USFS Very Large Aerial Tanker

Operational Test and Evaluation

Summary Report

March 2, 2009

10 Tanker DC-10

Evergreen B-747

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This report, delivered under Modification 2 to Interagency Agreement SAA2-402113 between NASA and the U.S. Forest Service, has been approved for public release.

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1.0 Executive Summary

The objective of this limited assessment was to evaluate the safety and utility of the DC-10 and Boeing-747 (B-747) in the Aerial Retardant Delivery role using best available data. Specific objectives associated with this effort were to:

a. Verify the **airworthiness** of the DC-10/B-747 aircraft with the Aerial Retardant Delivery mission environment and flight profiles.
b. Determine the **mission compatibility** of the DC-10/B-747 aircraft with the Aerial Retardant Delivery mission environment and flight profiles.
c. Develop (if one/both aircraft are assessed as airworthy and compatible with the Aerial Retardant Delivery mission) **recommended operational usage regimes, policies, and procedures** for incorporation by USFS and Department of the Interior (DOI)

All of these objectives were accomplished. To do so, NASA utilized data provided by the customer, vendors, and other sources to analyze the performance, handling qualities, systems, and structural suitability of the DC-10 and B-747 as potential Very Large Aerial Tanker (VLAT) aircraft. Simulator and – in the case of the DC-10 – in flight evaluations of the aircraft during mission-representative tasks were performed. Based on this analysis, conclusions and recommendations were developed and are provided in Sections 5.0 and 6.0 of this report. Very brief summaries are provided below.

AIRWORTHINESS: Both aircraft were judged to be airworthy in the configurations under evaluation. These assessments were made based on review of supplemental type certificate (STC) and retardant delivery system documentation, as well as limited inspections performed on the DC-10 airframe and retardant delivery systems. Long term fatigue-related structural life remains an area in need of further study, but the test team concluded that the ongoing USFS continuing airworthiness program (CAP) should enable adequate monitoring of fatigue life issues.

MISSION COMPATIBILITY: It was concluded that VLAT aircraft are probably compatible with the wildland fire suppression mission, provided that they are used to supplement other aerial retardant delivery platforms rather than replace them in all environments. Steep or rugged terrain, reduced visibility due to smoke and ash, and situations where topography or other factors result in irregularly-shaped delivery zones will affect any aerial retardant delivery aircraft, but it is believed these scenario characteristics will affect VLATs to a larger degree, and may preclude their effective use for certain classes of fires, particularly those with small or irregularly shaped delivery zones. Extremely rugged terrain will make setting up for stabilized deliveries challenging, particularly where the pilot must judge wingtip terrain clearance while maneuvering over irregular terrain for setup. These conclusions are based on pilot comments generated during multiple simulated deliveries using high-fidelity visual simulators over various terrain types. Dispatch decisions will need to take these and other factors into account.

USAGE RECOMMENDATIONS: The major recommendations for employment that result from this study relate to required terrain clearance, the type of terrain, availability of qualified lead planes, low-altitude maneuvering limitations, and size and shape of the desired delivery zones. The analysis suggests that for level or gently rolling terrain where level to slight descents (< 6-7%) are required, VLAT-class aircraft could probably be employed with few restrictions as long as they remained above 300' AGL during the delivery. Power margins for this class of aircraft, even considering the possibility of single engine failure during delivery, may actually permit climbing deliveries over very gradual slopes of less than 3 – 4 % grade, provided suitable egress options are available. Usage in very steep or rugged terrain is not recommended unless deliveries can be performed with minimal maneuvering, a lead plane is available, and adequate terrain clearance is available at the wingtips as well as on centerline. Until significant experience is gained on VLAT platforms, at least 400' terrain clearance should be maintained in this kind of scenario, and a climb must be initiated before any turns. It was also found that on-board systems like auto-throttles and combined use of both radar and barometric altitude alerts could reduce pilot workload as well as provide improved situational awareness. These findings are also based on pilot comments generated during multiple simulated deliveries using high-fidelity visual simulators over various terrain types, as well as on direct observation of experienced aerial firefighting crews performing both airborne and simulator retardant delivery runs.

More detailed discussion of these and other results are provided in the remainder of this report.

2.0 Introduction

A brief background for this program is given in Sub-Section 2.1 while objectives are provided in Sub-Section 2.2.

