INVESTIGATION OF CHARACTERISTICS OF A BLOWER USED AS AN AIR SOURCE IN AN EXPERIMENTAL RIG FOR STUDIES OF HELICAL INSTABILITIES IN FLOWING FLUIDS

Václav Tesař, Libor Kukačka, Radka Kellnerová
Institute of Thermomechanics of the Academy of Sciences of the Czech Republic v.v.i.

Abstract
For investigations of aerodynamic properties of helical instabilities in flowing fluids, an experimental rig is currently built [1]. It is intended on the one hand for visualisations of acoustically excited helical structures and on the other hand for model experiments with flows of cyclonal character. As the universal air source for both purposes, a blower is used for which no loading characteristics were available - and which, at any rate, is to be operated in some of the regimes at very low Reynolds numbers where one has to expect deviation from characteristics obtained under standard conditions. The authors investigated the blower loading characteristics experimentally and used this opportunity to apply and test practical validity of the general ideas about universal representation of characteristics and criterial similarity parameters of turbomachines, published considerable time ago [2] but seemingly little known and used.

1. Introduction

Some instabilities in fluid flows have helical character and hence exhibiting chirality. This property makes them extraordinary [3] and even in some aspects paradoxical [4]. According to some researchers, the chiral character makes these structures capable of self-organisation. Apart from interesting resultant properties of potential importance for engineering applications (e.g., [5]) and meteorology (tropical cyclones), the formation and growth of the large-scale structures means an inverse energy transfer towards the larger scales, of important consequences to studies of turbulence - the extremely important phenomenon of basic importance for fluid mechanics in general.

An experimental rig for investigation of these phenomena is currently built at the Institute of Thermomechanics of the Academy of Sciences of the Czech Republic v.v.i., under the support by GAAV grant No. 207 60705. General concept of the rig is described in reference [1]. As the source of the air flows in this rig, it was decided to use an industrial blower STORM 10 supplied by SEPLAST s.s r.o., Kroměříž, Czech Republic. It is a small blower with surfaces exposed to fluid made of organic polymer material. Unfortunately, the supplier was unable to provide the loading characteristics needed for proper operation of this blower. Moreover, to obtain a wider flexibility of the blower uses, it was decided to drive it by means of the frequency variator Hitachi L200 - 004NFEF2 that permits adjustment of the driving electric current frequency and hence the rotational speed in a wide range. This is particularly beneficial for the intended operation aimed at flow visualisation in low Reynolds number transitional regimes where the speed has to be very low. In such regimes, the loading properties may deviate substantially — because of different stalling on the rotor blades — from the characteristics obtained at standard conditions.

It was therefore decided to investigated the loading properties of the blower in the low speed regimes experimentally. This provided a useful opportunity to apply and test practical validity the general ideas about universal representation of characteristics and criterial similarity parameters of turbomachines that were published considerable time ago [2] but unfortunately remain little known and little used.

2. Quadratic model of blower behaviour

Engineers designing and developing new blowers need a detailed knowledge of the their aerodynamics. It is this group from which the engineering faculty members, teaching the theory of turbomachines in general, are recruited. However, designing new turbomachines is nowadays a rare activity and most engineers are unlikely to do so in their career. What most engineers are likely to do quite often is being users of these machines. Users do not need the deep knowledge of what happens inside the machine - but they need a perfect knowledge of the machine behaviour, as it is expressed by the characteristics. In other words, the engineering education should be based on the "black box" approach. Even more valid is this premise for high school and university graduates graduating in other fields than engineering but likely to encounter the necessity of working with blowers and other turbomachines. The "black box" approach was advocated in the course for B. Eng. degree, for which the textbook [2] was intended.

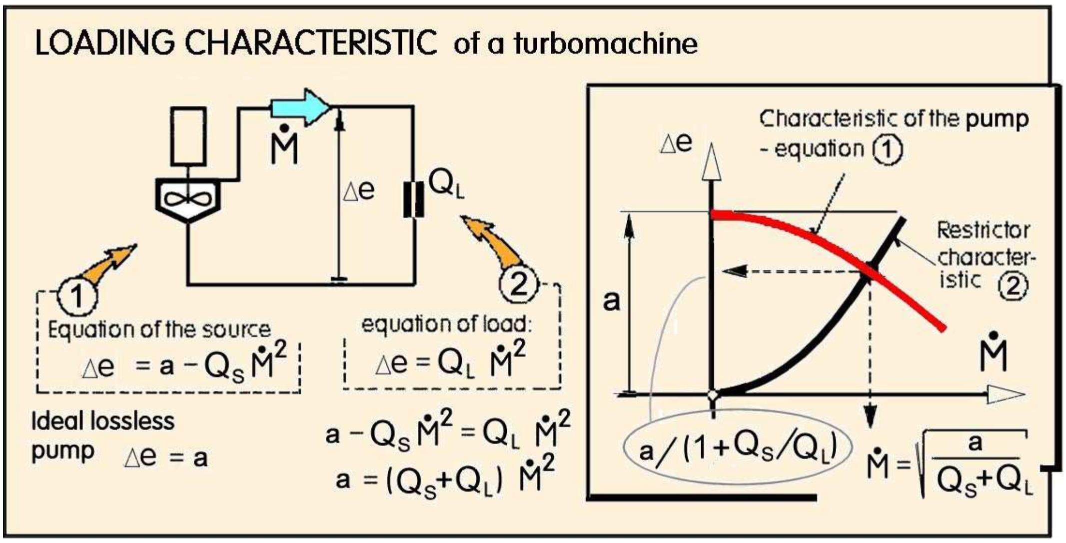

Figure 1 **General idea of evaluating the conditions in an aerodynamic circuit driven by a turbomachine blower by the "black box" approach - by locating the intersections of the characteristics of the blower and of the load. The mathematics of this solution presented here is based on the assumption of purely quadratic behaviour of the blower as well as of the load.**

Another description of this approach and of the quadratic model used to characterise properties of turbomachines (at least in a certain neighbourhood of the operating point) is also in references [6] in Czech and [7] in English.

The basic principles of working with the loading characteristic of turbomachinery are summarised in Fig. 1. The characteristic is a dependence between the pressure difference (or, more generally, a difference in some other ***across*** variable, analogous to voltage in electric circuits) between the outlet and inlet of the machine while the flow rate (- or, or again more generally, perhaps some other ***through*** variable, analogous to current in electronics). As far as the through and across quantities are concerned, it is advisable to use the most general ones, mass and energy for which conservation laws apply without any restrictions. In Fig. 1, the across variable is accordingly the specific energy of the fluid e [J/kg]. The through variable is the mass flow rate $\dot{M}$ [kg/s]. In this paper, the dot above a symbol of a variable has the meaning of a derivative with respect to time - this regressive usage replaces here the progressive use of a multiplicative derivative operator in reference [2]. The use of the drop of the specific energy to characterise the difference in fluid state between the fluid inlet and outlet is not common. Fortunately, for incompressible regimes it may be evaluated rather easily from the usually measured pressure difference. It is a sum of the difference of the specific kinetic energy Δe_k and the difference of the pressure energy Δe_P

$$\Delta e = \Delta e_k + \Delta e_P \qquad \text{... (1)}$$

The former is in many cases near to zero - especially if the inlet and outlet aere of the same cross section (so that the difference is just due to the different shapes of velocity profiles). The latter is evaluated for an incompressible flow as

$$\Delta e_P = v \, \Delta P \qquad \text{... (2)}$$

— where v [m³/kg] is the specific volume of the fluid.

