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3

SIMILARITY IN FANS AND FAN LAWS-1

3.1. Similarity Concept

Since the equations of Theoretical Fluid Mechanics are not enough to determine the geometry of flow machines like fans, solutions obtained with different assumptions can only be compared experimentally and the best solution can be chosen in this way. It is economical in all respects to carry out such researches on small-sized models. Moreover, air or other fluids can be used as fluids; Models can also be used with the help of cheap materials such as wood, plaster, cardboard. The characteristic size of the industrial machine can be calculated from the experimental results of the model, which can be found with a sufficient accuracy. The similarity theory that provides this is important in this respect. However, since extensive experimental studies today bring a lot of time and cost, besides the flow analysis made mainly with Theoretical Fluid Mechanics equations, CFD (Computational Fluid Dynamics) where solid and deformed bodies mechanics, and machine theory and dynamics (vibration, noise, mechanical balancing, critical speeds, etc.) can be analyzed very successfully in the computer environment in the design and manufacture of current machines and Structural Analysis Programs have been developed. These techniques, which are based on the solution of basic equations based on experimental data and with the help of computer programs using appropriate physical boundary conditions, are called "Numerical Experiment or Numerical Simulation" in this respect. However, the accuracy of these numerical simulations must be tested in real experimental environments.

3.2. Mechanical Similarity

There are four similarities between two current machines that are mechanically similar to each other at the same time;

1. Geometric Similarity
2. Kinematic Similarity
3. Dynamic Similarity
4. Thermodynamic Similarity

3.2.1. Geometric Similarity

In Figure 2.1, sectional images of **(a)** a real (prototype) fan and **(b)** a model fan wheels are given. Here D'_0, D'_1, D'_2 , b'_1 , b'_2 , R' , k' , ... shows the geometric lengths of the model fan, D_0, D_1 , D_2 , b_1 , b_2 , R , k , ... and the geometric lengths of the real (prototype) fan. Geometric similarity is provided by finding a constant ratio given by the equation (3.1) between the mutual geometric lengths of the two machines.. This constant ratio is called the "geometric similarity ratio" and is indicated by λ. Since the walls that limit flows are similar, wall roughness should be geometrically similar in both machines. If a length k (average roughness height) that can characterize roughness, express its frequency, and curvature radii of curved surfaces are indicated by R;

$$\lambda = \frac{D_0'}{D_0} = \frac{D_1'}{D_1} = \frac{D_2'}{D_2} = \frac{L'}{L} = \frac{b_1'}{b_1} = \frac{b_2'}{b_2} = \frac{R'}{R} = \frac{k'}{k} = \cdots = \text{constant} \qquad (3.1)$$

Must be.

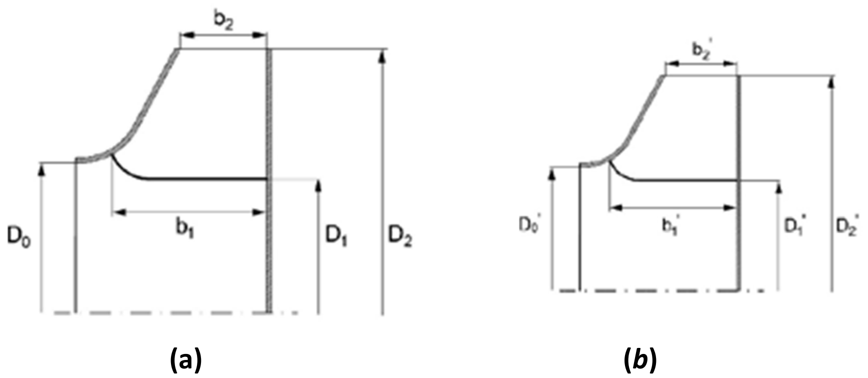


Figure 3.1. Fan wheel section pictures; **(a)** Real **(Prototype)** Fan Wheel and **(b)** Model Fan Wheel.

3.2.2. Kinematic Similarity

If streams in both machines have a constant μ ratio between the same types of speeds or components at the corresponding points in the flows, the streams will be "kinematically similar" and this value is called the kinematic similarity ratio.

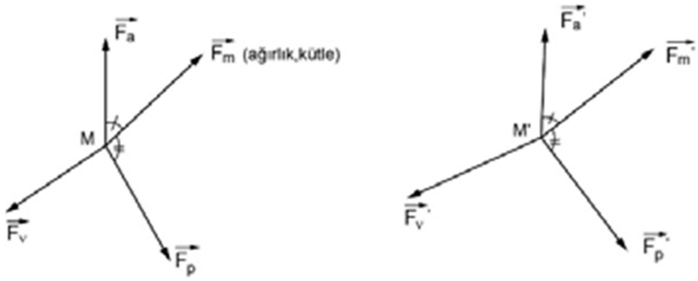
$$\mu = \frac{U_1'}{U_1} = \frac{W_1'}{W_1} = \frac{C_1'}{C_1} = \frac{C_{m1}'}{C_{m1}} = \frac{C_{u1}'}{C_{u1}} = \frac{U_2'}{U_2} = \frac{W_2'}{W_2} = \frac{C_2'}{C_2} = \frac{C_{m2}'}{C_{m2}} = \frac{C_{u2}'}{C_{u2}} = \cdots = \text{constant} \quad (3.2)$$

As such, the velocity triangles at identical points are mutually similar, and their angles are mutually equal.

$$\alpha_1 = \alpha_1' \quad ; \quad \alpha_2 = \alpha_2' \quad ; \quad \beta_1 = \beta_1' \quad ; \quad \beta_2 = \beta_2' \qquad (3.3)$$

3.2.3. Dynamic Similarity

Figure 3.2 shows the forces at **(a)** a real (prototype) fan and **(b)** a model fan at the points that match each other. The requirement of dynamic similarity is that there is a constant ratio between forces at points that are identical to each other. Different forces such as inertia, weight (mass), viscosity (friction), pressure, surface tension, or the dimensionless numbers obtained by appropriately proportioning these forces must be equal in both machines.



