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Trials Assessment Report Prototype Air Filtration System

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November 2000

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Authorisation

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Issue	Date	Details of changes
1.0	November 2000	New Document

Abstract

In commercial aircraft there is a risk of spreading biological infection amongst passengers and crew through breathing recirculated cabin air. Hall Vantage Ltd proposed a novel technology to deal with this problem and constructed a prototype filtration module for testing by DERA Porton Down. Encouraging results have been obtained from preliminary experiments against a challenge aerosol of living bacteria, and recommendations are made for design improvements and further testing. Other potential applications of the technology include treatment of air inside hospitals and offices (including 'sick building' syndrome) and filtration/inactivation of biological warfare agents in military collective protection. (UKR)

Executive summary

The efficiency of a new prototype aircraft filter was demonstrated against BG bacterial spores resistant to disinfection. The filter employs a novel antimicrobial coating on a mesh support, followed by an in-line bank of UV lamps. The antimicrobial coating and UV irradiation are designed to kill disease organisms present in recirculated passenger cabin air. With UV lamps on, the efficiency was measured to be 99.924% at 140-170 m³/hr. This exceeded the 95% kill rate target set by the customer prior the trial. With UV lamps switched off, efficiency dropped from 99.924% to between 73-88%. Efficiency with the UV lamps on was better than the measured efficiency of a standard HEPA filter as presently fitted to some aircraft (average 99.78%). The standard HEPA filter is normally specified at 99.99% efficiency at 0.3 µm and there was evidence that it may not have been fully sealed in place which would account for the somewhat lower result. If assessed therefore against the HEPA specification, the non-optimised prototype system would appear to be similar in performance to that of the HEPA filter. Results confirmed the effectiveness of UV treatment but the effectiveness of the special antimicrobial treatment could not be fully assessed in the absence of running a non-treated control. A number of suggestions are made for design improvements to optimise performance of the system and improve the significance of information obtained in future trials.

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1 Introduction

- 1.1 In commercial aircraft there is a risk of biological infection via the oral route to passengers and crew from breathing recirculated cabin air. There has been recent medical concern, for example, over spread of tuberculosis during long-haul flights [1]. Some aircraft manufacturers such as Boeing fit HEPA particulate filters on long-haul aircraft but these can be difficult to maintain and may not be totally effective against the smallest bioaerosol particles (under 0.3 μm in size).
- 1.2 In particular there has been recent concern over the ability of current filters to remove viruses from air. In recent evidence to The House of Lords Science and Technology Committee, manufacturers suggest that if the filters are allowed to become dirty they remove more viruses. This would imply efficiency of filters is likely to vary throughout their useful life, making performance difficult to predict and creating problems with instituting correct maintenance procedures.
- 1.3 Hall Vantage Ltd filtration experts have developed novel technology to overcome these difficulties. The new technology employs an in-line particulate filter treated with a patented antimicrobial coating sited prior to a set of lamps which expose the filtered air to UV irradiation. The prototype module has been specially designed to fit a passenger aircraft such as a Boeing 747. CBD Porton Down were tasked by Hall Vantage to test the effectiveness of this system in removing biological hazards.
- 1.4 To demonstrate the performance of the prototype design, it was necessary to test it under representative, controlled, conditions against a challenge bioaerosol containing living material. CBD proposed use of the bacterium *Bacillus globigii* (BG) which is approved for use in trials under carefully regulated safety procedures. This organism is useful because it forms resistant spores, making it a better test of disinfection systems. It is also used a simulant for the biological warfare agent *Bacillus anthracis* which would be relevant to potential military applications.
- 1.5 At the commencement of the project, it was made clear by the customer that performance of the prototype was unlikely to have been optimised. CBD were therefore asked to recommend possible design improvements that could, if results were encouraging, be incorporated into further development and testing.

2 Aim

- 2.1 To test the effectiveness of a prototype air filtration unit against aerosolised simulant bacteria, to compare it with currently available systems and, where necessary, recommend possible design improvements prior to further development and testing.

3 Trials plan

3.1 Hall Vantage Ltd were responsible for providing the prototype air filtration unit, air mover and electrical control unit for the UV lamps. Also for providing technical and safety advice on operation of the equipment.

3.2 The biological challenge was undertaken at CBD Porton in the Boscombe Laboratories exposure chamber facility by qualified DERA scientists.

3.3 Trial preparation, biological dissemination and disinfection procedures were performed in accordance with established safety protocols and safe working procedures as approved by CBD Health & Safety Department.

3.4 Trial dates

3.4.1 Trials were conducted on 14 and 15 September 2000 following three days of setting up. A further day was spent in decontaminating equipment and test facility on completion of the trial.

3.5 Test conditions

3.5.1 Schematic drawings of the equipment (as provided by Hall Vantage) are shown in Figures 1-3. The layout of the apparatus is shown Figure 4 and in the Trials Photographs.

3.5.2 A series of tests were requested to encompass the following [2]:

1. Control test with HEPA filter.
2. Test without UV.
3. Test with UV.

3.5.3 Three flow rates were also requested in order to assess the performance over a wide range of air velocities. The air volumes which were specified as follows:

20 m³/hr, 40 m³/hr, and 100 m³/hr.

3.5.4 Relatively low flow rates were chosen to allow reasonable UV exposure in the absence of more powerful amalgam UV bulbs which were unavailable in time for the trial. Unfortunately, the air mover apparatus supplied could not be regulated sufficiently to achieve these lower flow rates (see below).

3.5.5 A number of difficulties were encountered in setting up the equipment:

- The sample collection filter holder supplied by CBD had not been fitted as discussed (see Figure 5). This necessitated use of smaller open-faced sample filters situated in the airflow, thereby increasing the potential error in the results.
- No flow rate monitor had been provided with the equipment as agreed (this posed a particular problem as the specified flow rates were low and not easy to measure).

