A STUDY OF STALL IN A LOW HUB/TIP RATIO FAN

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ABSTRACT

An investigation has been carried out in order to define the process of rotating stall inception in a low speed, low hub-tip ratio fan. Based on elementary cascade analysis, the fan would be expected to stall from the root, however, considerable experimental evidence indicates that tip stall is more frequently incurred. Although the analysis has been undertaken for a specific fan it is considerd to be representative of a broad range of machines. The analysis has involved two primary considerations, first the effect of streamtube contraction which has been studied theoretically and secondly real flow effects (those not contained in the theoretical model) which have been studied experimentally.

The study of streamtube contraction indicates that the root rematches to a more stable operating point thus alleviating some of the problems in that region. The experimental investigation was undertaken on an isolated rotor, with successive build modifications to increase the likelihood of rotating stall inception at the root. It was apparent that real fluid effects tended to steepen the root pressure rise characteristic, thus enhancing the stability in that region. The performance of the fan at the tip tended to be poor providing a pressure characteristic with a lower negative gradient than anticipated indicating less stability than simple flow models would suggest. Hot wire flow mapping at the rotor exit supported the overall conclusion that the rotor showed a strong reluctance to stall at the root apparently due to "centrifuging" of the boundary layer towards the tip.

NOMENCLATURE

AVR	Axial Velocity Ratio (Inlet/Outlet)
$\bar{C}_a$	mean axial velocity
i	incidence
P_2	downstream static presure
P_{o1}	upstream total pressure
U_m	mean blade speed
δ	deviation angle
ϕ	flow coefficient, $\bar{C}_a / U_m$

INTRODUCTION

The aerodynamic design of blading for low hub-tip ratio fans is complicated due to the different conditions occuring along the span and the downstream static pressures the various blade sections have to provide (the downstream static pressures being controlled by the performance of the various blade sections and radial equilibrium considerations).

Stall is a widely used term associated with flows which are considered to be partially or completely separated. In the present context, however, the term stall is used to describe the condition where the compressor flow regime changes from a nominally axisymmetric flow to one characterised by one or more cells of reduced throughflow which rotate in the direction of rotation but at about half rotor speed i.e. the rotating stall condition. Rotating stall is an undesirable flow condition and research into its prediction and control has been pursued for over forty years (Cheshire, 1945, Dring et al., 1982, Freeman, 1985, Moore and Greitzer, 1985, Greitzer and Moore, 1985, Smith, 1974).

Stability analysis of the compressor flow field, usually employing an actuator disc model of the blade rows, has made a strong contribution to the understanding of stall inception in a two-dimensional sense. Almost any reasonable physical model used in such a stability analysis is able to predict the growth of circumferential perturbations (i.e. rotating stall). The stability criterion employed are similar for all the models, (i.e. the compressor will stall at or near the zero slope point of the pressure rise characteristic (Emmons et al., 1959, Fabri, 1970, Dunham, 1965)) but this is of limited validity since a good proportion of compressors stall while still on the negatively sloped part of their characteristic, (Day et al., 1978, Fattner, 1990). It is probable that further improvements would require inclusion of modelling of radial and circumferential effects in considerable detail. This in turn would rely on a more thorough understanding of the stall inception process.

Until recently, experimental knowledge of the inception process had largely been based on correlative studies of conventional steady state parameters such as the casing boundary layer thickness and the blade row static pressure rise (Koch, 1981, Zika, 1985). While such studies have certainly increased the data available leading to a better general understanding of the factors affecting the process, they are inherently limited in their ability to describe the inception process in more detail. This is due in part to the fact that it is difficult to study the influence of any one factor in isolation. Concepts such as the blade stall/wall criterion (Greitzer, 1979) point to the important role that may be played by the different regions of the flow field. The development of transient experimental techniques has also permitted the problem to be analysed more closely. Recent investigations in a high hub-tip ratio stage (Jackson, 1986), have revealed that forward spillage of the tip clearance vortex can play an important role in the inception process.

The current paper is concerned with stall in a fan of low hub-tip ratio consisting of rotor and stator although much of the study has been undertaken on the isolated rotor. Matching of the various streamtubes through a fan is controlled by the downstream static presure which in turn is influenced by radial equilibrium. A common design feature of rotors is a uniform radial distribution of work and as a consequence the tip presure rise characteristic tends to be steeper than those at the root and therefore the root sections tend to suffer greater variation in local flow condition for a specified change in back pressure. As the mass flow is reduced, therefore, the blade root section tends to reach the peak of its characteristic well before the tip region (Fig. 1a). Operation at, or near, the peak of the total-to-static characteristic is linked, both experimentally and theoretically, to stall inception and therefore this simple model would suggest the fan would stall at the root before doing so at the tip.

Existing experimental data of stall cell patterns in low hub-tip ratio fans indicates that both part span and full span cells may occur. If stable part span cells occur in isolated rotors, however, then they have generally been found to occur at the tip although measurements on compressors (rotor and stator) (Giannissis et al., 1988, Wood et al., 1960) indicate that