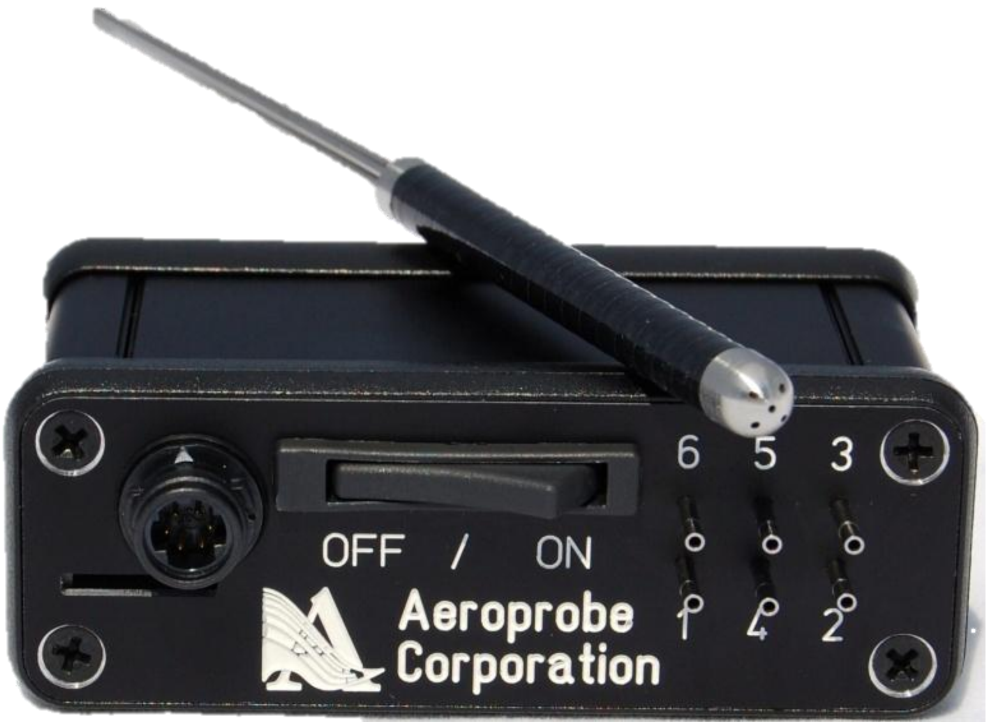
On-The-Fly! Air Data System



User's Manual

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Section 1: Introduction & Overview

Introduction

The *On-The-Fly!* Air Data System (*OTF!* ADS) is a complete solution for acquisition and processing of air flow data at an unprecedented size and scale. This system is specifically designed for use on lightweight UAVs and other small, low power systems.

The *OTF!* consists of two primary components: an Air Data Probe and an Air Data Computer. The air data probe is a Multi-Hole Probe (MHP) in a 5-hole + static ring configuration. This efficient design allows for calculation of the complete airflow vector without using a bulky air data boom. *OTF!* improves on traditional air data solutions by eliminating pitch and yaw vanes, whose moving parts and inertial effects introduce inaccuracy, increase weight, and lengthen response time.

The air data computer is an extremely compact microprocessor-based embedded system consisting of hardware and software to calculate flow field data in real time. The system is lightweight, draws little power and is well suited for small UAV applications.

Air Data System Key Features

Air Data Probe

- 5-Hole Probe with Static Ring
- Multiple Configurations and Lengths Available
- Construction Material: Stainless Steel or Carbon Fiber & Stainless Steel Hybrid

Air Data Computer

- Complete Airflow Vector Calculation: Velocity, Angle of Attack, Angle of Sideslip, and Altitude
- Air data reporting over standard RS-232 link
- Reconfigurable Calibrations: Use any air data computer with any air data probe
- MicroSD™ Card to log data and provide calibration visibility
- Auto-zero functionality to correct offset errors

General Specifications

System	
Minimum Measurable Velocity *(At Sea Level)*	8 m/s
Maximum Measurable Velocity (*Depending on Model, At Sea Level)*	45 m/s (100 mph, 87 knots) 63 m/s (140 mph, 122 knots)
Velocity Resolution (*Depending on Model)*	0.02 m/s 0.03 m/s
Velocity Error (Max)	*See Graph, Section 1.4*
Flow Angle Ranges	±20° Angle of Attack ±20° Angle of Sideslip
Flow Angle Resolution	0.01°
Flow Angle Error (Max)	*See Graph, Section 1.4*
Altitude, Max (*Relative to Sea Level)*	1600m (5250 ft)
Altitude, Min (*Relative to Sea Level)*	0m
Altitude Resolution	1m
Altitude Accuracy	±5m