Trials plan

- The flow control on the air mover consisted of a simple flap and did not provide the range or accuracy of control necessary to regulate the airflow. Nor could the flow rates be achieved as specified by the customer (see above). A Variac controller was introduced (and flow rate meter traced) to enable comparative flows to be obtained between each of the equipment configurations without significantly affecting the pressure drop across the filter. However, the flows remained well in excess of those specified at 140 and 170 m³/hr.
- No stands were attached to the equipment as had been agreed and means had to be found to support the assembly.
- The equipment was delivered for trials a day late leaving a shortage of time for inspection and setup.

3.5.6 Resolving the difficulties involved an extra two days work by CBD staff to enable tests to be conducted. However, despite these problems (which were reported to the customer during the trials) work went ahead in order to complete the work on time as required.

3.5.7 Because of the risks of cross contamination, the order of trial runs was arranged to progress from the potentially cleanest (HEPA) setup to the one which was likely to be most contaminated (prototype system with UV lamps off).

3.6 Analysis by plate count method

3.6.1 Each sample filter was placed in a 30 ml universal bottle and 10 ml of buffer (10 mM HEPES) was added. The filters were then vortex mixed for several minutes until the filter started to disintegrate.

3.6.2 Immediately after vortexing (so that the spores would not have sedimented) a sample (100 µl) of the liquid was pipetted out and serially diluted in water to an appropriate dilution. Aliquots (100 µl) of the diluted or undiluted samples were spread on Tryptone Soya Agar plates (Oxoid). This was done in duplicate. The plates were incubated at 37°C overnight until BG colonies were visible. The BG colonies were counted and the values used to estimate the total number of BG spores on the filter.

3.6.3 For each sample, at least three dilutions were tested by the above method.

3.7 Calculation of results

3.7.1 The total number of spores on each filter were used to calculate calculate efficiency as follows:

$$\% \text{ Efficiency} = \frac{\text{Challenge concentration} - \text{Collected spores}}{\text{Challenge concentration}} \times 100$$

4 Results

- 4.1 Results for the challenge with BG are shown in Table 1. It should be noted that efficiency figures relate to significantly higher flow rates (140-170 m³/hr) than those requested by the customer (20-100 m³/hr). These higher rates are a consequence of the equipment supplied not being able to operate at the lower flow rates without significant modifications to the air mover design, which in turn would have required more resources and time than was available.
- 4.2 Performance of the HEPA filters averaged 99.78% efficient with the BG spores when each of the flow rates was incorporated. This was somewhat lower than the manufacturer's quoted performance data (99.99% efficiency at 0.3 microns)⁽¹⁾. The reason could be that the HEPA filter was not sufficiently well sealed into the filter mounting.
- 4.3 With the new prototype assembly and UV lamps on, performance was better than with the HEPA filter (average efficiency 99.924%), although this figure could be slightly high due to the physical layout of the sampling filters. The efficiency achieved exceeded the 95% target kill rate set before the trial [3]. This result is therefore encouraging despite the use of a significantly higher flow rate than originally specified, which would have reduced the exposure time. Had it been possible to use a lower flow rate then the efficiency of the UV treatment might have been expected to be higher still.
- 4.4 The potential for the lamps to irradiate spores collected on the filters was checked by placing an additional filter behind the air mover, in a position where it could not be irradiated. Results showed no significant difference. Also, when the lamps were off, the filter again showed no significant difference, indicating that spores were undamaged by passage through the air mover (selecting this position to judge the influence of UV was therefore valid).
- 4.5 With the UV lamps switched off, there was a significant loss of efficiency to between 73-88%. Here efficiency relies upon filtration through the antimicrobial mesh filter (average 10 microns mesh size) which is much coarser than the HEPA filter.
- 4.6 It was difficult to determine the contribution made by the antimicrobial coating as an untreated mesh was not provided for comparison. It is possible that the efficiency of this stage might be improved by using a smaller mesh size together with possible improvements in filter configuration (eg as in military collective protection filters).
- 4.7 The use of sample filters in place of a filter disc as originally envisaged introduced greater error in calculating the results. It was not therefore possible to differentiate effects of using different flow rates. In future trials all of the sample passing through the unit should be collected as was originally envisaged. It should also be possible to make improvements to the air mover and overall construction.

