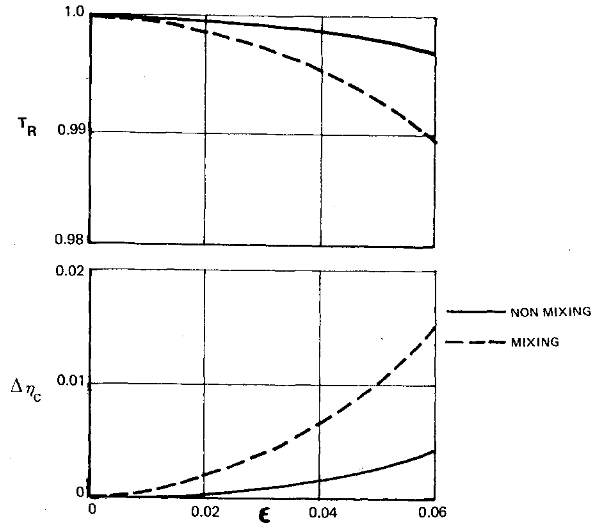

Fig. 2 Effects of fan exit profiles on nozzle thrust and breakeven fan efficiency.

Results

Sample results were calculated for the case where the compressure pressure ratio is 1.5, $M_0 = 0.85$, and $M_c = 0.5$.

The reduction in net thrust of the fanstream vs ϵ is shown in Fig. 2. It can be seen that the mixing losses introduce a substantial penalty. It is also evident that substantial increases in compressor efficiency must be achieved to overcome the losses due to nonconstant enthalpy distribution if substantial mixing occurs. The quadratic nature of the losses due to nonconstant enthalpy make the concept of using slight variations in enthalpy quite attractive.

Although these calculations are based on the simplified model of a perfect engine, it is expected that the predicted tendencies for the ratio of the net thrusts will remain quite accurate.

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Estimating Aircraft True Airspeed Using Temperatures from Two Different Probes

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I. Introduction

THE National Hail Research Experiment (NHRE) has used aircraft extensively to obtain meteorological measurements around and inside hailstorms. During an interesting multiaircraft thunderstorm research investigation, the electronic signal from the dynamic pressure sensor on one aircraft was "lost," rendering the meteorological data useless. The following describes a procedure employed to estimate the missing true airspeed (TAS) in order to correct the raw meteorological measurements.

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II. Concept and Equations

The TAS of an aircraft can be determined by measuring the pitot-static pressure, $\Delta P = P_0 - P_s$ (P_0 is total pressure representing combined dynamic and static effects), the static pressure P_s, and the total air temperature T_0; and applying Bernoulli's equation in the form:

$$(V_1^2/2) + C_p T_1 = (V_2^2/2) + C_p T_2 \tag{1}$$

where C_p is the specific heat at constant pressure. At the stagnation point of the pitot tube, airflow relative to the aircraft is zero, so that $V_2 \equiv 0$, $T_2 \equiv T_0$ = total air temperature; $V_1 \equiv V_a$ = aircraft TAS; $T_1 \equiv T$ = ambient air temperature; and the TAS may be expressed as:

$$V_a^2 = 2C_p (T_0 - T) \tag{2}$$

In reality, the dynamic effect on an aircraft temperature-sensing element is not a purely adiabatic process, and the measured temperature is less than T_0. The ratio of heating actually experienced by the sensor to the adiabatic heating is referred to as r, the recovery coefficient of the probe, and the practical form of Eq. (2) becomes

$$T_p = T + r(V_a^2/2C_p) \tag{3}$$

where T_p is the temperature measured by a specific probe. According to Eq. (3), the temperature sensed by a probe is a function of the airspeed. Similarly, the difference between temperatures sensed by two probes having different recovery factors is a function of TAS and, conversely, TAS is proportional to the difference in probe temperatures. By designating the temperature measured by two different probes as T_{p_1} and T_{p_2}, we may write

$$T_{p_1} - r_1(V_a^2/2C_p) = T_{p_2} - r_2(V_a^2/2C_p) \tag{4}$$

and, after rearrangement,

$$V_a^2 = [(T_{p_2} - T_{p_1})/(r_2 - r_1)]2C_p \tag{5}$$

Fortunately, the aircraft was equipped with two different temperature sensors: a Rosemount Model 102, deiced configuration b, total temperature probe[1] and a probe of a reverse flow type.[2] The recovery factors for these probes, as mounted on the aircraft, have been determined experimentally by a series of aircraft speed runs to be:

$r_1 = r_{rf} = 0.6425$ (reverse flow)

$r_2 = r_{rm} = 0.972$ (Rosemount model 102)

By defining $T_{p_1} \equiv T_{rf}$ and $T_{p_2} \equiv T_{rm}$, Eq. (5) can be rewritten as

$$\mathrm{TAS}_c \equiv V_a = 78.0973\ (T_{rm} - T_{rf})^{1/2} \tag{6}$$

and can be used to calculate the missing true airspeed.

