The E-AMDAR Humidity Trial (2006 - 2009)

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Acronyms Table

AAA	AMDAR On-Board Software Standard (**A**CMS / **A**CARS / **A**MDAR)
ACARS	**A**ircraft **C**ommunications **A**ddressing and **R**eporting **S**ystem
ACARS MU	**ACARS M**anagement **U**nit
AMDAR	**A**ircraft **M**eteorological **Da**ta **R**elay
ACMS	**A**ircraft **C**onditioning and **M**anagement **S**ystem
AEEC	**A**irlines **E**lectronic **E**ngineering **C**ommittee
ARINC	**A**eronautical **R**adio **Inc**.
ARINC 620	AMDAR On-Board Software Standard stated by ARINC
BUFR	**B**inary **U**niversal **F**orm for the **R**epresentation of Meteorological Data
CMU	**C**ommunication **M**anagement **U**nit
COSMO-EU	Non-Hydrostatic Limited-Area (Region: **Eu**rope) Atmospheric Model of the **Co**nsortium for **S**mall-scale **Mo**deling
DLK	**D**ata **L**in**k** between Aircraft and Airline's Center
DWD	**D**eutscher **W**etter**d**ienst / German Meteorological Service
E-ADAS	**E**UMETNET-**A**MDAR **D**ata **A**cquisition **S**ystem
E-ADOS	**E**UMETNET-**A**MDAR **D**ata **O**ptimization **S**ystem
E-AMDAR	**E**UMETNET-**AMDAR**
EUCOS	**EU**METNET **C**omposite **O**bserving **S**ystem
EUMETNET	The **Net**work of **Eu**ropean **Met**eorological Services
FELG	DWD-Bereich **F**orschung und **E**ntwicklung, Observatorium **L**indenber**g** / DWD Meteorological Observatory Lindenberg
FMS	**F**light **M**anagement **S**ystem
FZJ	**F**orschungs**z**entrum **J**ülich / Research Center Jülich
GTS	**G**lobal **T**elecommunication **S**ystem
SEB	**S**ystem **E**lectronics **B**ox
TAT	**T**otal **A**ir **T**emperature (Air temperature at the stagnation point of a flow)
UKMO	**U**nited **K**ingdom **M**eteorological **O**ffice
WVSS-II	**W**ater **V**apour **S**ensor **S**ystem No. **II**

1 Abstract

Since 1999 the DWD within a network of Europe's national meteorological services takes part in E-AMDAR (EUMETNET Aircraft Meteorological Data Relay). Worldwide, the AMDAR fleets are successfully collecting meteorological data, such as pressure, temperature, and wind. The aircraft have to be additionally equipped with sensor units for the humidity. This will complement the traditional radiosonde sounding system and potentially allow for partly replacing the soundings. AMDAR profiles, even if humidity is included, are significantly cheaper. The only limitation which will persist is the maximum altitude of around 200 hPa given by the typical aircraft performance limits. E-AMDAR decided to ask the airline Lufthansa for aircraft of their fleet to carry airborne humidity instruments.

Thanks to an excellent cooperation with Lufthansa it has been possible to equip three aircraft of the A320 family with airborne humidity sensor systems. Since early 2007 the measurements are permanently transferred via the DWD and the central data switch of E-AMDAR into the Global Telecommunication System worldwide to all national weather services. Apart from some deficits in the signal quality the employed instruments of the 2006 production series are working constantly without any dead losses.

The following report describes the trial's realization and results as well as some conclusions for the future.

2 Preparation

2.1 The Sensor Type WVSS-II of SpectraSensors Inc., USA

2.1.1 Selection

A lot of different humidity sensor principles have been in use on atmospheric research aircraft, such as:

- chilled mirrors,
- Lyman-Alpha hygrometers (absorption as well as luminescence),
- capacitors,
- other optical methods, i.e. Tunable Diode Laser.

The system solution having been looked for had to approach the following requirements:

- the data quality to be comparable to that of radiosondes or even better,
- the measurement range to reach from the maximum humidity values on ground to the typical values in the upper troposphere,
- the time lag of the measurement method to be within a few seconds,
- the output of a humidity parameter to be converted to the ambient air data or to a conservative parameter like a mixing ratio or a specific humidity,
- the measurement principle to have a large degree of insensitivity against pollutants as well as cleaning and anti-icing substances,
- the maintenance period to be at least one year or longer,
- the weight and the size of the system to be small enough for permanent integration on a medium range passenger aircraft.

The only product which gave the perspective to fulfil this specification has been the optical sensor WVSS-II of SpectraSensors Inc., USA.

2.1.2 Functionality

The complete system (see Fig. 1) consists of

- the Air Sampler, the intake and outlet unit to be mounted on the aircraft skin,
- the System Electronics Box (SEB), consisting of the Laser, the sampling tube for the absorption path, and the corresponding electronics,
- the hoses for the connection between the Air Sampler and the SEB.

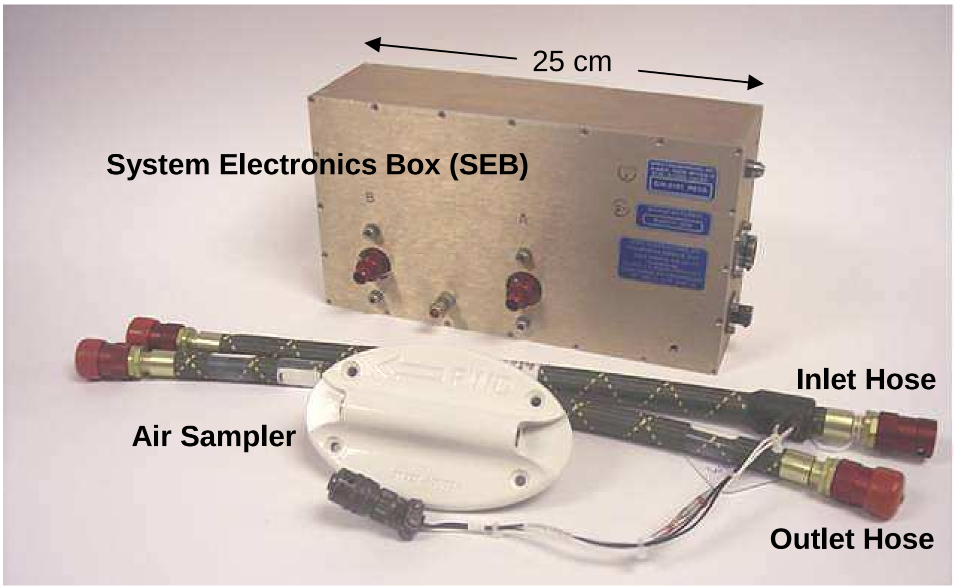

Fig. 1: The components of the aircraft humidity sensor type WVSS-II (©SpectraSensors Inc., USA).

The interaction of these components is shown in Fig. 2. The Air Sampler mounted with its length axis parallel to the outward flow provides for the sampling air flow through the SEB. In order to avoid any condensation the inlet hose as well as the sampling tube are electrically heated. The targeted temperature inside of the sampling tube is about 35 °C. This once has been chosen to be always beyond the maximum dew point the atmosphere ever can reach.

The water vapour mass mixing ratio, the sampling tube's temperature and pressure as well as some house-keeping data and quality information are sent out via a serial interface according to ARINC 429.

