DEVELOPMENT OF AN EXPERIMENTAL SETUP FOR THE INVESTIGATION OF AEROACOUSTIC EFFECTS INSIDE AIRCRAFT AIR-DISTRIBUTION SYSTEMS

Syed Fawad Bokhari, Otto von Estorff
Institute of Modelling and Computation, Hamburg University of Technology

Eike Grunau, Melanie Stoob, Wolfgang Gleine
Department of Automotive and Aeronautical Engineering,
Hamburg University of Applied Sciences

Abstract

Advanced aircraft cabin noise insulation technologies have resulted in significant improvements towards quieter interiors. Against these lower background noise levels, however, the noise from the air-distribution system has become more noticeable than before and a significant contributor to the overall interior noise level. With respect to an efficient design of this system it is important to be able to investigate its aeroacoustic behavior and mechanism by the means of a suitable experimental setup, adaptable to specific system components or component clusters. Moreover, such an experimental setup may be used to validate numerical models, which are currently under development at the Institute of Modelling and Computation. The present paper deals with an experimental setup which, in particular, incorporates the usage of a traversable Laser Doppler Anemometer. This allows non-intrusive locally resolved fluid velocity measurements, from which velocity profiles and associated turbulence energies can be derived. Special actuators, namely a variable frequency fan and throttle system, are used to produce the flow conditions close to those inside the real air-distribution system. The whole system is controlled and monitored by a special input-output (I/O) configuration and software environment (MATLAB and LabView). The measured data are processed in a parameter identification environment and evaluated with respect to the information needed for the design of the air-distribution system. Finally, results of representative measurements conducted on one of the most common parts of the air-distribution system are presented and discussed in detail.

1. MOTIVATION & INTRODUCTION

The growing passenger demand for a comfortable cabin has become a major issue for many airlines. In view of this, the acoustics of the interior cabin is of significant concern. For the designer it is important to appreciate this fact at the system design level and to incorporate the noise analysis into the design without going into a rigorous experimentation of hit & trial nature. One of the main sources of aircraft cabin noise is the air distribution system (ADS) [1]. The noise is generated due to air-flow in the different parts of the ADS. Predicting this noise is among one of the challenges in system cabin design.

So far, the acoustic design and optimization is being done on the basis of general experience and trial. In addition, usually the entire ADS is built up rigorously through continuous observations and improvement hence requiring time and cost.

Therefore, it is important to investigate the aeroacoustic behaviour of the ADS, at system level, by the means of a suitable experimental environment (EE) in order to understand the dominating noise generation principles and to derive and validate numerical models also containing noise guidance within the ADS ducting, which are currently under development. The objective is to significantly replace laborious investigations of complete prototypes, which will help the designer to efficiently identify the aeroacoustic parameters that may be used for further steps in the design process.

The current paper presents an EE which incorporates, various components including hardware, i.e. sensors, actuators, input/output (I/O) cards [7], [8] , signal processing units, etc. and software, i.e. statistical tools that ensures the reliability, repeatability and reproducibility of the results. This EE without embedded statistical tools is referred to as experimental setup (ES) in this paper.

A feasibility study has been conducted for different parts of the ES (sensors, actuators, data acquisition parts, etc.) and components were identified as well as specified. The parts were procured, assembled and installed to form an automated and functional experimental setup including a computer based data monitoring, recording, and process control.

2. AEROACOUSTIC LAB ENVIRONMENT

The experimental environment consists of totality of hardware and software features. It will be able to produce flow conditions close to those inside a real ADS. From this point onward particular flow condition is referred as an operating point (OP). An appropriate investigation of the ADS requires that the ES must be able to produce a variety of different OPs, which brings the need to use appropriate actuators capable of producing an OP with a certain level of acceptability. In this regard, different sensors are embedded to record the data not only to control and monitor the OP but also for further analysis.

With regard to the aspect mentioned before, it became necessary to embed statistical tools that not only quantify the certainty in OPs but also introduce reliability and reproducibility in the results. These tools are implemented in an offline calculation environment.

The offline calculation tool converts the measured data into a useable form for further analysis. It will employ the statistical tools to remove any random noise error that is not required during analysis. In addition, it also confirms that the data being produced are reliable and that the ES is capable of producing a particular OP. An analysis of variance (ANOVA) is included to establish the fact that the data being produced are reproducible [2], [3]. Once these data are approved for further analysis, they will be routed to the parameter identification environment [4], [5], [6] for further analysis.

