Design Aspects of Three-Dimensional Flow in High Performance Axial Flow Ventilating Fans

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Introduction

Tunnels are widespread in long-distance and urban continental transport networks (i.e. 6979 km of European transport tunnel – shared as 25% motorway and 75% railway tunnels), raising many problems connected with comfort, pollution control and above all safety under prevailing or emergency conditions (1). The critical role of tunnels within transport infrastructures and the increasing transport capacities necessitates the continuous improvement of tunnel ventilation systems. The proposed way to support the facing of such needs is to improve the design concept for the fan unit.

A competitive design concept is the non-free vortex (NFV) method, ensuring a greater contribution of blade sections at higher radii to fan performance by means of prescription of spanwise increasing blade circulation.

As an improvement of traditional NFV methods, based on the assumption of rotationally symmetric stream tubes through the blading, guidelines are outlined in the present paper for a proper consideration of three-dimensional (3D) blade-to-blade flow in rotor optimization. With the use of such advanced method, fan units of high global and specific performance (high total head rise and flow rate, reduced size and weight) and of improved efficiency can be realized.

Design Aspects of 3D Rotor Flow

A concerted experimental and computational investigation on a high performance isolated rotor pointed out that the spanwise changing (NFV) blade circulation results in a 3D secondary flow filling the dominant part of the rotor blade passages, manifesting itself in a torsion of inter-blade stream surface segments (2). According to the

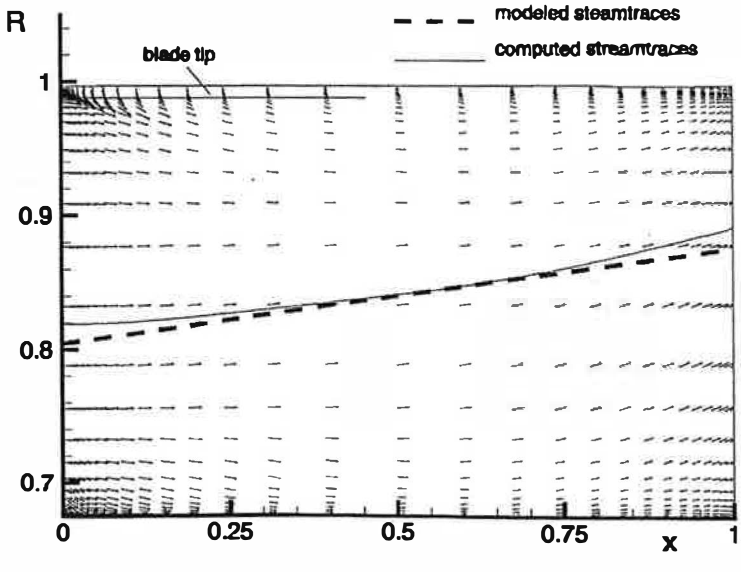

Figure 1a. Conical stream trace near midspan - suction side

3D internal flow field, the streamlines in the vicinity of the blades have been modeled at midspan fitting to outward and inward conical stream tube segments on the blade suction side (SS) and pressure side (PS), respectively (Figures 1a, b) - termed "cone couple".

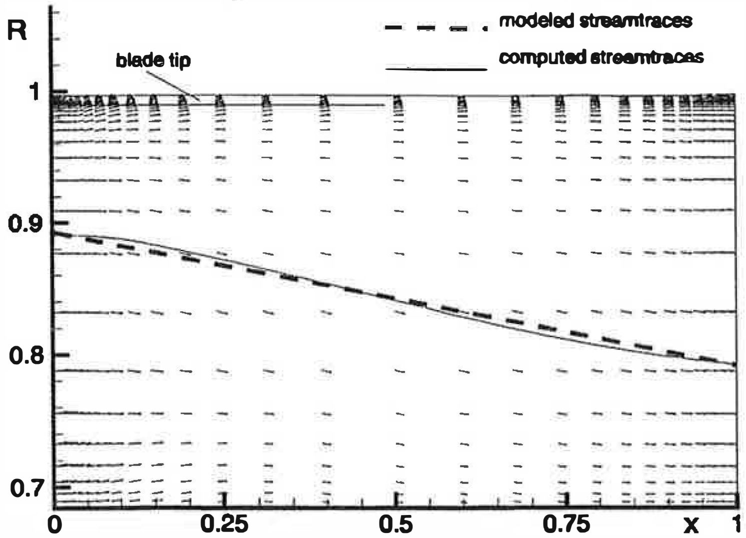

Figure 1b. Conical stream trace near midspan - pressure side

In a recent paper (3) it has been illustrated that the blade lift can be satisfactorily described at midspan in a synthesized manner, with the use of "cone couple" model.

