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# How to Conduct Static Tests of Aerial Retardant Delivery Systems



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## Overview of Static Testing

Since the 1950s, the U.S. Department of Agriculture (USDA) Forest Service has performed numerous drop tests to quantify the ground pattern deposition of aerial retardant delivery systems. During drop tests, aircraft drop retardant onto a grid of cups. The amount of retardant in each cup is measured to determine the amount of retardant reaching the ground at particular points (the ground pattern of deposition).

For a history of drop testing, refer to *Drop Testing Airtankers: A Discussion of the Cup-and-Grid Method* (0057–2868–MTDC, <http://www.fs.fed.us/t-d/pubs/htmlpubs/html00572868/>, Username: t-d, Password: t-d). During the course of these tests, scientists developed a relationship between drop configuration factors and deposition characteristics. The drop configuration factors include drop height, drop speed, ambient wind, temperature, humidity, retardant rheological properties, and flow history (flow rate). Of these factors, variation in flow rate produces the most variation in deposition characteristics.

In the early 1980s, a procedure known as static testing (Blakely, George, and Johnson: *Static Testing to Evaluate Airtanker Delivery Performance*, Gen. Tech. Rep. INT–78, February 1982) was developed to measure airtanker flow rate data that could be applied to ground pattern prediction models. The procedure is called static testing because it is performed with the aircraft on the ground rather than in flight (figure 1).



Figure 1—A static test of the Neptune P2V. An auxiliary power unit can supply power, eliminating the need to run the plane's engines during the test.

The tank can be mounted in the aircraft or on a test stand that allows the tank to be operated as if it was installed in the aircraft. In either case, the drop controller that electronically controls the flow rate and power to the system must be identical to that used during normal operation. The Forest Service performs static tests to gather information about system performance that can be applied to field use. Several Forest Service Technology and Development Program employees perform static tests.

Any owner, designer, or operator of a tank and gating system may request a static test to gather information about the system. If the operator intends to bid for a Government Exclusive Use contract, the Interagency Airtanker Board (IAB) must first approve the system. In the early 1980s, the IAB established airtanker performance criteria. The IAB has made several revisions since then. For a copy of the current criteria, send an e-mail message to: [glovellette@fs.fed.us](mailto:glovellette@fs.fed.us). Section 1 of the criteria lists the steps that operators must complete to attain IAB approval. One step is to complete a static test or drop test to evaluate system performance. The IAB determines which test is required on a case-by-case basis.

Usually, a static test will suffice if a similar system has been drop tested. The operator must make the initial contact with the IAB and complete the approval steps that lead to the static test. Then, the operator can contact the test team to begin preparations for the static test. The test team works as an advisor to the IAB and performs static tests at the board's request. The test team makes recommendations to the IAB based on the results of static tests.

An operator may request a static test for reasons other than IAB approval. For example, systems that carry less than 800 gallons or those used outside the United States do not need to be approved by the IAB. Operators may wish to document that a system meets IAB criteria to make their products more marketable. If the test team is notified by the operator, the team will determine whether the operator needs to contact the IAB before proceeding further.

Once a static test is complete, the test team will send the results to the operator and to the IAB. If the operator is seeking IAB approval, and the test is successful, the test

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## ***Static Testing Overview***

team also will include a letter recommending approval to the IAB. This does not mean the system is approved. Final approval is made only by the IAB through a formal letter of approval. Systems tested outside the IAB approval process may require additional testing if the operator seeks approval later.

Forest Service policy requires the operator to pay all costs associated with the test through a collection agreement. The costs include wages, travel, and per diem for the test

team. The collection agreement includes an estimate of the cost of performing the test and outlines the responsibilities of the USDA Forest Service and of the operator. Payment must be received before testing begins.

To start preparing for a test, the team needs a general description of the tank including tank drawings (preferably in electronic form). Knowing the type, design, and size of the tank will help the team identify the test goals and discuss them with the operator.

## Equipment

The test team maintains an inventory of equipment, including linear displacement transducers (floats), pressure transducers, door potentiometers, a turbine flow meter, battery packs, power converters, data acquisition hardware and software, laptop computers, and video equipment. Certified calibration of test equipment is performed by the manufacturer at recommended intervals.