(a) **(*b*)**

Figure 3.2. The forces at **(a)** real (prototype) fan and **(b)** model fan at the same points.

$$\frac{F_a'}{F_a} = \frac{F_m'}{F_m} = \frac{F_p'}{F_p} = \frac{F_v'}{F_v} = \cdots = sabit \tag{3.4}$$

there is a dynamic similarity. By measuring the forces in the above equations, dimensionless number equations known as follows can be obtained.

$$\frac{F_a}{F_v} = \frac{F_a'}{F_v'} \Rightarrow Re = Re' \Rightarrow Re = \frac{VL}{\nu} = Re' = \frac{V'L'}{\nu'} \tag{3.5}$$

$$\frac{F_p}{F_a} = \frac{F_p'}{F_a'} \Rightarrow Ne = Ne' \Rightarrow Ne = \frac{\Delta P}{\rho V^2} = Ne' = \frac{\Delta P'}{\rho' V'^2} \tag{3.6}$$

$$\frac{F_a}{F_m} = \frac{F_a'}{F_m'} \Rightarrow Fr = Fr' \Rightarrow Fr = \frac{V^2}{gL} = Fr' = \frac{V'^2}{g'L'} \; veya \; \frac{V}{\sqrt{gL}} = \frac{V'}{\sqrt{g'L'}} \tag{3.7}$$

$$\frac{F_a}{F_\sigma} = \frac{F_a'}{F_\sigma'} \Rightarrow We = We' \Rightarrow We = \frac{\rho V^2 L}{\sigma} = We' = \frac{\rho' V'^2 L'}{\sigma'} \tag{3.8}$$

$$\frac{F_a}{F_E} = \frac{F_a'}{F_E'} \Rightarrow Ma = Ma' \Rightarrow Ma = \frac{V}{a} = Ma' = \frac{V'}{a'}; \dots \dots \dots \dots \dots \tag{3.9}$$

If the fluids are incompressible (as in hydraulic machines and fans where the compressibility effects are often negligible because Ma < 0.122 or v < 40 m/s), Mach numbers do not need to be equal, so there is no need for Mach similarity.

In order to ensure full similarity in Flow Machines, the following equations should be provided.

1. Re = Re ’⇒ Reynolds Similarity (important in pressurized flows such as closed ducts, pipes etc.)
2. Ne = Ne’⇒ Newton Similarity (important in pressurized flows / fans and hydraulic machines)
3. Fr = Fr’⇒ Froude Similarity (important for free surface flows)
4. Ma = Ma⇒ Mach Similarity (important in compressible flows)

However, it is impossible to achieve full similarity. For example, both Re and Fr similarities cannot be achieved at the same time.

$$Re = Re' \Rightarrow \frac{VL}{\nu} = \frac{V'L'}{\nu'} \qquad ve \quad Fr = Fr' \Rightarrow \frac{V^2}{gD} = \frac{V'^2}{g'D'} \tag{3.10}$$

If g = g ’ is accepted,

$$\frac{V'^2}{V^2} = \frac{D'}{D} \quad ; \quad \frac{V'}{V} = \frac{D}{D'}\frac{\nu}{\nu'} \quad \Rightarrow \frac{D'^3}{D^3} = \frac{\nu''^2}{\nu'^2} \tag{3.11}$$

$$\lambda = \frac{D'}{D} = \left[\left(\frac{\nu'}{\nu}\right)^2\right]^{\frac{1}{3}} \tag{3.12}$$

Since λ ≠ is 1, it will be ν'≠ ν, meaning that the same type of fluid cannot be used in two machines, or if one of them will work with water and the other air, the geometric similarity ratio cannot be chosen well.

In fans, Fr and Ma similarities are neglected. In order to ensure similarity in fans, it is necessary to provide Re and Ne similarity. If the Re number is too large, the Re similarity is also neglected (assumed to be achieved). Thus, it remains only to provide Ne similarity for similarity.

3.2.4. Thermodynamic Similarity

The requirement of thermodynamic similarity is that there is a constant ratio between absolute temperatures at points that are identical. So;

$$\frac{T_1'}{T_1} = \frac{T_2'}{T_2} = \frac{T_3'}{T_3} = \frac{T_4'}{T_4} = \cdots = \text{constant} \tag{3.13}$$

there is a thermodynamic similarity.

3.3. Partial Similarity

While it is impossible to fully provide the geometric similarity of the surface roughnesses, the conditions of dynamic similarity cannot be met at the same time. Some similarities (which have little or no effect) are discarded, depending on the situation of the event. Therefore, partial similarity is achieved. For example, Mach similarity can be omitted in hydraulic machines and fans where compressibility effects are often negligible, since the Mach number is very small (Ma <0.122 or V <40 $m\ /\ s$). In the absence of free surface flows, Froude and Weber similarities do not matter. In this case, providing Reynolds and Newton similarities in the fans is considered sufficient to provide dynamic similarity.

According to the experiments of Nikuradse, the constant load loss coefficient in very large Re numbers does not depend on the Re number and only relative roughness depends on $k\ /\ D$. In these cases or in cases where the number of Re is the same in both fans, it will be sufficient to ensure that the Newtonian similarity is sufficient since Re similarity will already be achieved. Thus, even if the surface roughness is not exactly alike, if the geometrical similarity λ and Newtonian similarity is achieved in the remaining issues, the two fans are considered to be “approximately similar” to each other, and this type of similarity is called “partial similarity” and similarity relations are applied as if there were exact similarity. Errors arising from this are either very small, or the results are corrected by appropriate empirical (experimental) relations.

In fact, if it is necessary to ensure the similarity of Re, it may not be possible most of the time. For example, if two fans will operate with the same fluid (ν '= ν), the equation of Re numbers;

$$\frac{VD}{\nu} = \frac{V'D'}{\nu'} \qquad \text{or} \qquad \lambda = \frac{D'}{D} = \frac{V}{V'} = \frac{1}{\mu} \tag{3.14}$$

In order to meet such a condition, a model fan wheel with a scale of λ = 1/5 must be tested under a speed of 25 times the industrial fan and a pressure head of 25 times again!

3.4. Fan Laws (Fan Similarity Relations)

The questioning of the validity of the laws called "Fan Laws or Fan Similarity Relations" may seem like a contradiction to many fan engineers. These laws, in many well-defined situations, are actually close approximations, although they are quite close approximations. Since these laws are widely used without questioning or interpretation, it seems appropriate to take a look at their derivatives. Considering the performance of a fan series, it is clear that they can be made in a geometrically similar size range and can be operated with an infinite number of rotating speeds. Fans can also work with gases or air with variable physical properties, such as temperature, humidity, density, viscosity, and specific temperatures. Since it will be impossible for the manufacturer to test the fans under all these changing conditions, it will be possible to estimate the performance of a fan series by using the fan laws and the performance of one fan's rotation speed and change in gas conditions.

