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COMPARATIVE PERFORMANCE OF VARIOUS CONTRACTION PROFILES

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ABSTRACT

This paper brings out the studies carried out on the performance of various contraction profiles.A new family of profiles "Curvature Defined Profiles", has shown better performance than the earlier profiles considered.A systematic comparison of the performance of 2-D contraction profiles has been made.The new family of profiles offer very low exit flow non-uniformity compared to all the other profiles for the same margin of separation.

INTRODUCTION

It is well known that all the finite length contractions give raise to some amount of adverse pressure gradient on the wall near the entry and exit sections and also non-uniformity of flow at the exit station and these features cannot be avoided.Therefore the objective of practical contraction shapes is to keep the adverse pressure gradients small enough to avoid boundarylayer separation and minimise the non-uniformity of flow at the exit for a given length and contraction ratio. Bradshaw(Ref 2) has mentioned that atleast first and second derivatives of the wall profile should be continuous and they be zero at the entry and exit stations.However the practical profiles which have been proposed in the past by Morel(Ref 3)and Downie(Ref 1) have discontinuity in the second derivatives of the wall profiles.

It was felt,that though the boundarylayer might somewhat effectively smoothen out the discontinuity of the second derivative of the profile,it was still desirable to avoid such discontinuities.Strictly speaking,boundarylayer equations may not be valid if large jumps in curvature occurs.

It was therefore felt that the following families of smooth profiles need to be looked into and their performance compared with the cubic and elliptic profiles for the 2-D case.One such profile earlier proposed is a profile with fifth degree polynomial which is unique for a given contraction ratio and length.One of another new profiles we considered is the matched sine profiles which has the location of the matching station as a free parameter.Another family of new profiles,say,"Curvature Defined Profiles" which has the flexibility,viz,the matching location,the ordinate and slope at the matching point as in the elliptical profiles have been analysed.

For obtaining the performance of these profiles a computational method which numerically solves the Laplace equation by the line relaxation method was developed.It is shown that "Curvature Defined profiles" are considerably superior to all the other profiles considered here.

CHARACTERISTICS OF VARIOUS PROFILES

Fifth order profile

$$y=1.0-(7.5/L^3)x^3+(11.25/L^4)x^4-(4.5/L^5)x^5 \quad \text{for } 0 \leqslant x \leqslant L$$

Cubic profile

$$y=1.0-(1-r/L)x^3/X_m^2 \quad \text{for } 0 \leqslant x \leqslant X_m; \quad y=r+(1-r/L)(L-x)^3/(L-X_m)^2 \quad \text{for } X_m \leqslant x \leqslant L$$

Sine profile

$$y=1.0-(1-r/L)x+(1-r/L)(X_m/\pi)\sin \pi/x \quad \text{for } 0 \leqslant x \leqslant X_m$$

$$1.0-(1-r/L)x-(1-r/L)(L-X_m/\pi)\sin \pi(x-X_m)/(L-X_m) \quad \text{for } X_m \leqslant x \leqslant L$$

Elliptic profile

$y = d+e\,(1-(x/f)^2)^{0.5}$ for $0 \leq x \leq X_m$; $y = a - b(1-(x/e)^2)^{0.5}$ for $X_m \leq x \leq L$; a,b,c,d,e and f are functions H,T,r,L,X_m

Curvature defind profiles

$y'' = -k_1\, x^{n1}$ for $0 \leq x \leq x_1$; $y''=-k_1 x_1^{n1}(1-(x-x_1)/(X_m-x_1))$ for $x_1 \leq x \leq X_m$
$= k_2(L-x_2)^{n2}((x-X_m)/(x_2-X_m))$ for $X_m \leq x \leq x_2$; $y''= k_2(L-x)^{n2}$ for $x_2 \leq x \leq L$

where,k_1 k_2,x_1,x_2 are functions of X_m,H,T,r and L for a given n1 and n2.
For all the above profiles X_m=matching location; H=Height at the matching location;T=slope at the matching location;L=length of the contraction profile;c=contraction ratio; r=exit co-ordinate=1/c

