AN EXPERIMENTAL INVESTIGATION INTO THE EFFECT OF ERRORS IN BLADE SETTING ON THE LOW - SPEED PERFORMANCE OF A COMPRESSOR CASCADE

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دراسة تجربية لأثر أخطاء الموضع على اداء مصفوفة اجنحة لضاغط محوري

يتعرض هذا البحث بالتحليل والمناقشة لنتائج دراسة تجر يبية لاداء مصفوفة أجنحة لضاغط محوري في ظل أخطاء موضع دورية وعشوائية في احد الأجنحة . وتتضمن هذه الأخطاء ازاحات متعمدة في اتجاه وتر الجناح واتجاه المصفوفة وكذلك ازاحة زاوية حول نقطة منتصف الوتر .

ويتضح من الدراسة أن توزيع الضغط بالنسبة للجناح الذي تتركز فيه الأخطاء وكذلك بالنسبة لجناح على كل من جانبية يتأثر كثيراً بسبب أي من الأخطاء المذكورة في الفقرة السابقة . ومن ناحية اخرى – فان القيمة المتوسطة لزاوية السريان عند المخرج تتأثر بشكل واضح بوجود خطأ زاوي دوري أو عشوائي بينما يبدو ذلك الاثر طفيفاً بالنسبة للأخطاء الأخرى .

واستناداً الى النتائج السالفة الذكر فانه يجب النص على أخطاء الموضع كيفا وكما عند عرض أية دراسة تجربية لأداء مصفوفات الأجنحة . فمثل هذا النص من شأنه ان يجعل المقارنة بين النتائج التي يحصل عليها باحثون مختلفون مقارنة منطقيــة وسليمة .

The main findings of some recent experiments on the effect of one-blade periodic as well as non-periodic (random) setting errors on the performance of a plane compressor cascade are reported and discussed. The tests were conducted on a low speed blower tunnel and at a Reynolds number in the region of 3×10^5 *(based on blade chord and upstream averaged velocity). During all tests the percentage increase in the pitch-averaged axial velocity of the flow was limited to about* 17. *Moreover, the incidence angle was kept away from the stalling region.*

Three types of error were introduced, namely, chordwise, cascadewise, and angular displacement in the error blade. Positively signed as well as negatively signed errors were tested. The results which are displayed in the full text of paper show that the performance of the test cascade is markedly affected by angular errors more than it is by other types of error. However, substantial alteration in the pressure distributions of the error blade and one blade on each side results in the presence of any of these errors. Further, the outlet flow angle is significantly affected by angular errors and hardly by other types.

It is emphasized that errors in blade setting must be reported along with cascade data and be taken into account when comparing results obtained by different investigators.

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INTRODUCTION

The effect of blade setting errors on turbomachine performance has been reported in a very few cases. For example, in axial-flow pumps it was observed that impellers manufactured according to the same design had repeatedly non-identical characteristics [2]*. This variation was attributed to probable errors in blade setting due to inadequate care in the assembly process. Further, it is believed that setting errors are responsible, at least in part, for the discrepancy and scatter observed with experimental data reported by different investigators for cascade of identical geometry. Unfortunately, such possible errors do not usually appear along with cascade data given in the literature. Gostelow (1) who reports measured errors in the stagger angle of his cascade blades is perhaps the only exceptional case.

Blade setting errors may be classified as periodic and random. In practice, periodic distribution of setting errors relates to the class of axial turbomachinery where the number of blades in each row is relatively small (e.g. axial-flow fans and probeller pumps). The equivalent two dimensional model for such case is an infinite cascade with periodic setting errors in one blade or more. On the other hand, in axial machines having large number of blades in each row (e.g. axial compressors and turbines), the error distribution, if any, may be considered non-periodic, i.e. random.

A blade setting error may be resolved into three components: displacement parallel to the chord line (chordwise error), displacement parallel to the cascade direction (cascadewise error), and angular displacement about the mid-chord point (angular error). Any of these components may be positive or negative. The sign notation used in the present experiments is shown in Fig.(3)

In the present experimental work two distinct but basic problems are considered. A cascade with non-periodic setting error in one blade, being the basic model for the problem of random errors, is first tested The same cascade with periodic error in one blade is next investigated as the basic model for the periodic error problem. In both cases the cascade was tested over a range of values of the setting error components with a view to obtaining the individual effects of varying each component on cascade flow parameters.

