

## Corke Requests

1. Bibliography of reports, studies, documents, presentations, data etc... provided to Joseph F. Horn and Continuum Dynamics, Inc.

All of the material provided to us by IDOT is available on the IDOT CMH website with following exceptions:

IDOT provided the following documents in support of the flight dynamics simulation:

BHT-206L3-MD-1: Rotorcraft Manufacturer's Data for the Bell 206-L3.

Select pages from BHT-207L3-MM: Bell 206-L3 Maintenance Manual.

Note that the input geometry used for CFD analysis was provided to CDI in a digital format from RWDI (as discussed in the Final Report).

2. CFD data used to develop report Figures 3.6-1 through 3.6-5, including the mean and fluctuating velocity components for the vertical and horizontal directions.

CFD data will be provided on DVD. Included on this DVD will be Matlab scripts/functions that were used to generate the figures (a README file is included on the disk in the "tools" directory to provide additional details).

3. Grid dependence study and time stepping study for the CFD model.

Documentation of the CFD model sensitivity study has been provided separately via e-mail. In addition, the documentation is included on the DVD containing CFD data.

4. Validation results used to define CFD model accuracy bounds for subsequent calculations/predictions and conservatism assessment.

Accuracy bounds may be assessed qualitatively based on the results provided in the report, and some quantification of model bounds may be derived from the CFD data provided on the DVD.

5. Uncertainty analysis for the time averaged and fluctuating velocity of the CFD model.

No formal uncertainty analysis was performed beyond benchmarking of the model as discussed in the Final Report.

6. Representative time series at a location along the flight path in the wake of a building and at a location over the heliport used as input to the helicopter flight dynamics simulation and its corresponding spectrum.

CFD data and tools provided on DVD are identical to the data/airwake “loader” used in the flight dynamics analysis. Thus, representative data may be extracted directly for additional analysis and study. In addition, representative time histories are plotted in response to Item 8 below.

7. Uncertainty analysis on the time length and blending period of the time history used for the airwake database.

There was no specific uncertainty analysis of the time length and blending period of the time history used for the airwake database. The flight dynamics used all of the valid time history available from the CFD calculations. Note that CDI ran the CFD cases for an extended time history until the flow fields were observed to be approximately stationary, after which the early part of the CFD time history was discarded (since it is affected by the start-up of the flow simulation). The data time histories discussed in Table 4.3-1 describe the remaining stationary flow field data that was used in the flight dynamics simulations.

The blending period is required to ensure a continuous time history of the velocities, when replaying the data. This can be seen in Figures 1 and 2 below, the velocity value at the end of the time history is equal to that at the start. The first three seconds of the velocity time history is a weighted average of the initial 3 seconds and the final 3 seconds of the original velocity time history. The blending period (3 seconds) was selected to be as small as possible while still producing a qualitatively smooth transition at the replay of the flow time histories.

It is standard engineering practice to use this kind of replay / blending method when simulating ship airwake effects on Navy rotorcraft.

8. Representative time series for wind case S11 with a scale factor 1 and rep. time series for wind case S11 with a scale factor of 0.839.

Representative time series are plotted in Figures 1 to 3 below in terms of the North, East, and Down components, as they were input to the flight dynamics simulations (including blending effect discussed in item 7). Note that positive values indicate wind blowing *from* the North, East, Down directions respectively. Figures 1 and 2 show wind velocity time histories over the heliport for case S11 with scaling factors of 1 and 0.839. Figure 3 shows wind velocity time histories at a point near the beginning of the approach path for case S11, scaling factor 0.839 (this is a representative time series along the approach path in the wake of a building as requested in item 6). The exact location is 1050 ft East and 680 ft North of the landing spot, and the altitude is 657 ft AGL. Sample data will also be provided on DVD.

9. List of CFD input conditions used to generate the data in Figures 4.4-1 and 4.4-2

Figures 4.4-1 and 4.4-2 show the power required and control positions for the Bell 206-L3 in trimmed flight as predicted by the flight dynamics model. Some data from the manufacturers data are also shown in the power required curve. These data are for the helicopter flying in

clean air. No CFD data was required to generate this data. It is based solely on the flight dynamics model.

