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Design and the Development of an Anemometer Positioning System

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Abstract. *Measurement of air flow through a fan is required during routine testing of several student projects using an existing two-metre-long wind tunnel at the University. Measurements of air velocity uses a handheld weather kit anemometer which is connected to a data logger. Inaccuracies in holding the equipment resulted in the basis of a project. This paper investigates and reviews the findings of the project, based on designing, prototyping, and evaluating a suitable system to hold the anemometer and allow positioning of it at any desired position within the cross-section of the wind tunnel. A rail system allows the anemometer to be positioned in the Z-axis for shorter wind tunnels, or in close proximity to fans without the tunnel or ducting. The paper shows the methodology of the design process, the development of a working prototype and the implementation of the initial readings.*

Keywords: Experimental methods; design and manufacture, design, and simulation.

1. Introduction

A regular project held in the first year for manufacturing students is to design and manufacture fan blades. The fan performance is currently determined by evaluating the velocity of the downstream airflow, a value which is obtained through experimentation within a wind tunnel. Currently, airflow velocity is measured by means of a handheld anemometer positioned at the exit of the wind tunnel (**Figure 1**). Holding the anemometer for long periods can induce errors in the readings. Ligęsa (2018) discusses some of these errors. This formed the basis for the project: to design, manufacture and evaluate a rail system, where an anemometer can be mounted and used in conjunction with a data logger. Furthermore, it was also suggested that the uniformity of airflow can be evaluated by placing the anemometer at any position within the specified envelope of airflow, thereby capturing a velocity distribution across a designated measurement plane. The data logger has a number of modes, where a timed duration of data collection is required for statistical analysis. This reinforces the need for the

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positioning system as hand movements are likely to induce further errors when undertaking timed experiments.

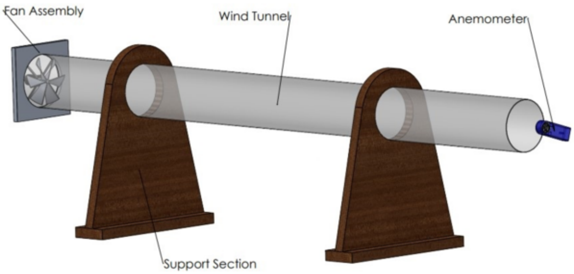

Figure 1. Existing set-up of the tunnel with positions of the fan and anemometer.

2. Project Methodology

Following the implementation of a Gantt chart, project risk analysis and review of resources, the development of a full product design specification (PDS) was carried out. Candidate solutions were then proposed based on the requirements of the PDS and available materials that would allow the project to be prototyped to the project budget of £200.

The four concept designs **(Figure 2)** were evaluated using the Analytical Hierarchy Process (AHP). Saaty (1987) reviews the key benefits of this analytical tool for decision-making, which is highly justified for this type of project.

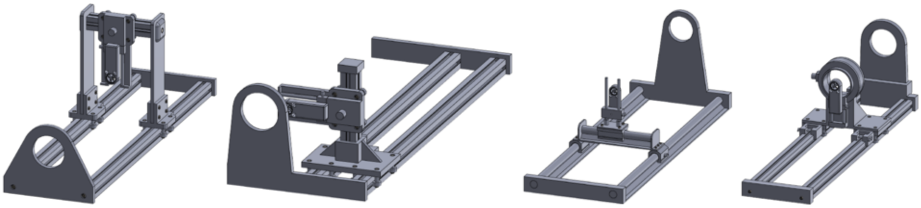

Figure 2. Four concept designs for the proposed new positioning system

Within the concept designs there was a strong desire to utilise the University's facilities; in particular laser cutting, additive manufacturing and traditional project workshop. The system had to accommodate the existing anemometer, which forms part of a weather kit. Dimensions are shown in **Figure 3**.

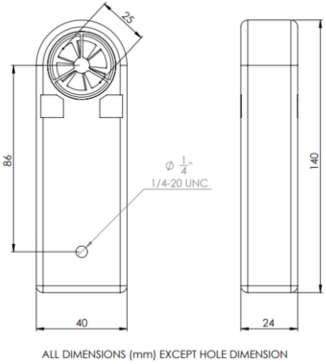

Figure 3. Drawing showing the anemometer and associated dimensions.

Currently a 2 m long single wind tunnel is used for project work, but the University is keen to acquire more wind tunnels of different lengths to enable a wider scope of projects. The building stage of the project was around 8 weeks, which constrained the manufacturing time. Designs needed to minimize costly outsourced parts, whilst balancing the in-house machining. Part sizes and the final design were based on worst-case scenario loading calculations, and the final design was evaluated using finite element analysis (FEA) to review von mises stresses and displacements of members.

3. Detailed design

The final design, as shown in **Figure 4**, presented a range of challenges. It is important to emphasize the need to fully evaluate the potential resources for this type of bespoke project. One of the first key issues was to source a type of economical bearing to use for the radial movement of the anemometer on the carriage. Given the high cost of bearings, a common serving table bearing, known as a "Lazy Susan" was utilised as the main bearing. This was very cost effective did not require any modifications. The rail system had been investigated early in the project during the definition stage as part of the feasibility study. Similar previous projects with rail-type components had employed aluminium alloy extrusion which is readily available in a range of sections and sizes. A 20 mm x 20 mm V-slot was selected which was available with runners.

Another major part of the design was the gantry which utilised prefabricated plates, although extra members were needed to join them together. A relief gap was included between the two gantry plates to mitigate issues with poor alignment of the extrusion rails. This may not have presented itself as a problem on completion of the project, however over time misalignment can occur due to repeated use and accidental mishandling. **Figure 5** shows the linear stage spacers that were incorporated into the carriage system and locking nuts, which were removed from bicycle quick-release spindles.

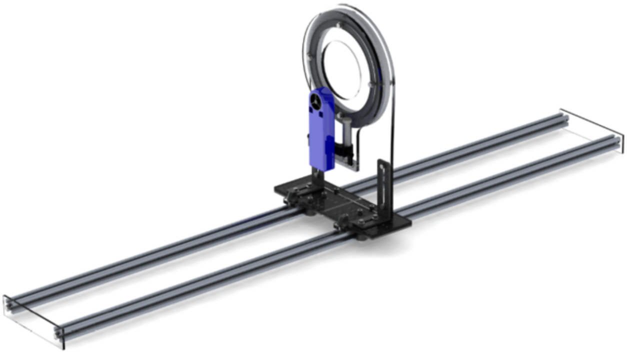

Figure 4. Final design of the complete rail system.

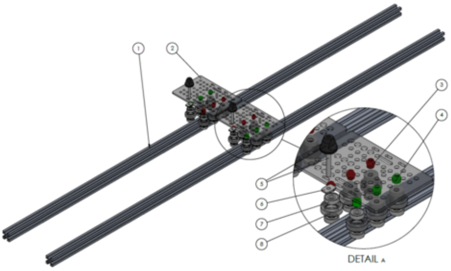

Figure 5. Gantry plates, bottom plate assembly including locking nuts.

A design for manufacture and assembly (DFMA) approach was sought, to help facilitate the production and assembly. Principles were sought from a range of sources and are covered extensively by Bayoumi (2000). Areas of the design required moving parts which had to be locked into position. The vertical movement of the anemometer required a column mount or dual mounts with a lockable moving bracket. This was more difficult to source than the extrusion, as the design needed to allow for the existing anemometer and the surrounding parts. Existing camera mounting equipment offers a range of brackets in sizes which are suitable. These were obtained but did requiring further machining (shortening, facing off and tapping a thread for end caps at the top and the mounts at the bottom). One of the latter challenges was to provide a locking method for the main rotating bearing. Initially, parts were planned to be fabricated, however the complexity and lead-time, it was decided that using toggle clamps, as shown in **Figure 6** as these could be fitted directly onto the main supporting member. Two clamps are required, since at some positions a single clamp would interfere with the bolts on the main bearing.

Materials selection was carried out using appropriate materials selection software. The most suitable polymeric sheet for this project considers polycarbonate. However, this would have increased the project cost and increased the lead time on delivery. For a working prototype model, PMMA (acrylic) was readily available. Calculations on the stresses and displacements were completed and verified the suitability for use in the prototype. The sheet acrylic was used for most of the large section pieces. Laser cutting was efficient and there were a few changes to the plate designs were required after student-mentor meetings, which required fresh pieces to be cut. This did not add any lead time and minimal costs, which had an advantage over additive manufacturing in this case.

Figure 6. Toggle clamp used to lock the main bearing.

The main concerns governing the final design were to ensure that friction, rigidity, alignment, and repeatability were not compromised in any way. Rigidity was verified using finite element analysis (FEA) software. Manufacturing/modifying parts took around 8 hours. This allowed time for initial testing.

3.1. Testing and FEA simulation-based results evaluation

Finite Element Analysis (FEA) was conducted on parts to ensure that the factor of safety was appropriate for all conditions. The factors in some areas were considerably higher than they needed to be; although there was no benefit from removing more material and this would have resulted in higher deflections. The maximum stress from static simulation was found to be 9.2 MPa with a minimum factor of safety (FOS) to be 19 **(Figure 7)**.

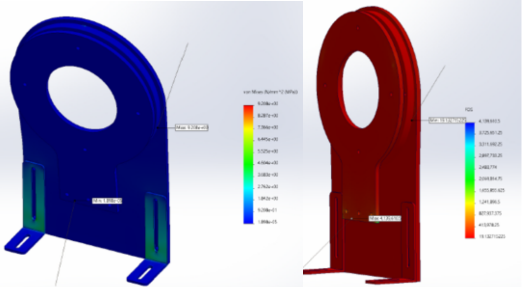

Figure 7. FEA static structural simulation shown maximum stress and factor of safety (FOS).

Previous tensile testing of this particular grade of PMMA was found to be 50 MPa. The presence of holes for bolts added stress concentration sites which could not easily be avoided. Impact forces are not anticipated for this type of testing however any attempt to remove material may have made the structure more prone to localised brittle failure through accidental impacts. Weight was not excessive and any attempt at reduction through optimisation could have had similar consequences.

Computational Fluid Dynamic (CFD) modelling was carried out prior to testing, so that some comparisons could be made to the actual initial testing. **Figure 8** shows the results, which evaluated the velocity streams moving through the main bearing and the pressure on the assembly.

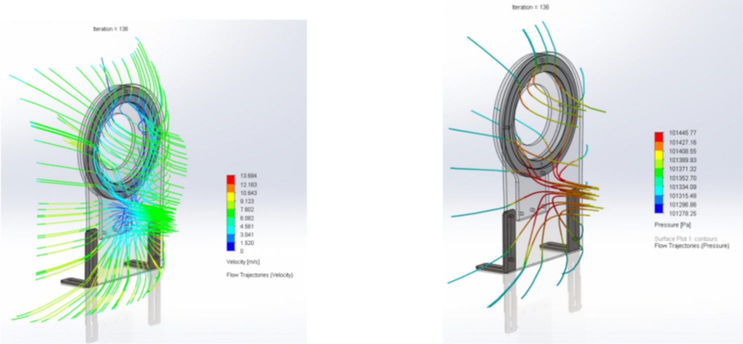

Figure 8. CFD modelling of the air velocity (left image) and pressure (right image) on the main plate.

The initial testing was limited to the length of the wind tunnel, as well as some close proximity testing to a fan. A grid of velocity measurement points was devised, and readings could then be taken with the data logger at these points. The layout is shown in **Figure 9**. The data logger was operated in statistics mode, which requires a timed interval from which the maximum, minimum, mean, and standard deviation are computed with a graph displaying the output overall the interval.

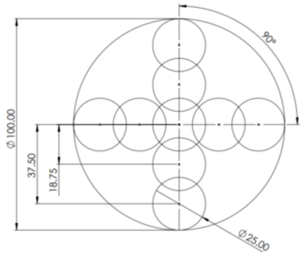

Figure 9. Measurement points used during initial testing.

4. Conclusions

The project culminated in the production of a successful working prototype, as shown in **Figure 10**.

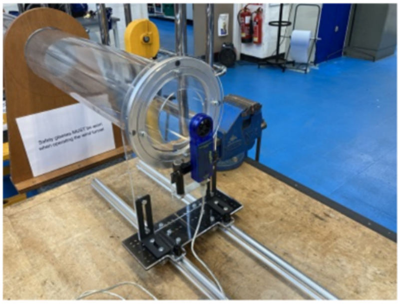

Figure 10. Positioning system set up at the end of the wind tunnel to carry out initial testing.

This was tested and yielded interesting results. One area that could be developed further is to consider adding a coordinate measurement system. concentrations in design work as well promote laboratory testing. The next stage requires a set of shorter length wind tunnels which would allow for testing in the Z-plane. Another possible expansion of this project could include using a smaller anemometer, or possibly even a pitot tube, which could yield more results in the field area of testing in the X-Y plane. Reduction of variables in wind speed is another area of improvement, which would allow for comparisons between measurement equipment used on the wind tunnels, as well as projects. There is a large scope of research activities which can be carried out, although factors affecting the anemometer need to be evaluated, as discussed by Morris, Beck, and Hosni (2001) before projects researching into the fans (or wind tunnels) can be carried out. This successful project will allow for future projects to now be undertaken which is likely to attract interest from students, sponsoring companies, and staff within the engineering department.

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