The float (figure 2) consists of a stainless steel rod with a sensor attached to the top. A floating steel ball with a hole through it travels along the length of the rod as it tracks the fluid level in the tank. Voltage output depends on the position of the ball along the length of the rod. The length and number of floats needed for a test depends on the tank's design. For example, if the tank has compartments with different geometries, each compartment will have to be instrumented. If the geometry of an individual compartment is not uniform, several floats may have to be mounted in the same compartment.

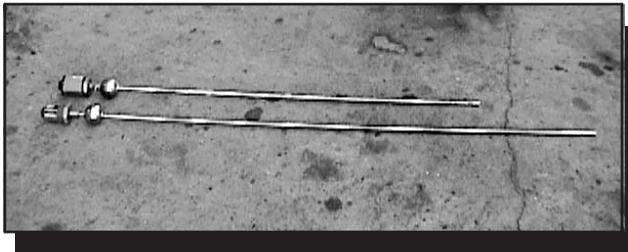


Figure 2—The proper length of the float depends on the size of the tank.

A differential pressure transducer (figure 3) is used to measure negative pressure in the tank when it is being emptied. This transducer has two ports. The active port is exposed to the inside of the tank through a length of plastic hose. The reference port is exposed to atmospheric pressure. Voltage output depends on the differences in pressure between the two ports. Power input is regulated to keep the baseline output constant. Often, the plastic hose is moved to different tank locations during a test to check for pressure differences.

Door potentiometers record door movements as the tank is being emptied. The potentiometers are mounted to a bracket, which is mounted on the tank so that the potentiometer shaft

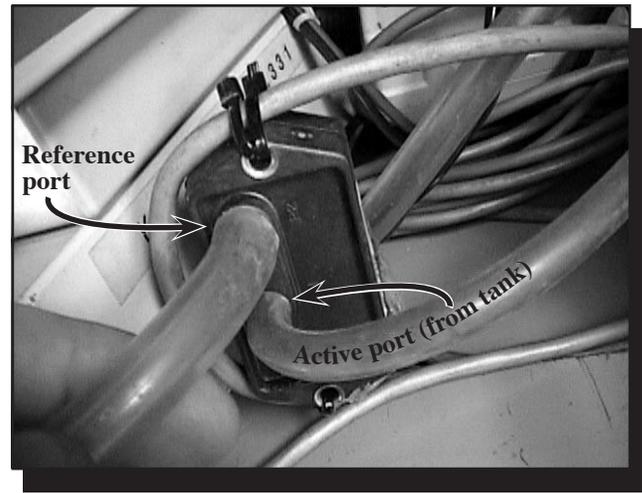


Figure 3—A hose must be attached from the reference port to the aircraft's exterior if the tank relies on cabin air for venting.

lines up with the door hinge. A stiff wire is attached to the potentiometer shaft and the door. As the door swings open, the wire turns the potentiometer shaft. Voltage output changes as the shaft rotates. Power input is regulated to keep baseline output constant. Video equipment may be used to measure door movement and operation rather than door potentiometers.

A turbine flow meter and totalizer are used to calibrate the floats and to confirm the volume of the system being tested. The meter is placed inline with the loading hose. The totalizer converts meter output into gallons and provides an output of one pulse per gallon.

Gel-cell battery packs (12 volt) are the most reliable and simplest power sources for static test instruments. They are relatively light, compact, and rechargeable. Aircraft power may be used for test instruments but the current drawn by the instruments can interfere with the tank controller or the aircraft's electrical system. It is safer to use gel-cell battery packs.

Data acquisition hardware consists of a connection board, a laptop computer, and a PCMCIA card for the laptop computer. The connection board's terminal block connections provide a simple and versatile means of attaching wire leads from instruments (figure 4).