For the signal routing purpose, an interface layer connects the fan, the throttle, the by-pass system, and different sensors with the software environment via an I/O card, which not only can receive the sensor signal but also provides a control signal to the corresponding actuator. A man-machine-interface is realized by developing a control panel in LabView; see section 2.1 and figure A.2 for more details. Once the OP is reached, the data, being gathered can be routed for offline work. Figure 1 shows the systematic flow of data routing.

In short one can say that this experimental environment can be divided in three main categories

1. Hardware
2. Interface
3. Embedded offline calculations

A systematic work flow is shown in the figure 2**.** The double line shows the signal from sensors while the single line shows the control signal passing through the ES. The dotted block marks the interface part and the dashed block shows the complete hardware part.

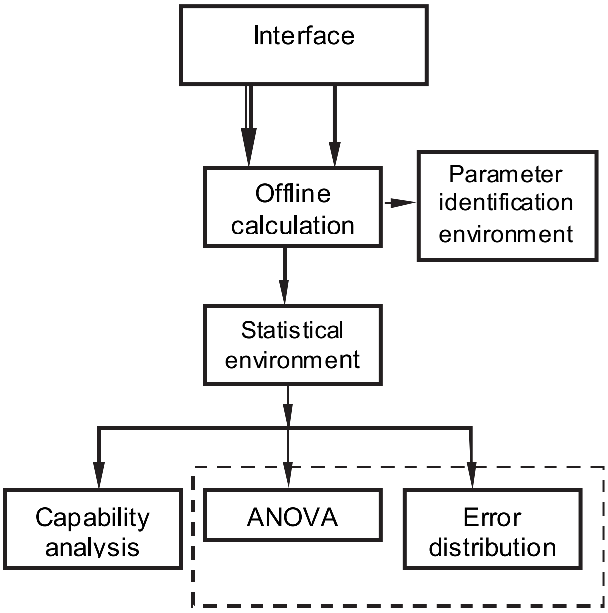

Fig 1: Systematic flow of data from hardware to software environment

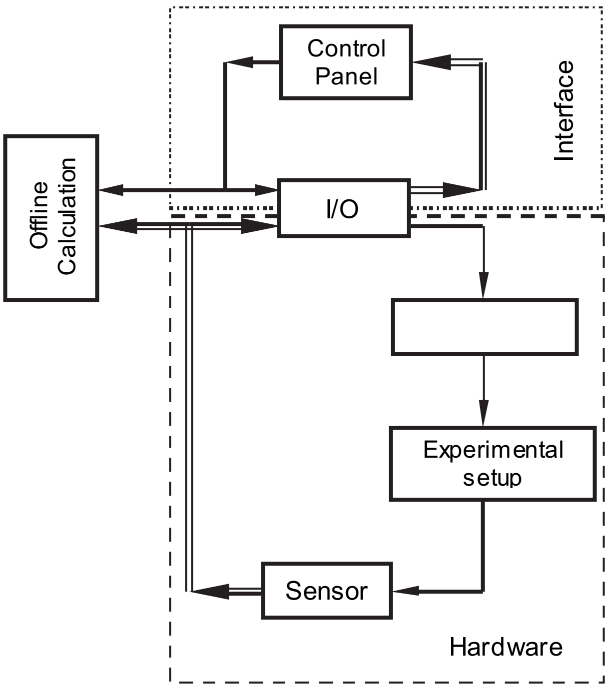

Fig 2: Systematic work flow diagram of the experimental environment

2.1 Sequential construction of the experimental setup

The goal is to develop an experimental setup to investigate the aeroacoustic behaviour of different ADS components. This will primarily focus on the effect of different flow conditions (OPs) -inside the particular component- on its acoustic output. The acoustic output is a spectrum for which the sound power level is known in a range of frequencies of interests.

“Volume flow” or “mean velocity” is the main flow condition that shall be controlled. Besides this, the velocity and the turbulence profile as well as acoustic spectrum are important factors that need to be measured and recorded.

Flow of desired values, i.e. variable flow, can be achieved by using a variable frequency fan. The flow is refined by introducing a combination of throttle and by-pass valves at the end of the fan flow exit. These valves work via electrical motors and a worm wheel mechanism. The worm wheel enables it to self lock at a desired angular position. The actuators have frequency and position sensors respectively and integrate directly with the control panel of the software.

