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1.0 Data Set Overview

The data contained in this folder is the result of the TORUS 2019 campaign as recorded with the sensor suite onboard the University of Colorado RAAVEN (Robust Autonomous Aerial Vehicle-Endurant Nimble) sUAS (small Unmanned Aircraft System) Platform. Currently the data has been saved as netCDF files and Matlab files. The data contained in these files has been processed to **L1 (level 1)**. For the purposes of this data set, this means data that data has been examined, using dynamic pressure, to determine when the aircraft was in flight. Any data before and after these times have been removed. Furthermore, global time is recorded using the VectorNav-200 GPS (more information below). A microprocessor onboard the sensor data collection system is then used to take sample times that correspond to the sensors (time since sensor power-on). Since there is inherent error in microprocessor second measurements, the L1 data has accounted for this using the PPS (pulse-per-second) signal received by the GPS. However, it is important to note that this data is still in a sense raw. No estimators or calibration corrections have been applied to this data.

Included in this data set 'master' folder:

- RAAVEN_README.md - markdown file of the CU TORUS19 data sets
- RAAVEN_L1_mat - the MATLAB(.mat) files of the data
- RAAVEN_L1_nc - the NetCDF(.nc) files of the data The data set/flights are summarized by the following table:

Aircraft	Mission	Flight Number	Location (Lat Lon)	Date (UTC)	Flight Duration (min)	GPS Percent of Flight Acquired	MHP Data Check Pass for Percentage of Flight
RAAVEN2	Test Flight	1	39.0596 -98.7982	15-May-2019 21:37:42	10.0501	100	99.9488

Aircraft	Mission	Flight Number	Location (Lat Lon)	Date (UTC)	Flight Duration (min)	GPS Percent of Flight Acquired	MHP Data Check Pass for Percentage of Flight
RAAVEN2	Right Flank	1	39.3496 -100.2733	16-May-2019 22:18:59	78.4574	100	99.999
RAAVEN5	Left Flank	1	38.953 -100.1316	16-May-2019 21:35:11	36.5078	100	99.8618
RAAVEN2	Right Flank	1	40.31368 -100.2155	17-May-2019 23:22:50	64.7905	100	99.9597
RAAVEN4	Near Inflow	1	40.46036 -100.2295	17-May-2019 23:16:33	3.0683	100	100
RAAVEN4	Near Inflow	2	40.4604 -100.2296	17-May-2019 23:29:38	8.3415	100	99.9929
RAAVEN4	Near Inflow	3	40.52204 -100.0857	18-May-2019 00:18:48	6.98	100	99.5124
RAAVEN5	Left Flank	1	40.49674 -100.2323	17-May-2019 23:14:16	70.1994	100	90.1793
RAAVEN2	Right Flank	1	--	18-May-2019	--	0	95.6254
RAAVEN5	Left Flank	1	37.0207 -98.3019	18-May-2019 23:13:40	35.1722	100	85.7794
RAAVEN2	Right Flank	2	33.9823 -99.6834	21-May-2019 00:51:24	16.1782	100	99.7749
RAAVEN4	Near Inflow	1	34.6692 -99.6845	20-May-2019 20:51:52	60.8707	100	72.2007
RAAVEN4	Near Inflow	2	33.9827 -99.6833	21-May-2019 00:48:10	22.0664	100	69.093

