IDEAL 2017 data archive information

The IDEAL field campaign was conducted at Dugway Proving Grounds, Utah, USA. The field campaign was organized combining the efforts of University of Colorado Boulder, GATS, NCAR and the Meteorology division at Dugway proving Ground, Utah.

Data Source

University of Colorado, Boulder:
In situ measurements of differential pressure (high resolution), atmospheric pressure (low resolution), temperature (high and low resolution) and relative humidity (low resolution).

Authors

Lead Author: Abhiram Doddi, abhiram.doddi@colorado.edu. University of Colorado, Boulder, CO, USA.

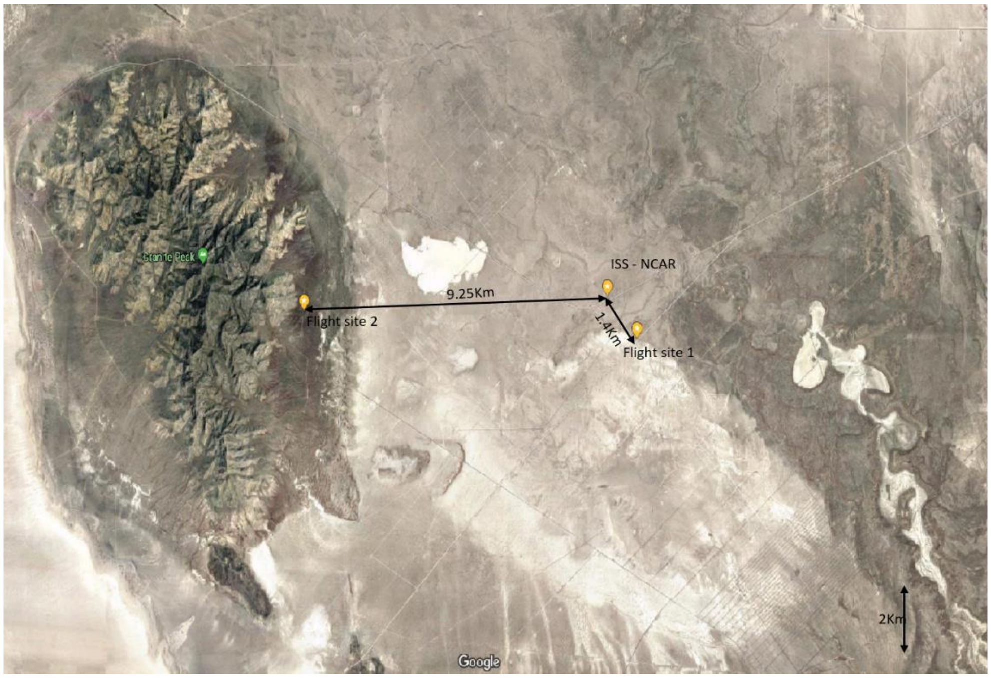
Mailing Address: Smead Aerospace Engineering Sciences, 3775 Discovery Drive, #244-23. Boulder, CO, 80303

Co-Author: Dale Lawrence, dale.lawrence@colorado.edu. University of Colorado, Boulder, CO, USA.

Mailing Address: Smead Aerospace Engineering Sciences, 3775 Discovery Drive, #271. Boulder, CO, 80303

Data set Overview:

The In situ observations conducted by the University of Colorado, Boulder using the Data Hawk UAS during the fall of 2017 at Dugway Proving Grounds (DPG), Dugway UT is presented here. The measurements span from the 24th of October to the 11th of November of 2017. A total of 32 sorties with roughly 2-3 flights per sortie (lasting for a maximum sampling duration of 90 minutes) were flown to accumulate the data at two designated locations within the DPG. The launch locations can be found on the map below.



Instrument Description:

The DataHawk obtains measurements from a variety of sensors, and stores this data in several forms and at several different sampling rates. The discussion below groups the measurements by location of the sensors in the DataHawk avionics system.

All this data is handled by the DataHawk processor module in the autopilot, then routed to two destinations: the on-board SD card, and the radio telemetry. All radio telemetry packets are also sent to the SD card, to provide a complete record without radio link drop outs. Thus, the SD card contains a superset of the telemetered data, with additional data fields and at higher sample rates. The SD card file is a binary format that must first be unpacked using a Matlab .m file, to result in a .mat file that is easier to read by Matllab (and other programs). The discussion below refers to variables in the unpacked SD .mat file.