Numbers in brackets designate References at end of paper.

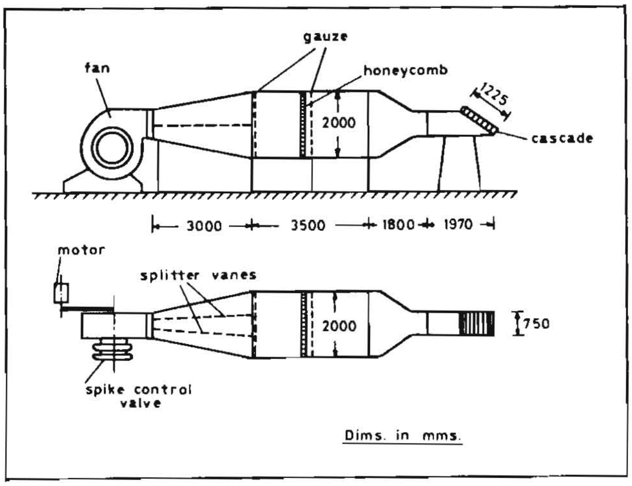

Fig. (1) Arrangement of cascade blower tunnel

Both problems were analysed theoretically in references [3] and [4].

EXPERIMANTAL SETUP

The experiments reported here were conducted on the solid-side-wall blower tunnel sketched in Fig. (1) The geometry of the test cascade when error free was as follows:

Profile	10c4/30c50 (British profile)
Space/chord	0.85
Stagger angle	36 degrees (measured from cascade normal)
Blade length	750 mm
Blade chord	180 mm
Aspect ratio	~4:1
Number of blades	9

The general arrangement of the test cascade is shown in Fig. (2) with blades numbered 1 through 9. Blades numbered 1,3,4,6,7, and 9 were permanently fastened to the side walls and were therofore considered error free blades. Other blades , numbered 2,5, and 8 were made adjustable so that any combination of setting error components could be imposed on any of these three blades, using the error-selection machanism shown schematically in Fig. (3) Thus for the periodic error problem, the period n_r was 3. For the problem of non-periodic error, only blade number 5 was set in the error specified. All blades were cast from fibre glass using the same mould to ensure all profiles are identical. The tunnel working section was equipped with flow traversing facilities and also

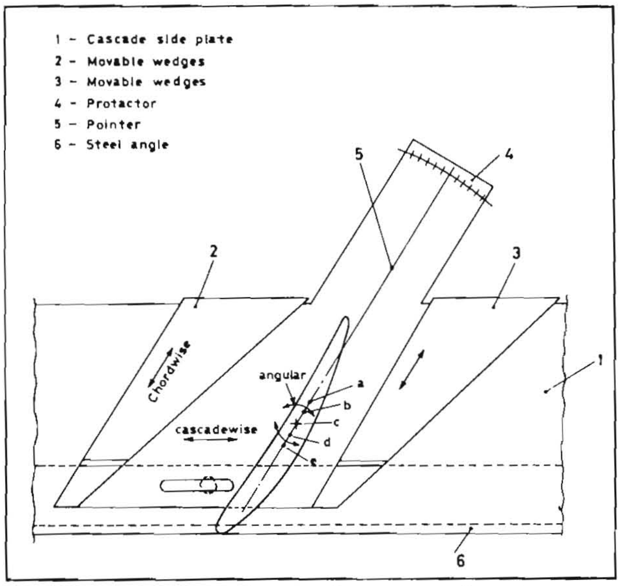

Fig. (2) *Test cascade configuration* (10C4/30C50, $s/c = 0.85, \sigma = 36°$)