Aircraft	Mission	Flight Number	Location (Lat Lon)	Date (UTC)	Flight Duration (min)	GPS Percent of Flight Acquired	MHP Data Check Pass for Percentage of Flight
RAAVEN4	Near Inflow	3	35.2648 -99.6417	20-May-2019 17:54:06	0.0006713	100	100
RAAVEN5	Left Flank	1	34.6692 -99.6845	20-May-2019 20:51:52	60.8707	100	72.2007
RAAVEN5	Left Flank	2	33.9827 -99.6833	21-May-2019 00:48:10	22.0664	100	69.093
RAAVEN2	Right Flank	1	36.20383 -100.2787	23-May-2019 23:58:49	65.9449	100	100
RAAVEN5	Left Flank	1	36.20183 -100.2782	23-May-2019 23:57:40	26.8995	100	81.8687
RAAVEN5	Left Flank	1	34.00647 -100.8578	24-May-2019 20:07:35	35.6782	100	59.8242
RAAVEN5	Left Flank	1	38.15892 -102.7373	26-May-2019 21:29:44	43.0576	100	97.9939
RAAVEN2	Left Flank	1	40.23342 -103.7761	27-May-2019 20:21:53	21.236	100	99.8182
RAAVEN2	Left Flank	2	40.26324 -102.7176	27-May-2019 22:56:51	70.43	100	74.6338
RAAVEN3	Left Flank	1	39.4464 -98.1141	28-May-2019 22:40:33	46.4979	100	94.1641
RAAVEN4	Near Inflow	1	39.35 -98.1117	28-May-2019 22:53:39	34.754	100	99.2731
RAAVEN4	Near Inflow	1	36.80787 -102.463	03-Jun-2019 00:35:51	15.0154	100	99.7429

Aircraft	Mission	Flight Number	Location (Lat Lon)	Date (UTC)	Flight Duration (min)	GPS Percent of Flight Acquired	MHP Data Check Pass for Percentage of Flight
RAAVEN5	Right Flank	2	--	02-Jun-2019	--	0	100
RAAVEN3	Left Flank	1	39.3556 -101.7304	08-Jun-2019 21:08:30	48.1353	96.1612	100
RAAVEN4	Near Inflow	1	--	08-Jun-2019	--	0	99.5696
RAAVEN4	Near Inflow	2	39.25305 -101.6522	08-Jun-2019 21:50:42	12.3043	100	98.7579
RAAVEN4	Near Inflow	3	39.13524 -101.3392	09-Jun-2019 00:32:16	39.8927	100	99.8774
RAAVEN5	Right Flank	2	39.34186 -101.6373	09-Jun-2019 00:17:37	13.6244	100	98.8525
RAAVEN3	Left Flank	1	36.86211 -100.9662	11-Jun-2019 20:47:02	60.8297	100	100
RAAVEN3	Left Flank	2	37.6853 -99.3183	12-Jun-2019 00:07:39	84.0251	100	98.9254
RAAVEN4	Near Inflow	2	--	11-Jun-2019	--	0	96.0136
RAAVEN5	Right Flank	1	36.86215 -100.9638	11-Jun-2019 20:45:14	30.2469	100	98.995
RAAVEN5	Right Flank	2	37.7252 -99.3253	12-Jun-2019 01:00:18	33.2611	100	97.7192
RAAVEN2	Left Flank	1	36.56019 -102.609	14-Jun-2019 00:42:31	47.0229	100	98.6108

Aircraft	Mission	Flight Number	Location (Lat Lon)	Date (UTC)	Flight Duration (min)	GPS Percent of Flight Acquired	MHP Data Check Pass for Percentage of Flight
RAAVEN4	Near Inflow	1	36.72792 -102.5005	13-Jun-2019 19:10:20	0.0016779	100	100
RAAVEN5	Right Flank	1	36.55927 -102.6068	14-Jun-2019 00:36:06	15.5571	100	99.9835
RAAVEN0	Right Flank	1	36.28879 -100.8179	14-Jun-2019 20:58:48	86.6904	99.8978	99.8948
RAAVEN2	Left Flank	1	36.50024 -100.8191	14-Jun-2019 21:16:00	93.1189	100	99.9979
RAAVEN4	Near Inflow	1	36.35063 -100.8748	14-Jun-2019 21:04:27	83.1288	100	99.903
RAAVEN0	Right Flank	1	35.04186 -102.4034	15-Jun-2019 22:24:34	58.8517	100	98.1984
RAAVEN2	Left Flank	1	35.0424 -102.3998	15-Jun-2019 22:29:15	79.3634	100	91.4065
RAAVEN2	Left Flank	2	35.03243 -102.7977	16-Jun-2019 00:01:59	20.3502	100	99.9621
RAAVEN4	Near Inflow	1	34.9822 -102.4296	15-Jun-2019 22:34:49	7.1205	100	99.6246
RAAVEN4	Near Inflow	2	35.08736 -102.6308	15-Jun-2019 23:15:08	20.7223	100	98.3854
RAAVEN4	Near Inflow	3	35.20386 -102.7462	16-Jun-2019 00:13:24	8.2331	100	99.9327