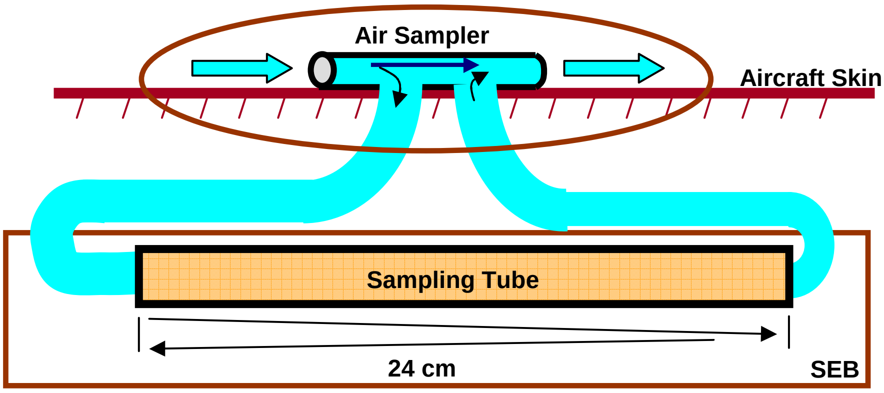

Fig. 2: The functionality of the WVSS-II components.

The Air Sampler once has been designed for three goals:

- A separation of water and ice particles out of the intake flow.
- A flow rate to get a minimum of two sampling tube's flushes per sampling period of 2 seconds.
- A pressure inside of the sampling tube to be near to the ambient pressure.
- Small extent above the aircraft skin to get a low drag and to avoid any application of de-icing power.

The principle inside the SEB is the so-called 2f method. It is based on the use of a Tunable Diode Laser used for a relative absorption measurement in the infra-red range. The extent of a suitable spectral absorption line of the water vapour is scanned and characteristically surveyed by an especially developed mathematical tool. The locally measured pressure and temperature of the absorption path are input parameters for an internal processing yielding the water vapour mass mixing ratio. This process is the instrument's part which has to be calibrated under the manufacturer's control.

2.1.3 Laboratory Tests

Before being mounted on the aircraft the WVSS-II was tested at two different institutions who successfully operate climate chambers for the air data simulation of the complete troposphere up to the lower stratosphere.

2.1.3.1 Test in the year 2005 at the Research Center Jülich (FZJ)

The WVSS-II version of late 2005 was tested at that time in the environmental simulation chamber at the FZJ (Smit & Sträter, 2006). Pressure, temperature and frost point temperature were varied in the same fashion as they are typically observed during aircraft flights between surface and up to 12 km altitude. WVSS-II tracks humidity structures very well at water vapour mixing ratios between 100 and 20,000 ppmv. At these moderate humidity levels typical for the lower and middle troposphere the performance is good with relative accuracy of ± (5 to 10) %. However, particularly at upper tropospheric conditions where water vapour mixing ratios are well below 100 ppmv the accuracy of WVSS-II declined rapidly down to the detection limit of about 70 ppmv. Fig. 3 gives a plot about the relative deviations (scattered points with adapted graph inside) and the 1:1 diagram of the frost point temperature (diagonally oriented dark graph). More details can be seen in Smit & Sträter, 2006.

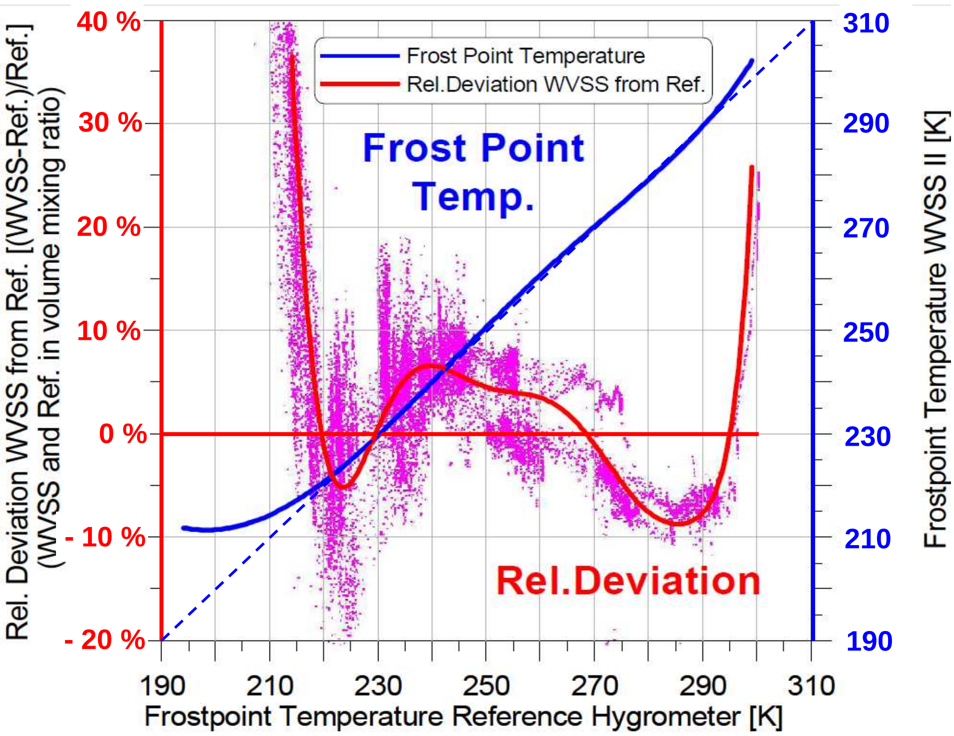

Fig. 3: Results of the climate chamber test at the FZJ (Research Center Jülich): Relative deviations of water vapour mixing ratio measured by WVSS-II (Version 2005) compared to the reference instruments as function of frost-point temperature. The points represent the individual measurements while the line inside represents a running mean. The dark fat line represents the corresponding 1:1 graph of frost point temperatures WVSS-II against the reference values (see Report Smit & Sträter, 2006).

2.1.3.2 Test in the year 2006 at the DWD Meteorological Observatory Lindenberg (FELG)

Several sensors of a batch of WVSS-II units delivered to the DWD in 2006 where subject of a climate chamber test at FELG. Fig. 4 shows the 1:1 plot of the WVSS-II water vapour mass mixing ratio readings versus the corresponding reference values. At a level of about 0.04 g/kg (70 ppmv) the lower detection limit has been reached. 40 ppmv once had been specified.