3.4.1. Similarity Rate for Fan Head Heights:

The size of the model fan is exponential, the size of the real (prototype) fan is exponential and the fan's suction (inlet) mouth index is indicated by the pressure (outlet) mouth and the index of three, the energy in the form of the energy gained by the unit weight of the fluid between the fan outlet and the inlet. By using the definition of Head of Head;

$$\frac{H'}{H}=\frac{\left[Z_{ç}'+\frac{P_{ç}'}{\gamma'}+\frac{V_{ç}'^{2}}{2g}\right]-\left[Z_{g}'+\frac{P_{g}'}{\gamma'}+\frac{V_{g}'^{2}}{2g}\right]}{\left[Z_{ç}+\frac{P_{ç}}{\gamma}+\frac{V_{ç}^{2}}{2g}\right]-\left[Z_{g}+\frac{P_{g}}{\gamma}+\frac{V_{g}^{2}}{2g}\right]} \tag{3.15}$$

can be written. If piezometric pressures at the inlet of the model and real (prototype) fan are also defined as exponential,

$$\frac{P_{g}'^{*}}{\gamma'}=\left[Z_{g}'+\frac{P_{g}'}{\gamma'}\right] \quad ve \quad \frac{P_{g}^{*}}{\gamma}=\left[Z_{g}+\frac{P_{g}}{\gamma}\right] \tag{3.16}$$

$$\frac{P_{ç}'^{*}}{\gamma'}=\left[Z_{ç}'+\frac{P_{ç}'}{\gamma'}\right] \quad ve \quad \frac{P_{ç}^{*}}{\gamma}=\left[Z_{ç}+\frac{P_{ç}}{\gamma}\right] \tag{3.17}$$

$$\frac{\Delta P_{ç}'^{*}}{\gamma'}=\frac{P_{ç}'}{\gamma'}-\frac{P_{g}'^{*}}{\gamma'}=\left[Z_{ç}'+\frac{P_{ç}'}{\gamma'}\right]-\left[Z_{g}'+\frac{P_{g}'}{\gamma'}\right] \tag{3.18}$$

$$\frac{\Delta P_{ç}^{*}}{\gamma'}=\frac{P_{ç}^{*}}{\gamma}-\frac{P_{g}^{*}}{\gamma}=\left[Z_{ç}+\frac{P_{ç}}{\gamma}\right]-\left[Z_{g}+\frac{P_{g}}{\gamma}\right] \tag{3.19}$$

is written and the magnitude of the kinetic energy of the unit weight of fluid in the outlet at the outlet is neglected besides the size of the inlet, $\left(\frac{V_{g}'^{2}}{2g}\ll\frac{V_{ç}'^{2}}{2g}\right);\left(\frac{V_{g}^{2}}{2g}\ll\frac{V_{ç}^{2}}{2g}\right)$ If equation (3.15) is arranged,

$$\frac{H'}{H}=\frac{\left[\frac{P_{ç}'^{*}}{\gamma'}+\frac{V_{ç}'^{2}}{2g}\right]-\left[\frac{P_{g}'^{*}}{\gamma'}\right]}{\left[\frac{P_{ç}^{*}}{\gamma}+\frac{V_{ç}^{2}}{2g}\right]-\left[\frac{P_{g}^{*}}{\gamma}\right]}=\frac{\frac{V_{ç}'^{2}}{2g}\left[2\frac{\Delta P_{ç}'^{*}}{\rho' V_{ç}'^{2}}+1\right]}{\frac{V_{ç}^{2}}{2g}\left[2\frac{\Delta P_{ç}^{*}}{\rho V_{ç}^{2}}+1\right]} \tag{3.20}$$

is obtained.

For the prototype and model fans, when Ne Newton similarity is provided at the output of the machine since it wil be;

$$Ne_{ç}=\frac{\Delta P_{ç}^{*}}{\rho V_{ç}^{2}}=Ne_{ç}'=\frac{\Delta P_{ç}'^{*}}{\rho' V_{ç}'^{2}} \tag{3.21}$$

$$\frac{H'}{H}=\frac{\frac{V_{ç}'^{2}}{2g}}{\frac{V_{ç}^{2}}{2g}} \tag{3.22}$$

and kinematic similarity ratio, Since it is defined as;

$$\mu=\frac{V_{ç}'}{V_{ç}}=\frac{V_g'}{V_g} \tag{3.23}$$

thus, the proportionality of the head to the fans, obtained as;

$$\frac{H'}{H}=\left(\frac{V_{ç}'}{V_{ç}}\right)^2=\left(\frac{V_g'}{V_g}\right)^2=\left(\frac{V'}{V}\right)^2=\mu^2 \tag{3.24}$$

3.4.2. Similarity Rate for Fan Total Pressures:

Using fan total pressure definition,

$$\frac{\Delta P_t{}'}{\Delta P_t}=\frac{P_{tf}{}'}{P_{tf}}=\frac{\left[P_{ç}{}'+\frac{1}{2}\rho' V_{ç}'^{2}\right]-\left[P_g{}'+\frac{1}{2}\rho' V_g'^{2}\right]}{\left[P_{ç}+\frac{1}{2}\rho V_{ç}^{2}\right]-\left[P_g+\frac{1}{2}\rho V_g^{2}\right]} \tag{3.25}$$

can be written and

$$\Delta P_{ç}'=P_{ç}'-P_g' \quad ve \quad \Delta P_{ç}=P_{ç}-P_g \tag{3.26}$$

by defining the size of the kinetic energy of the unit weight of fluid in the outlet mouth as well as the size of the inlet mouth, $\left(\frac{1}{2}\rho' V_g'^{2}\ll\frac{1}{2}\rho' V_{ç}'^{2}\right);\left(\frac{1}{2}\rho V_g^{2}\ll\frac{1}{2}\rho V_{ç}^{2}\right)$ if the equation is arranged;

$$\frac{\Delta P_t{}'}{\Delta P_t}=\frac{P_{tf}{}'}{P_{tf}}=\frac{(P_{ç}{}'-P_g{}')+\frac{1}{2}\rho' V_{ç}'^{2}}{(P_{ç}-P_g)+\frac{1}{2}\rho V_{ç}^{2}}=\frac{\Delta P_{ç}'+\frac{1}{2}\rho' V_{ç}'^{2}}{\Delta P_{ç}+\frac{1}{2}\rho V_{ç}^{2}}=\frac{\frac{1}{2}\rho' V_{ç}'^{2}\left[2\frac{\Delta P_{ç}'}{\rho' V_g'^{2}}+1\right]}{\frac{1}{2}\rho V_{ç}^{2}\left[2\frac{\Delta P_{ç}}{\rho V_g^{2}}+1\right]} \tag{3.27}$$