Operating condition in the circuit consisting of a blower and it load are determined (as shown in Fig. 1) by the locus of the intersection of the blower characteristic and the load characteristic. Of course, if actual characteristics are available from the manufacturer or supplier, they should be used - especially if the are of a complex shape. Experience, however, shows that most characteristics — at least in the vicinity of the

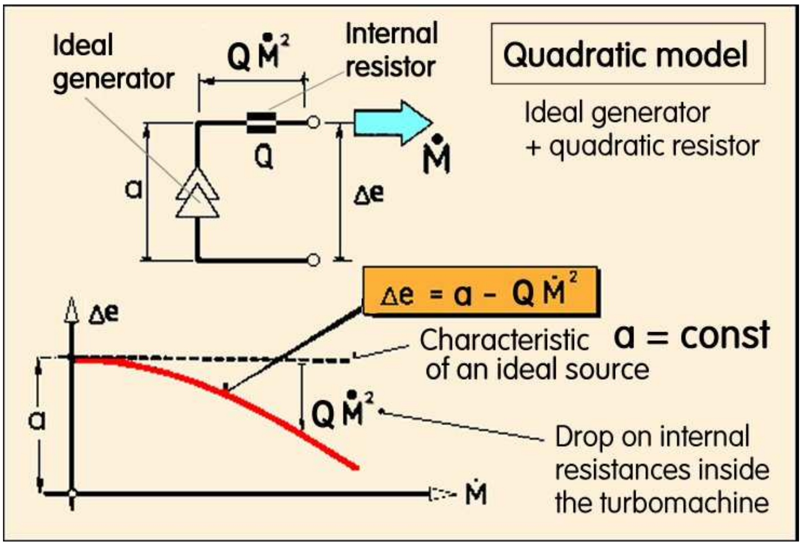

Figure 2 **The quadratic model of the blower behaviour. The model explaining the usually encountered decrease of the available specific energy ay the blower exit with increasing delivered mass flow rate is based on an imagined series connection of an ideal generator, which would exhibit a simple horizontal line characteristic, and a quadratic restrictor.**

recommended operating point — are very near to a quadratic dependence. In Fig. 1, the expressions for the condition in the circuit are evaluated for a situation where the characteristic curves may be approximated by the quadratic dependences. The quadratic model of a turbomachine, Fig. 2, operates with the quadratic approximation to the loading characteristic of the machine

$$\Delta e = a - Q\dot{M}^2 \qquad \text{... (3)}$$

The behaviour of the model (and, perhaps with some approximation errors, also that of the turbomachine) is determined by tvo parameters: the specific work transferred to the fluid inside the turbomachine a [J/kg] , and the value of dissipance Q [m^2/kg^2], which characterises the hydraulic losses taking place inside the machine.
The former may be roughly estimated by applying the Bernoulli Theorem according to Fig. 3. Of course, this is just a rough approximation assuming that the energetic changes of the fluid may be described by a one-dimensional approach - while the flowfield in turbomachines is invariably extremely complex, three-dimensional and unsteady. Nevertheless, even a simple approximation may be useful.

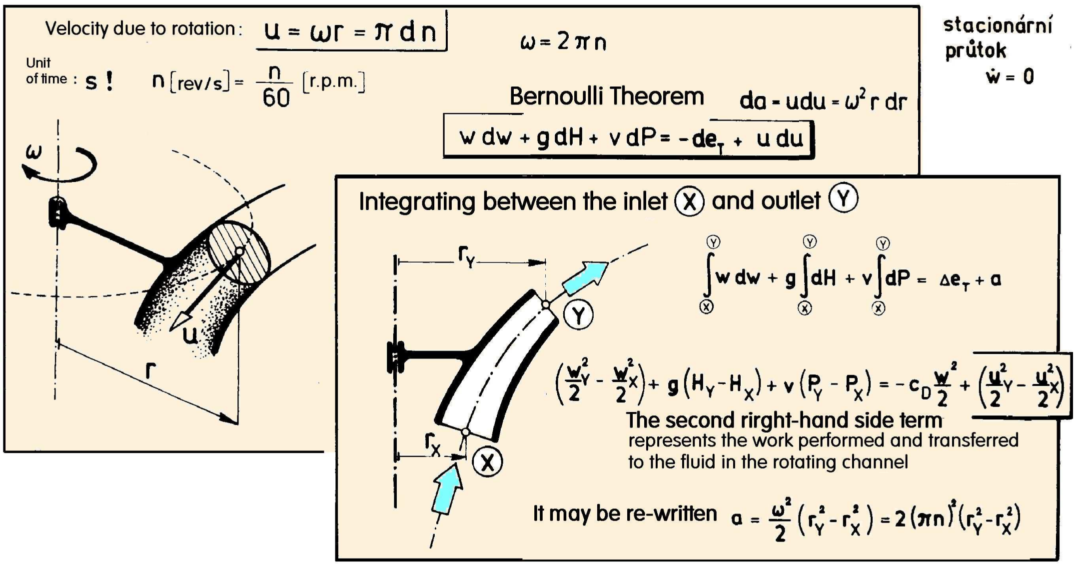

Figure 3 **(Taken from textbook [2]) the expression for evaluation of the specific work a in Fig. 2 is obtained very simply by expansion of the Bernoulli Theorem, adding to it the term representing the kinetic energy of the velocity u of the rotational motion.**

One of the basic steps in the present investigation was to establish whether actual loading behaviour of the investigated blower may be usefully expressed by an formula according to eq. (3) and to find the values of the corresponding parameters a and Q. The magnitude of the work parameter a is then compared with the expression according to Fig. 3 so as to learn about the plausibility of this quadratic modelling approach. The blower is to be operated at different rotational speeds of the driving motor. In principle, this experimental task should be repeated again for each adjusted speed, kept constant during a particular experimental run. However, the theory explained in [2] has lead to an universal dimensionless representation which, if found valid, may be applied to any particular driving speed. This potential universality - validity for any driving speed - is considered an important factor, deserving the effort spent on the evaluation of the characterization parameters.

3. Experiment

When the blower was received from the supplier, it was disassembled for inspection of the internal components. Considering the very high price of the blower, the appearance of these components was rather disappointing. There is no stator; all the pressure rise has to take place in the volute body. The rotor also does not show signs of particular care in its design. Its photograph is presented in the accompanying Fig. 4. Its shape, without the rotor cover disk and obviously not very carefully shaped blades, did not lead to particular confidence - the more so that the fixing of the rotor to its shaft was obviously of very poor quality so that the rotor wobbles visibly when slowly rotated. At this stage, however, it was decided not to apply any improvements.