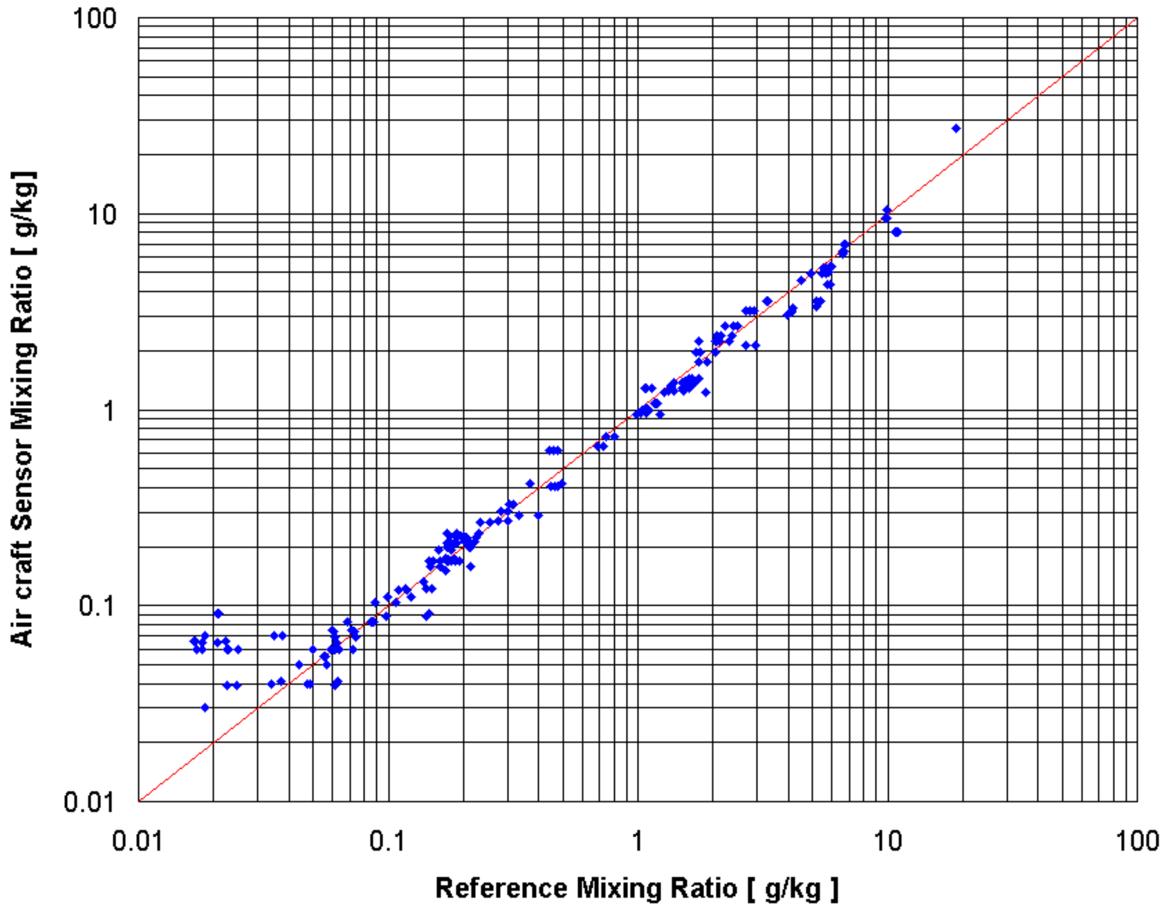

Fig. 4: The test result of the WVSS-II version 2006 achieved in the climate chamber of the DWD Meteorological Observatory Lindenberg.

2.1.3.3 Summary of the Lab Tests

The results of both of the laboratory tests can be summarized in the following table:

	Relative Accuracy	Lower Detection Limit
Specification	± 5 %	0.025 g/kg (40 ppmv)
Result	± (5 to 10) %	0.04 g/kg (70 ppmv)
Comment	The accuracy is slightly worse compared to that of standard radiosondes	The sensor has a usable range in the mid latitudes atmosphere reaching from ground to about 300 hPa in summer and to about 500 hPa in winter

Despite the results showing a limited instrument's performance E-AMDAR and DWD decided to go on with an aircraft trial. A lot of fruitful additional insights about both the sensor's behaviour as well as the aircraft integration and the data logistics gave the perspective to be sufficiently large. Anyhow, on the market no alternate instrument with comparable technical features (see 2.1.1) was available.

2.2 Suitable Aircraft Type

In the beginning, the most suitable type of aircraft of the Lufthansa fleet had to be chosen. In order to achieve a maximum number of vertical atmospheric profiles over Europe the short or medium range flights were to be preferred because of

- a large number of vertical profiles per day by frequent ascends and descends,
- getting most of the profiles inside the EUCOS area.

The use of the aircraft type Airbus A319-100 offered by Lufthansa turned out to be the best to fulfil this request. At that time 17 units of this type have been in operation. This gave the perspective to use the same certification for further instrumentation units later on.

Fig. 5: The aircraft type Airbus A319 selected for the operation of the humidity sensor (©Lufthansa).

2.3 Integration

2.3.1 Integration on the Aircraft

In order to get the sampling air's contact with the fuselage as small as possible its upstream way over this surface should be short. As can be seen in Fig. 6 the intake point has been located as close as possible to the aircraft's nose. In addition to that the intake is apart for enough from the spray cloud of the gear's front wheel. The so-called 4 o'clock position means the angular location below the widest waterline of the airframe. By this kind of orientation no running water during ground parking can enter into the sampling system. The risk of damages by freezing left-overs of water is minimized.

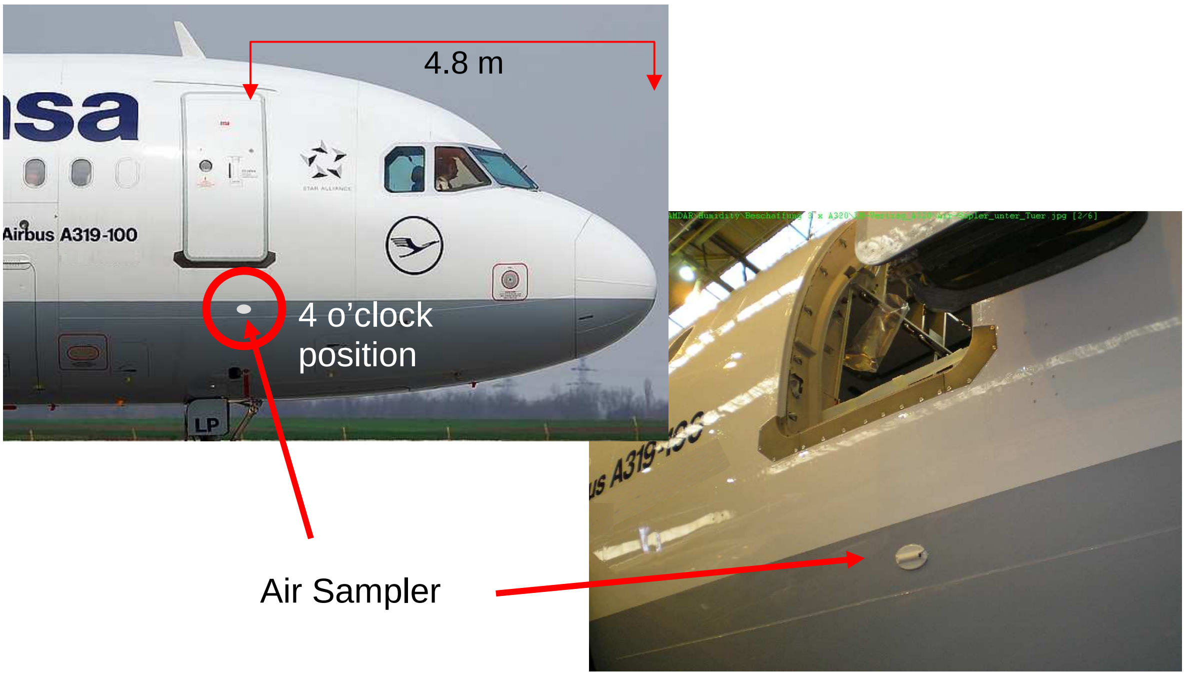

Fig. 6: The exterior view of the Air Sampler's position on the fuselage. (©Lufthansa)

The SEB has been installed inside the airframe by mechanical connection to the ribs (see Fig. 7). The Air Sampler has been attached by use of doubler plates on the inner side of the skin.

