The DLR Meteorological Research Aircraft FALCON

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Abstract

The German Aerospace Research Establishment (DLR) uses a Falcon for meteorological research flights. The meteorological instrumentation is described and indications, obtained by intercomparison flights, on the high quality of the data are given.

1. Introduction

The German Aerospace Research Establishment (DLR), in special the Institute of Atmospheric Physics, has a long tradition to use aircraft as platforms for atmospheric research. Since 1978 a Dassault Falcon 20E (Fig.1) is part of the DLR fleet of research aircraft.

Fig.1: The meteorological research aircraft Falcon D-CMET

The two engine jet aircraft was expanded and modified to be used as a meteorological research aircraft:

- A noseboom, 1.8 m in length, allows the installation of a flow angle sensor in an area, where the airflow is little disturbed.
- On an attachement point under the fuselage external installations can be installed. It is mainly used for droplet spectrometers.
- Two photographic windows, 490 mm in diameter, allow downward facing optical equipment, for instance Lidar systems, to be used in the pressurized cabin. They

can be replaced by pressure proof pots to operate optical sensors (radiometer or scanner) without a window in front of them.

- Four ports, 80 mm in diameter, on the upper side of the fuselage can be used as inlets for air chemistry sensors or to install upward facing optical sensors, for instance pyrradiometers.
- A sealable aperture, 250 x 570 mm on the left hand side of the fuselage allows the installation of special windows for optical or microwave remote sensors.

The flight time (2:30 - 3:00 hours) and the range (1.200 - 1.800 km) is dependent on the height. Over sea the minimum flight height above the surface is 100 m, the maximum height is about 12 km. The speed varies between 100 and 175 m/s, depending on the flight height.

The Falcon is operated by the DLR Flight Operations Division, the meteorological sensors are handled by the DLR Institute of Atmospheric Physics.

2. Meteorological instrumentation

The instrumentation is in part permanent installed, in part optional depending on the missions to be flown. Details of the sensors, the errors, that influence their performance and on the data handling are given in the user's manual of the Falcon (Jochum,1991).

2.1. Permanent installed sensors

This sensors provide the measurement of 'state parameters' of the atmosphere (Temperature, humidity and wind as a function of the position and height of the aircraft) and those data with high frequency resolution, that are necessary to compute the turbulent energy fluxes of heat, moisture and momentum.

The sensors are:

- Pressure and wind:
  A flow angle sensor on the tip of the noseboom gives the static pressure as a measure of the height and the vector of the airflow relative to this sensor. An inertial reference system, that is part of the aircraft avionics, gives the vector of the movement of the flow angle sensor relative to an earth fixed coordinate system. From the small difference of this two large vectors the wind components (horizontal in east-west- and north-south-direction and vertical) can be derived.
- Temperature:
  Two probes, one slow and stable and one fast, but less reliable, that is mainly used to measure the temperature fluctuations for the flux calculations, are used.
- Humidity:
  Three sensors measure the humidity:
  A dew point sensor makes accurate, but slow (mainly at low humidities) measurements.
  A dielectric sensor measures the relative humidity with moderate speed and good reliability.
  A fast Lyman-α sensor measures the absolute humidity. It has a reduced long term stability, but gives a good time resolution of the humidity fluctuations to be used for the flux calculations.

The long term absolute accuracies of the measurements influence the reliability of the state parameters. For the flux calculations, where the fluctuations of the data, the deviations from the mean values over a timescale of about 10 minutes, are important, the short term relative accuracies are of interest. Tab.1 gives the errors of the data, that were obtained by numerous tests and sensitivity studies.

Parameter	Absolute Accuracy	Relative Accuracy
Static pressure	±1.0 hPa	±0.1 hPa
Temperature	±0.5 K	±0.03 K
Dew Point	±1.0 K	[1])
Relative Humidity	±2.0 %	[1])
Absolute Humidity	±0.5 g/m^3	±0.01 g/m^3
Horizontal Wind	±1.5 m/s	±0.10 m/s
Vertical Wind	±0.5 m/s	±0.05 m/s

Tab.1: Absolute longterm and relative shortterm accuracies of the measured parameters. [1]) These parameters are not used for flux calculations.

