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Pitot Pressure Measurements for Atmospheric Density Determination between 50 and 120 km (Western Europe Winter Anomaly Campaign, January 1976)

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Abstract. Within the Westeuropean Winter Anomaly Campaign (December 75/January 1976) this experiment was set up to furnish from pitot pressure measurements total neutral densities and temperatures. The data were taken by two pressure measuring instruments, a strain gage transducer for pressures higher than 10 N/m^2 and an ionization vacuummeter for pressures lower than 10 N/m^2.

For data analysis a computer program was written which contains the following elements

— systematic pressure correction for viscous and thermomolecular effects in the probe
— determination of densities from pitot pressures for continuum flow and free molecular flow conditions
— transport properties (viscosities, mean free paths)
— determination of temperatures by integration of density gradients.

The results show that there is an agreement in order of magnitude between data and CIRA-model atmosphere. However, a detailed inspection of the temperature profile shows substantial deviations from CIRA. The data suggest a wave character which should be considered in the context of winter anomalous behavior of the atmosphere.

Key words: Winter anomaly — Pitot pressures — Densities — Temperatures — Pressure transducer — Ionization vacuummeter.

Objectives of Investigation

The Western Europe winter anomaly campaign 1975/1976 was an effort to gather in a well coordinated way many forms of information concerning this effect. Our activities were related to the investigation of the total neutral atmosphere, specifically the mesophere and lower thermosphere. Our experiment (DP 1) was

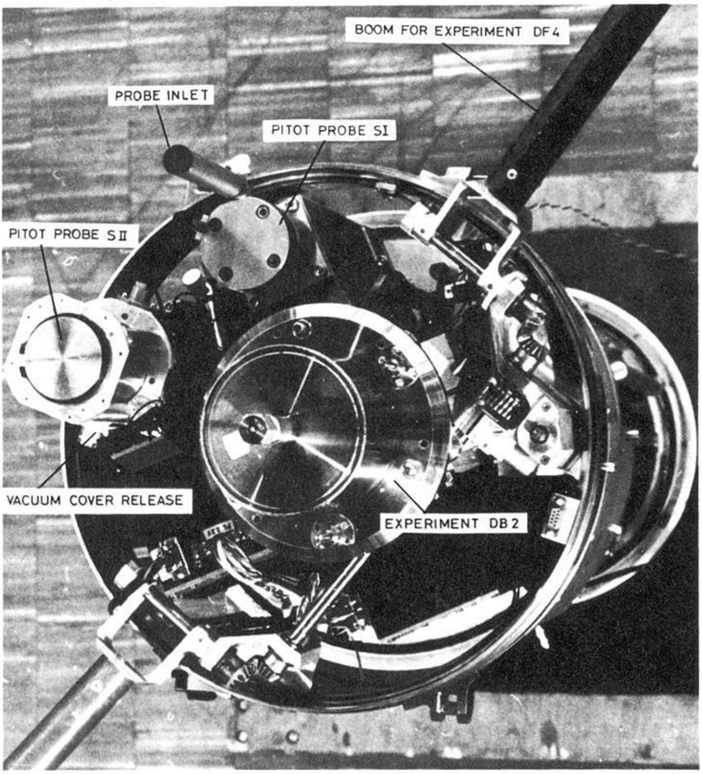


Fig. 1. Arrangement of experiments of payload B II on the front platform

applied to the measurement of pitot pressures, as outlined by Papanikas and Baete, for which our group had a broad spectrum of experiences from wind tunnel investigations under rarefied flow conditions.

In the design phase a few wind tunnel tests were performed to simulate the most critical conditions of heat transfer, shock interaction and angle of attack behavior in altitudes near 80 km for the forward facing experiments of payload B II on a Skylark-rocket. The investigation of a dummy probe gave important hints concerning geometries and optimization of flight requirements (see Papanikas and Becker). The front view of the actual version is shown in Figure 1.

