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Forest Service National Technology & Development Program

NTDP Tech Tips

Induced Wind From Fixed-Wing Aircraft During Fire Suppression Operations

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In 2006, before U.S. Department of Agriculture, Forest Service, National Technology and Development Program (NTDP) staff began drop tests with the 747 and DC-10 airtankers (also known as very large airtankers [VLATs]), members of the wildland firefighting community raised concerns about potential safety issues the aircraft could create during fire suppression operations. In particular, the community wanted to know about the occurrence and magnitude of turbulence generated by the aircraft and how this turbulence might affect fire activity on the ground.

Measuring 747 and DC-10 Turbulence

During preparation for the 747 and DC-10 drop tests in 2009, NTDP staff decided to determine if, and to what magnitude, these aircraft produce turbulence at or near ground level when performing retardant drops. At the drop test, the staff erected five towers and attached wind vanes and anemometers (sensors) to each tower to measure ambient wind direction and speed, as well as the wind direction and speed generated by each aircraft as it passed over. They attached the sensors to each tower at 8 feet, 24 feet, and 40 feet above the ground, and placed the 40-foot high towers in a line perpendicular to the downrange side of the drop zone at 60-foot intervals (figures 1 and 2). They also installed two weather stations at each end of the drop zone. Each weather station included a wind vane and anemometer mounted 15 feet above the ground. All sensors measured the horizontal wind component only. The staff programmed data loggers to continuously record wind direction and speed, measured by the sensors at 1-second intervals, and synchronized the data logger time stamps with a Global Positioning System unit mounted inside the aircraft to correlate sensor measurements with the passage of the aircraft.

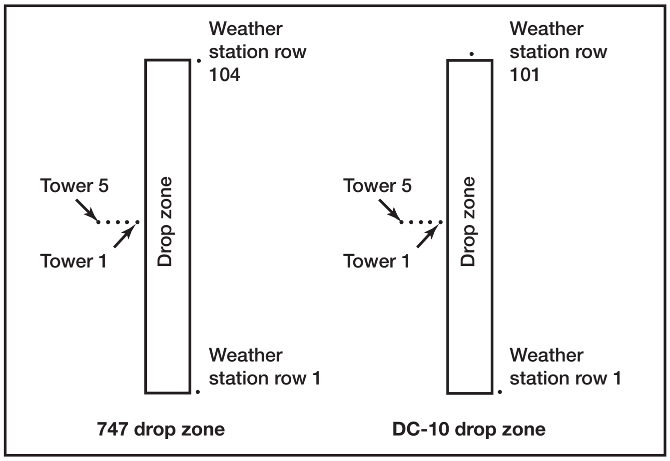

Figure 1—Diagram showing an aerial view of the 747 and DC-10 drop zones and the placement of the towers and weather stations.

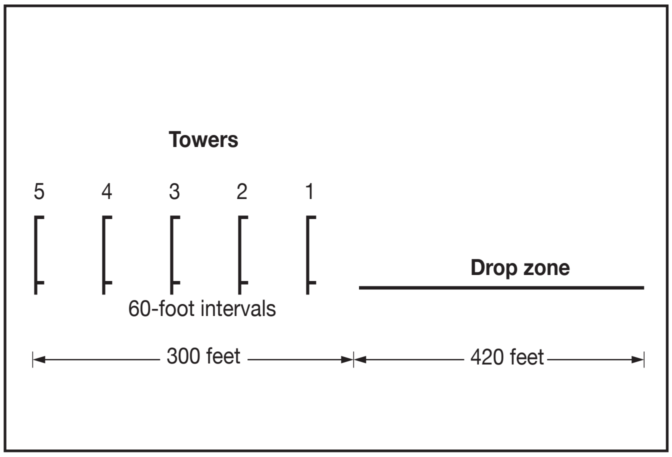

Figure 2—Diagram showing a ground view of the tower placement in relation to the drop zone.

People commonly refer to turbulence generated by flying aircraft as wing-tip vortices. However, wing-tip vortices are not necessarily the only turbulence generated by flying aircraft. Furthermore, wing-tip vortices are cylindrical in form and contain multidirectional wind components. Because the sensors only measured the horizontal wind component, NTDP staff could not determine if aircraft-induced deviations from ambient wind (wind events) were specifically wing-tip vortices. For this reason, this tech tip refers to the wind events as turbulence rather than wing-tip vortices.

Figure 3 shows windspeed data at tower 1 immediately before, during, and after the 747 passed over the drop zone flying at a drop height of 388 feet and a drop speed of 154 knots. In this example, the ambient windspeed before the aircraft passed over was 4 miles per hour (mi/h). The anemometer 8 feet above the ground recorded a peak windspeed of 10 mi/h above ambient, and the anemometer 40 feet above the ground recorded a peak windspeed of 12 mi/h above ambient. About 40 seconds elapsed from the time the wind event began to the time windspeeds returned to ambient levels.

Table 1 summarizes windspeed data for the 747 and DC-10 drop tests from sensors on tower 1 at 8 feet above the ground. NTDP staff calculated the average windspeeds above ambient from the number of observations with measurable turbulence.

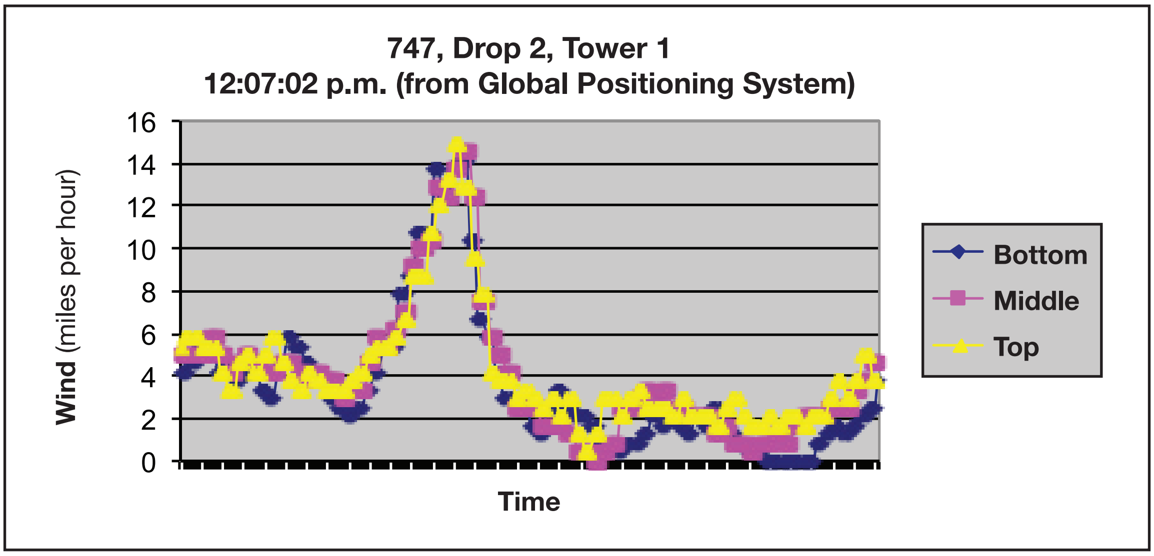

Figure 3—Windspeed measurements recorded by tower 1 anemometers before, during, and after the flyby of a 747 airtanker. The peak in the graph represents the measurements recorded during the flyby.

Table 1—Summary of wind sensor data from tower 1 and the weather stations during the 747 and DC-10 airtanker drop tests.

Aircraft and sensor position	Total number of observations	Number of observations with turbulence	Percentage of total observations with turbulence	Highest windspeed above ambient (miles per hour)	Average windspeed above ambient (miles per hour)
747 towers	32	29	91	19	10.2
747 row 1	26	20	77	21	7.6
747 row 104	31	11	35	25	8.3
DC-10 towers	23	11	48	14	8.5
DC-10 row 1	17	6	35	15	6.8
DC-10 row 101	23	14	61	17	9.7

Observations and Conclusions From 747 and DC-10 Turbulence Measurements

Ambient winds carry turbulence. In general, the sensors recorded turbulence when ambient winds blew in a direction from the aircraft to the towers or from the aircraft to the weather stations. During the 747 drop tests, the towers and weather stations stood on opposite sides of the drop zone. The direction of ambient winds prevailed from the drop zone toward the towers. Therefore, the tower sensors measured more occurrences of wind events than the weather station sensors.

Peak windspeeds varied, ranging from 2 to 25 mi/h above ambient for the 747 and 2 to 17 mi/h above ambient for the DC-10. In general, peak windspeeds recorded at 40 feet above the ground were 2 to 4 mi/h higher than the peak windspeeds recorded at 8 feet above the ground. The wind events generally lasted 20 to 40 seconds, with peak windspeeds lasting for only 1 to 2 seconds.

There was a 10- to 20-second delay between the aircraft passing and the start of a wind event with aircraft drop heights between 200 and 300 feet. Sensors on the tower closest to the drop zone detected the event first, with increasing detection delays by the tower sensors farther away. Turbulence magnitude decreased as it spread outward and away from the drop zone.

The ground effects of turbulence were not uniform along the line of flight. NTDP staff attributed this to the fact that not every pass of the aircraft generated measurable turbulence, even when the ambient wind direction was favorable. This did not indicate that these flights created no turbulence, but rather that no turbulence occurred within the vicinity of the sensors. Although it might be intuitive to conclude that turbulence magnitude depends on altitude, the lowest altitude passes did not always generate the most turbulence.