2.2. Optional installed sensors

Depending on the missions to be flown additional sensors or measuring systems can be installed.

The Institute of Atmospheric Physics handles systems for three areas:

- Cloud Physics:
  On a pylon under the fuselage two droplet spectrometers can be attached.
  Two liquid water content sensors give additional information on the integrated water content of clouds.
- Radiation:
  Two pyranometers and two pyrgeometers measure the downward and upward directed fluxes of shortwave and longwave radiation.
  A narrow beam infrared radiometer measures the temperature of the surface (land, water or cloud) below the aircraft.
- Lidar systems for remote sensing of atmospheric parameters:
  A system to measure the scattered signals of aerosol or cloud particles (ALEX-F) (Mörl et al, 1981) and a system to measure the differential absorption of water vapor (DIAL) (Ehret and Renger, 1990) were built up in our institute to be used in the Falcon.

In addition special equipment, provided by users from outside the DLR, can be installed. Fig.2 shows the the location of the sensors on the Falcon.

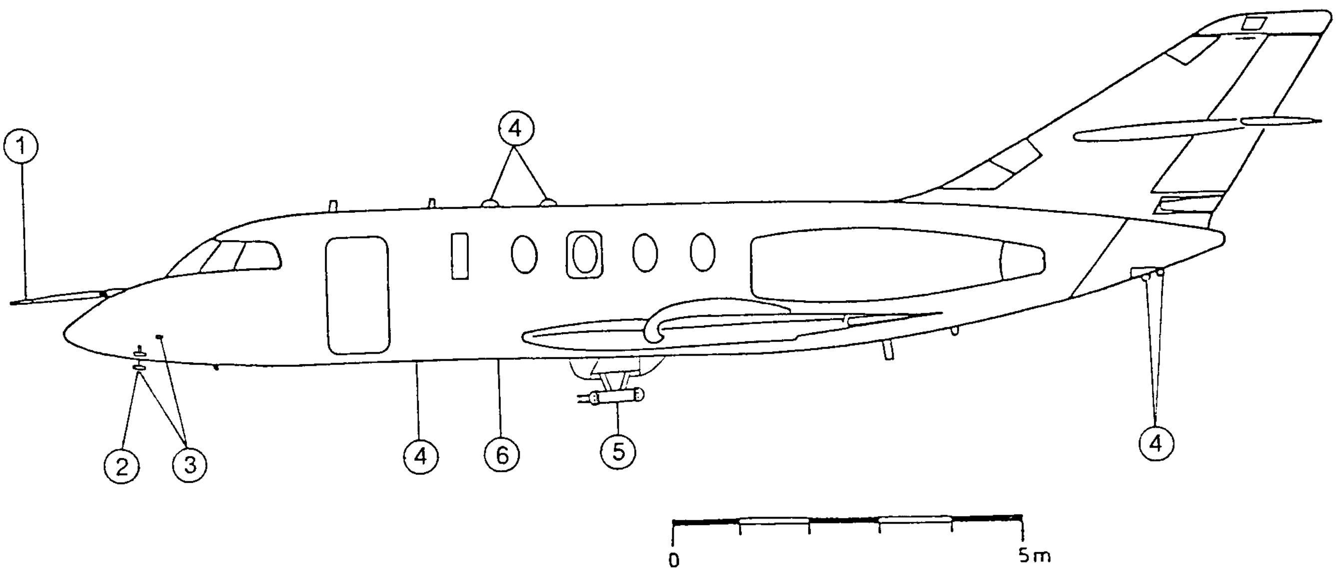

Fig.2: Location of the sensors on the Falcon: Flow angle sensor (1); temperature sensors (2); humidity sensors (3); radiation sensors (4); droplet spectrometers (5); and Lidar (6).

