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EFFECT OF BACKGROUND FLOW ON HELICAL JET CHARACTERISTICS

Helical jet in moving air was used to simulate the flow downstream of a helicopter blade tip or a wing tip. The jet was generated by means of an opened pipe supplied tangentially (tangential nozzle), and placed in a wind tunnel. Flow properties were investigated in several cross-sections downstream of the nozzle. The flow direction and the total pressure were measured in function of the azimuthal angle and the distance from the axis of the system. The flow was visualized using the planar laser scattering technique. The decay of swirl intensity was measured by means of a probe with a rotating plate fixed to a miniature voltage generator.

1. Introduction

A swirling jet of asymmetric flow velocity distribution is defined as a helical jet. Such a jet issues from a pipe when it is supplied tangentially (tangential nozzle). The characteristics of helical jet had been previously investigated by the present authors for the jet issuing into stationary air [1]. In that case, one had observed two azimuthal angles for which the jet expands in the surrounding air most intensively. One of them corresponded to the azimuthal angle of the maximum tangential velocity of the jet leaving the nozzle, whereas the other one existed to maintain the total radial momentum of the jet equal to zero. (Radial momentum of the confined jet is equal to zero).
In various cases, however, like in burners with coaxial jets the swirling (helical) jet is surrounded by an external flow. To some extent, analogous flow pattern exists when a vortex shed from a helicopter blade tip or from an aircraft wing

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tip is convected in surrounding flow. In these cases, the tangential flow velocity inducted by the vortex is superimposed on the axial flow of the surrounding air. The present paper aims at investigating of the characteristics of the helical unconfined jet issuing from the pipe into the uniform air flow (the background flow). The experiments described in the paper had in view, first of all, the flow downstream of the helicopter rotor blade tip.

1. Experimental Set-Up

The experiments were conducted in a closed-circuit wind tunnel having an opened test section of 0,5 m in diameter. The tangential nozzle of diameter 105 mm was located along the axis of the test section (Fig. 1). The nozzle was supplied with compressed air through a pipe of diameter 30 mm.

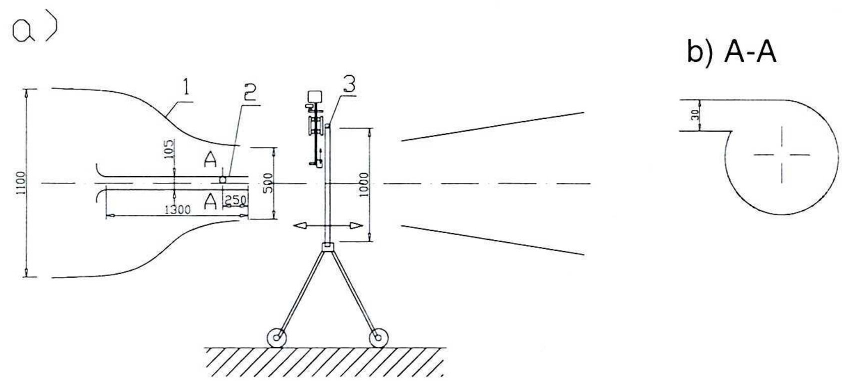


Fig. 1. Experimental set-up. 1 – wind tunnel, 2 – tangential nozzle, 3 – support of the probe

The flow under investigation is three-dimensional with very high turbulence. In such a case, the instruments mostly used to measure the flow velocity (hot-wire x-probe, 5-points sphere and the like) show results of low reliability. This takes place because of strongly varying flow direction. In the present work, like in the previous one [1], the attention was focused on the spatial distribution of the time mean flow velocity. To this end, the probe shown in Fig. 2 was used. It contained a rigid flag (16x10x0.2 mm) made of metal sheet fastened to a tube 3 mm in external diameter. The tube was bended at its end and connected with a precise pressure transducer (piezorezistive type) at the other end. The Pitot tube obtained in this way took position against the flow due to the aerodynamic force acting on the flag. The tube was supported in a fine ball bearings and fixed to a potentiometer of low mechanical resistance. The inertia of the moving elements of the probe was sufficient to maintain the flag in stable position parallel to the time mean flow direction independent of the turbulence. The probe was kept in a support (Fig. 2) driven around the axis of the system. In this way, the azimuthal coordinate of the probe was adjusted. The radial and axial coordinates were changed by shifting the tube in the arm of the support and shifting the whole support along the axis of the wind tunnel, respectively.