The flow fitting to both of SS and PS cone was characterized by the related pitch-averaged inlet and out-let flow data. Hence a 2D cascade concept could be applied, with the assumption that two series of blade sections bounded by the SS and the PS conical stream tube segments can be developed into distinct cascade planes. Applying such way of approach already to the blade design phase, it is anticipated that for consideration of 3D flow effects a distinct but parallel optimization of the blade SS and PS geometry should be carried out. Namely, the blade cascade sections enclosed in the coupled SS and PS cones must fulfill different geometrical demands.

In the following section, a sample calculation is outlined for the rotor studied in (2, 3) in order to present how an optimization of blade solidity can be carried out separately for the blade SS and PS. The input data of calculation are collected in (3) and the intermediate results are presented in Table 1. As shown in (3), the non-uniform inlet axial velocity profile and spanwise gradients of swirl and outlet axial velocity (which are characteristics of NFV operation) manifest themselves in inlet and outlet flow angles different for the SS and PS cones. These different flow conditions result in different optimum c_λ* lift coefficients for the SS and PS, according to the optimization relationship recommended by Howell and cited in ((3), Eq. 7.). The force factor $(\lambda/t)c_\lambda$ can be calculated using the pitch-averaged flow data on the basis of work equation of elemental axial flow rotating cascades ((3), Eq. 6). Dividing $(\lambda/t)c_\lambda$ by c_λ*, optimum solidity values

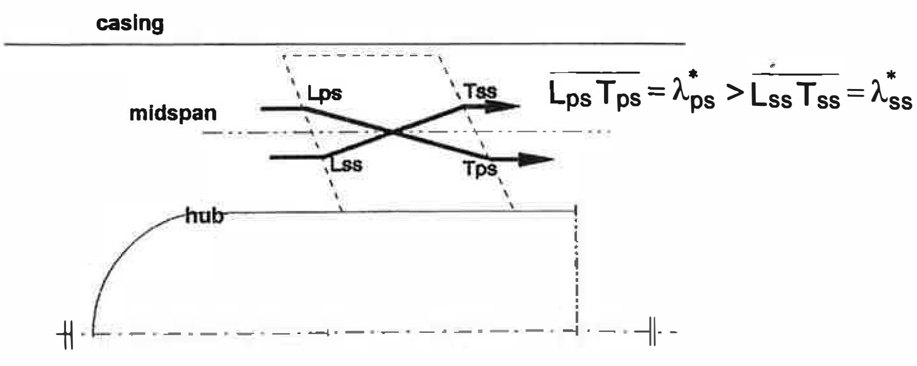

Figure 2. Forward swept blade fitting to 3D blade-to-blade flow

$(\lambda/t)^*$ can be de-rived. It is conspicuous in Table 1 that the optimum blade solidity is considerably lower for the SS conical section than for the PS. Such geometry can be realized only if the blade is swept forward, as illustrated in Figure 2.

The above perception suggests that an advanced design (optimization) of isolated NFV axial flow rotors can be carried out with consideration of 3D internal flow by means of a separate but parallel optimization of the blade SS and PS geometry.

This approach leads eventually to the necessity of sweeping the blade forward in order to accommodate the blade geometry simultaneously to the different conical through-flow conditions being present on the SS and PS. As a next phase of research, an appropriately swept version of model rotor in (2) (3) will be designed and investigated by computational and experimental means in order to justify the tendencies of improvement in design accuracy, fan performance and efficiency.

Table 1. Results of two-side blade solidity optimization at midspan (modified on the basis of (2))

	$c_\lambda{}^*$	$(\lambda/t)c_\lambda$	$(\lambda/t)^*$
SS cone	0.893	1.004	1.124
PS cone	0.591	0.859	1.453

List of Symbols

c_λ	lift coefficient
λ	conical blade chord
(λ/t)	blade solidity (conical blade chord divided by midspan blade pitch)
L_{ps}, L_{ss}	leading edge position of conical traces (pressure and suction side)
R	fraction of casing radius
T_{ps}, T_{ss}	trailing edge position of conical traces (pressure and suction side)
x	fraction of axial chord
ps, ss	pressure side and suction side (subscripts)
*	optimum value (superscript)

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