WORLD METEOROLOGICAL ORGANIZATION

COMMISSION FOR INSTRUMENTS AND METHODS OF OBSERVATION

TASK TEAM ON AIRCRAFT-BASED OBSERVATIONS (TT-AO)

Geneva, Switzerland, 18-20 February 2014

CIMO/TT-AO/Doc. 3.3

(18.02.2014)

ITEM: 3.3

Original: ENGLISH ONLY

AMDAR AND WATER VAPOUR MEASUREMENT (WVM) INTEGRATION INTO EXISTING AVIONICS AND AIRFRAMES

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Summary and purpose of document

On overview is given about the physical and technical rules as well as about the possibilities of infrastructures into which the aircraft-based water vapor measurement can be integrated.
The reader gets an insight into the different possibilities of scenarios to be dealt with, if an aircraft-based meteorological observation system, preferably including water vapor measurement, is planned to be realized on existing airframes and their avionics.

ACTION PROPOSED

The meeting is invited to note and discuss the information and consider the recommendations made in the document

References:

1. A-SIP
2. AOSFRS
3. ARINC 620
4. AAA
5. ARINC 429
6. DO-160

AMDAR AND WATER VAPOUR MEASUREMENT (WVM) INTEGRATION INTO EXISTING AVIONICS AND AIRFRAMES

Contents

1. Background

Since the eighties of the last century airlines began to equip their fleets with systems enabling the aircraft to transmit flight operational data to their headquarters via a worldwide communication network. One component of this data flow consists of meteorological data like pressure, temperature and wind. Specific software puts these communication systems in the ability to transmit those data to an NMHS or directly into the GTS. This kind of in-situ measurement method yields an effective worldwide coverage with vertical profiles and en-route data series.

The assimilation processes of the NWP models are well attuned on AMDAR. To catch up with the parameter range of radiosondes AMDAR has to be completed with water vapour measurement (WVM). Then, these instrument platforms will be an economic and efficient complementation of the radiosondes. In some places and time slots the comparatively expensive radiosonde launches could be conserved.

Up to now, AMDAR just benefits of an instrumentation already existing on each aircraft because of immediate flight operational reasons. The equipment of the aircraft with humidity sensors needs to become a standard component. But the first step is to realize the usability of humidity measurements. Therefore it is necessary to integrate the measurement systems on already existing samples of aircraft.

The development of the Aircraft-based Observation Programme (ABOP) is outlined in the document “ABOP Strategy and Implementation Plan” (A-SIP).

2. General Technical Requirements for WVM implementation

2.1. Physical requirements for WVM

A universal specification for inlet and outlet device has to be created. It has to cover the features outlined in the following sub-items.

2.1.1. Location and Orientation on the Airframe

A set of rules has to be kept to determine the best or even the only possible zones on the fuselage for WVM inlet’s location:

- The upstream path of the sampling air over the fuselage
  - shall be as short as possible,
  - shall not pass any critical parts of the pressurized cabin, such as doors, hinged windows or lids, gear box, etc., which could tend to have small leaks.
- The depth of the fuselage’s boundary layer shall either
  - be as small as possible

  or far better
  - be smaller than the intake’s distance to the fuselage.
- The position shall be outside of the spray range of rolling landing gear.
- The inclination of the pipe ends being the intake and outlet orifices should be orientated downwards to avoid the entering of rainwater during parking of the aircraft.

2.1.2. Aerodynamic and Thermodynamic Features of the Instrument Itself

- The orientation of the intake shall be well aligned with the local airflow direction. This direction should have a limited variation over the different speeds and aerodynamic configurations the aircraft can fly.

- The impact process shall always lead to an increased spread between temperature and dew point or frost point of the sampled air. This effect of adiabatic heating caused by the air impact should not be eluded.
- The inner wall surfaces of the impact tubes shall be heated at least to the value of the total temperature of the sampled air. This precaution makes sense because any internal condensation or sublimation process gets avoided.
- In optical measurement methods in case of heating of the optical chamber this should be done cautious to avoid inhomogeneities across the absorption or scattering path.

2.1.3. Contact Surfaces for the Sampled Air

The solid surfaces the sampled air gets in contact to need to be hydrophobic. The inner surfaces of pipes or hoses shall have the most neutral behaviour in contact to water vapour as well as to liquid or solid water. These surfaces have to be non-hygroscopic and they shall be free of condensation nuclei.

