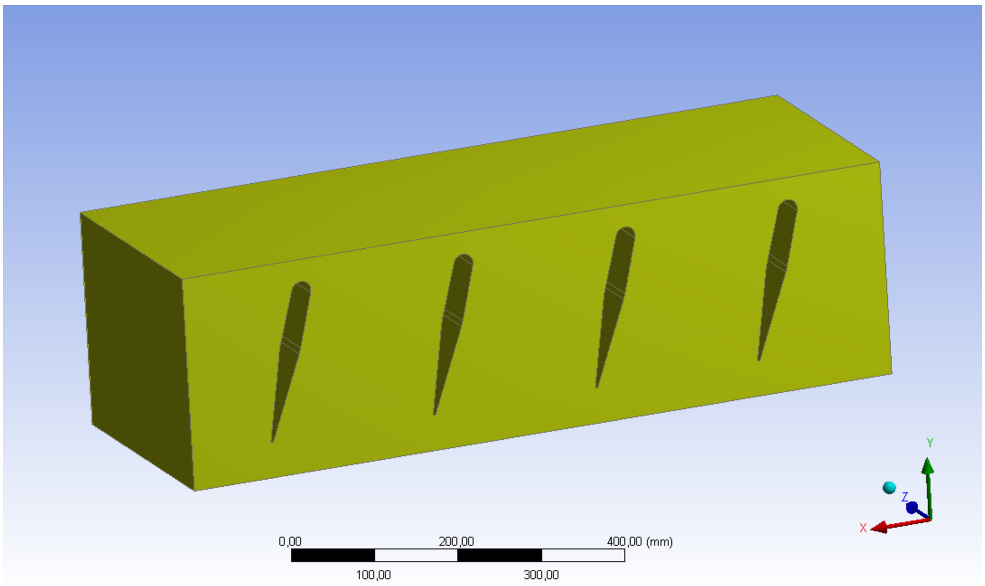

Fig. 5 Generated IGV_4BLADE_VOLUME (15 deg.)

Outline of All Parameters

	A	B	C	D
1	ID	Parameter Name	Value	Unit
2	Input Parameters			
3	IGV_4BLADE_VOLUME (C1)			
4	P1	AngleOfBlades	15	
*	New input parameter	New name	New expression	
6	Output Parameters			
*	New output parameter		New expression	
8	Charts			

Fig. 6 Parameters tab. – Setting angle of blades

Each part was exported as an .igs file (IGV/GEOMETRY/IGS_FILES). These files was used to build an assembly, which is the 4th project in this source file. In this project are generated the last modifications on geometry and exporting the whole model (Fig. 7).

Note: For further meshing into ICEM-CFD is recommended to export the whole assembly into .agdb files (IGV/GEOMETRY/AGDB_FILES).

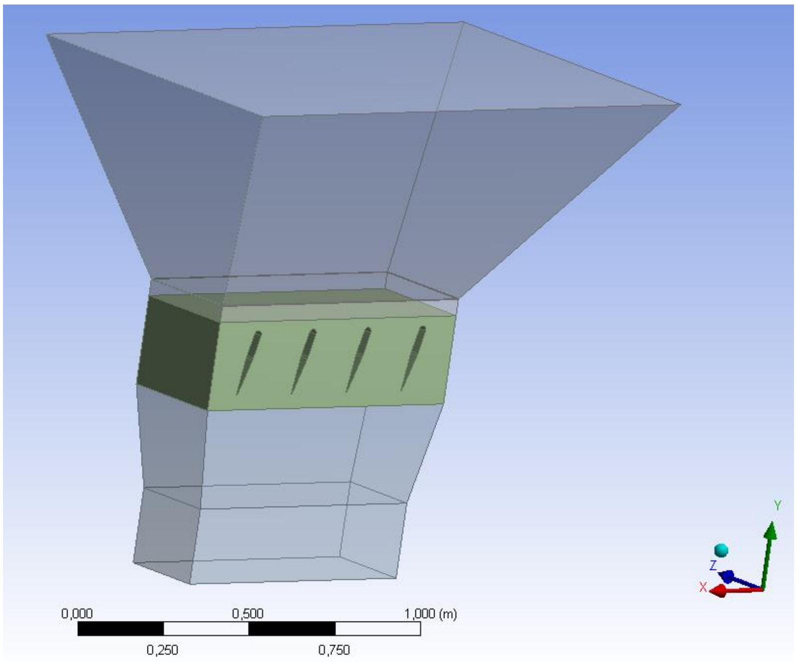

Fig. 7 IGV assembly generation

There were generated several geometries with different guide vane angle settings. There is a geometry for angle: **0°; 15°; 20°; 30°; 36°; 40°; 45°; 50°** and **60°.**

5 MESH

5.1 SOLVER AND ARRANGEMENT OF THE FILES

All mesh files for above mentioned cases can be found into IGV/MESH/IGV_CHANNEL_FILES folder. Folders contain ICEM-CFD files, which allows to reproduce the entire meshing process. CFX5_FILES folder contains .cfx5 mesh files, which are prepared for import into CFX-Pre. Meshes were prepared into ICEM-CFD ver. 14.0.