PERFORMANCE OF VARIOUS PROFILES

Laplace equation in stream function is solved in the transformed rectangular computational plane.The code was validated by comparing the results with the exact solution for a 2-D contraction duct with straight wall contours(Fig 1).The performance of the contraction profile is assessed by the non-uniformity of velocity at the exit(U_2) as defined by Morel(Ref3) and the avoidance of boundarylayer separation based on Stratford's turbulent separation criterion (Ref 4)which is given below. Here the results are discussed for a contraction ratio of 4 only.

$$C_p(s\, dC_p / ds)^{0.5} < 0.35\,(10^{-6}\ Re\ s)^{0.1} \quad \text{-------------(1)}$$

The length along the wall 's' is non-dimensionalised with respect to entry ordinate and Re is based entry ordinate.In the analysis Re is taken as 10^6 and (RHS-LHS) of equation (1) is defined as the margin of separation,S_m(negative values mean separation present) Re is Reynolds Number; C_p is pressure coefficient and dC_p/ds is the pressure gradient.

Fifth order profile

This has a unique profile and gives U_2 =1.4% and separation margin S_m =0.05

Cubic and Sine profiles

For these profiles only one parameter,the matching location X_m can be varied.It was found that as X_m increases S_m improves but non-uniformity also increases.The performance of cubic and sine profiles are shown in Fig.3 and they are very close to each other.

Elliptical profiles

There are three independent parameters for generating the profiles.A lot combinations of these parameters were studied in detail.For a given X_m and H , the variation of U_2 and S_m are insignificant with change in T.Hence one can choose T equal to -1.5.Increasing the values of both X_m and H improved S_m but increases U_2 also.From the considerations of reasonable non-uniformity and sufficient separation margin it was found that range of H between 0.4 and 0.5 and X_m from 1.0 to 1.2 need only be considered.From these analysis, for H=0.4 and H=0.5(T=-1.5) cross plots of U_2 with S_m as X_m varies from 0.8 to 1.4 were obtained and they are also shown in Fig .3.

Curvature Defined Profiles

Studies carried out for various combinations of n1 and n2 indicated that n1=1.0 and n2=3.0 was the optimum choice from the considerations of preventing boundary layer separation on the wall and minimising the non-uniformity at the exit.Here also analysis was carried out for various values of X_m ,H for varying T, and U_2 and S_m were found out.The variation of U_2 with S_m for combinations of X_m and H are shown in Fig .2 .The envelope of these curves which gives minimum U_2 for a given S_m is also shown in Fig 2.This envelope is also plotted in Fig. 3 to permit comparison of these profiles.

COMPARISON OF PERFORMANCE OF VARIOUS PROFILES

From Fig.3, the comparitive performance of various profiles can be assessed.It is obvious that "Curvature Defined Profiles" are far superior to all the other profiles since U_2 is far lower for a given S_m.For S_m=0.05,sine,cubic and fifth order polynomial have more or less similar performance,ie, U_2 of 1.4%.The elliptical profile with H=0.4 seems to have better performance than cubic and sine profiles but it is seen from Fig.4 that wall velocity variation is not very smooth for the elliptical profile.In any case the performance is nowhere near that of the newprofile for which the wall velocity variation is very smooth.Fig 4 provides comparison of wall and centreline velocitiy distribution for all the profiles analysed for a separation margin of 0.05 .

CONCLUSIONS

For the first time a systematic comparison of the performance of 2-D contraction profiles has been made.Elliptical profiles do not seem to have any advantage over the sine and cubic profiles except at very high margin of separations with corresponding high values of flow non-uniformity at the exit.Sine and cubic profile performances are more or less same.The Curvature Defined Profiles offer very low non-uniformity compared to other profiles for the same margin of separation.