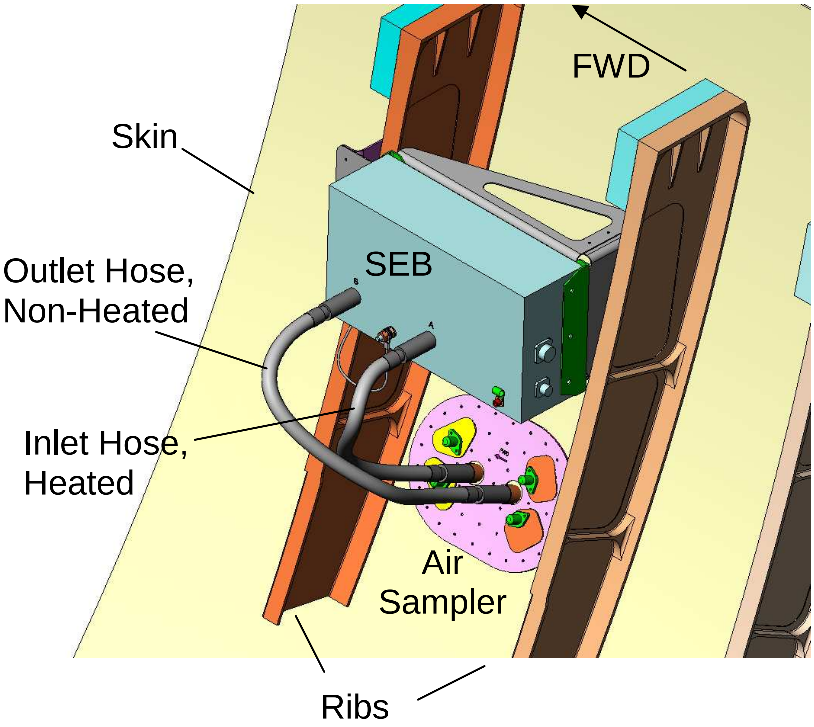

Fig. 7: The interior view of the WVSS-II installation (©Lufthansa).

2.3.2 Integration into the Data Network

The interfacing to the AMDAR world had consequences at several points of the data flow. Fig. 8 gives an overview about the modifications applied to the AMDAR data network. On the aircraft itself as well as in several system components on ground some upgrades took place.

The output of the WVSS-II, a serial data stream has been connected to the unit executing the AMDAR on-board algorithms. This software was modified in conformity with the ARINC 620 standard of 2006. This means the additional integration of the water vapour mixing ratio value plus a quality parameter “***Q***” into the data transfer to the ground. In the coding of this transfer one digit “***p***“ for the decimal power is reserved. For the decimal mantissa only 2 digits “***nn***” are allowed by the ARINC standard. The measurement values of the water vapour mass mixing ratio between the ground level and 200 hPa are covering the range between 100 and 0.001 g/kg (6 decades). Each pass over of the value from one decade to another turns up as the change between 99 and 10 or reversely. In the first number 99 the last digit gives a relative step of 1 % whereas in the second number we get 10 %. Hence, the ARINC 620 format “nnpQ” leads to a relative uncertainty between 1 % and 10 %. Considering the envisaged improvement in the relative accuracy of the instrument itself, the standard must be modified adequately as soon as possible to achieve a better resolution in the data transfer.

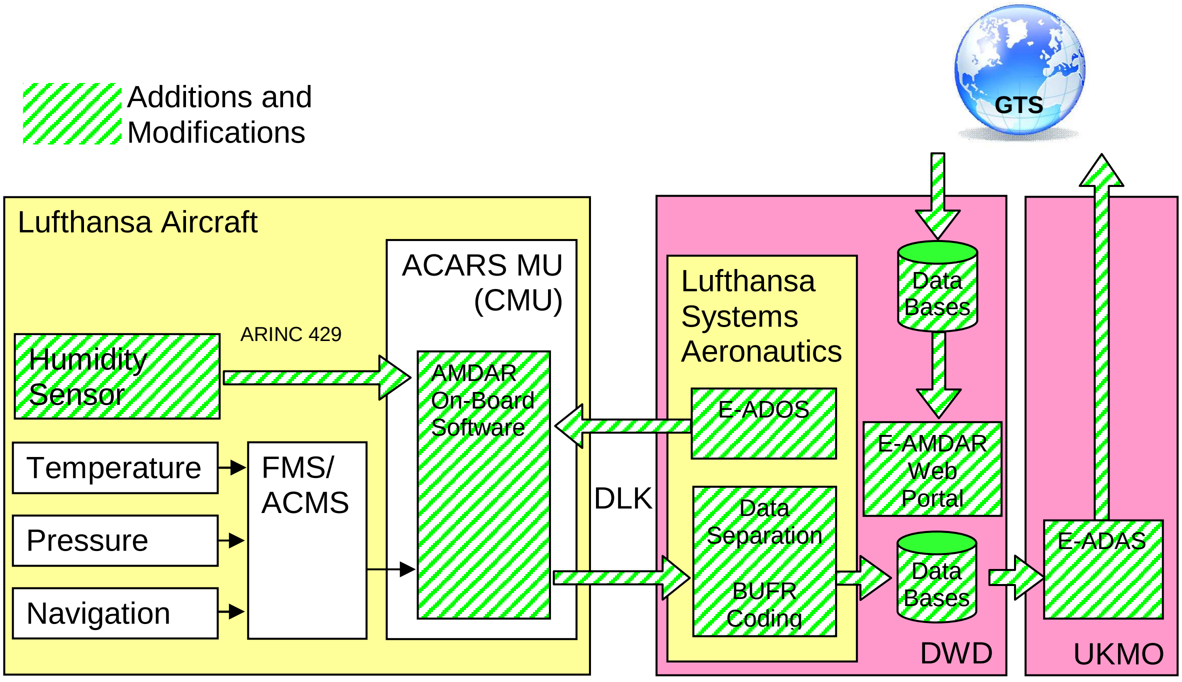

Fig. 8: Overview about the AMDAR system components having been modified for the addition of the humidity parameter.

Congruently with the modified data link to the ground the process for the separation of the atmospheric data (“MetConcentrator”) has been adapted too. The quality indicator is checked before the humidity is integrated as a valid value in the BUFR message. The three aircraft got the AMDAR identification numbers EU4593, EU5331, and EU6564.

As well the data handling at the DWD has been upgraded for the new variables in the BUFR messages. The final output of E-AMDAR via E-ADAS into the GTS has been another package of adaption work.

Another modification took place with the E-AMDAR Web Portal. All pages with alphanumeric as well as graphical displays of the meteorological data have been upgraded.

Last but not least the optimizer software E-ADOS regulating the amount of aircraft actively sending reports has been equipped with a distinct prioritization of selectable platforms. Otherwise the three humidity aircraft would have been sorted out too often, especially over the highly frequented hubs.

3 Airborne Operation Results

3.1 Flight Operation

Lufthansa obliged E-AMDAR very much by operating the humidity aircraft most of the time in the central part of Europe. The airport of Munich was chosen as the aircraft's base. The only breaks in the data delivery have been pared down to the routine maintenance periods.

3.2 Data Analysis

The measurements began in January 2007. The unit EU4593 had to be exchanged very early because of remarkably biased values. In June 2007 E-AMDAR could start the transmission of the data via GTS.

3.2.1 Examples of Profiles

Since the three humidity aircraft are stationed at the airport of Munich there have been several opportunities to get ascend profiles of the same location at nearly the same time. Fig. 9 shows T-LogP diagrams with the temperature and dew point profiles of a collocation in September 2008. As expected the structure of the temperature as well as of the dew point curves is nearly identical. But between the aircraft there are systematic offsets in the dew points. These deviations have been the instrument's biases drifting back and forth over several months.