5.2 MESH GENERATION

- Mesh for each case was generated separately (Tab. 1).
- All hexahedral with global quality criterion > 0.4
- Tab. 1 shows number of elements for each case and global maximum of the Y^+ value
- First layer distance 0.0001 [m]
- Growth rate: 1.2
- Additional volumes were created

Tab. 1 Mesh size and Y+ values for different cases

Version	Mesh size [mil]	Y+ (max) for 5,0 [kg.s^{-1}]
0_B	5.21	12.14
15_B	5.90	14.10
20_B	5.24	14.73
30_B	6.44	17.30
36_B	5.17	16.45
40_B	5.20	21.18
45_B	5.31	17.24
50_B	5.44	18.33
60_B	8.32	23.38

According the Tab. 1 the mesh size was more or less normalized around 5,5 mil. elements. In case of the versions 60_B and 30_B was expected imbalances caused by the flow behavior, and that's the reason of higher number of elements.

There were created additional extra volumes. Cases **DO NOT** include a compressor part, so the lower part was replaced by extra volumes during the meshing process (Fig. 8).

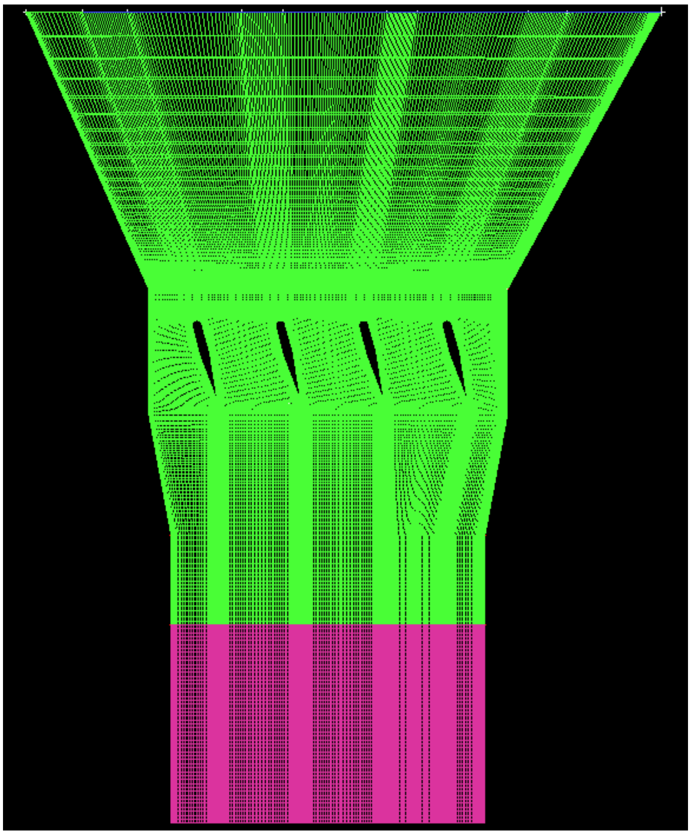

Fig. 8 IGV's mesh (green) with extra volume (purple)

6 BOUNDARY CONDITIONS AND CALCULATION

6.1 SOLVER AND ARRANGEMENT OF THE FILES

Calculation was provided by ANSYS CFX ver. 14.0. Files for modifying calculations are in IGV/CALCULATIONS/CFX_FILES folder. Prepared .def files to run calculation are situated into IGV/CALCULATIONS/DEF_FILES folder. There are another subfolders inside the folders. Numbers indicates the current mass flow rate e.g. 5_0 means 5,0 [kg.s^{-1}].

6.2 BOUNDARY CONDITIONS AND NUMERICAL SOLVER SETTINGS

- Steady state calculation with stationary domain
- Material: Air Ideal Gas
- Reference Pressure: 1 [bar]
- Fluid models:
    - Total energy heat transfer
    - Shear Stress Transport turbulence model with automatic wall function
- Inlet:
    - Subsonic flow regime
    - 4,4 – 5,4 [kg.s^{-1}] mass flow rate were tested
    - Medium intensity turbulence (5%)
    - 288 [K] Static temperature
- Wall:
    - No slip and smooth wall
    - Adiabatic heat transfer
- Outlet:
    - Subsonic flow regime

  - Static pressure: – 0,13 [mbar] **RELATIVE TO REFFERENCE PRESSURE**

- Solver:
  - High resolution advection scheme and turbulence numeric
  - 1000 iteration per each case with auto timescale
  - RSM 1e-3 and conservation target 0.01 was reached

- Additional settings:
  - Pressure drop inside the entire domain and into IGV part were monitored

