Flow Characteristics of the Dyson Air Multiplier

December 7, 2014
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Abstract

In this CFD report, the fluid physics of the Dyson Air Multiplier is simulated using Ansys Fluent (ver. 14.5.7). The purpose of the simulation is to demonstrate the governing air flow phenomena inducement, entrainment, and air loop amplification, and to study the theoretical performance characteristics of the Dyson Air Multiplier. The model parameters used in the simulation are based on an acquired real copy of the product, which gives rise to not only qualitative, but also quantitative comparisons between the simulated and the real performance. In the industry, this kind of prototype-simulation coupling is termed SDPD (simulation driven product development) and can greatly reduce costly investments and speed up the R&D phase of product development.

Keywords: CFD, inducement, entrainment, air multiplication, loop amplification, SDPD.

1 Introduction and motivation

The Dyson Air Multiplier (depicted in figure 1.1) is a ventilating fan with no external blades. It consists of a cylindrical base stand, in which the electric motor and internal blades draw in air. The base supports an approx. 30 cm diameter hollow airfoil-shaped ring with a 1.3 mm narrow slit (jet nozzle).

Dyson claims that the suction system in the base stand can produce an input air flow of 20 litres per second[1], meaning a velocity of approximately 1.2 m/s considering the cross-sectional area of the base. The air is then forced through the inner volume of the hollow airfoil ring. In order for the fan to effectively "multiply" (amplify) the air flow, it needs to draw in air from behind the fan. This suction, also called inducement, is obtained by accelerating the input air flow by use of the narrow jet nozzle and a loop amplifier[1] so that the air is rushed over the airfoil. This generates a low pressure in the the volume encapsulated by the airfoil.

\[1\] Mechanical curvature that accelerates fluid motion
airfoil ring that sucks in the air from behind the fan. Actual measurements show that the velocity of the jet of air at the nozzle is approx. 24 m/s[3]. This fact is used as a validation reference in the forthcoming simulations. In addition, air surrounding the cylindrical output flow produced by the fan is accelerated and carried along due to viscous shearing. This effect is also termed entrainment. The total air flow amplification is claimed to be approx. 15 times[4], mimicking the output flow of a traditional fan.

The purpose of this report is to study the flow characteristics of the Air Multiplier. E.g. where does turbulence arise, and to what extend? Turbulence is a known source of acoustic noise problems, and is thus desired to be minimized. Depending on the flow type, several appropriate simulation models exist (e.g. $k - \varepsilon$, $k - \omega$, laminar). This report gives a brief overview of the significant differences in the results when changing between these models. The actual functionality of the Air Multiplier is a combination of the reach of the fan and the magnitude of the flow that it can produce. Thus, by use of simulations, the reach and the center-axis air velocity (at maximal inlet air velocity) are estimated and compared to empirical observations\textsuperscript{2}. The near-field/far-field characteristics of the fan are briefly studied, and so are the effects of inducement and entrainment.

In the industry, this kind of SDPD (simulation driven product development) is a prototype-simulation-prototype iteration approach to product development. This can in many cases reduce costly research investments and increase vital knowledge about the working physics\textsuperscript{[2],[5]}.

2 Simulation methods

The geometry for simulating the Dyson Air Multiplier is the airfoil-shaped ring, that is shown in the left of figure 2.1, and the base cylinder is not taken into account. The ring is created from an airfoil-shaped 2D sketch that is also shown in the left of figure 2.1. This 2D sketch is then revolved $360^\circ$ with respect to a center axis (17.5 cm offset in the $y$-direction) in order to get the shape of a ring. The narrow jet nozzle and the flow inlet can be seen in the figure. All the other sides and edges in the geometry are defined as no-slip walls.

![Figure 2.1: 3D geometries in the upper part and 2D geometries in the lower part. Left: Geometries without mesh. Right: Geometries with mesh.](image)

\textsuperscript{2}Accurate measurement equipment are not available, so results throughout the paper are rough estimates.
The right side of figure 2.1 shows the 3D and 2D geometries including mesh. The mesh is a mix of tetrahedrals and quadrilaterals, and in the far-field of the fan the mesh is structured by using Mapped Face Meshing. The resolution of the mesh is higher close to the fan due to the relatively small dimensions, and since turbulence is expected here.

When simulating the flow from the fan, air is used as the medium, where \( \rho = 1.225 \text{ kg/m}^3 \) and \( \mu = 1.7894 \cdot 10^{-5} \text{ kg/ms} \) are density and dynamic viscosity, respectively.

For solution initialization, the standard initialization method is used together with the default settings, and the initialization is done by using initial values from the inlet. Velocities in \( x, y \) and \( z \) directions are defined as -2, 0 and 0 m/s, respectively, in correspondence with empirical results (the jet speed has to be approx. 24 m/s).

\( k-\varepsilon \) and \( k-\omega \) models are used as turbulent viscous models, and their Turbulent Dissipation Rates are \( 0.1386289 \text{ s}^{-1} \) and \( 102.688 \text{ s}^{-1} \), respectively. In both of the models the Turbulent Kinetic Energy is \( 0.015 \text{ m}^2/\text{s}^2 \).

The boundaries of the simulation are defined by a box with symmetry boundary conditions. Other boundary conditions such as pressure outlet and wall have been studied, but the most reliable results (compared to reality) are obtained with the symmetry conditions.

The criteria of convergence is defined as \( 10^{-3} \) for all simulation variables.

### 3 Simulation results

In figure 3.1 velocity contour plots in the \( xy \)-plane of the 3D geometry are shown. The simulation result to the left is for the \( k-\varepsilon \) turbulence model while the result to the right is for the \( k-\omega \) turbulence model. The velocity range is \([0.5 \text{ m/s} , 5 \text{ m/s}]\).