Electrical	
Input Voltage Range	7-15 VDC (12VDC Nom.)
Current Draw:	70 mA @ 12VDC
Power:	<1 Watt
SD™ Card Specifications	MicroSD , 2GB, Fat16
Output Data Rate (*Depending on Model):*	1 Hz-100 Hz
RS-232 Specification (*Depending on Model)*:	115200 Baud, 8-N-1, 19200 Baud, 8-N-1
Sensor Accuracy:	0.25% Full Scale
Sensor Range (*Depending on Model)*	5” H_20 10” H_20
Analog to Digital Resolution	16 Bit
Microprocessor	80 MHz, 32 bit

Mechanical	
Size	42 x 78 x 49 (mm) 1.62” x 3.07” x 1.92” (in)
Weight	83 g (approx.)

1.1 PRECAUTIONS

The air data probe (or probes) that you have received are precisely engineered and constructed components. Damage to these parts can result in errors in calculation of air data components. Take care to keep the probe cap on the probe tip when not in use. Should the Air Data Probe ports become clogged, do not attempt to clean them while the Air Data Probe is still attached to the Air Data Computer.

The Air Data Computer is a sensitive electronic device containing both electronic and mechanical parts. The Air Data Computer is not user serviceable; do not attempt to open it! Care should be taken not to drop, strike, or otherwise impact the Air Data Computer. Additionally, the Air Data Computer is vulnerable to short circuits, voltage spikes, ESD, and other electrical disturbances. Ensure supporting circuitry is operating properly before connecting the Air Data Computer!

The Air Data Computer uses highly sensitive pressure sensors to sense changes in the air flow vector at the tip of the Air Data Probe. Never put the Air Data Computer or Air Data Probe near any sources of high pressure air!

1.2 COMPONENT INTRODUCTION

The *On-The-Fly!* Air Data System consists of two primary components: the Air Data Probe (ADP) and the Air Data Computer (ADC).

AIR DATA PROBE

The air data probe (ADP) included with the *On-The-Fly!* Air Data System is a 5 hole + static ring multi-hole probe. These probes have been used extensively to provide velocity magnitude and direction (i.e. the velocity vector) and local total and static pressures. Multi-hole probes are rugged, straightforward to use and accurate, providing one of the most cost-effective methods for examining flow.

Air data probes are typically constructed with a stainless steel tip and either a stainless steel or carbon fiber shaft. The probe mount is usually integral to the probe shaft. This mount additionally provides a reference surface for straight probes.

No two probes can be machined exactly the same, requiring a calibration be performed on each probe. Air data probes included with the *On-The-Fly!* Air Data System are calibrated at many different flow angles for each given calibration speed in a wind tunnel. The results of this calibration are used to generate the air data computation equations used by the air data computer to calculate flow angles and speeds with the highest possible accuracy.

AIR DATA COMPUTER

The air data computer (ADC) included with the *On-The-Fly!* Air Data System houses mechanical and electronic components required to properly sense, compute and output all components of the air flow vector at the air data probe tip.

1.3 INITIAL SET UP

Before powering or installing your *On-The-Fly!* Air Data System, please follow these set-up instructions.

1. Upon receiving your *On-The-Fly!* Air Data System, verify that all components are present and were not damaged during shipping.
2. The ADS may have shipped with one or more SD cards with calibration information stored on them. Immediately make copies of this data and save it in a secure location, in case of SD card damage or loss.
3. Follow mechanical and electrical installation instructions (located in Sections 2 and 3 of this manual, respectively) to mount, secure and power your *On-The-Fly!* Air Data System.
4. The user may wish to test the *On-The-Fly!* Air Data Computer with a terminal program attached to a PC. Instructions for this test are contained in Section 4.
5. The communication protocol and format are outlined in Section 4 of this manual. Verify that any user-written software is compatible with this format.
6. Once the user has verified hardware and software performance, the *On-The-Fly!* Air Data System is ready for use!

1.4 Accuracy Graphs

The graphs below indicate the velocity and flow angle error under various circumstances of the *On-The-Fly!* Air Data System.