3-Wire Sensor Module

1) **Uncalibrated Coldwire**
   A custom 5um diameter Platinum wire resistance temperature detector (RTD) is used. The wire is excited at software-selectable constant voltage as a “coldwire”, i.e. at a very low overheat ratio, so that its current is dependent on its resistance, and this resistance is primarily sensitive the flow temperature, rather than flow velocity, resulting in a temperature change less than 0.002C per m/s airspeed change. The wire current is converted to an amplified voltage with a range of +/- 4.096V, and digitized to 20-bit resolution (7.8 uV/bit). Upon airplane initialization, the autopilot adjusts the wire excitation voltage to compensate for manufacturing variation among wire resistances, so that the offset voltage at ground initialization is always near the top of the range, preserving a wide dynamic range for subsequent voltage reduction due to temperature reduction at high altitudes, resulting in an approximate un-saturated temperature range of -60C to +40C across all manufactured wires. This enables broken wires to be replaced in the field without electronics component changes to accommodate differing nominal wire resistances. The coldwire itself has a thermal time constant at the nominal 15 m/s airspeed of approximately 0.5msec, for a temperature measurement bandwidth of about 300 Hz. The amplified voltage is anti-alias filtered at 300Hz and digitized/sampled at 800Hz. Coldwire voltage (in V) is saved in the on-board SD card .mat file at 800Hz (in the **coldwire.coldwire** field), along with the associated time vector coldwire.Time (in sec), and telemetered to the ground station at 10Hz (saved in the **payload_data(:,7)** field in the .mat telemetry file). The excitation voltage level is saved as a digital potentiometer reading in the **payload_data(:,10)** field. The SD file also has an associated elapsed time variable (in sec) stored in the field **coldwire.Time**. The coldwire signal is calibrated to temperature in post flight analysis by comparison with a slow, but calibrated, temperature sensor co-located in the 3-wire sensor module (item 4 below).
2) **Uncalibrated Hotwire**
   The hotwire uses the same type of Platinum wire as the coldwire, but it is excited with a larger voltage to produce a very large overheat ratio, making the wire resistance a strong function of flow velocity. The same type of conversion from wire current to voltage with amplification is used, with a conversion to digital form with a 0-4.096V range and 16 bit resolution (62.5 uV/bit). Since the wire resistance is also a function of flow temperature, the coldwire voltage is fed into the hotwire stage to reduce the hotwire signal variation with temperature, keeping it in range. The hotwire stage also incorporates a software-adjustable excitation voltage to accommodate differing wire resistances, but since the ground initialization occurs at near zero flow speed, this cannot provide a reliable offset for reasonable un-saturated signal swing at typical airspeeds in flight. Thus, the

hotwire excitation adjustment is always in effect, so that reasonable offsets can be obtained when the aircraft reaches typical airspeeds, as well as to keep the signal from saturating over a large airspeed range. Unfortunately, this complicates the hotwire calibration, since both coldwire voltage and hotwire excitation level variations must be removed from the hotwire signal before flow velocities can be extracted and calibrated against pitot airspeed. The hotwire signal has the same 300Hz thermal time constant as the coldwire, and is anti-aliased filtered at the same 300Hz bandwidth, and sampled at the same 800Hz rate. The raw hotwire signal (in V) is saved on the on-board SD card in the field **coldwire.hotwire** at 800Hz, and sent to the ground station via telemetry at 10 Hz (and subsequently saved in the field **payload_data(:,8)**). The excitation voltage level is saved as a digital potentiometer reading in **the payload_data(:,11)** field.

3) **Uncalibrated Smallwire**

The small wire channel on the 3-wire module is currently configured as an auxiliary coldwire channel. This operates the same as the coldwire channel with 800 Hz sampling of the amplified voltage signal, but has a lower 16 bit resolution. This raw voltage data is saved on the SD card in the **coldwire.smallwire** field, and in the telemetry as the **payload_data(:,9)** field. The excitation voltage level is saved as a digital potentiometer reading in the **payload_data(:,12)** field.

4) **Calibrated Temperature**

This measurement uses the commercial Sensiron SHT-31 sensor, that provides a digital output with a -40 to 125C range, 15mC resolution, and accuracy of +/- 2C, with a time constant of about 2sec. and at a sample rate of 44.4Hz. This is stored on the SD card in the field **coldwire.T** with the associated elapsed time field **coldwire.HT_Time** (in sec), and sent over telemetry at 10Hz, and saved on the ground station .mat file in **payload_data(:,18)**.

5) **Calibrated Relative Humidity**

This measurement also comes from the Senriron SHT-31 sensor, providing a digital output with a range of 0-100 % releative humidity, with a +/-3% accuracy, 0.01% resolution, and a 44.4Hz sample rate. Sensor time constant is approximately 8 sec. This is stored on the SD card in the field **coldwire.H** at 100Hz with the associated elapsed time variable (in sec) in the field **coldwire.HT_Time**. The humidity data is also sent over telemetry at 10Hz, then saved in the ground station .mat file in **payload_data(:,17)**.

DataHawk Autopilot

6) **Barometric Pressure**

Utilizes the Measurement Specialties MS-5611 (micromachined diaphragm) absolute pressure sensor with digital output. Specified accuracy is 2.5 mbar over a 10-1200 mbar range, with a resolution of 0.01 mbar and a (sampling limited) response time of 0.022 sec. This is sampled at 44.4Hz, and stored on the SD card in the field **rawBaro.P**, in uints of mbar, with an associated elapsed time (in sec) field of **rawBaro.Time**, and sensor temperature (in C) in **rawBaro.T** .

7) **Pressure Altitude**

This is estimated from the MS-5611 barometric pressure using a standard atmosphere model, and an offset-zeroing process that matches pressure altitude to GPS altitude during the plane initialization before flight. This is computed at the 44.4Hz sampling rate and stored on the SD card in the field **rawBaro.A**. A corresponding elapsed time field (in sec) is stored in the field **rawBaro.Time**, as well as the sensor temperature (in C) in **rawBaro.T**

8) **GPS Location**

This is obtained from a uBlox LEA-6 module that reports solution at 5Hz, and is stored on the SD card as latitude (**gps.Lat** in deg), longitude (**gps.Lon** in deg), and altitude (**gps.Alt** in m MSL).

9) **GPS Velocity**

This is obtained from the same uBlox module, also at 5Hz, with data stored on the SD card as **gps.Vnorth**, **gps.Veast**, and **gps.Vdown** (all in m/s).

10) **GPS Time**

An elapsed time variable for the GPS data is stored on the SD card in **gps.Time** (in sec), as well as the GPS time of week (in msec since Sunday UTC) in **gps.TOW**.

11) **Pitot/Static Differential Pressure**

Data Format:

The aircraft performance and sensor data gathered by the DataHawk UAS is stored (digital data – binary format) in the SD card onboard. This includes the data gathered by sensors during flight, aircraft performance data, telemetry data (relayed to GS for guidance and control) and GPS data. The data on the SD card is unpacked and assigned relevant array names. The data is passed through 4 stages of processing before the turbulence parameters are computed using the sensor feeds. Data arrays stored on the SD card are listed in the table below.

Storage rate (Hz)	**Data Type**	**Comments**	**Array name**
5	GPS latitude	North latitude, [degrees]	GPS_lat
5	GPS longitude	West longitude, [degrees]	GPS_lon
5	GPS altitude	Above Mean sea level, [m]	GPS_alt
5	GPS velocity	North, [m/s]	GPS_vel_north
5	GPS velocity	East, [m/s]	GPS_vel_east
5	GPS velocity	Down, [m/s]	GPS_vel_down
5	GPS time	Relative to GS start, local time, [s]	time_GPS
100	Baro pressure	[mbar]	DH_baro_pres
100	Rel. humidity	[%]	DH_rel_hum
100	Slow temp.	[C]	DH_slow_temperature
100	100Hz time	Relative to GS start, local time, [s]	time_100Hz
800	Coldwire voltage	[V]	coldwire_voltage
800	Hotwire voltage	[V]	hotwire_voltage
800	Pitot pressure	[psi]	pitot_pressure
800	800HZ time	Relative to GS start, local time, [s]	time_800Hz
10	Aircraft performance data packet	29 fields in total (debug data packet)	debug_data
10	Debug time	Relative to GS start, start, local time, [s]	debug_time
10	Sensor data packet	42 fields in total (payload data packet)	payload_data
10	Payload time	Relative to GS start, local time, [s]	payload_time

The array names in column 5 are tagged with data processing levels e.g., GPS_vel_down_level_1, pitot_pressure_level_2. These data processing levels are described below.

Level 0: raw data, unpacked from the SD card

The binary data stored on the SD card is unpacked by a MATLAB script and stored in .mat format. This is called the level 0 data, but the “level 0” tag is not attached explicitly.

Level 1: time aligned data

The DataHawk autopilot samples and stores the data from various sensors at different rates (800Hz, 100Hz, 5Hz and 10Hz). Data are buffered into large blocks (at different rates) for time-efficient writing to the SD card, and some of these blocks fail to write. Also, an in-flight reset causes processor clock time to be reset and the normal SD writing process is suspended until the autopilot is re-initialized after a reset. Thus, the data fields are often found to be misaligned in time. In level 1 processing, the data fields are time aligned with each other using the GPS time of the week as a standard reference, inserting NaNs as necessary where data is missing. The output at the end of level 1 processing is stored with a tag "_level_1".

Level 2: calibrated data

Raw sensor data for some fields need to be calibrated to obtain relevant physical units. (Detailed calibration procedures are discussed elsewhere). The additional data fields created in level 2 are presented in the table below. The outputs at the end of level 2 processing are stored with a tag "_level_2".

Data array to be stored	**Array name**	**Sampling rate (Hz)**
Coldwire temperature [C]	coldwire_temperature	800
Hotwire airspeed [m/s]	Hotwire_airspeed	800
Pitot_airspeed [m/s]	Pitot_airspeed	800
Pressure altitude [m MSL]	GPS_cal_pres_alt	800

Level 3: spikes removed

The barometric pressure sensor, slow temperature sensor, and the relative humidity sensor data contain spurious "spikes". They also contain some NaNs from missing points inserted in the time alignment steps above). In level 3, the NaNs are first interpolated over, then the data fields are sifted through a median filter to identify spikes and the contaminated data points. These points are replaced by the interpolated mean value (mean of the previous and following data point). The outputs at the end of level 3 processing are stored with a tag "_level_3".

Level 4: interpolated NaNs

The calibrated airspeed, hotwire airspeed and the coldwire temperature (at level 2) data has some NaNs in it (from missing points inserted in the time alignment steps above). These are replaced by identifying consecutive NaN values (up to 4 consecutive data points) and apply linear interpolation to fill the data gaps. (Larger gaps are left as NaNs, because this interpolation can affect the spectral analysis, and these NaNs will then mark the spectral values with NaNs to indicate that the spectrum is corrupted.) The outputs at the end of level 4 processing are stored with a tag "_spec".

Summary

A table showing the list of variables stored at different processing levels is given for reference.

Sampling frequency (Hz)	**Level 0 Array (unpacked)**	**Level 1 Array (time-aligned)**	**Level 2 Array (calibrated)**	**Level 3 Array (de-spiked)**	**Level 4 Array (nan interpolation)**
800	rawPres45xx.P{1}	Pitot_pressure_level_1	-	-	-

800	coldwire.coldwire{1}	coldwire_voltage_level_1	-	-	-
800	Coldwire.hotwire{1}	hotwire_voltage_level_1	-	-	-
800	Coldwire.Time{1}	time_800hz_level_1	-	-	-
800	rawAccel.X{1}	x_accel_level_1	-	X_accel_level_3	-
800	rawAccel.Y{1}	y_accel_level_1	-	Y_accel_level_2	-
800	rawAccel.Z{1}	z_accel_level_1	-	Z_accel_level_2	-
100	rawBaro.P{1}	DH_baro_pres_level_1	-	DH_baro_pres_level_3	-
100	coldwire.H{1}	DH_rel_hum_level_1	-	DH_rel_hum_level_3	-
100	coldwire.T{1}	DH_slow_temp_level_1	-	DH_slow_temp_level_3	-
100	Batt.Time{1}	time_100hz_level_1	-	-	-
5	Gps.Lat{1}	GPS_lat_level_1	-	-	-
5	Gps.Lon{1}	GPS_lon_level_1	-	-	-
5	Gps.Alt{1}	GPS_alt_levele_1	-	-	-
5	Gps.Vnorth{1}	GPS_vel_north_level_1	-	-	-
5	Gps.Veast{1}	GPS_vel_east_level_1	-	-	-
5	Gps.Vdown{1}	GPS_vel_down_level_1	-	-	-
5	Gps.Time{1}	time_GPS_level_1	-	-	-
800	-	-	pitot_airspeed_level_2	-	DH_pitot_airspeed_spec
800	-	-	coldwire_temperature_level_2	-	DH_coldwire_temperature_spec
800	-	-	GPS_cal_pres_alt_level_2	-	-
800	-	-	-	-	-

Only the data from Level 1 – level 4 is made available to the end user. Missing data is represented with Not-A-Number (NANs) values in every array of all the data sets. The filename of each dataset is tagged with date and time prescribed in local time at the measurement location.

Data Remarks:

On analyzing the spectral content of the pitot airspeed data field, it was found that the airspeed measurements contain periodic artifacts corresponding to the structural mode of the UAS airframe. The analyst should use caution in using the spectral content of the pitot airspeed data as the spectra could be prone to biases due to the presence of the periodic artifacts.

It is strongly recommended to use the attached spreadsheet describing the sortie number, Flight number, time of the day and the flight launch location to gain additional insights into the science of the data.