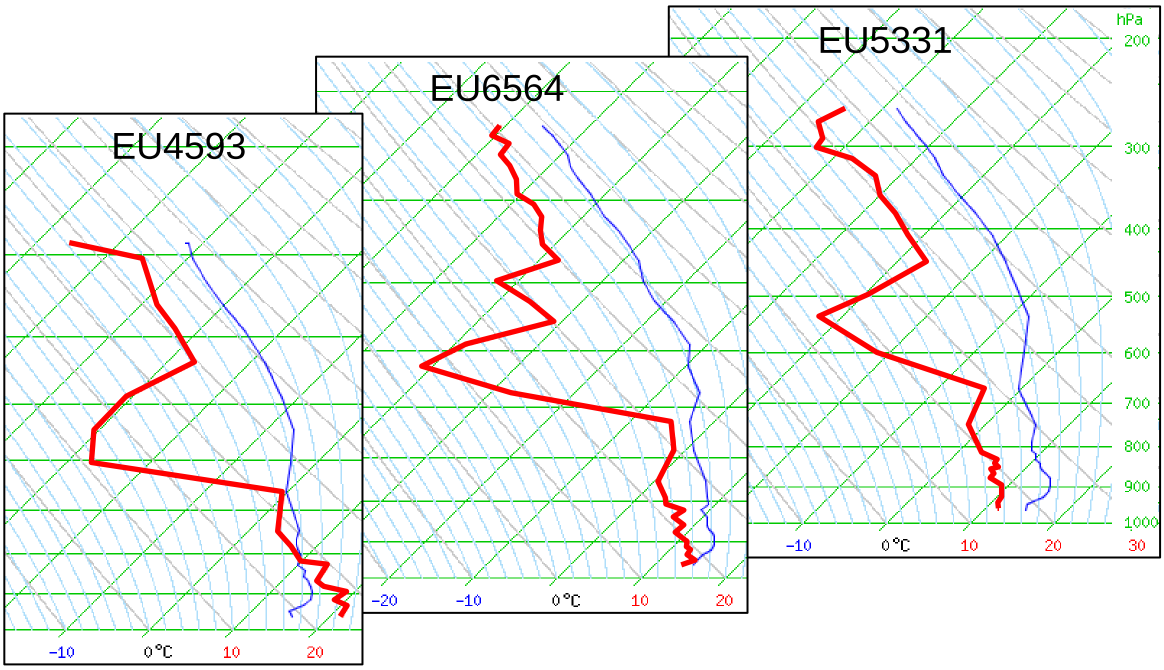

Fig. 9: T-LogP diagrams with temperature (blue / thin) and dew/ frost point (red / thick) over Munich on the 2nd of September 2008 at around 05:30 UTC measured by the three humidity aircraft.

3.2.2 Monthly Profile Statistics

The forecast results of a numeric model are normally checked against the later on acquired measurements. Vice versa, the short term forecasts as being a statistically good estimate for the true atmosphere can be used as a reference for the measurements. This method is generally well proven.

EUCOS operationally monitors observational data from ground-based observing systems, which include the data from E-AMDAR aircraft. In order to assess the accuracy of those data a comparison against short-term forecasts of DWD's regional model COSMO-EU is currently employed. Furthermore EUCOS asked the data assimilation sections of member states via its "EUCOS Scientific Advisory Team" to start a monitoring of E-AMDAR humidity data. However, for the time being longer-term comparisons of those humidity observations and NWP results are only available from COSMO-EU. Therefore the quality monitoring results shown in this document are based on COSMO-EU solely. An extended monitoring against further NWP models is desired.

An exemplary set of vertical profile plots of the instrument's biases and root mean square errors (RMSE) as mean monthly values is shown in Fig. 10. As being typically the biases are sometimes in the order of up to 20 % rel. humidity to the dry side. Nearly always the root mean square values are found to be at about 20 % rel. humidity. One part of this large amount is due to the limited size of the mantissa in the data transfer from air to ground resulting in a contribution of 1 to 10 % (see 2.3.2).

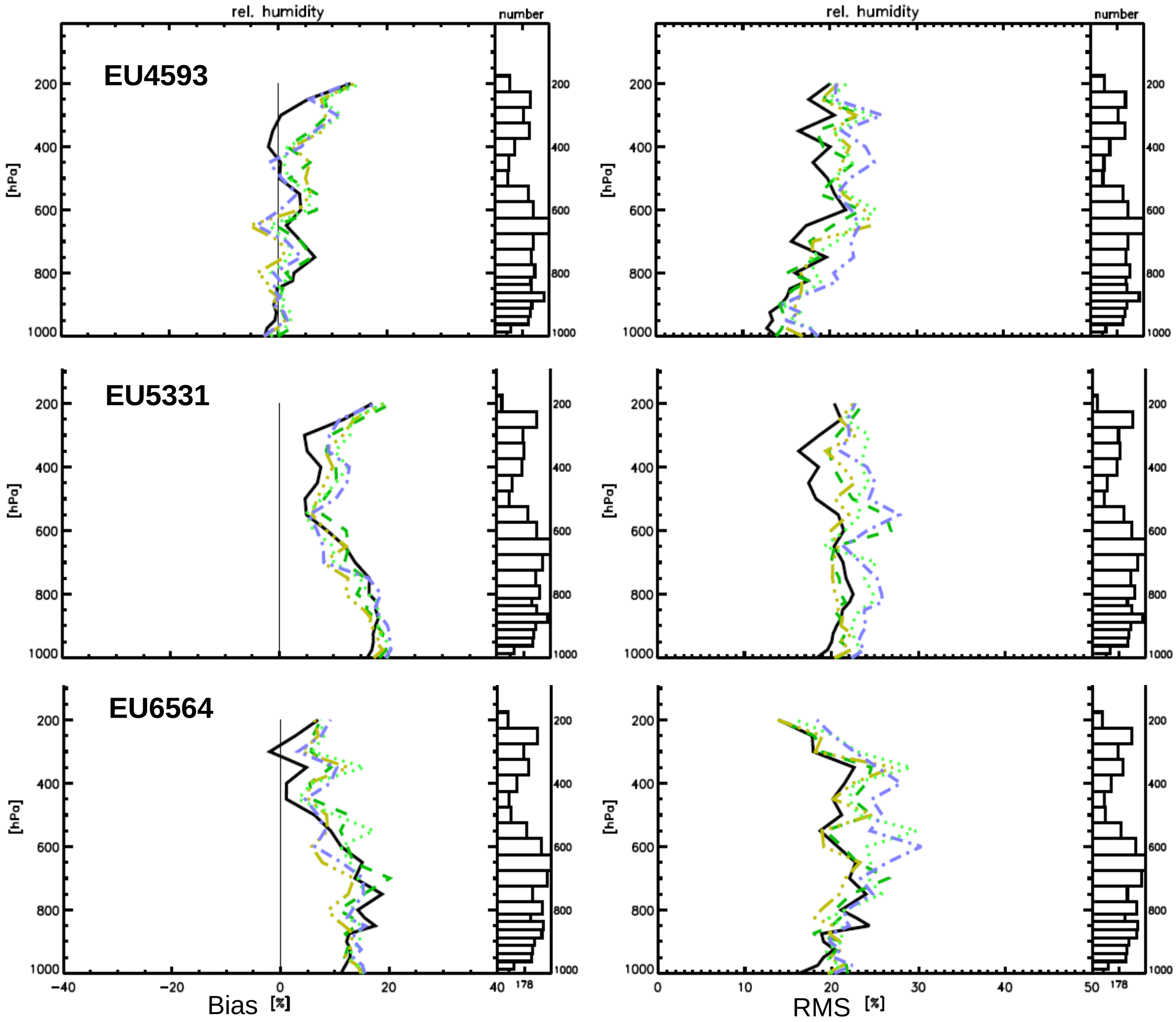

Fig. 10: Comparison of the aircraft's relative humidity data (example of July 2008) against the COSMO-EU results (rel. humidity) of always 12:00 UTC.
The black curves denote the reference to the model's initialization status. All other curves refer to the longer forecast lead times being of lower interest here. The histograms on the right side of each diagram give the number of observations involved. The diagrams on the left side give the mean biases (here: model minus observation).
The diagrams on the right side give the root mean square of the deviations.