2.1 Background

The U. S. Forest Service (USFS) is evaluating the potential of employing converted commercial B-747 and/or DC-10 aircraft for wildland fire fighting in the Aerial Retardant Delivery role. These aircraft are termed "Very Large Air Tankers", or VLAT, by the USFS. The USFS has no previous experience operating aircraft of this size, and wishes to develop a plan to utilize these aircraft safely and effectively. However, neither the USFS nor the Department of the Interior feels they possess the necessary flight test related skills to develop this plan or to properly assess the aircraft. Therefore, the USFS engaged the NASA Dryden Flight Research Center (DFRC) (in conjunction with the Ames Research Center) to plan and conduct an evaluation of the VLAT aircraft to provide the necessary data to support the eventual development of a USFS VLAT implementation plan. The NASA VLAT Operational Test & Evaluation (VOT&E) team included simulator expertise provided by Ames' Aerospace Simulation Research and Development branch; Dryden's Operations, Aerodynamics and Propulsion, Dynamics & Controls, and Aerostructures branches; and contractor support provided by Computer Sciences (CSC) Corporation, and Systems Technologies Inc (STI). This report describes the methods used, the test results, as well as the conclusions and employment recommendations that flow from those findings.

2.2 Objectives

The primary objective of this assessment was to evaluate the safety and utility of the DC-10/B-747 in the Aerial Retardant Delivery role. Specific top-level objectives associated with this effort include:

- Verify the airworthiness of the DC-10/B-747 aircraft with the Aerial Retardant Delivery mission environment and flight profiles.
- Determine the mission compatibility of the DC-10/B-747 aircraft with the Aerial Retardant Delivery mission environment and flight profiles.
- Develop recommended operational usage regimes, policies, and procedures for incorporation by USFS and DOI.

To support the USFS objectives and verify airworthiness of the aircraft, NASA conducted inspections of contractor activities concerning structural integrity, procedures, quality assurance, and unique systems. To determine mission compatibility NASA analyzed handling qualities and performance characteristics of large supertankers relevant to the fire-fighting role. In addition to these activities the intended flight operations of the airplanes were evaluated.

This report documents the approach, analysis, results, and conclusions of NASA to meet airworthiness and mission compatibility objectives for the use of large supertankers in the fire-fighting role. Based on the analysis, recommendations to the USFS are provided regarding operational usage, policies, and procedures for the deployment of these airplanes. Future research work is also suggested.

3.0 Technical Approach

This Section describes the approach to analyzing the airworthiness and mission compatibility of large transports in the fire-fighting role. Structural issues, as well as maintenance processes and procedures are addressed in Sub-Section 3.1. Flight operations, performance, and handling qualities issues are addressed in Sub-Section 3.2 and 3.3.

3.1 Airworthiness Evaluation Approach

The airframe airworthiness review focused on the FAA FAR parts that provide the loads and structural analysis requirements for the two types of VLAT aircraft considered. The two FAA FAR Parts reviewed were FAR Part 25 “Airworthiness Standards: Transport Category Airplanes” and Part 26 “Continued Airworthiness and Safety Improvements for Transport Category Airplanes”. Part 25 is used by the industry for analyzing large commercial passenger and cargo aircraft. Part 26 establishes requirements for support of the continued airworthiness of and safety improvements for transport category airplanes. These requirements may include performing assessments, developing design changes, developing revisions to Instructions for Continued Airworthiness (ICA), and making necessary documentation available to affected persons. Holders of type certificates and supplemental type certificates similar to those that apply to Aerial Tankers are bound by the provisions of Part 26.

VLAT aircraft operate differently from typical commercial aircraft by spending a larger percentage of their flight time at low altitudes, where gust levels are higher and more frequent. In addition, VLAT aircraft are required to fly at low altitudes to drop fire retardants, often in mountainous areas. This often requires them to maneuver more aggressively than passenger and cargo aircraft. FAR Part 25 & Part 26 were reviewed to determine if they provide the same level of airworthiness to VLAT aircraft as they do for typical large transport aircraft.

The airworthiness of the retardant delivery systems themselves was also evaluated along with aircraft maintenance and operations. The process for performing these evaluations had three parts: First, retardant delivery system documentation provided by the aircraft operators was reviewed to provide familiarity with the basic system design. Second, where the opportunity presented itself, an on-aircraft inspection of the actual system installation was performed. Areas where airworthiness or safety might be in question were noted. Third, the aircraft maintenance processes and procedures were reviewed, as well as aircrew and maintenance training practices and documentation. The results of these evaluations are presented in Section 4.

To conduct the airworthiness evaluation several resources were examined including instruction, operating, maintenance, and flight manuals, experts in the field, and other relevant material.