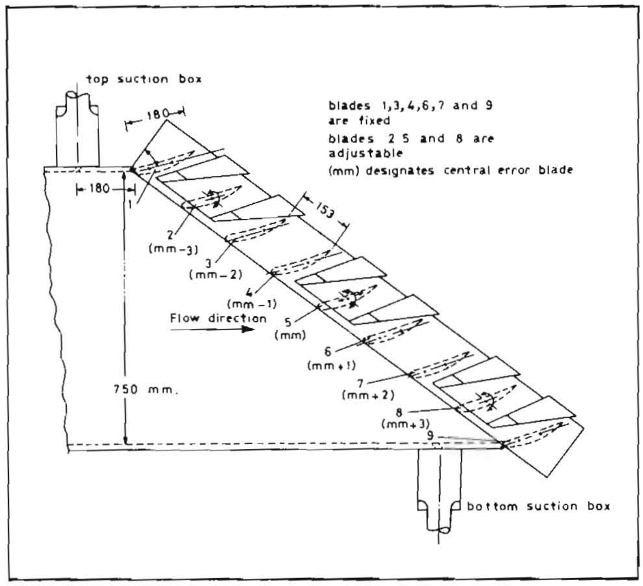

Fig. (3) *Error-selection mechanism*

with the necessary instrumentation for pressure recording and flow angle measurements.

EXPERIMENTS

First, the cascede blades were assembled between the leading and trailing edge lines previously marked on the end walls. The stagger angle half way between the end walls was then checked for all blades and the error was found to vary within 0.1 of a degree; which was adequate to consider the cascade as error fiee. Next, the cascade assembly was mounted on the working section and a preliminary error-free test was run in which the Reynolds number was maintained in the region of 3 x 10^5 (based on blade chord and upstream velocity). In this error-free test which was carried out at an incidence angle of 1.4 deg., the axial velocity ratio was estimated at 1.17. These values of Reynolds number, incidence angle, and axial velocity ratio were fixed for all subsequent experimentss within as close limits as possible.

Two series of tests were carried out. In the first series of tests, the central blade only (numbered 5) was set in error as predetermined, chordwise, cascadewise, or angular, testing a range of one error component at a time. Positive as well as negative values of eirors were considered. This series of tests was meant to represent the basic case of non-periodic error distribution. The second series of tests was cairied out as an example of the basic case of periodic error distribution. In this case, the three adjustable blades (numbered 2,5, and 8) were equally set in

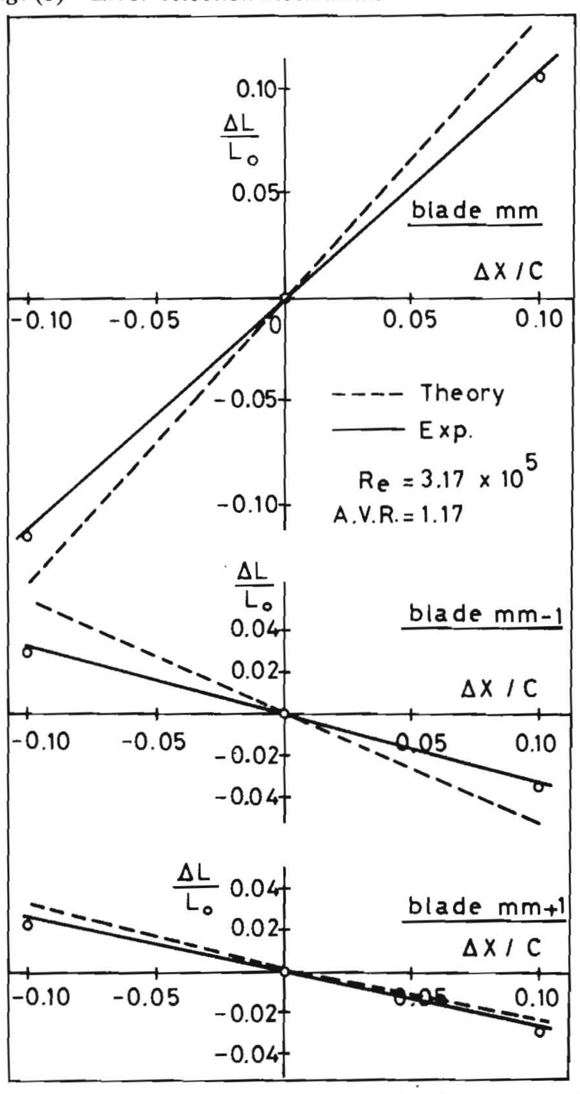

Fig. (4) *Change in lift versus one-blade* **non-periodic chordwise** *setting error.*

error, resulting in a cascade with one-blade periodic error distribution, the period n_r being equal to 3.

Pressure distributions and other flow parameters were recorded in each test. The momentum-weighted averaging method was applied wheie appropiiate and, hence, the aerodynamic performance was obtained. The individual effects of varying error components on the aerodynamic performance are displayed in Figs.(4) through 15. Discussion of these effects is given in the next section of the paper.