2.2. Aeronautical Requirements

2.2.1. Elecrical Aircraft Integration

- The interface to the carrier system’s power supply has to be compliant to international standards for commercial aircraft, preferably 115 VAC, 400 Hz.
- If the impact of supercooled droplets is expected to be too intense, the intake units will have to be heatable against the accretion of ice.
- The data interface has to comply with aeronautical standards (e.g. ARINC 429).

2.2.2. Mechanical aircraft integration

For maintenance reasons the measurement system’s mounting has to comply with the aviation standards for avionics components (tray for fast assembly and disassembly).

2.2.3. Covering tools

If possible, the instrument has to be integrated in the standard procedures for aircraft care on airports. Covering caps with appropriate vanes are to be taken into the aircraft’s standard equipment.

2.2.4. Maintenance

The instrument’s maintenance cycles have to match with those of the aircraft.

3. Data Infrastructure of Aircraft-based Observations including WVM

Table 1 gives an overview of already existing as well as theoretically possible utilisation combinations between standard aircraft equipment and added system components like WVM systems.

The possible options of architectures of aircraft observation systems are numbered on the left side of the table. The columns split into the appropriate avionics systems or measurement parameters to be taken into account. The separation of the header in two rows holds for the view to the obligate information sources (primary data) and the parameters finally sent to the ground.

The upper part of the table's content is the group of already existing systems, such as AMDAR, TAMDAR, Mode S or ADS-B or -C. The lower part gives a view on other thinkable constellations either based on the given communication system or by adding such a unit on the aircraft.

	Primary Data					Ground Speed Vector	Heading	Impact Pressure	Static Pressure	Total Temperature			WVM e. g. m or Rel. H. or ρ_w or T_d etc.	Vertical Acceleration	
	Final Data (transmitted)	Communication System	Identification	Date and Time	Position			Indicated Airspeed	Pressure Altitude	Static Temperature	Mach No.	Wind		Turbulence	Icing
Existing:															
1	AMDAR convent.	O	O, T	O, T	O, T	O	O	O	O, T	O, T		O, T		Ad, T **	O, T *
2	AMDAR + WVM	O	O, T	O, T	O, T	O	O	O	O, T	O, T		O, T	Ad, T	Ad, T **	O, T *
3	TAMDAR	Ad	Ad, T	Ad, T	Ad, T	Ad	O	Ad	Ad, T	Ad, T		Ad, T	Ad, T	Ad, T	Ad, T
4	Mode S	O	O, T	O, T	O, T	O, T	O, T	O, T	O, T		O, T				
5	ADS-B/ -C	O	O, T	O, T	O, T	O, T	O, T	O, T	O, T		O, T				
Thinkable options:															
6	AMDAR + WVM + Icing	O	O, T	O, T	O, T	O	O	O	O, T	O, T	O	O, T	Ad, T	Ad, T **	Ad, T
7	Added Communication Provider	Ad	O, T	O, T	O, T	O	O	O	O, T	O, T		O, T			
		Ad	O, T	O, T	O, T	O	O	O	O, T	O, T		O, T	Ad, T	Ad, T	O, T * or Ad, T

Table 1: The possibilities of system component combinations for aircraft-based observations (commercial aircraft) including WVM.

Legend:

O	System unit/ instrument is **o**n-board by default
Ad	System unit/ instrument is **ad**ded to the aircraft
T	Parameter **t**ransmitted to ground system
*	If instrument is on-board and data-link software corresponds to latest standards (2012 or later)
**	If corresponding software is installable on the existing avionics
m, RH, ρ_w, T_d	Mixing ratio, relative humidity, absolute humidity or dew point/ frost point

3.1. Use of the Airline's own bidirectional Communication System

This chapter refers to all those aircraft based observation systems using a communication system having been already on-board initially for other flight operational purposes.

The acronym "AMDAR" is taken for the use of the already existing aircraft communication system and the aircraft's own instrumentation. This infrastructure is generally called the "**A**ircraft **M**eteorological **Da**ta **R**elay". In the USA from the beginning it has the name MDCRS (**M**eteorological **D**ata **C**ollection and **R**eporting **S**ystem).

3.1.1. Data Infrastructure (conventional AMDAR)

In the first step of the AMDAR job it is necessary for the flight management system to have access to the primary data

- static pressure,
- impact pressure,
- total temperature,
- heading (true or at least magnetic),
- ground speed vector,
- vertical acceleration (for turbulence),
- ice detection
  - > partly available as standard aircraft instrument
  - > or thinkable as instrument separately added for the meteorologic use (see line 5 in Table 1).