Due to probe temperature changes associated with sensor wetting, the technique of calculating TAS by Eq. (6) is not applicable to in-cloud flight segments.[3] The calculation is also sensitive to temperature measurement errors and requires very stable temperature sensors, signal conditioning, and recording components. For example, the TAS of the aircraft involved during normal thunderstorm research flights would be within

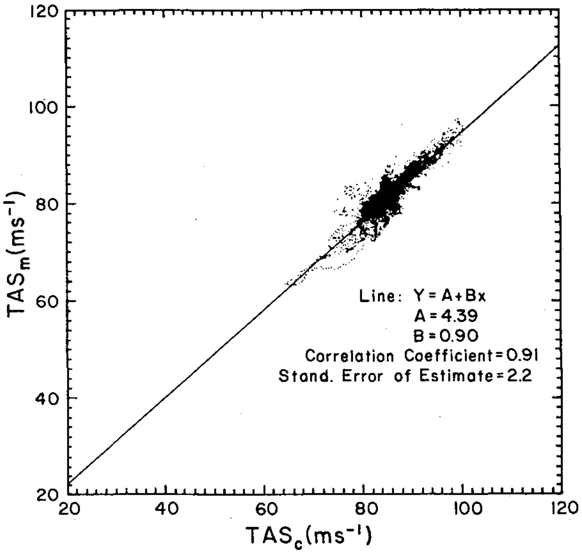

Fig. 1 Regression of TAS_c and TAS_m.

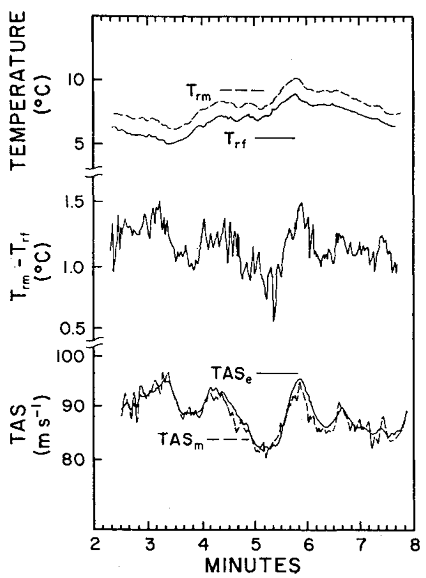

Fig. 2 Example of the technique applied to one of the six dependent data segments. The measured probe temperatures are shown by the top two curves. The middle curve shows the difference between the measured probe temperatures with the lag and smoother applied. The bottom two traces show the comparison between TAS_m and TAS_e.

the range of 70-100 m/s, and at those speeds, an error of 0.1°C in the difference between the probe temperatures would contribute to a corresponding error in the calculated TAS of ~3.3 m/s.

III. Test and Application

To test the technique, flight data obtained by the aircraft during flights before and after the research flight were scanned for periods of clear air flight, in which the normally measured true airspeed was available and the environmental conditions and aircraft flight profile were similar to the period of interest. Six data segments from three different days fulfilled these constraints and were selected for testing.

For each segment the normally measured true airspeed (TAS_m) was compared on a second-by-second basis, with the true airspeed (TAS_c) calculated by using Eq. (6). The mean square error between the TAS_c and TAS_m time series was minimized for all segments when: 1) the reverse flow temperature series was lagged 2 s with respect to the Rosemount temperature, and 2) an 11 s running smoother was applied to the temperature from each probe prior to computing the temperature difference. The lagging and smoothing help to account for differences in time constants of the two sensors (see Refs. 1 and 2) and noise superimposed on the recorded temperature signals.

Figure 1 shows the comparison of TAS_m and TAS_c for the six combined data segments, where TAS_c has been computed using Eq. (6) with the lag and smoother applied. The best estimate of TAS_m, denoted by TAS_e, is obtained from the regression (least-squares fit) of TAS_c on TAS_m and with substitution of the coefficients from Fig. 1 is:

$$TAS_e = 4.39 + 0.09 TAS_c \tag{7}$$

The standard error of estimate $S_{y/x}$ derived from the six dependent segments suggest that 68% of the time TAS_e, the best estimate of the true airspeed, will be within ±2.2 m/s of the 1-s values of TAS_m, the actual measured true airspeed. Figure 2 shows an example of the technique applied to a segment containing a large fluctuation in the TAS_m. The standard error of estimate $S_{y/x}$ equals 1.3 m/s in this case.

If the aircraft TAS is 90 m/s, an error of ~2 m/s, as indicated earlier, results in an error of <0.2°C when the temperatures are corrected for dynamic heating. This is within the requirements for most meteorological applications. A 2 m/s TAS error is more critical in the calculation of horizontal winds, and utility of the technique is questionable, except in the case of relatively strong winds.

In summary, an estimate of aircraft true airspeed can be derived from temperatures measured by two probes with different recovery coefficients. The computation is sensitive to temperature errors and is only applicable to out-of-cloud data. Nevertheless, it can produce a TAS that is sufficiently accurate to correct the raw temperature measurements and can be used in wind computations when the windfield is relatively strong, as in the vicinity of a thunderstorm.

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