Figure 4 **Photograph of the rotor of the investigated blower (taken by Mr. J. Šafář). Note the absence of the rotor cover disk. The essential geometric parameters (as defined in ref. [2]) are as follows: rotor outer diameter: d_Y = 147 mm, blade exit length b_Y = 39.7 mm. Calculated from these values, the exit area is $F_Y = 18.334 \ 10^{-3}$ m^2.**

The layout of the experiments is seen in the schematic representation in Fig. 5. The task of investigating the whole length of the characteristic curve gave rise to the operation with an auxiliary air source. The capacity of the source was limited and also the orifice meter used was of rather small internal diameter so that the blower could be reasonably investigated only at relative low speed values. This, however, was not considered a substantial drawback, due to two circumstances. First, the blower was intended for use at low Reynolds numbers in the flow visualisation runs (where the inevitable turbulence

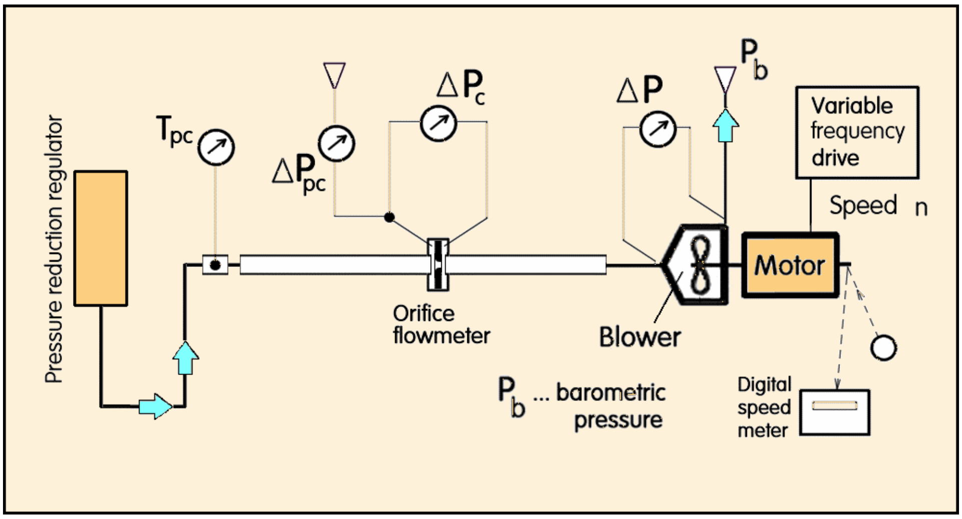

Figure 5 Schematic representation of the performed experiments. The air flow rate is dictated by the external source. While the speed of the driving motor is kept constant, the air flow supplied from the regulator is gradually increased and measured by the orifice flowmeter.

Figure 6 Photograph of the experimental set-up. The investigated blower is the black body, slightly to the right from the centre of the picture. The grey driving electric motor is connected to the blower body. Also visible as connected to the blower body are two grey pipe stubs, one vertical and one horizontal, located in which are the pressure taps for measuring the pressure drop across the blower. The vertical pipe is the air exit into the atmosphere, the horizontal inlet pipe is connected via the green garden hose with the orifice flowmeter, only partly visible in the background. The small red, white, and blue meters are the digital instruments (thermometer and two manometers) for reading the values input manually into the notebook computer in the foreground.

associated with high speeds would disturb the motion of the tracer particles. The second reason was the expectation that if the blower behaviour is deteriorated by flow separation on the leading edges of the blower blades, the effect is expectedly more pronounced at low Reynolds number values.
Properties of the used orifice flowmeter were investigated earlier and the experience gained is described in reference [8].
The pressure taps at the inlet and outlet of the blower were placed in polymer tubes (grey colour in Fig. 6). Both tubes were of the same diameter, so that the differences in the kinetic energy Δe_k were very small - in fact negligible, because the blower was operated at the low speeds where the velocity and hence kinetic energy of air in the inlet tubes was insignificant.

.

5. Loading characteristics

These characteristics are graphical presentations of the measured specific energy drop across the blower, evaluated according to eq. (2) from the measured pressure difference, as a function of the measured mass flow rate. The first example is the diagram in Fig.7. The red data points indeed do follow the quadratic dependence according to eq. (3).

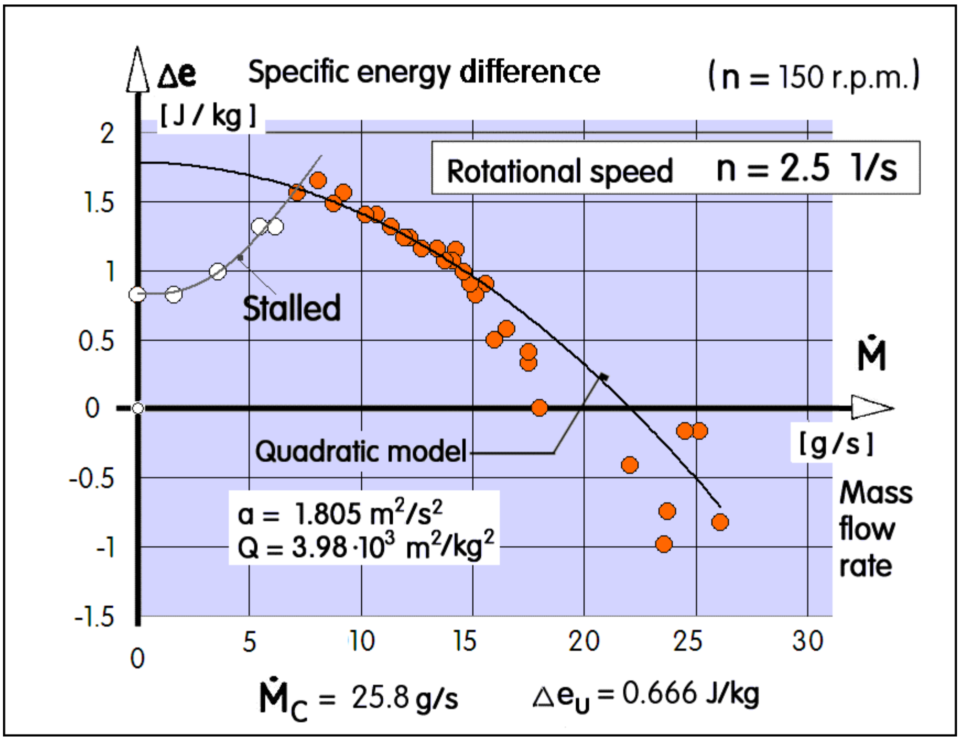

Figure 7 Experimental results: loading characteristic of the blower at a constant rotational speed of the driving motor. The quantities used in plotting the result correspond to those in ref. [2], except of a small change in symbols: the multiplicative operator of derivation with respect to time in the symbol for the mass flow rate in [2] is here replaced by the dot symbol. The measured pressure drops were very small, especially at the right-hand end of the curve, and this has led to the considerable scatter. Nevertheless, the representation by the quadratic model discussed above is quite reasonable, except for the region of very small flows, at the left-hand end of the curve, where the flow obviously separates from the rotor blades.

