Engineering Notes

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Short, Multi-Step, Afterbody Fairings

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Introduction

THE use of ribbed and stepped divergent conical surfaces for diffusers used in internal flow systems has been suggested in the literature on several occasions The benefit claimed for such geometries is a potential for obtaining diffusion in a shorter flowpath length as a consequence of steepening the effective divergence angle relative to typical values acceptable with more conventional smooth surface designs The maximum divergence angle of conventional smooth surface diffusers is normally restricted by the requirement that major flow separation be avoided In a stepped diffuser the flow is deliberately arranged to separate over each step the resultant recirculation behind each step contributing to turning the flow towards the wall prior to passing over the next step downstream

It appears that it should be possible to adapt the multiple step diffuser concept to external flow situations thereby permitting the use of shorter and possibly lower cost afterbodies than are customarily acceptable for low drag bodies of axisymmetric or approximately axisymmetric cross section Simple wind tunnel tests were accordingly carried out to verify in an elementary manner the potential of such an afterbody fairing concept in the subsonic incompressible flow regime

Apparatus

The test facility used was a low speed open jet wind tunnel This tunnel is equipped with a simple pendulum type drag balance which also serves to keep the model being tested in alignment with the freestream No blockage correction was applied to the test results since the model tested represented a blockage of less than 0 5% of the jet cross sectional area

The inherent turbulence level of the freestream in the streamwise direction at the model station with the model removed was approximately 0 5% as determined from hot wire anemometer results The streamwise turbulence level is defined here as the root mean square value of the streamwise turbulent velocity component divided by the steady component of the freestream velocity The Reynolds number based on the overall length of the constant maximum diameter variable geometry model ranged from $1\ 3 \times 10^5$ to $2\ 1 \times 10^5$

The model is illustrated in Fig 1 all dimensions being expressed as multiples of the invariant diameter D of the cylindrical portion The nose was of elliptic form The model was provided with four alternative basic afterbody configurations as depicted in Fig 1a to 1d inclusive The short conical afterbody, Fig 1b was of the same axial length as the stepped afterbody of Fig 1d In addition to the basic stepped afterbody illustrated in Fig 1d four additional subconfigurations, each featuring an open ended ring added to the flat base of the configuration of Fig 1d, were also tested The four subconfigurations are documented in Fig 2

Design of Stepped Afterbody

In the absence of rigorously defined procedures for the design of stepped afterbodies it was decided to arrange for both steps of the basic stepped afterbody (Fig 1d) to be of equal area each step being equal in area to the base It was also decided to limit the basic model to only two steps plus a base, the aim being merely to illustrate the validity or lack of validity of the stepped afterbody concept Clearly a more extensive program would be required to establish an optimum geometry or geometries

In order to further simplify the design of the basic stepped afterbody it was further decided to arrange for the length of each step to be a constant multiple m of the step height This choice implies that the apex of each step lies on the surface of a cone which has a (negative) slope $1/m$ joining the cylindrical portion of the axisymmetric body to the center line (see Fig 1d) It further implies an expected similarity of the recirculation flow pattern in each step

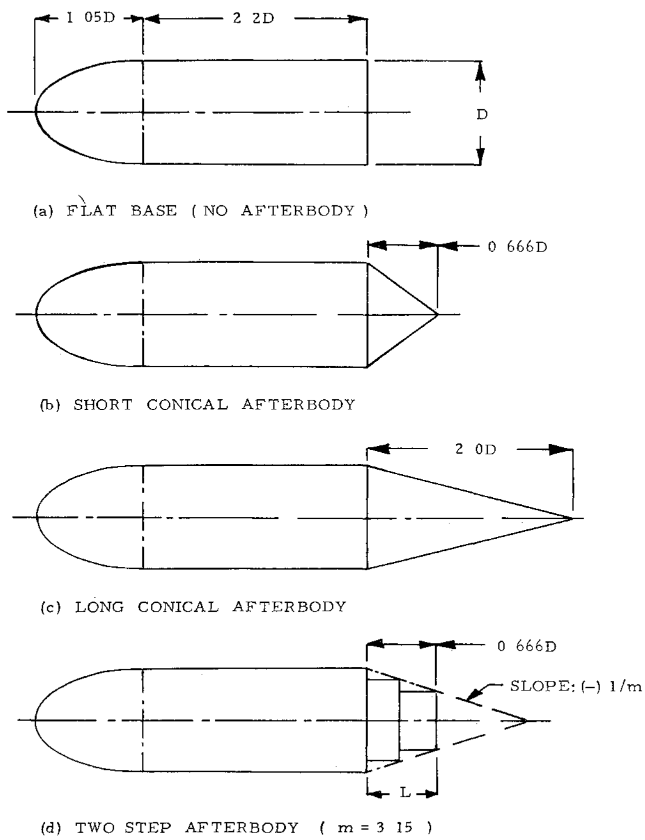

Fig 1 Basic configurations tested

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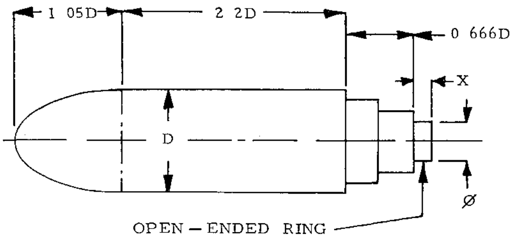

	X	Ø
RING A	0 17D	0 42D
RING B	0 34D	0 42D
RING C	0 17D	0 33D
RING D	0 34D	0 33D

Fig 2 Open ended rings added to basic two step afterbody model

Table 1 Test results

Model configuration	Length/diam ratio Overall	Length/diam ratio Afterbody only	Drag coefficient based on maximum cross sectional area
Fig 1 a	3 250	0	0 20
Fig 1 b	3 916	0 666	0 23
Fig 1 c	5 250	2 000	0 06
Fig 1 d	3 916	0 666	0 10
Fig 2 ring A	4 086	0 836	0 08
Fig 2 ring B	4 256	1 006	0 10
Fig 2 ring C	4 086	0 836	0 10
Fig 2 ring D	4 256	1 006	0 09

The physical length L of a stepped afterbody of n steps and a base all of equal cross sectional area is given by Eq (1)

$$L=\frac{mD}{2}\left[1-\frac{1}{\sqrt{n+1}}\right] \tag{1}$$

This represents the cone length minus the length of the $(n+1)$ step if in fact such a step existed In reality the $(n+1)$ th step does not exist, simply because the afterbody terminates as a base following the nth step (see Fig 1d) From an academic viewpoint it is apparent that the smooth cones Fig 1b and 1c can be thought of as stepped afterbodies (for which m is constant) having an infinite number of steps

Test Results

The results of the tests are presented in Table 1 in the form of drag coefficients based on the maximum cross sectional area of the body The results for the stepped afterbodies constitute the last five entries of the table A point of interest relating to the first pair of entries in Table 1 is that the flat base does not produce as high a drag coefficient as the steep cone As indicated by a tuft held in the flow this seems to be a consequence of the flow remaining attached to the steep cone adjacent to the cylindrical body prior to separating from the cone surface a little downstream of the cone/cylindrical surface junction It appeared that the inward inclination towards the axis of the body given to the flow adjacent to the body, commencing to pass over the conical fairing resulted in a suction on that surface The subsequent separation presumably implied that a compensatory pressure recovery was not achieved

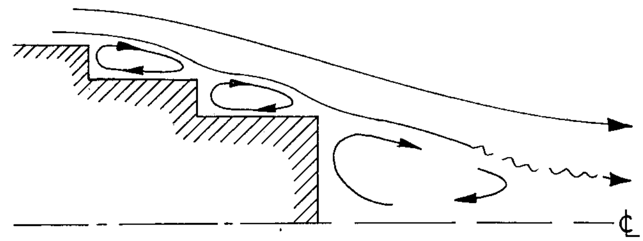

Fig 3 Sketch of flow pattern as deduced from a wire supported tuft immersed within the flow for the basic two-step afterbody model of Fig 1 d

Another point of interest is that the drag coefficient based on the body cross sectional area with a long conical afterbody was a little lower (0 06) than the value of 0 065 deduced from the literature[3] for a well faired body of revolution having the same Reynolds number of $2\ 1 \times 10^5$ based on the overall length of the body This is probably due to the relatively high inherent turbulence level in the wind tunnel flow, which tends to give a greater turbulent momentum diffusion than would otherwise occur and thus helps the flow to pass over the afterbody without separation Flow visualization using a tuft yielded no evidence of flow separation

The drag coefficient with the simple two step afterbody was half that obtained with a flat base and was less than half the coefficient corresponding to the short conical afterbody of equal length The minimum drag coefficient 0 08 which was achieved using the stepped afterbody, was attained when a short open ended ring of length 0 17D and diameter 0 42D was attached to the flat base of the basic two step afterbody Attempts to visualize the flow over the stepped afterbody using a tuft revealed a flow pattern of the type sketched in Fig 3

Conclusions

Simple wind tunnel drag measurement tests indicated that a stepped afterbody can be an effective device for fairing bodies of revolution, particularly when it is necessary to minimize the length of the afterbody The tests showed that the minimum drag attained using a stepped afterbody was only 33% greater than that obtained using a conical afterbody of 2 4 times the length The drag coefficient achieved with that conical afterbody corresponded fairly closely based on data reported in the literature [3] with the coefficient expected from a well faired body of equal overall length to diameter ratio operating at the same Reynolds number

It may be possible to improve the results obtained with stepped afterbodies by careful optimization of the configuration geometries

References

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