

# Report of EUFAR Expert Workshop on Thermodynamics

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On December 10<sup>th</sup> and 11<sup>th</sup> the first EUFAR workshop on 'Thermodynamics' was held. Experts from several European countries and the USA working in the field of Thermodynamics attended the workshop.

Within the first two sessions an overview about new research platforms and existing thermodynamic instrumentation was given in short presentations of the international experts. These talks were followed by three discussion sessions concerning quality management, future developments and possible synergy effects.

## Quality Management

The large fleet of aircraft within EUFAR hosts a wide diversity of thermodynamic instrumentation. Therefore quality management is an important and quite challenging task to ensure reliable quality of data within EUFAR. There was a long but finally fruitful discussion in Session III about this point. Before all a general agreement was found that redundancy is quite essential for all thermodynamic measurements. This allows not only to detect erroneous measurements but also strongly reduces the risk of loss of data.

As a first step to homogenise quality management within EUFAR a desirable standard for laboratory calibrations was discussed. To guarantee comparability of the laboratory calibrations within EUFAR the following action items were agreed on:

- Setup of an overview list of calibration facilities within EUFAR.
- Proof of traceability of calibration to national standards.
- Documentation of calibration method.
- Documentation and proof of specified accuracy.

Each thermodynamic instrument operator is responsible to post the above information on the EUFAR website as soon as possible.

Finally common recommendations for calibration of temperature, pressure and humidity sensors were discussed with the following results:

### Temperature

accuracy: <0.1 K

frequency: annually for platinum resistors and thermocouples, eventually after flights under severe conditions (e.g. clouds, seaspray, dust)

### Pressure

accuracy: 0.1 hPa

frequency: annually

### Humidity

accuracy: <0.3 K (dew-/frostpoint)

3% of measured value (relative-/absolute humidity)

frequency: strongly depending on instrument

A check of cross dependencies between all three measurements especially for the humidity measurements is essential and should be done at least once for each instrument.

To avoid expensive build-up of new calibration facilities access to existing facilities fulfilling above recommendations should be supported by EUFAR.

As a first check of the existing calibration procedures within EUFAR it was decided to organise a 'low cost' laboratory intercomparison. Therefore MetAir (Bruno Neiningner) will provide a combined temperature, pressure and humidity sensor as 'black box' that will be sent around all instrument operators for calibration. All calibration results will be collected at a neutral place (EUFAR office) and finally analysed by the thermodynamics expert co-ordinator.

Inflight calibration are essential for static pressure measurement to reduce the aircraft induced flow distortion error. Approved methods are trailing cone measurements in combination with low altitude tower fly-by. Some times 'race track' manoeuvres are used for validation but therefore extremely constant meteorological conditions are necessary which can hardly be found in Europe. LIDAR based calibration methods are in development but not yet used for calibration of research aircraft.

A last step in quality management are inflight intercomparison between different research aircraft.

Since several aircraft can not probe the same airmass such an intercomparison has to be planned very carefully to get reliable results. It is very essential to have precise information about the relative

position and speed of the aircraft. Dropsondes can be helpful in intercomparison campaigns but are not recommended as reference.

## Future Developments

There is a strong need for instrumental development in the future. Most commercial instruments used for thermodynamic measurements either run out of service or became extremely expensive within the last years. It was proposed to install a discussion group on the EUFAR website with restricted access for fast communication of experience with new sensors and first test results.

### Water vapor

The widely used Lyman-alpha absorption instrument (at the moment the only proven 100Hz instrument) runs into great problems since no more light sources are produced. Possible solutions

- find a new manufacturer for the light sources (Hamamatsu, Dutch, Russian)
- use different light sources (Krypton line source)
- find/develop new instruments (TDL, IRGA, LICOR).

There is **no** real alternative instrument available at the moment!

### Temperature

Rosemount, a leading supplier of aircraft certified temperature sensor housings and sensors, drastically increased the prize for his fast temperature sensor and housing.

Another problem is temperature measurement within clouds, since 'sensor wetting' caused by small droplets hitting the sensor can lead to erroneous measurements up to a few Kelvin. Some experience exist with different techniques (radiometric, ultra sonic) to measure temperature in clouds. There is no commercial instrument available at the moment and complex data evaluation make them not suitable as standard instrumentation. Therefore precise temperature measurement within clouds is an important but still unsolved topic.

### Pressure

Same problem as with temperature: commercial aircraft sensors became too expensive. Off the shelf sensors often suffer from at least one of the following problems:

Slow time response, sensitivity (differential pressure), acceleration dependence, humidity dependence, temperature dependence, large hysteresis, insufficient long term stability. There are different sensors under test at several institutions at the moment.

## Synergy Effects

As most promising common project was found:

Characterization of existing temperature sensor and design of a new sensor to improve temperature measurements. This project will include airflow and particle flow studies (wind tunnel / CFD) as well as heat transfer calculation.

## Recommendations

From this workshop the following recommendations are given in short form:

### To the scientist

- Documented quality management is essential to guaranty continuous and comparable quality of thermodynamic measurements within EUFAR.
- There is a strong need for instrumental development in the field of pressure, temperature and humidity measurements.

### To the aircraft operator

- Sensor redundancy is essential for high quality thermodynamic measurements
- There is a strong need for instrumental development in the field of pressure, temperature and humidity measurements.
- Flight hours are needed for inflight calibration and intercomparison

To the funding agencies

- Support for access to calibration facilities within EUFAR
- Support for development of new instrumentation
- Support for intercomparison flights
- Support for common project 'Temperature Sensor'