The towers and weather stations provided comparable data in terms of peak windspeeds and the duration of wind events. This is important because NTDP staff collected weather station data for drop tests of other fixed-wing aircraft types throughout the years. The following section summarizes the data collected for these systems.

Peak windspeeds varied, ranging from 2 to 25 miles per hour (mi/h) above ambient for the 747 and 2 to 17 mi/h above ambient for the DC-10. In general, peak windspeeds recorded at 40 feet above the ground were 2 to 4 mi/h higher than the peak windspeeds recorded at 8 feet above the ground. The wind events generally lasted 20 to 40 seconds, with peak windspeeds lasting for only 1 to 2 seconds.

Measuring Large Airtanker (LAT) and Single-Engine Airtanker (SEAT) Turbulence

Wind sensor data from the 747 and DC-10 drop tests revealed that these aircraft generate measurable turbulence at ground level. NTDP staff wanted to assess how these measurements compared to large airtankers (LATs) and single-engine airtankers (SEATs) performing fire suppression operations. The staff analyzed wind sensor data from drop tests performed by various aircraft during a period from the middle of the 1990s to the most recent tests. All of these tests included one weather station that recorded wind data from a position 25 to 50 feet from the downrange edge of the drop zone. Table 2 summarizes the windspeed data for various airtanker drop tests.

Table 2—Summary of weather station wind sensor data from various airtanker drop tests.

Aircraft	Total number of observations	Number of observations with turbulence	Highest windspeed above ambient (miles per hour)	Average windspeed above ambient (miles per hour)	Average height of observations with turbulence
Aero-Flite DC-4	45	15	7	3.7	291
Aero-Flite RJ85	24	20	11	7	215
Erickson MD-87	24	11	10	6.5	158
MAFFS II	46	29	13	6	163
Minden BAe-146	14	10	16	6.9	168
Martin Mars	8	7	11	7.9	217
Neptune BAe-146	53	20	9	4.4	186
L-188 Electra	86	34	22	7.5	188
S-2T	156	45	10	4.2	213
SP-2H	32	20	12	5.6	191
Coulson L-382G	8	7	10	4.3	185
Hatfield AT-802	9	7	4	2.6	79

Observations and Conclusions from LAT and SEAT Turbulence Measurements

For several reasons, drawing hard conclusions from the data presented in table 2 may be problematic. First, NTDP staff conducted the tests in various locations with different ambient windspeeds and prevailing direction (or lack of prevailing direction) relative to the position of the weather station. Second, the staff collected each datum from a single point along the length of the drop zone. The aircraft may have generated higher ground-level turbulence at a location where there was no sensor and, consequently, no data. Third, variation in the number of observations may have influenced peak windspeed values. For example, in spite of the difference in size and weight between the S-2T and the Martin Mars, the peak windspeed above the ambient windspeed was very similar. However, NTDP staff recorded 156 observations for the S-2T and only 8 observations for the Martin Mars.

In general, the data indicated that turbulence magnitude depends on aircraft size and weight. However, considering the size and weight difference between the VLATs and the LATs, the difference in turbulence magnitude is small.

Ambient winds during most observations were less than 12 mi/h. In the few observations with ambient winds above 12 mi/h, NTDP staff measured little or no turbulence or had difficulty determining if changes in windspeeds were the result of random wind gusts or aircraft-induced turbulence. Operationally, turbulence can be carried, mixed, or dispersed by ambient winds and may not be detected at ground level.

To request raw or additional data for any or all of the airtankers identified in this tech tip, please contact NTDP at 406–329–3900.

About the Author

Greg Lovellette is a physical scientist for the Forest Service National Technology and Development Program aerial delivery project. He has worked with the technical tank and gating aspects of aerial retardant delivery systems since joining the Forest Service in 1989.

About NTDP

The U.S. Department of Agriculture, Forest Service, National Technology and Development Program, provides Forest Service employees and partners with practical, science-based solutions to resource management challenges. We evaluate, design, and develop new technologies, products, and systems to solve problems and deliver solutions.

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Lovellette, G. 2019. Induced wind from fixed-wing aircraft during fire suppression operations. Tech. Tip. 1751–2304P–NTDP. Missoula, MT: U.S. Department of Agriculture, Forest Service, National Technology and Development Program. 6 p.

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This tech tip describes methods used by NTDP staff to collect wind data—specifically, wind turbulence—at or near ground level. It includes results from the 747 and DC-10 drop tests as well as results from drop tests of smaller airtankers.

Keywords: 747 airtankers, DC-10 airtankers, drop tests, large airtankers, LATs, single-engine airtankers, SEATs, turbulence, very large airtankers, VLATs, wingtip vortices, wildfires, wildland fires

Contact Information

Contact the National Technology & Development Program (NTDP) for additional technical information:

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