True-Scale Testing
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From: Sample, Student Engineer

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Subject: Results of performance tests on prototype blower and scaled results for miniature version

INTRODUCTION

The Real Blowers, Inc., has received an urgent request from NASA to determine if miniature blowers could be used to cool circuitry on their spacecrafts. Due to the tight time constraints, you have asked us to test and analyze the performance of an existing large prototype blower and scale the results to the needs of NASA. Specifically, you have asked that we determine the dependence of the pressure rise on blower speed and flow rate, determine how the flow rate affects the head coefficient and efficiency, and determine what flow rate would be possible from a blower operating at the same speeds as tested, but with a diameter of 1 inch rather than 5 inches. We have completed these tasks. The purpose of this report is to provide the results, conclusions, and supporting documentation of our tests on your large prototype blower, and to provide the scaled down performance for NASA's requested miniature blowers.

We have found all of the requested information on the dependency of the pressure rise across the blower on blower speed and flow rate, the effect flow rate has on head coefficient and efficiency, and the maximum flow rate possible through a 1 inch blower of the same configuration as the tested unit. The pressure rise initially increases with increasing flow rate, peaks, and then decreases. Increasing blower rotation speed also results in the pressure rise increasing. The head coefficient initially increases with flow coefficient, reaches a peak, and then decreases. Blower efficiency increases with flow coefficient. The maximum achievable flow rate in a 1 inch impeller diameter blower is 858 ± 31 cm^3/s. A sampling of calculated values can be seen in Table 1 below.

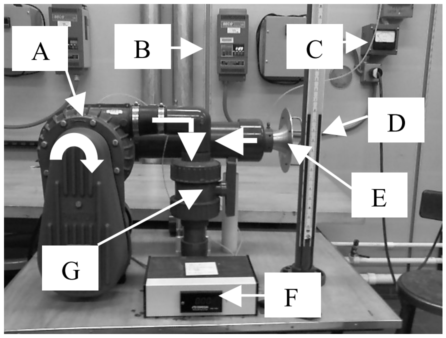
Table 1: Sample of calculated system values and their relation to blower rotation speed

Blower rotation speed (rad/s)	986.5 ± 1.4	1315.3 ± 1.4	1644.1 ± 1.4	Trend
Max. Flow Rate (m^3/s)	0.065 ± 0.002	0.086 ± 0.001	0.107 ± 0.001	Increases with rotation speed
Max.Pressure Rise (Pa)	3171.6 ± 34.5	5722.6 ± 34.5	9032.1 ± 34.5	Increases with rotation speed
Max. Head Coef. (Dimensionless)	0.180 ± 0.002	0.183 ± 0.001	0.184 ± 0.001	No dependence on rotation speed Values equal within error
Max. Efficiency (Dimensionless)	0.879 ± 0.077	0.882 + 0.118/-0.127	0.841 + 0.159/-0.191	No dependence on rotation speed Values equal within error

METHODS

The Real Blowers, Inc. provided us with a large prototype blower consisting of a Paxton Model RM-80-C centrifugal blower powered by 3 H.P. U.S. Electrical Motors ID# R03P2580294F 3-phase motor. We powered this unit with a Seco AC adjustable speed drive power supply. A Dwyer water manometer, (in inches of water), an Omega digital pressure gauge process indicator (in psi), and a Simson model 59 ammeter (in amps) were used for measuring appropriate values needed for analysis. The primary components of the system can be seen in Figure 1 below.

Figure 1: System schematic showing components and flow of laboratory set-up



A – Blower
B – Power supply
C – Ammeter
D – Water Manometer
E – Flow Horn/Air Inlet
F – Digital Pressure Gauge
G – Flow Valve
* Arrows on pipes indicate direction of air flow

Before starting the system, we made sure that the power supply frequency was set to no greater than 10 Hz in the forward direction. We then set the flow valve to the open position and turned the blower unit on. We then adjusted the power supply frequency to 30 Hz, and began to record data. Specifically, we recorded the pressure reading by the manometer, (which gives the pressure drop across the flow horn), the digital pressure reading, (which gives the pressure gain across the blower), and the current from the ammeter. These recordings were taken at 5 different flow rates, which were chosen based on varying positions of the flow valve, (open, 22.5 degrees, 45 degrees, 67.5 degrees, and closed.) At a given power frequency, we measured the values at each valve position and repeated the measurements for a total of 3 times, using the digital pressure gauge as a reference to determine the exact position of where we had previously set the control valve. This process was done for 6 frequencies: 30, 36, 42, 48, 54, and 60 Hz.