These data, except for the separately added ice detection, are available as well calibrated values for the flight management system on each commercial aircraft. In Table 1 these parameters are marked at least with the icon "O". The parameters finally utilized such as

- aircraft identification,
- date and time,
- position,
- pressure altitude,
- static temperature,
- wind,
- turbulence (depending on specific software implementation on avionics),
- icing (depending on the presence of an ice detector)

are to be downlinked by the aircraft's communication unit (CU) being the avionic's part for managing ACARS (**A**ircraft **C**ommunications **A**ddressing and **R**eporting **S**ystem). In Table 1 these parameters are marked with the icon "O, T". The software on the CU has to follow the standards AAA, AOSFRS or ARINC 620.

Finally, the second step of the AMDAR process takes place, where
- either the communication service provider like ARINC or SITA
- or the airline receiving the downlink

detours the meteorological data to the NMHS or the corresponding regional program facility.

3.1.2. Implementation of AMDAR plus WVM on Aircraft

In Table 1 in the column “WVM” and the row no. 2 “AMDAR + WVM” the icon “Ad, T” occurs. The addition of a water vapour measurement system and the corresponding data transmission to the ground consist of some consequences for the aircraft:

a) Hardware to be added in case of WVM integration

The humidity instrument itself has to be physically added to the aircraft. All other sensor systems used for the meteorological observation job belong to the standard aircraft equipment. The modifications to be done on the airframe then consist of

- Integration of the unit for intake and outlet of the sample air in an appropriate position (see 2.1) on the fuselage. At that location one or two holes have to be drilled and doubler plates as well as blind plates have to be applied.
  The structural strength has to be attested. Weight and Balance has to be adapted.
- Integration of the measurement system unit in the vicinity of the intake unit. An empty space has to be available.
  The structural strength has to be attested. Weight and Balance has to be adapted.
- The wiring (cables, connectors, circuit breakers, etc.) for power supply has to be installed. Appropriately the power balance of the aircraft has to be adapted. EMI tests for the prototype integration are necessary.
- The instrument itself has to comply with the aviation standard DO-160. It consists of a large set of prototype test processes.

b) Capabilities of the Avionics Hardware

The CU or another avionics unit in the data stream part before it has to provide an interface for the input of the humidity data. Standards preferably like ARINC 429 are to be covered normally.

c) Software

The AMDAR software on the CU has to be adapted to

- the latest standard (AAA, AOSFRS or ARINC 620) ensuring the appropriate sampling and coding of all the downlinked meteorological data.

and in case of the addition of WVM

- reading of the humidity instrument’s interface (e.g. ARINC 429 as being used on the system type WVSS-II of SpectraSensors Inc.)
- adding the data into the downlinked stream.

Depending on the capacity of the CU’s processor and memory the performance of the implemented software may differ from that requested by the corresponding standards (AAA, AOSFRS or ARINC 620).

It depends on the architecture of the avionics, wether this software modification needs an airworthiness certification.

d) Engineering and Certification

At least all the aircraft modifications concerning

- the airframe’s and the mounting’s structure,

- the weight and balance,
- the wiring,
- the power balance,
- the aerodynamics,
- the icing risk

need an engineering process to be finished by an airworthiness certification. In the case that the same type of aircraft is envisaged to be used also on other fleets, an STC (Supplemental Type Certificate) is advisable. An STC has to be obtained at the aeronautical authority (FAA, EASA, CASA, JCAB, CAAC, etc) by the aircraft holder, the airline. The STC holds for the combination of a specific aircraft type or type group with one well defined type of instrument. Then the engineering work for this constellation has to be done only once. But each switch-over to another aircraft type or to a modification of the instrument leads to additional engineering work for the review or even the complete renewal of the STC.

The instrument's manufacturer and WMO are able to support NMHSs with information about available STCs. However, the owner of this certificate is the aircraft holder who applied for it.

e) Contracts and Administration

The NMHS or the corresponding commissioner needs to make a contract with the appropriate airline. This partner has to embark on operating especially modified aircraft. The NMHS has to confide in the airline to keep these aircraft as long as possible within their fleet. Normally these aircraft will have to be restored before they get sorted out of the fleet.

3.2. Use of Unidirectional Communication Systems Working for Air Traffic Control

During the last years a new group of communication systems is finding its way into the aviation. They are sending the current flight data either triggered by a Radar (Mode S) or in a Squitter mode (ADS-B) in fixed sequences. As outlined in Table 1 in the rows 4 and 5 these data consist of identification, time and position but also of

- pressure altitude,
- vectors of the groundspeed and the true airspeed, giving the basis for the wind calculation to be done on ground,
- and Mach number, being applicable for the calculation back to the temperature to be done on ground.