2.0 Instrument Description

The RAAVEN aircraft body is made by Ritewind rc (http://ritewingrc.com/) and outfitted by University of Colorado IRISS (Integrated Remote and In Situ Sensing). More information on the aircraft can be found at https://www.colorado.edu/engineering/2019/07/01/meet-raaven-drone-gathers-data-storms or on the IRISS webpage https://www.colorado.edu/iriss/.

Sensors include:

- GPS - VectorNav Rugged vn-200
    - Website: https://www.vectornav.com/products/vn-200
    - Known issues: the rugged version of the VN can lose GPS connection and doesn't save previous satellite data to memory (takes longer to locate satellites on boot up)
- Autopilot - PixHawk Cube
    - Website: http://ardupilot.org/copter/docs/common-thecube-overview.html
- PTH sensor - RSS421
    - Website: https://www.vaisala.com/en/products/instruments-sensors-and-other-measurement-devices/soundings-products/rs41
- MHP - Black Swift Technologies/IRISS custom probe
    - Black Swift Website: https://bst.aero/
    - We are still performing calibrations on this probe. There is a known calibration error in the reported airspeeds and wind angles. Therefore, this data can be used qualitatively, but please exercise caution when comparing with other data sets.

3.0 Data Collection and Processing

Data is recorded using the flex-logger, a data collection board developed at the University of Colorado. All data is saved as binary files and then converted in the first level of data processing (L0). As mentioned above, this is L1 data (data narrowed down to time of flight and the sample time has been corrected to the gps time). As mentioned above, a correction factor for the sample time is calculated by comparing the difference to the second measured on the microprocessor of the flex-logger and the PPS signal received by the gps. Each of the L1 data sensors has had the vn position, vn gps time data, and autopilot position data interpolated (nearest neighbor) to the frequency of the sensor.

The position of each sensor:

- The vn gps is located below the MHP sensor, both of which are located on the nosecone of the aircraft.
- The autopilot is located in the controls stack, near the rear of the aircraft.
- The RSS421 PTH sensor is located just behind the leading edge of the left wing, close to where the wing attaches to the fuselage. Current work is focused on obtaining inter comparison data sets for the RAAVEN data. However, none are currently available at this time. We are still working to calibrate and characterize the RAAVEN as a sensor suite.
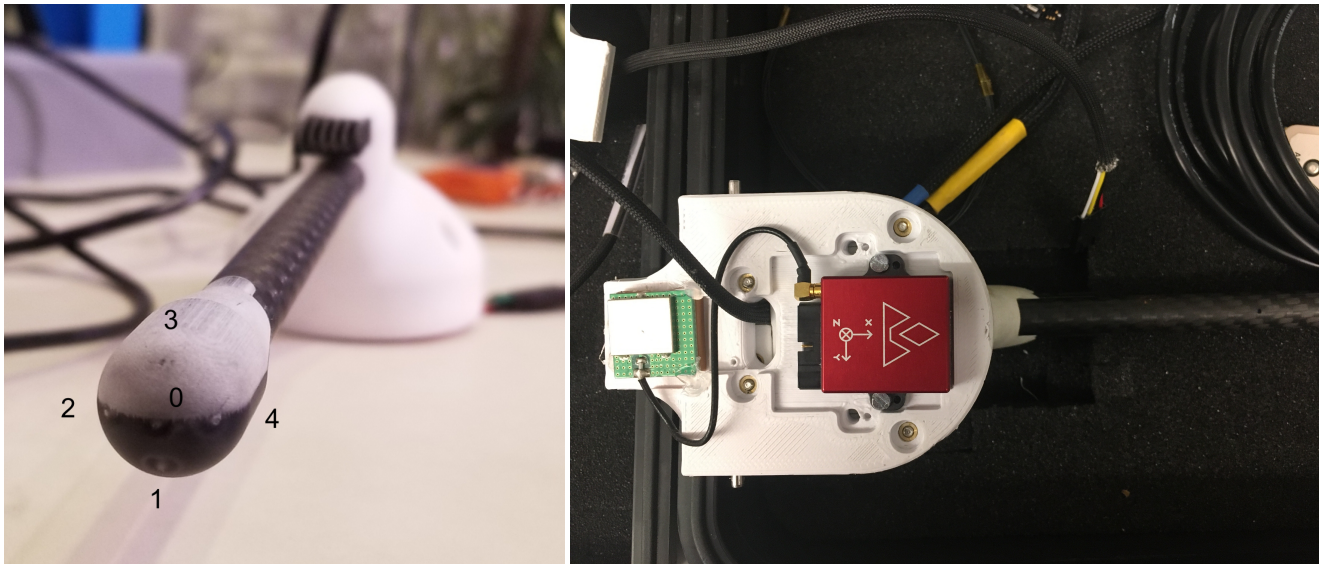
Above: MHP port numbering (left) and the placement of the vn on the MHP sensor (right).

4.0 Data Format

Important Repeated Variables

The following variables are repeated throughout the data TIME:

- gps_time
  - NANOseconds since the epoch January 06, 1980.
  - gps_time/1e9 = seconds since 1980-01-06\
  - This variable is measured by the VectorNav (GPS). The VectorNav does not usually acquire GPS immediately upon poweron. Therefore, the corrected sample_time(described below) is used to calculated the gps_time at power on. The corrected sample_time for each sensor is then used to calculated the gps_time for each sensor as well.
- sample_time -MICROseconds since the microprocessor that collects the data was powered on (~=time since aircraft was powered on).
  - Each sensor samples at a different frequency, therefore there is a different sample_time associated with each sensor. All microprocessors have a small amount of error in their measured second. Therefore, the sample_time_corrected variable has been corrected due to the gps second that is measured.

LOCATION:

- vn_lat, vn_lon, vn_alt
  - the VectorNav measures the GPS location of the aircraft. This is then interpolated (nearest-neighbor) for each sensor rate. Therefore rss421_vn_lat (netcdf file) or rss421.vn_lat (mat file) is the latitude of the aircraft, interpolated to the sensor rate of the rss421. Altitude is in meters MSL
- autopilot_lat, autopilot_lon, autopilot_alt
  - same as above but using the GPS coordinates measured by the autopilot.

Note: the VN measures at a higher frequency. Therefore, you will likely want to take the vn_… quantities for location. The autopilot values are really there as a backup

Data Variables

If using the .mat files, all data is contained in the mL1 structure (fields/sensors below are indicated by the filled in bullet point, non-filled in bullet points indicate variables). Example: roll variable measured by the autopilot attitude can be accessed in the .mat file by: *mL1.autopilot_attitude.roll* If using the .nc files, the sensors are indicated in the first part of the variable name. An underscore seperates the sensor name and the variable name. Example: the roll variable measured by the autopilot attitude is named in the .nc file as: *autopilot_attitude_roll*

A few notes:

- As mentioned above, the time and location data from the VN and autopilot are interpolated to the frequency of each sensor using nearest neighbor interpolation.

- The MHP data is not fully calibrated. Can be used qualitatively, but should not be directly compared to other measurement systems.

- There are three quality checks in the data.

    - vn_gps_fix or mL1.vn.gps_fix
        - This is checking whether or not the VectorNav has acquired a gps signal.
        - 0 : no signal
        - 1 : signal
    - mhp_MHPQuality or mL1.mhp.MHPQuality
        - This is checking whether or not the MHP pressure values are whithin a reasonable range.
        - 0 : they are not and the data should not be focused
        - 1 : they are (data should still be used with caution, see other notes on MHP data)
    - mhp_rh_check or mL1.mhp.rh_check
        - Occasionally the RH sensor on the MHP 'locks up'. When this happens, the sensor is no longer collecting new RH data for the flight. This is either 0 or 1 for the entire flight.
        - 0: RH sensor locked up
        - 1: has not locked up

- autopilot_attitude

    - sample_time (microseconds since microprocessor power on. units: microseconds)
    - yaw (rotation about aircraft vertical axis. units: degrees, -180 to +180)
    - pitch (rotation about aircraft transverse axis. units:degrees, -180 to +180)
    - roll (rotation about aircraft longitudinal axis. units:degrees, -180 to + 180)
    - ang_rates_x (angular rates about longitudinal axis. units: deg/s)
    - ang_rates_y (angular rates about transverse axis. units: deg/s)
    - ang_rates_z (angular rates about vertical axis. units: deg/s)
    - gps_time (NANOseconds since the epoch January 06, 1980. Interpolated from the VN gps time. units: nanoseconds)
    - vn_lat (VN latitude position, interpolated to frequency of autopilot note: -9999 if VN didn't acquire GPS)
    - vn_lon (VN longitude position, interpolated to frequency of autopilot. note: -9999 if VN didn't acquire GPS)
    - vn_alt (VN altitude position, interpolated to frequency of autopilot. note: -9999 if VN didn't acquire GPS)
    - autopilot_lat (autopilot latitude position, interpolated to frequency of autopilot)
    - autopilot_lon (autopilot longitude position, interpolated to frequency of autopilot)
    - autopilot_alt (autopilot altitude position, interpolated to frequency of autopilot (MSL))

- rss421

    - sample_time (microseconds since microprocessor power on. units: microseconds)
    - serial_num

- temp (temperature. units: K)
- press (pressure. units: hPa)
- rh (relative humidity. units: none(%)) \
- *for following variables see description above:*
  - gps_time
  - vn_lat
  - vn_lon
  - vn_alt
  - autopilot_lat
  - autopilot_lon
  - autopilot_alt

- autopilot_science

  - sample_time (microseconds since microprocessor power on. units: microseconds)
  - temp (temperature. units: K)
  - press (pressure. units:hPa)
  - wind_dir (wind direction (measured from N), ESTIMATED by autopilot. units: degrees, -180 to + 180)
  - wind_speed (wind speed ESTIMATED by autopilot. units: m/s)\
  - *for following variables see description above:*
    - gps_time
    - vn_lat
    - vn_lon
    - vn_alt
    - autopilot_lat
    - autopilot_lon
    - autopilot_alt

- vn

  - sample_time (microseconds since microprocessor power on. units: microseconds)
  - time_at_pps (time measured at the PPS - pulse per second)
  - time_since_last_pps (time since last pulse per second)
  - yaw (rotation about vn vertical axis (aircraft vertical/-Z direction). units: degrees, -180 to +180)
  - pitch (rotation about vn transverse axis (aircraft transverse/-Y direction). units: degrees, -180 to +180)
  - roll (rotation about vn longitudinal axis (aircraft longitudinal/+X dir). units:degrees, -180 to + 180)
  - ang_rates_x (angular rates about longitudinal axis. units: deg/s)
  - ang_rates_y (angular rates about transverse axis. units: deg/s)
  - ang_rates_z (angular rates about vertical axis. units: deg/s)
  - vel_x (velocity component along longitudinal axis. units: m/s)
  - vel_y (velocity component along transverse axis. units: m/s)
  - vel_z (velocity component along vertical axis. units: m/s)
  - acc_x (acceleration component along longitudinal axis. units: m/s^2)
  - acc_y (acceleration component along transverse axis. units: m/s^2)
  - acc_z (acceleration component along vertical axis. units: m/s^2)
  - temp (temperature. units: K)
  - press (pressure. units: hPa)
  - gps_fix (was GPS aquired by VN? 0 - no, 1 - yes)
  - *for following variables see description above:*
    - gps_time