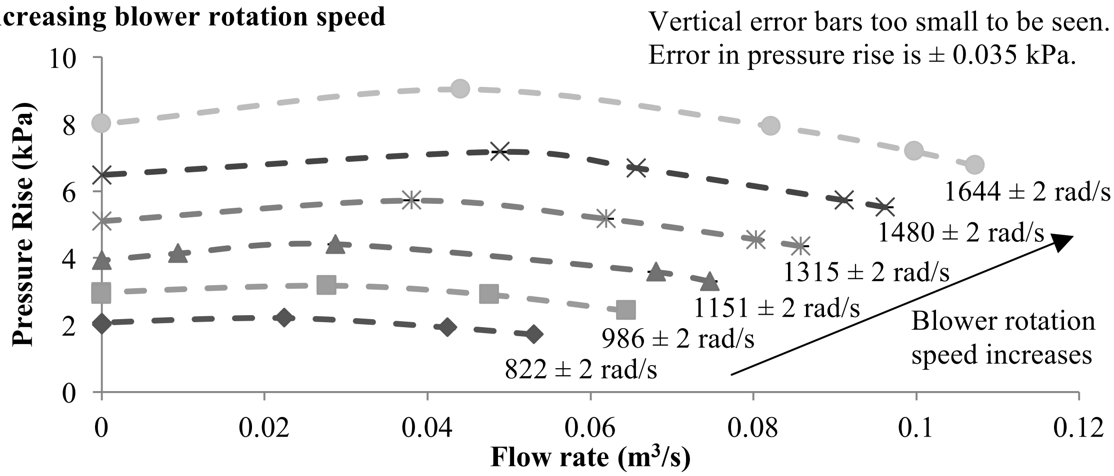
RESULTS

The pressure rise across the blower initially increases with increasing flow rate, reaches a peak, and then decreases as the flow rate continues to increase. Increasing blower rotation speed also results in an increasing pressure rise. The head coefficient initially increases with flow coefficient, then reaches a peak and begins to decrease as flow coefficient increases. Blower efficiency increases with flow coefficient. The maximum achievable flow rate in a 1 inch impeller diameter blower is 858 ± 31 cm^3/s.

Effects of Flow Rate and Blower Rotation Speed on Pressure Rise

We have determined that the pressure rise across the blower initially increases with increasing flow rate, peaks at a moderate flow rate, and then decreases as the flow rate continues to increase. The pressure rise increases with increasing blower rotation speed. These trends can be seen in Figure 2 below.

Figure 2: Pressure rise across blower peaks at moderate flow rate and increases with increasing blower rotation speed



Pressure rise was recorded during testing with the digital pressure gauge component of the system. We found the flow rate (Q) of the air through the measured values of the pressure difference across the flow horn (P_1), the ambient pressure (T_{amb}), and the ambient temperature (P_{atm}). We used the ambient pressure and temperature to calculate the density of the air (ρ) which was then used in Eq. 1 below with R=287.05 $\mathrm{Jkg^{-1}K^{-1}}$. With the density known, we then used Eq. 2 below to find the velocity of the air (V_1) at the 2 inch section of the flow horn. We used this velocity to find the flow rate using Eq. 3 below, where D_1 is the 2 inch diameter of the flow horn. Uncertainty in flow rate was calculated from the uncertainty in V_1, which was primarily the result of resolution error in P_1 and precision error in ρ.

The blower rotation speeds (ω) in rad/s were calculated with Eq. 4 below, with 261.67 being a constant with units of RPM/Hz and f being the frequency of the power supply. Uncertainty in the rotation speeds resulted from the resolution error of the frequency gauge.

$$\rho = \frac{P_{atm}}{RT_{amb}} \quad \textit{Eq. 1} \qquad V_1 = \sqrt{\frac{2P_1}{\rho}} \quad \textit{Eq. 2} \qquad Q = \pi V_1 \left(\frac{D_1}{2}\right)^2 \quad \textit{Eq. 3} \qquad \omega = 2\pi(261.67)\left(\frac{f}{60}\right) \quad \textit{Eq. 4}$$

DISCUSSION
When the data are presented in dimensionless form, with flow coefficient being reported rather than flow rate, all of the data should collapse into one general trend that applies to all scales of the tested system.

Dependence of Head Coefficient and Efficiency on Flow Rate
We have determined that the head coefficient and efficiency both depend on flow rate. The head coefficient initially increases with flow coefficient, then reaches a peak and begins to decrease as flow coefficient increases. Efficiency increases with flow coefficient. These trends can be seen in Figures 3 and 4 below.