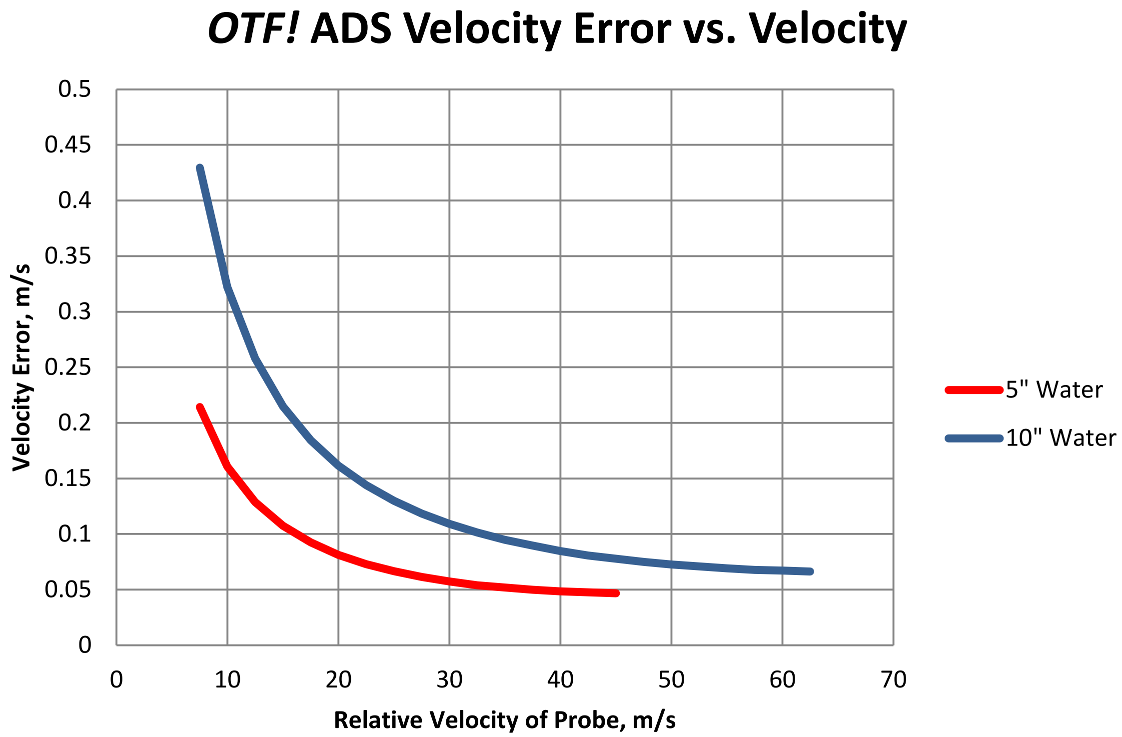

Figure 1.1. *OTF!* ADS velocity accuracy as a function of relative flow velocity, for each available sensor range.