is found. For the prototype and model fans, when Ne Newton similarity is provided at the output of the machine;,

$$Ne_{ç}=\frac{\Delta P_{ç}}{\rho V_{ç}^{2}}=Ne_{ç}{}'=\frac{\Delta P_{ç}'}{\rho' V_{ç}'^{2}} \tag{3.28}$$

and also according to kinematic similarity,

$$\frac{V_g'}{V_ç'} = \frac{V_g}{V_ç} \tag{3.29}$$

similarity ratio of total pressures for fans, obtained as;

$$\frac{\Delta P_t{}'}{\Delta P_t} = \frac{P_{tf}{}'}{P_{tf}} = \frac{\rho'}{\rho}\left(\frac{V_ç'}{V_ç}\right)^2 = \frac{\rho'}{\rho}\left(\frac{V_g'}{V_g}\right)^2 = \frac{\rho'}{\rho}\left(\frac{V'}{V}\right)^2 = \frac{\rho'}{\rho}\mu^2 \tag{3.30}$$

3.4.3. Similarity Rate for Fan Static Pressure:

$$\frac{P_{sf}{}'}{P_{sf}} = \frac{\Delta P_t{}' - P_{df}{}'}{\Delta P_t - P_{df}} \tag{3.31}$$

writable.

$$\Delta P_t = P_{t2} - P_{t1}, \Delta P_t{}' = P_{t2}{}' - P_{t1}{}', P_{df}{}' = P_{d2}{}', \quad P_{df} = P_{d2}, P_{t2}{}' = P_{s2}{}' + P_{d2}' \tag{3.32}$$

$$P_{t2} = P_{s1} + P_{d1} \tag{3.33}$$

Expression is regulated by writing the above equation,

$$\frac{P_{sf}{}'}{P_{sf}} = \frac{\Delta P_t{}' - P_d{}'}{\Delta P_t - P_d} = \frac{(P_{t2}{}' - P_{t1}{}') - (P_{d2}{}')}{(P_{t2} - P_{t1}) - (P_{d2})} = \frac{P_{s2}{}' - P_{t1}{}'}{P_{s2} - P_{t1}} = \frac{P_{s2}{}' - P_{t1}{}'}{P_{s2} - P_{t1}} \tag{3.34}$$

are found and

$$\Delta P_ç' = P_ç' - P_g' \quad ve \quad \Delta P_ç = P_ç - P_g \tag{3.35}$$

if the above definitions are made and the equation is arranged,

$$\frac{P_{sf}{}'}{P_{sf}} = \frac{P_{s2}{}' - \left[P_g{}' + \frac{1}{2}\rho' V_g'^2\right]}{P_{s2} - \left[P_g + \frac{1}{2}\rho V_g^2\right]} = \frac{(P_ç' - P_g') - \frac{1}{2}\rho' V_g'^2}{(P_ç - P_g) - \frac{1}{2}\rho V_g^2} = \frac{\Delta P_ç' - \frac{1}{2}\rho' V_g'^2}{\Delta P_ç - \frac{1}{2}\rho V_g^2} \tag{3.36}$$

$$\frac{P_{sf}{}'}{P_{sf}} = \frac{\frac{1}{2}\rho' V_g'^2\left[2\frac{\Delta P_ç'}{\rho' V_g'^2} - 1\right]}{\frac{1}{2}\rho V_g^2\left[2\frac{\Delta P_ç}{\rho V_g^2} - 1\right]} \tag{3.37}$$

obtained. For the prototype and model fans, when the Ne Newton resemblance is provided at the entrance of the machine,

$$Ne_{ç} = \frac{\Delta P_{ç}'}{\rho V_{ç}^{2}} = Ne_{ç}{}' = \frac{\Delta P_{ç}}{\rho' V_{ç}'^{2}}$$

and also according to kinematic similarity,

$$\frac{V_g'}{V_g^2} = \mu^2$$

similarity ratio of static pressures for fans,

$$\frac{P_{sf}{}'}{P_{sf}} = \frac{\rho'}{\rho}\left(\frac{V_g'}{V_g}\right)^2 = \frac{\rho'}{\rho}\left(\frac{V'}{V}\right)^2 = \frac{\rho'}{\rho}\mu^2 \qquad (3.38)$$

obtained as.

3.4.4 Similarity Rate for Fan Dynamic Pressures:

Similarly, if the similarity ratio is calculated for the fan dynamic pressures defined as $(P_{df} = \frac{1}{2}\rho V_{ç}^{2})$ equivalent to the dynamic pressure at the fan outlet,

$$\frac{P_{df}{}'}{P_{df}} = \frac{\frac{1}{2}\rho' V_{ç}'^{2}}{\frac{1}{2}\rho V_{ç}^{2}} = \frac{\rho'}{\rho}\left(\frac{V_{ç}'}{V_{ç}}\right)^2 = \frac{\rho'}{\rho}\mu^2 \qquad (3.39)$$

As a result, it is concluded that the similarity ratios for total pressures, static pressures and dynamic pressures for fans are equal to the same value ($\frac{\rho'}{\rho}\mu^2$ that is the product of the square of the mathematical similarity ratio with density ratio).

$$\frac{\Delta P_t{}'}{\Delta P_t} = \frac{P_{tf}{}'}{P_{tf}} = \frac{P_{sf}{}'}{P_{sf}} = \frac{P_{df}{}'}{P_{df}} = \frac{\rho'}{\rho}\left(\frac{V_{ç}'}{V_{ç}}\right)^2 = \frac{\rho'}{\rho}\left(\frac{V_g'}{V_g}\right)^2 = \frac{\rho'}{\rho}\left(\frac{V'}{V}\right)^2 = \frac{\rho'}{\rho}\mu^2 \qquad (3.40)$$

If the same fluid is used or the density does not change (p '= p), it can be written that the pressure ratio for fans, total pressures, static pressures, and dynamic pressures are similar to the same value (μ', squared of kinematic similarity ratio).

$$\frac{H'}{H} = \frac{\Delta P_t{}'}{\Delta P_t} = \frac{P_{tf}{}'}{P_{tf}} = \frac{P_{sf}{}'}{P_{sf}} = \frac{P_{df}{}'}{P_{df}} = \left(\frac{V_{ç}'}{V_{ç}}\right)^2 = \left(\frac{V_g'}{V_g}\right)^2 = \left(\frac{V'}{V}\right)^2 = \mu^2 \qquad (3.41)$$