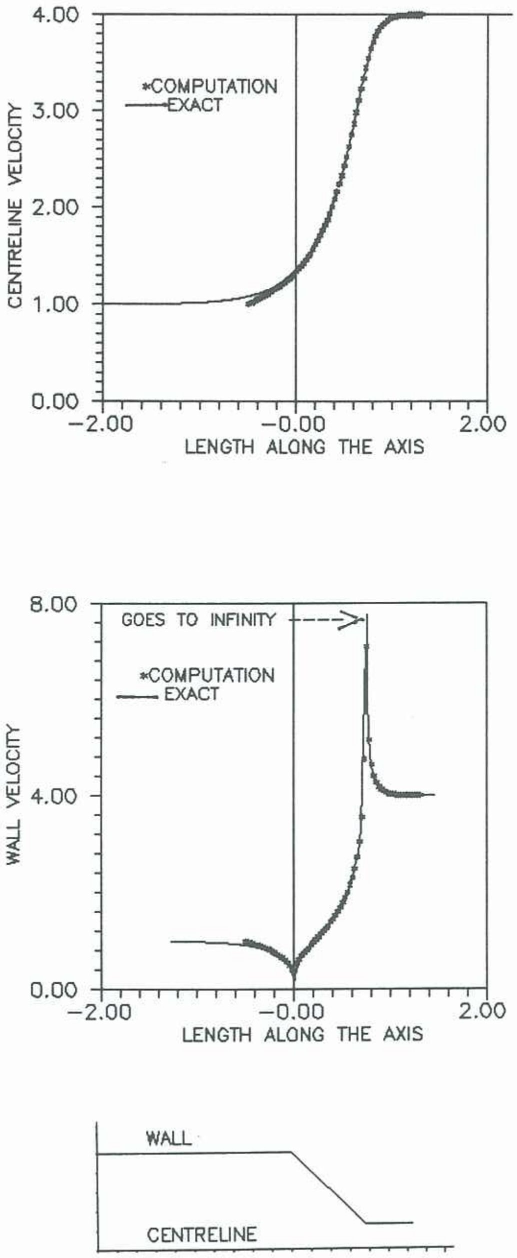

FIG 1 COMPARISON OF WALL AND CENTRELINE VELOCITIES FOR 2-D DUCT WITH STRAIGHT WALLS

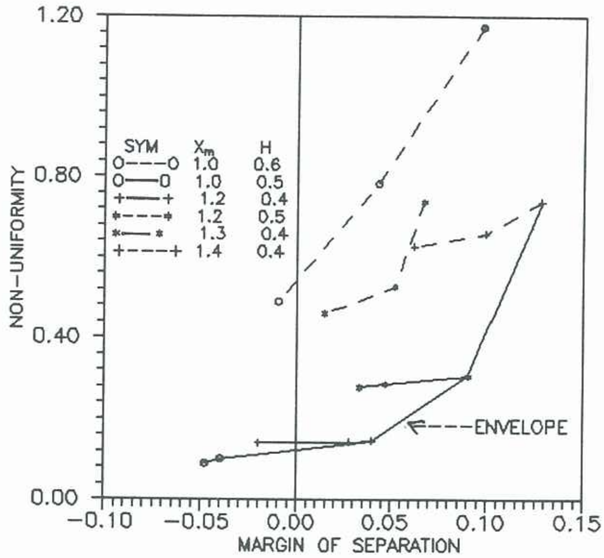

FIG 2. CURVATURE DEFINED PROFILES TO ARRIVE AT MINIMUM U_2 FOR GIVEN S_m

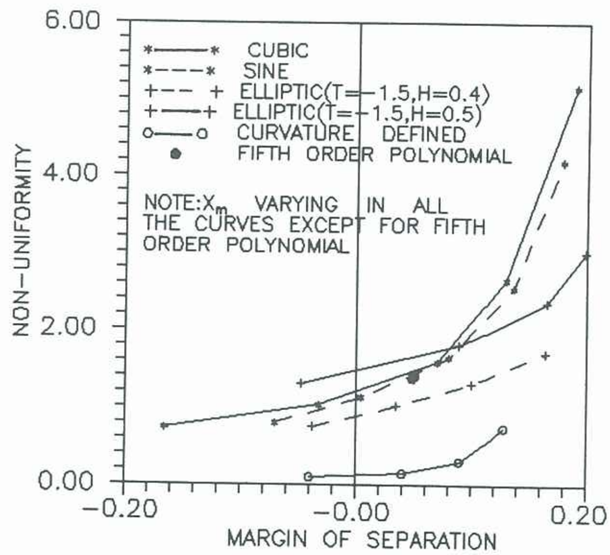