The measurements in flight were taken between 50 and 120 km by two different types of instruments, a strain gage transducer (Probe S I) and an ionization gage (Probe S II). The informations determined from the data gathered by these instruments were geared to serve as standards for other classes of experiments of which the objectives were to find out the compositions and concentrations of atmosphere.

To deduce from pitot pressures the densities the procedure is a continuum flow and free molecular flow approach in lower and higher altitudes respectively and a linearization in the transition regime. Taking into account the probe geometries the transition (outer probe diameter/mean free path = 0(1)) occurs between 78 and 90 km. The flight velocities of the Skylark-rocket were known from radar tracking.

The relation between pitot pressure and density, then, is given for continuum flow condition by

$$\rho = f_1(M;\gamma)\; p_{2,0}/U^2. \tag{1}$$

The Mach number M is dependent on temperature and ratio of specific heats γ, which is weakly influenced (in these altitudes) by gas composition. So the factor $f_1(M;\gamma)$ changes for the Mach number range in question here (3.98 – 4.15) between 1.062 and 1.065. Then the inaccuracy of density determination is less than 0.1 %.

For free molecular flow the relation between pitot pressure and static pressure is from kinetic theory in the form of Becker:

$$\frac{p_{2,0}}{p} = \left(\sqrt{\frac{\gamma}{2\pi}}\,M + \frac{1}{2}\sqrt{\frac{T_w}{T}}\right) e^{-\frac{\gamma}{2}M^2} \cdot \left[\sqrt{\frac{\gamma}{2}}\,M^2 + \frac{1}{2} + \sqrt{\frac{\gamma\pi\, T_w}{8T}}\,M\right] \left(1 + \operatorname{erf}\sqrt{\frac{\gamma}{2}}\,M\right), \tag{2}$$

which gives basically

$$\rho = f_2(M;\gamma)\, p_{2,0}/U^2. \tag{3}$$

This factor f_2 changes from 0.65 to 0.75 for Mach number from 2.4 to 3.98 and results in an inaccuracy of density determination of ca. 1 %.

The inaccuracies quoted here deal with the procedure of calculating γ from the CIRA-gas composition which is a topic of investigation for other experiments in the campaign. From those results under anomalous conditions an improvement of our results will stem in the near future.

Experimental Set Up

Since the pitot pressures to be measured covered the range from $3.5 \cdot 10^3$ to $1 \cdot 10^{-3}$ N/m^2 two probes with different methods were used. For the higher pressures from $3.5 \cdot 10^3$ to $3 \cdot 10^0$ N/m^2 corresponding to altitudes from 50 to 90 km pitot probe S I was operated. The measuring system is a strain gage absolute pressure transducer. For the lower pressures from $3 \cdot 10$ to $1 \cdot 10^{-3}$ N/m^2 pitot probe S II was applied. The measuring system is an ionization vacuummeter with an ion source which was developed on the basis of a University Bonn design (U.v. Zahn).

Both probes were mounted together with instruments for experiments DB 2 (mass spectrometer, University Bonn) and DF 4 (Retarding Potential Analyzer, MPI Freiburg) on the front platform of payload B II with inlets of probes facing exactly forward. Figure 2 shows the schematic set up with pitot tubes on top, measuring system, and electronic equipment in the bottom portion.

The measuring system of probe S I is composed of an absolute pressure transducer, an installation for nulling the transducer, power supply and electronics