Figure 3 shows the results produced by the probe in function of azimuthal angle in the case when the swirl was switched off. The measurements were repeated at constant radius r/R=3 (here R denotes the radius of nozzle) in four cross-sections of the test section. One can note that the results are reproducible with relatively good accuracy. The probe, however, shows varying angular position of the flag in the swirless flow field. This is the effect of gravitation; the probe was not balanced accurately. Due to this, it could change its position inside a small margin as it was rotated around the axis of the system. The curve shown in Fig. 3 was taken into account to correct the results obtained for swirling flow.

The decrement of swirl intensity along the jet was measured by means of another probe prepared in Ref.[2]. It contained a plate 100x20x0,5 mm, parallel

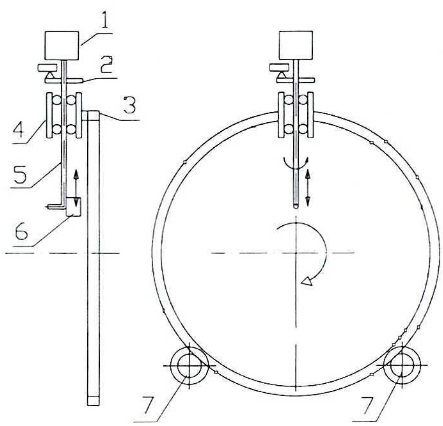


Fig. 2. Probe with its support. 1- pressure transducer, 2- potentiometer, 3- frame, 4- ball bearing, 5- Pitot tube, 6- flag, 7- roller

to the flow direction in the test section of the wind tunnel, fixed to the axis of miniature electric generator. The voltage of the generator (V) was proportional to the rotation velocity of the plate (driven by the vortex) and thereby approximately proportional to the strength of the vortex.

Constant flow velocity in the test section of the wind tunnel and constant flow rate of the compressed air supplying to nozzle equal to 24 m/s and 0,044 kg/s, respectively, was maintained during the experiments.

The jet was visualised using the planar laser scattering technique (PLS). The laser and the optical system were mounted on the traversing platform which enabled one to iluminate the jet in selected cross-sections. Aluminium powder was added to the air supplying the nozzle to make the flow visible. Now, to avoid the dirtying of the wind tunnel used for flow velocity measurements, the flow visualisation was conducted in an open-circuit wind tunnel. In this case, the nozzle was located of the outlet of the tunnel.

3. Results

Figure 4 shows the azymuthal distributions of flow direction and the pressure measured by means of the probe described in the previous section. As it was mentioned above, the axis of the probe was directed radially in the circular cross-section of the wind tunnel. Due to this, the flag of the probe was sensitive to the flow velocity component in the x, θ plane. (The radial component of the