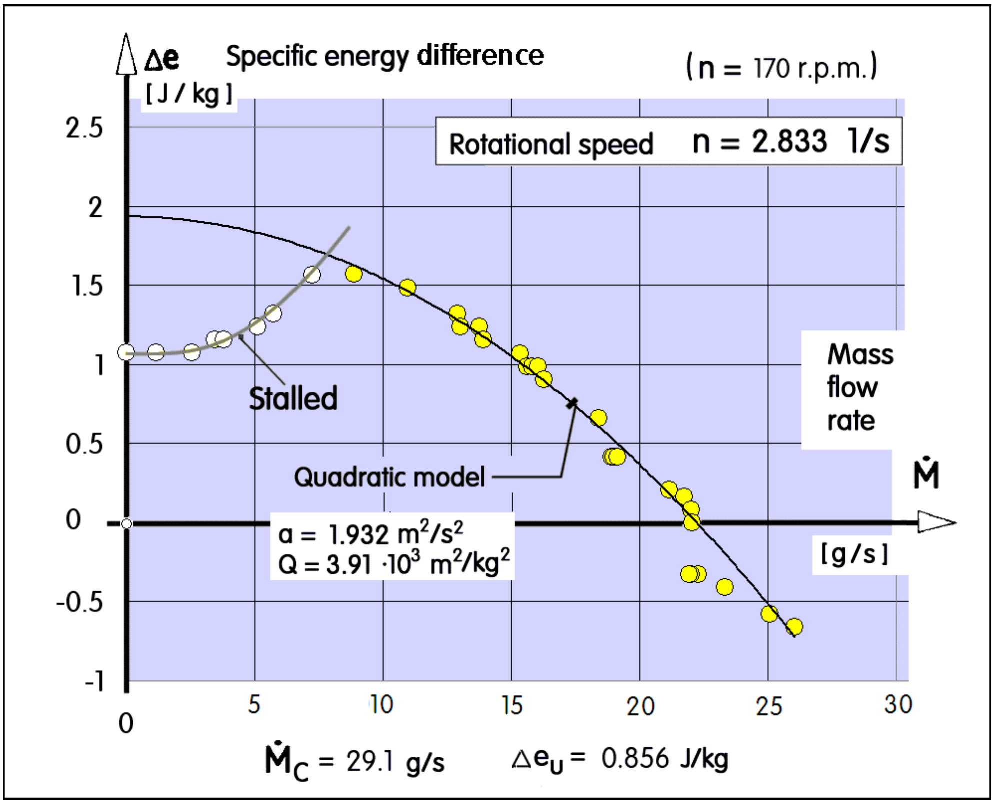

Figure 8 **The same general character of the behaviour as that shown in Fig. 7, is found here for another set of experimental data obtained at a slightly higher rotational speed. In the region of interest it is again well represented by the quadratic model of Fig. 2. Again, the motor speed was kept constant during the test run. The higher generated pressure differences could be obviously measured more exactly, so that the diagram exhibits less scatter. Interestingly, as in the other two diagrams (Fig. 7, Fig. 9) also the data points for the stalled regime may be best expressed by a quadratic dependence, different of course from the one which is suitable for characterising the regime in which the blower is to be operated.**

Unfortunately, they fail to do so at very small flow rates, when the flow through the blower is strongly blocked by the connected load. It is not intended to operate the blower in such regimes (as described in part 7, we plan to operate it at or near to the optimum, which is at higher flow rates) so that the quadratic model of blower behaviour is a useful proposition. At any rate, the positive slope of the loading characteristic in the region of small flows means that the blower in this regime would be unstable.

The data points in the small-flow region, deviating from the predictions of the quadratic model, are shown empty (white). The plausible explanation for the deviation is doubtlessly a separation of the flow from the rotor blades. The air in this regime comes towards the leading edges of rotor blades (at the small, entrance diameter) at a too large attack angle. Inspection of Fig. 4 shows the blades there to be not far from radial, certainly an unsuitable inclination for flows with small radial component. The separation as the most likely cause is to be also expected because of the very low Reynolds numbers, normally not encountered in turbomachines: when evaluated from the conditions at the exit from the rotor, and the rotor exit width (= blade height) the Reynolds number in this case is as low as

$$Re_{bY} = 2\ 460 \qquad \text{... (4)}$$

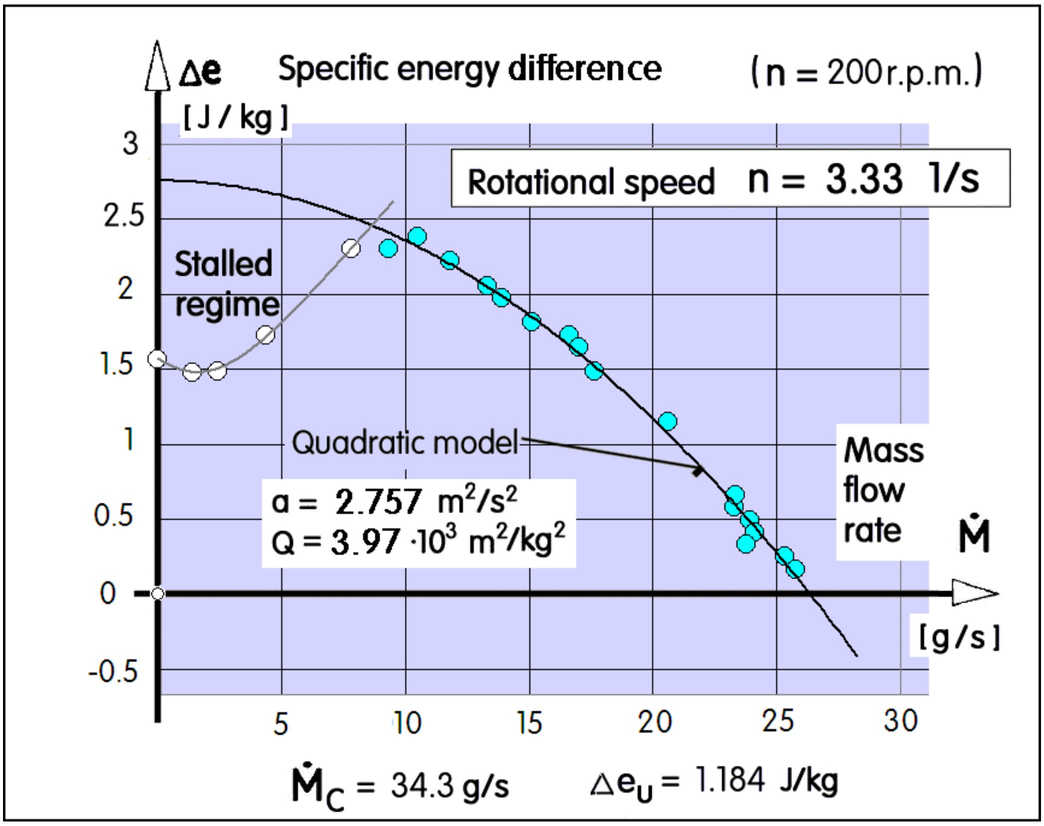

Figure 9 **Yet another set of experimental data for the loading characteristic of the blower was obtained at another, higher still rotational speed. The relative extent of the stalled regime region (where the symbols are empty, white) decreases as the motor speed in increased and this phenomenon becomes less prominent as the speed is increased.**

