UNIVERSITY OF CAMBRIDGE

ENGINEERING TRIPOS PART IIB

Friday 23 April 2004 9 to 10.30

Module 4A11

TURBOMACHINERY II

*Answer not more than **two** questions.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of the question is indicated in the right margin.*

There is no attachment to this paper.

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator

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1 A two-dimensional section of a transonic fan rotor with a straight blade section has the following design parameters:

Solidity = chord/pitch = σ = 1.4;
Stagger angle β = 62.76°;
Blade thickness $\cong$ 0 (assuming very thin blade, maximum thickness/pitch << 1);
Blade rotating speed = 412.4 $\mathrm{ms^{-1}}$.

The flow conditions at inlet: (for air $R = 287\ \mathrm{J\ kg^{-1}\ K^{-1}}$ and $\gamma = 1.4$)

Axial inflow;
Stagnation pressure = 101330 Pa;
Stagnation temperature = 288 K;
Inlet Mach number: $M_\infty = 0.65$.

Assume that the leading edge shock wave is very weak and is negligible, the compression is achieved through a strong normal passage shock wave, and the surface static pressure distribution on the blade surfaces is as shown in Fig. 1.

(a) Draw the velocity triangles upstream and downstream of the blade section. [10%]

(b) Assuming the viscous loss is negligible, calculate the static pressure ratio, the stagnation pressure ratio and the isentropic efficiency of the blade section. [25%]

(c) Sketch the shock wave pattern. [15%]

(d) Show that the exit absolute flow angle α_2 is given by

$$\tan\alpha_2 = \frac{v_{\theta 2}}{v_{x2}} = (1-K)(\pi_s - 1)\frac{\sigma\cos\beta}{\gamma M_1^2}\frac{M_1^{rel}}{M_2^{rel}}\sqrt{\frac{T_1}{T_2}}\,.$$

where K is the shock location relative to the axial chord ($K = 0$ at the leading edge and $K = 1$ at the trailing edge) and π_s is the static pressure ratio p_2/p_1. All other symbols have their usual meanings. [50%]

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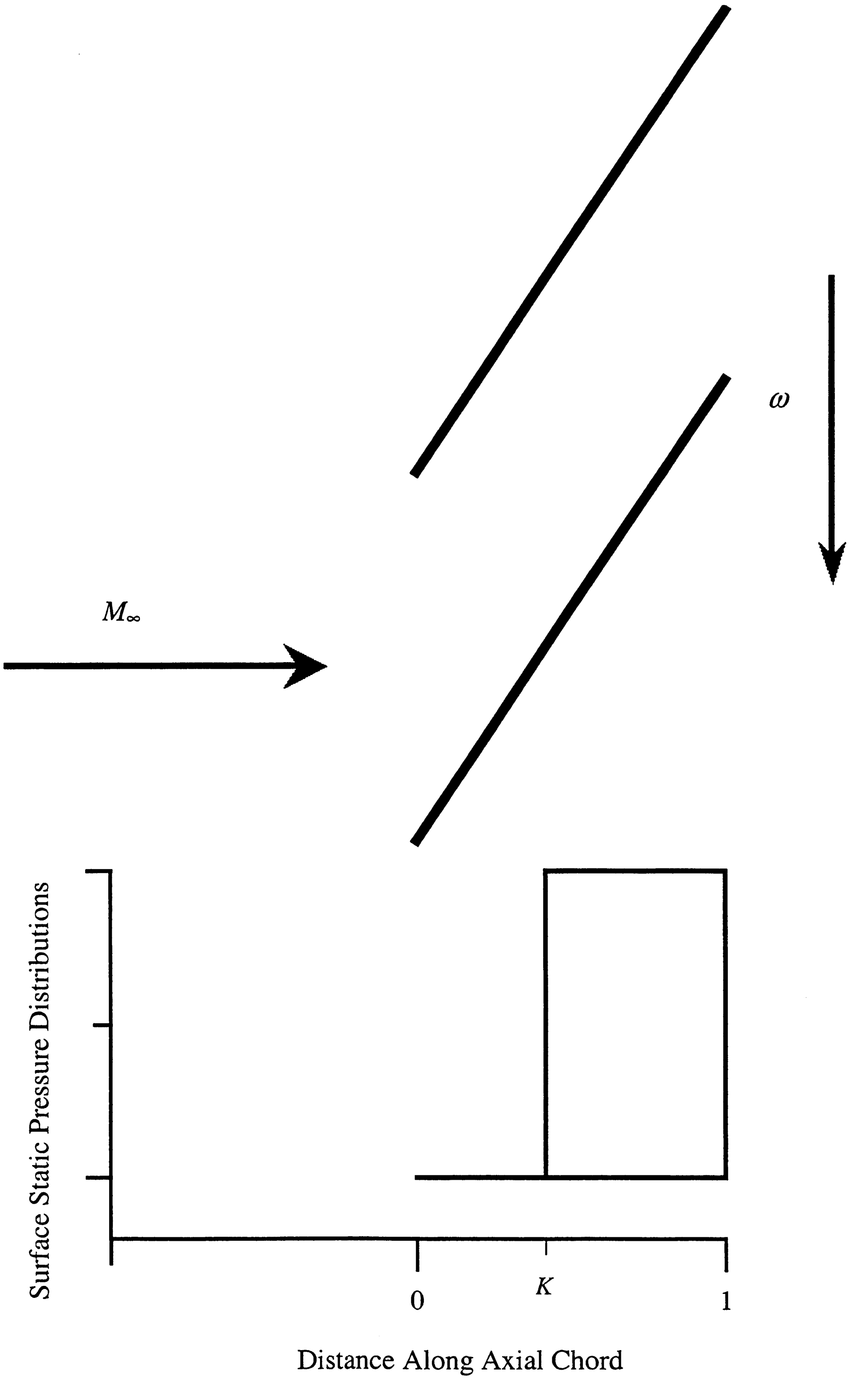

