

ST. NO. R13296

U.D.C.

AUTH.

THE COLLEGE OF AERONAUTICS
DEPARTMENT OF AERODYNAMICS

An investigation of the flow in an axial compressor inlet casing and its effect on the performance of the first stage of the axial compressor

-by-

G. M. Lilley, M.Sc., D.I.C., A.F.R.Ae.S.

and

B. R. Townsend

of the Department of Aerodynamics

Summary

The present report is a continuation of an interim report dated 8th August, 1951. The latter report dealt with the flow in a model casing whereas the present reports deals with a similar investigation on the 'Reavell' compressor inlet casing which is to be part of the 9in x 9in supersonic wind tunnel installation.

In the basic condition the flow had a circumferential instability* caused by the splitting of the inlet flow around the central shaft fairing. In addition the main flow through the casing was under-turned by approximately 20° . Consequently the flow at the exit annulus was unsteady and changes of 30° in the exit flow direction were found. It was also found that at least four guide vanes were stalled in any one flow configuration.

The instability was prevented by a flat dividing plate placed behind the central shaft fairing, but smooth flow at exit, in the vicinity of the plate, was only possible when curved fairings were added to both sides of the plate. A gauze screen, of 30 wires per inch, placed at entry, partly reduced the unsteadiness at exit but it had little effect on the flow direction and did not unstall the guide vanes. A perforated plate, having $\frac{1}{2}$ inch diameter holes and 50 per cent blockage, similarly placed, had little or no effect.

The guide ...

* In the previous report this same type of instability was called radial. It is now considered that circumferential instability is a better description of the phenomenon.

The guide vanes were unstalled by adding curved extensions to their leading edges. The large changes in the flow direction across the annulus at exit were, however, only reduced by modifying the internal contour of the casing. With these modifications flow angle variations of between 5° and 10° were obtained at exit. The velocity at exit was not uniform over the exit passages between the guide vanes, but the variations, which were not unduly large, were caused by secondary flows and the wakes from the vanes.

This investigation has clearly shown that in the basic condition the unsteady, non-uniform flow at the exit from the inlet casing, which is immediately upstream of the first stage of the compressor, will tend to cause periodic stalling of the rotating blades in that stage. Since the relative velocities are high the danger of running into stalling flutter cannot be overlooked, especially as the cascade effect may reduce the critical flutter speed of the isolated blade. Stalling flutter, which usually takes place in the fundamental torsional mode, may be aggravated by a high order resonance occurring at the given rotational speed of the compressor.

The suggested modifications to the design of the inlet casing should prevent stalling of the first stage blades of the compressor caused by upstream, unsteady, non-uniform flow.

1. Introduction

It was found in an earlier investigation (see interim report dated 8th August, 1951) of the flow in a model inlet casing, having similar design features to the 'Reavell' compressor inlet casing, that the flow at the exit annulus could be made reasonably uniform by the addition of a curved dividing fairing at the rear of the central shaft fairing and two circular arc turning vanes. The present report deals with flow observations in the 'Reavell' compressor inlet casing incorporating these and other modifications.

The flow in the basic condition was subjected to careful investigation in order to ascertain whether or not the suspected unsteadiness and non-uniformity of the exit flow was of sufficient magnitude to cause periodic stalling of the rotating blades in the first stage of the axial compressor.

In this report a flow is described as unstable when the complete body of fluid in the section under consideration oscillates with a regular or irregular period, and each flow configuration can be visually observed. The flow is described as unsteady when in a small region under consideration, the 'mean'

velocity (as recorded by a manometer) varies with time in a very irregular manner.

The flow is described relative to the geometrical configuration used in these tests (see Fig. 1) and should not be confused with that of the final installation. The words under or over and above or below relative to the upstream wind direction are used for convenience. (See Fig.1).

2. Apparatus

The 'Reavell' compressor inlet casing was connected to an extension to the No.2 Blower type wind tunnel.

The flow observations were made with the aid of nylon threads fixed to the inside of the casing, and a traversing rod with a nylon thread attached.

The guide vanes and fairings were constructed of stiff cardboard and thin sheet metal.

The guide vanes and the passages are numbered in accordance with the notation given in figure 1.

3. Flow Observation

3.1 Basic Condition

The tuft investigation showed that the flow over and around the central shaft fairing was unstable. The upstream fluid showed a tendency to flow either over or under the central shaft fairing with a consequent movement of the stagnation line on the central shaft fairing (see Fig.2, ref.1). In each configuration the overall flow was steady except in the region behind the central shaft fairing where the wake oscillated through approximately 90° . On only one occasion did the flow change unaided from one configuration to the other. It was however, possible to effect this change by disturbing the flow at inlet.

The positions of the tufts at exit in the clockwise and anticlockwise flow configuration are sketched in figures 2 and 3 respectively. These diagrams show the tufts on the developed surfaces of the outer casing and the central shaft fairing. It is shown that the flow direction is not constant across the annulus and in passages 3 and 7 the flow is under-turned (negative angle) by approximately 20° . Vanes 2,3,6,7 and 8 were partially or completely stalled. Very unsteady flow was present in passages 2,4,5,6 and 8. It is impossible in diagrams of this type to indicate the random and rapid changes about a mean in fluid direction due to the oscillatory nature of the flow and it must be noted that the unsteadiness is much greater than the diagrams show.

3.2 Basic Condition plus a gauze (30 wires per inch) at entry

The flow over and around the central shaft fairing now divided equally at a stationary stagnation line, and was steady apart from the wake oscillations behind the inner casing. (See para. 3.1). It was not possible, on disturbing the flow downstream of the gauze, to cause the fluid to flow mainly under or over the central shaft fairing.

The flow at exit, although somewhat steadier than in the condition described in para. 3.1, nevertheless still suffered large changes in flow direction caused by the oscillatory flow, the stalling of the guide vanes and the underturning.

3.3 Basic condition plus a rear dividing plate (passage 5)

The position and shape of the plate are shown in figure 6a. The oscillations of the wake were now prevented, but a large region of 'dead' flow was present on both sides of the plate.

The flow pattern at exit is sketched in figure 4. It is shown that large angular variations in flow direction across the annulus are present and vanes 2, 3, 6 and 7 are stalled. It was noticed that the dividing plate had increased the flow unsteadiness but had eliminated the oscillatory nature of the flow.

The addition of a gauze at entry reduced the unsteadiness but the flow configuration was unchanged.

3.4 As 3.3 plus a curved fairing around the flat dividing plate

The geometry of the curved fairing can be seen in figure 6b and the flow pattern in figure 5. It is shown that the flow has been improved in passages 4, 5 and 6 but vanes 2, 3, 6 and 7 are still stalled. Leading edge slats of small chord fitted upstream of these vanes eliminated the stalling but the large angular variations in the flow direction at exit still remained.

It should be noted that the shape of the curved fairing was unchanged throughout the remainder of the test. The optimum shape was difficult to determine and it is likely that its shape could be modified to advantage. In fact later tuft investigations showed that a slightly different shape blending more into the shaft fairing would be desirable.

3.5 As 3.4 plus a perforated plate at entry

The perforated plate had 0.5 inch diameter holes and 50 per cent blockage. The flow downstream of the plate was very unsteady especially in the region between the entry and the central shaft fairing, and was greater than in the basic condition (see para. 3.1). The flow at exit showed little or no change from that described in para 3.4 above. When the perforated plate

/was ...

was replaced by a gauze (30 wires per inch) the unsteadiness at exit was reduced.

3.6 As 3.4 plus a long central guide vane

The position of the vane, in passage 3 only, is shown in figure 7a. It can be seen that the leading edge of the vane was not in the direction of the oncoming flow. This vane was completely stalled. Vane 2 was unstalled although eddying flow was present in passage 2. The flow was very unsteady in passage 4.

3.7 As 3.4 plus a short central guide vane

The position of the vane in passage 3 is shown in figure 7b. Although the leading edge was now set in the direction of the upstream flow 'breakaway' was present on the upper surface and both vanes 2 and 3 were stalled.

3.8 As 3.4 plus a vane extension forward of guide vane 3.

This vane extension was set so that its profile coincided as closely as possible with the local stream directions. It was noted that vane 3 was unstalled and the flow in passage 2 was more uniform. The flow in passage 4 was however, worse. A careful investigation showed (i) that the guide vane extension had partly prevented the flow in the upper part of the casing from reversing its direction and entering passages 2 and 3 and (ii) the reversed flow from the outer casing had entered passage 4 and had mixed with the stalled region on the upper surface of the vane extension.

3.9 As 3.8 plus a vane extension forward of guide vane 2.

The vane extensions to guide vanes 2 and 3 together with the flow configurations are shown in figure 8. The leading edge of the extension to vane 2 had to be carefully set to prevent stalling. The change in flow direction across the annular passage in section 3 was still approximately 20° and a standing eddy could not be eliminated by local movements of the guide vane extensions. The guide vanes were now in turn lengthened and shortened but the exit flow configuration could not be changed.

3.10 As 3.4 plus a gauze (30 wires per inch) placed in the annulus upstream of the guide vanes

The position of the gauze is shown in figure 9. The tuft configuration was very similar to that described in paragraph 3.4 above but the flow was much steadier although not as steady as might have been expected. Vanes 2, 3, 6 and 7 were stalled and large angular variations in flow direction occurred.

No doubt some improvement could have been obtained with a gauze of greater resistance but the losses involved would not have been acceptable.

3.11 As 3.10 plus vane extensions forward of guide vanes 2 and 3.

The addition of guide vane extensions (see para. 3.9) unstalled vanes 2 and 3 but large changes of the outlet flow angle (0° to $+25^\circ$) occurred across the annulus of passage 3.

3.12 As 3.11 plus a gauze at entry

The flow disturbances were reduced and it was now found that the flow in passage 8, in the lower half of the casing in which guide vane extensions were not fitted, was better than in passage 2. This suggested that the vane extension to the guide vanes were disturbing the flow unduly.

3.13 As 3.10 plus a gauze at entry and a vane extension forward of guide vane 3

In this condition all vanes in the upper half of the casing were unstalled and the flow was steadier than in any of the previous tests. The large change in angle across the annulus was however still present.

In order to correct this large annular variation in the outlet flow it was necessary both to prevent the air in the outer sections of the casing from reversing its direction and entering passage 4, and to a lesser extent passage 3, and to improve the flow in these outer sections.

3.14 As 3.4 plus an outer casing flat plate fairing

The position and extent of the plate is shown in figure 10. (It was fitted in the lower half of the casing only). It was hoped, by this method, to improve the flow in the outer sections of the casing by suppressing the large angle of the casing at entry.

No change in the flow configuration, described in paragraph 3.4 above, could be observed.

3.15 As 3.4 plus a long internal splitter plate

The plate is shown in figure 11. It was hoped to feed passages 1, 8 and 7 from the 'inner' and passages 6 and 5 from the 'outer' flows. Observations showed that disturbed flow in passage 7 was caused by a partial breakaway from the sharp radius between the external casing and the outlet annulus. Disturbed flow in passage 8 was due to uneven mixing at the trailing edge of the splitter plate as well as a reversal in the direction

of the flow in the outer channel.

3.16 As 3.4 plus a short internal splitter plate

The plate is shown in figure 12. It was shown that little change in flow direction occurred across the annulus at passage 7. This decided improvement had therefore been obtained by suppressing the small radius on the external casing (see para. 3.15). The flow was, however, disturbed in passages 8 and 6 owing to interference of the upper and lower flows at the ends of the plates.

3.17 As 3.4 plus modified outer casing

The outer casing (lower half only) was modified as shown in figure 13. The new inner surface provided a smooth entry at its forward end, and joined the rear plate curved fairing at its downstream end. In addition the sharp radius in the outer casing was eliminated.

Observations showed that the angle distributions across the annulus in passage 7 were uniform within 5° , but guide vanes 6 and 7 were stalled. A surprising feature, in this condition, was the steadiness of the flow in section 8 whereas the flow in section 6 showed a tendency towards reversal.

3.18 As 3.17 plus guide vane extensions forward of vanes 6 and 7

The size and shape of the vane extensions were changed until vanes 6 and 7 were unstalled. The geometry of the vanes is shown roughly in figure 13. The tendency to flow reversal was still present in section 6.

3.19 As 3.18 plus a guide vane extension forward of vane 5

This vane extension is also shown in figure 13. This modification prevented the flow reversal in section 6 by diverting the flow in the outer sections of the casing through the lower part of section 5.

In this condition the angular variation of the flow over the annulus of the complete lower half of the casing was between $+5^\circ$ and $+10^\circ$.

3.20 As 3.19 plus a gauze at entry

The addition of the gauze did not change the flow configuration but it did improve the steadiness. It was now noticed that disturbed flow in passages 5 and 6 was caused by the joint between the curved fairing on the rear dividing plate and the new internal fairing.

3.21 As 3.19 plus a fillet at the joint between the inner fairing and the curved fairing on the rear dividing plate

The disturbed flow in passages 5 and 6 was now reduced by the addition of this curved fillet. The flow configuration is shown in figure 15.

Further modifications were now considered unnecessary as the flow at exit satisfied approximately the conditions of uniform steady flow and the angle distribution varied from $+5^\circ$ to $+10^\circ$ outside the wakes from the guide vanes. Total head distributions confirmed that the flow was approximately uniform (see paragraph 4).

3.22 As 3.21 less the curved fairing on the rear dividing plate

The fairing on the rear dividing plate was now removed to investigate whether or not, in view of the other modifications, its presence was necessary.

Flow observations showed that extremely unsteady flow was present in passage 5 and to a lesser extent in 6.

4. Total head distribution at exit

Accurate total head distributions at exit could not be obtained in the basic condition owing to the flow unsteadiness. In the final condition (see para. 3.21) the total head distribution is given in figure 14. This contour diagram shows clearly that secondary flows between the guide vane annular passages are responsible for the slight non-uniformity.

5. Discussion

The flow observations in the basic condition have shown that the front stagnation line, on the central shaft fairing, is only stationary when the flow upstream has no asymmetry. The flow at the exit annulus has variations in direction, outside the wakes and 'dead water' regions behind the guide vanes, of about 30° . In certain cases in the vicinity of the 'dead water' regions complete reversal of direction is found. First stage periodic stalling in the axial compressor will therefore occur.

Since the relative velocity of the rotating blades in the axial compressor is high it is probable that the blade stalling may precipitate stalling flutter. Unfortunately no theory of the latter phenomenon exists and no experimental results are to hand to predict accurately the critical stalling flutter speed in the present case. It is known, however, that this speed is considerably lower than the binary flutter speed, and may be further reduced owing to the cascade effect. In addition,

/experimental ...

experimental results have shown that stalling flutter occurs in the fundamental torsional mode but this may also be modified by the cascade effect. Blade stall flutter may therefore be aggravated by a high order torsional resonance occurring at any compressor rotational speed in the running range. The above discussion shows that it is imperative to prevent first stage periodic stalling. This can only safely be accomplished if the inlet casing is modified to give a velocity distribution at exit which is sensibly uniform.

The unstable circumferential flow was eliminated by the introduction of a curved divided fairing at the rear of the central shaft fairing. The steadiness of the flow at exit was improved by adding a gauze at entry but a perforated plate had little or no effect.

A gauze having 30 wires per inch was used in the tests but for strength and safety considerations in the actual installation a gauze having 10 wires per inch is considered adequate.

The flow path around the central shaft fairing was approximately helicoidal at a pitch angle of nearly 45° although this angle varied along the shaft fairing and in the vicinity of the curved rear fairing. The flow in the outer section of the casing was circumferential and reversed its direction in moving towards the exit passages. The majority of the first stage guide vanes were therefore operating at very high incidence and in regions of severe cross flow.