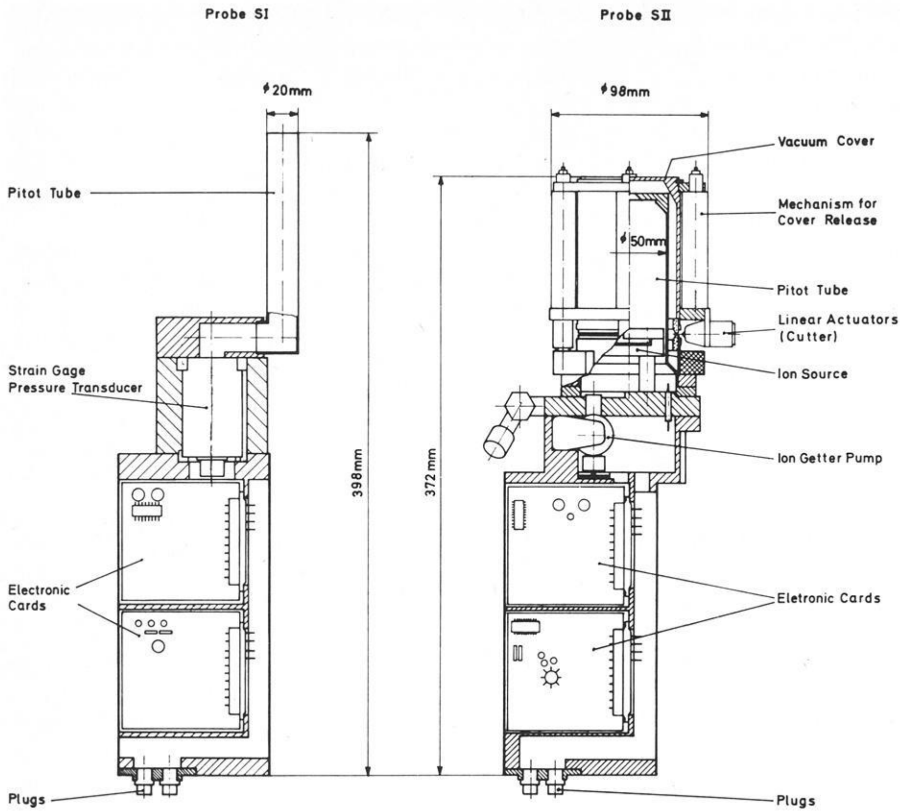


Fig. 2. Schematic view of pitot probes including gages and electronic equipment

for data acquisition. The cranked pitot tube leads to a rigid aluminium tank in which all other components are assembled.

The transducer (type Bell and Howell 4-353) consists of a full bridge with unbounded strain gages. This instrument is extremely rugged with respect to accelerations and shocks because it is designed for airborne application. Pressure measurements can be performed in a temperature range from $-35°$ C to $+135°$ C.

The electronic unit of probe S I has as shown in Figure 3

— power supply and null balance for the strain gage transducer
— bridge signal amplifier (error $\leqq \pm 0.3\%$ F.S.) with automatic calibration program
— thermo voltage amplifier including power supply
— resistance network for thermistors.

All units have insert cards with printed circuits and are separately mounted in the lower section of the tank. This arrangement provides a perfect shielding of cards under each other and guards against accelerations during start and vibrations in flight.