Fig. 1

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2 A low speed model axial turbine stage has a cylindrical casing and hub, radially stacked blades and a hub-to-tip ratio of 0.8. The flow is uniform and axial at turbine inlet, and axial at exit. A free vortex design for rV_θ distribution is used. The stator has the following design parameters at midspan:

$V_1 = V_{x1} = 10 \text{ ms}^{-1}$;
$P_{01} = 101330$ Pa;
$T_{01} = 288$ K;
$r_{\text{mid}} = 0.45$ m;
Exit flow angle $\beta_2 = 70.53°$;
Pitch/axial-chord ratio $(S/C_x) = 1.35$;
Blade aspect ratio (blade height/axial chord at midspan) $(h/C_x) = 1.2$.

(a) Justify that the Simple Radial Equilibrium Equation can be used behind the stator to determine the pressure distribution along the span and use the Simple Radial Equilibrium Equation to find the static pressure distribution behind the stator. Use the result to find the average pressure gradient $\Delta p/h = (p_{\text{tip}} - p_{\text{hub}})/h$. [30%]

(b) The hub section of the stage has low reaction. It is suggested that the situation may be relieved by leaning the stator circumferentially. Comment on how leaning the stator can change the reaction near the hub. [20%]

(c) Explain how the Simple Radial Equilibrium Equation must be modified to take into account the lean of the blade. [20%]

(d) Estimate the angle and direction of the lean required to reduce the pressure difference between hub and tip to 50% of its original value.

[Hint: the mean pressure gradient in the circumferential direction due to the blade loading can be expressed by the average pressure difference between the pressure surface and the suction surface divided by the blade pitch.] [30%]

3 (a) Panel methods and finite volume Euler/Navier-Stokes flow solvers are commonly used for the calculation of blade-blade flows on a stream surface. Describe the two methods. Particular emphasis should be placed on the advantages and disadvantages of each method and the boundary conditions that are used in the turbomachinery environment. [30%]

(b) Describe what is meant by *secondary flow* in a turbine stator blade row. Give a physical explanation for the generation of secondary flow and describe the major impact it has on the behaviour of boundary layer fluid within a turbine stator blade row. [20%]

(c) Fig. 2 shows the variation of flow angle α_{te} and loss coefficient Y_p at the exit of a turbine stator blade. The blade is not leant or swept and has the same shape at all spanwise positions. Explain the causes of the non-uniformity in the flow angle and the loss coefficient, giving physical reasoning where possible. [20%]

(d) Describe what is meant by blade sweep and the effects it has on the flow at the leading edge and the trailing edge of a low aspect ratio turbine stator blade. [30%]

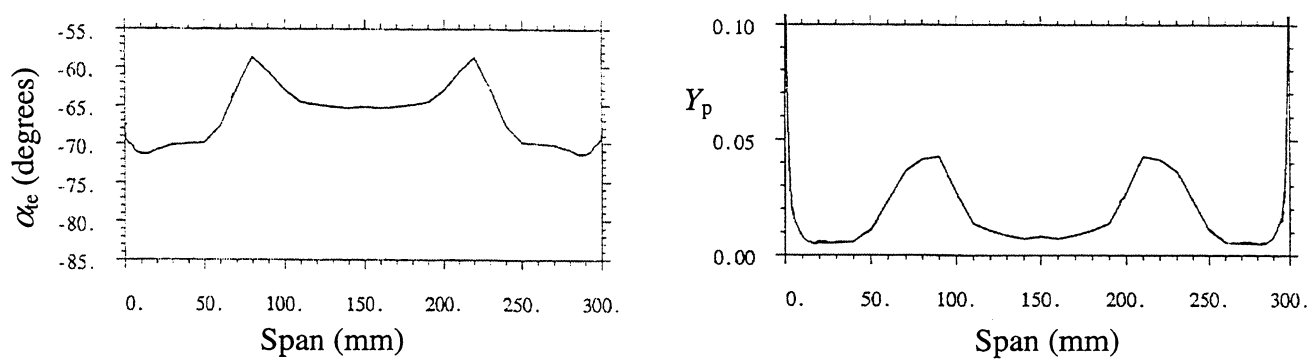

Fig. 2

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