3.2 Mission Compatibility Approach

Three main elements are included in the mission compatibility evaluations: aircraft performance, handling qualities, and operational usage. The evaluation was performed in four phases.

The first phase consisted of interviews with current tanker pilots and others familiar with current aerial fire-fighting operations, as well as review of pertinent documents on the subject of aerial firefighting.

The second phase consisted of analysis of existing B-747 and DC-10 aircraft performance data, with comparison to the performance of current air tankers such as the P-3, to determine basic suitability of the aircraft for the mission.

The third phase utilized full motion B-747 and DC-10 flight simulators, to evaluate handling qualities, aircraft performance, and operational processes and procedures. This phase used the simulators to evaluate a representative sample of mission profiles and generate data that was used to analytically determine key airplane parameters, and evaluate the operation of VLAT class airplanes in various terrain and configurations.

The fourth phase consisted of flight observations in the candidate VLAT aircraft. These flights were conducted with the DC-10 VLAT aircraft operated by 10 Tanker and the lead plane normally used in their operations as part of routine aircrew training/proficiency flights.

3.3 Understanding Current Operations

In order to gain a basic understanding of fire fighting operations with the current generation of aerial tankers, the NASA VOT&E team conducted multiple interviews with experts familiar with the mission. The team then conducted separate interviews with operators familiar with the operational capabilities of the VLAT class of retardant delivery aircraft. The results of these interviews have been incorporated in Sections 4 – 7 of this report.

The team also examined the Interagency Tanker Board "Multi-Engine Air Tanker Requirements" dated 1998 as a benchmark for VLAT aircraft mission compatibility and compared predicted and simulator performance characteristics against those required by the IATB. Other references, including studies of mishap rates and causes, FAA TFR procedures, information on Fire Traffic Areas, and company Flight Manual Supplements were also reviewed.

Other documents created for or by the Forest Service were also reviewed. Previous flight qualities and stability and control studies were also examined.

To support the operational analysis of VLAT class aircraft, simulator sessions were performed to investigate a variety of operationally relevant aircraft configurations and settings. Approaches and drops were flown with variations in flap settings, restricted visibility, landing gear deployment, and active or inactive auto-throttles. Where appropriate, altimeter and airspeed reference settings were varied. A major component to be evaluated was flying approaches in a variety of terrains, including gentle hills and rugged mountains. Attacking simulated fires going up-slope and down-slope with profile variations to match descent rates to the slope of the terrain were also a part of the investigation.

Three basic retardant delivery evaluation tasks were established as simulation tasks for the purpose of stressing the pilot-vehicle system. The tasks were designed to be relevant to the fire-fighting mission, yet challenging, so that potential undesirable characteristics in the pilot-vehicle system could be identified and documented. The tasks included a nominal straight-in approach with roughly 3-5% glideslope; a level off, and a pass over a targeted fire line where retardant delivery was simulated (Figure 3.1).

