AERODYNAMIC COMPENSATION IN PRESSURE SENSORS
USED FOR THE MEASUREMENT OF FLOW PARAMETERS

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A method is described for compensating the errors of measurement of flow parameters in wind tunnels and
determination of the high-speed flight parameters of aircraft. The method is based on design modifications of
the measurement system sensing devices with a view toward affecting the local characteristics of flow past the
total- or static-pressure intakes.

Aerodynamic compensation in the design of instruments for measuring the parameters of a moving gas and the high-
speed flight parameters of aircraft customarily entails deliberate modification of the local flow conditions past the sensing
devices of measurement systems in such a way as to eliminate or minimize measurement errors.

The impinging flow conditions are modified by:
- local modification of the sensor geometry (compensating rings and axisymmetrical nubs on air-pressure sensors);
- energy-lossless transformation of oblique flow past a sensor into axial flow (flowthrough total- or dynamic-pressure
  sensors);
- transformation of supersonic flow before a sensor into subsonic flow in the wake of a weak shock wave and
  subsequent, almost-lossless redirection of flow over a compression surface (isentropic total- or dynamic-pressure sensors);
- variation of the local flow velocity in the zone of static-pressure intakes on a conical compression surface (static-
  pressure and Mach-number needle probes at high supersonic velocities, \( M \leq 4 \)).

The pressure detected in a flow by any static-pressure sensor depends on the local flow characteristics in the zone of
the intakes due to the structure of the sensor itself and also to the structure of the object on which the sensor is mounted, in
this case the aircraft or a model of it. There are scarcely any locations on an airplane where the static pressure read by the
aircraft air-pressure sensor is not affected by elements of the vehicle. As a result, the measurements have systematic errors,
which influence the reliability of determination of the high-speed flight parameters of an aircraft in flight tests or in actual
flight. The same influence is present in wind tunnel tests of aircraft models. The effects encountered here can produce either
negative or positive measurement errors. Compensating rings are installed to offset the deleterious influence of local flow on the
readings of aircraft-mounted cylindrical air-pressure sensors at low speeds [1]. If external disturbances make the pressure
readings too low, a ring is placed after the intakes. There it creates a backwash (pressure excess) in the vicinity of the intake
port. If the influence of flow is such as to make the pressure reading too high, a compensating ring is placed in front of the
cross-section with the intake ports, lowering the pressure in the intake zone. The dimensions and cross-section of the rings and
their placements are chosen experimentally according to the value and sign of the error induced by the external influence.

In PVD-18 aircraft air-pressure sensors (Fig. 1) static pressure at Mach numbers \( M > 1 \) is compensated
aerodynamically by means of a local bulge of the sensor casing. The profile of the bulge is formed by two smoothly connected
conical surfaces, one forward (\( \beta_{c} = 5-7^\circ \)) and one reversed (\( \beta_{c} = 7-11^\circ \)).

A specially profiled bulge is used in static-pressure needle probes [2] mounted on the bow spike in front of the fuselage
of an aircraft with a ram intake. The bulge is in the shape of a paraboloid of rotation with a relative elongation of 9.1, equipped
with four static-pressure intake ports at a distance equal to 65% of the total length from the vertex of the paraboloid, at stations
with meridian angles of \( \pm 20^\circ \) and \( \pm 142^\circ \); their readings are averaged in a mixing chamber.

Preliminary calculations and subsequent wind tunnel experiments have shown that the pressure coefficient of the sensor
\( C_{p} = (p_{s} - p)/p \) with this configuration of the intake ports is independent of the angle of attack for values of the latter
Fig. 1. Static-pressure measurement errors of the PVD-18 aircraft air-pressure sensor with intake ports located on the cylindrical part of the casing ($\Delta p_1$) and on an aerodynamic compensation element ($\Delta p_2$).

Fig. 2. Flowthrough total-pressure sensor. a) Flow diagram inside the sensor; b) shifted sequence of "strong shock" positions at the sensor inlet.

$\alpha = 0-8^\circ$. An aerodynamically compensated sensor in the configuration shown here with a bow spike measures true static pressures in the range of Mach numbers from 0.4 to 1.2, ensuring the determination of flight altitude within 50-m error limits at $M < 1$.

Aerodynamic compensation has gained widespread acceptance for the measurement of total pressure in subsonic and supersonic flows impinging obliquely on the sensor. The angular (directional) sensitivity of sensors to downwash can be assessed from the error of detection of total pressure in oblique flow past the sensor.

It follows from the downwash sensitivity characteristics of total-pressure sensors with various intake zone configurations [3] that downwash measurement error can be reduced by replacing the "well-streamlined" intake section with a "poorly streamlined right-angle blunted cylindrical section. In total-pressure sensors without a flowthrough configuration the downwash error decreases as the ratio of the diameter of the intake port to the sensor diameter is increased and when the cylindrical intake channel is replaced by a convergent channel.

The angular sensitivity of nonflowthrough total-pressure sensors to downwash is determined by the length of the stagnant air zone ahead of the sensor and the position of the critical point (zone) on the sensor surface relative to the intake port. Of all the known total-pressure sensors, the bypass or flowthrough types (see Fig. 2a) are the least sensitive to downwash. Their intake tube is situated in an outer sheath, and air flows through the annular channel between them. In this case the flow in the sensor is coaxial with the intake tube over a wide range of angles between the freestream velocity vector and the axis of the sensor.

On the basis of optical studies of flow past a supersonic flowthrough sensor at various downwash angles, the author has previously [4] postulated the flow pattern before and inside the sensor (Fig. 2a). Figure 2b shows a sequence of schematic diagrams of a "strong shock" in front of a sensor for various downwash angles.