The modified internal contour of the outer casing, which increased the radius of curvature just upstream of the exit annulus, in combination with extensions to the first stage guide vanes was found sufficient to produce a velocity distribution at exit which was sensibly uniform. Without these extensions the guide vanes were badly stalled. The test procedure was not of sufficient accuracy to predict the most efficient shapes for the guide vane extensions, especially as the existing guide vanes were cambered aerofoils set at an incidence to produce a pre-swirl of about $+6^\circ$. The experimental leading edge angles of the extensions are probably within $\pm 2^\circ$. It is suggested that the extensions should be about 1/8 inch thick at their curved leading edges and that their thickness be gradually increased to blend with the shape of the existing vanes. A further minor improvement could be obtained by thinning the trailing edges to a minimum dimension.

The present series of tests have been conducted on modifications to either the lower half or the top half of the casing but only in one or two cases were the modifications effected

/in both ...

in both halves simultaneously. This method of procedure had the advantage that the flow in the basic condition could always be compared with an improved flow. It was noted in all cases that the flow pattern in the unmodified half of the casing was unchanged when various modifications were introduced to the other half. This fact, together with the knowledge that a symmetrical flow configuration was obtained in the case of the basic condition plus a curved, divided rear fairing, suggested that the final modifications, when fitted to both halves of the casing, would produce at exit a velocity distribution which is symmetrical and sensibly uniform.

Reference

1. An interim report on flow observation tests on a model of an axial compressor inlet casing. College of Aeronautics Note dated 8/8/51.

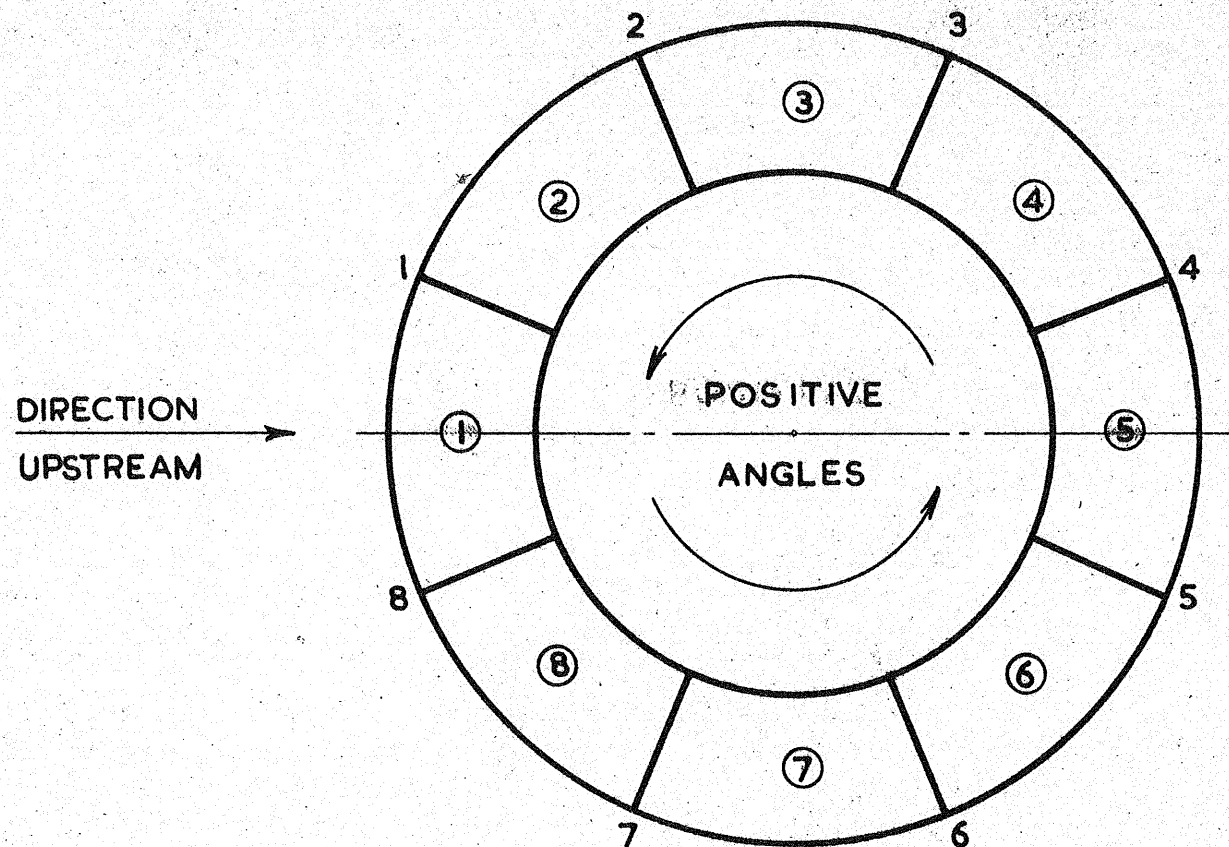
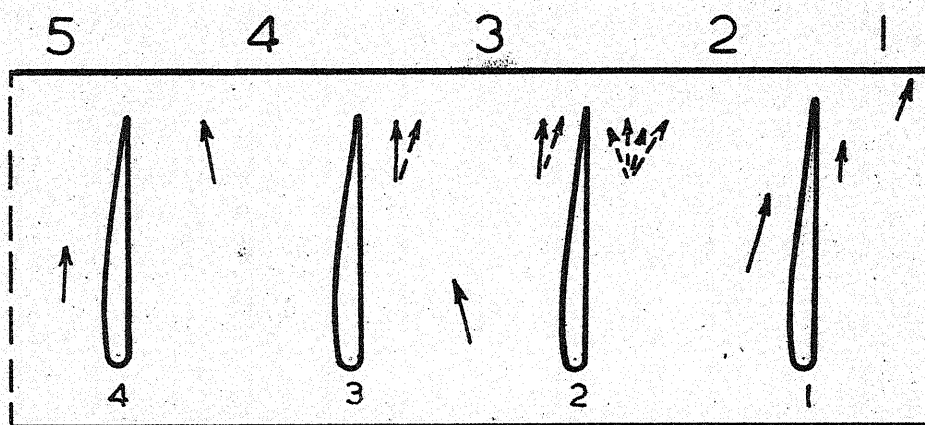
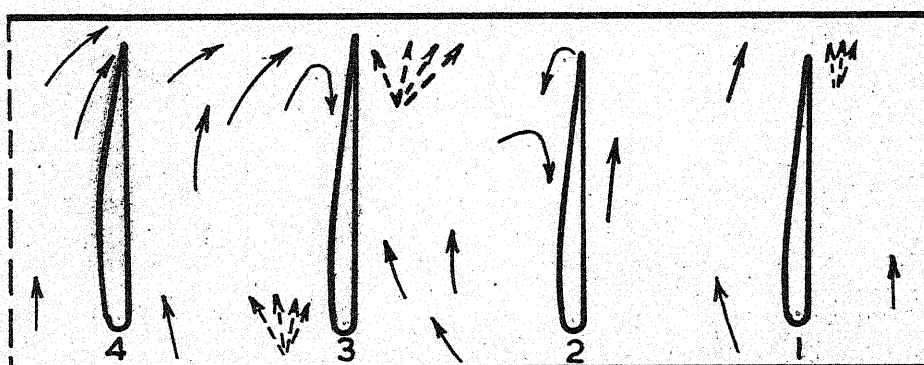


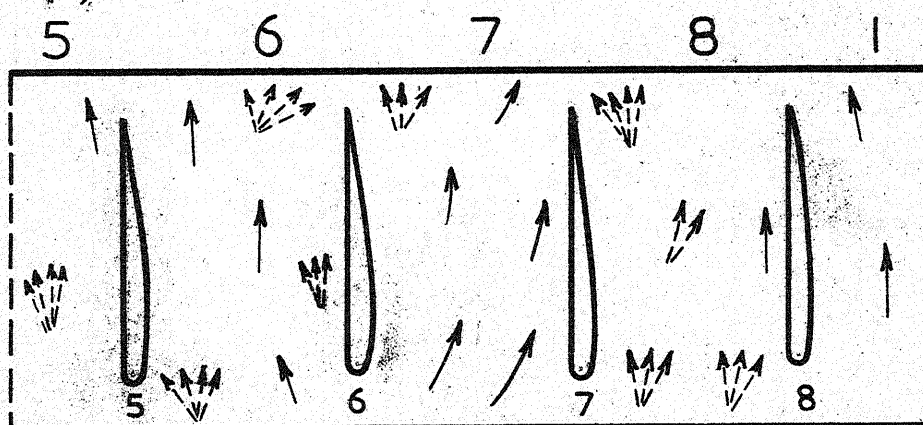
FIG. 1. NOTATION. VIEW FACING OUTLET.



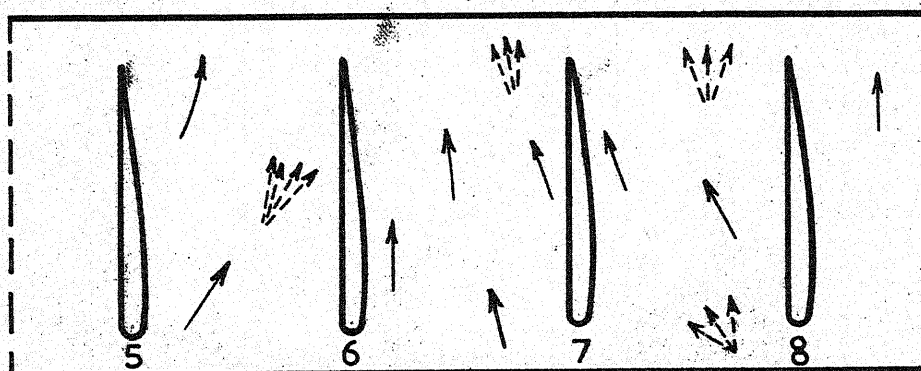
(i) TOP OF OUTER CASING.



(ii) TOP OF INNER CASING.



(iii) LOWER SIDE OF OUTER CASING.



(iv) LOWER SIDE OF INNER CASING.

FIG. 2. ORIGINAL CONDITION - MAIN FLOW CLOCKWISE

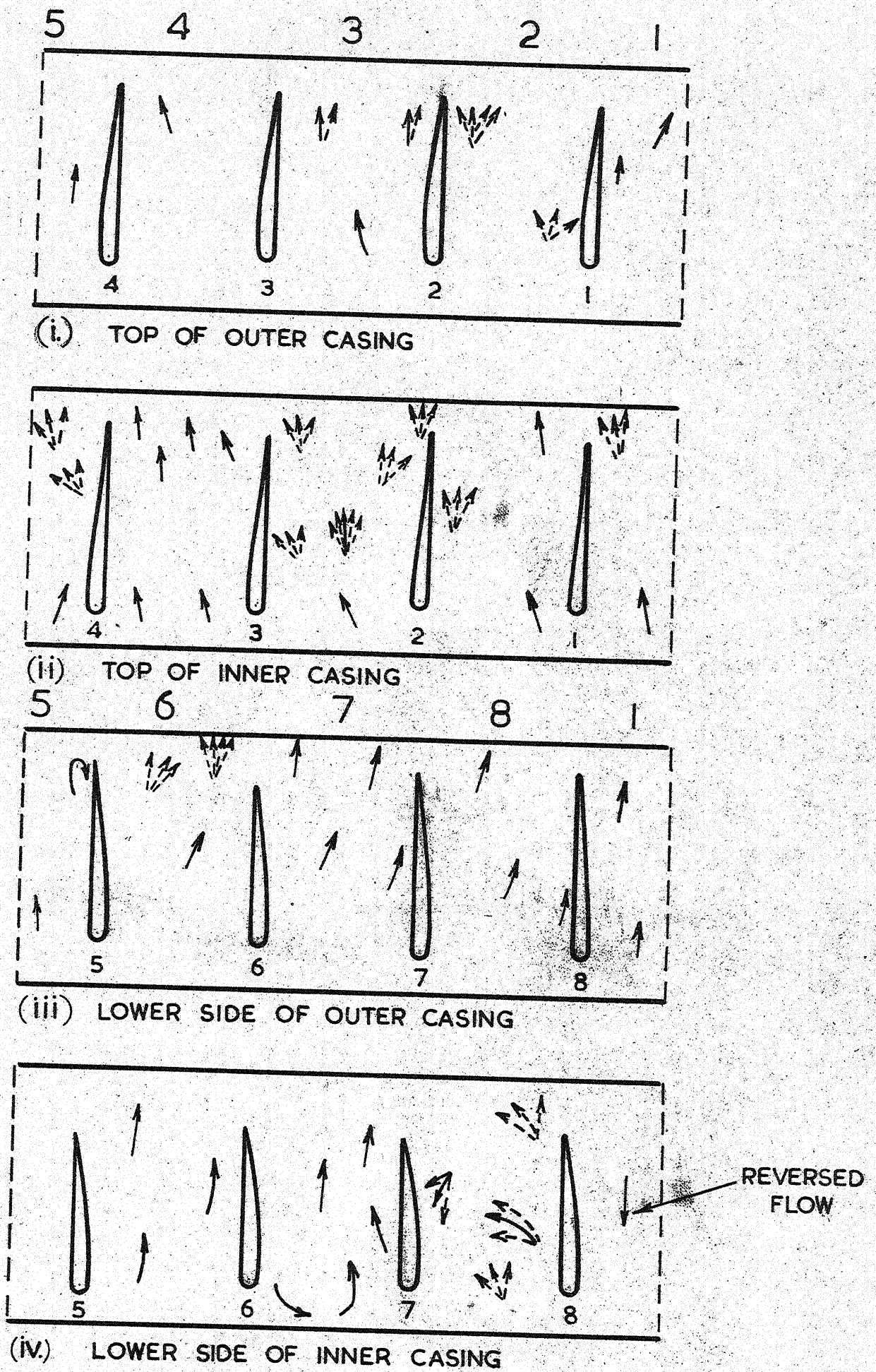
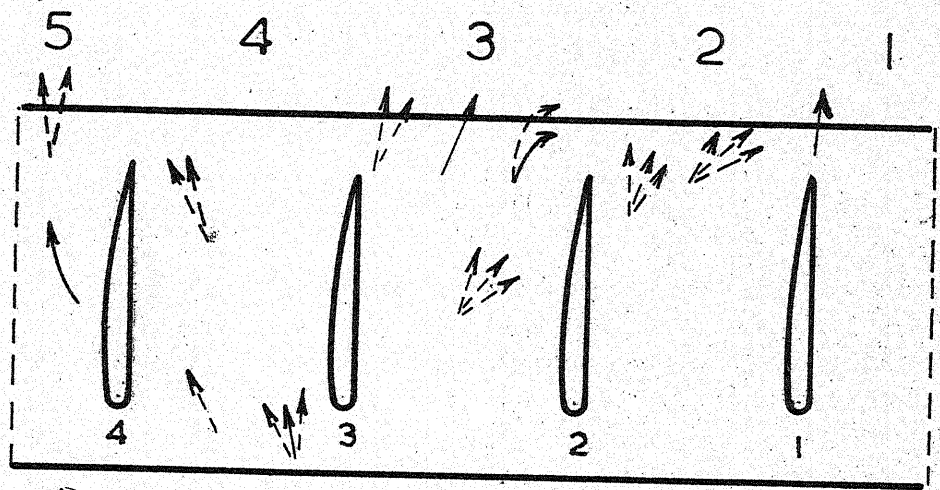
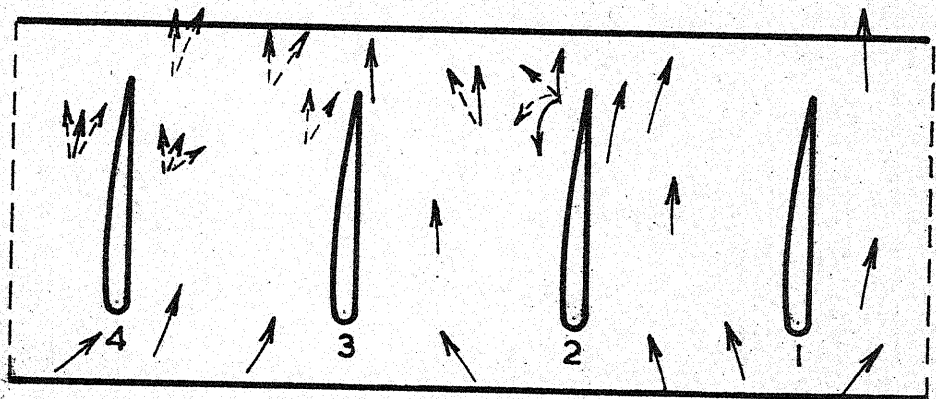