Figure 3: Plot shows data for all speeds collapsing into one general head coefficient curve, which increases, peaks, then decreases with flow coefficient

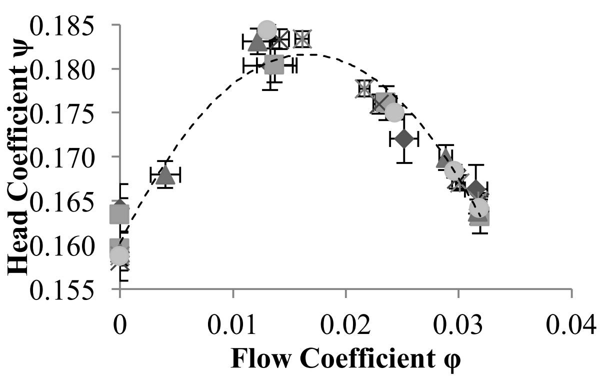
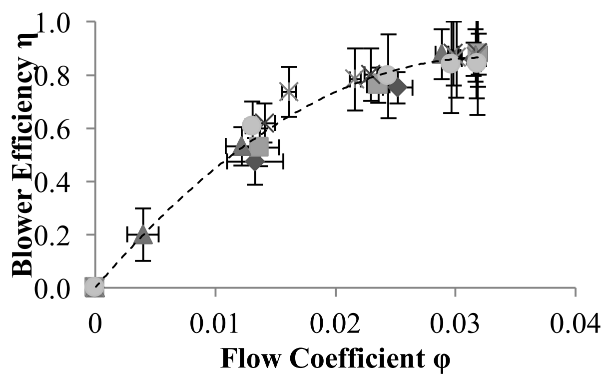


Figure 4: Plot shows data for all speeds collapsing into one general efficiency curve, which increases with flow coefficient



We determined the head coefficients (ψ), efficiencies (η), and flow coefficients (φ) using Eq.'s 5, 6, 7, 8, and 9 below. For Eq. 5, ΔE is the fluid energy rise across the blower, P_{rise} is the pressure increase across the blower, V_3 is the air velocity at the outlet of the blower, and V_2 is the air velocity at the inlet of the blower. In Eq. 6, P is power input, V is voltage, and I is current. Eq. 9 uses the blower impeller diameter, D, which is 5 inches for the tested system.

$$\Delta E = \frac{P_{rise}}{\rho} + \frac{({V_3}^2 - {V_2}^2)}{2} \quad \textit{Eq. 5}\ [1] \qquad P = VI\left(0.5329\left(\frac{f}{60}\right) - 0.0483\right) \quad \textit{Eq. 6}$$

$\psi = \frac{\Delta E}{\omega^2 D^2}$ *Eq. 7* $\eta = \frac{Q\rho\Delta E}{P}$ *Eq. 8* $\varphi = \frac{Q}{\omega D^3}$ *Eq. 9* $\tau = \frac{P}{\rho\omega^3 D^5}$ *Eq. 10* [2]

Uncertainty in ψ, η, and φ was calculated from the respective uncertainties in the variables that they were calculated from. Some of these uncertainties are relatively large due to complex equations with many variables that cause the variable uncertainties to be compounded together in the calculation of overall uncertainty.

Maximum Flow Rate of 1 inch Impeller Diameter Blower

The achievable flow rate for a scaled down version of the blower that we tested was found to be 858 ± 31 cm^3/s. This value was obtained with the assumptions that the new 1 inch diameter blower will be geometrically similar to the tested version, will be large enough so that flows can develop and not be affected by the Reynolds number, and that it is small enough that the Froude number does not affect the flow behavior. With these assumptions, we were able to assume that the η and ψ coefficient values are constant from the tested model to the scaled prototype. In addition, we can assume that the power coefficient (τ) described in Eq. 10 on pg. 3 is constant. Since we know D changes to 1 inch, ρ stays constant, and you have asked us to keep ω constant, we were able to use Eq. 10 to find the new power value and Eq. 9 on pg. 3 to find the new ΔE for the 1 inch blower. With these values, we used Eq. 8 on pg. 3 to find the flow rate for the scaled blower. Uncertainty in this value was calculated through a combination of the associated uncertainties of the variables used in Eq.'s 7, 8, and 10.

CONCLUSIONS

This report examines the blower system provided by The Real Blowers, Inc., with regards to the effect of the flow rate and blower rotation speed on the pressure rise across the blower, the dependence of the head coefficient and efficiency on flow rate, and the maximum flow rate achievable by a scaled down blower with an impeller diameter of 1 inch. We determined that the pressure rise across the blower initially increases with increasing flow rate, peaks at a moderate flow rate, and then decreases. The pressure rise increases with increasing blower rotation speed. These trends can be seen in Figure 2 on pg. 2. We have also determined that the head coefficient and efficiency both depend on flow rate, and that when presented in unitless form, the data collapses and displays general trend curves (see Figures 3 and 4 on pg. 3). Maximum efficiency is achieved at the maximum flow rates for each rotation speed. The maximum flow rate attainable by a 1 inch impeller diameter blower is 858 ± 31 cm^3/s.

REFERENCES

[1] White M., 2008, *Fluid Mechanics*, 6th Edition, Frank McGraw-Hill Companies Inc. New York, NY 10020, pp. 185

[2] White M., 2008, *Fluid Mechanics*, 6th Edition, Frank McGraw-Hill Companies Inc. New York, NY 10020, pp. 765-768