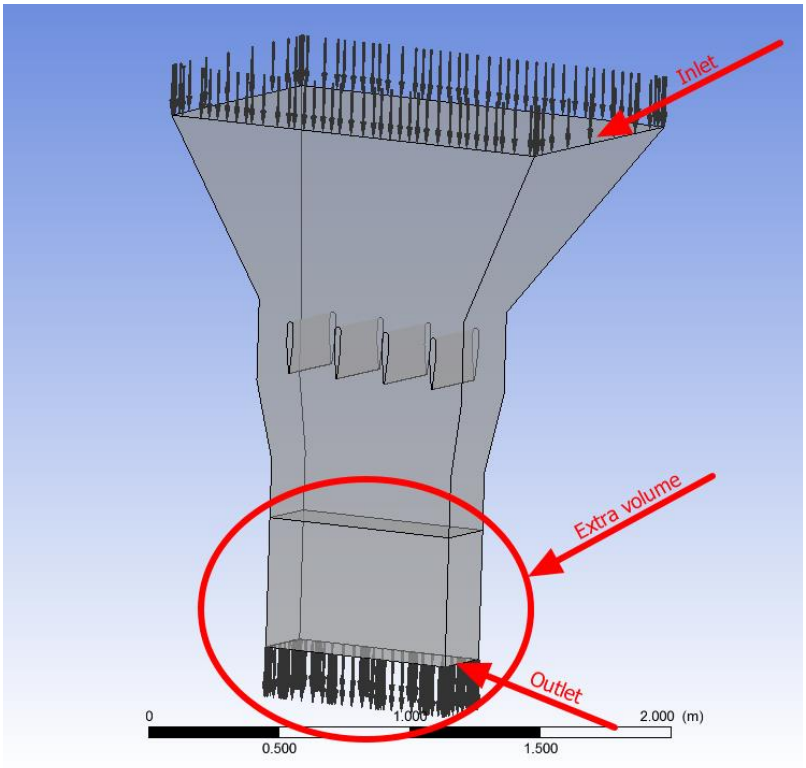

Fig. 9 Boundary conditions for the IGV channel

7 RESULTS

7.1 SOLVER AND ARRANGEMENT OF THE FILES

Calculation was evaluated by ANSYS CFD-POST ver. 14.0. Result files are situated at IGV/CALCULATIONS/RESULTS folder. There are another subfolders inside the "RESULTS" folder. Numbers indicates the current mass flow rate e.g. 5_0 means 5,0 [kg.s^{-1}].

7.2 INVESTIGATED PARAMETERS

Main goal of this project was to investigate:

- Pressure drop generated by the IGV with different blade position and with different mass flow rate.
    - Investigation at measurement point
    - Investigation at the plane which is situated at the same level as the measurement point is situated
    - Investigation along the wall, where is measuring device is situated
- Investigation of flow behavior inside the channel

Evaluated areas are displayed in the Fig. 10.

7.3 TABLES DESCRIPTION

- First column (from left) display which position of IGV blades is investigated 0_B = 0 angle; blended inlet
- Second "Pdiff(manuf.)" indicates pressure drop given by the manufacturer
- Pdiff (AreaAve) – Indicates pressure drop:
    - Area averaged static pressure at "Inlet" - Area averaged static pressure at "Measuring Plane"

- Pdiff (Point) – Indicates pressure drop:
    - Area averaged static pressure at "Inlet" - Static pressure at "Measuring Point"
- Pdiff (versions) – Indicated difference of values of the Pdiff (AreaAve) and the Pdiff (Point) between different blade positions.

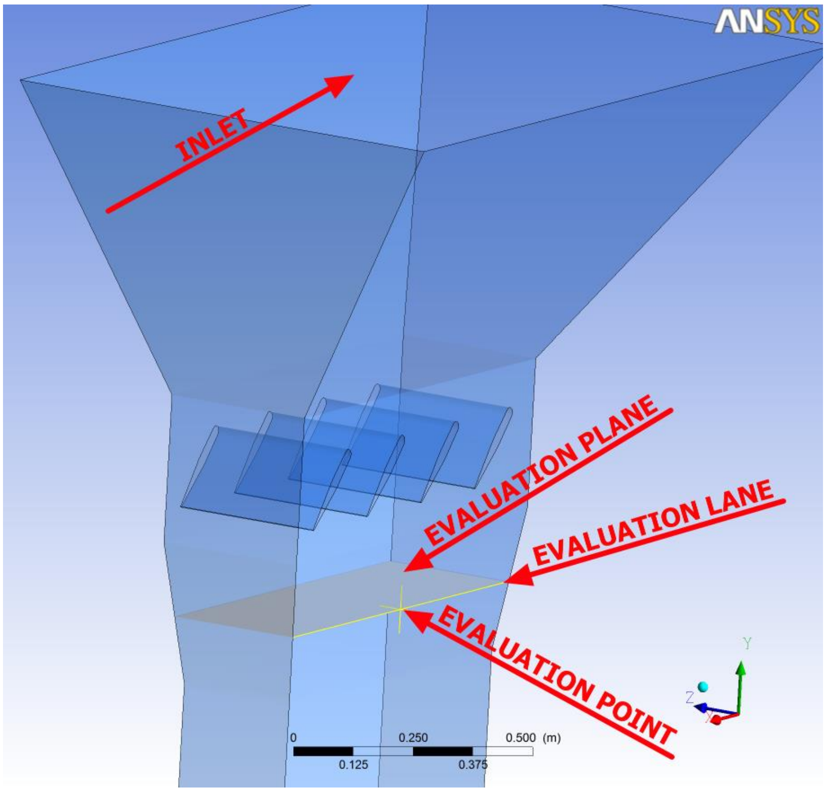

Fig. 10 Evaluated areas

7.4 TABLES

Tab. 2 Pressure drop for different blade positions and mass flow rate (4,4 [$kg.s^{-1}$] – 4,8 [$kg.s^{-1}$])

		Mass flow 4.4 kg.s-1		Mass flow 4.6 kg.s-1		Mass flow 4.8 kg.s-1	
Version	Pdiff _(manuf.)	Pdiff (AreaAve)	Pdiff(Point)	Pdiff (AreaAve)	Pdiff(Point)	Pdiff (AreaAve)	Pdiff(Point)
0_B	1.34	1.4021	1.42218	1.53014	1.55309	1.66396	1.68961
15_B	1.55	1.64575	1.64879	1.79804	1.81237	1.95007	1.94791
20_B	N/A	1.83885	1.84102	2.00998	2.0148	2.18749	2.19093
30_B	2.05	2.42762	2.31881	2.64045	2.52514	2.86339	2.74238
36_B	N/A	3.51415	3.2161	3.80988	3.50871	4.12725	3.78901
40_B	N/A	3.30638	2.99385	3.56819	3.22817	3.86064	3.49751
45_B	3.14	5.41641	5.08174	5.90843	5.54207	6.41838	6.0196
50_B	N/A	6.98147	6.9592	7.62102	7.59253	8.29828	8.26434
60_B	5.9	10.2379	12.1098	11.1884	13.1505	11.9296	13.8525

