this time appears to be the elimination of the arbitrary prescription of length scales, resulting in a more realistic estimation of the eddy viscosity in the wake.

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A Simple Device for Wind Shear Measurement

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Introduction

WIND shear at low-level altitudes has been recognized as a potential safety problem to aircraft, especially during final approach and landing. Accidents of a DC-10 at Boston in December 1973 and a Boeing 727 at New York in June 1975, identified as wind shear accidents,[1,2] focused attention on this atmospheric phenomenon. Hazard may arise from the shear-induced change in horizontal wind velocity along the flight path or from the existence of a vertical wind component. In these conditions, a significant change in the wind velocity vector can result in a dangerous rate of descent.

Research activities are under way involving ground-based and airborne equipment to provide a pilot with suitable wind shear alert and energy management information. An airborne sensing system, if available, could also be used to gather meteorological data, especially wind vectors, and could be used to study their dependence on altitude and orographic conditions. These measurements could help to model the atmosphere in a more realistic way than at present, which is needed for realistic computer simulations.

Various physical effects can be used for sensing wind shear. Optical methods such as Laser Doppler Anemometers (LDA) and a combination of air and inertial data are the main candidates for airborne equipment.

This Note suggests a simple pneumatic sensing device that measures the difference of the dynamic pressures at two height positions on an airplane. This difference causes a mass flow through a pneumatic duct system. The velocity of this flow is measured by a special hot-wire probe.[3]

Experimental Approach

A single-engine light airplane, Socata Morane 893E, was used as the platform for the sensor system. A movable boom 2.3 m long was pivoted at the wing tip on the left-hand side and could be turned in a vertical position. The boom carried a pair of pitot tubes at each end connected by a hose. In case of a vertical shear flow the pitot tubes sense different total pressures which lead to a mass flow in the hose. The velocity of this mass flow is measured by a special hot-film probe (Westerboer type) operating in a constant-temperature mode and imbedded in the duct. The error due to varying air temperature is reduced by regulating the temperature before the flow passes the probe. The Morane carried an elaborate data acquistion system which additionally provided airspeed, altitude, and climb speed for determining shear flow and wind profiles. The flight data were recorded by an analog and a digitial recording system supported by an Apple II E microcomputer, which was also used for processing the data immediately after each flight. The testing of the sensor and the data acquisition system have been accomplished. The first application, planned in cooperation with meteorologists, is concerned with a field analysis of airplane approaches under strong wind shear conditions. In this program shear gradients and dynamical reactions of the disturbed airplane will be evaluated simultaneously.

Analysis Scheme

The total pressures at two different probe positions (locations 1 and 2) are given by

$$P_{t1} = P_{s1} + \tfrac{1}{2}\rho_1 (\bar{V}_{\text{TAS}} + \delta\bar{U}_1)^2 \tag{1}$$

$$P_{t2} = P_{s2} + \tfrac{1}{2}\rho_2 (\bar{V}_{\text{TAS}} + \delta\bar{U}_2)^2 \tag{2}$$

where the wind field vector U is partly included in the measurement of the true airspeed so that only the wind variation related to the position of the airspeed sensor has to be considered in δU_1 and δU_2. If the pitot probes are arranged at different height positions (distance Δh), the differences of the data between locations 1 and 2 may be written as

$$\frac{\Delta P_t}{\Delta h} = \frac{\Delta P_s}{\Delta h} + \tfrac{1}{2} V_{\text{TAS}}^2 \frac{\Delta \rho}{\Delta h} + \rho \bar{V}_{\text{TAS}} \frac{\Delta \bar{U}}{\Delta h} \tag{3}$$

where we have put $\rho = \tfrac{1}{2}(\rho_1 + \rho_2)$ and assumed that $\delta U \ll V_{\text{TAS}}$. The difference in the static pressure is eliminated

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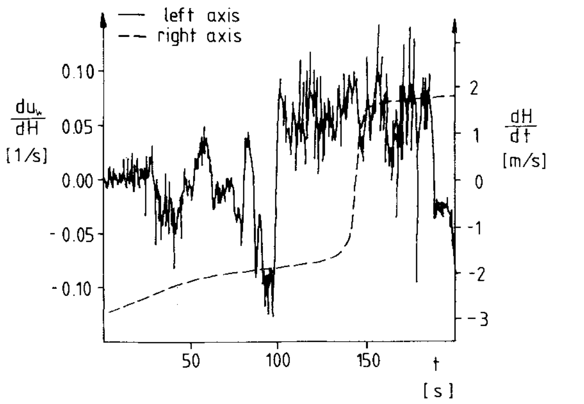

Fig. 1 Vertical wind shear and vertical speed of test airplane.

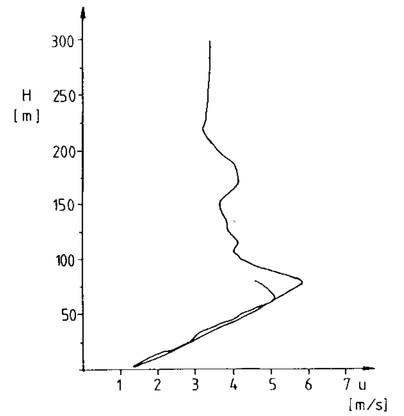

Fig. 2 Wind profile of a low-level jet.