10. Uncertainty bounds on the flight dynamic model validation for the Bell 206-L3 for the conditions along the flight path and at the heliport.

The MIDG-II IMU/GPS system provides uncertainty estimates for its measurement of aircraft attitude, velocity, and position. Uncertainties are estimated as “average” and “maximum” uncertainty bounds. These can actually change as the aircraft maneuvers. Typical values during an approach maneuver are:

Position: 2.6 ft Ave, 4.8 ft Max

Altitude: 2.0 ft Ave, 2.8 ft Max

Horizontal Velocity: 1.0 ft/sec Ave, 1.7ft/sec Max

Vertical Velocity: 0.22 ft/sec Ave, 0.30 ft/sec Max

Roll and Pitch Attitude: 0.76 deg Ave, 1.0 deg Max

Heading: 5.6 deg Ave, 6.6 deg Max

It should be noted there were bias errors in the pitch and roll attitudes of about 4.5 deg and 2 deg respectively. These were estimated by comparing the IMU/GPS output to the ADI display as seen in the video. The bias is probably due to some inclination of the mounting surface relative to the level reference plane of the helicopter.

There is significant uncertainty in video-based measurement of cyclic stick motion as used in the approach / departure maneuvers. However, no formal uncertainty bound calculation was performed. Based on engineering judgment, I estimate uncertainty in the range of  $\pm 5\%$  full throw. Since max stick motions in the approach and departure maneuvers were less than  $\pm 20\%$  of full throw, and thus this represents a significant uncertainty.

There is no specific uncertainty or sensitivity analysis of the flight dynamics model beyond what is presented in the report. Flight dynamics model accuracy was benchmarked against the flight test data (“truth data”) in Figures 5.3-1 to 5.3-8 of the report. Comparison of doublet responses between simulation model and flight data is standard engineering practice for benchmarking the accuracy of a flight dynamics model.

11. Any and all data used as the bases for the report’s conclusions regarding the super AWOS. Assumptions regarding sensitivity and time response of the super AWOS to wind gust, wind direction, and wind shear which were used to develop the report’s conclusions. Assumptions regarding the uncertainty of the super AWOS in measuring mean wind velocity, wind gust, wind direction, and wind shear which were used in the report’s conclusions.

There was only one conclusion regarding super AWOS in the report. This was conclusion #9, which said “There is potential for flow blockage effects to cause the proposed AWOS system to under predict the free stream winds at the altitude of the heliport ...”

This study is focused solely on the effects of urban airwake. Thus, the analysis of super AWOS was focused on the potential for urban airwake flow distortions to alter the measurements of the AWOS. This was done by simply comparing the mean velocities at various locations around the heliport and at a location near the start of the approach path, as described in Section 6.4. The study did not consider details of the AWOS instrumentation itself.