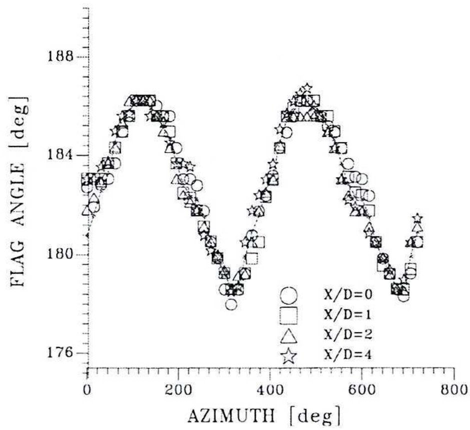
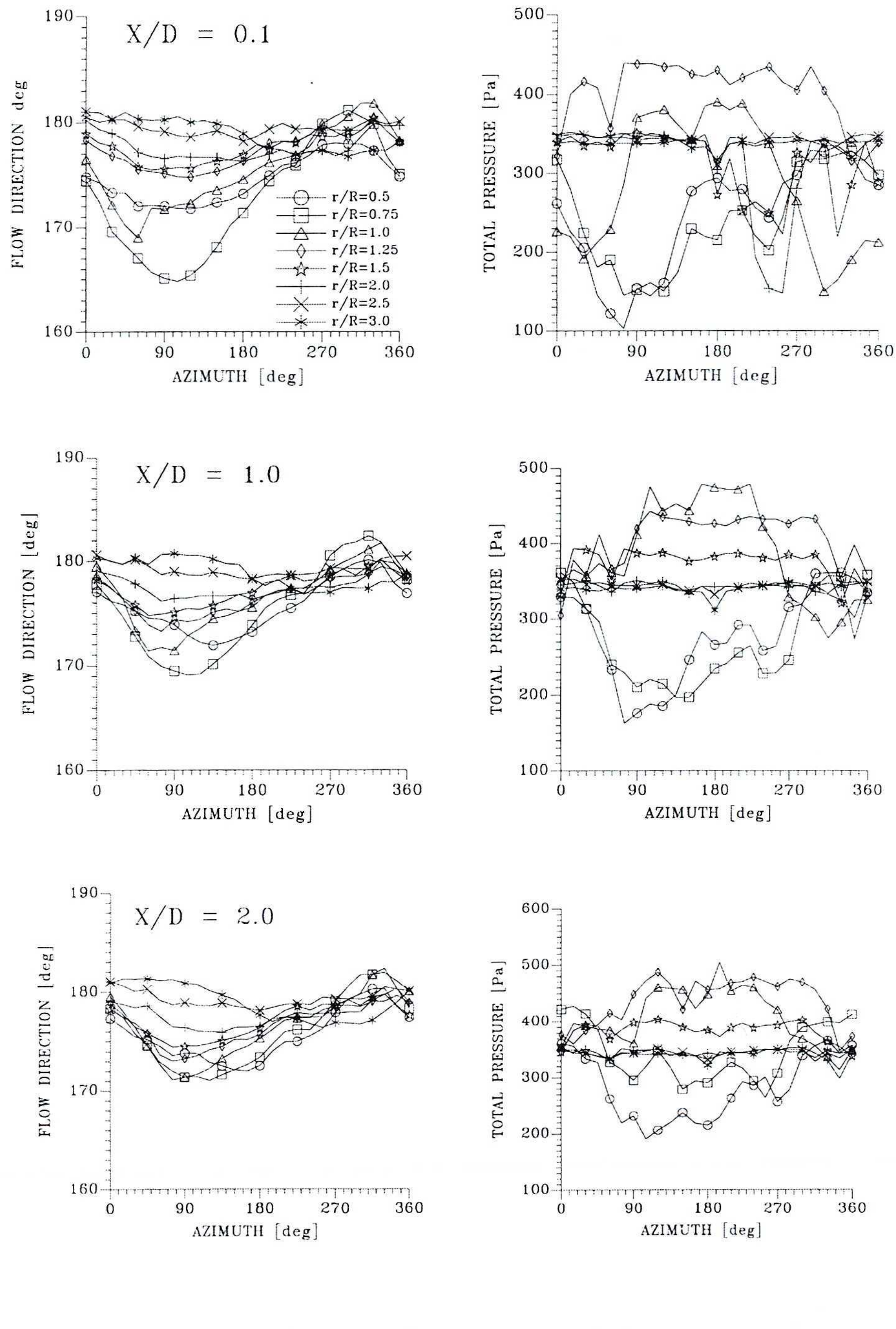


Fig. 3. Characteristics of the probe in uniform flow field

flow velocity did not affect the flag position). In the present case, the radial velocity component was low in relation to the remaining ones. Therefore, the pressure measured by the probe was close to the total pressure. This allowed us to calculate the flow velocity distribution for the static pressure assumed to be constant. (It was not possible to measure the static pressure distribution in the considered flow).