Pdiff (versions)

0_B - 15_B	0.21	0.24365	0.22661	0.2679	0.25928	0.28611	0.2583
0_B - 20_B	N/A	0.43675	0.41884	0.47984	0.46171	0.52353	0.50132
0_B - 30_B	0.71	1.02552	0.89663	1.11031	0.97205	1.19943	1.05277
0_B - 36_B	N/A	2.11205	1.79392	2.27974	1.95562	2.46329	2.0994
0_B - 40_B	N/A	1.90428	1.57167	2.03805	1.67508	2.19668	1.8079
0_B - 45_B	1.8	4.01431	3.65956	4.37829	3.98898	4.75442	4.32999
0_B - 60_B	4.56	8.8358	10.68762	9.65826	11.59741	10.26564	12.16289

Tab. 3 Pressure drop for different blade positions and mass flow rate (5,0 [$kg.s^{-1}$] – 5,4 [$kg.s^{-1}$])

		Mass flow 5 kg.s-1		Mass flow 5.2 kg.s-1		Mass flow 5.4 kg.s-1	
Version	Pdiff (manuf.)	Pdiff (AreaAve)	Pdiff(Point)	Pdiff (AreaAve)	Pdiff(Point)	Pdiff (AreaAve)	Pdiff(Point)
0_B	1.34	1.80503	1.83338	1.94923	1.98018	2.10046	2.13411
15_B	1.55	2.10605	2.12867	2.27182	2.27293	2.44151	2.46651
20_B	N/A	2.36367	2.37749	2.53926	2.56203	2.74258	2.75252
30_B	2.05	3.09386	2.96314	3.33095	3.20299	3.57475	3.42825
36_B	N/A	4.46303	4.10849	4.82391	4.42249	5.18405	4.77926
40_B	N/A	4.17138	3.75669	4.04043	4.04043	4.82076	4.3258
45_B	3.14	6.95675	6.52303	7.49049	7.02345	8.07022	7.57287
50_B	N/A	8.98576	8.94575	9.68132	9.6357	10.4193	10.3685
60_B	5.9	13.1706	15.782	13.9831	16.656	14.9785	17.5996

Pdiff (versions)

0_B - 15_B	0.21	0.30102	0.29529	0.32259	0.29275	0.34105	0.3324
0_B - 20_B	N/A	0.55864	0.54411	0.59003	0.58185	0.64212	0.61841
0_B - 30_B	0.71	1.28883	1.12976	1.38172	1.22281	1.47429	1.29414
0_B - 36_B	N/A	2.658	2.27511	2.87468	2.44231	3.08359	2.64515
0_B - 40_B	N/A	2.36635	1.92331	2.0912	2.06025	2.7203	2.19169
0_B - 45_B	1.8	5.15172	4.68965	5.54126	5.04327	5.96976	5.43876
0_B - 60_B	4.56	11.36557	13.94862	12.03387	14.67582	12.87804	15.46549

7.5 PRESSURE DISTRIBUTION ALONG THE WALL

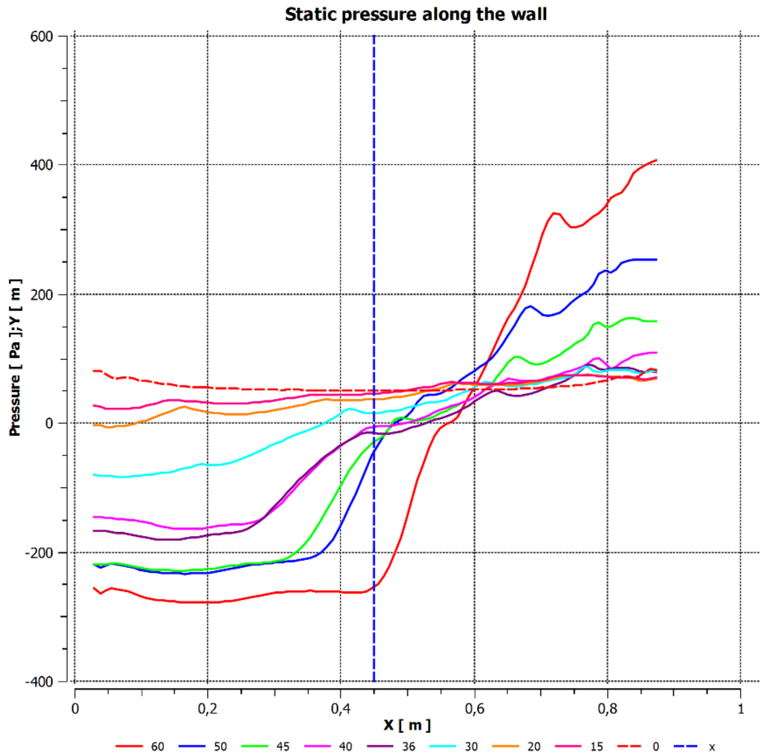

Fig. 11 Static pressure distribution along the wall for 4,4 [$kg.s^{-1}$]