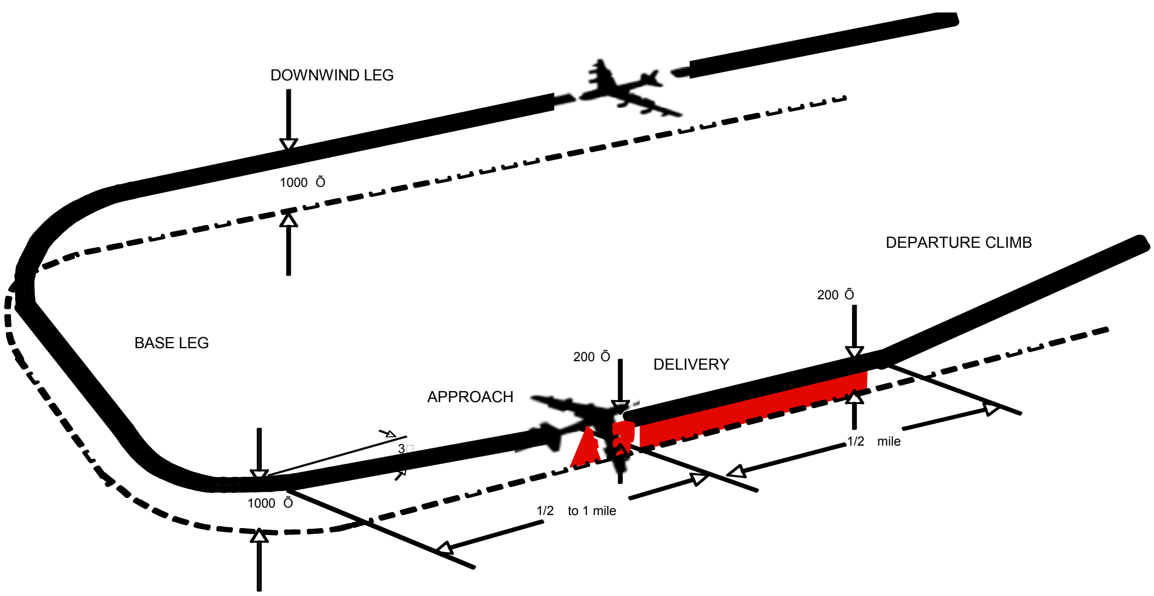

Figure 3.1: Nominal Retardant Delivery Profile

4.0 Results

Note: These results are based on technical analysis of available aircraft performance data validated where possible via simulator. In flight evaluations of the DC-10 were also performed, and those results are documented here as well.

Results fall into two categories. The first category is basic airworthiness of the VLAT airframes and the retardant delivery systems as integrated into those airframes. The second category is the operational compatibility of this class of aircraft with the basic and/or specially tailored aerial retardant delivery mission as envisioned. This report addresses the airworthiness for each aircraft individually. It then discusses mission compatibility for the VLAT class as a whole.

4.1 DC-10 Airworthiness Results

Structural evaluation, retardant delivery systems, and inspections and maintenance evaluations for the DC-10 are provided in the following sub-sections.

4.1.1 Structural Evaluation Results

FAR 25.571 Damage Tolerance and Fatigue Evaluation of Structure require "the typical loading spectra" be used in the analysis. This should include the appropriate gust and maneuver loading magnitudes and frequencies VLAT aircraft are going to experience. Furthermore the gust levels stated in FAR 25.341 Gust and Turbulence Loads and Part 25 Appendix G "Continuous Gust Criteria" are altitude dependent. For VLAT aircraft that spend much of their flight time in low altitudes, this means higher gust level assumptions need to be used in the analysis, which was done in this case. As always, such assumptions are only estimates, so actual gust loads data captured via the CAP will be valuable in confirming the structural analysis performed.

The recently released FAR Part 26 subpart E requires Type Certificate and Supplemental Type Certificate holders to perform Damage Tolerance Evaluation for alterations and baseline structures are affected by the alterations. According to the Federal Register (Vol 72, December 12, 2007, DoT FAA Damage Tolerance Data for Repairs and Alterations), "…in some cases, air carriers improperly classified repairs and alterations that affect fatigue critical structures as "minor" and damage tolerance evaluations were not conducted.". With the newly created FAA rules, Part 26 ensures damage tolerance evaluation is done for all alterations.

4.1.2 DC-10 Retardant Delivery System Results

After examination of system documentation and explanatory discussions with the operators, NASA engineers found the retardant delivery systems to possess a suitable level of engineering design and redundancy.

4.2 B-747 Airworthiness Results

Structural evaluation, retardant delivery systems, and inspections and maintenance evaluations for the B-747 are provided in the following sub-sections.

4.2.1 Structural Evaluation Results

See Section 4.1.1

4.2.2 B-747 Retardant Delivery System Results

After examination of system documentation and explanatory discussions with the operators, NASA engineers found the retardant delivery systems to possess a suitable level of engineering design and redundancy.

5.0 Conclusions

All three objectives were addressed and, in part, met.

The first objective, to evaluate the airworthiness of the VLAT Class or aircraft, was too broad to completely meet in a limited test program. Since the mission tasks are entirely within the normal flight envelope of the aircraft, airworthiness can be assumed based on certification of the aircraft. The simulator tasks showed that the required maneuvers could, with some reasonable limitations, be conducted within the certified flight envelope. Since the simulator was not quite “production representative”, an unqualified statement about airworthiness cannot be made. However, based on aerial fire retardant delivery simulations conducted in the simulators, it can be stated that the aircraft exhibit no performance or handling qualities short falls that would cause them to be non-airworthy in the environment tested. We also concluded that they are basically suitable for the mission, with some limitations. The testing conducted in this program led to a preliminary evaluation of what those limitations might be, and several limitations are suggested. Further testing and analysis is needed to provide a comprehensive set of limitations for the VLAT Class of aircraft.

The second objective was to determine compatibility of the aircraft for the fire retardant delivery mission. Again, with limitations and further testing/analysis required, the aircraft were found to be suitable for the mission.

The final objective was to develop procedures for use of this class of aircraft for this mission. The testing led to several possible procedural recommendations that are discussed in Section 6. Again, more testing would be needed to refine these ideas and make specific recommendations.

5.1 B-747 Airworthiness and Mission Compatibility Conclusions

The B-747 airworthiness and mission compatibility conclusions are presented in the following sub-sections.

5.1.1 Airworthiness Conclusions

The team concluded that complying with FAA Part 25 and Part 26 (Damage Tolerance Evaluation should be updated to Part 26 if it was completed before Part 26’s release) should provide the same level of safety for the VLAT aircraft as for regular commercial large transport aircraft, provided suitable maintenance and inspection protocols are put in place. The USFS CAP program designed for extensive, long-term structural monitoring of these airframes should provide a suitable method to capture relevant structural integrity data and enable operators to sustain these airframes in an airworthy condition for the long-term.

5.1.2 Mission Compatibility Conclusions

Based on the limited simulator flight-testing conducted in this study, the B-747 Supertanker was considered suitable for the USFS fire fighting mission. Further testing should be conducted to refine the results of the Phase II tests, and develop additional operational procedures and techniques. Options for even better results include changes in airspeed control procedures and possibly to flap settings in the drop zone.

5.2 DC-10 Airworthiness and Mission Compatibility Conclusions

The DC-10 airworthiness and mission compatibility conclusions are presented in the following sub-sections.

5.2.1 Airworthiness Conclusions

The team concluded that complying with FAA Part 25 and Part 26 (Damage Tolerance Evaluation should be updated to Part 26 if it was completed before Part 26's release) should provide the same level of safety for large firefighting aerial tankers as for regular commercial large transport aircraft, provided suitable maintenance and inspection protocols are put in place. The USFS CAP program designed for extensive, long-term structural monitoring of these airframes should provide a suitable method to capture relevant structural integrity data and enable operators to sustain these airframes in an airworthy condition for the long-term.

5.2.2 Mission Compatibility Conclusions

No adverse performance or handling qualities problems were observed that would make the DC-10 unsuitable for the fire retardant delivery mission. The generally pleasing handling qualities inherent in the DC-10 made the operational tasks relatively straightforward. The DC-10 flights validated some findings from the simulator as both lateral and vertical offsets and corrections were observed.

The NASA VOT&E team viewed the 10 Tanker operations for several hours around their facility on 13 Nov 2008. The operation appeared to be professionally run and manned by dedicated pilots, crew, and maintenance personnel. The flights permitted the team to view the spotter aircraft operation from inside the Lead Aircraft and also observe operations from the flight deck of the DC-10 as they conducted several deliveries. The accuracy of the drop appeared suitable for the planned mission.

5.3 VLAT Overall Mission Compatibility

Although the majority of operational task evaluations were performed in the B-747 simulator, owing to the higher fidelity of the visual system, a limited number of runs were also performed in the KC/DC-10 simulators. As a result, the test team concluded that the VLAT class as a whole is airworthy and compatible with the mission. Some specific compatibility aspects are addressed in Table 5.1.

Table 5.1: Mission Factor Compatibilities

Mission Factor	Compatibility			Remarks or Employment Considerations
	none	partial	full	
Required Infrastructure		X		May need added ramp area and specialized servicing equipment
Deployability		X		See above
Lead Plane Requirements		X		Specially trained lead pilots will be needed during initial ramp-up
Range/Endurance			X	
Airspace Usage		X		May need special handling to avoid wake turbulence issues for others
Terrain/Density Alt			X	
Delivery Speeds			X	At top end of desired range
Accuracy			X	When used in appropriate scenarios
Coverage Levels			X	
Reserve Performance			X	Excellent

6.0 Deployment Recommendations

This section includes initial recommendations for usage based on available data. Most recommendations are provided along with the basic rationale for each.

6.1 Recommended Pre-Flight Preparations

1) Recommended minimum equipment requirements: No changes are proposed. Current operational procedures appear to be satisfactory.
2) Changes to crew training to enhance safety and effectiveness: See the recommended changes to delivery procedures in section 6.3 below.
3) Changes or refinements to maintenance and inspection regimes: No specific changes are proposed at this point, but it should be expected that as data are captured under continued airworthiness program, operators will be positioned to make appropriate adjustments to maintenance and inspection routines to ensure long-term airworthiness.