3.4.5. Similarity Rate for RPM Numbers

If kinematic similarity relation is written by using drift (circumferential, tangential) speeds,

$$\mu = \frac{U'}{U} = \frac{\pi D' n'/60}{\pi D n/60} = \lambda \frac{n'}{n} \Rightarrow \frac{n'}{n} = \frac{\mu}{\lambda} \tag{3.42}$$

In this case, the similarity ratio of fan head heights, total pressures, static pressures and dynamic pressures,

$$\frac{H'}{H} = \frac{\Delta P_t{}'}{\Delta P_t} = \frac{P_{tf}{}'}{P_{tf}} = \frac{P_{sf}{}'}{P_{sf}} = \frac{P_{df}{}'}{P_{df}} = \mu^2 = \lambda^2 \left(\frac{n'}{n}\right)^2 = \left(\frac{D_2'}{D_2}\right)^2 \left(\frac{n'}{n}\right)^2 \tag{3.43}$$

can also be written as.

If the same fan is in question; Since $\lambda = 1$,

$$\mu = \frac{n'}{n}$$

Becomes. Also, if the same fluid is used or the density does not change, it will be ($\rho! = \rho$). Thus, if the same fan is operated using the same fluid but at different speeds, the head of the head, total pressure, static pressure and dynamic pressure can be calculated from the relation below.

$$\frac{H'}{H} = \frac{\Delta P_t{}'}{\Delta P_t} = \frac{P_{tf}{}'}{P_{tf}} = \frac{P_{sf}{}'}{P_{sf}} = \frac{P_{df}{}'}{P_{df}} = \mu^2 = \left(\frac{n'}{n}\right)^2 \tag{3.44}$$

3.4.6. Similarity Rate for Flows

D_2, b_2 and C_{m2} similarity ratio for flow rates to show impeller diameter, impeller exit vane width and meridian velocity at impeller outlet, respectively;

$$\frac{Q'}{Q} = \frac{\pi D_2' b_2' C_{m2}'}{\pi D_2 b_2 C_{m2}} = \frac{D_2'}{D_2}\frac{b_2'}{b_2}\frac{C_{m2}'}{C_{m2}} = \lambda\lambda\mu = \lambda^2\mu = \lambda^2\lambda\left(\frac{n'}{n}\right) = \lambda^3\left(\frac{n'}{n}\right) \tag{3.45}$$

is given with the expression. If the same fan is in question; Since $\lambda = 1$;,

$$\frac{Q'}{Q} = \mu = \frac{n'}{n} \tag{3.46}$$

will be.

3.4.7. Similarity Rate for Theoretical Powers

If H indicates the head of the fan,

$$N = \frac{\gamma Q H}{75} \; ; \; N' = \frac{\gamma' Q' H'}{75} \tag{3.47}$$

Writeable. If these two statements are proportioned,

$$\frac{N'}{N}=\frac{\gamma'}{\gamma}\frac{Q'}{Q}\frac{H'}{H}=\frac{\rho'}{\rho}\frac{g'}{g}\frac{Q'}{Q}\frac{H'}{H}=\frac{\rho'}{\rho}\frac{g'}{g}\lambda^2\mu\mu^2=\frac{\rho'}{\rho}\frac{g'}{g}\lambda^2\mu^3=\frac{\rho'}{\rho}\frac{g'}{g}\lambda^2\mu^3 \tag{3.48}$$

obtained. Since the same type of fluid is used, it will be pp' = pp and if the experiment is carried out in the same place, it will be gg' = gg,

$$\frac{N'}{N}=\frac{Q'}{Q}\frac{H'}{H}=\lambda^2\mu^3=\lambda^5\left(\frac{n'}{n}\right)^3=\left(\frac{D_2'}{D_2}\right)^5\left(\frac{n'}{n}\right)^3 \tag{3.49}$$

located. Also, if the same fan is involved, it will be λ = 1,

$$\frac{N'}{N}=\mu^3=\left(\frac{n'}{n}\right)^3 \tag{3.50}$$

obtained.

3.4.8. Similarity Rate for Hydraulic Powers

$$N_h'=M'\omega'=\rho' Q_ç'.(C_{u2}'U_2'-C_{u1}'U_1') \tag{3.51}$$

$$N_h=M\omega=\rho Q_ç.(C_{u2}U_2-C_{u1}U_1) \tag{3.52}$$

$$\frac{N_h'}{N_h}=\frac{\rho'}{\rho}\frac{Q_ç'}{Q_ç}\frac{C_{u2}'}{C_{u2}}\frac{U_1'}{U_1}=\frac{\rho'}{\rho}\lambda^2\mu\mu\mu=\frac{\rho'}{\rho}\lambda^2\mu^3 \tag{3.53}$$

obtained. Since the same type of fluid is used, it will be $\rho'=\rho$,

$$\frac{N_h'}{N_h}=\lambda^2\mu^3=\lambda^5\left(\frac{n'}{n}\right)^3=\left(\frac{D_2'}{D_2}\right)^5\left(\frac{n'}{n}\right)^3 \tag{3.54}$$

Also, if the same fan is involved, it will be λ = 1,

$$\frac{N_h'}{N_h}=\mu^3=\left(\frac{n'}{n}\right)^3 \tag{3.55}$$

found.

3.4.9. Similarity Rate for Effective Powers

Technical Bulletin 1/2018, in Figure 1.2, the inlet (1 ') and outlet between the impeller triangles drawn for the inlet (1) and outlet (2) points between the impeller blades of a prototype fan and the outlet (1') between the impeller blades of the model fan Consider the velocity triangles drawn for points (2 ') together. If kinematic similarity is achieved, hydraulic efficiencies can be shown to be equal.

$$\mu = \frac{U_1'}{U_1} = \frac{W_1'}{W_1} = \frac{C_1'}{C_1} = \frac{C_{m1}'}{C_{m1}} = \frac{C_{u1}'}{C_{u1}} = \frac{U_2'}{U_2} = \frac{W_2'}{W_2} = \frac{C_2'}{C_2} = \frac{C_{m2}'}{C_{m2}} = \frac{C_{u2}'}{C_{u2}} = \cdots = \text{constant} \quad (3.56)$$