- evaluated for the ideal situation of the largest air mass flow rate (21.4 g/s) at which the pressure drop across the blower is zero.
The next two examples in Fig. 8 and Fig. 9 present analogous loading characteristics obtained in the experiments at higher rotational speeds. as before, the properties are found to be well represented by a quadratic dependence of eq. (3) – with the exception of what is doubtlessly the region of stalled flow on rotor blades as small mass flow rate values. It may be perhaps noted that even the relatively small increase of the speed increases the output pressure (and hence output specific energy) difference considerably – the consequent increase in pressure reading accuracy is reflected in diminishing scatter. A closer inspection of the stalled-flow region shows also decreasing extent of this part of the diagram (in which, for discriminating them, the data point symbols are empty). This decrease of the flow separation is quite probably a consequence of an increase in the Reynolds number values. The value of the Reynolds number obtained by an analogous procedure to that presented in eq. (4) is

$$Re_{bY} = 3\ 200 \qquad \dots (5)$$

- a value certainly still to low, of course. for the separation being eliminated altogether (even in fully turbulent high Reynolds number regime the separation is likely to occur because of the unsuitable, nearly radial shape of the rotor blades).

6. Application of the quadratic model

If a turbomachine loading behaviour is approximated by the simple quadratic model of eq. (3), its properties as far as the loading is may be fully characterized by the two characterisation parameters, the specific work input parameter a and and the dissipance Q specifying the internal losses. The magnitude of the parameter a may be increases with increasing rotational speed of the driving shaft through which the mechanical work is input. On the other hand, the dissipance Q is expected to be nearly constant - it varies only insignificantly due to the dependence of the hydraulic losses, which this quantity represents, on Reynolds number.

In the present case, the two parameters are to be evaluated by analysis of the experimental data. The best procedure for the evaluation is using the standard least-squares linear fitting to the data re-plotted in a form in which the data points fall on a straight line. Assuming validity of eq. (3), the desirable linear form is obtained by re-plotting the dependence of the specific energy difference Δe between the two fluidic terminals of the blower on the ***square*** of the mass flow rate $\dot{M}$.

This re-plotting is done in Fig. 10 for the two of the examples shown above. Indeed, the diagram shows that the characteristics in this representation are reasonably well converted into the required linear dependences. After fitting the straight line through the data points, the work input parameter a is obtained as the intercept of the linear dependence while its slope determines the dissipance Q. The values found in this way were actually already used above to draw the quadratic model curves in the three diagrams Fig. 7 to Fig. 9. Despite the scatter in the measured values, the dissipance values were indeed found to be very near to one another.

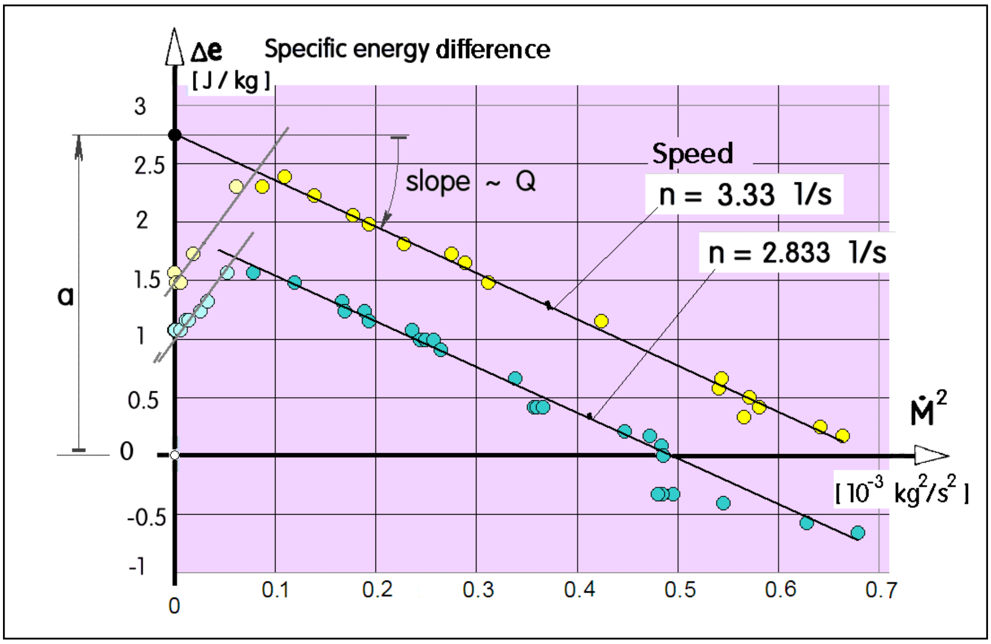

Figure 10 **The two coefficients a and Q that define the blower behaviour conforming to the quadratic model were evaluated from the experimental data by plotting the specific energy difference against the *square* of the mass flow rate – this transformation of the diagram should convert the dependences described by eq. (3) into straight lines, which is here seen to be indeed the case.**

7. Power characteristics and optimum loading

One of the output results of the present investigations was an information needed for designing the experimental rig operating with the investigated blower. Evaluating the blower properties should therefore provide data base for layout of the rest of the semi-closed recirculation aerodynamic circuit in which the blower would operate optimally, with best utilisation of its capabilities. It was decided that the performance parameter used as the criterion of optimality is the effectiveness of power transfer into the passive rest part of the air flow system. The power, of course, is the product of the two state parameters Δe and $\dot{M}$:

$$\dot{A} = \Delta e \ \dot{M} \ [W = kg \ m^2/s^3] \qquad \text{... (6)}$$

If, as is here assumed – and already supported by the experimental evidence - the dependence between the two parameters in the vicinity of the operating state is determined by eq. (3), the power characteristic are described by the cubic relation

$$\dot{A} = \Delta e \ \dot{M} = a\dot{M} - Q\,\dot{M}^3 \qquad \text{... (7)}$$

Experimentally determined values of the output power of the blower for the two different motor speeds are plotted in Fig. 11. They are there compared with predictions of eq. (7) into which were substituted the characterization quantities a and Q determined by the straight line fits in Fig. 10. Evidently, the correspondence is excellent.