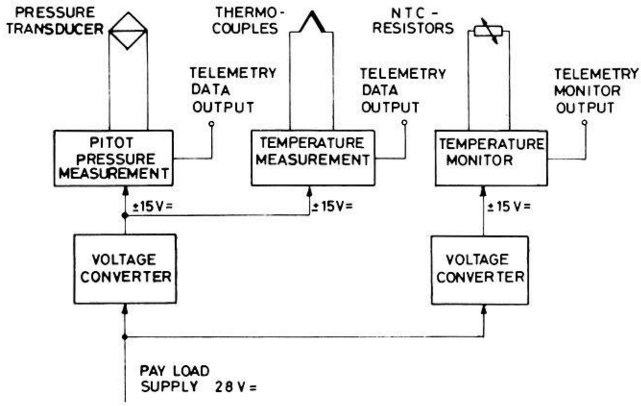


Fig. 3. Electronics block diagram of pressure transducer probe S I

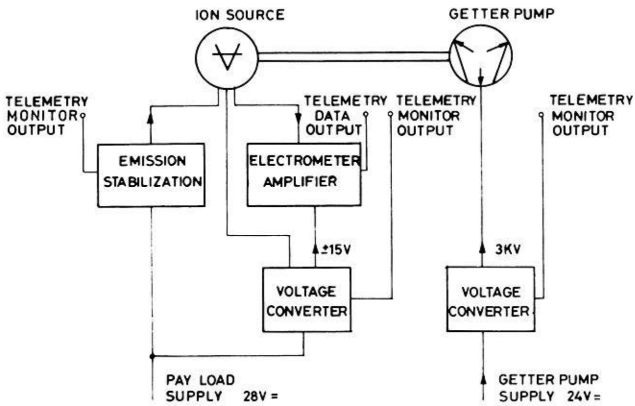


Fig. 4. Electronics block diagram of ionization vacuummeter probe S II

The measuring system of pitot probe S II has an ion source, power supply, and electronics for data acquisition (Fig. 4).

In the probe the incoming molecules are ionized by an ion source. In the calibration procedure the ion current was measured as a function of pressure for fixed cavity temperatures. The temperatures measured in flight were in the range used during calibration.

For operation of the ionization vacuummeter the following electronic units are used:

— emission stabilization of the ion source cathode
— linear electrometer amplifier (error $\leqq \pm 0.3\%$ F.S. $\pm 1 \cdot 10^{-14}$ A)
— power supply for ion source and amplifier
— high voltage supply for ion getter pump.

Otherwise the mechanical layout of the electronic tank is similar to that of probe S I.

The ionization process is initiated by electrons emitted from a cathode. The electrons become accelerated and focused by magnets to ionize the gas molecules

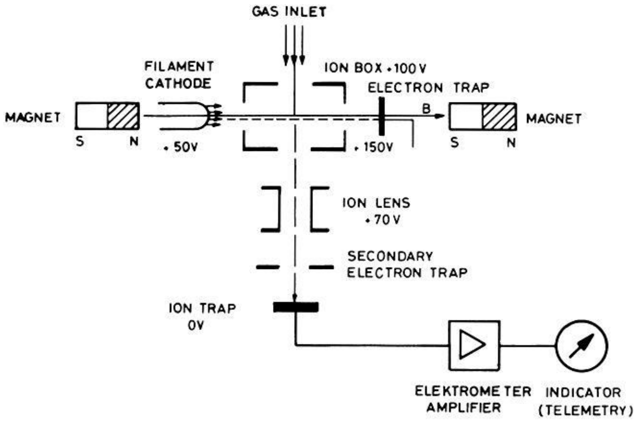


Fig. 5. Functional description of ionization vacuummeter

within the ion box. The generated ions travel through an ion lens and a trap for secondary electrons upon the ion trap (see Fig. 5). Here the ion current is measured by a linear electrometer amplifier. This unit is equipped with an automatic ranging between 10^{-12} A and 10^{-4} A F.S. An automatic nulling correction avoids temperature drifting. An inflight calibration program provides the monitoring of the probe functions.

The ion source is in the first part of upleg protected by a vacuum cover which is released at ca. 80 km altitude. The evacuation is ensured by an ion getter pump which operates until rocket lift off.

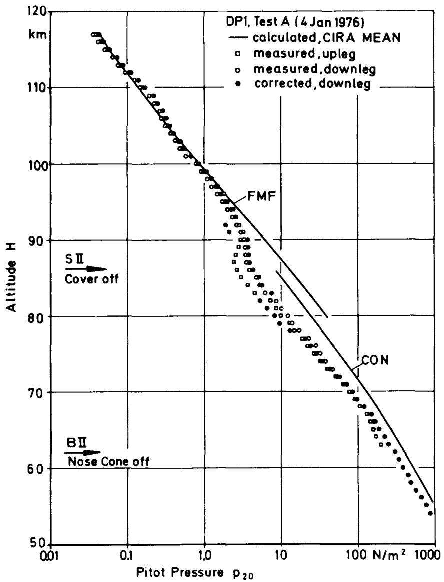
All measured data were transmitted by telemetry with a scanning rate of $100\,s^{-1}$, the house keeping informations were sampled with a rate of $6\,s^{-1}$.