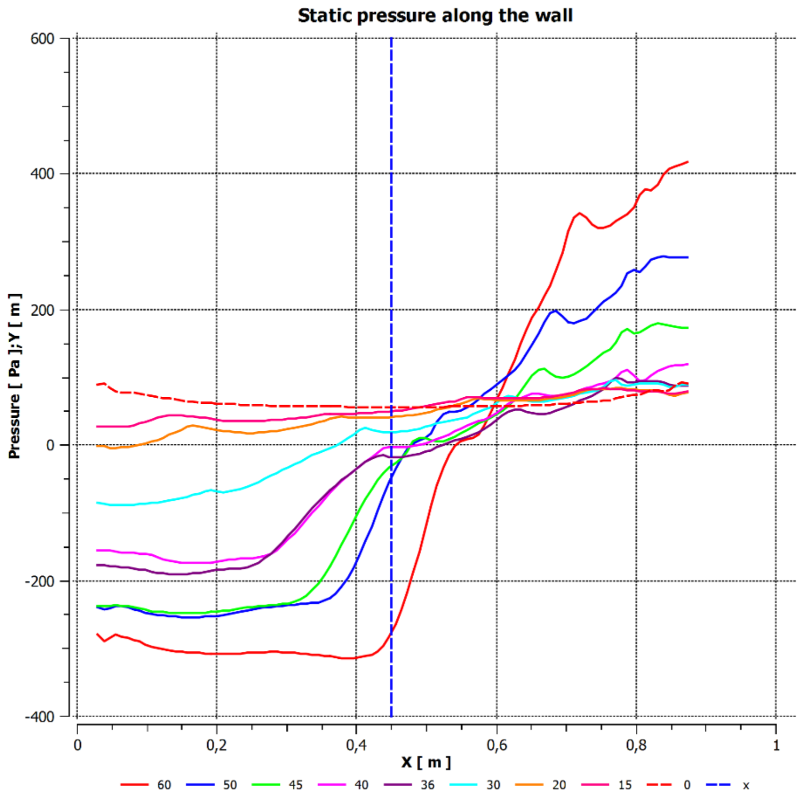

Fig. 12 Static pressure distribution along the wall for 4,6 [$kg.s^{-1}$]

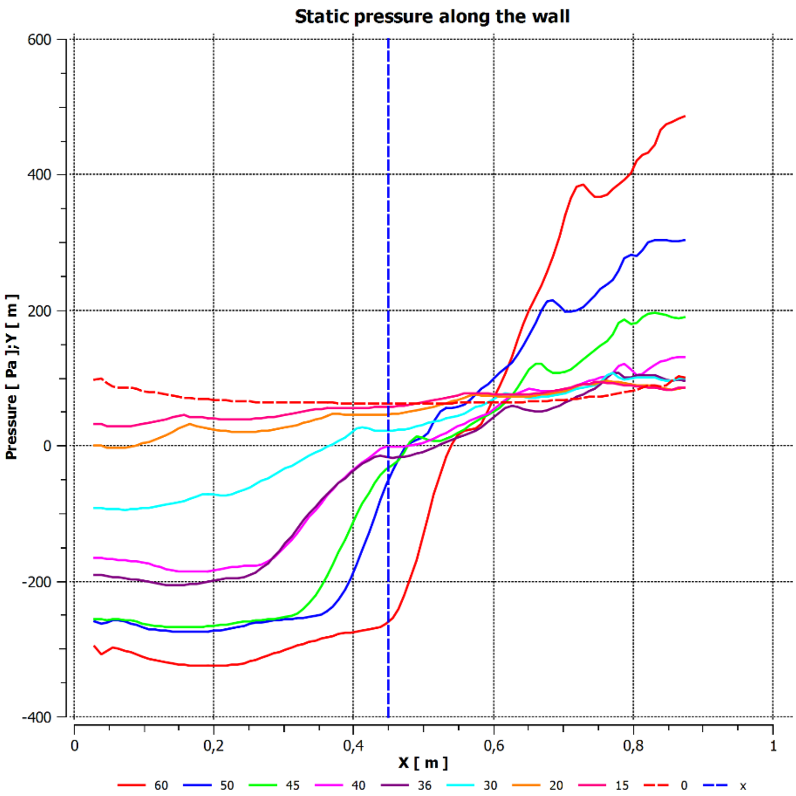

Fig. 13 Static pressure distribution along the wall for 4,8 [$kg.s^{-1}$]

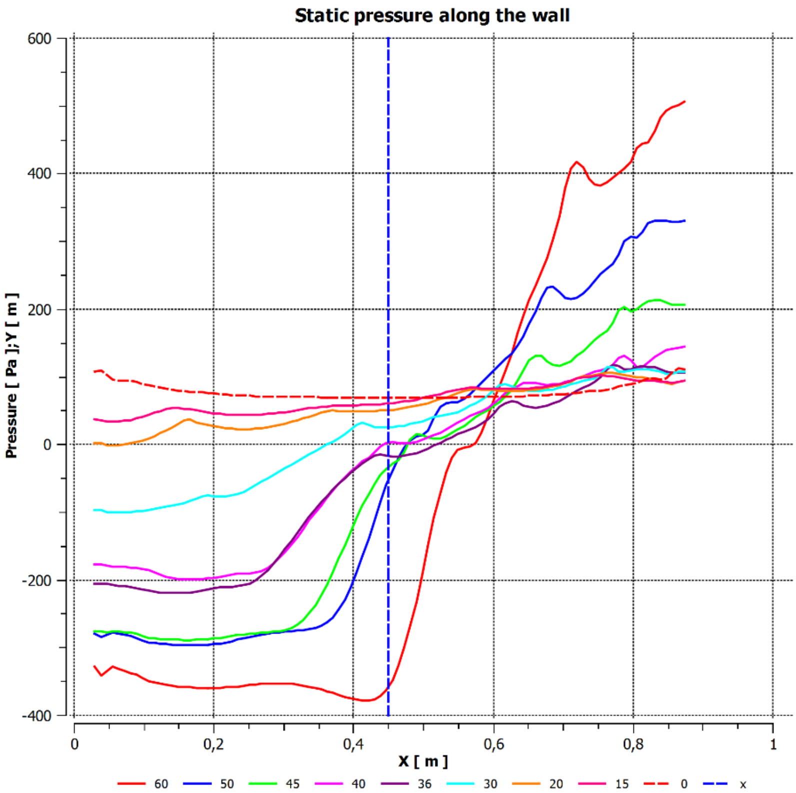

Fig. 14 Static pressure distribution along the wall for 5,0 [$kg.s^{-1}$]