After leaving the fan the volume flow then passes through an orifice. The pressure drop across the orifice is measured through the differential pressure sensor. The measured signal is directly used to calculate the volume flow according to standard DIN EN 5167 2004. It is the processed signal of volume flow that is used to control the frequency and angles of the valves to produce the required volume flow.

As per law of conservation of mass and assumption of incompressibility it is obvious that the volume flow remains constant through out the experimental setup. This is due to the fact that no flow enters or escapes from the throttle onward till it exits from the RP [9], [10], [11]. Once the OP is reached the volume flow signal is routed to the offline calculation.

At this point, this flow must not be used as the input for reference part (RP) (RP is a straight duct being replaced by components to be aero acoustically investigated), because it is polluted by the fan noise which must be filtered out. This is achieved by introducing series of mufflers that reduced the fan noise up to such a level that it becomes insignificant in the presence of flow noise of the RP. In addition, a long pipe is inserted after the mufflers to bring the flow into steady state conditions.

After the mufflers the RP is inserted. The Laser doppler anemometer (LDA) is used to measure the velocity and turbulence profile –upstream in our case- close to the RP and at any required cross section of the RP [12], [13], [14]. The flow exit cross section (FECS) of the RP is connected to the impedance convertor (IC) which is placed inside a reverberating room. IC ensures that sound pressure at the FECS remains unchanged when compared to the sound pressure at the exit of IC. Reverberating room is a special type of a room used for the acoustic measurements. In these rooms, average sound pressure level corresponding to particular frequency remains the same at all points far enough from the walls and at sufficient high frequencies. This is achieved by making all walls of the room as sound reflective as possible and to assure that the walls are made not parallel to each other.

ISO-DIN 3741 is used to measure the sound power level of any sound source inside the reverberating room by using the sound level meters (SLM), which are the sensor system used to measure the sound spectrum [15].

From figure 2 it is clear that the I/O card plays an important role in the experimental setup. Figure 3 shows the implementation of controllers that act through the I/O card. There are in total four controllers. Three are local controllers for the fan frequency, the throttle angle, and the by-pass angle respectively. A combination of fan frequency and both of the angles will result in a particular volume flow. A separate control scheme is used [16] which determines the reference values of these quantities such that their suitable combination –via controllers- results in the desired OP, i.e. in the particular volume flow of interest. Output signals from the fan frequency and valve angles are taken via I/O card as a feedback. The difference of these signals from the corresponding reference values –provided in the control panel- are provided to the controller for the generation of further control action. This iteration continues till the desired OP is reached.

The control panel consists of a graphical user interface that not only interacts with the user but also with process sensors and internally generated signals. This panel also sends the appropriate control signals to the Figure A.2, a detailed view of the control panel. In addition, a schematic diagram for the experimental setup is shown in the figure 4**.** Where in figure 4 the given numbers refer to

1. Fan
2. Throttle and by-pass
3. Orifice to measure the flow velocity
4. 2 mufflers, each 1 m long
5. Flow straightner
6. Long pipe to make the flow steady
7. Start of the reference part
8. Laser doppler anemometer (LDA)
9. An impedance convertor inside the reverberating room

Further views of the system can be found in figure A.3 and A.4 in the appendix.