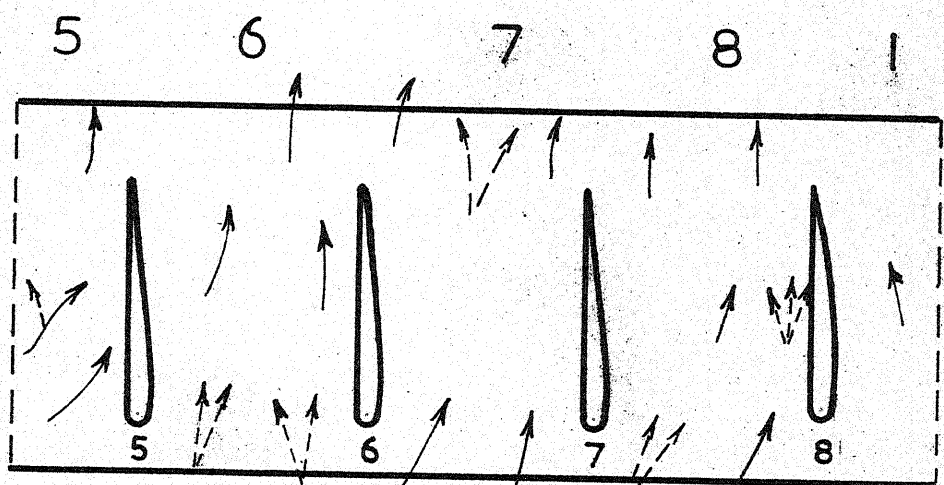
FIG. 3. ORIGINAL CONDITION — MAIN FLOW ANTICLOCKWISE.



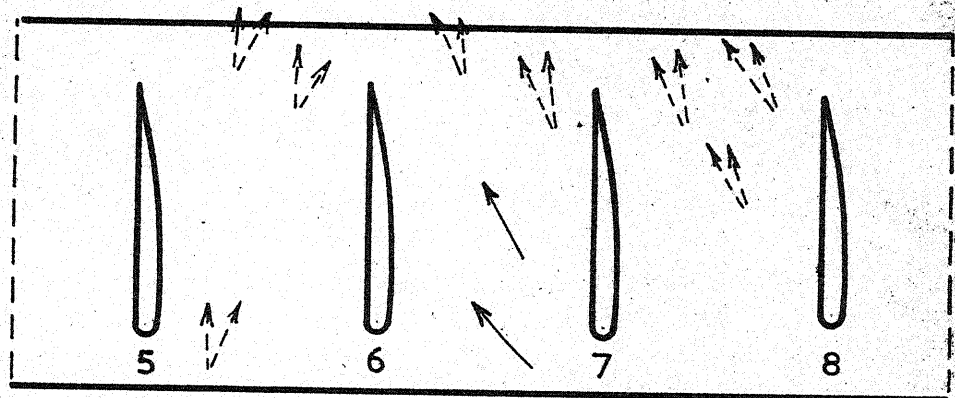
(i) TOP OF OUTER CASING



(ii) TOP OF INNER CASING

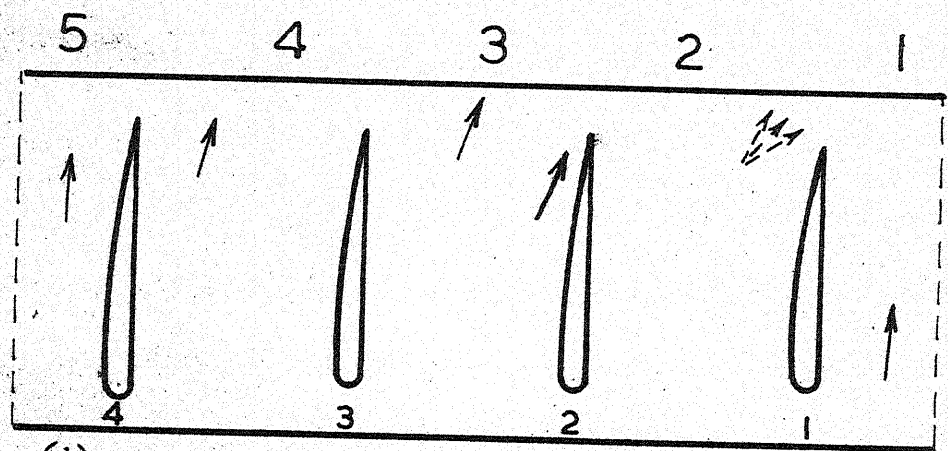


(iii) LOWER SIDE OF OUTER CASING

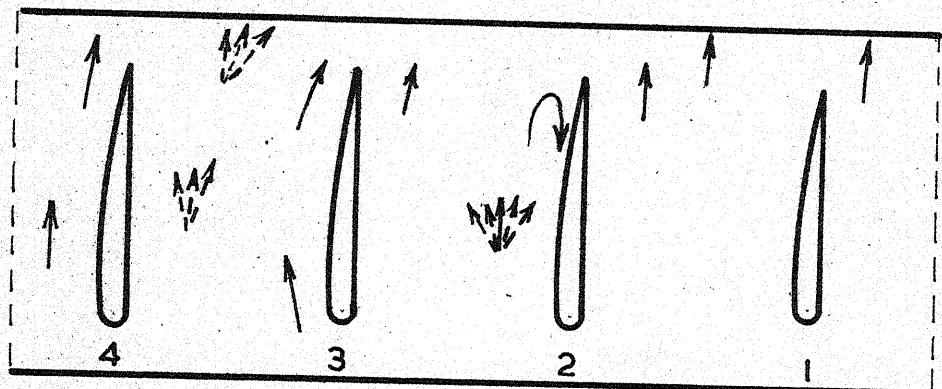


(iv) LOWER SIDE OF INNER CASING

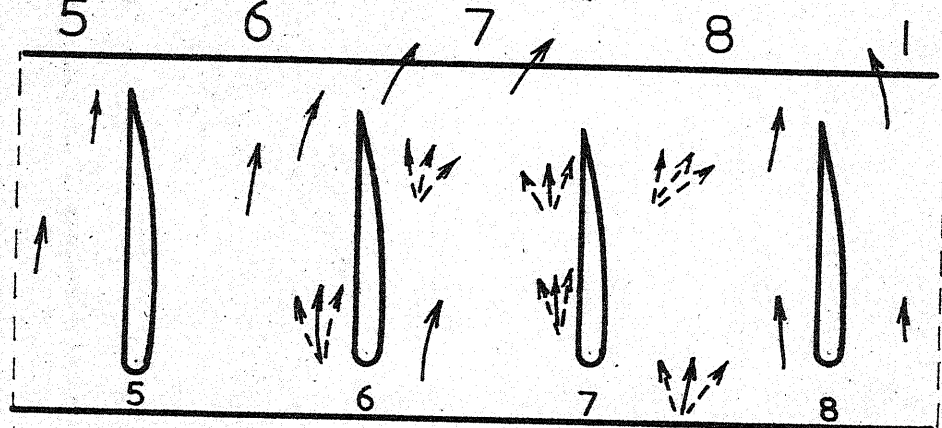
FIG. 4. ORIGINAL CONDITION-PLUS REAR DIVIDING PLATE.



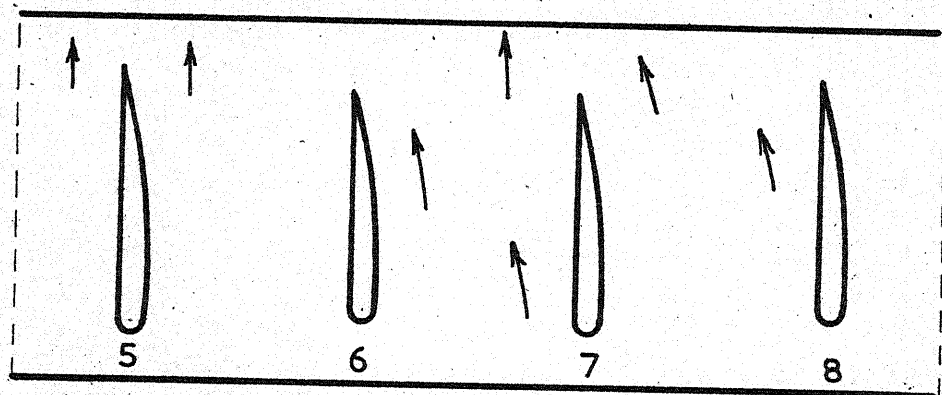
(i) TOP OF OUTER CASING



(ii) TOP OF INNER CASING



(iii) LOWER SIDE OF OUTER CASING



(iv) LOWER SIDE OF INNER CASING

FIG. 5. DOUBLE FAIRING AT REAR OF CASING

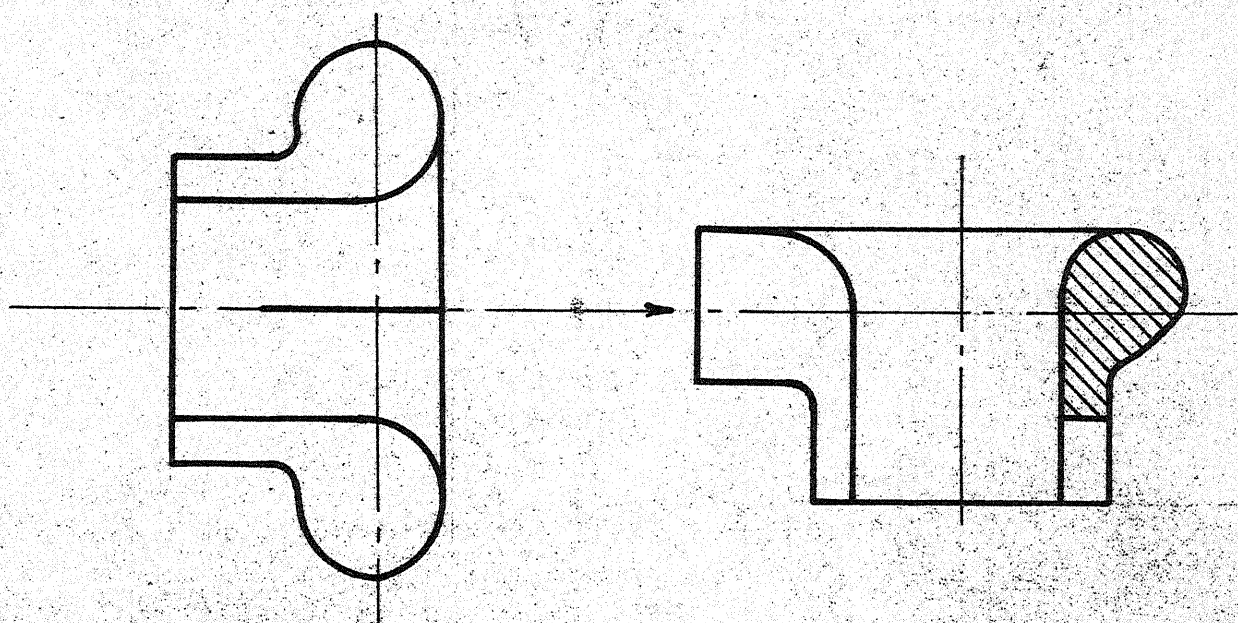


FIG. 6a. REAR DIVIDING PLATE.

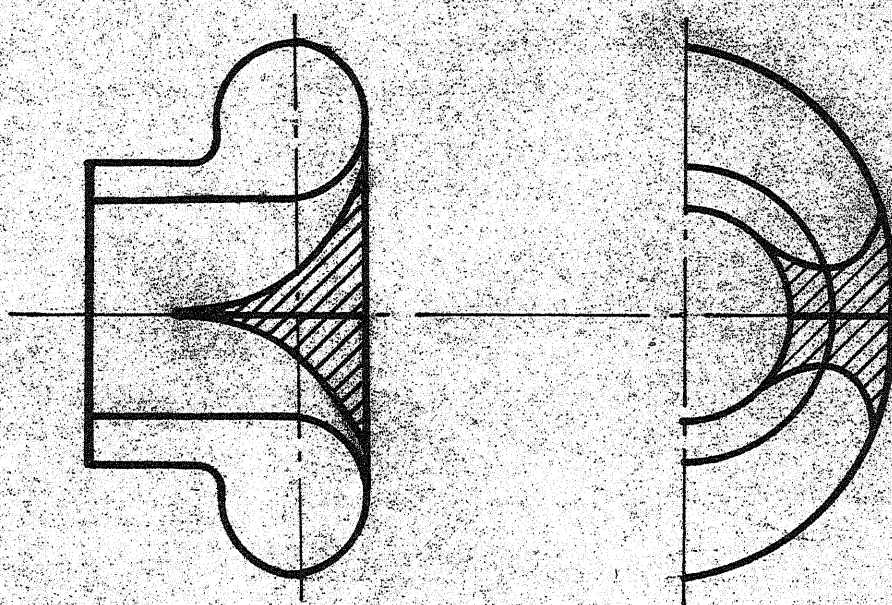


FIG. 6b. REAR FAIRING ON DIVIDING PLATE.

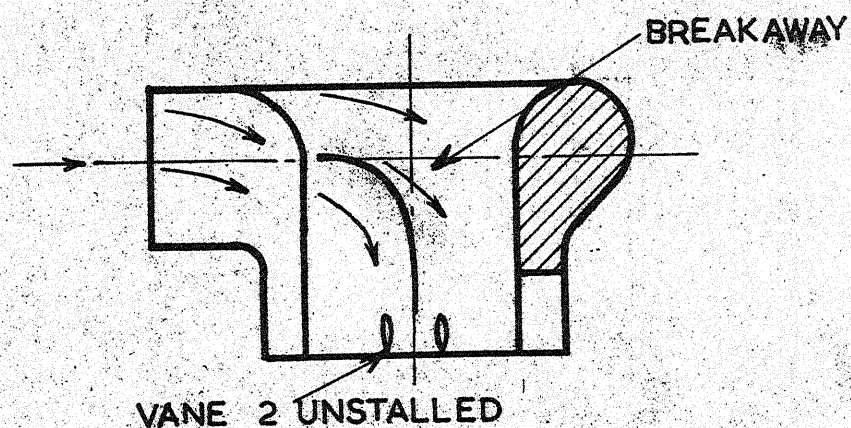


FIG. 7a. FLOW WITH LONG CENTRAL GUIDE VANE.