3.2.3 Time Series Statistics

Fig. 11 shows plots about the daily number of observations. The Airbus A319 aircraft of Lufthansa are able to do an average of about 500 samples per day. The breaks in the histograms are either due to aircraft maintenances or due to an outage in the model's data archiving from Sept. to Nov. 2008. There is a remarkable step in the average level of observations in April 2008. Because of another modification in the optimizer system E-ADOS the amount of activated flight phases could be increased significantly. From averagely 250 observations it went up to 500. Since the end of 2008 the amount of quality messages denoting a reduced instrument's operation must have increased. The MetConcentrator as the software on ground rejects all humidity values not being marked with the quality indication zero. This can be seen as some more little gaps in the histograms.

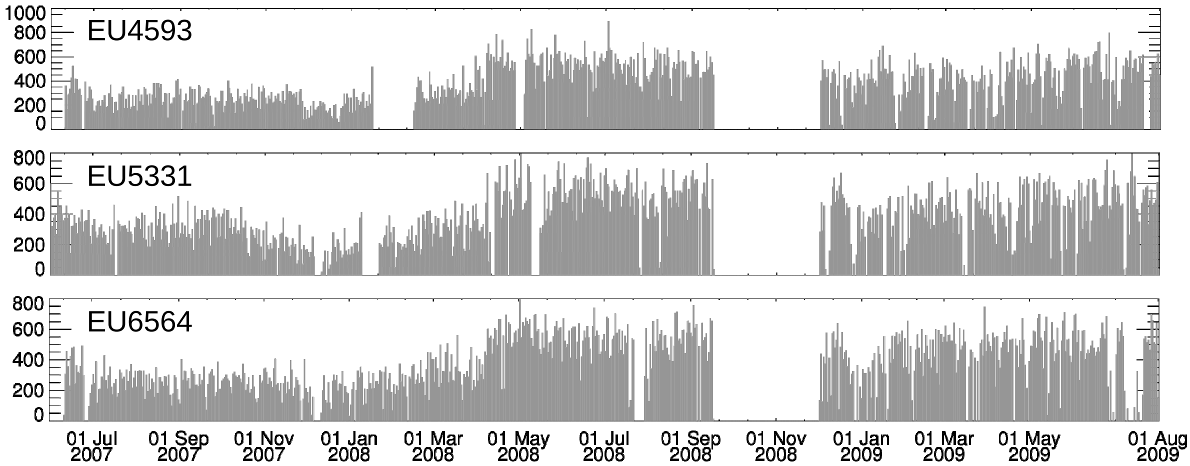

Fig. 11: Time series of the daily amount of observations of each aircraft.

In Fig. 12 the deviation statistics of the relative humidity are plotted as time series of their daily means. The time period reaches from June 2007 to July 2009. The dotted as well as the dashed lines denote daily values of the biases and the RMSEs respectively. The solid lines show the corresponding moving averages of one month.

Over the years the biases (dotted) are drifting between zero and partly more than 20 % rel. humidity. Parts of this drift may be caused by seasonal tendencies in the model. Its finite accuracy may also do a contribution. But note that the prevailing part of the model's initialization is done by the radiosondes having no systematic offsets at least in the lower troposphere. The manufacturer found out that the Laser would have had to be burned in for several days or weeks before the calibration in the factory. This had not been done with the units once delivered in 2006. The missing burn-in leads to a dry offset. The drifting part of the WVSS-II's deviations is probably due to a lack in the stability of the electronics. For the unit EU4593 the deviation increased to 50 % from March to May 2009.

The root mean square values (dashed) are always more or less around the level of 20 % rel. humidity. In addition to the instrument's and the model's error contributions the limited numeral coding for the air-to-ground transmission has its effect here (see 2.3.2).

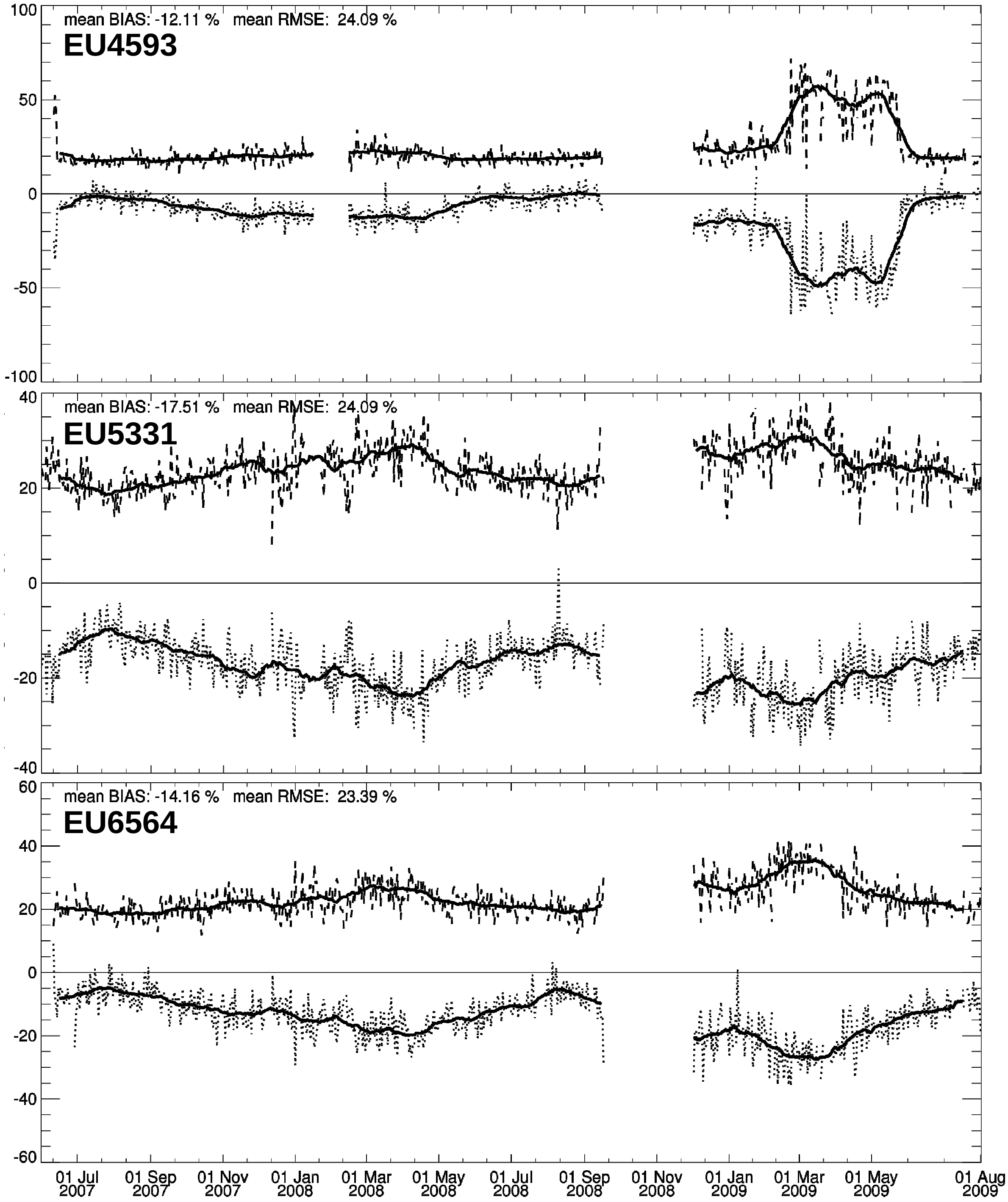

Fig. 12: Time series of E-AMDAR aircraft's daily mean relative humidity bias (obs. - model) and RMSE, all referring to COSMO-EU short term forecasts,
dotted: Relative humidity bias (% rel. hum.),
dashed: RMSE (% rel. hum.),
solid: Moving averages (1 month).