1. Filters fitted to Boeing 747 as supplied by Powell Aerospace (information supplied to DERA by BA London Heathrow).

5 Recommendations for design improvements and further work

5.1 Design improvements to the particulate filter system might include the following:

- 5.1.1 Use of higher intensity UV light sources. Unfortunately some candidate lamps of higher output were not delivered in time for the trial. Increased UV output will need to be matched against the flow rate intended to be used in practice, in order to determine the optimum UV exposure. Information should also be gained on the performance latitude with regard to flow rates.
- 5.1.2 UV exposure might be further enhanced if necessary by redesign of the reflectors and or a different lamp layout. However, the need for ease of maintenance and lamp replacement need to be born in mind. Another alternative method of enhancing the activity of UV irradiation, if required, could be to use a catalyst, although with the risk of adding some additional complexity to the design.
- 5.1.3 One of the best ways of optimising flow rate/exposure to the UV light source is to regulate the pattern of air flow through the system and some preliminary attempts were made at doing this in the trial on an ad hoc basis. That this approach can lead to significant benefits may be seen from some exploratory computational fluid dynamic modelling in Figures 6 and 7. The CFD model was scaled according to the dimensions of the lamp housing. Figure 6 shows the effect of laminar flow and Figure 7 the effect of applying a vortex. For a flow rate of 70 m³/hr, the laminar flow results in an average residence time of approximately 2 seconds, while the application of the vortex increases the time for a particle to traverse end-to-end to around 20 seconds.
- 5.1.4 The use of the CFD model demonstrates that a factor of 10 improvement might be readily achievable in residence time within the lamp unit. The vortex would greatly enhance the exposure time, as well as bringing the particles within closer proximity to the lamps and increasing the radiation dose. The particle size is not that important for this swirling effect. The adjustment parameters will be the degree of swirl and the residence time. It would be possible to the swirl more severe and increase the residence time significantly more - this would require a proper systematic investigation. Also we didn't include any cones or blades so once we've decided the degree of swirl we've then got to create a method of generating it. This could also be conveniently carried out by further computer modelling followed by wind tunnel testing (some of which might be possible using an innocuous simulatant rather than a bacterial agent).
- 5.1.5 The serials did not include the evaluation of an untreated mesh. This is recommended in future trials in order to evaluate the efficiency of the antimicrobial treatment itself. In this way it will be possible to demonstrate whether the anti-microbial treatment on the mesh kills the particles that remain in airborne suspension. Additional experiments might also be worthwhile to investigate to what extent the antimicrobial treatment is capable of preventing the mesh becoming a reservoir of potentially infective material (which might pose a risk of reaerosolisation or problems during maintenance and disposal of filters).

Recommendations for design improvements and further work

- 5.1.6 By singling out the effects of the mesh filter, it should be possible to investigate such aspects as coating efficiency and influence of mesh size on particulate removal (making for easier comparison with HEPA filters. Alternative filter configurations (eg radial designs) may be an option to improve air permeability if smaller mesh sizes need to be considered.
- 5.1.7 When undertaking further work, a number of design improvements to the filter unit should be implemented to improve the accuracy and precision of the test results. In particular with regard to regulation of the air flow and the sampling methodology (see section 3.5 above).

5.2 Other potential applications

- 5.2.1 Other possible areas of application where air treatment would be important include hospitals. Risk of infection is high in hospitals from common organisms as well as antibiotic resistant bacteria. Immunosuppressed individuals (eg those on specific medication or with AIDS) as well as the sick, very young and elderly are particularly at risk.
- 5.2.2 Indoor air quality in offices has also received much attention recently, in particular with regard to 'sick building' syndrome (SBS) which includes possible risks from infection, and is currently subject to review as regards new legislation, notably in the USA. In particular, the occurrence of periodic outbreaks of Legionnaires' disease have forced employers to look at the construction and environmental management of office buildings.
- 5.2.3 The US Environmental Protection Agency has recently determined that indoor air quality is currently one of the top five environmental health risks. Increasingly, local and state governments are recognising the damaging effects of SBS and are forcing employers to accommodate sufferers, in addition to making employers responsible for providing social benefits in the form of compensation and medical assistance. Thus preventive measures are increasingly being seen as important in ensuring a safe workplace.

6 References

1. *TB - A Killers Return*. Article by Aisha Labi. TIME Magazine, August 14, 2000 p.28.
2. Fax from Ray Malyon Climatec AQP to Adrian Clark dated 30 August 2000.
3. Fax from P Hall to DDA dated 28 July 2000.

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7 **Tables**

Flow rate (m ³ /hr)	System Type	Run	Filter	CFU/filter*	BG spores sprayed	Remainin g	Average BG	Efficiency %
140	HEPA	1	1	130000	5.E+09	5.0	5.0E+09	99.7
140	HEPA	1	2	149500	5.E+09	5.0	5.0E+09	99.7
140	HEPA	1	3	77000	5.E+09	5.0	5.0E+09	99.8
140	HEPA	1	4	31000	5.E+09	5.0	5.0E+09	99.9
170	HEPA	2	1	268000	8.E+09	2.5	7.7E+09	99.6
170	HEPA	2	2	209000	8.E+09	2.5	7.7E+09	99.7
170	HEPA	2	3	125000	8.E+09	2.5	7.7E+09	99.8
170	HEPA	2	4	73000	8.E+09	2.5	7.7E+09	99.9
140	HEPA	3	1	298000	9.E+09	3.0	7.8E+09	99.6
140	HEPA	3	2	384500	9.E+09	3.0	7.8E+09	99.5
140	HEPA	3	3	218500	9.E+09	3.0	7.8E+09	99.7
140	HEPA	3	4	118000	9.E+09	3.0	7.8E+09	99.8
71	UV ON	4	1	50	8.E+09	3.0	7.6E+09	100.0
71	UV ON	4	2	100	8.E+09	3.0	7.6E+09	100.0
71	UV ON	4	3	200	8.E+09	3.0	7.6E+09	100.0
71	UV ON	4	4	26300	8.E+09	3.0	7.6E+09	99.9
140	UV ON	5	1	600	8.E+09	3.0	7.6E+09	99.9
140	UV ON	5	2	100	8.E+09	3.0	7.6E+09	100.0
140	UV ON	5	3	500	8.E+09	3.0	7.6E+09	99.9
140	UV ON	5	4	134500	8.E+09	3.0	7.6E+09	99.8
170	UV ON	6	1	100	8.E+09	3.0	7.6E+09	100.0
170	UV ON	6	2	150	8.E+09	3.0	7.6E+09	100.0
170	UV ON	6	3	150	8.E+09	3.0	7.6E+09	100.0
170	UV ON	6	4	50800	8.E+09	3.0	7.6E+09	99.9
170	UV OFF	7	1	23550000	1.E+10	0.5	9.7E+09	75.3
170	UV OFF	7	2	21250000	1.E+10	0.5	9.7E+09	77.7
170	UV OFF	7	3	25600000	1.E+10	0.5	9.7E+09	73.1
170	UV OFF	7	4	12750000	1.E+10	0.5	9.7E+09	86.6
140	UV OFF	8	1	25050000	1.E+10	0.5	9.7E+09	78.3
140	UV OFF	8	2	23750000	1.E+10	0.5	9.7E+09	79.5
140	UV OFF	8	3	26100000	1.E+10	0.5	9.7E+09	77.4
140	UV OFF	8	4	13100000	1.E+10	0.5	9.7E+09	88.6