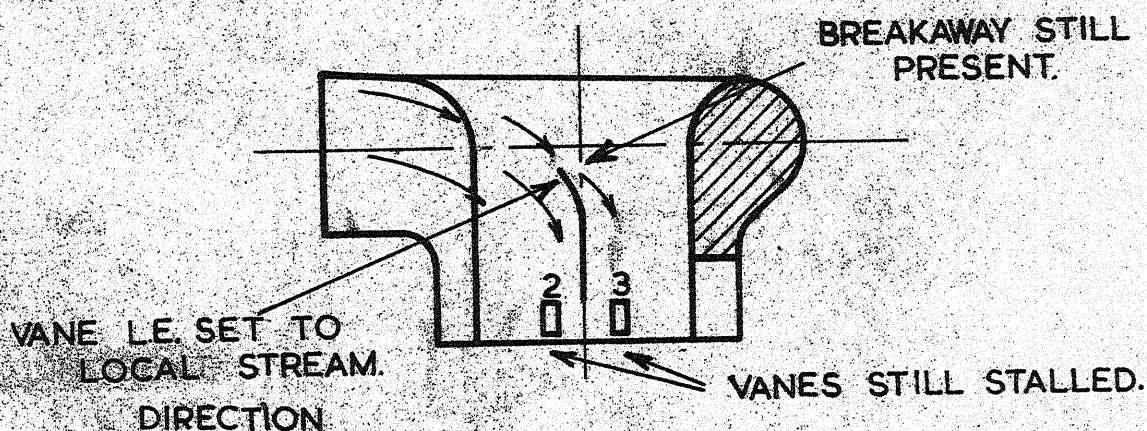


FIG. 7b. FLOW WITH SHORT CENTRAL GUIDE VANE.

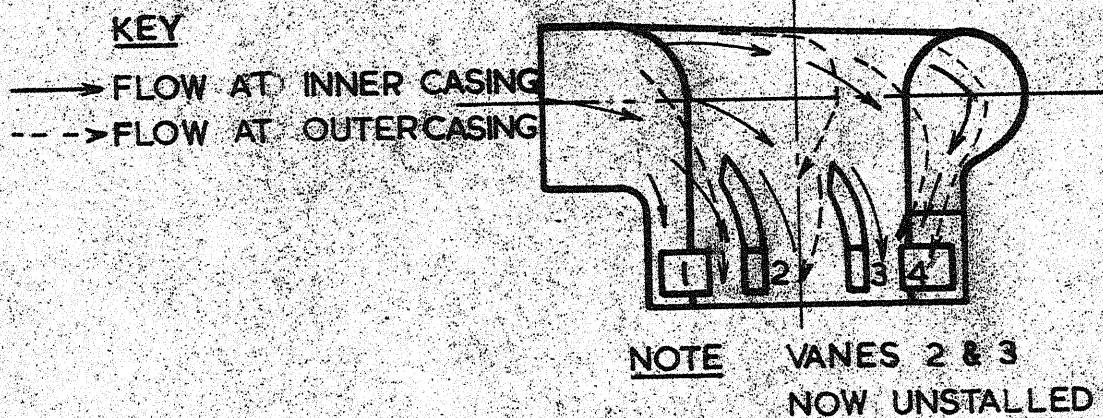


FIG. 8. FLOW WITH EXTENSIONS TO VANES 2 & 3.

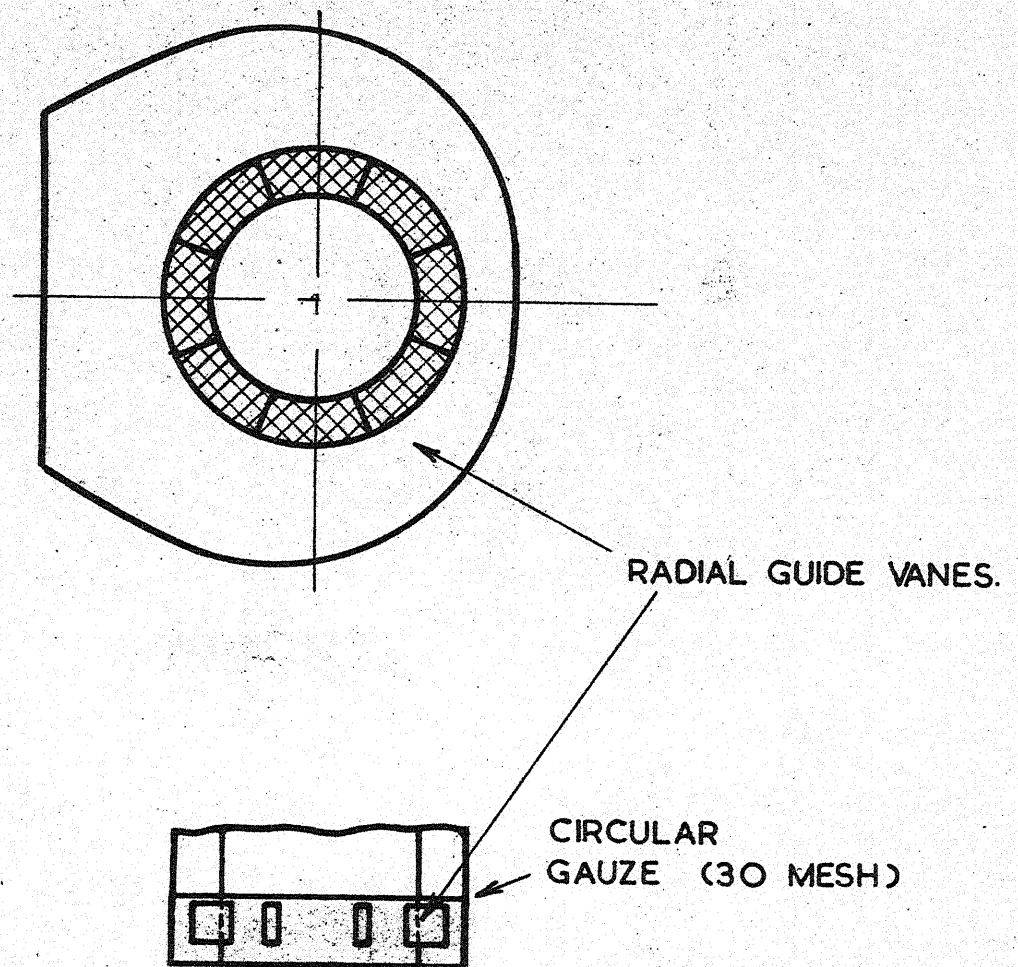


FIG. 9. CIRCULAR GAUZE.

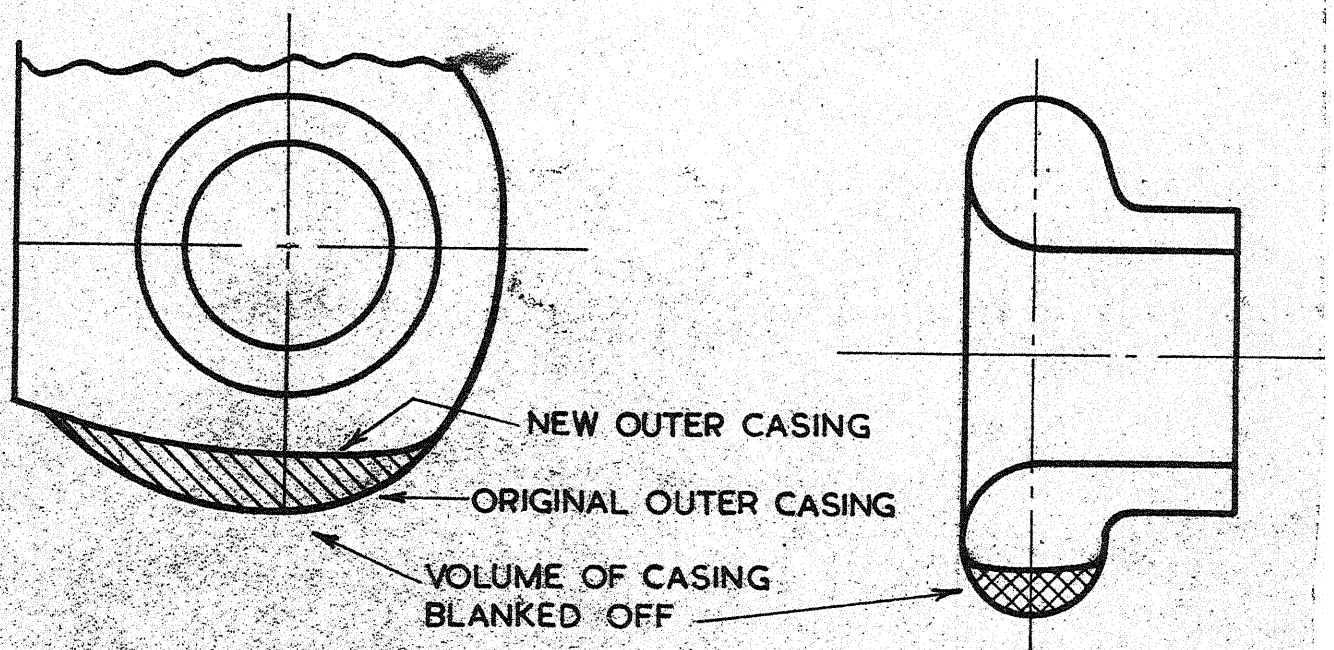


FIG. 10. LONG PLATE FORMING NEW OUTER CASING CONTOUR.

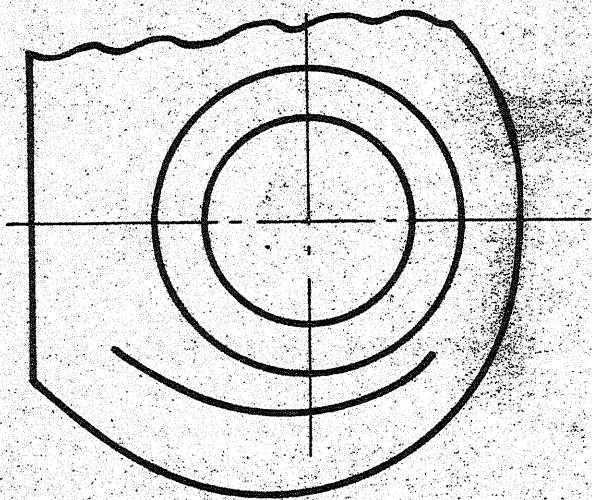
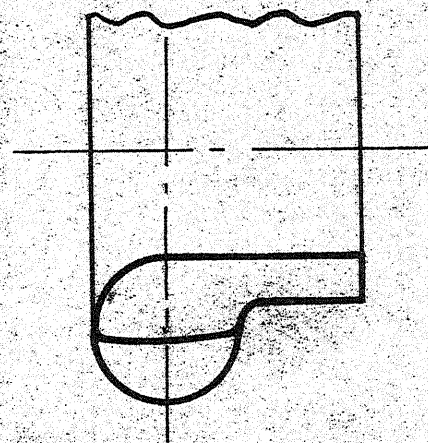


FIG. 11. LONG SPLITTER PLATE.

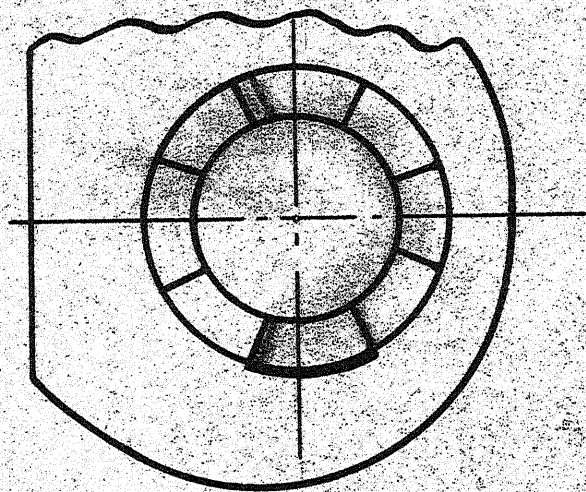
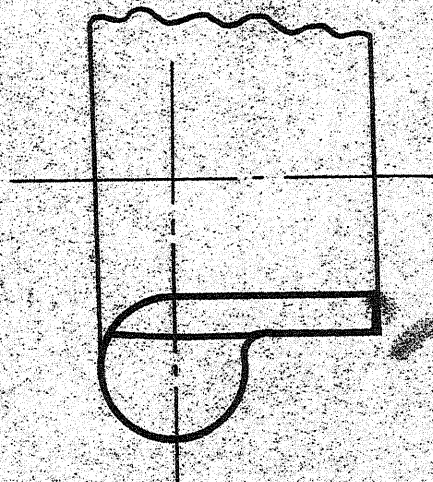


FIG. 12. SHORT SPLITTER PLATE.

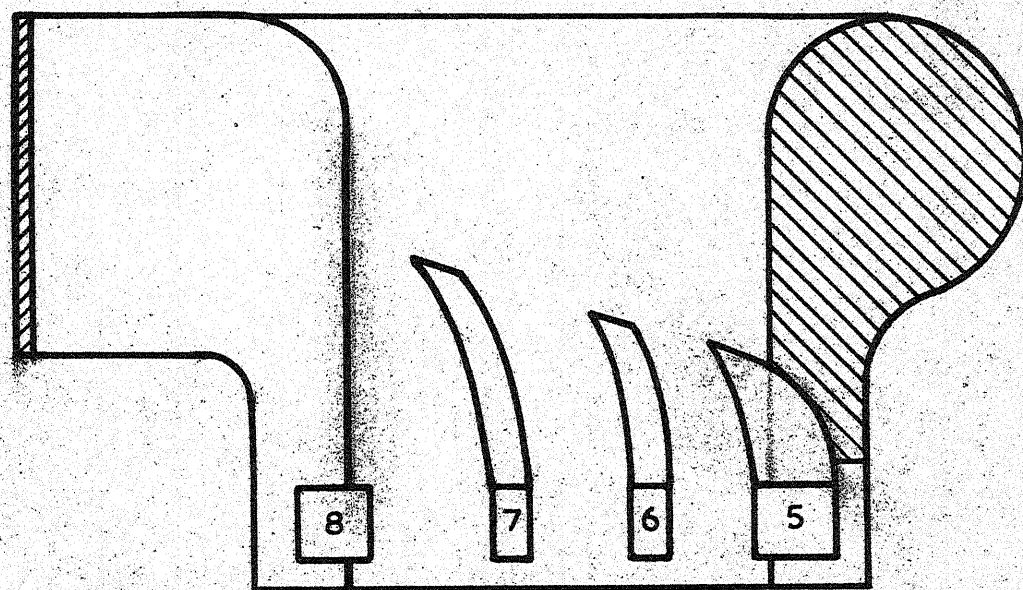
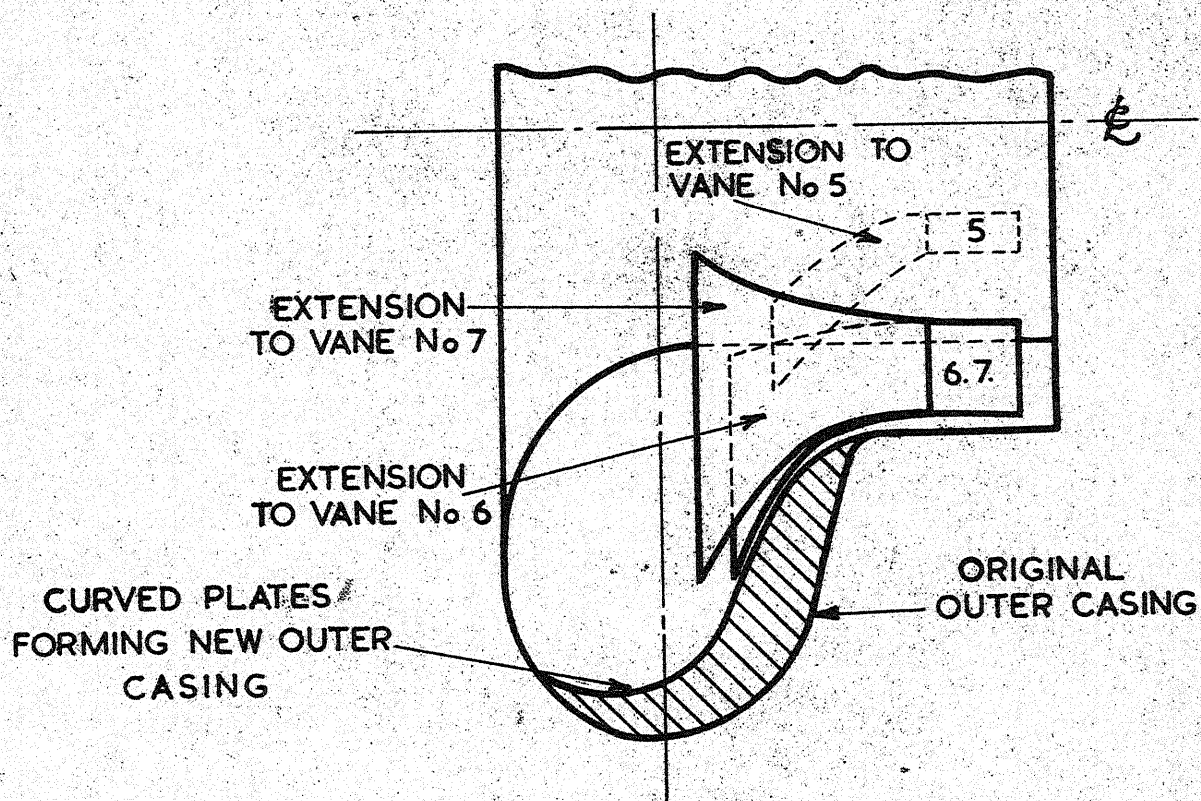


FIG. 13. FINAL CONFIGURATION.