RESULTS AND DISCUSSION

I - One-Blade Non-periodic Setting Error Effects

Chordwise Setting Error

Fig. (4) shows the variation of the change in the lift coefficient of various blades with chordwise error in the setting of the central blade. It appears that the change in the life coeffieient of one blade on each side of the error blade is generally of the same order of magnitude as the error blade itself but of opposite sign. The variation is approximately linear, at least in the test range, and appears in reasonable agreement, with the theoretical result obtained in reference (4) for the same cascade and superimposed on the same plot.

Fig. (5) shows the effect of a particular chordwise error ($\frac{\Delta x}{c} = 0.1$) in the central blade on the pressure distributions of the central three blades. The effect is evidently substantial and should, therefore, have its consequent effect on the profile boundary layer growth.

Fig. (6) shows the effect of a positive as well as a negative chordwise error on the wake traverses one chord length downstream. It seems that this component of error has but very little influence on the outlet total pressure traverse. On the other hand, the outlet angle, as indicated by Fig. (6), is affected assymmetrically with respect to the error blade itself.

Cascadewise Setting Error

In Fig. (7) is shown the variation of the change in lift coefficient of various blades with cascadewise error in the central blade. The result for the blade facing the concave side of the error blade turned out negligibly small and is therefore not shown.

Fig. (8) which shows the effect of cascadewise setting error in one blade on the pressure distribution

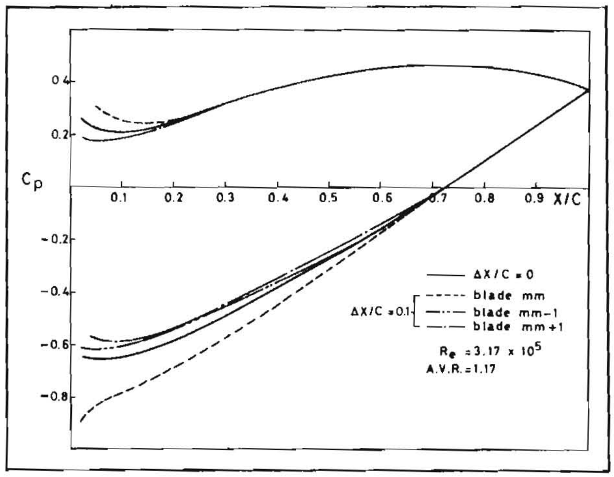

Fig. (5) Pressure distributions of various blades in presence of one-blade **non-periodic chordwise** *setting error.*

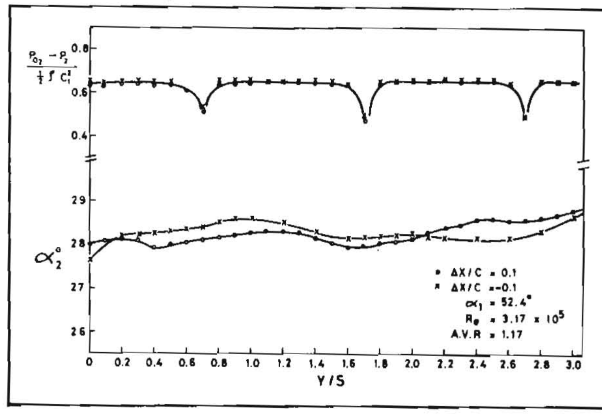

Fig. (6) Wake traverses with one-blade **non-periodic chordwise** *setting errors (one chord length downstream)*

of various blades may be compared with Fig. (5) indicating that the convex surface pressure distribution is relatively more sensitive to chordwise setting error than is the concave surface, whereas this effect is the other way round in the case of cascadewise error. It should be noted that a chordwise error in one of the blades is expected to result in a change in the position of the leading edge stagnation point of that blade and, to a lesser extent, of adjacent blades. On the other hand, a cascadewise error in one of the blades does not affect the position of the leading edge stagnation point of any blade, since the upstream flow is not disturbed in this case. Thus, it could be argued that the chordwise error effect on the pressure distribution is mainly due to shifting of the stagnation point whereas the cascadewise error effect is mainly due to change in blade interference effect.