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**Equipment**

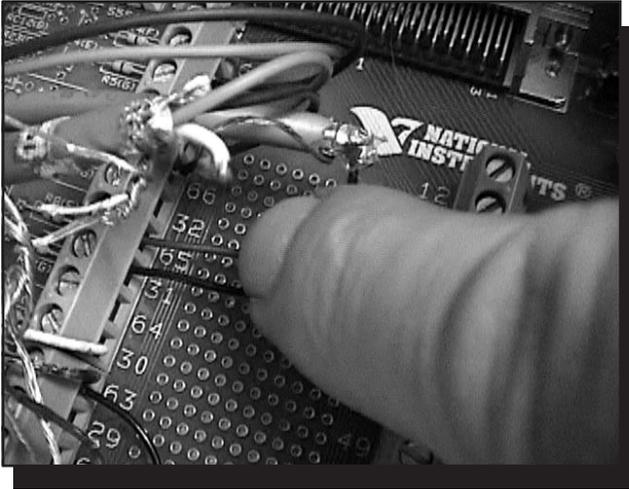


Figure 4—Instrument output connection board. MS-type (military specification) connectors are needed for permanent instrument installations, but connection boards with terminal block connections, such as the one shown, are suitable for temporary static test installations.

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## Test Preparations

**A**fter discussions with the operator and a review of the tank drawings, the test team will prepare equipment needed for the test. The test team will bench test all equipment before packing it for travel.

The operator also has responsibilities for test preparation. If the operator is seeking IAB approval, the operator must understand fully all requirements listed in the criteria, and be confident that the tank has been designed and modified to meet those requirements. As mentioned earlier, the operator is responsible for all costs associated with the test, including the cost of additional tests if the first attempt is unsuccessful.

The operator also must provide:

- A water source able to deliver 500 gallons per minute

- Hoses, fittings, and valves between the water source and the tank loading port
- 110-volt power supply to the aircraft or the tank test stand
- Personnel who can operate and repair the tank and gating system
- Auxiliary power to operate the system during testing (the operator may choose to run aircraft engines to provide power)
- A small workspace for data acquisition and reduction

Depending on the system, a static test may use up to 75,000 gallons of water. A barrier can be placed under the tank to capture and recycle water.

## Equipment Installation

Typically, the test team travels to the operator's facility. On arrival, the test team meets briefly with the operator to discuss test plans and makes a brief inspection of the tank to verify information about the system.

The test team works with the operator's personnel when installing test equipment (figure 5). To prevent the possibility of damage to the tank, aircraft, or instruments, the different pieces of test equipment and their mounting locations are discussed before the equipment is installed.

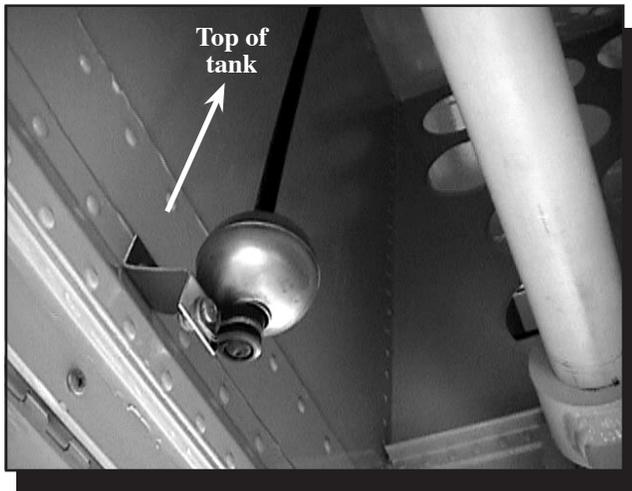


Figure 5—For this float installation, a rivet was drilled out near the bottom of the tank and replaced with a small bracket-mounting bolt. When the test was completed, the float was removed, and the rivet was replaced.

The floats are mounted so that the bottom of each float is as close to the bottom of the tank as possible without interfering with the door or other internal moving parts. The float needs to be long enough so that the head will not be submerged when the tank is filled (or overfilled). A  $\frac{3}{8}$ -inch hole is often drilled in the top of the tank and the float is mounted through it (figure 6). Because the float tracks the fluid level during evacuations, the float must be mounted where the change in fluid level is an accurate representation of flow out of the tank. There should be at least 3 inches of clearance between the float shaft and any tank walls or dividers. No internal shelves or hardware should be nearby to cause surface turbulence during evacuations (figure 7). Problems with some mounting locations may not be noticed until after initial data are collected. In these cases, the float may have to be relocated.

The pressure transducer is placed where the reference port is isolated from pressure variation during evacuations. If pressure measurements need to be made in different sections of the tank, the plastic hose connected to the measuring port can be moved to those locations without moving the transducer.

The data acquisition hardware can be set up in the aircraft, or in a vehicle or utility trailer parked next to the aircraft. The laptop computer requires 110-volt power.