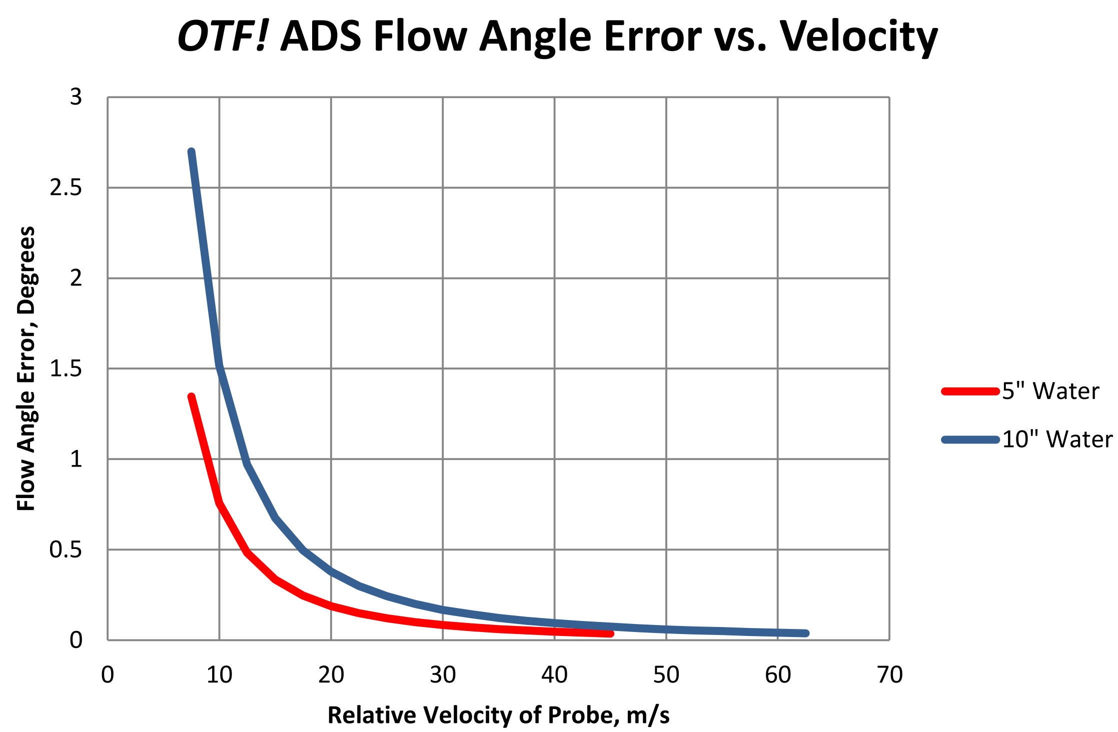

Figure 1.2. *OTF!* ADS flow angle accuracy as a function of relative flow velocity, for each available sensor range.

SECTION 2: MECHANICAL INSTALLATION

2.1 AIR DATA PROBE

ORIENTATION & MOUNTING

The air data probe axis definitions are shown for a straight probe in Figure 2.1 and for an L-shaped probe in Figure below. The coordinates are always defined into the tip of the probe where the x_p axis is along the axis of the tip. The z_p axis is always normal to the reference surface of the probe. This reference surface is the plane of the probe for an L-shaped probe, and is the reference flat (marked with an "R") on the mount of a straight probe.

Mounting the probe depends greatly upon the user's particular implementation. Great care should be taken to minimize orientation errors due to misalignment between the air data probe axes x_p and y_p and the airframe or body axes, as these offset errors cannot be accounted for by the *On-The-Fly!* Air Data System.

Table 2.1: Air flow and probe symbols.

Variable	Represents
$\bar{v}$	Air Flow Vector
α	Angle of Attack
β	Angle of Sideslip
x_p, y_p, z_p	Probe Coordinate Axes

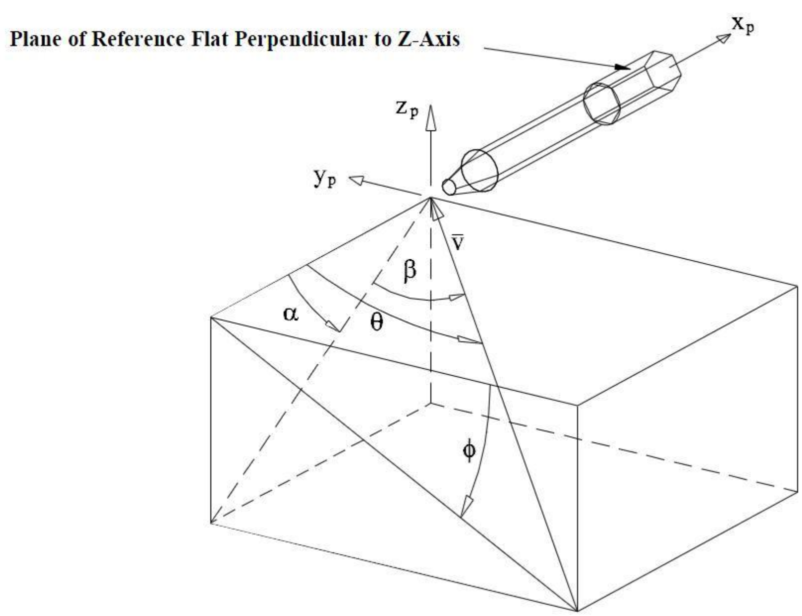

Figure 2.1. Coordinates for straight probe.