The direction denoted in Fig. 4 by 180° corresponds to the axial flow. The flag angle was adjusted initially in stagned air by means of a laser beam. One can note that the distributions presented in Fig. 4 change continuosly as the jet spreads in the surrounding air. The strongest deviation from the axisymmetric flow is observed in the cross-section close to the outlet of the nozzle (x/D=0.1, D is the nozzle diameter). This expresses in relatively large variations of the flow direction and the total pressure around selected circles. For the circle r/R=0,75 the deviation from the axial flow changes in the range from 0 to 15°. This is accompanied by the total pressure variations approximately equal to 200 Pa. It is observed that the total pressure for the circles r/R=1 and r/R=1.25 is larger then the pressure for external radii (in the free stream in the test section of the wind channel). This is due to the energy of the tangential stream supplying the nozzle. The energy of the radial flow in the jet is transmited to the surrounding flow.



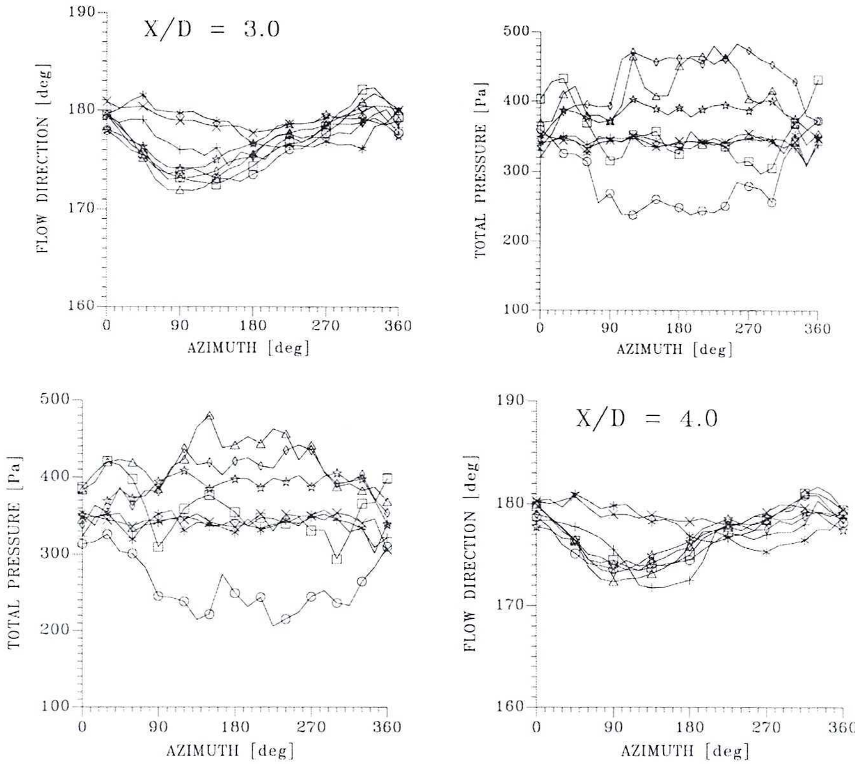


Fig. 4. Flow direction and total pressure in function of azimuthal angle

In another words, the pressure measured by the Pitot tube accounts for the tangential velocity component superimposed on the axial flow of the background flow.

One can see that the asymmetry of the flow decreases in the succeding cross-sections. This feature presents the essential difference between the characteristics of the jet issuing into stationary and moving air. In the former case [1] the asymmetry of the jet increased and the flow velocity decreased. This took place because the jet flow was attenuated as it spread in the surrounding air.