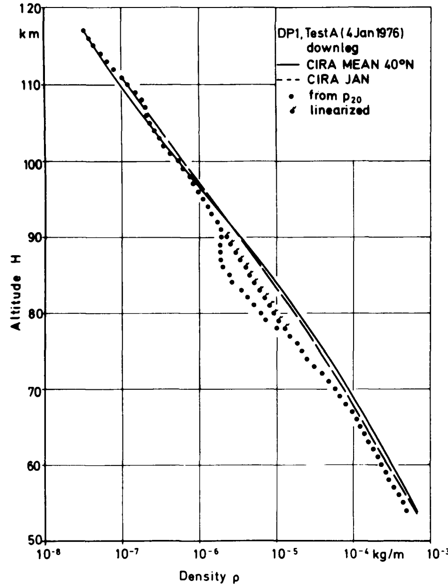
Computations

On the basis of the procedure described in the introductory chapter a computer program was set up following the schematic flow field calculations performed for a hypersonic free jet by Papanikas. This program contains the following elements:

- systematic pressure correction due to viscous and thermomolecular effects in the probe under supersonic, rarefied flow conditions
- determination of densities from pitot pressures for continuum and free molecular flow conditions including calculating pitot pressure values for CIRA atmosphere and given flight velocities
- transport properties (momentarily used: viscosities and mean free paths derived from these)
- determination of temperatures by integration of density gradients over altitude increments of 1 km by

$$T_2 = \frac{\rho_1 R_1}{\rho_2 R_2} T_1 + \frac{1}{\rho_2 R_2} \int_2^1 \rho g \, dH. \tag{4}$$





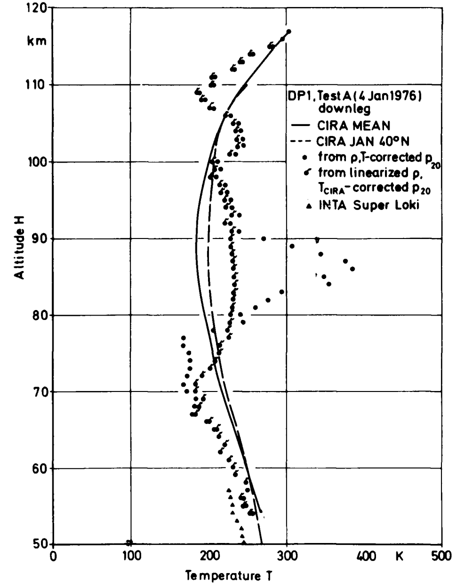


Fig. 6. Measured pitot pressures in up- and downleg; correction for downleg; comparison with CIRA-data

Fig. 7. Densities in downleg derived from pitot pressures in comparison with CIRA-data

Fig. 8. Temperatures in downleg determined from density gradients in comparison with CIRA-data

Results

Coordinated flights of all experiments in the campaign were performed on Jan. 4th and 21st 1976 in Arenosillo, Spain. In the Figures 6–8 some results of the first flight are shown representatively. Figure 6 gives the pitot pressures as raw data representation for up- and downleg. The good correlation between both sets of data justifies the measured flight path. The whole analysis, however, is applied to the downleg since here were clean measuring conditions, i.e. no cover releases, no interactions with other experiment activities.

The influence of pressure correction in Figure 6 is only apparent at higher altitudes.

Figures 7 and 8 show the computed densities and temperatures in comparison to CIRA-model atmosphere data. The temperature profile shows a marked wave structure which possibly stems from chemical events (anomalous behavior) and which is transported into the inner parts of the atmosphere. Damping of amplitude and wavelength is not clearly observable.

In conclusion it can be pointed out that the measurement and determination of total neutral gas data seems to be necessary under anomalous conditions as described. The information thus obtained is not just a steady state atmospheric model but also shows energy transport effects.

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