Figure 6—Two floats were mounted in this tank. The float head at the left is nearly flush with the tank cover. Because of the of the tank's vent design, the floats could not be mounted through vent openings.

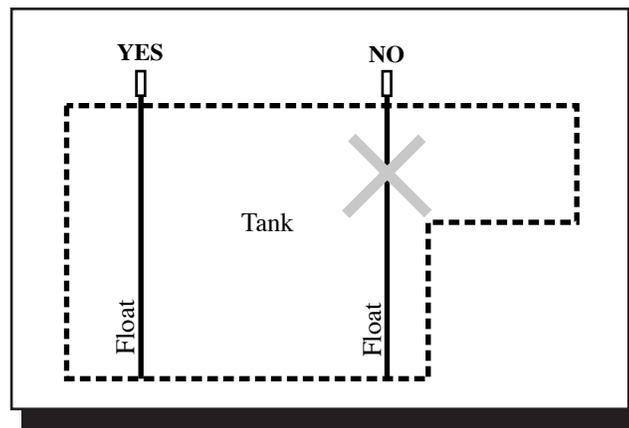


Figure 7—The float on the right is too close to the shelf. As the tank evacuates, fluid flows off the shelf, causing turbulence. Avoid mounting floats in turbulent areas.

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## Float Calibration

**A**fter the instruments have been installed and are working properly, the floats need to be calibrated. As the tank is filled using the turbine meter, the data logger counts gallons and records float voltage output as each gallon enters the tank. The resulting data logger file (fill file) for each float contains two data columns: the first

lists gallons in the tank and the second lists the corresponding output voltage. Each float is calibrated three times and the data from each calibration is graphed for comparison. The most representative fill files are selected and used to convert voltage output to volume for the rest of the test. If a float is replaced or relocated, calibrate it again.

## Data Acquisition

Flow data are collected from a series of drops that include all possible system drop configurations. Float output ranges from 0 to 10 volts. Voltage is highest when the ball is closest to the sensor. Voltage decreases as the ball travels to the lower end of the rod. In other words, voltage is high when the tank is full and falls as the tank is evacuated. While the tank is being evacuated, the data logger software records the voltage output of all the instruments at a selectable scan rate. Typically, a scan rate of 100 times per second is used. Immediately after each release is complete, the acquisition program displays a graph of voltage output over time. This display provides an initial interpretation of tank performance. The voltage curve on the display should drop off evenly as the tank is evacuated.

Effects of tank geometry may cause the curve to be non-linear. For example, if the tank is wide at the top and narrows at the bottom, the voltage curve will not be as steep at the top and will be steeper at the bottom. Because the fill file will contain the same nonlinearity, the calculated volume discharged will be accurate.

If the curve is irregular or contains a sine wave pattern (figure 8), causes other than the tank geometry may be generating the irregularities. In such cases, the problem must be investigated. A visual inspection, including a video record of the fluid surface during the evacuation, often will reveal the problem. The solution may be to move the float to a different location where the change in fluid height more accurately represents the flow from the tank.

After the test team collects and analyzes data from the first series of drops, the team can determine whether adjustments or modifications are needed to flow rates, door move-

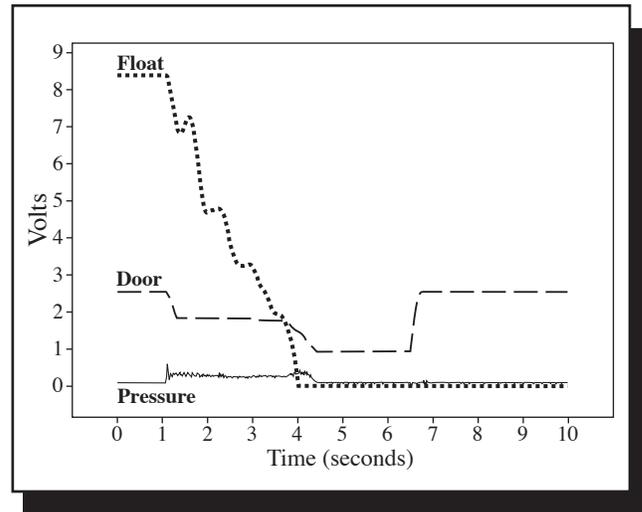


Figure 8—This raw voltage trace indicates uneven float movement due to surface turbulence during evacuation.

ment, or internal pressures. Often, the operator can make immediate adjustments and testing can continue. As adjustments are made, data are collected and analyzed to determine the effect of the adjustment. Additional adjustments may be needed depending on results. It is not unusual to repeat a drop configuration several times while adjusting the system to achieve the desired effect.