In contrast to this, in the latter case, the energy of the jet issuing into the background flow is maintained or even strengthened. The energy is transported due to the turbulence of both the background and the jet flow. This leads to equalization of the time mean flow velocity distributions in the jet.

As it has been presented above, the jet is asymmetric. This feature is distinctly visible in the photographs in Fig. 5 showing the regions of high density of aluminium powder in succeeding cross-section of the jet. The photographs on the right hand side of this figure visualise the mixing layer and thereby the contour of the jet cross-section. One can note that the contour is distinctly asymmetric. It rotates due to the swirl of the jet.

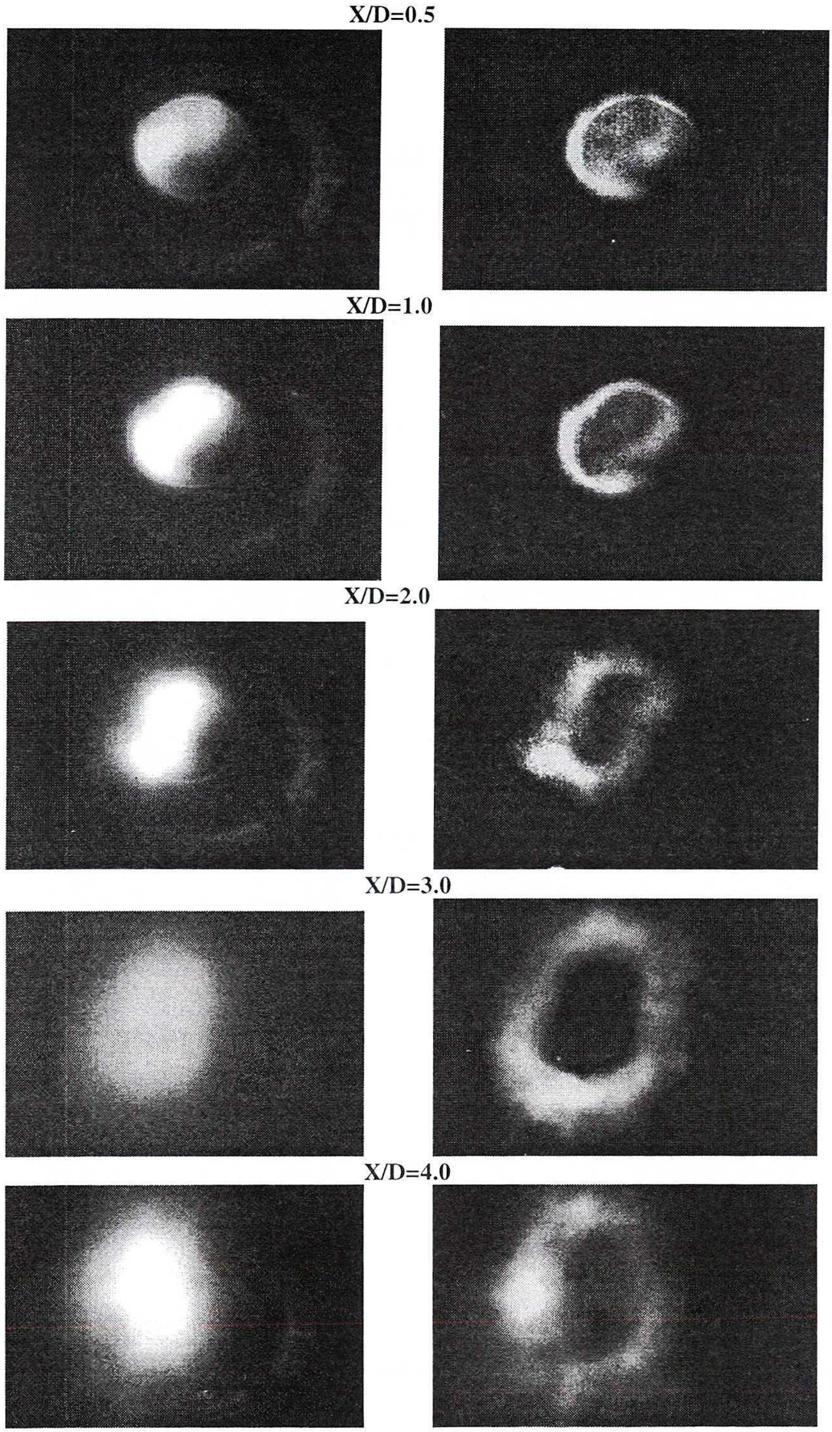


Fig. 5. Jet flow photographs in several cross-sections, left column – averaged 60 records, right column – rms of 60 records

It can be noted in Fig. 4 that the tangential component off the flow velocity decreases along the jet. In this consequence the strength of the vortex also decreases. The variation of the vortex strength (measured by means of rotating plate), as it is convected with the tunnel flow, is presented in Fig. 6. It is visible that the swirl intensity of the jet decreases relatively fast as the jet travels in the surrounding flow.

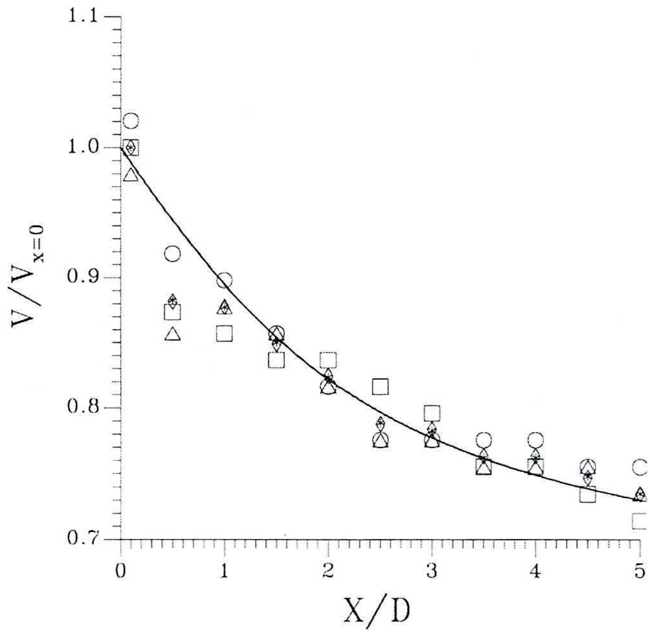


Fig. 6. Decay of swirl intensity; experimental points and curve fit

3. Conclusions