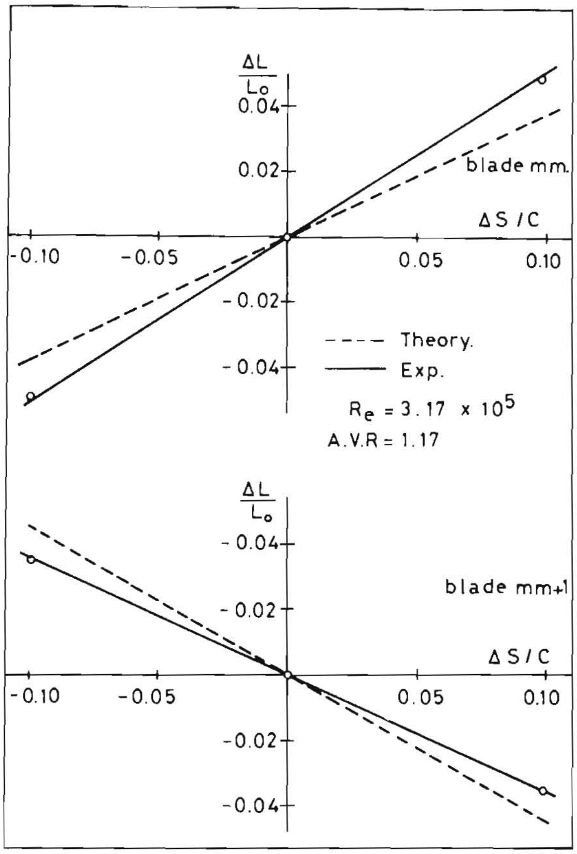

Fig. (7) *Change in lift versus one-blade* **non-periodic cascadewise** *setting error.*

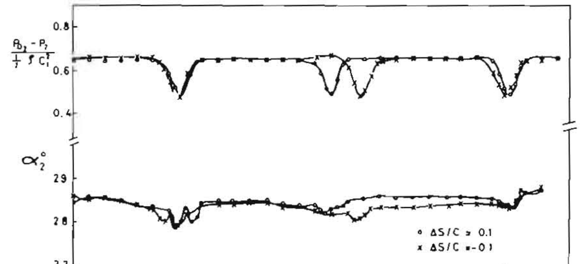

Fig. (9) *Wake traverses with one-blade* **non-periodic cascadewise** *setting errors (one chord length downstream)*

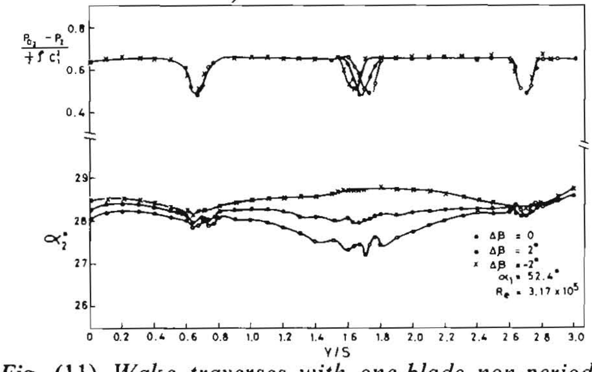

Fig. (11) *Wake traverses with one-blade non-periodic* **angular** *setting errors.*

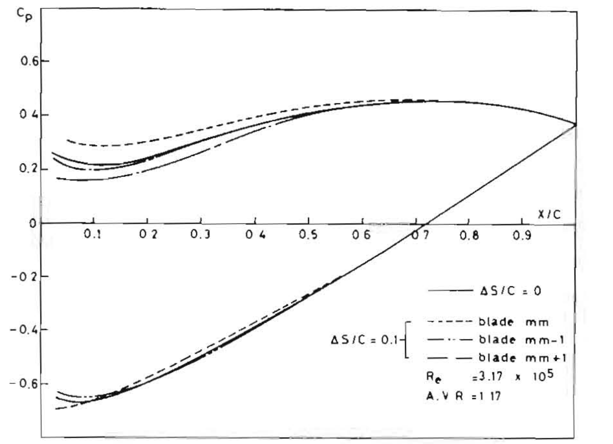

Fig. (8) *Pressure distributions of various blades in presence of one-blade* **non-periodic cascade wise** *setting error.*