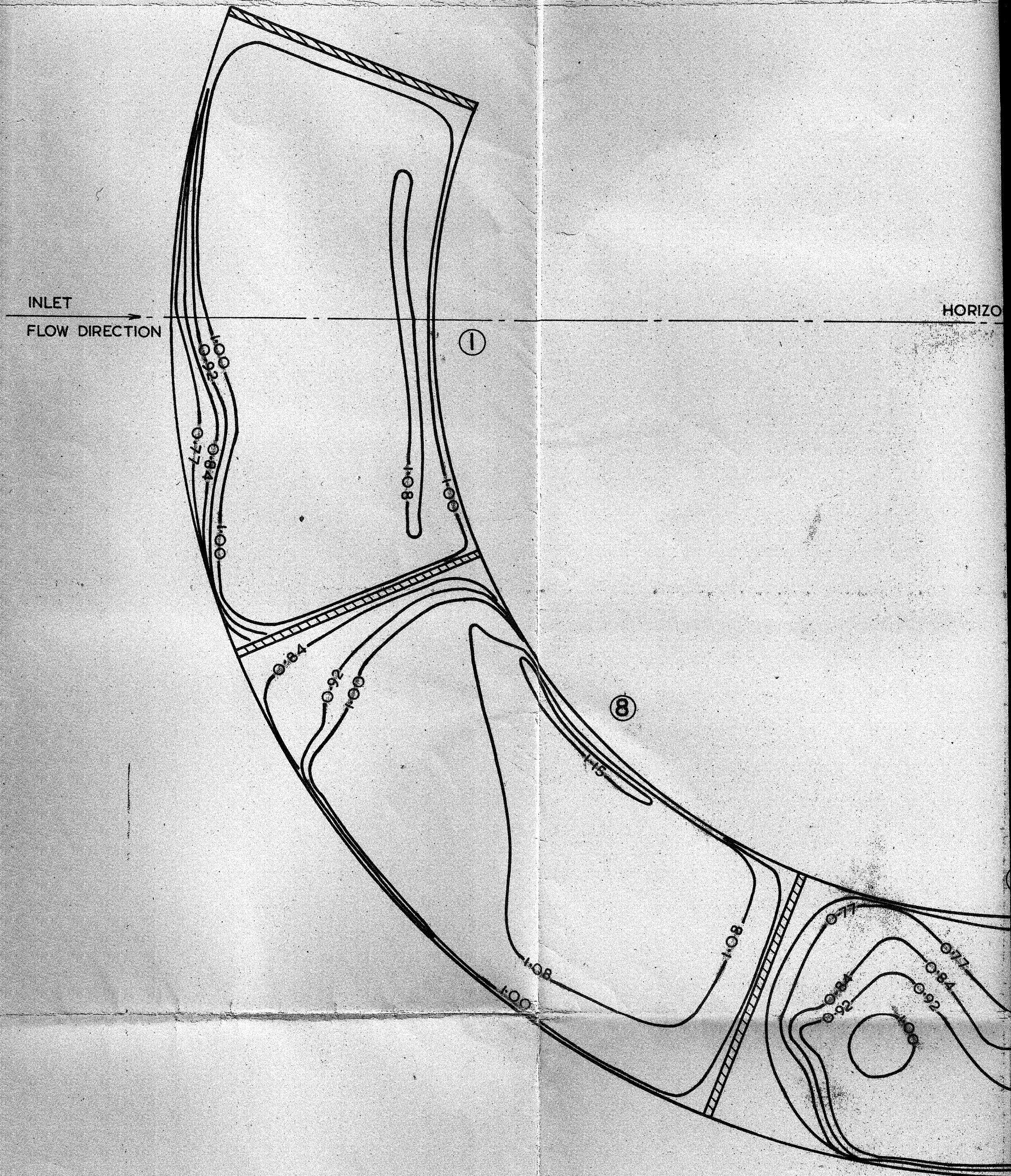


FIG. 14. TOTAL HE

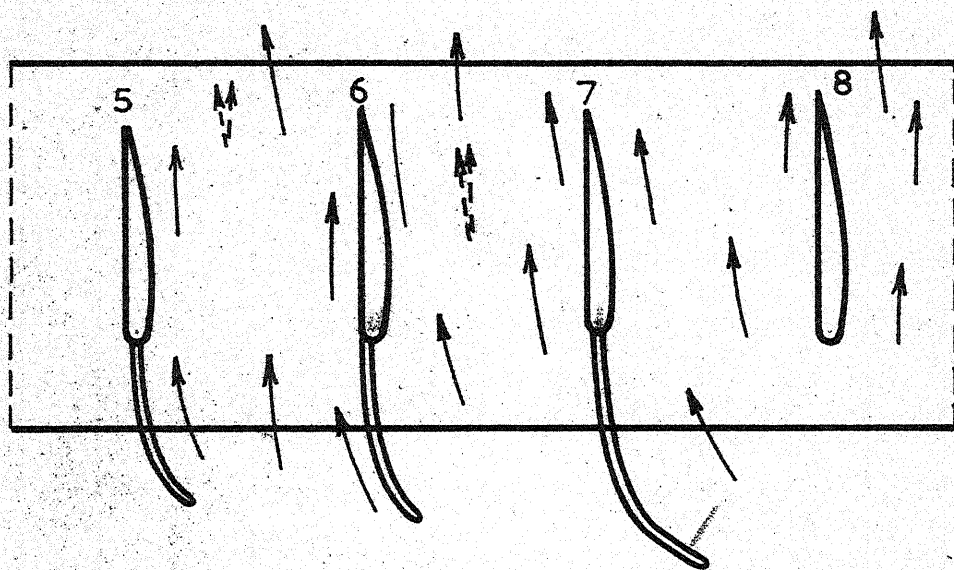
[illegible]

⑤

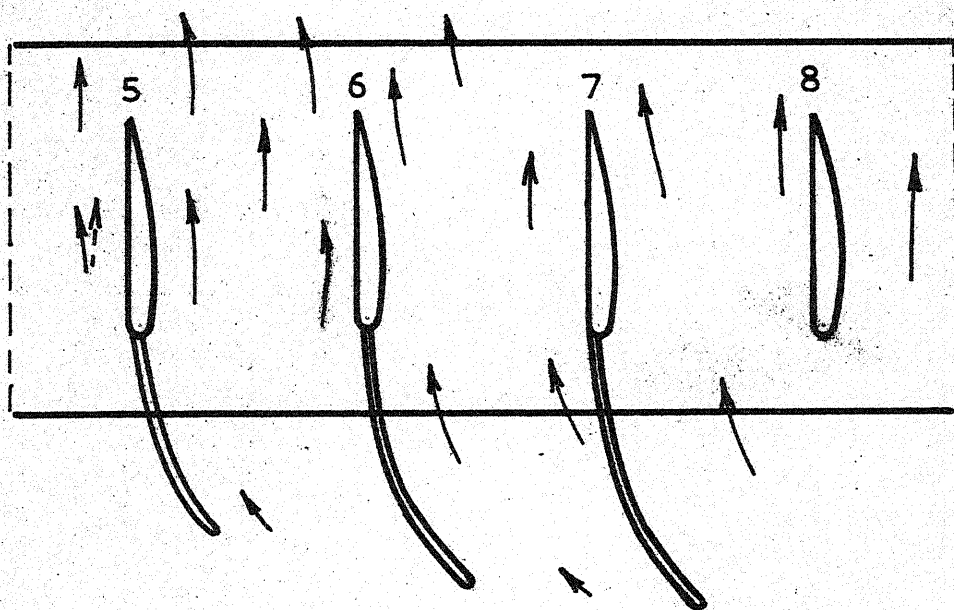
⑥

7

AD TRAVERSES AT OUTLET.



(i.) LOWER SIDE OF OUTER CASING.



(ii.) LOWER SIDE OF INNER CASING.

FIG. 15. FINAL FLOW CONDITION.— LOWER CASING.

Professor A.D. Young.
~~Aut No 1~~
 18

An interim report on flow observation tests on a model
of an axial compressor inlet casing

-by-

The Staff of the Aerodynamics Department.

Summary

In order to obtain information regarding the possible flow in the inlet casing of the 9in x 9in supersonic wind tunnel 'Reavell' axial flow compressor, flow observation tests have been made on a model casing connected to the working section of a straight-through type blower wind tunnel. The model casing geometry was different in some detail from the actual compressor although the main features were retained.

It was found that the flow in the basic condition had a radial instability caused by the splitting of the inlet flow around the central shaft fairing. A movement of the 'rear' stagnation region on the latter fairing of about 270° was experienced. The flow changed from one condition to the other in a random manner. The frequency varied from approximately 6 to 60 cycles per second. Considerable eddying of the flow occurred at the rear of the fairing where the two streams rejoined.

In addition, the main flow through the casing was under-turned by approximately 20° . Due to the radial instability and the under-turning, an instability of the outlet flow from the casing was experienced. The flow direction varied by $\pm 20^\circ$ with a frequency of the same order as stated above.

The radial instability was cured by a flat plate and fairing placed behind the central shaft fairing. It was found that the under-turning could only be prevented by guide vanes placed inside the casing. Two guide vanes were found to be sufficient to prevent breakaway of the flow around the inner bend of the casing and to render the outlet flow axial. In the latter condition the flow was not perfectly steady but it was considered that little further improvement could be made unless a complete cascade of vanes was used.

/The ...

The test results above should form a guide to the modifications necessary on the actual compressor inlet casing.

1. Introduction

The present series of tests were conducted in order to obtain information regarding flow conditions in the compressor inlet casing of the 'Reavell' compressor used on the new 9in x 9in supersonic wind tunnel. This information was required primarily to explain the fatigue failure of the blades on the similar compressor running at N.G.T.E. and to assist in the design of the necessary modifications to the inlet casing.

A detailed investigation was not undertaken, but sufficient experimental work was done to form the basis for future work using the actual compressor inlet casing.

2. Apparatus

A simple model of a typical inlet casing was manufactured from 16 gauge aluminium plate. The geometry is shown in figure 1. The model was not a true to scale representation of the actual 'Reavell' compressor inlet casing but was such as to be easily made and connected to the working section of the No.2 Blower type wind tunnel. (The distribution of velocity across the outlet section of this wind tunnel is sensibly uniform (± 1 per cent) and the boundary layer thickness is approximately 1in.)

The flow observations were made with the aid of nylon threads fixed to the inside of the casing, and a traversing rod with a nylon thread attached.

The guide vanes and fairings were constructed of stiff cardboard.

3. FLOW OBSERVATION

(1) Basic Condition

The tuft investigation showed that a radial instability of the flow was caused by unsymmetrical flow conditions over and around the central shaft fairing. The consequent movement of the 'rear stagnation region' was about 270° .

/The ...

The oscillatory flow was random and had a frequency varying from 6 to 60 cycles per second.

This flow condition is represented in figures 2a, 2b and 2c.

The remainder of the inlet flow was under-turned by approximately 20° in passing through the casing, as shown in figure 2d. The combination of the radial oscillatory flow and the under-turning caused an instability of the flow at the outlet from the casing as shown in figures 2b and 2c.

Photographs of the nylon threads around the outlet are shown in figures 3a, b and c. Figure 3a shows the tufts on the left hand side of the outlet are pointing 60° upwards from the horizontal whilst figure 3c shows the tufts pointing similarly but in a downwards direction. Figure 3b shows the tuft configuration in an intermediate condition.

4.

(ii) The casing plus a flat plate behind the central shaft fairing

The position of the flat plate is shown in figure 4 and details of the flow are given in figure 5. It is seen that the radial instability has been eliminated but the under-turning is still present as well as a breakaway of the flow around the inner radius and there is considerable eddying of the stream in the neighbourhood of both sides of the flat plate.

5.

(iii) As (ii) plus a curved fairing around the flat plate

In order to reduce the violent eddying of the flow near the flat plate and to improve the turning of the stream a curved fairing was added as shown in figure 6. The latter figure also shows the curved forward fairing, see § 6 below. The associated flow condition is shown in figure 7 where it can be seen that the flow is much steadier around the outer sections of the casing but under-turning and breakaway is still present near the inner sections.

6.

- (iv) As (iii) plus a curved forward fairing

A small fairing was added to the forward end of the central shaft fairing (diametrically opposite to the flat plate) in order to improve the flow around the inner radius. This is shown in figure 8. It was found that little further improvement to the flow was gained by this modification.

7.

- (v) The casing plus the small forward fairing only

The flow in this condition is shown in figure 9. It is seen that in this case, also, the radial instability is prevented but the flow behind the central shaft fairing is very unsteady and is worse than in case (ii) (see paragraph 4 above). The flow is however, steadier near the inner radius.

8.

- (vi) As (iii) plus a circular arc turning vane near to the inner radius

Cases (iv) and (v) suggested that the breakaway near the inner radius and the under-turning could be prevented by inserting a circular arc turning vane of span equal to the casing width. The geometry of the vane is shown in figure 10. The flow pattern is shown in figure 11 and it is seen that the breakaway has been eliminated but a small amount of under-turning still remains.

9

- (vii) As (vi) plus a circular arc turning vane on the casing centre line

The geometry of this vane is given in figure 10. From figure 12 it is seen that the under-turning has now been stopped. The outlet flow from the casing was, however, not completely steady but all the nylon threads oscillated through about 5° , the mean direction being approximately parallel to the axial direction.

10.

(viii) As (vii) but the inner guide vane was removed

In this condition the breakaway near the inner radius was not prevented.