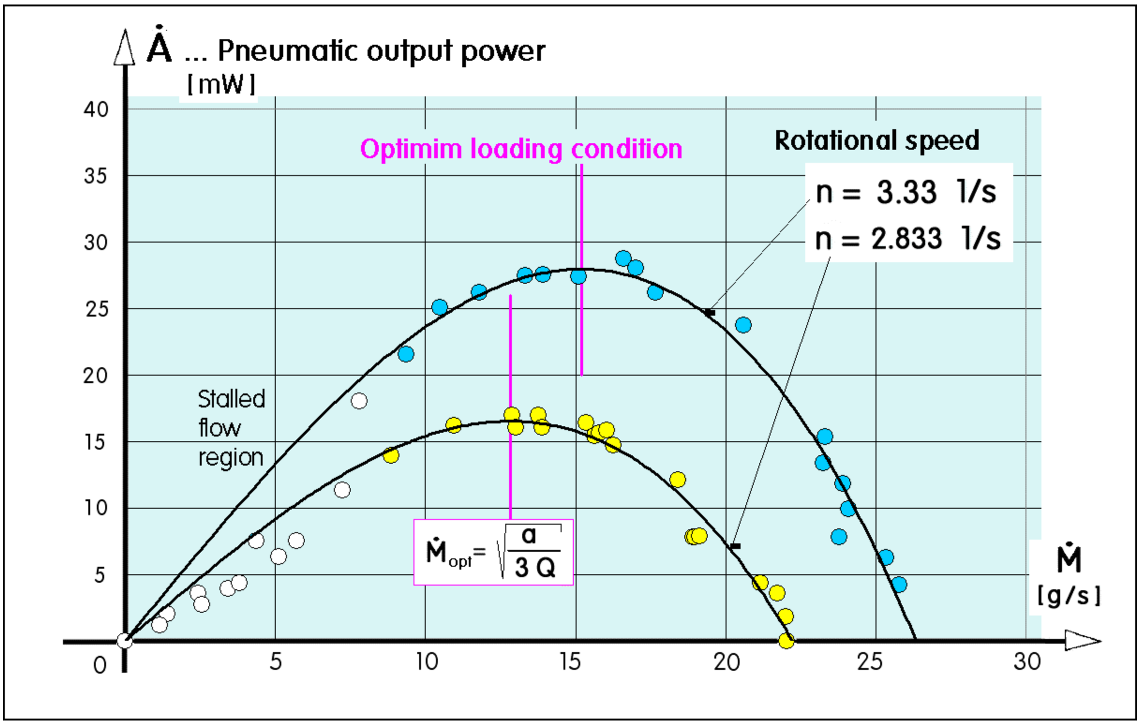

Figure 11 **Power characteristics the measured blower at two different rotational speeds. Values evaluated from the experiments are confronted with the optimum loading predictions resultant from the quadratic model of Fig. 2. Of course, the maxima are flat so that the prediction accuracy is not critical – nevertheless. it is apparent that the quadratic model predictions provide a very good tool for designing fluidic circuits.**

The optimum operating state of the blower is evaluated from eq. (7) by applying the condition of zero slope in the flat maximum

$$\frac{\partial \dot{A}}{\partial \dot{M}} = \quad a - 3 Q \dot{M}^2 = 0 \qquad \text{... (8)}$$

- from where the optimum mass flow rate is

$$\dot{M}_{opt} = \sqrt{\frac{a}{3\,Q}} \qquad \text{... (9)}$$

and the corresponding optimum difference in the fluid specific energy is

$$\Delta e_{opt} = \frac{2a}{3} \qquad \text{... (10)}$$

Again, the predictions of the quadratic model are shown in Fig. 11 to provide a very good information about the optimum operation of the blower and thus show the usefulness of this model for engineering purposes.

8. Universal dimensionless representation

The nondimensionalisation of turbomachine loading characteristics in [2] is based on relating the mass flow rate $\dot{M}$ to the characteristic value

$$\dot{M}_C = \frac{F_Y\, u_Y}{v} \qquad \text{... (11)}$$

evaluated from the rotational velocity u_Y at the rotor outer diameter (Fig. 3), and from the rotor outlet area

$$F_Y = \pi\, d_Y\, b_Y \qquad \text{... (12)}$$

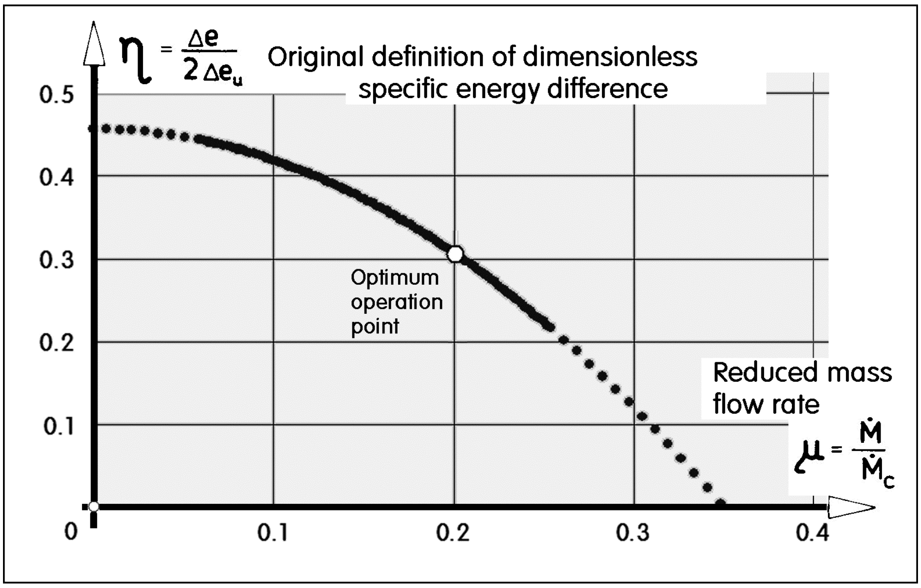

Figure 12 **The dimensionless co-ordinates μ and η for universal characterisation of blower behaviour at any rotational speed - as originally recommended in ref. [2]. The curve and the optimum point shown here are actually valid for a water pump used in thet reference as an example.**

To nondimensionalise the other state parameter, the difference Δe in specific energy of the fluid gained in the turbomachine, a generally accepted approach is to relate it to the predicition of the increase obtained from the simple one-dimensional calculation of the kinetic energy of the rotational motion. According to Fig. 3,

$$\Delta e_{\mathbf{u}} = u_Y^2/2 \qquad \text{... (13)}$$

- based on the assumption of the rotor blades designed so that the velocity of the rotational motion in the rotor inlet **X** is zero. In fact, the non-dimensionalised co-ordinates in ref. [2], as they are shown above in Fig.12, are based on relating the difference Δe to the square of the rotational velocity on the rotor circumference, i.e. to

$$2\,\Delta e_{\mathbf{u}} = u_Y^2 \qquad \text{... (14)}$$

Nevertheless, the reference quantity without the numerical factor **2.0** is better supported by logic of the resultant expressions: when applied to the quadratic model formula eq. (3), the non-dimensionalisation leads to the universal model relation

$$\eta = \alpha - c_{DY}\,\mu^2 \qquad \text{... (15)}$$

valid, for a given design of the turbomachine, for any driving speed. The first term

$$\alpha = \frac{a}{\Delta e_{\mathbf{u}}} \qquad \text{... (15)}$$

is obviously the effectiveness of idealised (loss-less) energy transfer in the machine, while the general expression for dissipance [2], [7]:

$$Q = \frac{c_D}{2}\left(\frac{V}{F}\right)^2 \qquad \text{... (16)}$$

- where cD is the drag (or loss) coefficient – when inserted into eq.(3) shows that the non-dimensionalisation of the internal loss term results provides also a useful physical meaning.
Universality of the expression eq. (15), which should completely describe the behaviour of a given machine geometry at any input shaft speed (as long as the deviations due to the Reynolds number dependence of the coefficients do not become too large) was tested in the present case. The experimental data for the blower were non-dimensionalised as shown in Fig. 13 and plotted simultaneously into the same diagram. The positive experience with plotting the characteristics – as was done in Fig. 10 – with the squared value on the horizontal axis was also used to get the final diagram as presented in Fig. 13. This converts also the dimensionless presentation into a form with simple linear shape of the characteristic curve. The general conclusion from the result in Fig. 13 is the fact that despite the inevitable scatter, the simple eq. (15) is a remarkably good universal representation of the blower properties, providing all the essential information for engineering purposes.