Once all the necessary adjustments have been made, another drop series is collected for all configurations. This drop series quantifies tank performance in its final design configuration. If no problems are encountered during this drop series, a replicate drop series is collected to establish reproducibility. If no problems are encountered after the second series has been completed, and the two series meet IAB reproducibility requirements, data collection is complete.

## Data Reduction

The collection of raw voltage outputs from the instruments is saved in data files. These files contain columns of data where each column represents the output of each instrument. For example, raw data files from a static test that uses two floats, a pressure transducer, and a door potentiometer would contain four columns of data. The number of data points in each column depends on the scan rate and duration. For example, if output was being recorded 100 times per second for 10 seconds, each column would contain 1,000 data points.

Data are collected several seconds before the start and several seconds after the end of the evacuation. The first step in data reduction is to “trim” the raw data files so they contain only the data collected during the evacuation. Using the fill file discussed above, the float data are converted to gallons. The scan rate allows float data to be related to time. The change in volume over time is used to calculate flow rate. A second test team member usually reduces the data that have been collected while the first member collects additional data.

The two methods of flow rate calculation are known as instantaneous flow rate (IFR) and average flow rate (AFR). Table 1, derived from raw static test data, contains time, volume discharged, instantaneous flow rate, and average flow rate.

Both IFR and AFR are calculated by dividing the volume discharged by the time required for evacuation. The IFR is calculated by dividing individual increments of volume discharged by the corresponding time increments (as defined by the scan rate) during the evacuation. The IFR data reveal changes in flow rate while the evacuation is taking place, but the data are sensitive to signal noise and surface turbulence. During the 0.1-second increment between 0.2 and 0.3 seconds into the evacuation (table 1), the volume discharged goes from about 57 to 44 gallons (negative 12.6 gallons discharged)

Table 1 — Volume discharged, instantaneous flow rate, and average flow rate for 2.1 seconds of a static test. *NaN* stands for *not a number*.

Time	Volume discharged	Instantaneous flow rate	Average flow rate
0	0	0	NaN
0.1	13	126	126
0.2	57	440	283
0.3	44	-126	147
0.4	44	0	110
0.5	57	126	113
0.6	69	126	115
0.7	69	0	99
0.8	82	127	102
0.9	94	125	105
1	100	60	100
1.1	107	64	97
1.2	113	65	94
1.3	120	63	92
1.4	126	67	90
1.5	132	62	88
1.6	139	64	87
1.7	145	61	85
1.8	151	59	84
1.9	157	65	83
2	164	62	82
<b>2.1</b>	<b>170</b>	<b>67</b>	<b>81</b>

with a corresponding IFR of negative 126 gallons per second. Obviously, fluid did not flow back into the tank. Surface turbulence caused the float ball to rise during this time increment.

Using the beginning of the evacuation as a reference point, the AFR is calculated by dividing the cumulative volume discharged by the corresponding time. For example,

after 1 second of the evacuation (table 1), 100 gallons had discharged with an AFR of 100 gallons per second. The complete evacuation took 2.1 seconds, discharging a total of 170 gallons for an AFR of 81 gallons per second. Typically, the AFR at or near the end of the evacuation is used to report the “flow rate” of a given release and also to qualify tank performance based on IAB criteria.

Figure 9 is a graph of instantaneous and average flow rate data. The IFR curve displays wide oscillations during the evacuation. These oscillations probably are caused by surface turbulence. Often, the IFR curve is smoothed to help interpret flow rate trends during the evacuation. The smoothed IFR curve indicates that the flow rate peaks early in the evacuation and decreases to zero at the end.