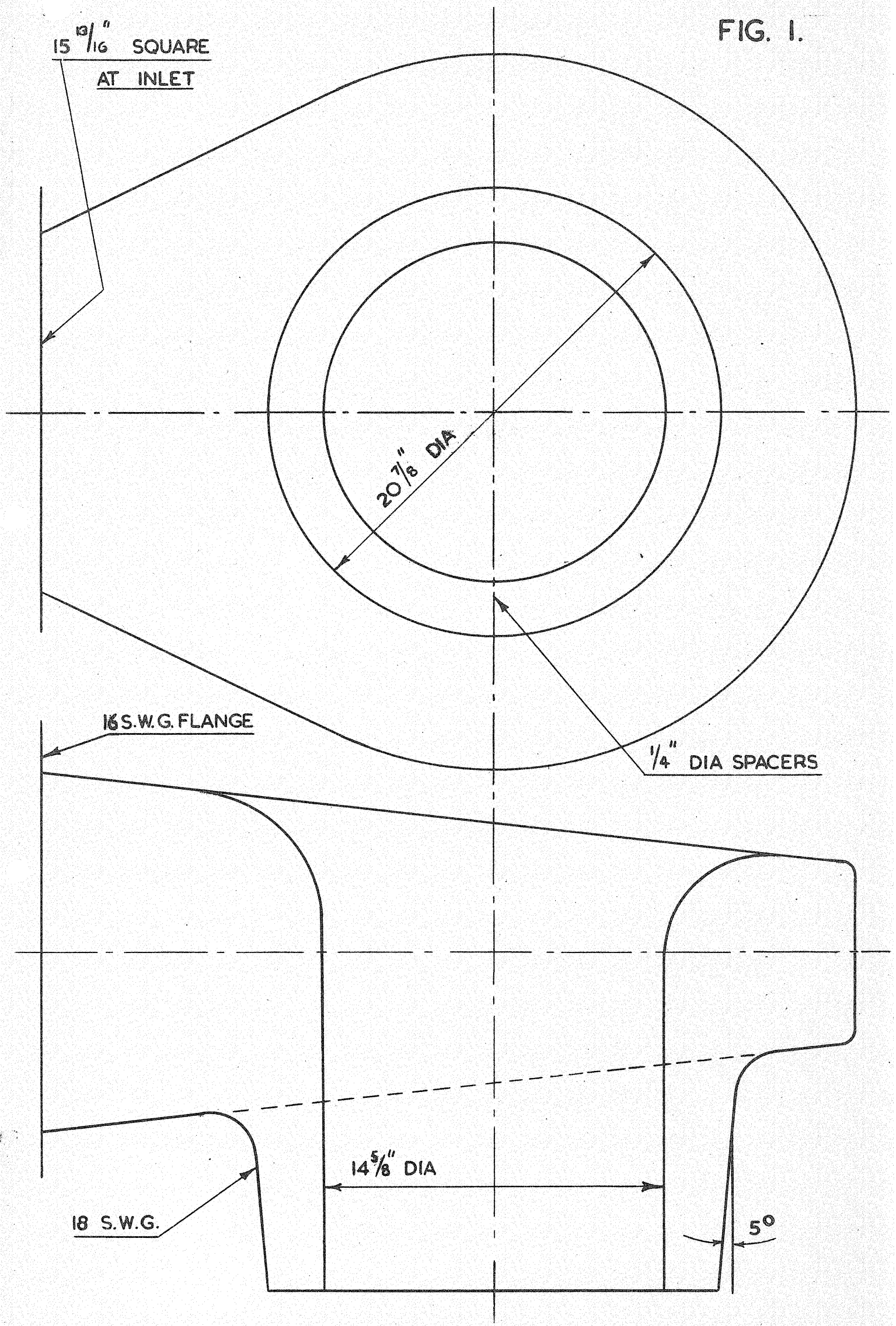
11. Conclusions

1. In the basic condition a radial instability of the flow in the casing existed caused by unsymmetrical flow conditions around the central shaft fairing although no assymetry of the inlet flow could be detected. The flow remained in any one state for a period varying from 1 to 6 seconds. The flow was under-turned by about 20° and breakaway of the flow was present near to the inner radius of the casing.
2. The radial instability was prevented by inserting a plate between the rear of the central shaft fairing and the outer radius of the casing, but the outlet flow was still unsteady and the under-turning and breakaway persisted.
3. The flow in the outer sections of the casing was improved by fitting a curved fairing to the flat plate.
4. The breakaway and under-turning were prevented by the insertion of two guide vanes inside the casing.
5. It is proposed to repeat this series of tests using the actual compressor inlet casing. It can then be seen whether the addition of the rear curved fairing and the two guide vanes will render the flow sufficiently steady, uniform and axial in order to be certain that the condition of the flow in the inlet casing will not be a factor in the stalling of the blades in the compressor.

MEP

8/8/51

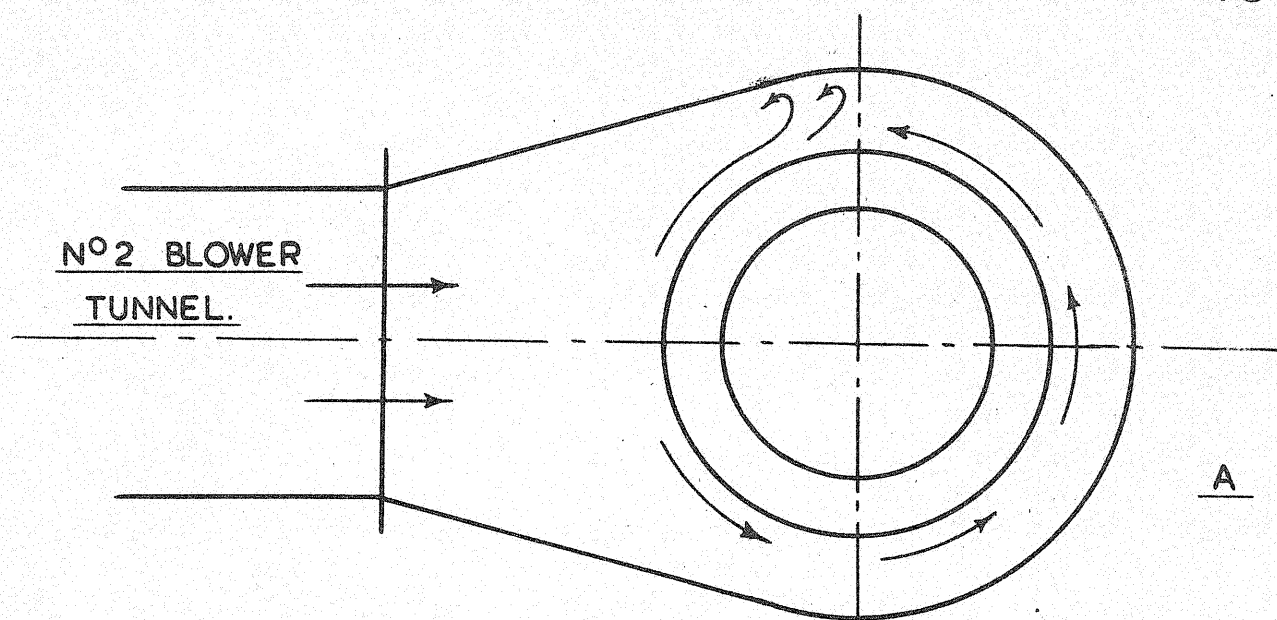
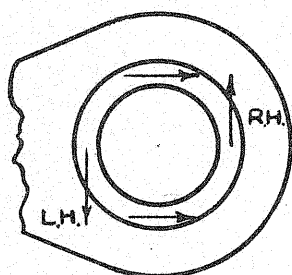
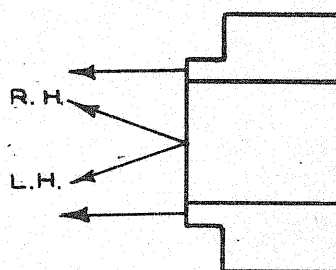
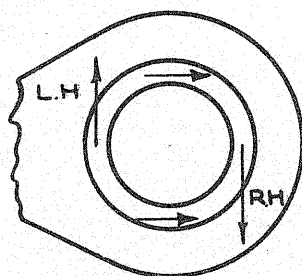
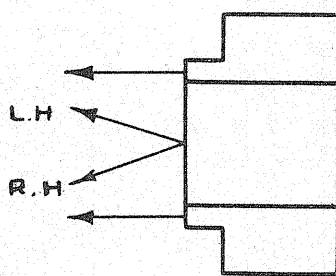
FIG. I.