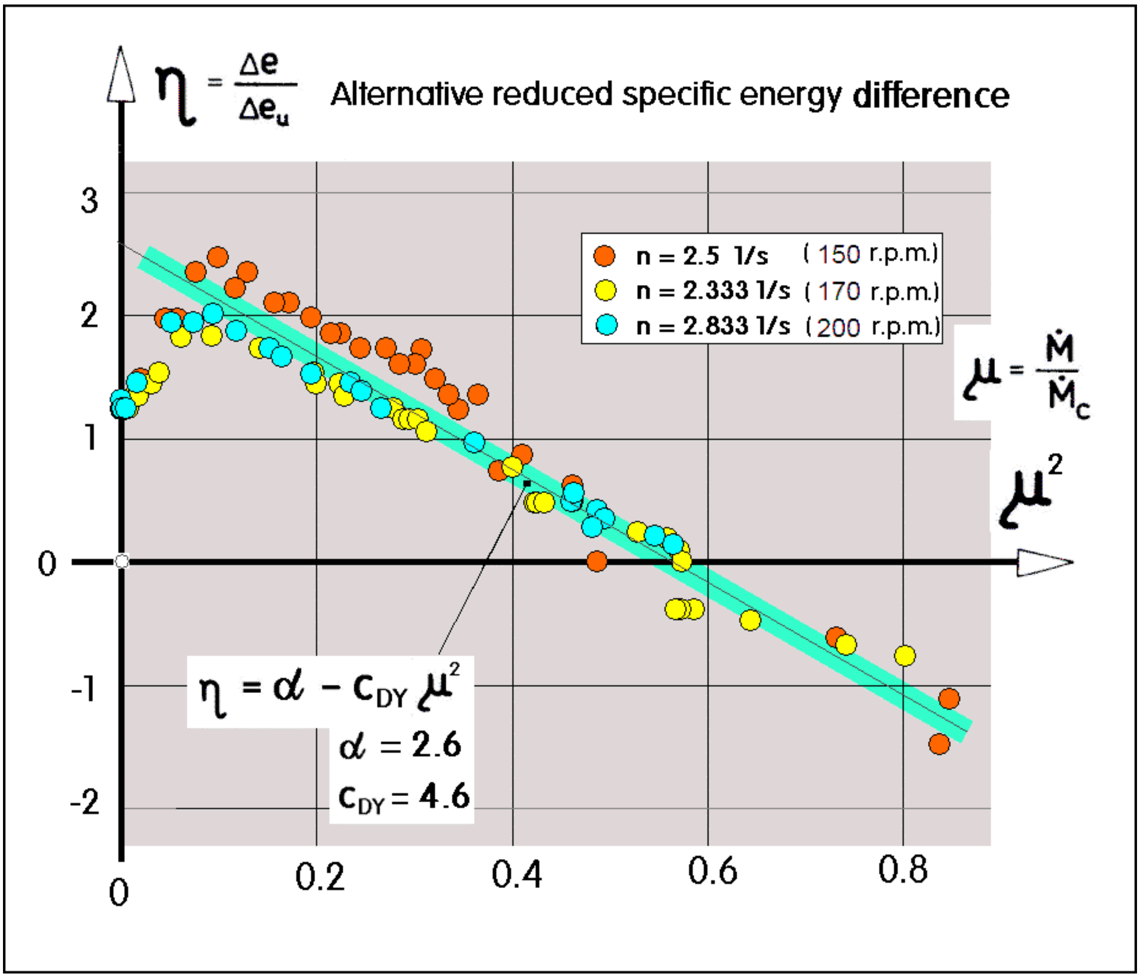

Figure 13 **The universal non-dimensional diagram describing the loading properties of the investigated blower. The non-dimensional representation squeezes the experimental data obtained in the three experiments practically into a single line. Note that the vertical co-ordinate differs by a numerical factor 2 from the non-dimensionalisation used previously in ref. [2]. The other difference, when compared to the standard co-ordinates as shown e.g. in Fig. 12, is the different horizontal co-ordinate that converts the characteristic curves into straight lines.**

The resultant eq. (15) ceases to be applicable at very small values of the dimensionless flow rate μ , roughly below $\mu = 0.08$. This is not likely to cause problems in practice as the blower is to be operated (Fig. 11) with larger flow rates.
Experimental data accumulated in the present measurements moreover show that the relatively large region of the stalled flow is a property found when of operating the blower at very low Reynolds numbers. As the rotational speed (and hence Reynolds number) increases the data in Fig. 14 indicate a considerable increase of the specific energy in the stalled region very near to the vertical axis of the diagram in Fig. 13. Even at quite high speeds, however, the values η in Fig. 14 are below the ideal point $\alpha = 2.6$ as evaluated in Fig. 13. This means that a small separation region remains there, no doubt because of the improper inclination of the rotor blades at the inlet, as was already noted when in Fig. 3 the blades were seen to be practically radial there.