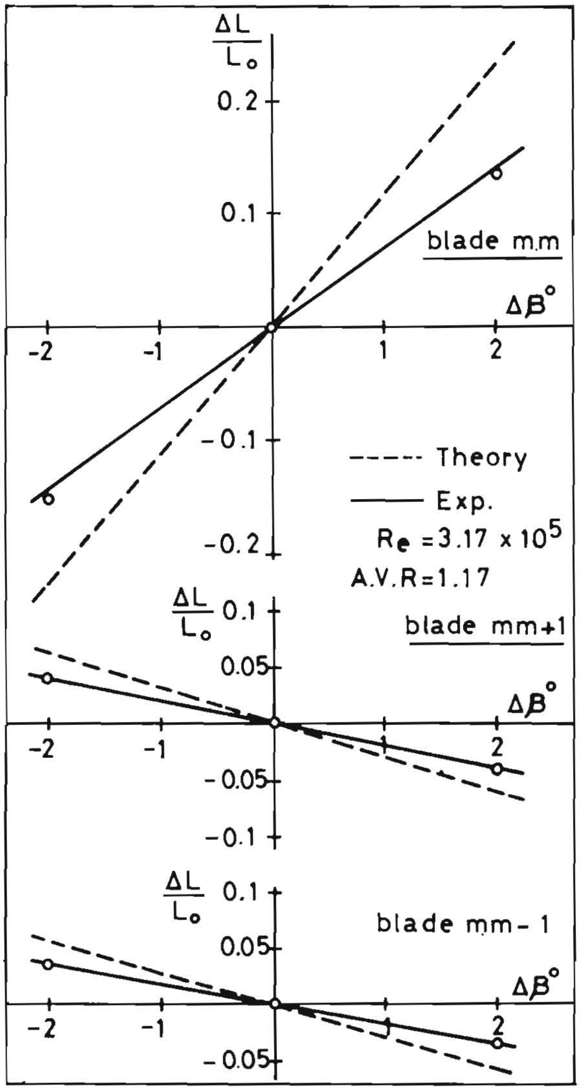

Fig. (10) *Change in lift vevsus one-blade* **non-periodic angular** *setting error.*

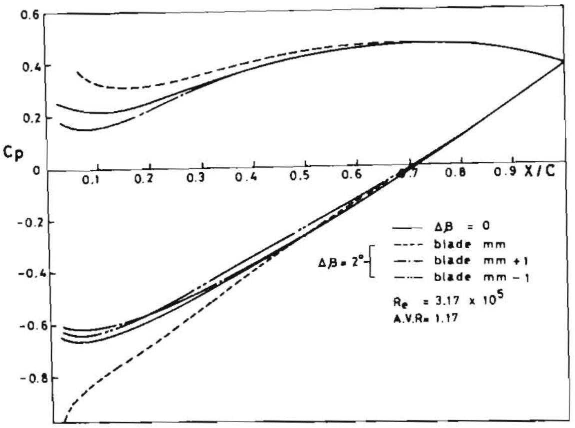

Fig. (12) *Pressure distributions of various blades in presence of one-blade* **non-periodic angular** *setting error.*

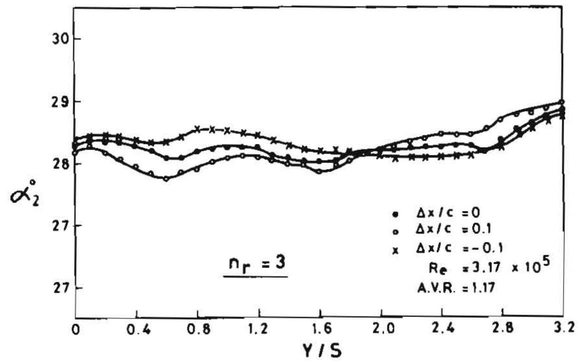

Fig. (13) *Wake traverses with one-blade* **periodic chordwise** *setting errors (one chord length downstream)*

Fig. (9) indicates that the cascadewise setting error in the central blade has only shifted the position of the central wake accordingly.

Angular Setting Error

The effect of an angular error in the setting of the central blade on the lift coefficient of various blades is presented in Fig. (10). It indicates that an increase in the loading of the error blade, due to a positive angular error, is accompanied by a decrease in the loading of adjacent blades. However, the algebraic sum of the changes in the loading of the central three blades (which are affected most by error in central blade) is significantly finite, producing a substantial change in the pitch-averaged outlet angle $\bar{\alpha}_2$ far downstream, as seen from Fig. (11).