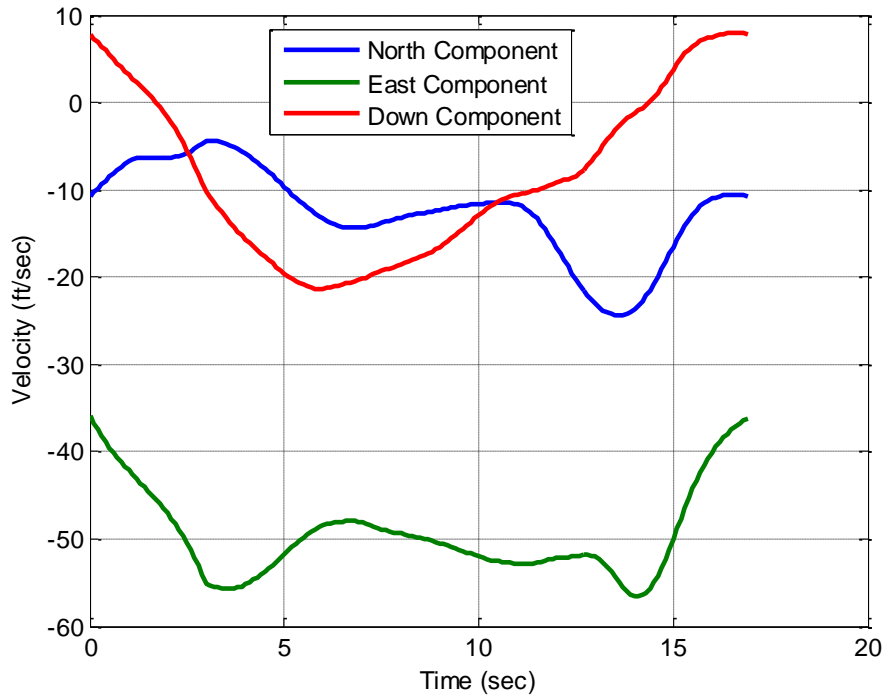


Figure 1 Complete Wind Velocity Time History, Case S11, 10m above Heliport, Scale Factor = 1

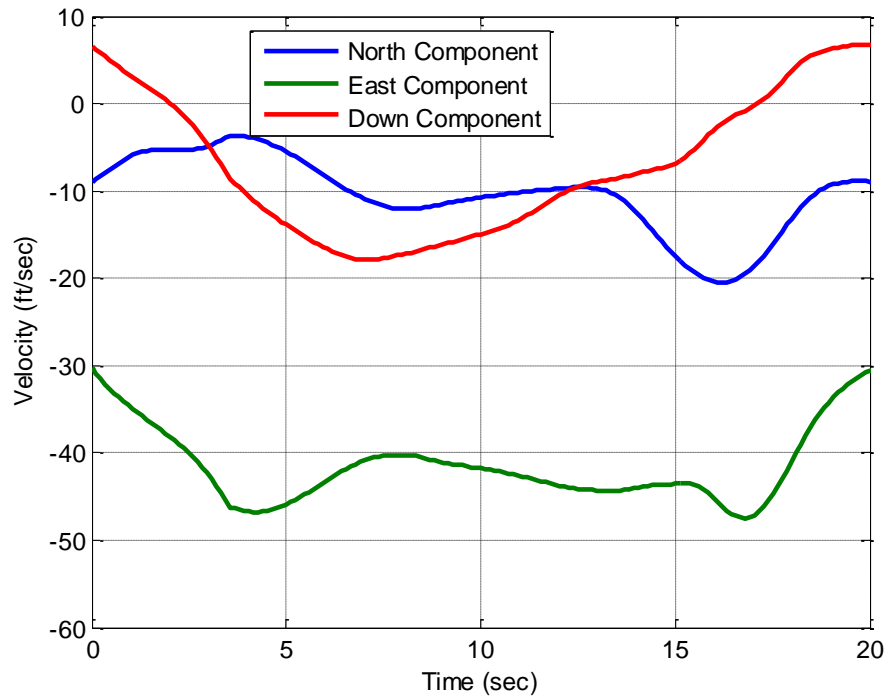


Figure 2 Complete Wind Velocity Time History, Case S11, 10m above Heliport, Scale Factor = 0.839