As such, the velocity triangles at identical points are mutually similar, and their angles are mutually equal.

$$\alpha_1 = \alpha_1' \quad ; \quad \alpha_2 = \alpha_2' \quad ; \quad \beta_1 = \beta_1' \quad ; \quad \beta_2 = \beta_2' \qquad (3.57)$$

Hydraulic efficiency relations,

$$\eta_h = \frac{H}{H_E} = \frac{gH}{C_{u2}U_2 - C_{u1}U_1} \quad ve \quad \eta_h' = \frac{H'}{H_E{}'} = \frac{g'H'}{C_{u2}{}'U_2{}' - C_{u1}{}'U_1{}'} \qquad (3.58)$$

if gg '= gg is taken,

$$\eta_h' = \frac{g\mu^2 H}{\mu C_{u2}\mu U_2 - \mu C_{u1}\mu U_1} = \frac{g\mu^2 H}{\mu^2(C_{u2}U_2 - C_{u1}U_1)} = \eta_h \qquad (3.59)$$

obtained. If there is no big geometric difference between the large real (prototype) fan and the model fan, the mechanical efficiencies are considered approximately equal,

$$\eta_m' \cong \eta_m \qquad (3.60)$$

We can also consider leak yields approximately equal,

$$\eta_k' \cong \eta_k \qquad (3.61)$$

Thus, overall yields will be approximately equal,

$$\eta_g' \cong \eta_g \qquad (3.62)$$

To show the head of the fan for H,

$$\frac{N_e{}'}{N_e} = \frac{\gamma'}{\gamma}\frac{Q'}{Q}\frac{H'}{H}\frac{\eta_g}{\eta_g'} \qquad (3.63)$$

equality can be written. As stated above, considering that it is $\eta_g' \cong \eta_g$

$$\frac{N_e{}'}{N_e} \cong \frac{\gamma'}{\gamma}\frac{Q'}{Q}\frac{H'}{H} \cong \frac{\rho'}{\rho}\frac{Q'}{Q}\frac{H'}{H} \cong \frac{\rho'}{\rho}\lambda^2\mu\mu^2 \cong \frac{\rho'}{\rho}\lambda^2\mu^3 \qquad (3.64)$$

Writeable. Since the same type of fluid is used, since p '= p,

$$\frac{N_e{}'}{N_e} \cong \lambda^2\mu^3 \cong \lambda^5\left(\frac{n'}{n}\right)^3 = \left(\frac{D_2'}{D_2}\right)^5\left(\frac{n'}{n}\right)^3 \qquad (3.65)$$

Also, if the same fan is involved, it will be λ = 1.,

$$\frac{N_e{}'}{N_e} \cong \mu^3 \cong \left(\frac{n'}{n}\right)^3 \qquad (3.66)$$

found.

3.4.10. Similarity Rate for Torques (Moments)

$$Ne' = M'\omega'; Ne = M\omega \Rightarrow \frac{M'}{M} = \frac{Ne'}{Ne}\frac{\omega}{\omega'} \qquad (3.67)$$

$$\omega = \frac{2\pi n}{60} \quad ; \quad \omega' = \frac{2\pi n'}{60} \qquad (3.68)$$

using relations;

$$\frac{M'}{M} = \frac{Ne'}{Ne}\frac{\omega}{\omega'} = \frac{\rho'}{\rho}\lambda^2\mu^3\frac{\eta_g}{\eta_g'}\frac{n}{n'} = \frac{\rho'}{\rho}\lambda^2\mu^3\frac{\eta_g}{\eta_g'}\frac{\lambda}{\mu} = \frac{\rho'}{\rho}\lambda^3\mu^2\frac{\eta_g'}{\eta_g} = \frac{\rho'}{\rho}\lambda^5\left(\frac{n'}{n}\right)^2\frac{\eta_g'}{\eta_g} \qquad (3.69)$$

$$\frac{M'}{M} = \frac{\rho'}{\rho}\left(\frac{D_2'}{D_2}\right)^5\left(\frac{n'}{n}\right)^2\frac{\eta_g'}{\eta_g} \qquad (3.70)$$

As stated above, $\eta_g' \cong \eta_g$ considering that it is and when using the same type of fluid, $\rho' = \rho$

$$\frac{M'}{M} \cong \lambda^3\mu^2 \cong \lambda^5\left(\frac{n'}{n}\right)^2 \qquad (3.71)$$

Also, if the same fan is involved, it will be λ = 1.,

$$\frac{M'}{M} \cong \mu^2 \cong \left(\frac{n'}{n}\right)^2 \qquad (3.72)$$

found.

3.4.11. Similarity Relation for Noise:

L, in dB (A) unit, to show the noise (sound pressure) level of the fan inlet or outlet, D the impeller diameter (m) and n the speed of the fan (rev / min), the indices 1 and 2 indicate similar operating points of the fan, respectively. ; The logarithmic similarity relation used in calculating the difference between fan noise levels between these working points is defined as follows.

$$L_2 - L_1 = 70\ Log_{10}\left(\frac{D_2}{D_1}\right) + 50\ Log_{10}\left(\frac{n_2}{n_1}\right) \tag{3.73}$$

This correlation is not as accurate as other similarity correlations used to estimate fan performance characteristics, but still sufficiently accurate results in estimated noise calculations.

3.4.12. 1., 2. and 3. Fan Laws Frequently Used in Application:

By using the fan similarity relations (fan laws) given in the sections, 3 fan laws (in fact 9 equations) which are used in practice are obtained. In these fan laws; fan pressure P (fan total pressure P_{tf} or fan static pressure P_{sf}), D generally indicates impeller size, D_1 impeller inlet (suction) diameter, D_2 impeller outlet diameter, b_1 impeller inlet blade width or b_2 impeller outlet wing width etc. The index of 1 (or ') indicates the first (or model) state of the relevant variable, and the index of 2 (or') indicates the second (or prototype) state, where these fan laws do not change the fan (overall, total) efficiency ($ng_1 = n_{g2}$ or $n'_g = n_g$) with acceptance It is written.

According to the AMCA 210 - 16 Standard, compressibility effects can be neglected in small changes in fan applications that do not exceed 10% in air density and 5% in rotational speed, depending on the inlet (suction) conditions in the test conditions. The relations below are valid for these situations.

1.Fan Law:

This law is on volumetric flow (Q), fan pressure P (fan total pressure P_{tf} or fan static pressure P_{sf}) and effective (mil) power N_e; implies the effect of fan size (impeller inlet (suction) diameter D_1, impeller (outlet) diameter D_2, impeller inlet blade width b_1, impeller outlet blade width b_2, etc.), speed (n) or fluid density (p). . Unlike other equations, it is stated that it will be more accurate to take the D_1 impeller inlet diameter in the volume flow expression.

$$\frac{Q'}{Q} = \frac{Q_2}{Q_1} = \lambda^3\left(\frac{n'}{n}\right) = \left(\frac{D_1'}{D_1}\right)^3\left(\frac{n'}{n}\right) = \left(\frac{D_2'}{D_2}\right)^3\left(\frac{n'}{n}\right) \tag{3.74}$$

$$\frac{P'}{P} = \frac{P_2}{P_1} = \mu^2\frac{\rho'}{\rho} = \lambda^2\left(\frac{n'}{n}\right)^2\frac{\rho'}{\rho} = \left(\frac{D_2'}{D_2}\right)^2\left(\frac{n'}{n}\right)^2\frac{\rho'}{\rho} \tag{3.75}$$

$$\frac{N_e{'}}{N_e} = \frac{Ne_2}{Ne_1} = \lambda^2\mu^3\frac{\rho'}{\rho} = \lambda^5\left(\frac{n'}{n}\right)^3\frac{\rho'}{\rho} = \left(\frac{D_2'}{D_2}\right)^5\left(\frac{n'}{n}\right)^3\frac{\rho'}{\rho} \tag{3.76}$$

2. Fan Law:

This law is on mass flow ($\dot{m}$ = pQ), speed (n) and effective (mil) power N_e; implies the effect of fan size (D_1, D_2, b_1, b_2, etc.), fan pressure P (fan total pressure P_{tf} or fan static pressure P_{sf}) or fluid density (p).

$$\frac{\dot{m}'}{\dot{m}}=\frac{\dot{m}_2}{\dot{m}_1}=\frac{\rho'}{\rho}\frac{Q'}{Q}=\frac{\rho'}{\rho}\frac{Q_2}{Q_1}=\left(\frac{\rho'}{\rho}\right)^{1/2}\left(\frac{D_1'}{D_1}\right)^2\left(\frac{P'}{P}\right)^{1/2}=\left(\frac{\rho'}{\rho}\right)^{1/2}\left(\frac{D_2'}{D_2}\right)^2\left(\frac{P'}{P}\right)^{1/2} \quad (3.77)$$

$$\frac{n'}{n}=\frac{n_2}{n_1}=\left(\frac{\rho}{\rho'}\right)^{1/2}\left(\frac{P'}{P}\right)^{1/2}\left(\frac{D_2}{D_2'}\right) \quad (3.78)$$

$$\frac{N_e{}'}{N_e}=\frac{Ne_2}{Ne_1}=\left(\frac{\rho}{\rho'}\right)^{1/2}\left(\frac{P'}{P}\right)^{3/2}\left(\frac{D_2'}{D_2}\right)^2 \quad (3.79)$$

3.Fan Law:

This law changes the fan size (D_1, D_2, b_1, b_2, etc.), volume flow (Q) or fluid density (p); speed (n), fan pressure P (fan total pressure P_{tf} or fan static pressure P_{sf}) and effective (mil) power expresses its influence on N_e.

$$\frac{n'}{n}=\frac{n_2}{n_1}=\left(\frac{D_2}{D_2'}\right)^3\left(\frac{Q'}{Q}\right) \quad (3.80)$$

$$\frac{P'}{P}=\frac{P_2}{P_1}=\left(\frac{D_2}{D_2'}\right)^4\left(\frac{Q'}{Q}\right)^2\frac{\rho'}{\rho} \quad (3.81)$$

$$\frac{N_e{}'}{N_e}=\frac{Ne_2}{Ne_1}=\left(\frac{D_2}{D_2'}\right)^4\left(\frac{Q'}{Q}\right)^3\frac{\rho'}{\rho} \quad (3.82)$$

Question 3.1. In the case of an AIR-A-U / 500-6 Series Aironn Ventilation fan with a volumetric flow of 3.2 m^3/s, the speed of the fan is increased by 10% and the same fluid is used; How much does the volume flow, head, dynamic pressure, static pressure, total pressure, torque and effective (mil) power vary in%?

Answer:

Since it is geometrically the same fan, λ = 1;

$$\frac{Q'}{Q}=\frac{n'}{n}=\frac{1.10n}{n}=1.10$$

So the volume flow of the fan will increase by 10%.

Discharge head;

$$\frac{H'}{H} = \left(\frac{n'}{n}\right)^2 = \left(\frac{1.10n}{n}\right)^2 = (1.10)^2 = 1.21$$

So the fan head will increase by 21%.

Fan dynamic pressure;

$$\frac{P_{df}'}{P_{df}} = \frac{\rho'}{\rho}\mu^2 = \frac{\rho'}{\rho}\lambda^2\left(\frac{n'}{n}\right)^2$$

Since it is geometrically the same fan, λ = 1 and since the same fluid is used, since p '= p;

$$\frac{P_{df}'}{P_{df}} = \frac{\rho'}{\rho}\mu^2 = \frac{\rho'}{\rho}\lambda^2\left(\frac{n'}{n}\right)^2 = \left(\frac{1.10n}{n}\right)^2 = (1.10)^2 = 1.21$$

Has found. In cases where the same fluid (p '= p) is used, it is seen that the similarity ratio for dynamic pressures is equal to μ^2, that is the square of the kinematic similarity rate. In

other words, the dynamic pressure of the fan will increase by 21%.

If similar operations are performed for fan static pressure and fan total pressure;

$$\frac{P_{sf}'}{P_{sf}} = \frac{\Delta P_t'}{\Delta P_t} = \frac{P_{tf}'}{P_{tf}} = \frac{\rho'}{\rho}\mu^2 = \frac{\rho'}{\rho}\lambda^2\left(\frac{n'}{n}\right)^2 = \left(\frac{1.10n}{n}\right)^2 = (1.10)^2 = 1.21$$

found. In other words, the static pressure of the fan and the total pressure of the fan will increase by 21%.

Fan torque;

Considering that $n'_g \cong n_g$, accepting that the same machine ($\lambda = 1$) and the same type of fluid (p'= p) are used;

$$\frac{M'}{M} \cong \lambda^3\mu^2 \cong \lambda^5\left(\frac{n'}{n}\right)^2 \cong \mu^2 \cong \left(\frac{n'}{n}\right)^2 \cong \left(\frac{1.10n}{n}\right)^2 \cong (1.10)^2 \cong 1.21$$

found. In other words, the torque of the fan will increase approximately 21%.