2.3. Data acquisition and processing

The central data system records the data of the permanent installed and the radiation sensors depending on their time response with three scanning frequencies, 10, 50 and 100 Hz, on digital tape. The resolution of this data is 14 bits. Special data systems with high capacity are used to record the data of the droplet spectrometers or the lidar systems.

During the flights online processing of the data provides alphanumerical and graphic displays and hardcopies for the monitoring of the measurements by the aircraft experimenters. The offline final processing is done by use of the high computing capacity of the DLR Central Data Processing Division.

3. Quality of the measured data

The data measured by the Falcon have to be controlled continuously to guarantee their high quality. Besides checks and calibrations of all sensors on the ground two kinds of test are performed, when the aircraft is flying, special flight maneuvers and intercomparisons with other aircraft or data sources.

3.1. Flight maneuvers

Flight maneuvers allow the calibration and give informations on the performance of the wind measurements. Special induced maneuvers are flown with the goal to minimize their effect on the three wind components. They are flown as part of experiments, when intensive turbulence measurements are performed, to control the measured data. Another reason for such flights arises, when changes in the installation of the sensors require a new calibration. The methods used and the results of such maneuver flights of the Falcon are described in detail by Bögel and Baumann (1991).

3.2. Intercomparison flights

The intercomparison of the measurements of an aircraft with other measuring systems (aircraft, radiosondes etc.) can be done by flying as close as possible to them. Doing so, the relative differences of the data can be studied, but hardly no information on the absolute accuracy can be obtained. Even when three or more systems are compared and only one shows significant differences to the other, one can not assume without further studies, that the measurements of the majority are correct. However this can give informations on malfunctions of a sensor or a data evaluation scheme. When the differences of the data lie within the errors, that were evaluated for the individual systems, one can assume, that the measurements are correct.

Experiment (Reference)	Platform	Remarks
JASIN 1978 (Hauf, 1984; Nicholls et al., 1983)	C 130 Electra	Intercomparison of turbulent fluxes
MESOKLIP 1978 (Hauf et al., 1987)	3 RS	Space-time interpolation of the data
KONTUR 1981 (Grant and Zank, 1986)	C 130	Intercomparison of turbulence data
ALPEX 1982 (Richner, 1985; Fimpel and Richner, 1986)	Electra P3	Extensive study of the data of a special intercomparison flight
Thermal and Dynamic Turbulence 1983 (Willeke, 1985)	3 ASK16	Intercomparison of turbulent fluxes
KONTROL 1985 (Busack and Pamperin, 1986)	Do 28 RS	Aircraft-aircraft: Special legs on two flights Aircraft-radiosonde: Falcon following as close as possible the radiosonde
Fronten 1986 (Hoinka et al., 1988)	Queen Air 3 ASK16 LDA, RS	Space-time interpolation of the data of six platforms
ICE 1987 (Quante, 1989)	C 130	Intercomparison of turbulence data
Arktis 1988 (Brümmer and Bakan, 1989)	Do 128	Intercomparison of time series and turbulent fluxes
ICE 1989 (Quante et al., 1991)	C 130 Merlin IV	Intercomparison of turbulence data

Tab.2: Overview of intercomparisons of the Falcon with other platforms. Aircraft: motorglider ASK16 (DLR); Hercules C 130 (Meteorological Research Flight, Farnborough); Do 28 and Do 128 (Institut für Flugführung, Technical University Braunschweig); Electra (NCAR) Merlin IV (Centre d'Aviation Météorologique, Bretigny); P3 (NOAA); Queen Air (DLR). Other platforms: LDA, ground-based Laser-Doppler-Lidar (Institute for Optoelectronics, DLR); RS, radiosondes.

Since the beginning of its service, the Falcon participated in intercomparisons whenever this was possible (Tab.2). Doing this, two means of intercomparing the data were used. In every case the differences of the absolute values of the data of the different sources and their variances were studied, to get informations on the absolute accuracy of the parameters. The time resolution of the data is for this purpose not a limiting factor, as long as it is similar for every platform. This kind of intercomparison is important, when the data have to be combined with those of other measuring systems to construct threedimensional fields of atmospheric parameters.