The helical jet issuing from the nozzle into the uniform air flow can be used to simulate the vortex shed from the helicopter blade tip or the wing tip. It was found in the present experiments that, due to the turbulence of both the jet and the background flow, the swirl intensity of the jet decreases relatively fast. Simultaneously, the asymmetry of flow velocity profiles disappears. This feature exhibits the essential difference between helical flow characteristics of the jet issuing into the stationary and those of the jet issuing into the flowing air. In the former case, the asymmetry of the jet intensifies as the jet travels in the surrounding air.

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Oddziaływanie przepływu zewnętrznego na strumień helikalny

Streszczenie

Przedmiotem badań jest strumień wirowy o niesymetrycznym (helikalnym) rozkładzie prędkości poruszający się w jednorodnym polu przepływu. Strumień wytwarzany jest w dyszy zasilanej stycznie do jej obwodu; umieszczony w przestrzeni pomiarowej tunelu aerodynamicznego. Wypływający z dyszy strumień helikalny jest rozpatrywany jako model wiru krawędziowego generowanego na zakończeniu płata nośnego, np. łopaty helikoptera lub skrzydła samolotu. W pracy badane są struktury przepływu w wybranych przekrojach strumienia poprzez pomiary kierunków prędkości, ciśnienia całkowitego oraz wizualizację metodą noża świetlnego. Zanikanie wirowości strumienia w miarę jego rozprzestrzeniania się badane jest przy użyciu płytki napędzającej miniaturowy generator napięcia.