* assuming 100% recovery from the filter

Table 1: Summary of results

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8 **Figures**

Figure 1: Schematic drawing of micro electronic purification system (MEPS). Drawing No. 1364/A

Figures

Figure 2: Schematic drawing of micro electronic purification system (MEPS). Drawing No. 1364/B

Figure 3: Schematic drawing of micro electronic purification system (MEPS). Drawing No. 1364/C

Figures

Figure 4: Equipment configuration for trial (diagrammatic representation)

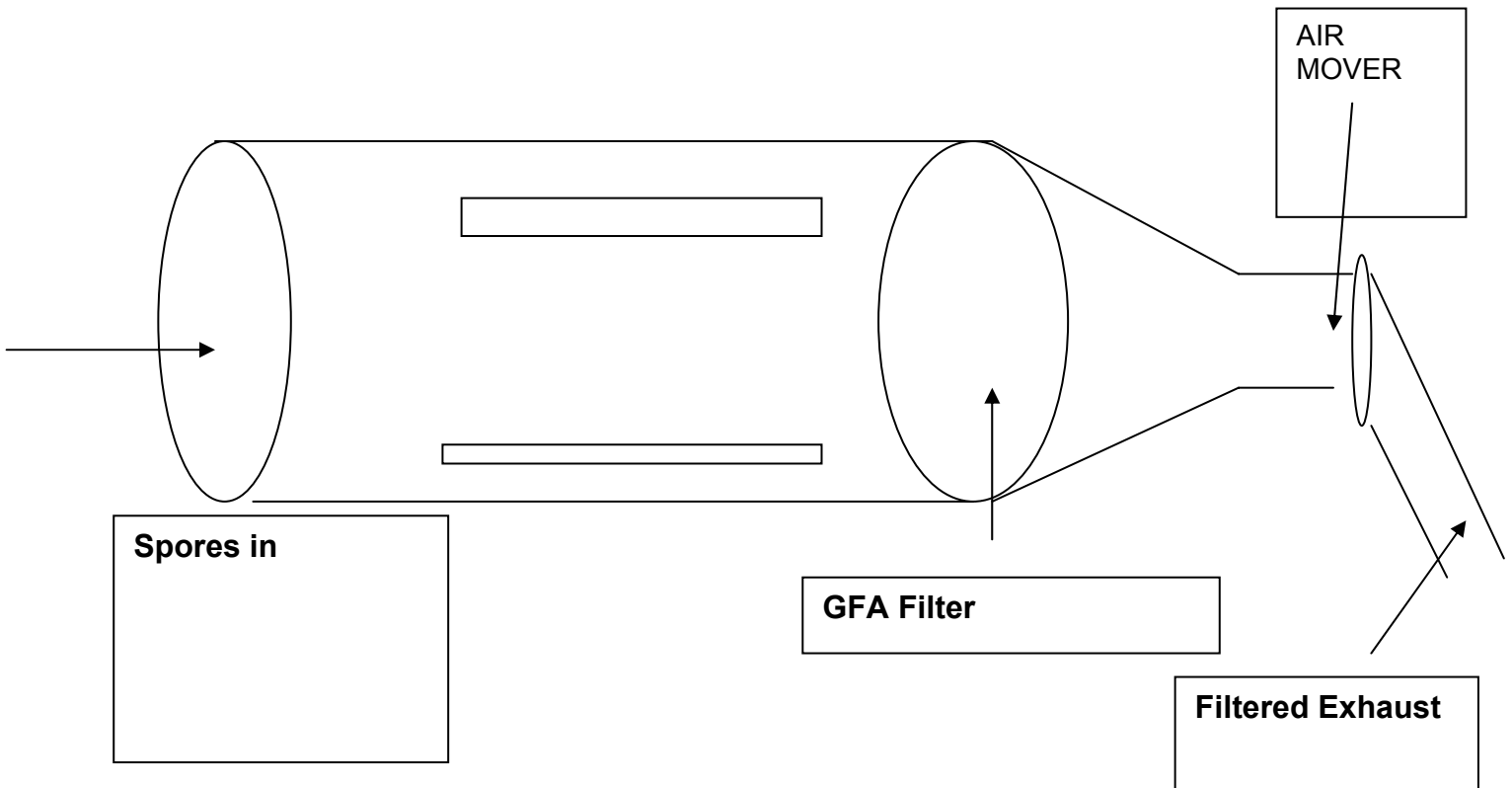


Figure 5: Proposed configuration for trial