When the data are used to calculate turbulent fluxes, the shorttime relative accuracy and the frequency resolution of the data is important (Quante, 1989). Therefore the best thing to intercompare different aircraft for this kind of measurements is to fly as close as possible along straight legs and then study time series of the data, that are plotted with high resolution, and calculate variances, covariances, powerspectra and crosspectra of the data.

In the beginning of our measurements with the Falcon we got some highly valuable indications how to improve the instrumentation from the results of the intercomparison flights. Having done this the results of all intercomparison flights showed no indication that data exceeded the errors that are given by the long term accuracy of the measurements. Also the shorttime relative accuracy and the frequency resolution of the turbulent data were always within the limits that we calculated from the ground tests and the results of the maneuver flights.

So one can be certain, that data measured with the Falcon have a high quality and are consistent with the measurements of other platforms.

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References:

Bögel W. and R. Baumann, 1991: Test and Calibration of the DLR Falcon Wind Measuring System by Maneuvers. J. Atmos. Oceanic. Technol. 8, 5 - 18.

Brümmer B. and S. Bakan, 1989: Intercomparison. Hamburger Geophysikalische Einzelschriften. B6, 200 - 205.

Busack B. and H. Pamperin, 1986: Intercomparisons. Hamburger Geophysikalische Einzelschriften. B5, 71 - 81.

Ehret G. and W. Renger, 1990: Atmospheric Aerosol and Humidity Profiling Using an Airborne DIAL System in the Near IR. Optical Society of America, Technical Digest Series, 4, 586 - 589.

Fimpel H. P. and H. Richner, 1986: Results of the ALPEX aircraft intercomparison on 19 April 1982. WMO/TD No. 108, 85 - 94.

Grant A. and S. Zank, 1986: An Intercomparison of Turbulence Data Obtained by Two Aircraft during KonTur. Beitr. Phys. Atmosph., 59, 185 - 194.

Hauf T., 1984: Turbulenzmessungen mit dem Forschungsflugzeug Falcon. Meterorol. Rdsch., 37, 163 - 176.

Hauf T., H. Walter and O. Walk, 1987: Ein Vergleich von Flugzeug- und Radiosondenmessungen während MESOKLIP. Meteorol. Rdsch., 40, 170 - 180.

Hoinka K. P., H. P. Fimpel and F. Köpp, 1988: An Intercomparison of Meteorological Data Taken by Aircraft, Radiosondes and a Laser-Doppler-Anemometer. Theor. Appl. Climat. 39, 30 - 39.

Jochum M. A. (Ed.), 1991: Nutzerhandbuch für das Falcon-System. Zweite, verbesserte Auflage. In Press.

Mörl P., M. E. Reinhardt, W. Renger and R. Schellhase, 1981: The use of the airborne LIDAR system 'ALEX F1' for aerosol tracing in the lower troposphere. Beitr. Phys. Atmosph., 54, 403 - 410.

Nicholls S., W. Shaw and T. Hauf, 1983: An Intercomparison of Aircraft Turbulence Measurements Made During JASIN. J. Clim. Apl. Met., 22, 1637 - 1648.

Quante M., 1989: Flugzeugmessungen der Turbulenzstruktur in Cirruswolken. Mitt. Inst. Geoph. Meteorol. Univ. Köln, Heft 65, 144 pp.

Quante M., P. R. A. Brown, J.-F. Gayet and B. Guillement, 1991: Results of Intercomparison Flight ICE 211 - Dynamical and Thermodynamical Measurements. International Cirrus Experiment. Third Workshop in Villeneuve d'Asq, France, 3 - 5 December, 1990. 6 pp.

Richner H., 1985: The Relative Accuracy of ALPEX Aircraft Data. Lapeth Report No. 23, 76 pp.

Willeke H., 1985: Ein Vergleich von "Falcon"-Daten mit "Motorsegeler"-Daten. DFVLR Mitteilung 85-04, 61 - 68.