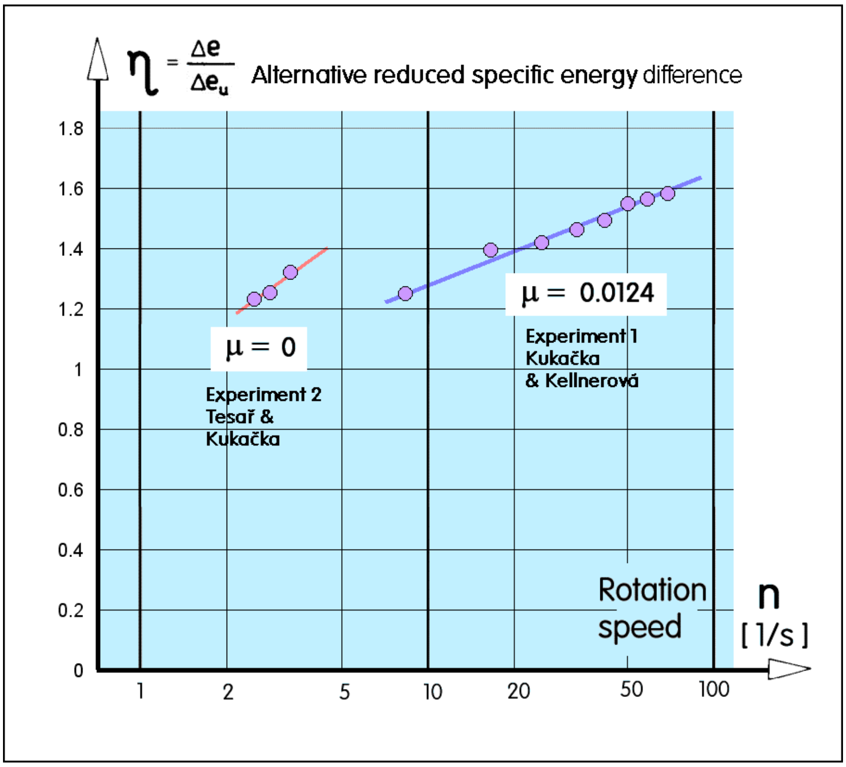

Figure 14 **The decrease of the stalled flow region with increasing Reynolds numbers (no doubt due to the less tendency to separation in flows with turbulence) was found in the experimental data and is documented here by the measured data showing an increase of the relative specific energy difference with increasing rotational speed at very small relative output flows.**

9. Criterial parameter of turbomachine similarity

Yet another interesting aspect discussed in ref. [2] was the conspicuous similarity of properties of those turbomachines that exhibit the same value of the coefficient

Reduced speed coefficient

$$c_\omega = \frac{2\pi n \sqrt{\dot{M}_{opt} . v}}{(\Delta e_{opt})^{3/4}}$$

- the so called reduced speed. This quantity was also evaluated from the present experimental data. Its numerical values was not found to be so much identical in the various experimental runs, as was expected and there was a considerable scatter in the data. The resultant value that may be claimed to characterise the investigated blower is

$$c_\omega = 1.6 \pm 0.2 \qquad \text{... (17)}$$

When compared with the available data, e.g. as presented in [2], this is a value that classifies this blower as a rather high speed machine, with a design that makes it more compact than majority of similar design.

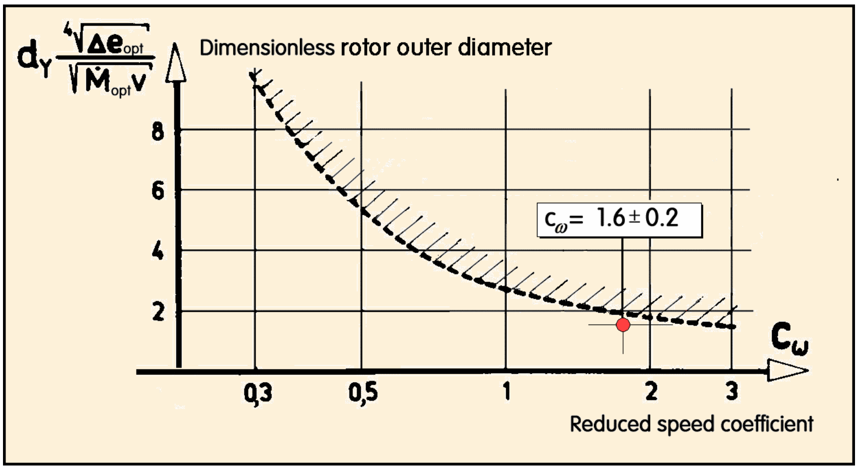

Figure 15 **The diagram of general dependence between the outer diameter of a machine rotor and its reduced speed - taken over form ref. [2]. The dependence is characterised by a large scatter, since the properties also depend on design details of a particular machine, not involved in the formula for the reduced speed. High-speed machine designs are chosen in situations demanding small size (which, of course, is directly related to the diameter of the rotor). The values evaluated for the investigated blower show that its design is rather good from the compactness point of view, its rotor diameter being smaller than could be expected on this basis of comparison with other machines.**

10. Conclusions

The authors performed experimental investigations of a supplied blower when used at very low absolute rotational speeds. The data obtained were used to test practical validity of the general ideas about universal representation of characteristics and criterial similarity parameters of turbomachines, as they were published considerable time ago [2] but seemingly little known and used. Also of interest in this investigation was the applicability of the simple quadratic two-component model of blower behaviour.

It was found that the properties of this blower are more complex than expected because of the presence of almost doubtlessly is consequence of stall in rotor blades. Outside from this region, which is not of practical importance for the intended use of the blower, the quadratic model of [2] was found to be extremely useful. It provides a simple and yet excellent approximation relations for loading and power characteristics. The deviations from this model are less than typical scatter of the experimental data.

The important conclusions from this analysis is that the quadratic model is applicable even at very low Reynolds numbers. It is useful even in situations where it may be applied to only a part of the of the loading curve. The non-dimensionalisation – practically equivalent to those discussed in [2] – was found useful for obtaining a universal loading curve dependence, valid practically for any rotational speed

New methods and approaches introduced in the present paper is on one hand the used method of determining the model parameters a and Q from experimental data and on the other hand the interesting method of presenting the dimensionless values – Fig. 13 – converting them so that they are fitted by a simple straight line.

11. Acknowledgement

The authors gratefully acknowledge the support of the Grant Agency of the Academy of Sciences of the Czech Republic by grant No. 207 60705.

References

[1] Tesař V.: "*Koncepce experimentálního zařízení pro výzkum proudění se šroubovicovými nestabilitami*", in Czech, Research report No. Z 1405/07, Institute of Thermomechanics of the Academy of Sciences of the Czech Republic v.v.i., June 2006

[2] Tesař V. : „*Mechanika tekutin pro 4-leté studijní obory*", in Czech, textbook ČVUT in Prague, various editions 1983 - 1990

[3] Moiseev S.S., Pungin V. G.: "*Analysis of Nonlinear Development of Helical Vortex Instability*", Fractals, p. 395, Vol. 10, No. 4, 2002

[4] Tesař V., Zimmerman W.B.J, Regunath G.: "*Helical Instability Structures in Swirling Jets*", Proc. of 8th International Symposium on Fluid Control, Measurement and Visualization, Chengdu, China 2005

[5] Regunath G., Tesař V., Zimmerman W.J.B., Russel N.: "*Novel Merging Swirl Burner Design Controlled by Helical Mixing*", Paper 0153 - 0027th World Congress of Chemical Engineering, Glasgow, 2005

[6] Tesař V.: *"Dvě zajímavá čerpadla pro mikrofluidické obvody"* Automatizace, ISSN 0005-125X, Volume, No. 1, January 2004

[7] Tesař V.: "*Fluidic Circuits*", pp. 255-304, a chapter in " *Microfluidics: History, Theory, and Applications"*, Editor W. B. J. Zimmerman, published by Springer-Verlag, Wien - New York, ISBN-10-3-211-32994-3, 2006

[8] Randa Z., Tesař V., Hrubý J.: "*Artifacts in the Calibration of an Orifice with a Rotary Piston Meter due to a Resonance of the System*", p. 133, Proc. of the Conference 'Topical Problems of Fluid Mechancs 2007', ISBN 978-80-87012-04-8, Prague, 2007