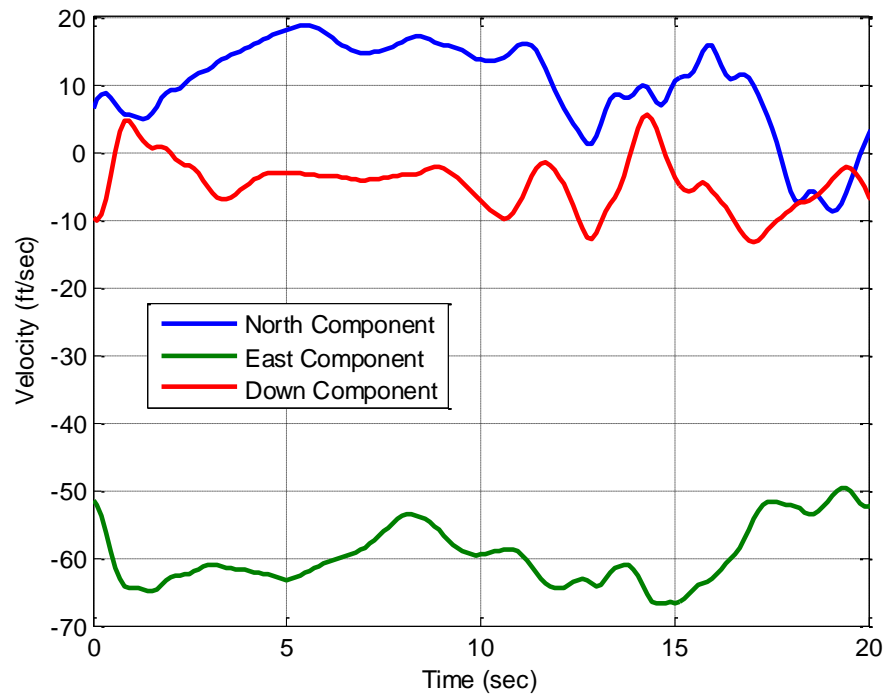


Figure 3 Complete Wind Velocity Time History, Case S11, at Location near the Start of NE Approach Path, Scale Factor = 0.839

## Veillette Requests

### 1. Aircraft airspeed, vertical speed, torque setting

Airspeed, vertical speed, and torque obviously varied throughout the approach, hover, and departure maneuvers. It also varied for the different cases due to differences in wind relative to ground speed.

Based on the inertial / GPS system used in flight tests, ground speed was between 80 and 100 ft/sec (50-60 kts) at the beginning and ending of each approach and departure maneuver in Runs 4, 14, and 15. The descent rate was on average 8 ft/sec (480 fpm) on the approaches. The climb rate was between 15 and 20 ft/sec (900 to 1200 fpm) during the departures.

For some of the cases the airspeed and torque data can be gathered from the videos. At least a portion of the instrument panel was visible in the videos of the approach and departure maneuvers. The VSI was also visible in some cases and essentially confirmed the vertical speeds measured by the inertial / GPS system. In the hovers, the airspeed drops below the threshold for accurate airspeed measurement (about 20 knots). In this condition the airspeed is basically equal to the wind speed.

During Run 4, the initial airspeed was 25 knots (do to a component of tail wind). The torque in descent was around 40-60%. Torque increases to close to 100% as the pilot arrests the descent. The hover was around 85-90% torque (the helicopter was hovering out of ground effect). Run 14 and 15 were similar but initial airspeeds were about 50-60 knots. Airspeed on the departures reaches about 60-70 knots in all cases.

In all of the simulation runs, the descent rate for the approach was set to 8 ft/sec, and the initial ground speed was 80 ft/sec, which is ramped down to 0 zero ground speed for the hover using a deceleration profile that was similar to that observed in flight tests. Initial airspeed is set to match the ground speed plus prevailing wind speeds at the start of the run.

### 2. Aircraft weight

During the flight tests aircraft weight was estimated to be approximately 4000 lbs. In the simulation runs, gross weight was set to the maximum takeoff GW of the Bell 206-L3: 4150 lbs.

### 3. Density altitude or assumed ambient temperature

The average temperature in the Chicago area on May 9, 2011 was 60°F (75°F High, 47° Low).

The assumed atmospheric conditions in all of the simulation runs was Sea Level, Standard (Sea Level pressure altitude, 59°F ambient temperature)

4. Uncertainty and sensitivity analyses

[See response to Dr. Corke's information request above.](#)

5. Videos

[The videos will be provided on DVD.](#)

6. Specification for zero reference point for all altitudes in simulation results.

[All altitudes in the approach simulations are plotted relative to the altitude of the heliport.  
I.e. Zero reference altitude is the altitude of the landing spot at the heliport.](#)