Fig. (12) shows the marked effect of angular error in the central blade on the pressure distribution of various blades. In this case, the shift of the leading edge stagnation point as well as influence on blade interference should be equally considered in interpreting the resultant effect of the angular setting error.

II - One-blade Periodic Setting Error Effects

Fig. (13) and (14) show an example of the effect of a one-blade periodic chordwise as well as angular setting error distribution on the outlet flow angle traverse. The result appears closely similar to the case of one-blade non-periodic error just presented. Close agreement between theory and experiment is exhibited by Fig. (15) in so far as the effect of a periodic angular error on the pitch-averaged deviation angle is concerned.

It should be noted that Fig. (13), (14), and (15) are presented here as examples of periodic error effects and also to substantiate the theoretical analysis given in reference [3].

CONCLUDING REMARKS

(i) Substantial changes in the aerodynamic parameters of cascades can result from errors, random or periodic, in the setting of the cascade blades. Such errors must therefore be reported in conjunction with cascade data to validate comparison of results by different investigators.

(ii) The effect of setting errors on the loading of the error blade is, in general, opposite in sign to their effect on the loading of blades on eitheir side of the error one.

(iii) Cascadewise errors do not seem to affect the outlet flow pattern. However, the outlet angle traverse is assymmetrically affected by chordwise errors although its pitch-averaged value hardly changes.

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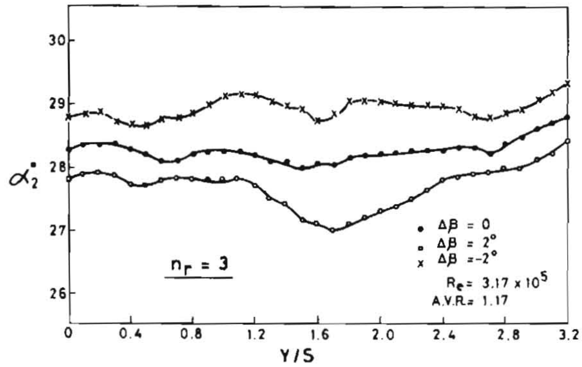

Fig. (14) *Wake braverses with one-blade* **periodic angular** *setting errors (one chord length downstream)*

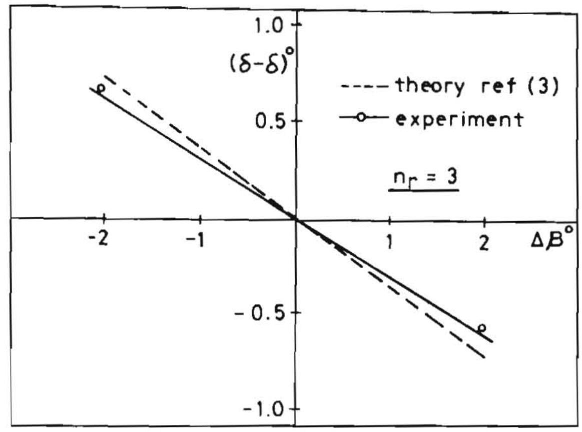

Fig. (15) *Comparison of experimental and theoretical changes in deviation with one-blade* **periodic angular** *setting error.*

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NOMENCLATURE

- C Fluid velocity
- c Blade chord length
- L Lift force
- x Distance along chord line measured from leading edge
- y Distance along cascade
- p Static pressure
- s Spacing

Definitions and Abbreviations

- C_p Local pressure coefficient $\left(= \frac{p-p_1}{\frac{1}{2}\rho C_1^2}\right)$
- n_r Period in case of periodic errors
- A.V.R. Axial velocity ratio $(= \bar{c}_{x2}/\bar{c}_{x1})$
- R_e Reynolds number $\left(= \frac{\rho\, c\, C_1}{\mu}\right)$

Greek Symbols

- α Air angle measured from cascade normal
- β Angle between chord line and cascade direction
- δ Deviation angle
- μ Viscosity
- ρ Fluid density
- ϱ Stagger angle $(= 90 - \beta)$
- Δ Incremental change in value.

Subscripts

- 0 For error-free cascade or stagnation value
- 1 At inlet
- 2 At outlet

Superscripts

- — Pitch-average value