6.2 The Dispatch Decision

1) Terrain types and clearances based on available climb gradients with 1 engine out do not suggest more restrictive operational criteria than existing aerial tankers or lead planes. There is actually higher performance than existing tankers due to the proposed VLATs operating at a much lower weight than their original design even taking into consideration their slightly faster speed.

   Recommendation: Temperature and pressure altitude conditions that are suitable for other firefighting assets should prove more than sufficient for a positive dispatch decision for the VLAT class of tankers.

2) Terrain types and clearances based on available non-accelerating descent gradients was not quantified in the limited time available in the simulators, but it was apparent that these aircraft are low drag optimized and do not provide a high non-accelerating descent rate without the use of drag devices. This was not explored in the simulations. A higher drag would also provide an extra margin of safety if the extra drag could be reduced quickly by forcing the engines to be "pre-spooled" at a higher thrust setting.

   Recommendation: Delivery situations that require steeper than average descent angles for a successful delivery may preclude use of the VLAT class until suitable drag devices and usage procedures are proven.

3) The VLAT class of aircraft is designed to handle the same approach and landing wind and turbulence for their normal operation as the other aerial tankers. The approach is currently flown in a similar manner, with an extended low pass before executing a go-around. High altitude airports are similar to high altitude fire locations with the exception of the close proximity to trees and rugged terrain. This very important difference is handled with the current procedure where the Lead Aircraft flies a pass above the target drop height. This should be continued in order to assess the turbulence and winds at a safe height, followed by another pass at the expected

drop height. The Lead Aircraft with its lower wing loading will be more sensitive to conditions than the VLAT and will call off runs that exceed safe operation. The extensive experience of the aerial tanker crews are of prime importance to determining safe conditions and staying within safe limits.

Recommendation: Maintain requirement for use of Lead Aircraft whenever terrain is questionable, and avoid sending inexperienced VLAT crews into steep or rugged terrain.

4) Because the VLAT aircraft are operating at a weight that is approximately half their maximum design gross weight, even a 2 G turn is well within their performance capability. These aircraft have an excess of performance that is not normally seen in passenger operations in order to provide a very high level of comfort to the ordinary traveler. That performance is rarely called upon to save the aircraft from danger, but is there if needed. The impression that the VLAT aircraft are slow and not very maneuverable comes from that standard operational experience where the slow, slightly banked turn is the norm. Takeoff performance and the steep climb angle that is obtained give some glimpse into what can be expected when that performance is needed.

   Recommendation: See item 1 above.

5) Predicted delivery effectiveness, if used in accordance with recommended procedures, is excellent and provides a wider and longer fire break than the smaller aerial tankers. This is a new tool that will enhance the existing fleet which would need to make multiple overlapping passes to create the same line. Techniques will be developed as the firefighting team learns the VLAT strengths and weaknesses. For example: where the terrain is too steep for the VLAT to follow the contours, the smaller tankers can overlap the line to complete the defenses with fewer drops and therefore less time consumed by the turn around.

   Recommendation: While VLAT aircraft have a good "partial load" capability, their use when multiple disjointed drops are required should be carefully evaluated for safety and cost-effectiveness prior to dispatch.

6) The handbooks used by the firefighters to determine coverage levels based on fuel and the flame length that an aerial drop is effective against will need to be updated to include the capability of the VLAT class of aircraft to lay a very wide, as well as long, line. The coverage level 8 setting at the nominal drop height of 300 or 400 ft would be reduced at higher drop heights, but would also be wider, with the ability to slow the advance of fires with longer flame length. By making multiple passes, the VLAT may actually be able to do this since it has a relatively quick turn around time and a high flight speed or could make partial drops in one sortie where current tankers would need to make many more flights, or require more aircraft in the circuit. There simply could be insufficient time available to create that kind of line before the fire advanced.

   Recomendation: See 5 above.

7) Current limits for aerial tankers limit their use to clear visual conditions for terrain and obstacle avoidance and should be followed for VLAT aircraft. Simulation with 3 mile visibility was at the limit of the ability of the pilot to make a successful approach to the drop point. The simulation did not have a lead plane and the difficulty that may pose to visually see the smaller aircraft against smoke plumes and ground clutter, nor the advantage that a lead plane provides in showing the VLAT where to fly, nor the sense of depth, detail, and wide field of view that is available to a pilot flying in the real world.

   Recommendation: Carefully consider the VLAT dispatch decision if visibility is a factor.

6.3 Retardant Delivery Profiles

Both aircraft have developed good retardant delivery profiles and crew coordination. The use of a Lead Aircraft on a single monitored frequency reduces the chance of radio distractions and improves drop communication. Crew coordination and division of aircrew duties are excellent.

The ride along with the DC-10 during practice runs was perhaps the most beneficial of the tests. The team was able to observe first hand how they used the procedures they developed for retardant delivery. Limitations of the simulator did not include following a Lead Aircraft or a good visual for changing terrain. The entire fire fighting mission hinges around being at a delivery altitude that optimizes the fire retardant without compromising the delivery aircraft. VLAT ridgeline crossings enroute or on exiting may need to be constrained more than the typical 200-300 foot AGL altitude minimum often used by current generation tankers.

Terrain clearance is visual with clearance based on pilot comfort. This is hard to do in a simulator because the visual system is not made for this mission. Despite the exceptional flying demonstration in the simulator, the approaches crossing ridges seemed to be unconstrained – almost overlooked – during the concentration to meet speed and altitude on target. Large aircraft have larger wingtip and fuselage clearance requirements and bear constant consideration. Everyone seemed to agree that this is the one area with a potential for disaster or problem, especially if the crew is distracted by reduced visibility, target fixation, or there is an error by the Lead Aircraft. The current generation aerial tanker technique of 30 degrees max bank angle at low altitude may be inadequate. Consideration should be given to making altitudes slightly more restrictive to account for the longer wing span of these aircraft. On those rare occasions when they do have to fly lower than the delivery height above a ridge line to set up for the drop, it is imperative that they be lined up for the drop to avoid ridge-crossings while still in a banked attitude.

Recommendation: Develop terrain clearance guidelines and training.

The aural warning (or similar) circuit breaker was pulled to eliminate nuisance warnings during drops. This may silence all warnings, however, and should not be done on the aircraft especially if forgotten to be reset during return to base.

Recommendation: VLAT warning systems could be designed so that nuisance warnings can be inhibited without disabling any other warnings. Operational procedures and checklists should include the reactivation of all warning systems prior to approach and landing.

Several runs were made with reduced visibility. When visibility was lowered to 3 NM, the task became much more difficult. Misalignment with the target required about a half mile for assessment, and correction to the target drove up pilot workload significantly. Adequate performance was achievable, but moderate or greater pilot compensation was needed. When visibility was increased to 5 NM, the task became much easier. With visibility at 10 NM, the visibility was almost not a factor at all. Experience has shown that the simulator becomes more realistic as visibility decreases. With the simulator, you may get poor height awareness in good visibility daylight conditions, but as the visibility decreases through 3 NM and the daylight gives way to night, the real world visual cues are very well represented in the simulator.

Recommendation: Based on the simulator tests, 3 NM should be the absolute minimum visibility required to attempt the mission.

7.0 Suggested Future Research

The following list suggests areas where future research may be warranted:

1. Conduct limited flight test evaluations to:

    - verify aircraft dynamics system identification and evaluation maneuvers discussed here.

    - investigate PIO potential for VLAT class airplanes

2. Consider further simulation research with following objectives:

    - evaluate the benefit in pilot workload and piloting performance of incorporating a HUD that displays flight path marker, altitude, speed, and heading. An option could be included to look at guidance cues as well.

    - evaluate the effect of a retardant dump on mission success using a representative model of the change in aircraft dynamics and aerodynamics.

    - define more rigorously the limitations associated with the lateral offset delivery. This could potentially lead to a better recommendation on how close to the drop area offset corrections can reasonably be expected to be made. It also would put a higher demand on the pilot-vehicle system, to see if the potential PIO tendency noted in the roll axis is uncovered with an evaluation task.

3. Better characterize the mountainous turbulence and wind profiles for testing aircraft against and simulation training of aerial tanker pilots.

4. Collect simulation data to characterize the altitude vs airspeed trade-off with an engine failure and the time required for spool up against a more realistic terrain visual system.

5. Determine what percentage of the potential fire scene is off limits due to terrain gradients and the VLAT aircraft's ability to fly non-accelerating decent profiles into the drop zone and climb out of a single engine failure scenario. An interactive map with varying approach directions and with the ability to show different aircraft types that can handle that terrain could be created for field use to help make the decision on where to create a fire break, and what aircraft to deploy. Integrate this with the existing maps that are fed data from IR sensor aerial platforms.

6. Investigate flow-shaping surfaces to direct more of the water or retardant down and away from the aircraft upon release. This could also help reduce maintenance issues with corrosion on the aft fuselage where retardant is caught in the standard airflow.