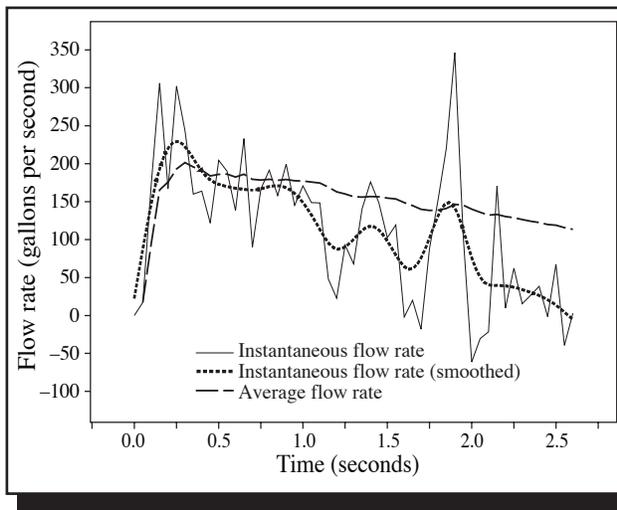


Figure 9—Graphs of instantaneous and average flow data recorded from a single tank release. The IFR curve often is smoothed to remove wide variations caused by signal noise and surface turbulence. The AFR curve provides an overall average of the flow rate

The AFR curve follows the IFR curve, but is smoother because variations in flow rate are averaged. Figure 9 is typical of a low-flow drop from a conventional tank. Throughout the evacuation, the door opening at the bottom of the tank does not change. At the start of the release, the head height is the greatest, producing the highest static pressure at the bottom opening and the highest flow rate. As the tank evacuates, head static pressure and IFR decrease.

Constant flow systems open the doors wider as the tank evacuates, producing an even IFR throughout the evacuation. As the tank evacuates, head and static pressure decrease, but the door opening increases to compensate, keeping the flow rate constant. Significant variation in IFR will cause uneven drop deposition patterns.

The test team maintains a notebook during the test. The notebook contains the date, system tested, drop series and sequences, drop configurations, and comments. The comments document problems encountered with test equipment or the system being tested, observations, and adjustments made to the system during the test. A comprehensive notebook is valuable when writing the final test report.

The test team uses video equipment during the test to measure door operation. Video footage often will reveal anomalies unnoticed at the time of the test. These anomalies can be quantified using video analysis. Video footage is used to measure the door speed, timing of trail drop sequencing, side deflection, residual flows, and internal tank dynamics during releases. Video narration should be included as much as possible. Video images are used as illustrations in test reports.

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## Test Timeframe

A static test usually takes 3 to 5 days to complete. The first day is spent traveling to the test site, and mounting and calibrating instruments after arrival. Data collection takes 1 to 3 days, depending on the complexity of the system and the problems encountered. The last day is spent removing instruments, packing equipment for travel, and discussing the test with the operator. During this debriefing, the test team discusses the test goals that were accomplished, the problems that were encountered, whether

problems were fixed or need additional attention, and any followup plans.

Once the test team returns to the office, members prepare a more formal report. This report includes reduced data presented in tabular form, a discussion about the test process, problems encountered, and recommendations. The report is sent to the operator and to the IAB chairman, usually within a few days after completion of the test.

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## Notes

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## Notes

## About the Author

**Greg Lovellette** is a physical scientist for the Aerial Retardant Delivery Program. He received a bachelor's degree in chemistry from the University of Montana in 1980.

Before joining the Forest Service in 1989, he worked as an oil well analyst throughout Montana, Wyoming, and North Dakota. He joined MTDC in 1998.

## Library Card

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Describes tests conducted, while an aircraft is on the ground, that can be used to measure the rate of retardant flow from tanks that deliver and drop retardant ahead of wildland fires. Generally, these static tests can be used only when more complex drop tests have been performed with a similar system. During drop tests an aircraft makes a drop over a grid of cups. The amount of retardant in each cup is measured to determine the pattern of the retardant's ground coverage. Because the flow rate is the biggest factor determining the

pattern of ground coverage, static tests that determine the flow rate of particular tank and gating systems can provide valuable information less expensively than drop tests. The Interagency Airtanker Board establishes criteria for tank and gating systems. The board determines whether static or drop testing is required for new or modified tank and gating systems. The tests are conducted by teams from the Aerial Retardant Delivery Program at the Missoula and San Dimas Technology and Development Centers following the procedures described in this report.

**Keywords:** aerial delivery, aerial methods, field tests, flow rates, Interagency Airtanker Board, tank and gating systems, test procedures, testing, wildland fire chemical systems

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