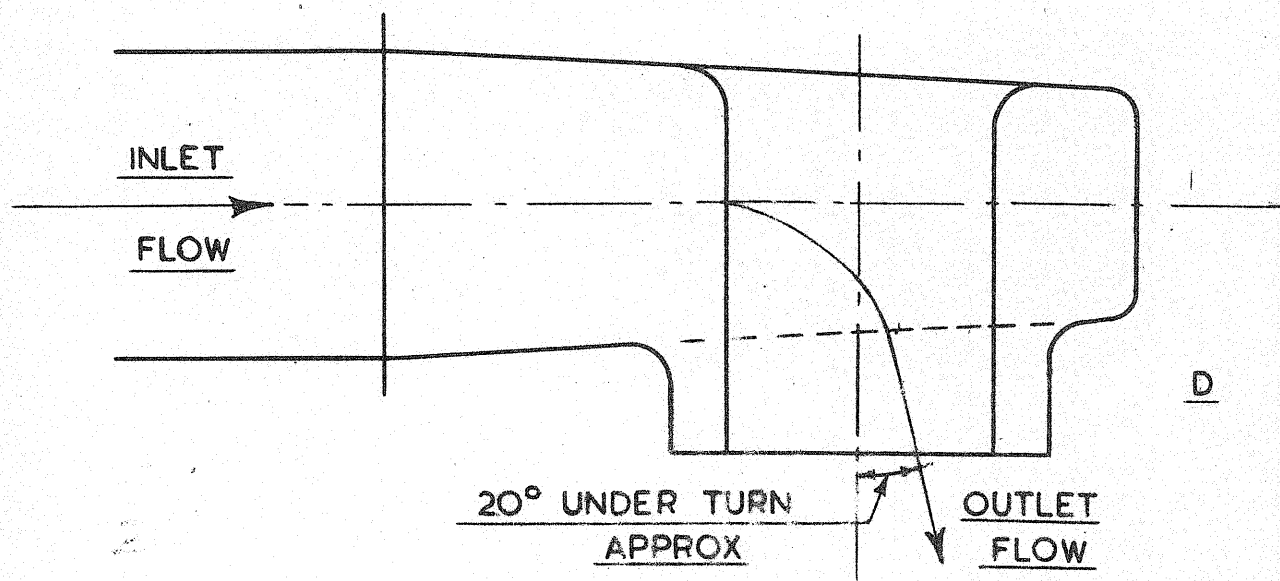
SIMPLIFIED INLET CASING



FIG 2



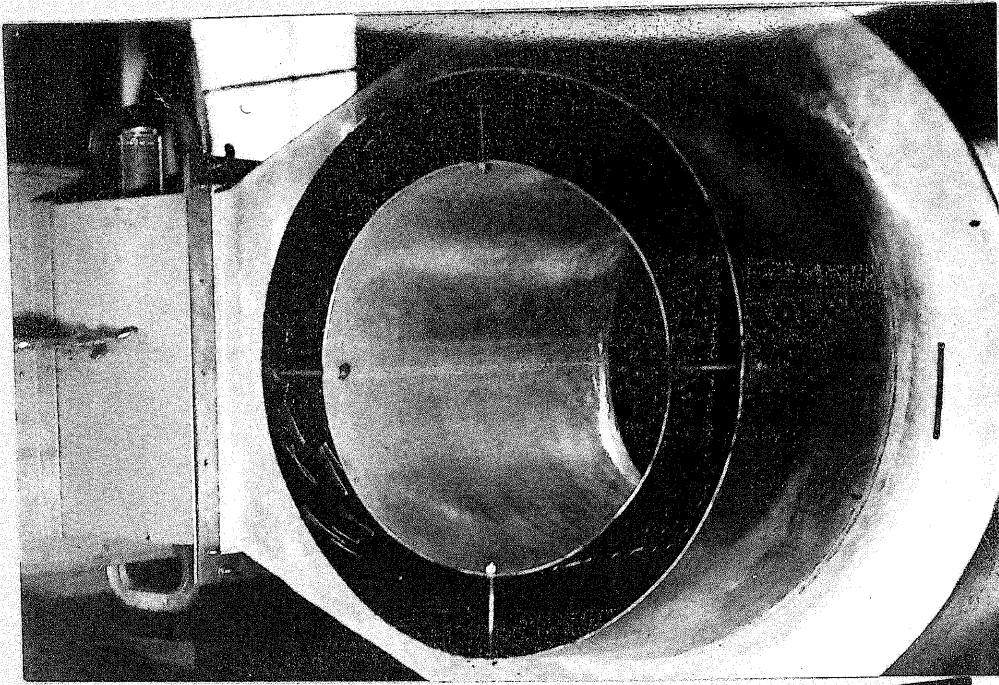
ALTERNATIVE FLOW CONDITIONS AT EXIT



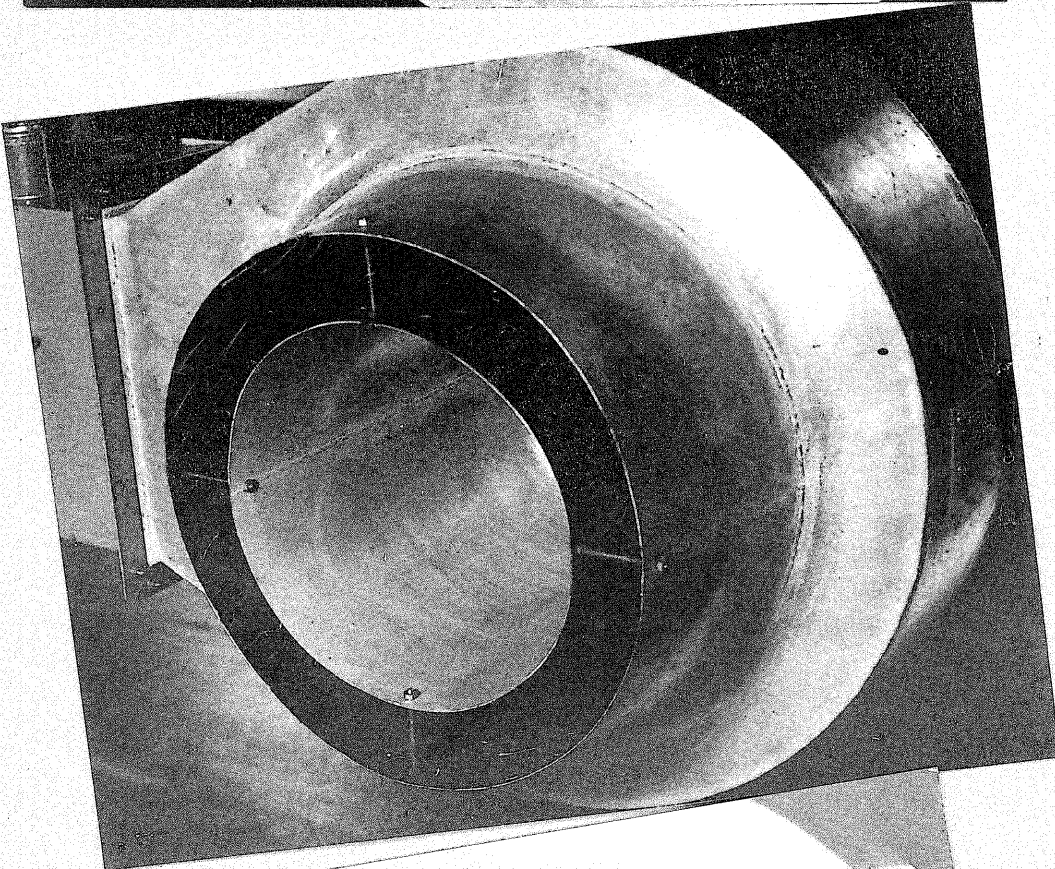
20° UNDER TURN
APPROX

FLOW CONFIGURATION IN BASIC CONDITION

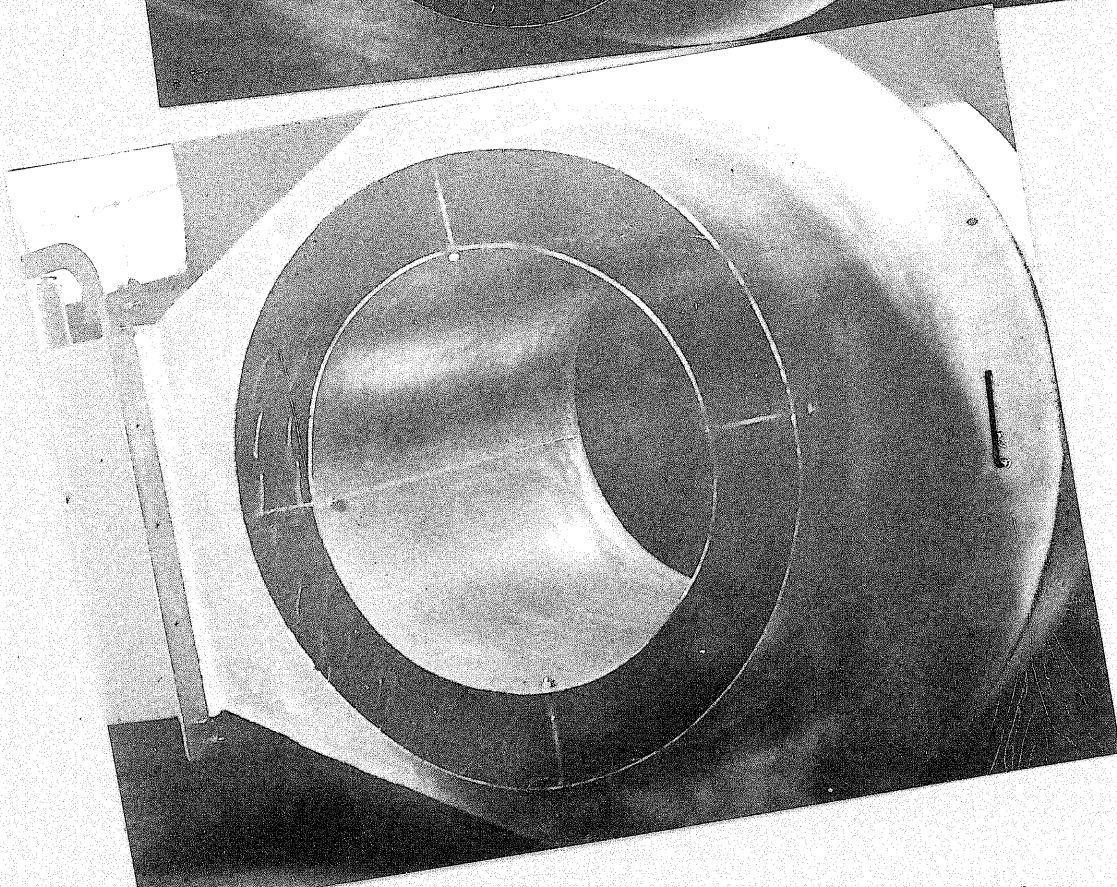
FIG. 3.



A



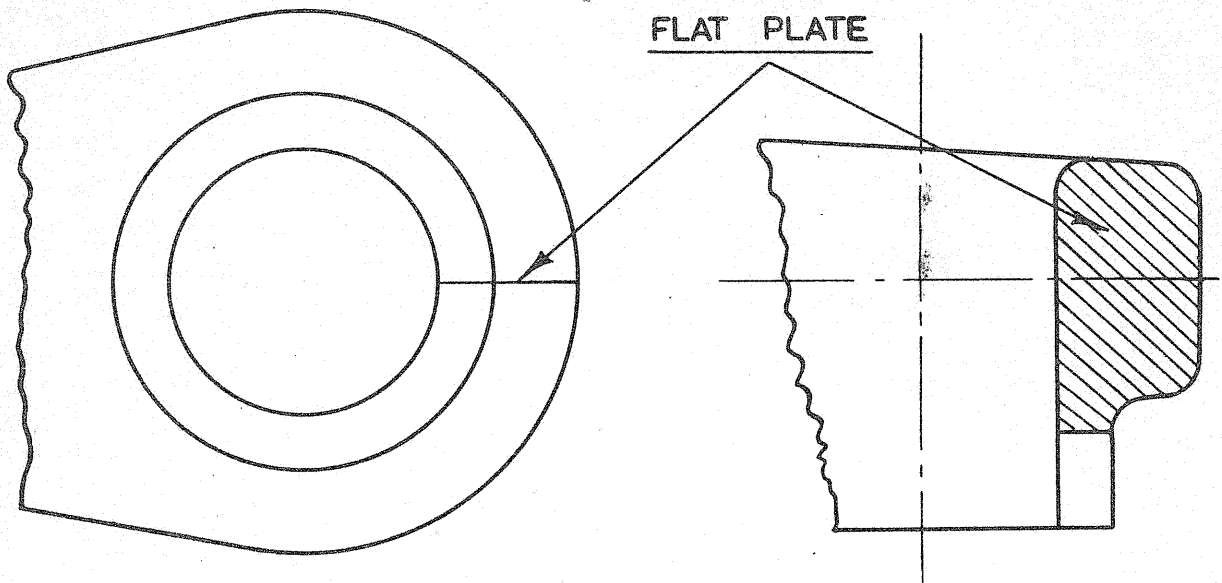
B



C

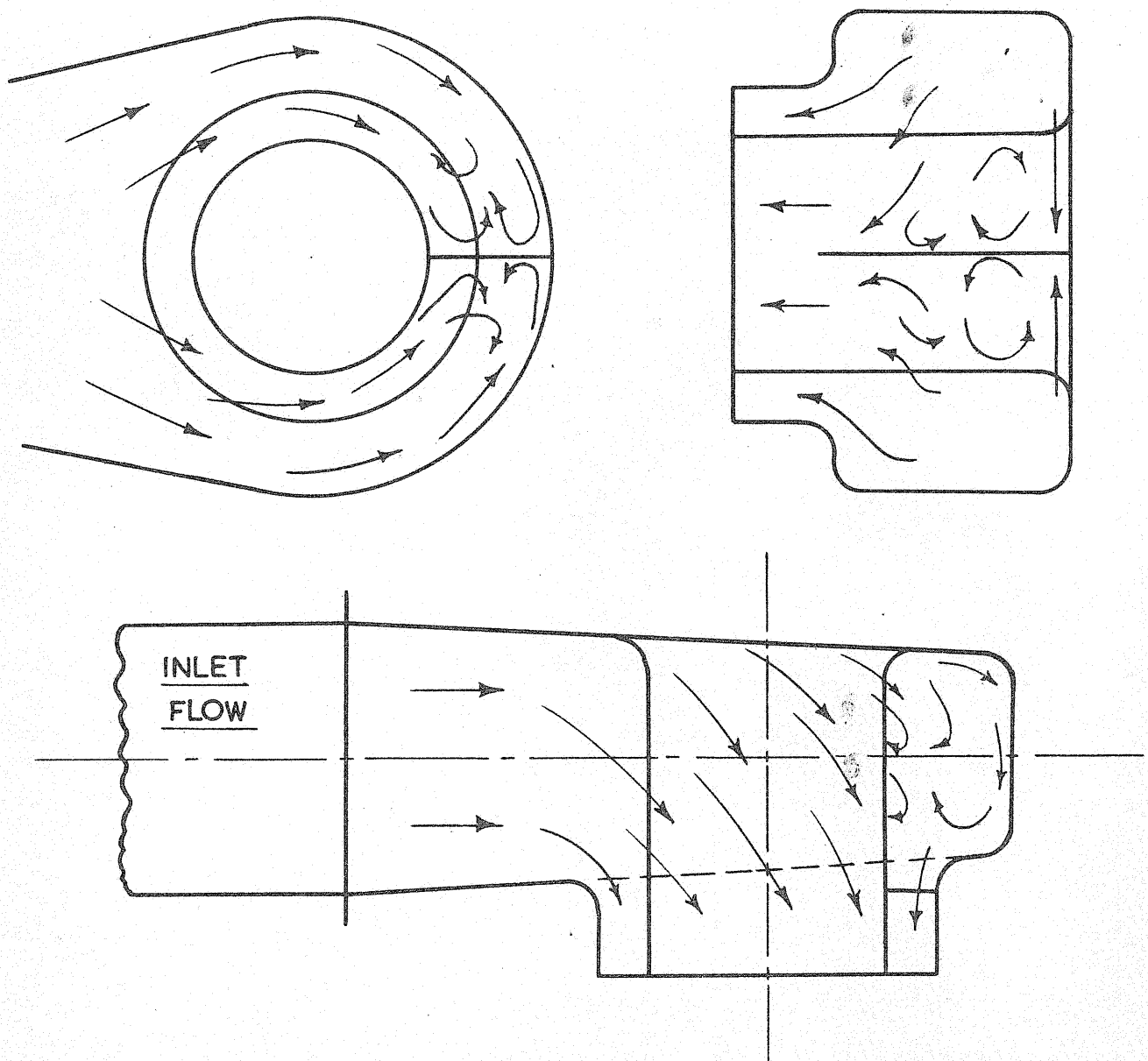
FLOW CONFIGURATION IN BASIC CONDITION

FIG. 4.



FLAT PLATE AT REAR OF SHAFT FAIRING

FIG. 5.



FLOW CONFIGURATION WITH FLAT PLATE

FIG. 6.

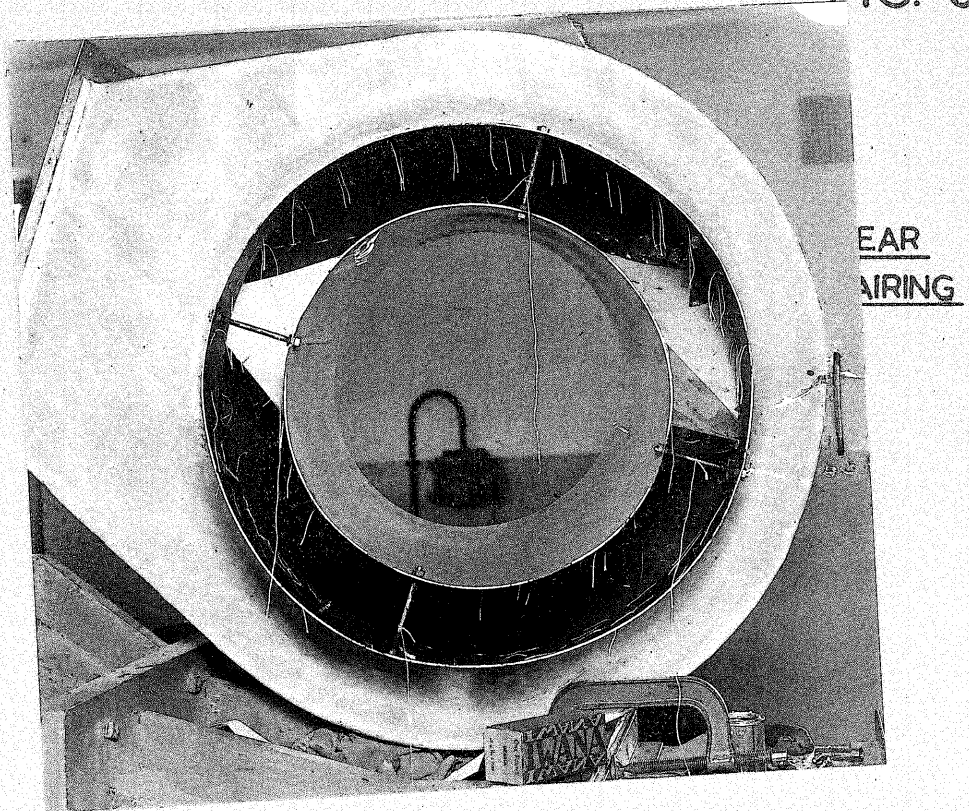
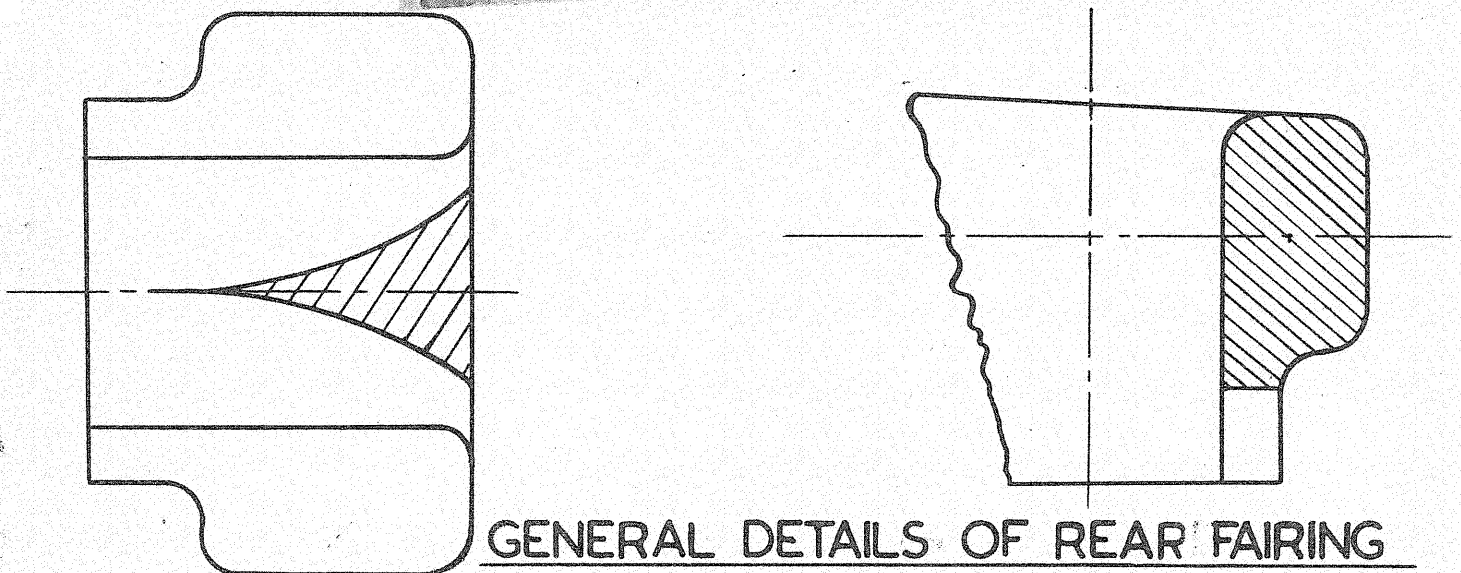
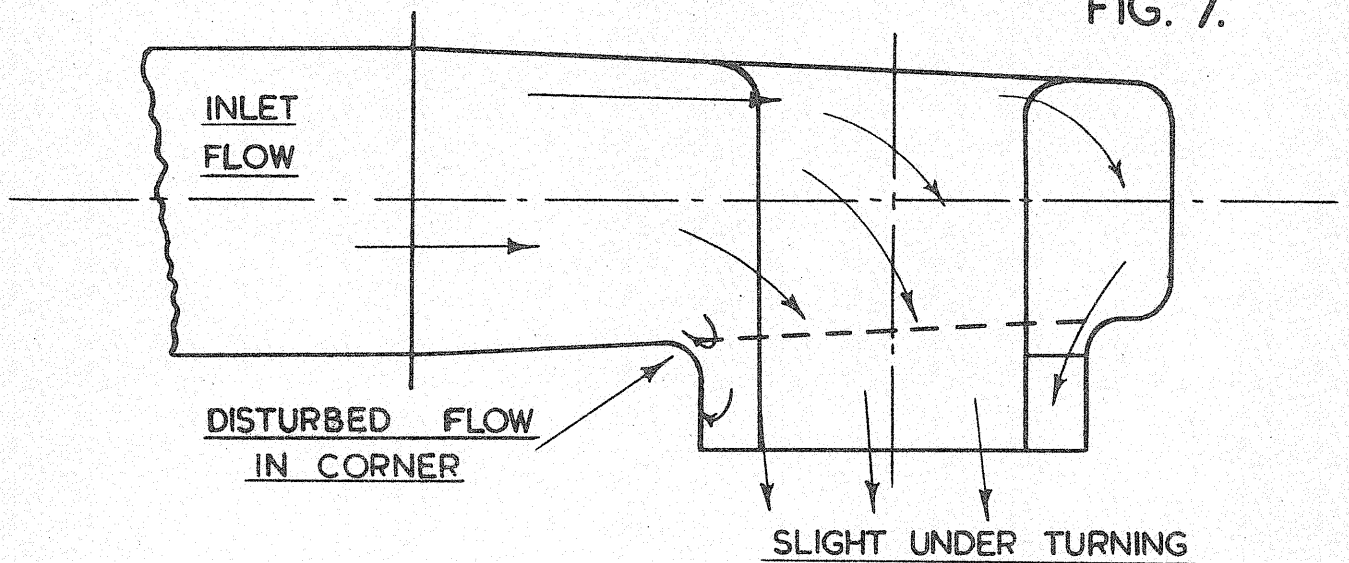


FIG. 7.



