SHORT DURATION EXPERIMENTAL TECHNIQUES IN TURBOMACHINES

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I. INTRODUCTION

Until recently, research and development work on turbomachines has been performed at two widely different levels: the first level, mostly basic research, uses simple flow and heat-transfer models in wind tunnels and makes extensive use of cascade-testing. At the second level, the bulk of research and development is performed on test rigs. Research and development on test rigs has always been arduous, expensive, and time-consuming, because proper simulation of Mach number, Reynolds number, and temperature fields appear to necessitate research on full-sized, full-speed test rigs. The severity of the operating conditions, and the expense of such testing have certainly precluded some fundamental and systematic studies of turbomachines aerodynamics, heat transfer, aeroelasticity, and studies of unsteady flow. In a few cases, the severity of the operating conditions can be somewhat relieved by proper simulation. For example, high molecular weight working fluid can be used for high Mach number testing. However, power limitations and costs have restricted the size and Reynolds number of the tests of compressors operating in freon at high Mach numbers.

The large disparity between the two levels of research and development is critically associated with the large differences in the total energies invested in the working fluid and in the rotating machinery.

The objective of the short duration facilities is (a) to reduce the total energy invested in the working fluid by orders of magnitude while keeping the power level unchanged for short operation, and (b) to decrease the energy stored in the machinery by reducing the speed of sound of the working fluid while maintaining the right values of Mach and Reynolds numbers. The advantages of these facilities are low-cost, low-power requirements, and the possibility of using more powerful instrumentation than in the test rigs.

The short duration facilities which will be discussed in these lectures are shock tunnels, light piston facilities, blowdown compressor, cascade and turbine facilities.

But first, a determination of the scale of critical times found in turbomachines will allow us the selection of short-duration facilities for a wide range of phenomena encountered in turbomachinery.

II. SCALE OF CRITICAL TIMES

1. Boundary-Layer Growth Time.

In a single-blade row, or in a flow-channel, steady-flow is reached when the boundary layer has reached its steady-state thickness. The boundary-layer growth time can, therefore, be taken as the criterion for the establishment of a steady state in a single-blade row.

At the downstream edge of a flow channel of length (ℓ), the steady-state laminar boundary-layer thickness (δ_e), we can write:

$$\frac{\delta_e}{\ell} = \frac{5}{\sqrt{\frac{\ell V}{\nu}}} = \frac{5}{\sqrt{R_e}}$$

where V is the flow velocity, ν the viscosity, and R_e is the Reynolds, the growth-time (τ_B) of a laminar boundary layer is:

$$\tau_b = \frac{\delta^2}{V} \simeq 1.5 \ \frac{\ell}{V}$$

For example,

with $\ell = 5.15^{-2}$m, V = 330 m/s

$$\tau_b = 2.5 \ .10^{-3} \ s$$

2. Rotational Time or Rotational Period

The rotational time can be written

$$\tau_R = \frac{2\pi}{\omega} = \frac{2\pi R}{\omega R}$$

where ω is the angular velocity and R is the wheel outer radius.

For example, with ωR = 310 m/s and R = 0.5 m/s

$$\tau_1 = 10^{-2} s.$$

3. Blade-Passing Time

The blade-passing frequency corresponds to the product of the angular speed by the number of blades of the wheel moving relative to the reference point.

The blade-passing time is:

$$\tau_p = \frac{2 \ \pi}{\omega \ . \ N} = \frac{2\pi R}{\omega R \ . \ N}$$

where R is the wheel radius, ω is the angular velocity and N is the number of blades.