1. INTRODUCTION

1.1 General Background

The cost of fuel burned by the engines typically accounts for 50% of the aircraft Direct Operating Costs in the medium and long range market segments. Competitive fuel burn is an essential ingredient for successful marketing campaigns, leading ultimately to profitable engine programmes. The thermodynamic cycles for large civil aero engines, such as the Rolls-Royce RB211 series and the International Aero Engine consortium V2500 are optimised to minimise fuel consumption with achievable levels of component efficiency, compressor pressure ratio and turbine entry temperature. As turbomachinery researchers find ways of reducing losses, it becomes worthwhile for engine designers to aim for higher cycle pressure ratios, as illustrated by fig 1.1. This presents compressor design engineers with the dual requirements for high shaft pressure ratios and high compression efficiency, while maintaining adequate surge margin for safe, transient operation.

As the cycle peak pressure and temperature are raised, the optimum bypass ratio increases, so the core engine size for a given thrust reduces and deleterious viscous flow phenomena make the achievement of high efficiency more difficult, particularly in the latter stages of high pressure core compressors.

Over the 50 year history of the aero gas turbine, the most significant progress in Compressor Technology has been in achieving well matched designs, more nearly 'right first time', and in reducing the levels of aerofoil profile loss, such that today's industry standard machines have polytropic efficiencies of around 90%. Much of the outstanding inefficiency which is potentially reducible is believed to be associated with interaction between blades and near end-wall flow phenomena.

Though this has long been recognised as a problem area, there has been relatively little published work to guide designers, and that which exists is not systematic and often contradictory.

For example, Rolls-Royce has demonstrated improvements in efficiency of the order of 1% (so a 10% reduction in losses) together with increased surge margin in tests of one of its research core compressors by improving the radial matching of rotor and stator blade geometries to annulus wall boundary layer velocities. This involves near-wall camber and stagger modifications known as 'end-bends'. (Freeman and Dawson, 1983).

Compressor performance levels are demonstrated using high-speed, multistage rigs which are expensive to manufacture and test and not well suited to detailed surveys of the internal flow because of their small physical size.

Cost effective research, which is aimed at establishing and understanding the important fundamental flow phenomena, can be carried out on simpler vehicles, such as the large-scale, low speed axial flow 4-stage compressor rig (LSRC) which is installed at the Cranfield Institute of Technology.

The content of this report is an element of an ongoing programme on this facility, which includes tests of end-bent blading compared directly to conventionally designed stages. This is aimed at increasing understanding of the flow/geometry interaction with the overall objectives of maximising end-bend benefits and improving design techniques. The work is reported in greater detail by Robinson (1991).

1.2 Outline of the Report

Section 2 reviews the literature which has most direct relevance to blading design in the end-wall region. Firstly, a brief description is given of the important 3D flow phenomena occurring in embedded stages of axial compressors. Most of the published material relevant to Compressor Technology concentrates either in describing conditions through conventionally designed machines, or on the achievement of well matched designs. Not much has been published on blading designed to reduce near-wall loss and the material reviewed in section 2.3 is believed to be comprehensive and not previously collated.

Section 3 starts with a brief description of the Cranfield LSRC, followed by details of the blading studied. There are four sets in total, two conventional and two with end-bends. The aerodynamic data from these are probably unique in their description of severe end-bend geometries and provide a comprehensive description of the flow through embedded core compressor stages, which is not available from any other facility in the UK.

Section 4 reports the application of a 3D Navier-Stokes (N-S) solver to the conventional and end-bent stators from the two low-reaction builds, with the objective of assessing the code from the point of view of potential 'effectiveness' in the compressor aerodynamic design process. Calculation results of exit whirl angles, losses and surface static pressures are compared with experiment and then the MEFP results are post-processed to reveal further details of the flow not normally visible to the experimentor.

This work has resulted in a much clearer understanding of the behaviour of end-bent blading in the buried stage environment and calculations with throughflow and N-S codes have paved the way towards improved design techniques.