FLOW CONFIGURATION WITH REAR FAIRING

FIG. 8.

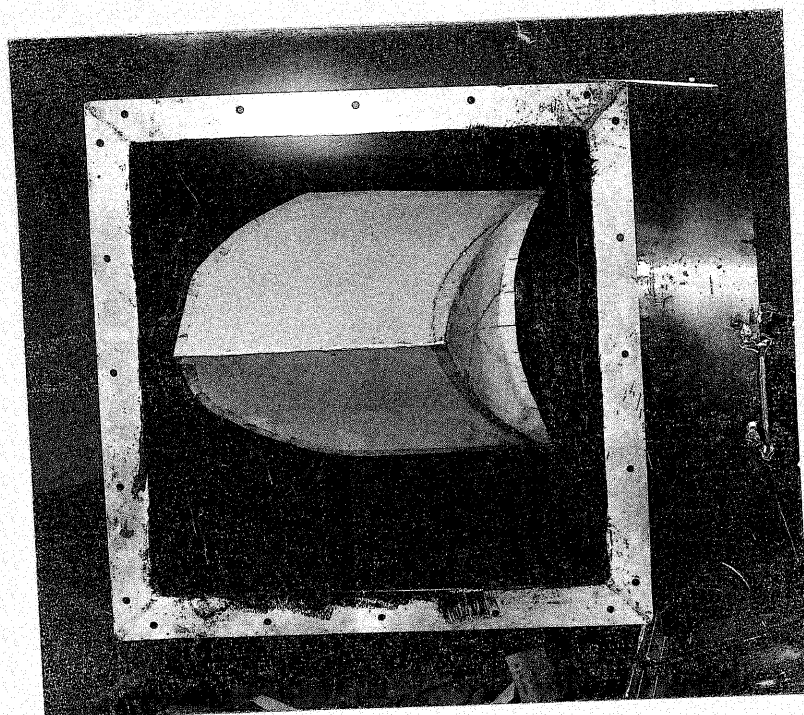
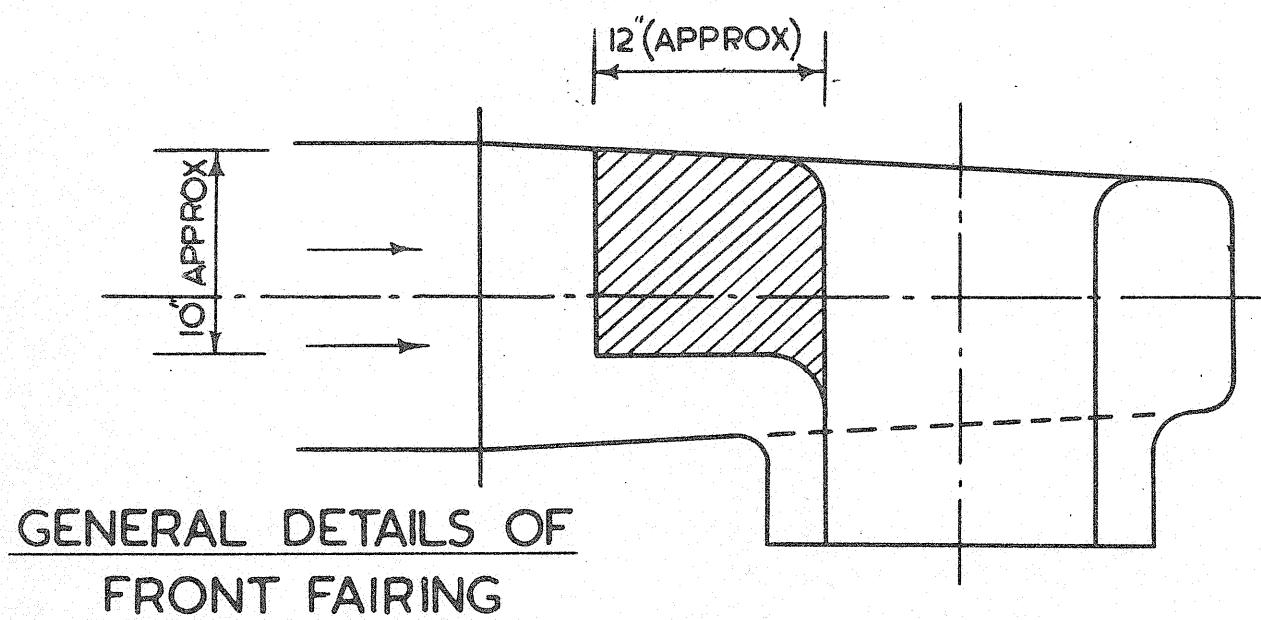
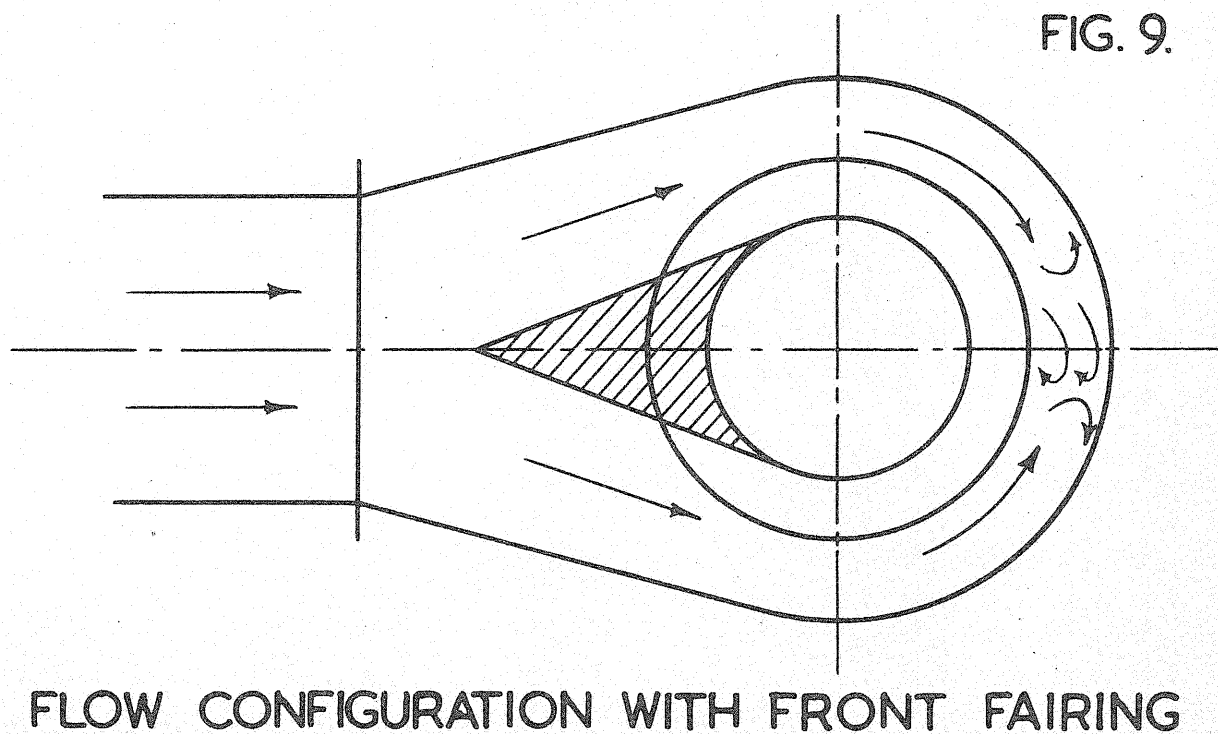
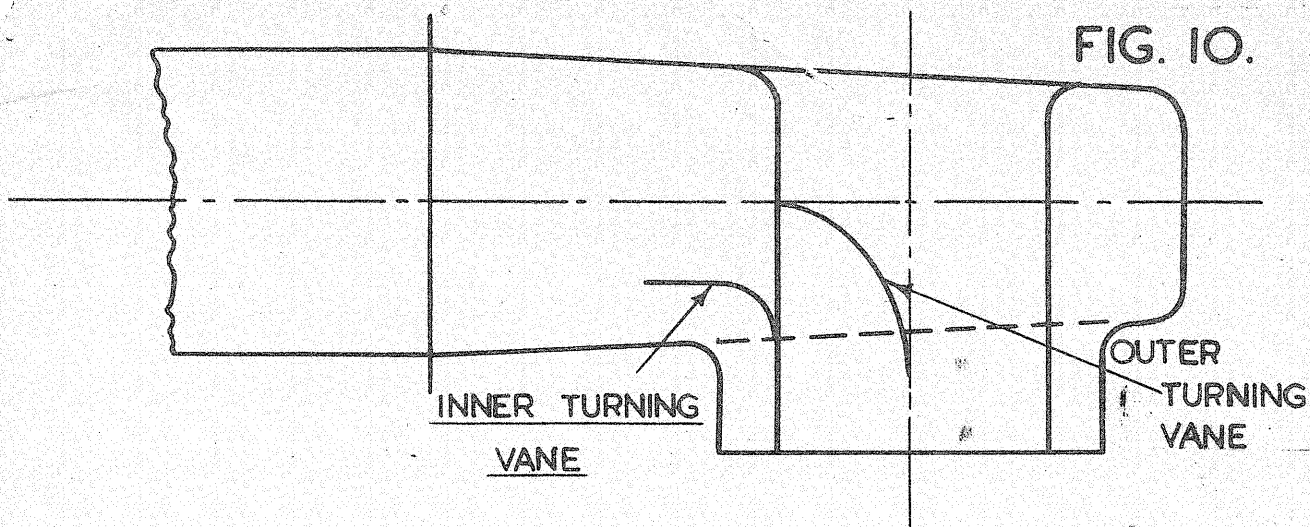
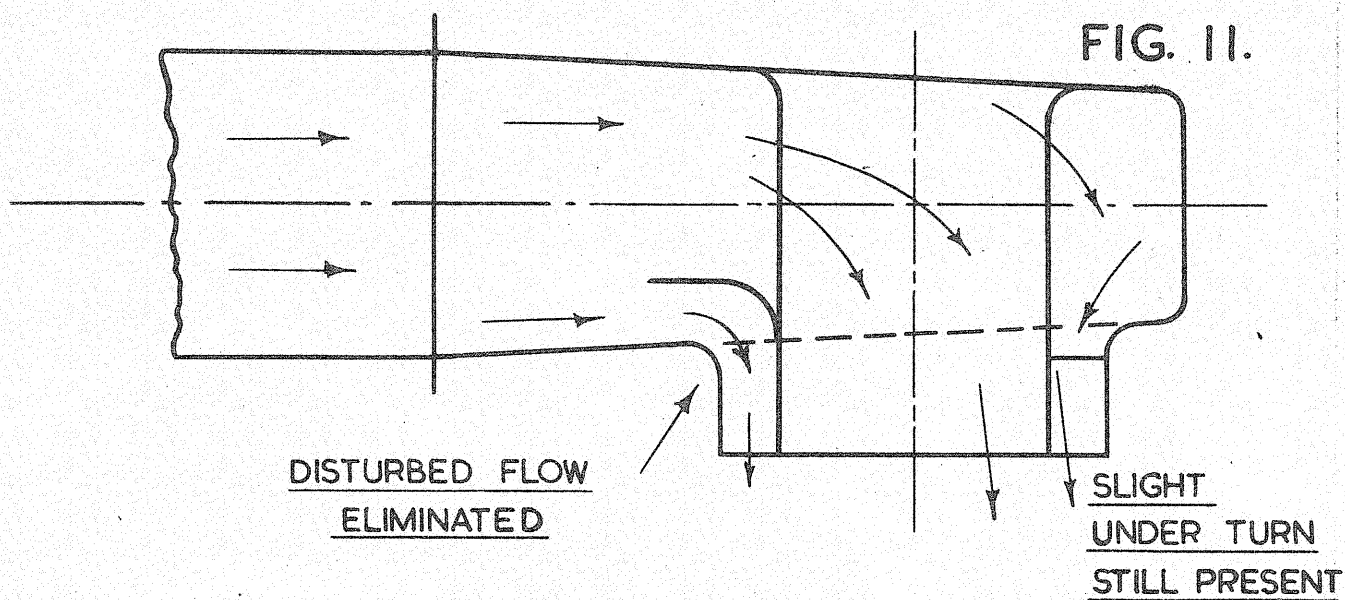


FIG. 9.

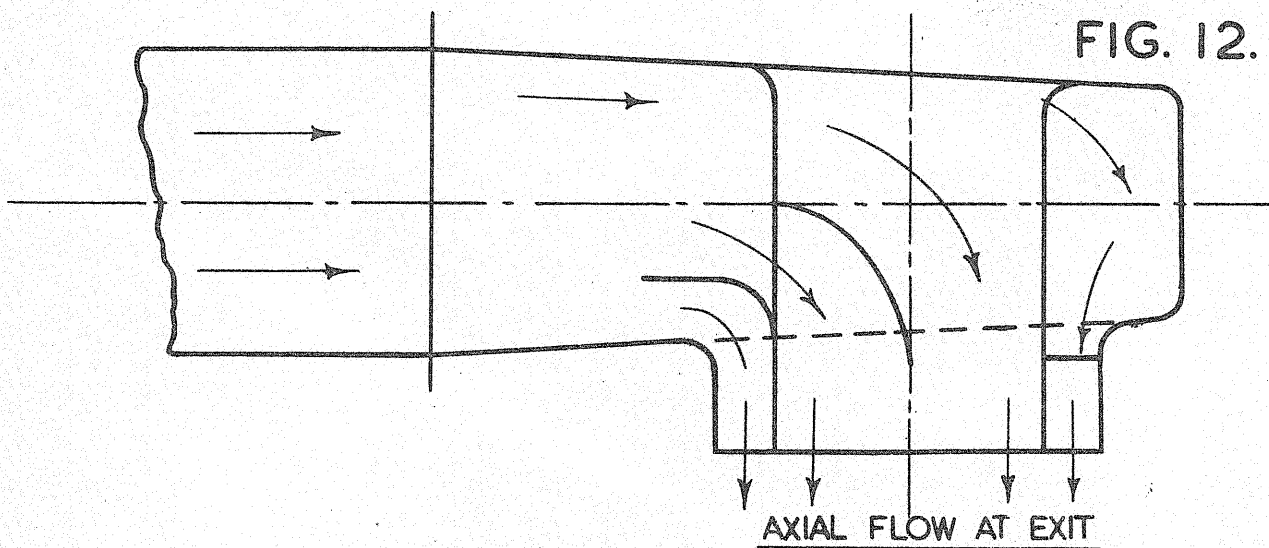




ARRANGEMENT OF TURNING VANES



FLOW WITH INNER TURNING VANE



FLOW WITH BOTH TURNING VANES