![Figure 3.1: Velocity contour plot in \( xy \)-plane of 3D geometry simulation. Left: \( k-\varepsilon \) model. Right: \( k-\omega \) model. Velocity range \([0.5 \text{ m/s} , 5 \text{ m/s}]\).](image)

Both turbulence models successfully predicts the behaviour of the fan, and the rear induction is particularly pronounced. It is seen how air from behind the fan is drawn into the ring and exits in a cylindrical-like shape that slowly expands as a function of distance from the fan. Both models predict an elliptical area, approx. 20 cm from the ring exit, with lower flow velocity. This phenomenon is also observed empirically. The two models differ slightly in the shape of the rear air suction. Compared with similar simulations found in other articles,[3] (see also appendix for more figures), the \( k-\varepsilon \) model seems to have the highest correlation. However, the magnitude of velocity in the \( k-\omega \) model has the highest correlation.

In the far-field of the fan (that is, a distance of 60 cm from the fan exit), when the air flow seems to be homogeneous, the center-axis velocity can be estimated to approx. 2.5 m/s through a cross-sectional area (in the \( yz \)-plane) of approx. \( A = (0.25 \text{ m})^2 \cdot \pi = 0.196 \text{ m}^2 \). This corresponds to an output flow of \( \phi_{\text{out}} = 2.5 \text{ m/s} \cdot 0.196 \text{ m}^2 = 0.49 \text{ m}^3/\text{s} \). Dividing this number by the assumed input flow of \( \phi_{\text{in}} = 20 \text{ litres per second} \) yields an air multiplication of approx.

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[3]Reynold’s number is approx. 3000 in the jet nozzle due to high velocity

[4]High velocities are omitted as they are only occurring in the jet stream near the nozzle
24, which is higher than the claimed value of 15 from Dyson[4]. However, it is not known how Dyson calculates their air flow amplification, and the errors in the above simulations are unknown as well.

![Figure 3.2: Velocity vector plot showing the inducement behind the Dyson fan. Left: $k - \varepsilon$ model. Right: $k - \omega$ model. Velocity range [0.5 m/s , 6 m/s].](image)

In figure 3.2 the air suction behind the fan is shown for the $k-\varepsilon$ and $k-\omega$ turbulence model, respectively. The former model predicts somewhat higher inducement velocities (approx. 19 % higher than the $k - \omega$ model), but otherwise, there is a good, qualitative correlation of the fan behaviour between the two turbulence models.

Another view of the directional air flow is achieved by using particle pathlines from a rake in the $xy$-plane. See figure 3.3. This clearly shows the air flow amplification and the suction of air from the back.

![Figure 3.3: Particle pathline plot showing the inducement behind the Dyson fan. Left: $k - \varepsilon$ model. Right: $k - \omega$ model. Velocity range [0.5 m/s , 6 m/s].](image)

Another key selling point of the Dyson Air Multiplier is the low noise produced by the fan due to minimal occurrence of turbulence. A traditional fan with visible blades ”chops” the air around it resulting in pulses of turbulent air. As seen in figure 3.4, some turbulence exists near the jet nozzles, while the cylindrical output flow is relatively steady.

![Figure 3.4:](image)

Finally, the reach of the fan is estimated by simulation (figure included in appendix) to approximately 2.5 meters, which is not in good correspondence with empirical results of 10 meters. This behaviour has not been studied more thoroughly, and may be subject to future studies. Besides the $k - \varepsilon$ and $k - \omega$ models, also the mathematically more simple laminar model has been evaluated, only to prove itself unsatisfactory for this simulation problem. Velocity vectors are divergent, and does not outline the general behaviour of the fan.
Discussion and conclusion

It has successfully been shown that simulations using the $k-\varepsilon$ and $k-\omega$ turbulent models qualitatively predict the behaviour of the Dyson Air Multiplier. The fluid flow phenomena, inducement and enstrainment, are clearly observed. The $k-\varepsilon$ model shows greater air suction velocities than the $k-\omega$ model, and also the shapes differ slightly. An estimation of the far-field flow velocity is 2.5 m/s through a homogeneous circular cross-section. This gives an air amplification of approx. 24, whereas Dyson claims an amplification of 15. The simulation models fail to predict the reach of the fan (2.5 m compared to 10 m observed in reality). The 2D geometry is estimated from sketches of the real geometry, and from here such errors might originate. The inlet velocity is kept at 2 m/s to satisfy the flow over the airfoil of approx. 24 m/s. The real turbulent circumstances inside the airfoil are unknown, but the simulations show turbulence around the jet nozzle. In the far-field of the fan, however, the flow is relatively laminar, which holds up to what Dyson claims. In a steady state simulation it can be problematic to use wall boundary conditions. Symmetry and pressure outlet boundary conditions are used in order to get the steady state solution.

References

Appendix

Figure 5.1 shows the reach of the fan when using the $k - \varepsilon$ turbulence model. The output flow is terminated approximately 2 - 2.5 meters after the fan exit.

Excerpt from patent application of the airfoil construction:

Figure 5.2: Excerpt from patent application of the airfoil construction. Sketch has been used as a basis for the simulation geometry in combination with physical measurements on the real product.
Figure 5.3: Similar simulations performed by others. Contours are used to compare qualitatively with own results. Source: www.gadgetreview.com/2011/08/dyson-air-multiplier-review

Figure 5.4: Similar simulations performed by others. Pathlines are used to compare qualitatively with own results. Source: http://www.symscape.com/newsletters/march-2012