3.3 Conclusions

First of all, it has to be said that there was always an excellent cooperation with the airline Lufthansa. During all the steps in the installation process as well as in the flight operation the flexibility and the responsiveness of this partner has been absolutely helpful.

Since June 2007 the instruments worked without any dead losses. The only breaks on the operational side have been by the routine aircraft maintenances. The technical performance of the WVSS-II generation 2006 has some limits in the long term signal stability leading to a lack in the relative accuracy of definitely more than 10 %. In addition, there is a detection limit of about 0.04 g/kg (70 ppmv) under ground pressure conditions which restricts the usability of the measurements to the lower half of the troposphere.

The results of the E-AMDAR humidity trial are very similar to those of the 25 units being operated on the UPS fleet in the USA. As a consequence of the US trial a new generation of the WVSS-II is under development since 2007. The laboratory tests of 2008 and 2009 give good hope that the stability as well as the detection limit are significantly improved.

4 Prospectus

The 2009 generation of the WVSS-II now being integrated on the 25 aircraft of the UPS fleet and on another 31 aircraft of Southwest Airlines should be seen as one of several steps in the development of a standard on-board humidity sensor system. The experience of the DWD with the WVSS-II's aircraft integration as well as the knowledge about the aerodynamics and thermodynamics of air data sampling leads to some ideas to be beared in mind for future generations (see 4.1.2 and 4.1.3).

Besides of the instrument's potential of improvements some aspects in the data flow to the NMSs will have to be considered (see 4.1.1). And last but not least, the ex-works configuration of aircraft has to be kept in mind (see 4.2).

4.1 Suggestions for the next System Improvement Steps

4.1.1 The Data Flow to the National Meteorological Service

ARINC 620

The on-board software was modified in conformity with the ARINC 620 standard (see AMDAR Reference Manual). This means the additional integration of the water vapour mixing ratio value plus a quality parameter "***Q***" into the data transfer to the ground. In the coding of this transfer one digit "***p***" for the decimal power is reserved. For the decimal mantissa only 2 digits "***nn***" are allowed by the ARINC standard. The format "nnpQ" leads to a relative uncertainty between 1 % and 10 %. As soon as possible, the ARINC 620 standard should be modified at that point. Two alternatives could be chosen.

1) At least one decimal digit has to be added. Then, 5 characters (nnnpQ) in the data link to the ground are occupied. A relative coding accuracy between 0.1 % and 1 % is achieved.

or

2) The Base-40 principle has to be applied as it has been done on the UPS aircraft in the USA. The complete set of alphanumeric characters is used for "nn" needing no additional space for characters. On the data link the humidity value then is not directly readable by maintenance personnel. In the floating point version a relative coding accuracy between 0.06 % and 2.5 % is achieved. Another possibility would be to make the coding by use of the three digits "nnp" completely as a fixed-point number without power digit. This would lead to reduced relative accuracy, if the smallest detectable value gets near to 1. The minimum and maximum of the humidity range to be resolved would have to be chosen in advance.

The decision about the number of digits and/ or the kind of numeral system (base 10 or 40) will have to be discussed in the AMDAR committees and later on at the AEEC.

AMDAR Template

The AMDAR BUFR template actually applied (recommendation to be seen in the AMDAR Reference Manual) is just covering the range of values measurable by the instruments being in use at the moment. The length of the binary number is 14 Bit where the number 1 represents 0.01 g/kg. But in the very next years the sensors may provide detection limits being one or two decades lower than today. A water vapour mass mixing ratio of 0.001 g/kg or even lower is in the perspective of the very next system generations. Hence, the new template should provide 23 Bit with a resolution of 10^{-5} g/kg.

4.1.2 Installation Technology

Mounting the SEB as being done with an Avionics unit

The actual layout of the hose fittings is ambiguous. The only coding being applicable is the labelling. From time to time during the installation this could lead to failures because of mistakes. An approach which would preclude this problem is the SEB to be mounted on a tray (see Fig. 13). All connections, such as cables as well as hose fittings are integrated in the back plane. For any maintenance the exchange of an SEB is done within seconds. No loose screws are to be fumbled with.

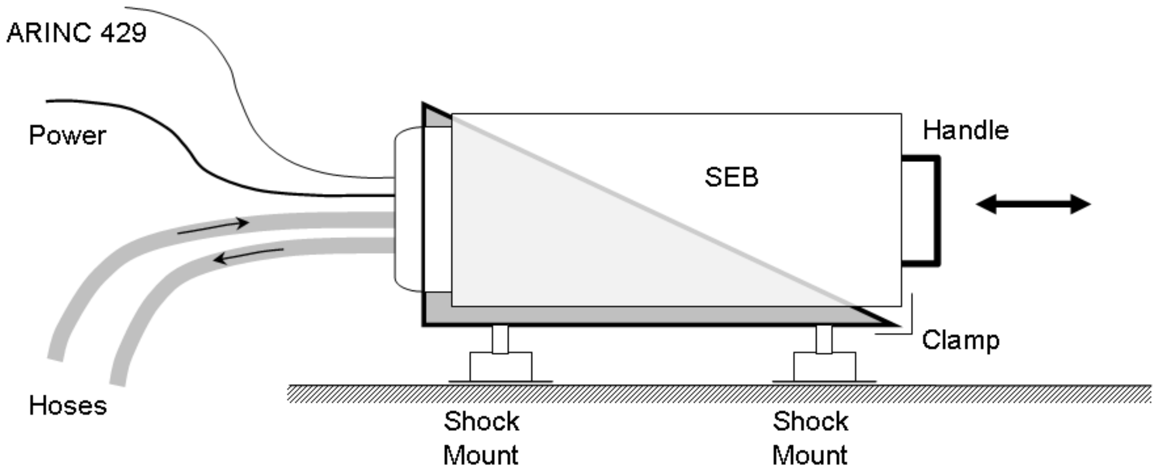

Fig. 13: Schematic view of the System Electronics Box (SEB) mounted on a tray. The use of shock mounts depends on the sensibility of the SEB's internal parts.

Power supply

Most of the airliners all over the world have an on-board power grid with 115 VAC, 400 Hz. Besides of a 28 VDC version the WVSS-II should also be offered as an AC version, ideally for all: 115 V/ 230 V, 50 Hz/ 60 Hz/ 400 Hz. The integration of the 28 VDC version always needs an extra power unit together with cables having a larger wire size on the output side.

4.1.3 Physics of the Instrument

Two or more different absorption paths

For example the use of two absorption chambers, mounted either parallel or in series, with different lengths, would considerably enlarge the range of use (0.04 g/kg to around 20 g/kg). The present measurement range of 3 decades could be increased to the size of 5 or more, which better corresponds to the real troposphere (0.001 to 20 g/kg).