Figures

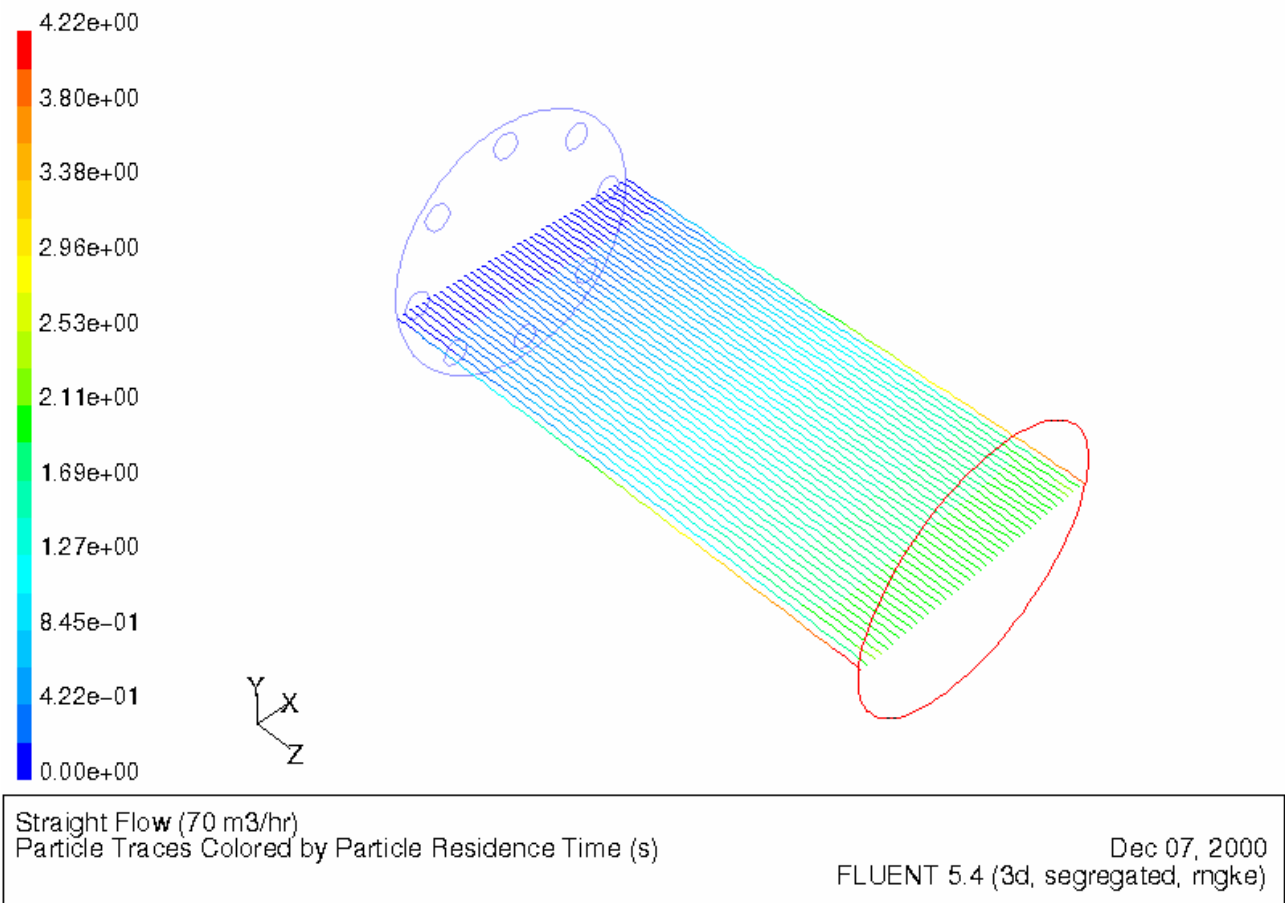


Figure 6: CFD picture showing straight flow

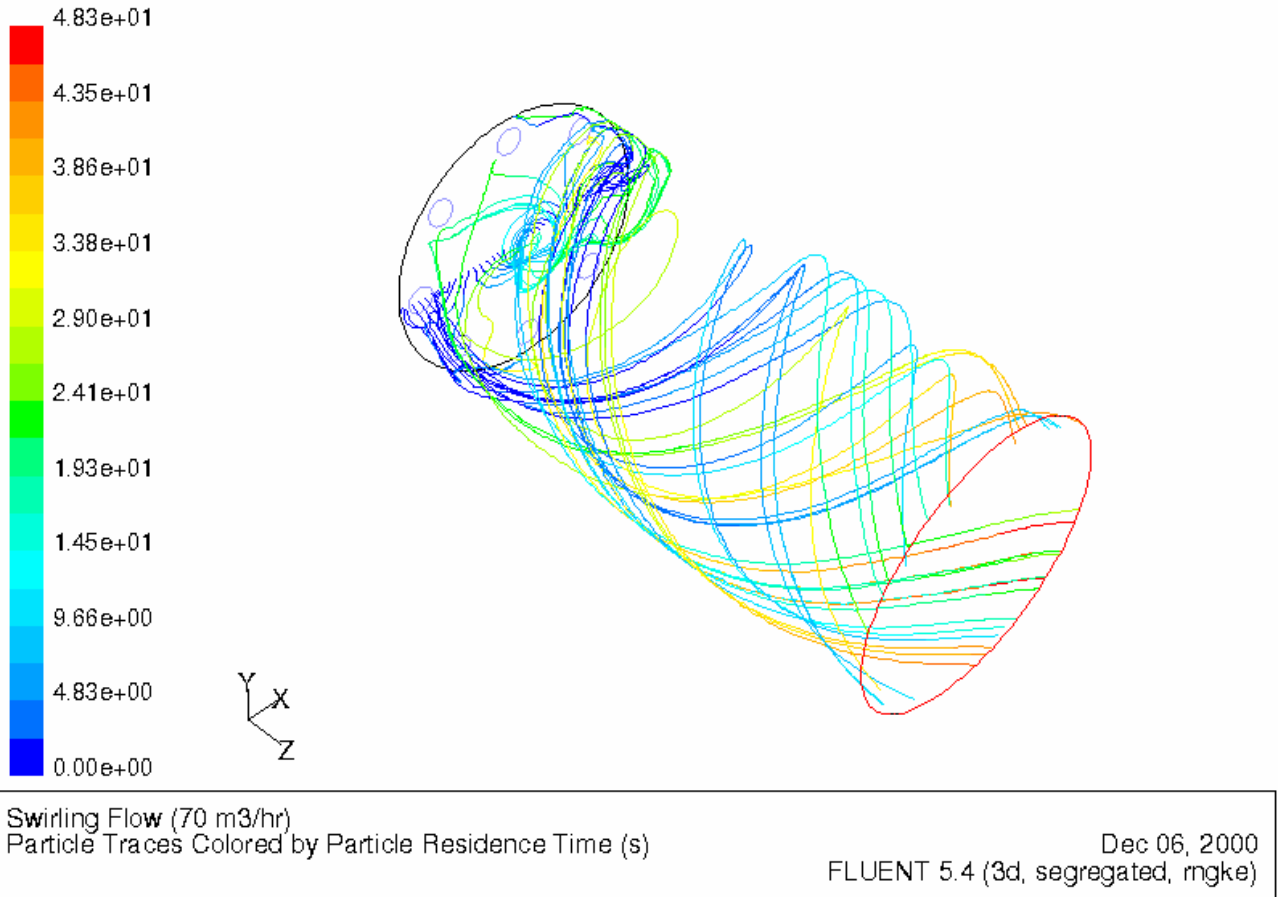


Figure 7: CFD picture showing swirling flow

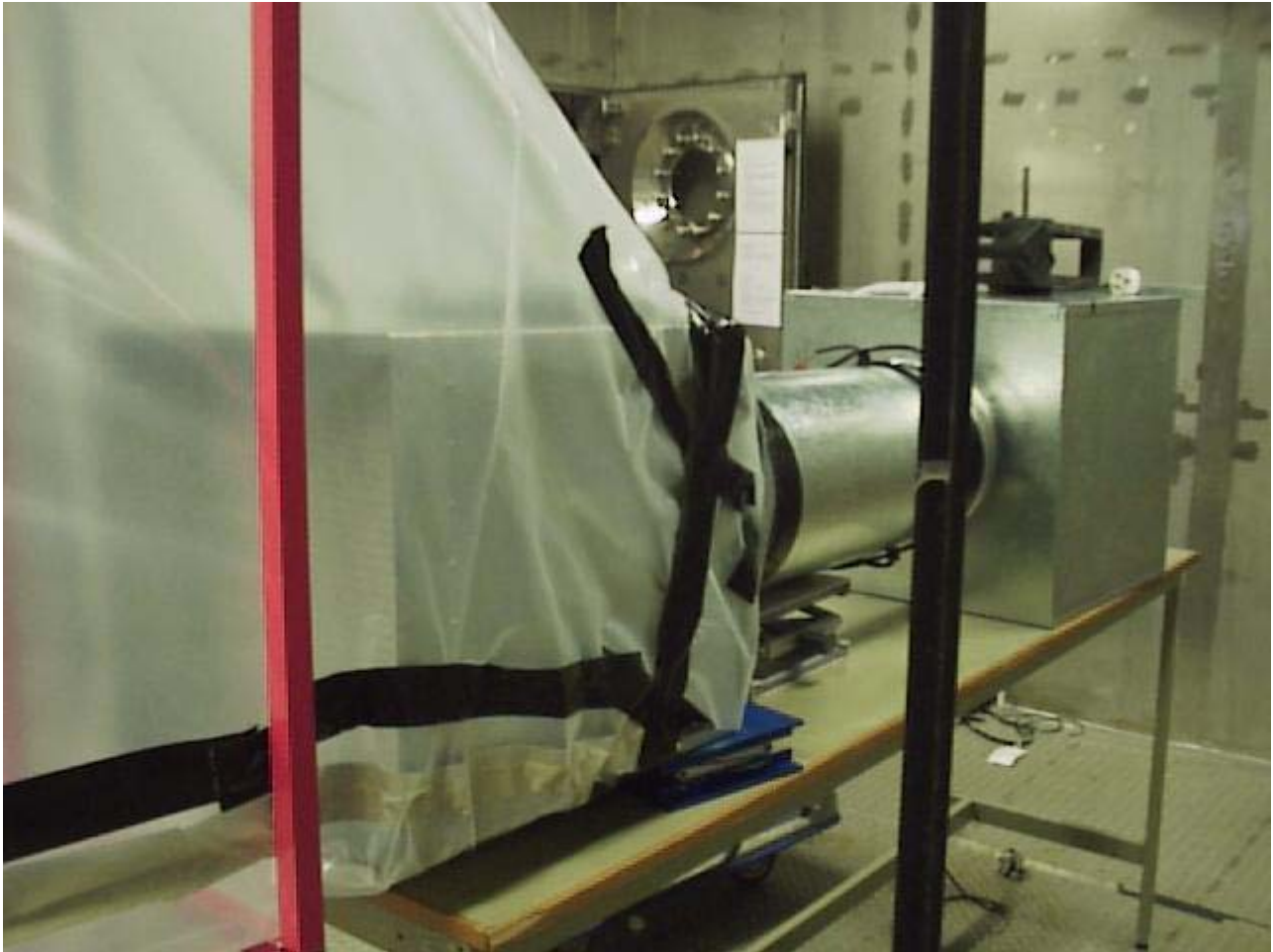
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9 Photographs

