

ESCAPE Data Release : Aircraft and Atmospheric State

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Ver. 1.0

Dataset Description

Executive Summary

This document accompanies the uploaded atmospheric and aircraft state dataset collected during the ESCAPE flight campaign (May – June 2022) onboard NRC’s Convair-580 aircraft. This document provides basic information about the sensors and brief notes on data processing and data structure and quality that can aid in use of the data.

The data contains the following products at a 1Hz temporal resolution, with the following uncertainties.

Parameter	Uncertainty($\pm 1\sigma$)
Latitude	± 1 meters
Longitude	± 1 meters
Altitude	± 2 meters
Aircraft North-South Velocity	± 0.1 m/s
Aircraft East-West Velocity	± 0.1 m/s
Aircraft Vertical Velocity	± 0.04 m/s
Aircraft True Airspeed	± 2 m/s
Aircraft Roll	$\pm 0.05^\circ$
Aircraft Pitch	$\pm 0.11^\circ$
Aircraft Heading	$\pm 1^\circ$
Static Air Pressure	± 1.3 hPa
Static Air Temperature	$\pm 0.1^\circ\text{C}$
Horizontal Windspeed	± 0.55 m/s
Horizontal Wind Direction	$\pm 1.25^\circ$
Vertical Windspeed	± 0.35 m/s
H2O Concentration	± 0.1 mmole/mole
Dew Point	$\pm 1^\circ\text{C}$
Icing Detector MSO Frequency ¹	N/A

¹ Please note the icing detector is meant to be used only as a qualitative indicator of aircraft icing

Instrument Description

In Figure 1, a frontal view of the NRC Convair is shown with labeled locations indicating placement of instrumentation. Table 1 provides a list of all the atmospheric and aircraft state instruments, and their location on the aircraft exterior. This is followed by list of instruments housed internally in the aircraft cabin (Table 2).

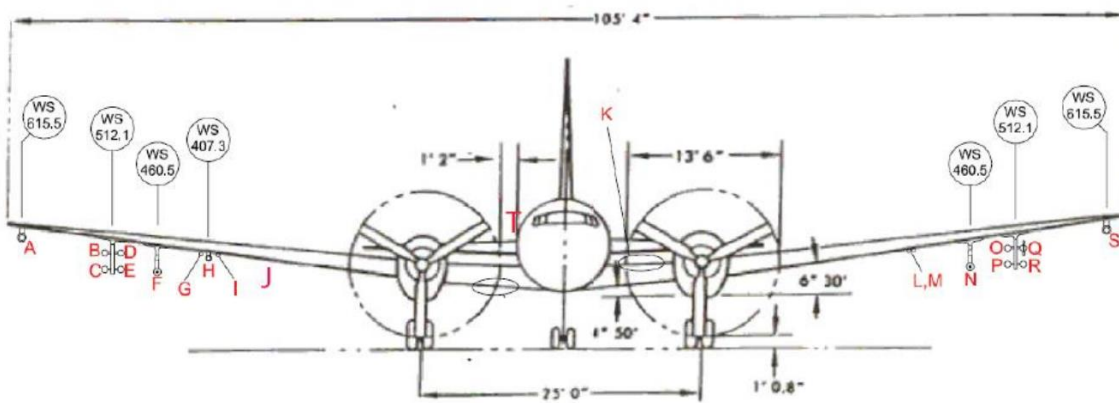


Figure 1 - A diagram of the NRC Convair with instrumentation locations labeled.

Table 1 - List of instruments located on the aircraft wing and fuselage

Diagram Label	Instrument	Location
T	Honeywell PPT2 Pressure Transducer	Starboard Fuselage (SF)
H	Rosemount 102 Total Air Temperature Probe	Starboard Scalarboom (SSB)
B	Rosemount 858 Airdata Probe	Starboard Pylon, Outboard Upper (SPOU)
A	AIMMS-20 Airdata Probe	Starboard Wingtip (SWT)
H	Collins Rosemount Icing Detector (RID) #1	Starboard Scalarboom (SSB)
M	Collins Rosemount Icing Detector (RID) #2	Port Scalarboom (PSB)

Table 2 - List of instruments located in the aircraft cabin

Instrument	Location
Novatel Flexpak6 GNSS Receiver(x2)	Aircraft Cabin (C)
KVH 1750 IMU	Aircraft Cabin (C)
Honeywell HG1700 IMU	Aircraft Cabin (C)
Licor 840a Gas Analyzer	Aircraft Cabin (C)
Licor 7000 Gas Analyzer	Aircraft Cabin (C)
Vigilant Chilled Mirror Aircraft Hygrometer System Model 137	Aircraft Cabin (C)

Data Collection and Processing

Data Collection and Preparation

The data described in this document are all collected through a real-time *Data Acquisition System (DAS)*. Transmitted packets are all collected into one file and then preprocessed before moving on to derivation of parameters. Below are the steps taken to generate data that is uniformly spaced in time and free of time anomalies.

1. **Data Conversion:** The data is converted to CSV from the raw network packets recorded on the DAS, and after pre-processing is then stored into a NetCDF file
2. **Time Anomaly Correction:** Timing errors do arise on rare occasions in the DAS. This includes issues of timestamps randomly resetting, a midnight transition from 11:59:59PM to 12:00:00AM and more. In this stage, all these time anomalies are corrected.
3. **Resampling:** The time spacing of all parameters is made uniform. This entails interpolation to make the time spacing intervals equal for the whole time series. Resampling in this case is resolved to 1 Hz.

Instrument Data Sourcing

The instrument sources for each parameter in this dataset are listed below.

1. **Position, Aircraft Velocities, Roll, Pitch and Heading :** Generated in real-time during flight using two custom *Integrated Navigation System (INS)*. Both INS systems use a *Novatel Flexpak6 GNSS Receiver*, and differ in the IMU model, with one INS system using a *KVH 1750 Inertial Measurement Unit (IMU)* and the other system using an *Honeywell HG1700 IMU*.
2. **Static Air Pressure :** The static air pressure is measured using the *Honeywell PPT2 Pressure Transducer* located on the aircraft *Starboard Fuselage (SF)*.
3. **Static Air Temperature :** The static air temperature is derived from the total air temperature, which is measured from the *Rosemount 102 Total Air Temperature Probe*, located on the aircraft *Starboard Scalarboom (SSB)*.
4. **Angles of Attack and Sideslip :** *Rosemount 858 Airdata Probe* located on the *Starboard Pylon* in the *Outboard Upper* location.
5. **Water Vapour :** *Licor 840a* and *Licor 7000* Gas Analyzers, both located in the *Aircraft Cabin*.
6. **Dew Point :** *Vigilant Dew Point Chilled Mirror Hygrometer* located in the *Aircraft Cabin*
7. **Icing Detector MSO Frequency :** Two *Collins Rosemount Icing Detectors* located on the *Starboard Scalarboom* and *Port Scalarboom* respectively.

Data Processing Description

Aircraft State Data Processing Summary

The aircraft state parameters (with the exception of True Airspeed) are generated in real-time during flight using a custom Integrated Navigation System (INS), which consists of a Novatel Flexpak6 GNSS Receiver and a KVH 1750 Inertial Measurement Unit (IMU), with a secondary INS system using an identical GNSS receiver and Honeywell HG1700 IMU instead of the KVH IMU. The INS combines measurements from these two systems using a real-time Kalman filter to minimize measurement error. No post-flight processing is applied to the aircraft state, with the exception of True Airspeed, which utilizes post-processed pressure and temperature data.

Atmospheric State Data Processing Summary

Static Air Pressure

The static air pressure is measured using the Honeywell PPT2 Pressure Transducer located on the aircraft Starboard Fuselage (SF). The raw measured static air pressure has a position error correction (PEC) applied in order to remove the dependence of the raw measurement on the specific location of the aircraft, as detailed in (Leach & Hui, 2001).

Static Air Temperature

The static air temperature is derived from the total air temperature, which is measured from the Rosemount 102 Total Air Temperature Probe, located on the aircraft Starboard Scalarboom (SSB). The air temperature measurements have a Mach Number dependency, which is removed via a recovery factor correction. With the recovery factor correction, we obtain the static air temperature.

Given a Mach Number M , the recovery correction ν is calculated as:

$$\nu = C_0 + C_1 \cdot M + C_2 \cdot M^2 + C_3 \cdot M^3 \quad (\text{Eq. 1})$$

Where the constants $C_0 \dots C_3$ are manufacturer-provided calibration constants.

Then the recovery factor is calculated as:

$$r = 1 - \nu \cdot \left(1 + \frac{2}{(\gamma - 1) \cdot M^2} \right) \quad (\text{Eq. 2})$$

where $\gamma = 1.4$ is the isentropic expansion factor. This leads to the final calculation of static temperature:

$$T_s = \frac{TAT}{1 + \left(\frac{\gamma - 1}{2}\right) \cdot r \cdot M^2} \quad (\text{Eq. 3})$$

True Airspeed

True airspeed is calculated from the pressure measurements (position-error-corrected), and static air temperature according to the following equation (Leach & Hui, 2001).

$$TAS = \sqrt{7.0 \cdot R_{gas} \cdot T_s \cdot \left(1 - \frac{P_s}{P_s + P_d}\right)^{\frac{2}{7}}} \quad (\text{Eq. 4})$$

Where R_{gas} is the gas constant, and P_s, P_d are the static and dynamic pressures respectively (Honeywell PPT2 Pressure Transducer located on the aircraft Starboard Fuselage), and T_s is the static air temperature (from the Rosemount 102 Total Air Temperature Probe, located on the aircraft Starboard Scalarboom).

Winds

For a full detailing of the wind processing steps, please consult (Leach & Hui, 2001). In succinct terms, the wind calculation involves subtracting the aircraft velocity components from the airspeed velocity components in order to obtain the wind contribution from the airspeed velocities. The steps involved are listed below:

1. Calculate the airspeed components u, v, w which correspond to the x, y, z components of the True Airspeed, using the angles of attack and sideslip from the Rosemount 858 Airdata Probe located on the Starboard Pylon in the Outboard Upper location, and the AIMMS20 Airdata Probe in the Starboard Wingtip location.
2. Apply a lever arm correction to the airspeed components to transform them to the same location of the aircraft INS. This allows for proper subtraction of the aircraft component of the airspeed velocities.
3. Transform u, v, w from an aircraft-relative reference frame to an earth-relative reference frame via an euler angle transformation
4. Subtract v_x, v_y, v_z from u, v, w

Water Vapour Concentration

No processing has been applied to the water vapour concentration data.

Dew Point

No processing has been applied to the dew point/frost point data.

Icing Detector MSO Frequency

No processing has been applied to the icing detector MSO frequency data.

Quality Control and Assurance Procedures

Data quality control and assurance has been achieved in two primary methods: Data removal and data corrections.

Data Removal

In cases of data removal, the data in problematic time periods is deemed irreparable for public data release. Data from these periods have been filled with the data fill value (-32767.0). There are three primary causes which result in data removal.

1. Error due to instrument failure : Instrument not transmitting measurements, or transmitting non-physical values which can not be adjusted to be useful.
2. Error due to environmental effects : Loss of data due to environmental effects like ice accumulation on a probe
3. Error due to Data Acquisition System failure : Data stops transmitting due to failure in the Data Acquisition System.

Data Corrections

Data corrections are applied to problematic measurements which, once corrected, can be utilized in scientific analyses. Overall, only two major corrections have been applied:

1. **Nonzero Mean Vertical Wind** : While the vertical wind measurements are highly robust, the mean vertical wind measured in flight is slightly above zero. For this campaign, these biases range from 0.1m/s to 0.4m/s. In order to remove the effect of this bias on data analysis, the data is “zeroed” by subtracting this offset.
2. **Licor 7000 Measurement Offset** : The Licor 7000 has a consistent offset of approximately 0.5millimole/mole relative to the Licor 840a and Vigilant Chilled Mirror Hygrometer, which has been observed over multiple flight campaigns. This offset has been corrected for this data release.

Data Substitutions

For C-RF09, the INS system with the KVH1750 IMU experienced data quality degradation, and was substituted with the equally accurate INS system using the HG1700 IMU. Other than this substitution, the only other variables where data substitution has been applied is the angles of attack and sideslip, which are then used to derive the horizontal windspeed/direction and the vertical windspeed. For the winds, the primary instrument used for angle of attack and sideslip measurements is the *Rosemount 858 Airdata Probe*. In cases where this probe is non-functional, it is substituted with the *AIMMS20 Airdata Probe* data for angle of attack and sideslip instead.

Non-Quality Controlled Data

Some parameters have not been corrected in this data release. This includes the water vapour measurements², dew point measurement, and the icing detector MSO frequencies. This is because in the cases of these parameters, multiple methods of correction and use of data are all equally valid. Thus, their use and interpretation are left to the user. For more details, please consult the **Data Remarks** section.

² with the exception of a 0.5 millimole/mole offset adjustment for the Licor 7000

Data Format

The data is packaged in a **NETCDF 4.0** format. The data follows NCAR-RAF NETCDF, conventions³.

Data Remarks

General Data Assessment

The data is largely of high quality, with minimal error. It has also been extensively quality controlled to remove periods of poor data quality. The only exception to this, is in the case of the water vapour concentrations, the dew/frost point measurements.

While measurements of these parameters⁴ is sufficiently accurate in clear air (0.1 millimole/mole accuracy), the accuracy suffers significantly in cloud sampling. This is because the sampling inlet which feeds in air to make these measurements is not adequately protected from entry of water into the sampling line, thus leading to over-estimates of water vapour concentrations in cloud, and subsequently unphysical calculations of relative humidity and dew/frost point. This issue affects subsequent data in the same flight where the aircraft exits cloud and enters clear air, as there is still residual water in the intake lines which will continue to result in over-estimates of water vapour concentration until the line dries out sufficiently. The only exception to this assessment would be the two aerosol clear air flights in the campaign, C-RF09 and C-RF10, where this water entry issue is not present, and the data can be relied upon with more confidence.

Additionally, care needs to be taken with the dew/frost point measurements. These measurements are taken from a chilled mirror hygrometer, which have slow response times to changing dew point measurements. Thus, dew point data needs to be heavily scrutinized, especially during shorter time periods. Furthermore, hygrometers will also have periods of no usable data, occurring when a moisture film fully develops on the mirror surface, and the device needs to dry itself out before resuming data collection.

Finally, care needs to be taken with the icing detector MSO frequency data. With the exception of subject matter experts, this data is only meant to be used qualitatively to identify periods of aircraft icing.

Missing Data Periods

The data availability for winds, water vapour and dew point temperature may be seen in Figures 2, 3 and 4, 5 and 6 below. No other measurements have significant periods of missing data. **Please note that a green colour indicates available data, and blue indicates no available data.**

³ More details can be found [here](#).

⁴ Water Vapour Concentration measured with the Licor 840a and Licor 7000 Gas Analyzers, and Dew/Frost point is measured with the Vigilant Chilled Mirror Hygrometer

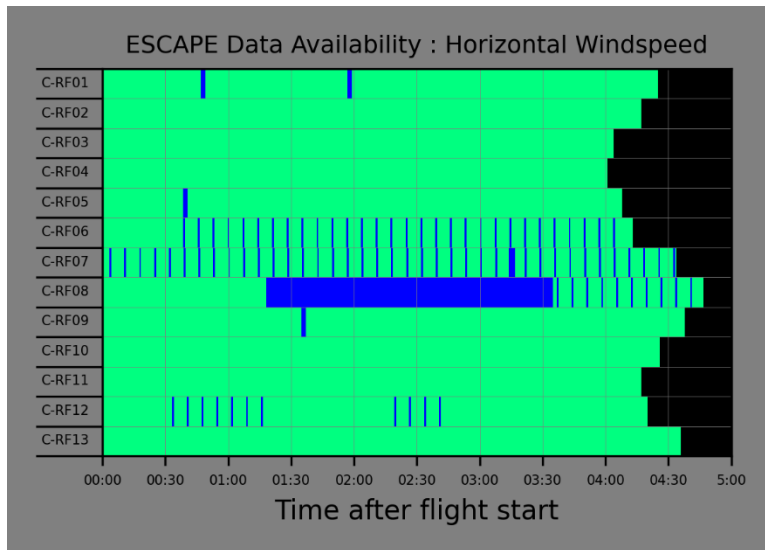


Figure 2 - Horizontal Wind Speed data availability

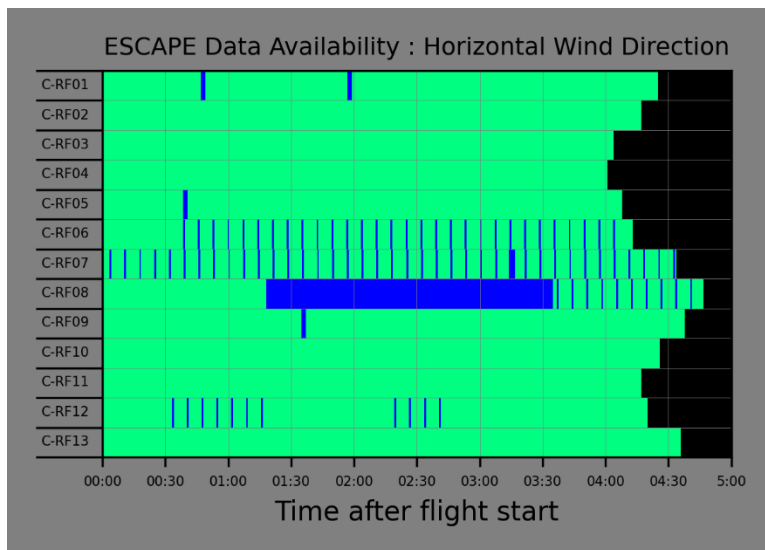


Figure 3 - Horizontal Wind Direction data availability

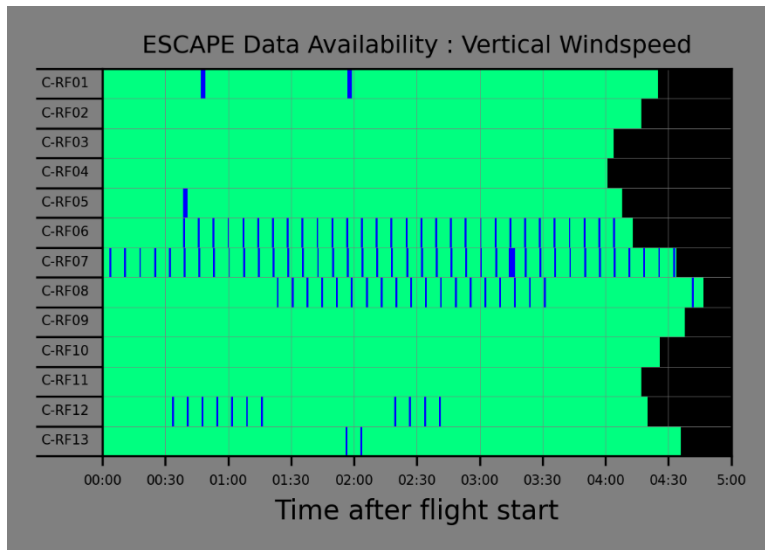


Figure 4 - Vertical Windspeed data availability

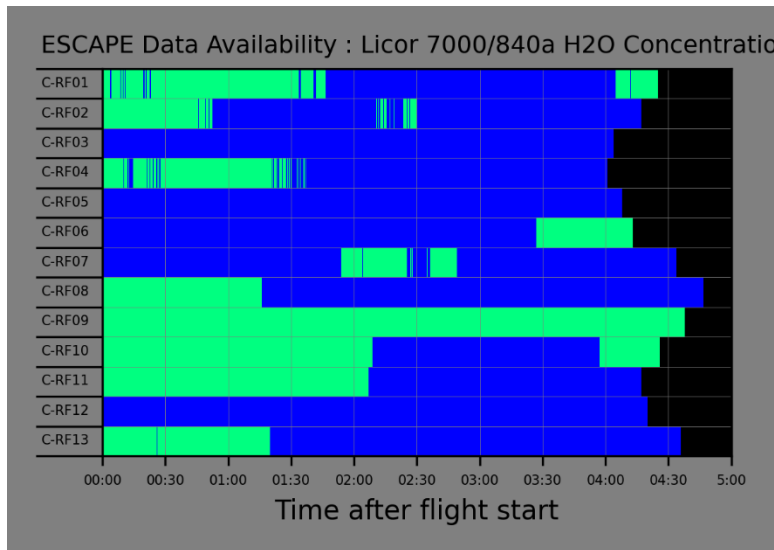


Figure 5 - H2O Concentration data availability

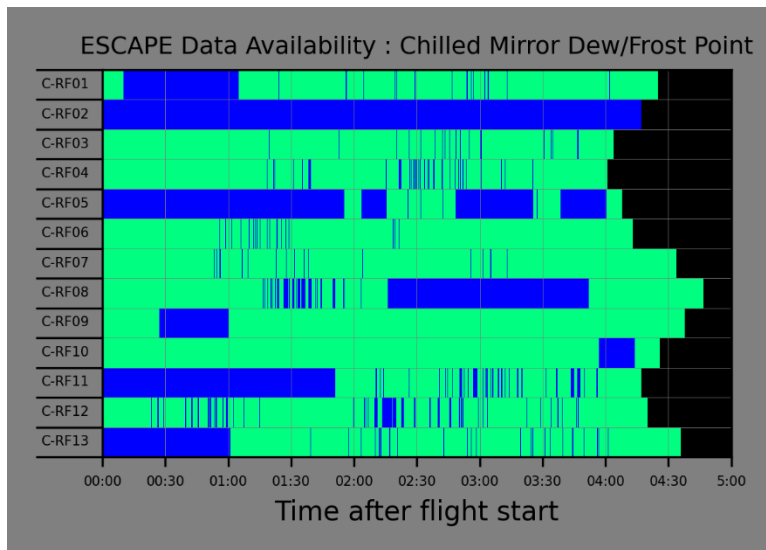


Figure 6 - Dew Point data availability

References

Leach, B., & Hui, K. (2001). In-Flight Technique for Calibrating Air Data Systems Using Kalman Filtering And Smoothing. *AIAA Atmospheric Flight Mechanics*.