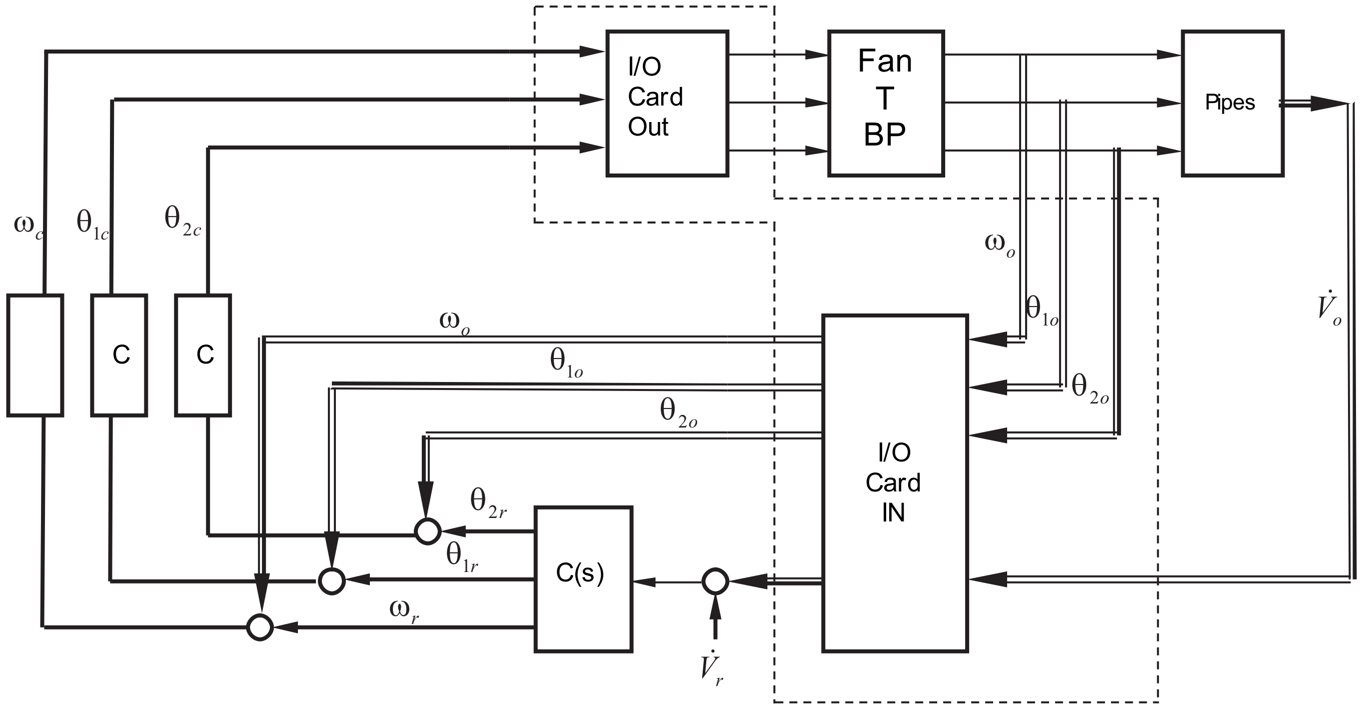

Fig 3: Implementation of controller through I/O card

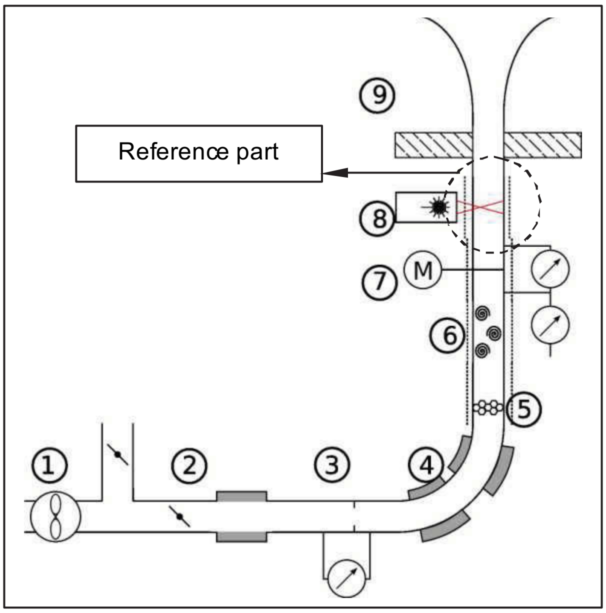

Fig 4: Schematic diagram of the experimental setup

3. RESULTS

As discussed before, the main purpose of the presented EE is to emulate the flow conditions as they occur in the ADS of an aircraft. This can be judged best by not only observing the accuracy of the mean velocity but also the complete velocity profile for any RP. Figure 5 shows the flow profile across the straight duct of 100 mm in diameter for different mean velocities ranging from 4 to 16 m/sec. The velocity profile is shown in figure 5. This profile ranges from -40 mm to 40 mm by considering “0” as the center of the pipe. It can be can see the that the profile is uniform and symmetric, which is consistent with the results given in literature [9],[10],[11].

To ensure the reproducibility of the acoustical spectrum at a given OP, the whole experiments were conducted many times on different days. Each time the ES was dissembled and assembled to introduce reliability in the reproducibility of the ES (e.g to exclude additional noise sources due to duct junctions possibly slightly stepped). Figures 6, 7 and 8 show the acoustical spectrum at velocities around 8, 12 and 16 m/sec. In addition to the visual consideration standard deviations have also been drawn and it is rather clear that the variations are well with in the certainty and acceptability. One can observe that these results are also consistent with engineering experience and the literature [16], [17].

The shaded areas in figures show the regions of no interest. For example, a sound power level below 10 dB is of no significance for the aeroacoustic investigation of the ADS. The frequency band of less that 300 Hz leaves the conditions for statistical room acoustics and must not be used. In the light of figures 6, 7, and 8 it becomes clear the EE is successful in reproducing the required OPs for the aeroacoustic investigations.

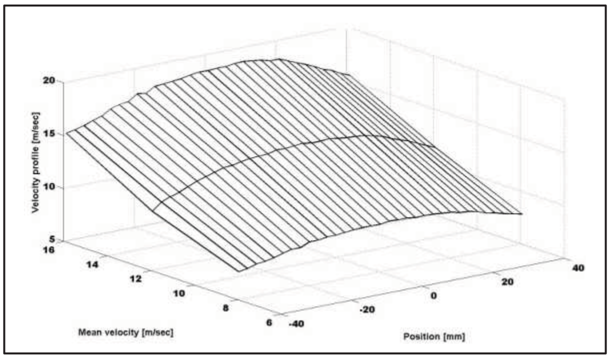

Fig 5: Velocity profile for different velocities

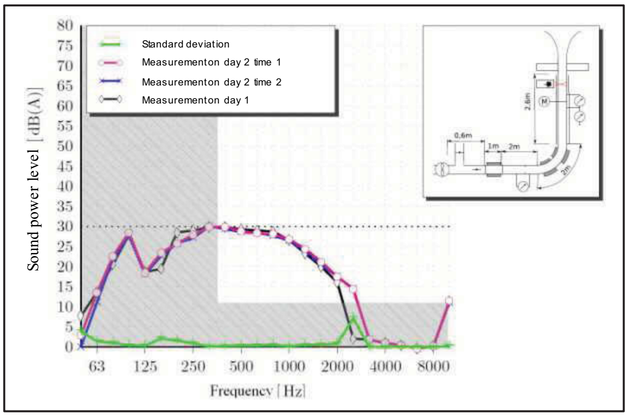

Fig 6: Acoustic profile at 8 m/sec

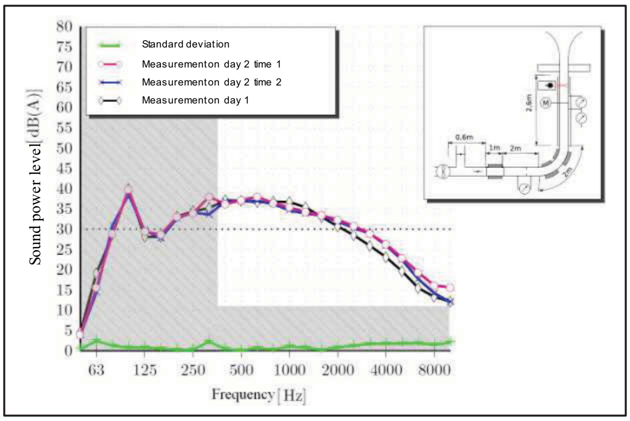

Fig 7: Acoustic profile at 12 m/sec

5. CONCLUSIONS AND OUTLOOK

The requirement to investigate the aeroacoustic behavior of air-distribution systems by means of a suitable experimental environment has been discussed.

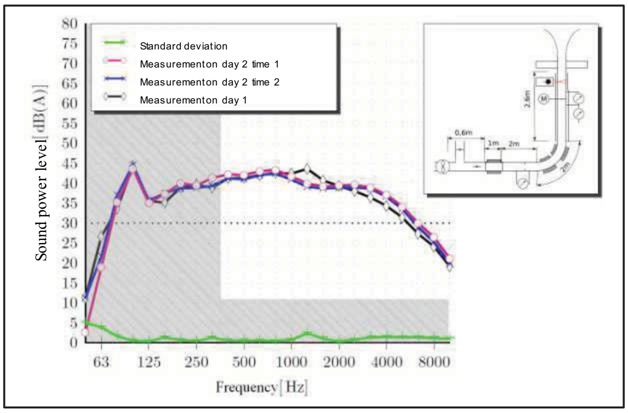

Fig 8: Acoustic profile at 16 m/sec

The experimental setup incorporates the usage of a traversable laser doppler anemometer, which allows non-intrusive and locally resolved fluid velocity measurements. This enables to determine the velocity profiles and associated turbulence energies can be derived. The experimental environment consists of totality of hardware and software components including actuators, sensors, signal routing and processing units, input/output (I/O) card, interface software, and offline embedded statistical tools. It has been used successfully to produce flow conditions close to those inside a real ADS.

At the end results have been presented, which show the velocity profile and acoustic spectrum for the reference part (RP). These results are consistent with the physics of the system hence demonstrating that the aeroacoustic behavior of the reference part (RP) has been represented successfully.

The experimental setup will be used to investigate the aeroacoustic behaviour of different components of the air-distribution system of an aircraft. For instance, different combinations of the parts and components will also be tested and the experimental setup will be used to validate numerical models, which are currently under development.

6. ACKNOWLEDGMENT

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7. APPENDIX

7.1 Laser doppler anemometer

Laser doppler anemometer is a very accurate, precise and non-intrusive flow measurement sensor system of a very high space resolution. Some of the advantages of a LDA are shown in table 1. LDA supplied by Dantec Dynamics Inc has been used. The working LDA is shown in figure A.1.

Table 1: Advantages of a LDA

Criteria	Advantages
Method	Non intrusive
Temporal resolution	High 10 KHz
Spatial resolution	Very high 100 micron to 1 mm
Calibration	Not required for 1 D
Precision	High

A coherent laser beam is split into two beams by a Bragg cell. The two beam parts cross each other and produce the interference fringes. The seeding particles –added to the flow- pass through this crossing point and scatter the light as per Doppler Effect. In the detector, the frequency shift due to doppler effect is measured. This frequency shift is used to compute the velocity component perpendicular to the bisection line of the two laser beams. For more information please see [12], [13], [14].

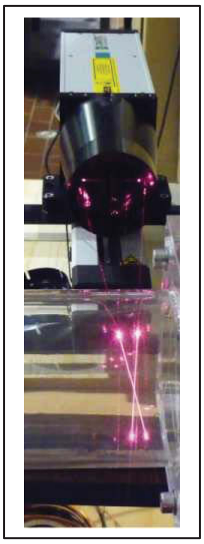

Fig A.1: Laser beam crossing at a point inside the straight pipe.

7.2 Control panel

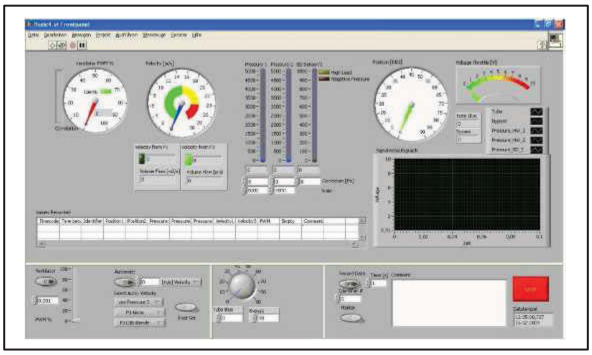

Fig A.2: Control panel developed in Labview

7.3 Experimental setup

Fig A.3: Developed experimental setup

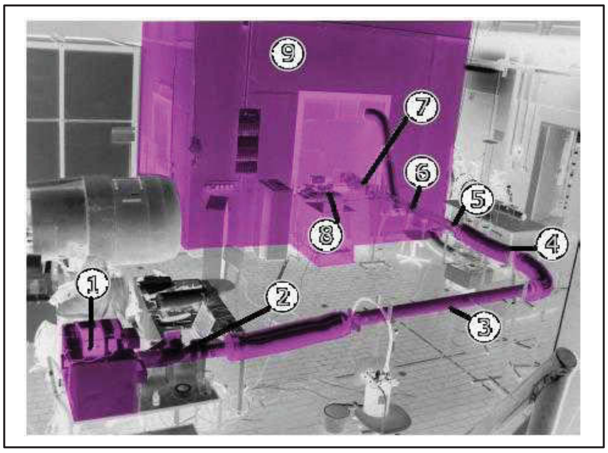

Fig A.4: Experimental setup

8. References

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