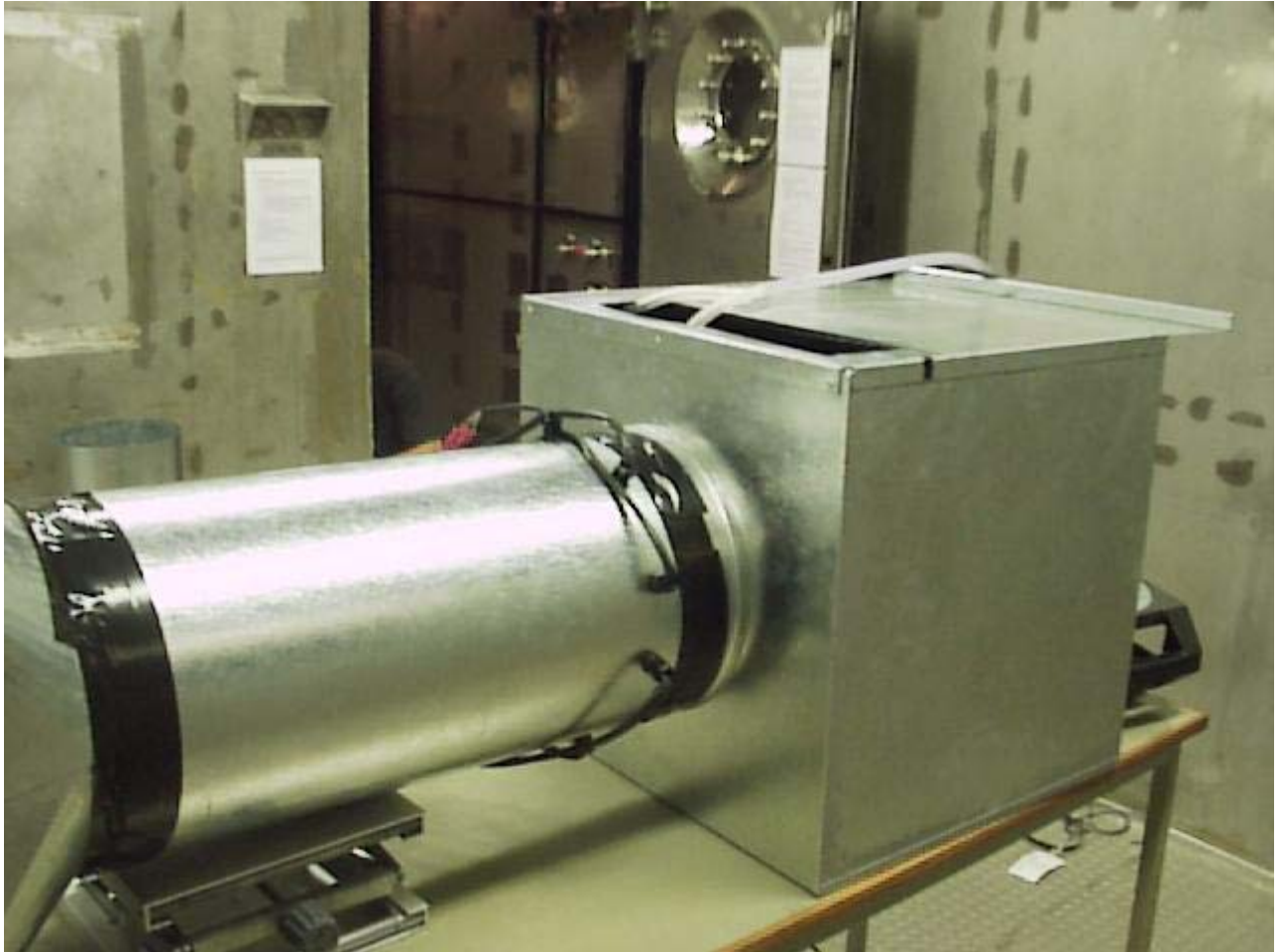


Photograph 1:

Photographs

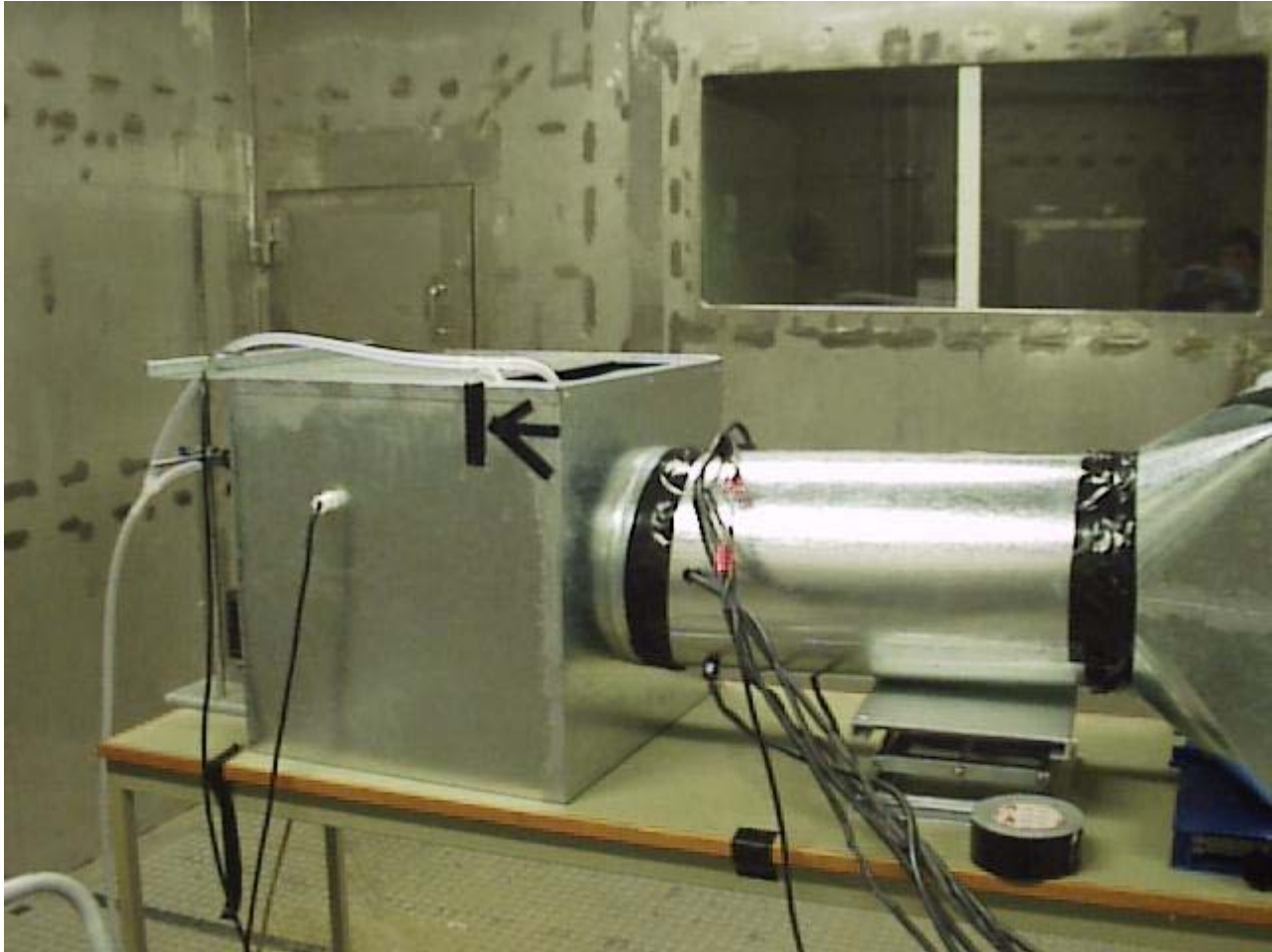


Photograph 2:



Photograph 3:

Photographs

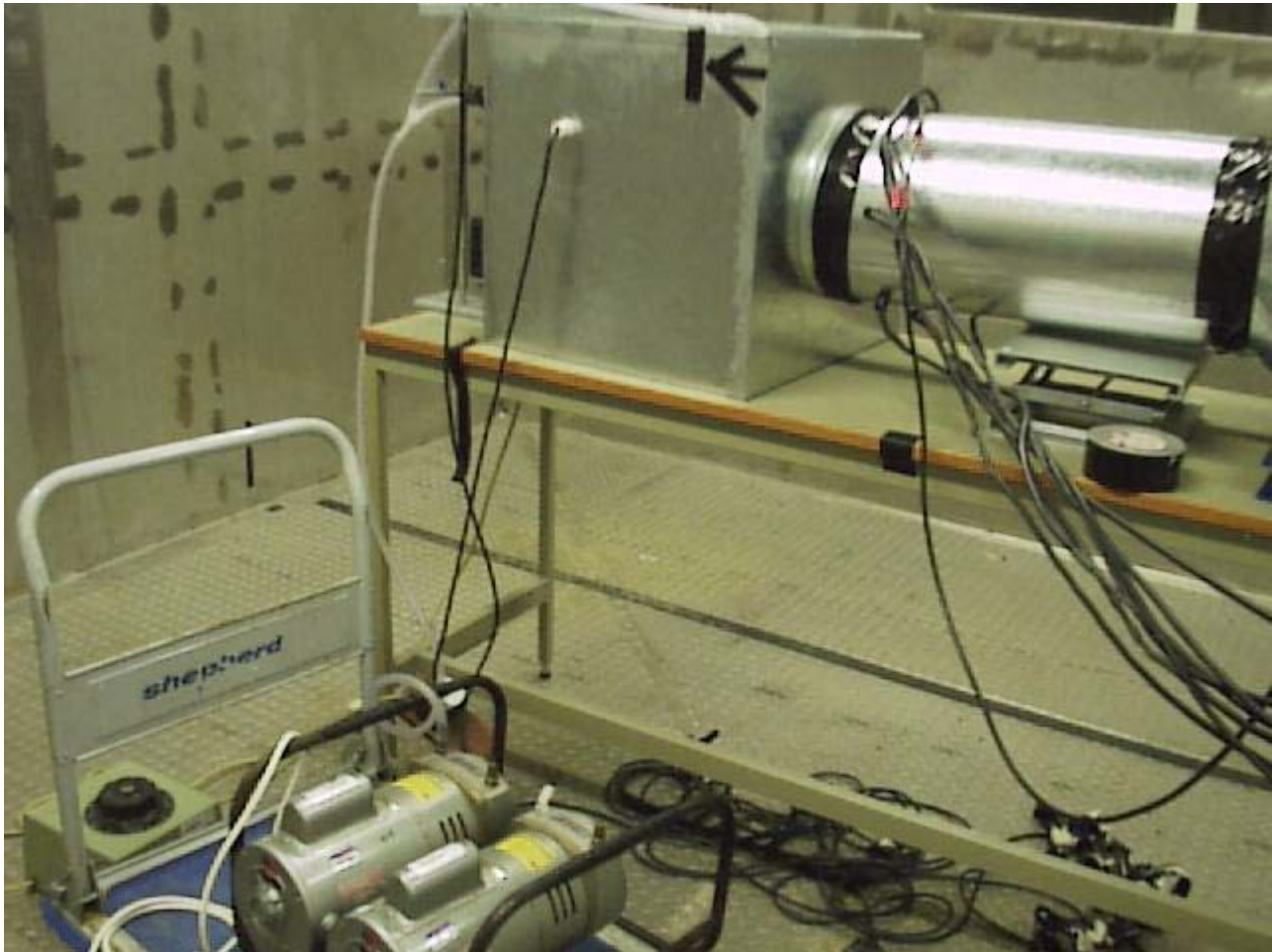


Photograph 4:



Photograph 5:

Photographs



Photograph 6: