

VKI LECTURE SERIES 1992

Stall and Surge in Axial Flow Compressors

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General Introduction

This lecture, and the subsequent one on Active Control, are intended as introductory lectures to be presented at the start of the Series. For this reason the content has been kept simple and conceptual ideas are developed from first principles. It is to the benefit of all that we start with a clear understanding of the physical properties of stall and surge so that subsequent theoretical treatise can be tackled from a sound footing.

The work presented here is primarily of an experimental nature. This comes about partly because of my own personal bent, but also as an attempt to balance the theoretical content of the course. Some years ago theoretical work led to the prediction of long length scale disturbance associated with stall onset. These disturbances were subsequently confirmed by experimental work, but it has likewise occurred that experimental work has revealed short length scale disturbances for which there is, as yet, no theoretical explanation. It is this interaction between experimental and theoretical work which makes this field of study so interesting.

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1) Introduction

The aerodynamic instabilities of rotating stall and surge have bedevilled compressor design right from the time of Whittle and the first engine. These instabilities place an upper limit on compressor performance and the uncertainty of where this limit actually is results in the wasteful use

of large safety margins. For many years there has been relatively little progress in our ability to predict the point of stall or surge onset but our physical understanding of what happens in the compressor is improving and recent theoretical work suggests that useful developments will follow.

Active control, which is the technique of damping out instabilities when they begin, has recently come to the fore because of improved theoretical models, and because of the driving need to cut down on wasteful safety margins. In one sense active control side steps the issue of when instability will occur but in another sense it has heightened our interest in how the instability begins. Stall inception and active control are a thus complimentary fields of study and will be presented here as inter-related subjects.

In historical terms, fully developed stall and surge were studied first before attention was given to the process of inception. This is rather like a doctor faced with a new problem; first he studies the nature of the disease and then he tries to find out what causes it. Following this train of thought, the details of fully developed stall and surge will be considered first and only after this will the process of stall inception be discussed.

2) Fully Developed Rotating Stall

Rotating stall is a flow disturbance which is restricted to the vicinity of the compressor blading. That is to say, it does not affect the flow far upstream or downstream of the compressor. Rotating stall occurs in a situation where the pressurized volume downstream of the compressor is relatively small and the amount of stored energy is low. This is often the case in industrial and laboratory situations, or in aero-engines when the speed of rotation is low. The insert in Fig.1. illustrates the idea with a compressor followed closely by a throttle valve.

The flow disturbance, or stall cell, is a well defined area of disturbed flow which rotates around the compressor at some speed less than rotor speed. Each rotor blade therefore passes into and out of the disturbed region and in the process adds energy (heat) to the disturbed flow. The amount of heat added is significant and sometimes leads to titanium fires in aircraft compressors. In addition, each blade is subjected to fluctuating loading conditions as it passes into and out of the stall cell and fatigue failures are often the result.

The occurrence of rotating stall in a compressor results in a sudden drop in the pressure rise of the compressor. This is also illustrated in Fig.1. where a typical pressure rise characteristic shows the difference