FIG 3. COMPARISON OF PERFORMANCE OF VARIOUS CONTRACTION PROFILES

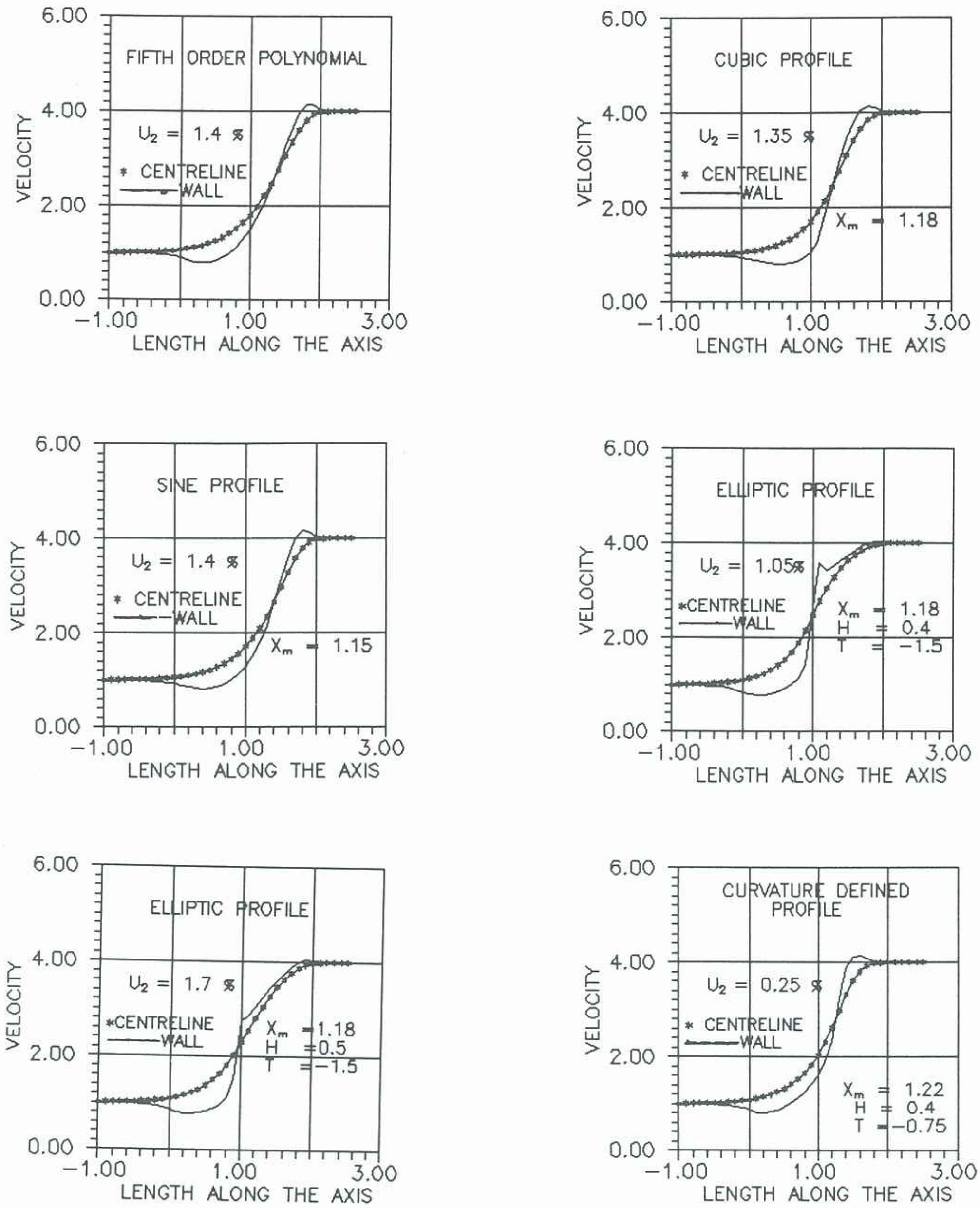

FIG 4 WALL AND CENTRELINE VELOCITIY DISTRIBUTION FOR ALL THE CONTRACTION PROFILES FOR A SEPARATON MARGIN OF 0.05

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