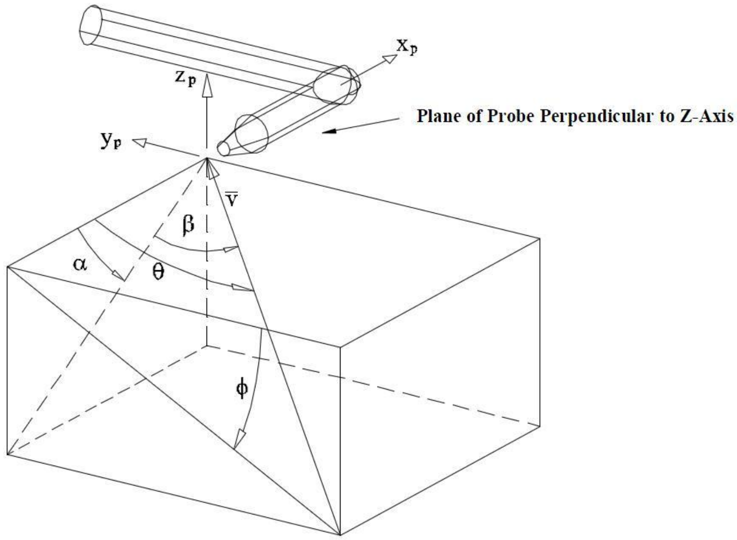

Figure 2.2. Coordinate System for L-Shaped Probe.

2.2 AIR DATA COMPUTER

MOUNTING

The ADC is not sensitive to mounting orientation. Care should be taken to avoid high-vibration environments, or areas exposed to water, fuel, oils or other contaminants. The back cover of the ADC incorporates a mounting flange that the user may utilize if desired.

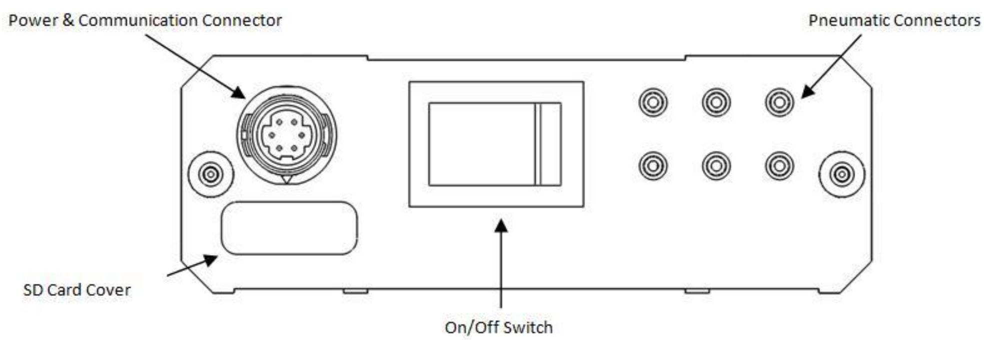

Figure 2.3. Air Data Computer Front Panel.

2.3 TUBING

TYPE

The tubing used for the *OTF!* ADS is 1/16th inch ID, 1/8th inch OD, 1/32nd thick Tygon™ PVC tubing. More tubing can be procured from a wide variety of sources, or from Sales@aeroprobe.com. Soft tubing (durometer 50A-60A) is preferable. One example of an acceptable tube type is Tygon™ formulation R-3603.

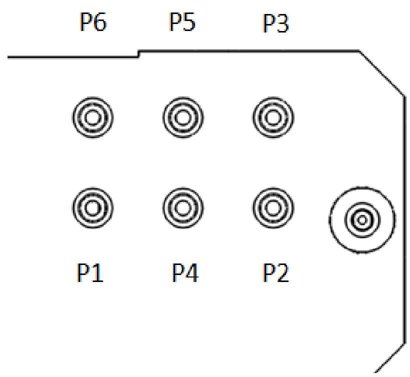

Figure 2.4. Air Data Computer Pressure Connectors.

Routing

Ensure that pneumatic tubing will not be split, severed, pinched, kinked or otherwise interfered with, even when the air data computer is powered off. These problems can result in output errors or damage to the air data computer's sensing technology. Routing the tubing with tape or other retaining mechanisms like zip ties is acceptable, and will not significantly affect the results of pressure computations.

Length

In general, tubing should be kept as short as possible when linking the air data computer to the air data probe. Excessively long tube lengths will limit pneumatic response. Tubing should be sufficiently long to eliminate the risk to tubes separating from the tube fittings on the air data computer or tubing connector.

Leaks

It is vital to ensure that there are no leaks in tubing connecting the air data probe and computer. Tubing that looks worn or is cracked should be replaced immediately.

Warning!

Never attempt to use high-pressure air to clean or attempt to detect leaks in the air data computer tubing. Blowing high pressure air into the air data computer will result in permanent damage.