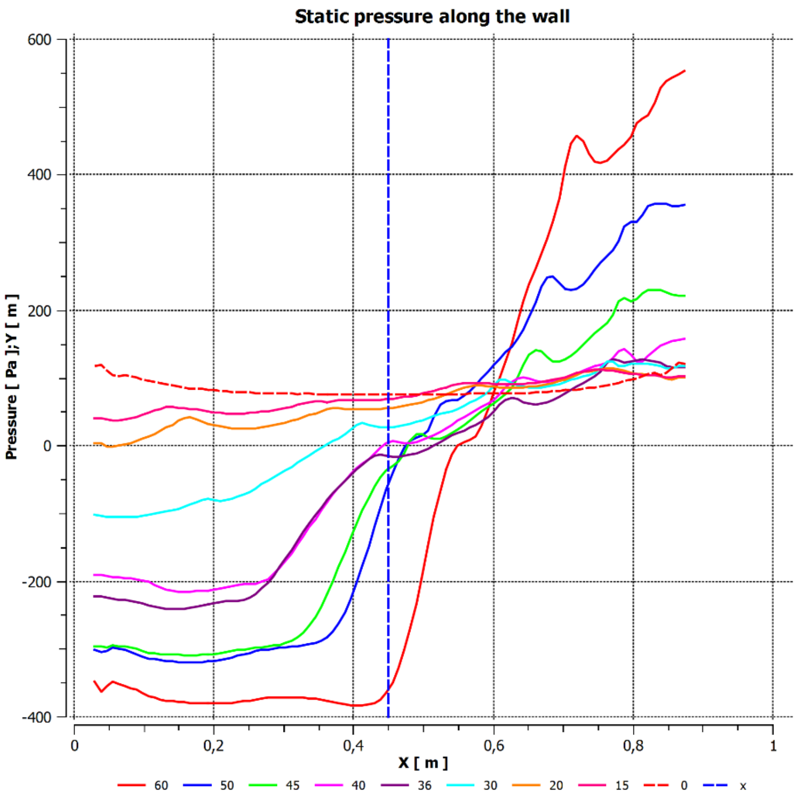

Fig. 15 Static pressure distribution along the wall for 5,2 [$kg.s^{-1}$]

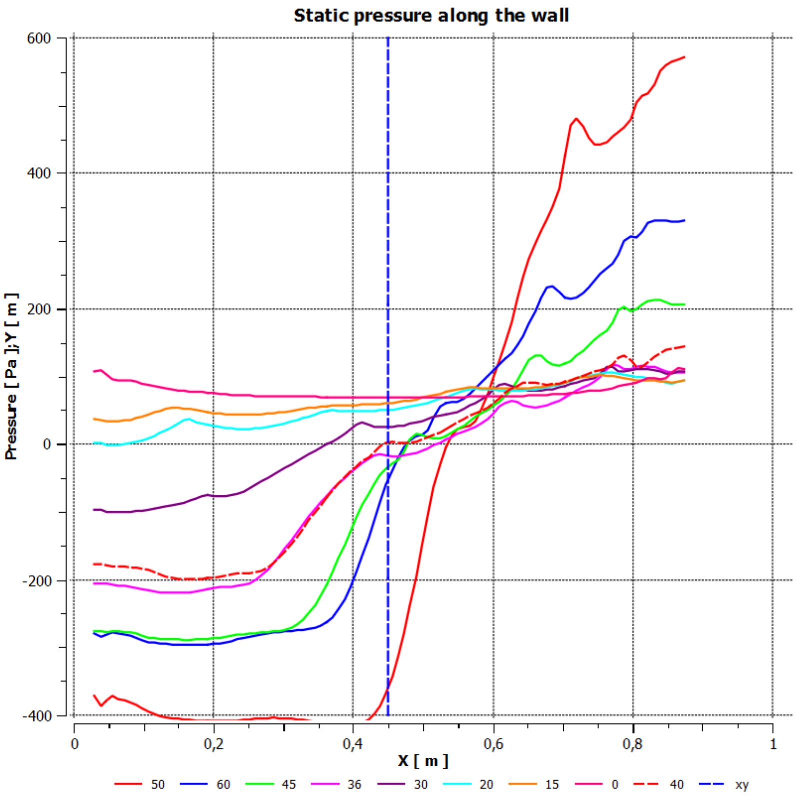

Fig. 16 Static pressure distribution along the wall for 5,4 [$kg.s^{-1}$]

7.6 VELOCITY FIELDS

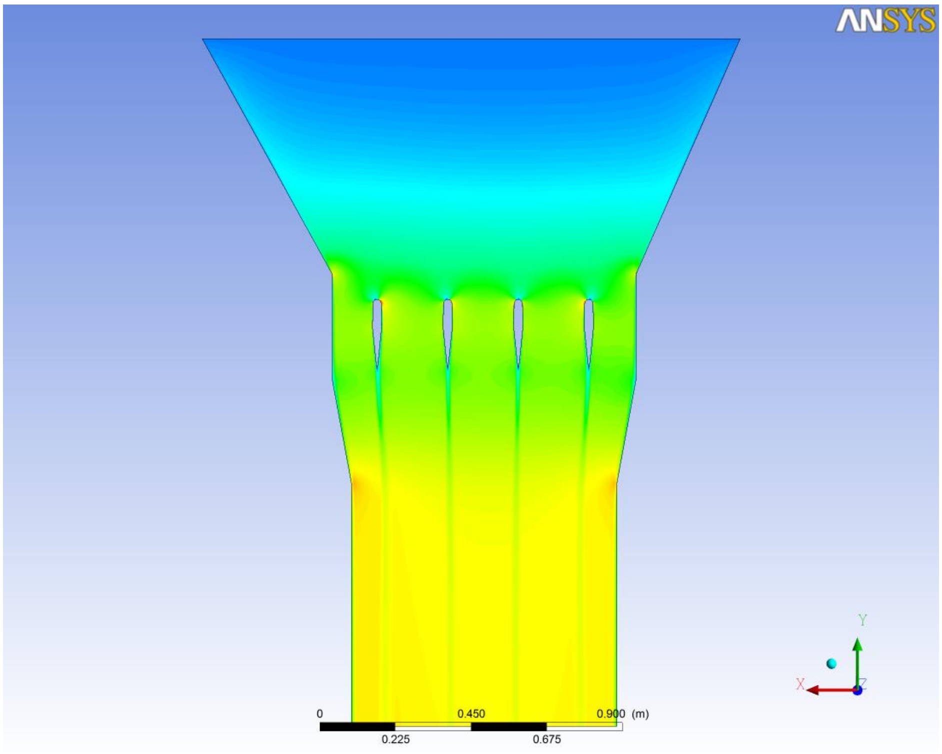

Fig. 17 Velocity field – blade position 0°; mass flow 5,0 [$kg.s^{-1}$]

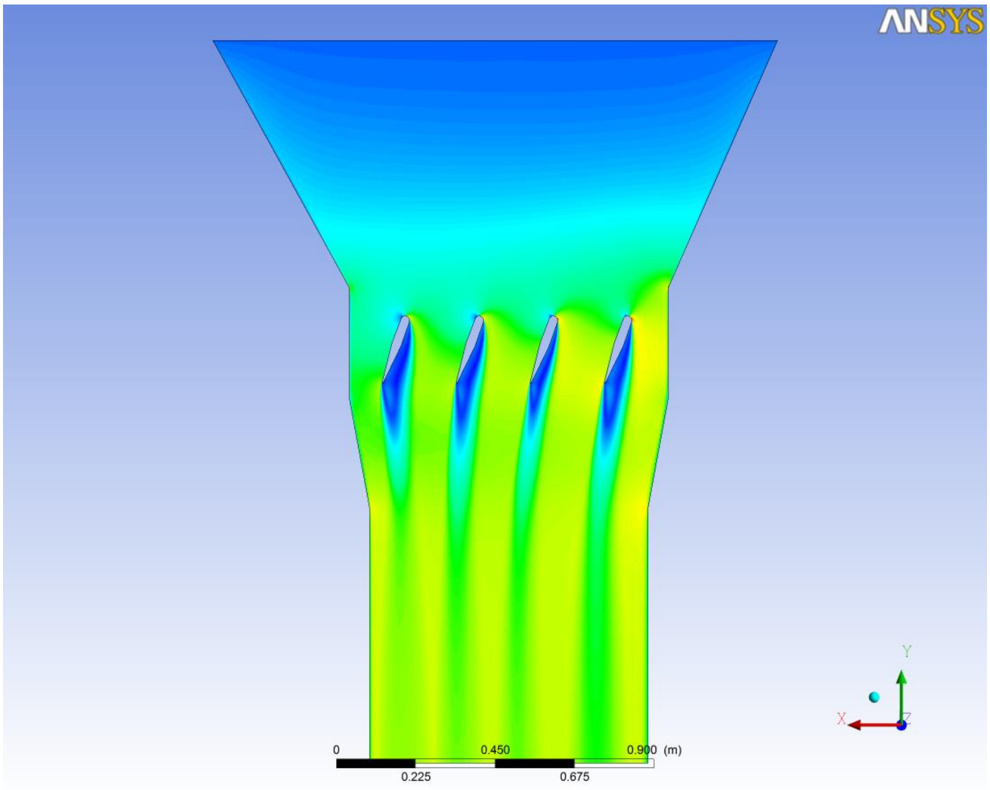

Fig. 18 Velocity field – blade position 20°; mass flow 5,0 [$kg.s^{-1}$]

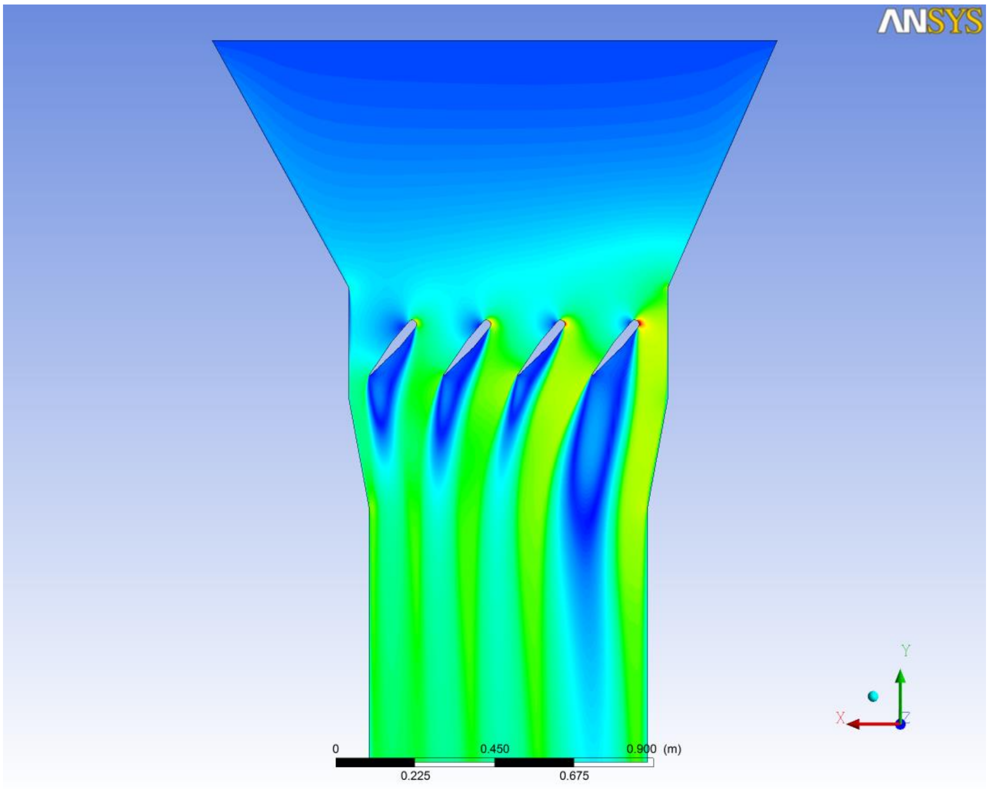

Fig. 19 Velocity field – blade position 40°; mass flow 5,0 [kg.s^{-1}]

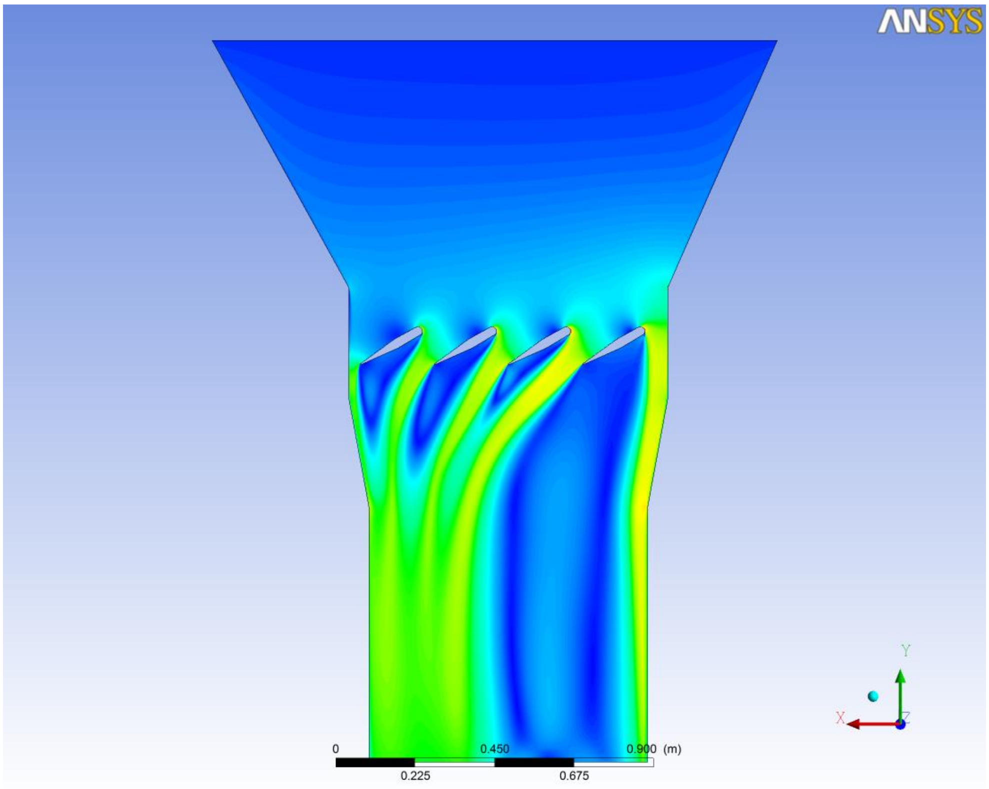

Fig. 20 Velocity field – blade position 60°; mass flow 5,0 [kg.s^{-1}]

8 CONCLUSIONS

This calculation was focused to investigate behavior of the IGV system. The calculation showed the evolution of the pressure drop and it's distribution along the IGV system. There are several conclusions from results:

- The pressure drop behavior is according the expectation. The pressure drop is changing according to the angle of rotation of the blades and mass flow rate (Tab. 2; Tab. 3)
- Difference between the values given by the manufacturer and calculation couldn't be explained at this moment. The manufacturer's evaluation process of the pressure drop is currently unknown.
- Difference between the values of measurement at laboratory is very promising.
- The calculated values of pressure drop are more pessimistic than the measured data. Which can be caused by absence of the lower part where the compressor is not included or bad boundary conditions Fig. 8
- Calculation revealed that the pressure distribution under the IGV blades is not homogenous (Fig. 11 – Fig. 16). When the blade rotates, one side creates tapering channel and the other diffuser channel (Fig. 17 – Fig. 20). These channels have high effect to the pressure distribution and its effect increasing with higher angles of the blade position.

8.1 SUGGESTIONS FOR FURTHER WORK

- Implement lower part of the IGV into numerical investigation, with compressor and improve boundary conditions
- Redesign the measurement of the pressure drop at the real machine to get data for comparison.