EXPERIMENTAL RESEARCH ON AEROELASTICITY

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1. Introduction

The present document aims at giving an introduction to experimental research methods in turbomachinery aeroelasticity. Experimental research is conducted such as to test components, study specific aspects of aeroelasticity in detail as well as to acquire validation data for the assessment of numerical tools. Despite the degree of sophistication attained in modeling of aerodynamics, structural dynamics as well as fluid-structure interaction, experimental research plays still an important role in the investigation of physical mechanisms of turbomachinery flow phenomena (Srinivasan, 1997). In order to serving the needs, any experimental investigation must have clear objectives, followed by a appropriate definition of the experimental apparatus. Below various aspects of aeroelasticity are elucidated first providing fundamental methods for performing experimental research in aeroelasticity. An overview over various test facilities is then given followed by a review of relevant measuring techniques.

2. Turbomachinery Aeroelasticity

Aeroelasticity denotes a family of phenomena arising due to interaction of fluid and structure. These phenomena can be of steady (static aeroelasticity) or of unsteady nature (dynamic aeroelasticity). Dynamic aeroelasticity typically causes vibration that can harm mechanical integrity of components unless properly damped. Static aeroelasticity is concerned with the balance of steady aerodynamic loads and elastic structural forces. In case of dynamic aeroelasticity the sources of excitation might be of distinct nature arising for example from blade row interaction phenomena or they might be of self-excited nature indicating that the vibration is a result of the balance between unsteady aerodynamic forces and dynamic structural forces. The former case is referred to as "forced response" whereas the latter case is referred to as "flutter". Collar (1946) has given a phenomenological expression of aeroelasticity as included in Figure 2-1.

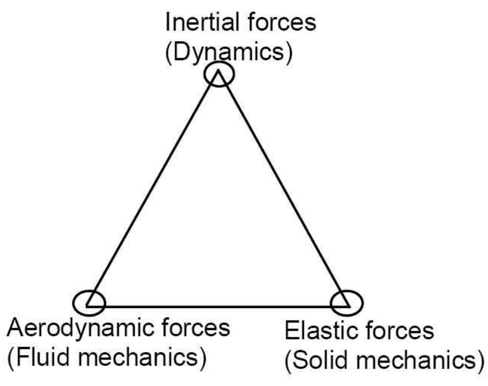

Figure 2-1. Collar's triangle of forces

The most relevant phenomena of aeroelasticity are grouped as follows:

Static aeroelasticity: balance of steady aerodynamic loads and structural forces. Turbomachinery blades deform during operation due to aerodynamic loads (gas loads) and centrifugal loads. This deformation is mainly of torsional nature (blade untwist). Other types of deformation include changes in profile section (uncamber) and bending. Static aeroelasticity needs to be accounted for when manufacturing blades. Blade geometries at running conditions (often referred to as “hot geometry”) need to be calculated back to their shape at rest. This process is referred to as “unrunning” (Marshall and Imregun, 1996).

Forced response: unsteady aerodynamic forcing due to certain (steady) spatial distribution of flow parameters in one frame of reference that can lead to unsteadiness in another frame of reference. Typical sources of forced response are blade row interaction phenomena or inflow distortion. Forced response is always characterized by deterministic forces that are synchronous to engine rotational speed (Srinivasan, 1997).

Flutter: self-induced vibrations due to initially small unsteadiness which grow rapidly in each oscillation cycle unless properly damped. At a state of flutter the unsteady aerodynamics is feeding energy into the structure leading to rapid escalation of oscillation amplitudes. Flutter can occur in various operating regimes (choke, stall, subsonic, supersonic) and is of primary concern in low-pressure compressor (including fan) and low-pressure turbine components (Srinivasan, 1997). As fan blades are exposed to gusts, cross-winds and foreign object damage (FOD) they are considered more critical with respect to flutter design.

Non-synchronous vibrations (NSV): vibrations, which are not initially induced by motion of blades but rather by inherent flow unsteadiness. Tip leakage flow unsteadiness is one of possible sources for NSV (Thomassin et al. 2007).

It is to be noted that there are other phenomena of unsteadiness that potentially could fall into the category of aeroelasticity from the point of view of their effect. Rotor whirling (Ehrich, 1993) is denoting a movement of the rotor center of rotation relatively to the casing leading to circumferentially non-uniform pressure distribution. In a state of stability the rotor is “pushed back” into its neutral position. Contrarily, whirling is occurring if the unsteady force generated by the displacement of the rotor is sustained by the motion. This situation indicates an inherent self-excited unstable situation and is from this viewpoint similar to flutter.
In the operation of compressors it is well known that the stable range of operation is limited towards low mass flow rates by the instability phenomena of rotating stall and surge. Whereas the former denotes the occurrence of spatial flow non-uniformities (cells with separated flow, so-called “stall cells”) travelling around a blade row, the latter denotes a system instability during which high-pressure fluid from a plenum downstream of the compressor discharges through the compressor until forward flow established again. Both these phenomena cause large but distinct unsteady blade forces and could therefore be attributed to the family of forced response.