SECTION 3: ELECTRICAL INSTALLATION

3.1 POWERING THE AIR DATA COMPUTER

The Air Data Computer has a wide input voltage range of 7-15 VDC. The supply should be stable and free from excessive noise. The air data computer has onboard voltage regulation, so using unregulated supplies is acceptable. The ADC can be powered by standard 2-Cell Lithium Polymer batteries.

WARNING!

The OTF! ADC *does not monitor external battery voltages, and will continue to draw current from batteries until disconnected or powered off. It is up to the user to ensure the ADC does not overdraw batteries.*

CONNECTOR

The pin out of the Air Data Computer is shown in the Table and Figure 3.1 below. The connector combines power supply and data communication functions.

Table 3.1. Air Data Computer Pin Names, Numbers and Descriptions.

Pin #	Name	Description
1	+VCC	7-15 VDC
2	GND	Power Ground Connection
3	TX (Data Out)	RS-232 Output Data from *OTF* ADC
4	RX (Data In)	RS-232 Input Data to *OTF* ADC
5	GND	RS-232 Ground Connection
6	N/C	No Connection

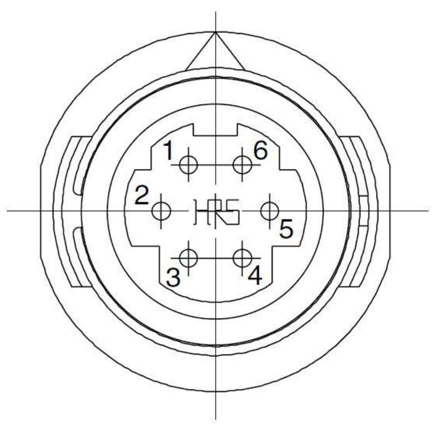

Figure 3.1. Air Data Computer connector pin numbering.
Mating connector is Hirose HR30-6P-6S.

3.2 CONTROLLING THE ADC

The user may wish to install a control switch or relay to reduce power consumption when the ADC is not in use. The ADC is compatible with most low voltage switches and relays.

WARNING!

If installing a custom switch or relay, ensure that the switch or relay is free from voltage spikes or other spurious operation when actuated. These conditions can damage ADC electronics.

4.1 RS-232 LINK

The Air Data Computer utilizes an industry standard RS-232 communication link.

CONNECTION SETTINGS

The RS-232 connection on your *On-The-Fly!* air data computer has the following settings:

Baudrate:	115200 bps
Parity:	No Parity
Data Bits:	8
Stop Bits:	1
Handshaking:	None

These settings are also known as "8-N-1". A simple 3-wire connection (TX, RX, and GND) is all that is needed to connect to the Air Data Computer.

Warning!
To avoid ground loops, make sure that communication ground and power ground are referred to the same ground plane. Ground loops can damage the Air Data Computer.

BOOTUP MESSAGE

When the air data computer is first started, it will go through its initialization procedure and output a series of bootup messages. These messages, detailed below, indicate important information to the user such as which firmware revision is in use, where the air data computer acquired its calibration information, and other user bulletins.

STRING SYNTAX

The the serial string is one continuous string followed by a carriage return and line feed. The data is formatted as ASCII standard characters, and should be visible over a serial terminal such as HyperTerminal or PuTTy. The output string contains the following parameters:

Table 4.1. Serial Output String Description.

Parameter	**Abbreviation**	**String Format**	**Units**
Sample Number	S	XXXXX	Counter
Velocity	V	XX.XX	m/s
Angle of Attack	A_OA	±XX.XX	Deg. From Centerline
Angle of Sideslip	A_OS	±XX.XX	Deg. From Centerline
Altitude	A	XXXX	m from Initial Altitude
Checksum	CS	XX	Hex Number

The string is in the following order:
S,V, AoA, AoS, A, CS

SERIAL STRING EXAMPLE

An example of the output serial string is shown below:

00012, 12.10, -3.48, 1.12, 310, 2e

These values correspond to:

Sample S:	00012
Velocity V:	12.10 m/s
Angle of Attack A_oA:	-3.48 deg

Angle of Sideslip A_oS: 1.12 deg
Altitude: 310 m
Checksum CS: 2e

4.2 Understanding the Serial String

Sample number

The sample indicator is a rolling sample counter which indicates the number of air data computations performed since it was last zeroed. The sample counter is zeroed at startup and when the counter reaches its maximum value (99999). The 100,000th sample is rolled over to 0.

Velocity

The velocity string represents the magnitude of the velocity vector over the air data probe tip in meters per second. Refer to Figure and Figure for visualizations of the flow vector. The air data computer reports calibrated air speed (CAS) in meters per second. It is the pilot's responsibility to provide the standard corrections for temperature, compressibility, and altitude.

Angle of Attack

The angle of attack indicator represents the calculated angle of the flow vector in the pitch axis. Positive angles of attack indicate the airfoil or airframe is ascending relative to the flow (i.e., the flow vector points to the bottom of the airfoil or airframe).

Angle of Sideslip

The angle of sideslip indicator represents the calculated angle of the flow vector in the yaw axis. Positive angles of sideslip indicate flow approaching the airfoil or airframe from the left side (considered facing forward, or pilot's view).

Altitude

The air data computer reports pressure altitude above sea level in meters. It is the pilot's responsibility to provide standard corrections for local pressure and temperature conditions at time of takeoff.

4.3 Checksum

The air data computer serial string includes a one-byte checksum to provide a basic data integrity check for the user. Use of this checksum is not mandatory, but is recommended to prevent erroneous, noisy or garbled transmissions being interpreted as valid data by the host.

Calculation

The checksum consists of a simple logical XOR operation performed on the outgoing bytes in the serial string. The checksum is zeroed before being computed for each packet (each packet's checksum is unique to that packet and not dependent on others). The checksum does not include the checksum byte itself, or the carriage return/line feed combination.

EXAMPLE CODE

The code below can serve as an example of one method of calculating the checksum value (code is written in C). The serial string is passed into the for loop as the pointer *ptr and the checksum variable as check. The loop simply performs a XOR assignment operation on each successive character of the string, returning the newly computed value. The checksum variable check must be zeroed for each new response packet from the Air Data Computer.

```
char      check = 0;
char     *ptr;
for (ptr = str; *ptr; ptr++) {
    check ^= *ptr;
}
```

SECTION 5: OPERATION

5.1 AIR DATA COMPUTER SETUP

Upon receiving the *OTF!* ADS, the user should immediately copy the contents of all SD cards included to a safe location, such as a local hard drive. This will ensure the user can replace the SD card if it is lost or damaged.

5.2 BASIC OPERATION

The ADC is extremely simple to operate. Simply power it using 7-15 VDC, and the ADC will initialize, and immediately begin reporting values, as well as saving values to the SD card.

Warning!

The ADC will not begin reporting air data below approximately 8 m/s.

CONTROL

The user will likely wish to shut off the *ADC* when not in operation to conserve power. This can be accomplished using the front panel switch provided on the ADC housing, or by another switch or relay wired by the user.

WARM-UP

The air data computer uses precisely calibrated pressure sensors to detect minute changes in air pressure around the air data probe. These sensors are subject to some warm-up drift before they reach stated accuracy. In order to achieve stated accuracy, the air data computer should be switched on for 10 minutes or more before pressure readings are to be taken. After this warm-up period, switch the air data computer off for 5-10 sec and then back on. The auto-zero functions (described below) will execute, and the sensors will be properly calibrated for operation.

If users are seeing particular offset errors persist during operation, it is possible that the sensors continued to drift after being zeroed. Repeat the warm-up procedure above to the re-zero the sensors.

Warning!

Failure to properly warm up and zero the air data computer will result in errors in reported data. Always follow the warm-up procedure before attempting to use the air data computer!

5.3 AUTO-ZERO FUNCTIONALITY

The ADC features an auto-zero function to eliminate sensor drift errors. The auto-zero function will automatically execute on power-up. The auto-zero function will not execute when the ADC detects that it is in flight. Therefore, the tip of the air data probe should be covered loosely and shielded from any wind or breeze when powering on the ADC.

NOTE:

Do not use the cap shipped with the probe to cover the tip when auto-zeroing. This cap seals tightly and can slightly pressurize the air data computer channels, resulting in data errors.

Warning!

Failing to cover or shield the air data probe while restarting the OTF! ADC *will result in offset errors to the measured air data!*

5.4 SELECTING A CALIBRATION

Calibrations for the ADC are stored on Secure Digital (SD) cards. If your *OTF!* system shipped with multiple air data probes (or multiple calibrations for the same probe), your package will include SD cards for each calibration. To switch calibrations, simply remove the previous SD card and insert the SD card which corresponds to the probe or calibration you wish to use.

NOTE:

Do not forget to change air data probes when changing calibrations! Calibrations made for one specific air data probe are not valid for other probes.

WARNING!

Mismatching an air data probe and a calibration will result in serious errors in calculated air data. Double check that all calculations are properly matched to their respective air data probes!

5.5 SD CARD FORMAT

Each SD card shipped with the *OTF!* ADS includes several files vital to the operation of the Air Data System. These files are detailed below. It is highly recommended that the user make and store copies of these files in the event of inadvertent data loss or corruption.

WARNING!

Do not attempt to use other SD cards with the ADC. SD cards vary widely from manufacturer to manufacturer and using cards not fully tested can prevent the ADC from operating correctly. See section 5.9 for information regarding a lost or damaged SD card.

CAL.TXT

This file contains calibration data for a particular probe calibration. It is formatted in ASCII text.

WARNING!

Do not modify cal.txt in any way! Doing so may compromise the calibration data and cause errors ranging from erroneous data to complete non-functionality in the ADC!

INC.TXT

This file contains a counter indicating the name of the most recently used data file name. It is modifiable by the user in certain circumstances, as detailed below.

5.6 DATA FILE FORMAT

Data files are stored on the SD card in an ASCII format, identical to .txt textfiles. These data files share the same output string syntax as detailed above in the RS-232 section. The data file does not store the bootup message.

DATA FILE NAMES

Data files are named incrementally. Each time the ADC is started, it will read the number stored in the INC.TXT file, increment that value by 1, and create a data file with that incremented number as the name. For example, if INC.TXT contains the number “12”, the data file created by the ADC would be “13.txt”. This is done to prevent previous data from being overwritten by new data in sequential runs.

5.7 READING DATA FILES

To read data files, remove the SD card from the ADC and insert it into a PC. Data files created by the ADC are present on the SD card, and the user should be able to open and peruse these data files in any text editor. Data files can be read and modified at will; once closed, they are no longer accessed by the *OTF!* ADC. It is advisable, however, to copy the data files to a local hard drive before modifying or plotting data.

5.8 CLEARING SD CARD

The user may never need to delete files from the SD card. For example, assuming a 10Hz output rate and a 2GB SD card, the user can log data continuously for over 1000 hours without filling the SD card! Even so, users may wish to remove old data files from the SD card to more easily find recent data, or some other reason. This is easily accomplished, but the user must be aware of several considerations.

REMOVING FILES

Removing files is as simple as copying them to a local hard drive (or other storage location) and deleting them from the SD card. No further action is needed. Do NOT format the SD card! This will result in the loss of important system data.

INC.TXT

As mentioned above, most recent file name used for data storage is stored in the SD card, in the file inc.txt. The user may wish to reset this number to 0 when clearing the SD card, to restart the data file name counter. Simply delete the previous and replace it with an ASCII "0". Starting at values other than zero is not supported.

Restarting the counter is not mandatory; the user can remove old data files without changing this counter if they wish to maintain data continuity.

Warning!

Resetting the INC.TXT counter without removing the data files will cause old files to be overwritten!

5.9 LOST/DAMAGED SD CARD

Losing or destroying a calibration SD card is not a serious issue if the user has backed up their calibration files. Upon receiving the *OTF!* ADS, the user should immediately copy the contents of all SD cards included to a safe location, such as a local hard drive. If this data is unavailable, the manufacturer retains copies of all calibrations and can provide them for the user upon request.

ACQUIRING A NEW SD CARD

Contact Sales@aeroprobe.com for replacement SD cards.

SECTION 6: NOTES

DOCUMENT REVISION HISTORY

January 2011: Initial Release. (Revision A)
February 2011: Updated for R1.1 Firmware. (Revision B)
March 2011: Updated to Velocity, Altitude definitions. Added section "Warm-up." (Revision C)
April 2011: Minor clarification updates. (Revision D)
Jul 2011: Updated for HW Revs 1.2, 1.3.
Jan 2012: Updated Specification Section. Added Section "Accuracy Graphs". Updated TOC. Updated for HW Rev 1.3.1. (Revision F).

FIRMWARE COVERED BY THIS DOCUMENT

Firmware Revision 1.1.2
Firmware Revision 1.1
Firmware Revision 1.0

HARDWARE COVERED BY THIS DOCUMENT

Hardware Revision 1.0a
Hardware Revision 1.1
Hardware Revision 1.2
Hardware Revision 1.3
Hardware Revision 1.3.1

NOTES: