Aero-Acoustics of Modern Transonic Fans — Fan Noise Reduction from Its Sources

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The noise of aerodynamic nature from modern transonic fan is examined from its sources with the perspective of noise reduction through aero-acoustics design using advanced Computational Fluid Dynamics (CFD) tools. In particular the problems associated with the forward propagating noise in the front is addressed. It is identified that the shock wave spillage from the leading edge near the fan tip is the main source of the tone noise. Two different approaches have been studied to reduce the forward arc tone noise and two state-of-art transonic fans are designed using the strategies developed. The following rig tests show that while the fans exhibit other noise problems, the primary goals of noise reduction have been achieved through both fans and the novel noise reduction concept vindicated.

Keywords: transonic fan, aero-acoustics, noise reduction.

Introduction

As airlines around the world facing increasingly tightened noise regulation, reduction of aircraft noise is becoming a pressing issue both aircraft and engine manufacturers must face. Although the noise of an airplane mainly comes from two sources, airframe and engine, as passenger aircraft increases in size and with increased bypass ratio of the engines, the engine noise dominates the noise generated by a modern jumbo jet. In 1992 NASA, together with US aviation industries and FAA launched Advanced Subsonic Technology (AST) program to develop technologies that enable a safe and highly productive global air transportation system that will be both environmentally compatible and economical. Engine Noise reduction is one of the main elements of the program, and is aimed at reducing the engine noise by 6 db in 2000 relative to 1992 level. This part of program has been followed up by the Quiet Aircraft Technology (QAT) program, launched in 2000 to further develop the technology required for reducing the perceived noise impact of future aircraft, in addition to those acquired in AST program. The overall target of the program is to reduce the aircraft noise by 10 db within 10 years and 20 db in twenty years’ time. It is projected that about 8 db improvement would come out through reduction of sources amongst which fan is the strongest. This highlights the importance of fan as the major source of noise as well as the source for potential improvement. During 1998 and 2001 European Commission sponsored a BRITÉ/EURAM project Reduction of Engine Source Noise through Understanding and Novel Design (RESOUND), with an aim to acquire the technology necessary to support the design of derivative and new engines with 4db quieter than those currently entering service. The project involves a consortium of all major European aviation industries together with government research establishments and universities as partners. Again fan noise reduction was addressed as the major component of the project.

The largest impact of engine noise comes from take-off and landing. As indicated in Fig.1, noise references are taken at these conditions for certification purpose. During take-off and approaching to landing, fan noise stems out to be the strongest source of all. Fig.2, taken from Owens shows the typical perceived noise level of an aircraft during take-off and approaching to landing. The levels shown have also been adjusted to allow for the acoustic liners. For solid walls, there is approximately 10 db increase for the fan exit (rear arc) and about 2 db increase for fan inlet (forward arc) for both conditions. Following the trend of further increasing...
engine bypass ratio, the jet noise contribution can be considered as relatively less significant. For example, a 25% reduction in jet velocity would bring approximately 10 dB noise benefit for the same rated power, and this reduction of jet velocity roughly trades for the increase of bypass mass flow by 25%, and the same amount of bypass ratio (BPR) if the core mass flow is kept unchanged. This means the relative noise contribution from the jet is significantly reduced from early 90's level as the BPR increased from 6 to the current level of 9. This leaves the fan noise a more pertinent noise source and makes the task for reduction of the fan noise more important and pressing.

The problem of the fan noise is traditionally attacked from two directions \cite{3-6}. The first is to attenuate noise while it is propagating from the source. This is typically achieved by using acoustic liners to absorb the sound in duct. As indicated in Fig.2 that this is a quite effective method and can achieve up to 10 dB attenuation for the rear arc and 2~3 dB for the forward arc. However the total surface area that can be treated with acoustic liner cannot increase without a limit, this is particularly true in front of the fan for attenuating the forward arc noise. The second approach is trying to reduce the strength of noise source. An example of this approach is to arrange the numbers of rotor and stator rows in such a way to make major interaction tones to be cut off so that the sound would not propagate out of the nacelle. The main theme of the AST project is actually to develop subsonic fan technologies in an attempt to weaken the noise source through reduced speed. The drive behind the efforts for a lower speed is the fact that the noise is a strong function of blade speed (\~M^6 for dipole source) and further more, the tone noise would be cut-off when blade tip speeds fall below unit Mach number (Tyler and Sofrin\cite{6}). However, to date the fan has mostly been treated as a rather generic source with noise production correlated with its speed and the pressure rise across it. If one examines the fan from aerodynamics point of view, with different design practices the detailed source distribution must differ from case to case for a given fan duty and speed, but little is known about how these source distributions would affect the overall noise. It seems there exist considerable potentials for fan noise reduction through optimised aerodynamic loading distributions.

Although the fan acoustics is closely linked with its aerodynamics, very little consideration on acoustics was given during the detailed fan aerodynamic design process in the past. This is partly because the complex nature of the flow in the fan means that the fan aerodynamics alone is a formidable task for a fan designer who, under the pressure of producing a fan to meet its aerodynamic specifications, would give a low priority for the acoustics. Further more, in pre-CFD age a designer rarely has a definite idea about the detailed flow structures in a transonic fan. Without knowledge of pressure loading distributions of the fan at a certain operating condition, it is almost impossible to evaluate the acoustics effects of the fan for different operating conditions. With availability of three dimensional CFD, however, it is now possible for a designer to examine in details the pressure distributions for various fan operating conditions during the design stage, thus opens the door for the acoustics optimisation through aerodynamic design. The research reported in this paper has been trying to address, and to provide with the answers to, the following questions: Is there any real acoustic benefits for transonic fans with the same duty but different aerodynamic design features? And, if so, how to achieve these potential acoustic benefits through aerodynamic design? The research, under the sponsorship of RESOUND program, answers the questions via analysing aero-acoustics features of the typical transonic fans operating conditions critical to the noise generation, analysing and design two low noise fans with the low