- vn_lat
- vn_lon
- vn_alt
- autopilot_lat
- autopilot_lon
- autopilot_alt

- autopilot _position

  - sample_time (microseconds since microprocessor power on. units: microseconds)
  - vel_n (north velocity component. units: m/s)
  - vel_e (east velocity component. units: m/s)
  - vel_d (down velocity component. units: m/s)
  - heading (units: deg, 0 to + 360)
  - relative_alt (units: m, AGL)
  - *for following variables see description above:*
    - sample_time_corrected
    - gps_time
    - vn_lat
    - vn_lon
    - vn_alt
    - autopilot_lat
    - autopilot_lon
    - autopilot_alt

- mhp

  - sample_time (microseconds since microprocessor power on. units: microseconds)
  - static_press (static pressure. units: hPa)
  - air_temp (air temperature. units: K)
  - rh (relative humidity. units: none(%))
  - acc_x (acceleration component along vn longitudinal axis, measured by the vn. units: m/s^2)
  - acc_y (acceleration component along vn transverse axis, measured by the vn. units: m/s^2)
  - acc_z (acceleration component along vn vertical axis, measured by the vn. units: m/s^2)
  - ang_rates_x (angular rates about vn longitudinal axis, measured by the vn. units: deg/s)
  - ang_rates_y (angular rates about vn transverse axis, measured by the vn. units: deg/s)
  - ang_rates_z (angular rates about vn vertical axis, measured by the vn. units: deg/s)
  - dynamic_press_0 (dynamic pressure, measured by MHP center port. units: hPa)
  - dynamic_press_1 (dynamic pressure, measured by MHP port 1. units: hPa)
  - dynamic_press_2 (dynamic pressure, measured by MHP port 2. units: hPa)
  - dynamic_press_3 (dynamic pressure, measured by MHP port 3. units: hPa)
  - dynamic_press_4 (dynamic pressure, measured by MHP port 4. units: hPa)
  - alpha (sideslip angle with relative wind. units: deg, -180 to +180)
  - beta (angle of attack with relative wind. units: deg, -180 to +180)
  - q (dynamic pressure. units: hPa)
  - ias (indicated air speed. units: m/s)
  - tas (true airspeed (taking into account true density). units: m/s)
  - MHPQuality (simple check on MHP pressure values. If this is 1, the data is okay. If it is 0, there is an issue with the data - likely a blocked port.)

- rh_check (this is a check of the RH value. Sometimes it has been known to 'lock up'. When this happens the value is zero. Note, this is one value for the whole flight.)
- *for following variables see description above:*
  - sample_time_corrected
  - gps_time
  - vn_lat
  - vn_lon
  - vn_alt
  - autopilot_lat
  - autopilot_lon
  - autopilot_alt

Sensor Measurement Frequencies:

VectorNav	BS Multi-Hole Probe	RSS421 PTH Sensor	Autopilot
100 Hz	85 Hz	5 Hz	1 Hz

5.0 Data Remarks

In the work that has been done since TORUS19, it has been found that there is a calibration error in the reported pressures, wind speeds, and angles of the multi-hole probe. Furthermore, it is expected that blockage problems occur at high relative humidity. Please keep this in mind when using the MHP data. The relative humidity sensor on the MHP is also known to occasionally 'lock up'. If this happens, the MHP is not measuring (or the flex-logger does not log) updated values of the relative humidity.