However, these communication systems will not be able to transmit additional data like WVM results. This example of aircraft-based observation systems is mentioned here just for the sake of completeness.

3.3. Use of a Specifically Added Communication System for an Aircraft-based Observation System

In an alternate scenario another communication network is used. Either ACARS does not exist on the corresponding airline's fleet, or it is studiously avoided. The job of communication with the ground is done by a purposefully added system. Not only this system but also instruments beyond just the humidity sensor can be additionally integrated in the aircraft. The composition of system components could be a mixture of the standard aircraft equipment and added units.

Anyhow, for all the additions the airline has to do all engineering and testing for the appropriate airworthiness certification. Corresponding to AMDAR plus humidity this also ends up in applications for STCs.

3.3.1. The WVM System TAMDAR

On the aircraft several system components are to be integrated:

- Antennas for GPS and for the communication via IRIDIUM or a frequency band supported by another satellite system,
- Measurement unit with its air sampling probe.

Except for the heading signal all other final data are measured and/or generated by the system itself (see “Ad, T” in line 3). However, TAMDAR inevitably relies on the full access to the aircraft’s data buses not only for the heading signal. At least for the beginning of operation on the carrying aircraft TAMDAR needs to be calibrated by the reference of the aircraft’s own air data, such as pressure altitude, impact pressure and static temperature. The relative humidity is measured by capacitor elements operated inside the probe. The icing process is detected at an extra sensing location on the probe’s leading edge. All the parameters finally calculated to the values of the ambient undisturbed (“static”) conditions are sent via the satellite network to the processing facility of the provider Airdat / Panasonic. There the quality control is done by use of numerical models. Marked with corresponding quality flags the data are sent exclusively to the NMHS or regional program being articled to the provider.

The contractual work of the NMHS or regional project just has to be done with Airdat / Panasonic. The payments normally are coupled to the amount of data. It is up to each NMHS or regional project to decide, if this kind of business model is easier or cheaper to handle than the solution like AMDAR + WVM (line 2 in Table **1**). All the contractual work and the engineering concerning the aircraft modifications is done between the provider and the airline. The range of their deal also consists of an additional benefit for the airline. They are profiting of the installed communication system’s functionalities.

3.3.2. Other Solutions with Added Comunication Systems

It is thinkable to do an approach in the following way:

- Add a separate communication system for the data transfer.
- Use
  > of the already existing atmospheric aircraft instrumentation
  or
  > of added sensor systems together with the aircraft’s own equipment.

The added communication system would have to get access to identification, date / time, navigation, translation and attitude data, the air data and the signals of the eventually added systems like WVM instrument. If necessary, all calculation processes for wind and turbulence could be done on that system.

A possibility for this kind of approach is e.g. given by using a communication system called AFIRS, a product of the company FLYHT Aerospace Solutions Ltd.. Presumably also other providers are offering communication systems with similar performance for meteorological applications.

4. The Pathways for Capturing Commercial Aircraft Fleets for Retrofitting of AMDAR Aircraft with WVM

This activity and its tasks encompasses the process of AMDAR Programme working together with partner airlines to advance the process of retrofitting of existing AMDAR aircraft platforms with a WVM.

4.1. Standardisation

Ensure that AMDAR including humidity is standardised within existing aviation communication frameworks. The AMDAR on-board software shall follow international standards.

4.2. Advertising

Write generic letter from WMO/CBS to existing AMDAR airlines to request participation in the WVM project.

4.3. Consideration of Future Aircraft Types

In future construction material of the aircraft planned to be purchased by the airlines may even change to carbon fibre. Consequences in STCs and/ or in the WVM system's concept have to be envisaged.

4.4. Survey Operational Programmes

The airline's flight profiles of different aircraft types are to be chosen appropriately for equipping with WVM systems.

4.5. Target Aircraft

Determine target aircraft models and fleets for retrofit. The selection of platforms should be done regarding the following rules

- Aircraft Types
  - flight ranges to achieve highest density of profiles,
  - high climb rates,
  - suitable measurement system for True Heading,
- Fleets
  - sufficiently large number of appropriate aircraft,
  - sufficiently large period of aircraft use,
  - communication system to be adaptable to aircraft-based observations including WVM data,
- Airlines
  - The covered regions should match the areas being envisaged for the measurements,
  - The cooperativeness of the airline is extremely important.

4.6. Coordination of Airworthiness Certifications

Coordinate the attainment of supplemental type certificates (STCs):

- Develop a list of STCs to be attained based on target aircraft models
- Develop a process for streamlining initiation of STCs.

- Achieve grants given by CASA, EASA, FAA, JCAB.