Effective (mil) power of the fan;

$$\frac{N_e'}{N_e} \cong \frac{\rho'}{\rho}\lambda^2\mu^3$$

writable. Since the same type of fluid is used, since p'= p,

$$\frac{N_e'}{N_e} \cong \lambda^2\mu^3 \cong \lambda^5\left(\frac{n'}{n}\right)^3$$

Also, if the same fan is involved, it will be λ = 1.,

$$\frac{N_e'}{N_e} \cong \mu^3 \cong \left(\frac{n'}{n}\right)^3 \cong \left(\frac{1.10n}{n}\right)^3 \cong (1.10)^3 \cong 1.331$$

found. In other words, the effective (mil) power of the fan will increase approximately 33.1%. This result shows that by adjusting the speed of the fans, significant energy savings can be achieved. This can be done with conventional but low-efficiency systems known as belt-pulley and gearbox (reducer), as well as with a frequency-controlled (inverter) system, which is a more modern and high-efficiency speed control system, as has been done frequently. In practice, it can also be done with a frequency controlled (inverter) system, the number of which is the control system.

Despite the fact that the first investment cost is high in practice, the control of the fan flow and pressure with frequency controlled systems (with speed control) is compared to the control of the fan flow and pressure by using the dampers with low initial investment cost at the fan inlet (inlet damper or drallregler) or outlet (outlet damper). Operation (Energy) Cost is much lower. As the "Operation (Energy) Cost" of the fans has a very large share in the "Lifelong Cost" which is the sum of the initial investment cost and the operating cost, the use of frequency controlled systems for the fans is more economical in terms of "Lifetime Cost".

In this context, AIRONN İKLİMLENDİRME SİSTEMLERİ SAN. VE TAAH. A.Ş.'s J-SMART "smart fan" automation application, all jet fans are operated with "frequency inverters" with Fire Mode feature. Thus, there is no need to use switchgear material such as contactor / thermal / auxiliary relay. Jet fans are manufactured with single winding since they are controlled by frequency inverter. Thus, it is possible to operate at the desired speed between 0% and 100% instead of double speed in jet fans. In addition, by saving 4x2.5 mm cable instead of 7x2.5 mm cable, cable and cable workmanship are also saved. Since the frequency inverter used and the central PLC in the panel communicate with only one cable, PLC input / output units are not required for the status, fault and control information of the jet fan. In addition, with the addition of J-Smart-CO, jet fan automation system and carbon monoxide alarm system can be offered in a single package. In this way, the user can see the average carbon monoxide value of each zone in detail from the J-Smart jet fan automation system panel screen. This allows the user to operate jet fans of different carbon monoxide density zones at different speeds. Thus, significant energy savings are achieved. Energy savings of 30 to 50% can be achieved with the use of inverters compared to stepped jet fans.

Question 3.2. If an Aironn Ventilation fan of the AIR-A-U / 1250-6 Series with a volumetric flow of 23.595 m^3/h is operating at 1200 rpm, its total pressure is 3000 Pa and its effective (mil) power is 128.7 kW. **a)** Find the overall (total) efficiency of the fan? **b)** If the fan's speed is reduced to 840 rpm; flow rate, total pressure and effective (mil) power?

Answer:

a) Overall (total) efficiency of the fan,

$$\eta_g = \frac{Q.\Delta P_t}{N_e} = \frac{23.595\ m^3/s\ x\ 3000\ \ N/m^2}{128700\ Nm/s} = 0.55$$

b) If the general (total) efficiency and air density of the fan are considered to be unchanged and similarity laws are written,

$$\frac{n'}{n} = \frac{840}{1200} = 0.7$$

$$\frac{Q'}{Q} = \frac{n'}{n} = 0.7 \ \Rightarrow\ Q' = 0.7Q = 0.7\ x\ 23.595\ (m^3/s) = 16.517\ m^3/s$$

$$\frac{\Delta P_t{}'}{\Delta P_t} = \frac{P_{tf}{}'}{P_{tf}} = \left(\frac{n'}{n}\right)^2 = (0.7)^2 = 0.49 \Rightarrow\ \Delta P_t{}' = 0.49\ \Delta P_t = 0.49\ x\ 3000\ Pa = 1470\ Pa$$

$$\frac{N_e'}{N_e} = (0.7)^3 = 0.343 \Rightarrow\ N_e' = 0.343 N_e = 0.342\ x\ 128.7 = 44.144\ kW$$

Question 3.3. An AIR-A-U / 400-6 Series Aironn Ventilation fan, with impeller diameter of 300 mm, provides 2000 m^3/h flow and a total pressure of 3000 Pa to a density of 1.244 kg/m^3 in case it operates at 900 rpm. At which flow and total pressure will another air fan of 400 mm impeller diameter from the same series as this fan operate at 1300 rpm ? In this case, how much will the fan power increase?

Answer:

1. Using the relations of Fan Law (2.74) , (2.75) and (2.76),

$$\frac{Q'}{Q} = \frac{Q_2}{Q_1} = \left(\frac{D_2'}{D_2}\right)^3 \left(\frac{n'}{n}\right)$$

$$Q' = Q_2 = Q_2 \left(\frac{D_2'}{D_2}\right)^3 \left(\frac{n'}{n}\right) = 2000 \left(\frac{400}{300}\right)^3 \left(\frac{1300}{900}\right) = 6848\, m^3/h$$

$$\frac{P'}{P} = \frac{P_2}{P_1} = \left(\frac{D_2'}{D_2}\right)^2 \left(\frac{n'}{n}\right)^2 \frac{\rho'}{\rho}$$

$$P' = P_2 = P_1 \left(\frac{D_2'}{D_2}\right)^2 \left(\frac{n'}{n}\right)^2 \frac{\rho'}{\rho} = 250 \left(\frac{400}{300}\right)^2 \left(\frac{1300}{900}\right)^2 \frac{1.244}{1.244} = 928\, Pa$$

$$\frac{N_e'}{N_e} = \frac{Ne_2}{Ne_1} = \left(\frac{D_2'}{D_2}\right)^5 \left(\frac{n'}{n}\right)^3 \frac{\rho'}{\rho} = \left(\frac{400}{300}\right)^5 \left(\frac{1300}{900}\right)^3 \frac{1.244}{1.244} = 12.7$$