This suggestion would only get its relevance, if the 2f absorption method using just one path length really does not exceed the range of 3 decades.

The intake point to be beyond the aircraft skin's boundary layer

The current inlet unit takes the air to be measured from the part of the flow which is in contact with the aircraft skin. Under very cold conditions (below - 30 °C) the memory effect may considerably distort the prevailing water vapour pressure. Up to now, the WVSS-II test results cannot at all serve as any proof for that kind of phenomenon. For the part of the troposphere being most relevant for the synoptic data collection the actual kind of air sampling can be considered as to be able to yield a data quality being comparable to that of the radiosondes. Future applications for the upper troposphere and lower stratosphere as well as for the oversaturated layers with their potential for contrail cirrus clouds may lead to a stronger need to take any possible memory effect into account.

This effect, which is difficult to calculate, could be completely excluded, if the air inlet into the hose system is located above the boundary layer (see Fig. 14). The aspects are as follows

- (+) the guaranteed exclusion of the memory effect and contamination,
- (-) the necessity of de-icing for flight safety reasons (300 to 500 W),
- (-) inlet position to be in the forward part of the aircraft's body.

The air inlet could be for example the housing of a total air temperature sensor (TAT). It is flush mounted with an extent of around 9 cm (see Fig. 15). By this housing a separation of the water and ice particles is performed in the same amount as it is done by the Air Sampler. The temperature measuring element inside the TAT housing could be replaced by an inlet/outlet unit to be connected via hoses with the SEB. The mounting location would have to be chosen according to the same rules applying to any similar standard TAT unit.

The use of the impact pressure

This could be achieved, for example with a TAT housing as well. The results at Mach 0.8 would be

- an adiabatic temperature increase by up to 30 K (6 K at Mach 0.3)
  - (+) prospect of no precautions against internal condensation and icing required. (The heating of the sampling tube may be no longer necessary. Hence, there won't be any doubts about the homogeneity of the water vapour density in the sampling tube.)
  - (-) maximum internal air temperature of + 60 °C at
    - 1000 hPa (low flight level)
    - ambient temperature at + 45 °C

- pressure increase by up to 250 hPa (70 hPa at Mach 0.3 and altitude 1000 hPa)
  - (+) increased sensitivity of the measurement method in the upper part of the troposphere,
  - (+) less strain on the system resulting from the pressure difference between the cabin and the air sampling system,
  - (-) slightly increased dew point, which makes it necessary to limit the thermal conduction of the air flow into the internal walls on its way to the measuring unit (a problem which is technically solvable).

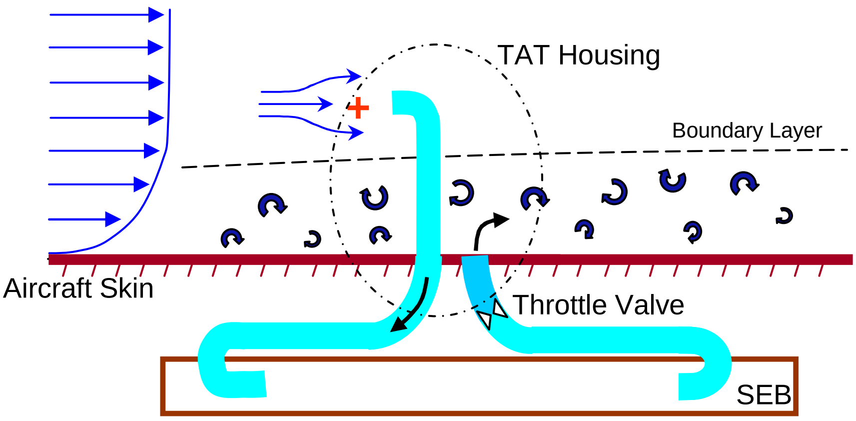

Fig. 14: Schematic view of the sample air flow, if the intake is beyond the boundary layer and if the impact pressure is used.

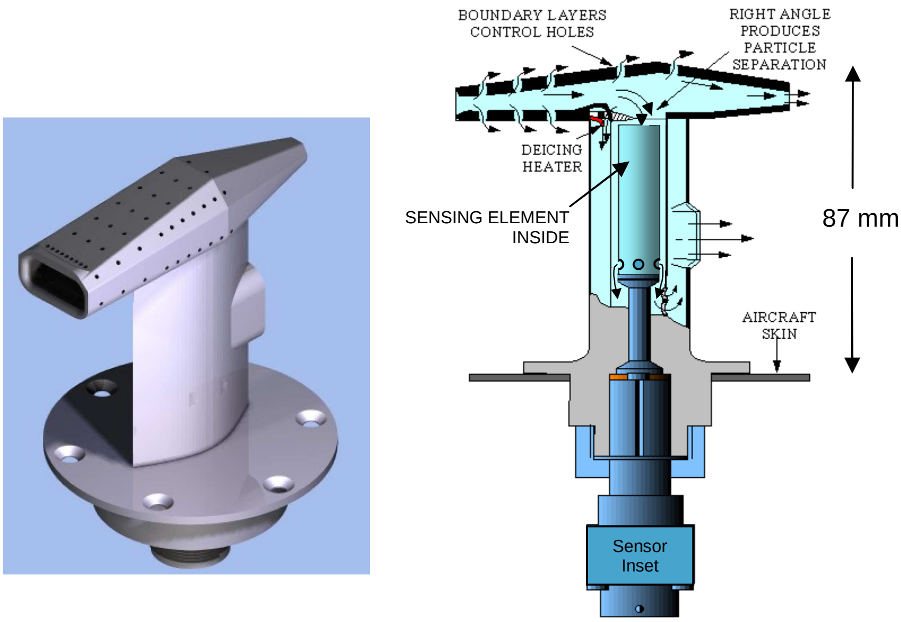

Fig. 15: The total temperature (TAT) sensor housing Rosemount 102 BX or BW (©Rosemount Aerospace Inc.). Instead of the sensor inset an appropriate intake and outlet unit could be applied for the connection to the SEB.

4.2 Outlook on an Ex-Works Aircraft Configuration for AMDAR plus Humidity

4.2.1 AMDAR On-Board Software

Nowadays the AMDAR on-board software corresponding to ARINC 620 or AAA has to be extra adapted for every new generation of the air-to-ground communications system. This is independent of any occasionally added humidity option. For each avionics modification touching the communications part an expensive AMDAR software integration has to be newly done.

In the long term it will be far cheaper to make an ex-works integration of the AMDAR on-board software including the handling of the humidity values. For the whole fleet of the manufacturer there would be the advantage of

- one-of expense for software installation
- one-of expense for later software modifications
- worldwide unique functionality.

The activation of the humidity operation would only be a simple switch to be set in a configuration table, not more. There would be no extra certification.

4.2.2 Installation on the Aircraft

Nowadays the mechanical and electrical integration of the humidity sensors on aircraft consists of new construction work for each aircraft type and subtype. This always turns out to be expensive. An alternative would be to have at every aircraft a pre-selected location with

- mechanical interfaces for system components,
- reserved space,
- reserved wiring paths and interfaces for power and data.

The pre-selection of the humidity sensor's location has another extremely important advantage:

- the manufacturer has the most complete information about the aerodynamic conditions at each point of the aircraft. This guarantees for three things:
  - a definable thickness limit of the aircraft skin's boundary layer,
  - a pressure perturbation as positive as possible with reference to the static pressure,
  - a well defined flow direction for the orientation of the intake housing.

The items listed above lead to minimized engineering expenses for the humidity sensor's aircraft integration. For each airline generally, the certification and the realization of the sensor installation gets far easier.

5 References

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