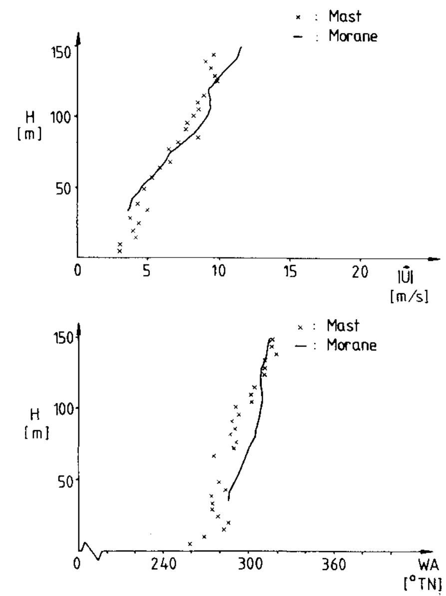

Fig. 3 Comparison of on-board and ground-based measurements of wind profiles.

in the measurement system by connecting the pitot probes. Then, instead of measuring ΔP_t, the system measures the difference in dynamic pressure q between the locations of the pitot probes

$$\frac{\Delta q}{\Delta h} = \tfrac{1}{2} V_{\rm TAS}^2 \frac{\Delta \rho}{\Delta h} + \rho \bar{V}_{\rm TAS} \frac{\Delta \bar{U}}{\Delta h} \tag{4}$$

For the speed range of the Morane, the difference in the density can be neglected even for small shear gradients so that we finally have

$$\frac{\Delta q}{\Delta h} = \rho \bar{V}_{\rm TAS} \frac{\Delta \bar{U}}{\Delta h} \tag{5}$$

This equation shows that the arrangement measures the wind shear component in the flight-path direction. To determine the wind shear as a vector, flights in two different directions are required.

The wind field can be modeled approximately by a superposition of basic atmospheric disturbances separated into uniform gusts, flow in the boundary layer (over flat terrain), and flow influenced by the terrain.

$$\bar{U}(x,y,z,t) = \bar{U}_g(t) + \bar{U}_{\rm bl}(z,t) + \bar{U}_t(x,y,z) \tag{6}$$

The second term contains contributions from steady shear flow and turbulence in the boundary layer. An aircraft flying through this wind field will experience variations in the flowfield corresponding to

$$\frac{d\bar{U}}{dt} = \frac{\partial \bar{U}_g}{\partial t} + \frac{\partial \bar{U}_{\rm bl}}{\partial t} + \frac{\partial \bar{U}_{\rm bl}}{\partial z}\frac{dz}{dt} + \frac{\partial \bar{U}_t}{\partial x}\frac{dx}{dt} + \frac{\partial \bar{U}_t}{\partial y}\frac{dy}{dt} + \frac{\partial \bar{U}_t}{\partial z}\frac{dz}{dt} \tag{7}$$

Using an airborne system, the wind field can be measured by a comparison of air and inertial data. However, in this way, it is generally not possible to separate the various components of the wind field given by the partial derivatives in Eq. (7). Especially vertical and horizontal wind variations cannot be separated. Furthermore, the necessary filtering of gusts results in considerable errors in the wind shear data.

The measuring arrangement proposed in this Note immediately can be used to determine the local vertical change in wind speed

$$\Delta \bar{U} = \frac{\partial \bar{U}_{\rm bl}}{\partial z}\Delta h + \frac{\partial \bar{U}_t}{\partial z}\Delta h \tag{8}$$

by flying at constant altitude. Uniform gusts are directly eliminated since they have the same effect on both pitot probes. The influence of turbulence in the boundary layer of the atmosphere is—within the approximation (6)—limited to vertical shear components.

Results

The results presented in this section have been achieved in an area near Sprakensehl in the Federal Republic of Germany (in the north of Braunschweig) between August 1983 and November 1984. While these measurements were made the Morane operated at low altitudes ($h < 300$ m). For some flights a comparison was made with data obtained at a meteorological tower.

Figure 1 shows the shear in the vertical direction measured in a low-level jet. The Morane approached the ground at a nearly constant sink rate. In the first phase, a negative value of the shear gradient indicates an increase in wind speed. After 100 s the maximum in the wind velocity has been passed and the sign of the shear changes. The following decrease in wind speed is coupled with a higher turbulence level. After the descent, the Morane resumed its climb and the shear was measured a second time. An evaluation of the shear data to obtain the corresponding wind profile is given in Fig. 2. It is to be noticed that the measurement in climb results in nearly the same profile—with a somewhat reduced maximum of wind—as was found in the descent.

In Figure 3, wind profiles measured by the Morane system are compared with results obtained at the tower. The data obtained by the tower show a considerably higher scattering in comparison to the flight data. The reason is that the Morane system eliminates uniform gusts and smoothes turbulence because the wind profile is obtained by integrating the shear gradient, while the tower measures the actual wind speed. Furthermore, attention should be given to the fact that the wind profile cannot be measured by both systems during the same time. The sensing devices of the meteorological tower are fixed at a platform that is moved at a vertical speed of not more than 0.5 m/s. In spite of all, the measurements are in fairly good agreement and confidence in the results achieved by the simple airborne system is strengthened.

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Errata

A Possible Causative Flow Mechanism for Body Rock

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IT is erroneously stated that all tail surfaces had been removed, together with the wing, when the body rock motion was observed.[1] In reality, the fin was not removed. This does not change anything in regard to the causative mechanism described. However, it probably means that in a dynamic subscale test, the amplification of the body rock mechanism provided by the fin is needed to overcome the mechanical roll damping present in the test.

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