8.0 Acronyms and Abbreviations

AFFTC – Air Force Flight Test Center

AGL – Above Ground Level

ARC – Ames Research Center

ARD – Aerial Retardant Delivery

CAP – Continued Airworthiness Program

DFRC – Dryden Flight Research Center

DOI – Department of the Interior

DOP – Dryden Operational Procedure

FAA – Federal Aviation Administration

FAR – Federal Aviation Regulation

FFT – Fast Fourier Transform

FREDA – FREquency Domain Analysis

HQR – Handling Qualities Rating

ICA- Instructions for Continued Airworthiness

KIAS – Knots Indicated Airspeed

LLC – Limited Liability Corporation

MSL – Mean Sea Level

NASA – National Aeronautics and Space Administration

Nz – g-loading (z axis)

PID – Parameter IDentification

PIO – Pilot Induced Oscillation

PRV – Pressure Regulating Valves

PSD – Power Spectral Density

RW – Runway

STC – Supplemental Type Certificate

STI – Systems Technology, Inc.

TBD – To Be Determined

USFS – United States Forest Service

VLAT – Very Large Aerial Tankers

VOT&E – VLAT Operational Test & Evaluation

9.0 Consulted Subject Experts

Telephone or face-to-face interviews were conducted with a number of experienced aerial firefighting personnel. Interviewees included:

Jack Maxey – 10 Tanker

Brian Lash – Butler Aircraft

Cliff Hale – Evergreen

Walt Darran – CalFire

Dennis DeGeus – 10 Tanker

Phil Johnson – CalFire

Pat Norbury – USFS

Scott Fisher – USFS

Greg House – USFS

Rick Hatton – 10 Tanker

10.0 References

1. "Instructions For Continued Airworthiness, 10 Tanker STC, LLC DC-10, Chapter 2, Fire Fighting System Description", Report No. 2547, Aircraft Technical Service, Inc., 11/21/2005.
2. "Commercial Operations Manual, Chapter 7, Flight Maneuvers and Techniques," 10 Tanker LLC.
3. "DC-10 Maintenance Manual, Revision 80," McDonnell Douglas Corporation, 1/1/2004.
4. "FAA Approved Airplane Flight Manual Supplement to the Boeing 747-200C Airplane Flight Manual for Evergreen International Airlines, Inc. Air Tanker Modification," Evergreen International Airlines, Inc., 10/27/2006.
5. "B-747 Aircraft Operating Manual," American Airlines Flight Department, 1983.
6. E-mail correspondence with Rick Hatton, 10 Tanker LLC.
7. E-mail correspondence with Cliff Hale, Evergreen International Airlines, Inc.
8. "Airtanker Drop Test Report, Evergreen Supertanker Tanker 947," USDA Forest Service, 8/10/2006.
9. "Section III – Multi-Engine Airtanker Requirements (2006 and forward)," Procedures and Criteria for the Interagency Airtanker Board (IAB), July 2006.

10. “Section VII – Tank System Criteria,” Procedures and Criteria for the Interagency Airtanker Board (IAB), July 2006.
11. Johnston, J.P., “Interagency Airtanker Board - Charter, Criteria, and Forms,” USDA Forest Service - National Interagency Fire Center, 9857 1803-SDTDC, July 1998.
12. Veillette, P. R., “Crew Error Cited as Major Cause of U.S. Aerial Fire Fighting Accidents,” Flight Safety Digest, Vol. 18, No. 4, April 1999.
13. USDA Forest Service Briefing; “What is a Fire Traffic Area?”, May 2003.
14. Fire Traffic Area (FTA) kneeboard and poster depiction, March 31, 2006.
15. “Boeing 747 Model 747-123 Operations Manual Volumes II and III,” The Boeing Commercial Airplane Company, Seattle, Washington, March 1978.
16. “Raytheon Aircraft Beech Super King Air 200 & 200C Pilot’s Operating Handbook and FAA Approved Airplane Flight Manual,” Raytheon Aircraft Company, Wichita, Kansas. Revision A13, January 2002.
17. “USAF Series KC-10A Aircraft Flight Manual Performance Data,” USAF TO 1C-10(K)A-1-1, October 1993.
18. “USAF Series C-130A, C-130D, C-130D-6 Airplanes Flight Manual Appendix 1 Performance Data,” T.O. 1C-130A-1-1, January 1980.
19. “Lockheed P-3C Flight Manual,” NAVAIR 01-75PAC-
20. “FAA Approved Airplane Flight Manual Supplement to the Boeing 747-200C Airplane Flight Manual for Evergreen International Airlines, Inc. Air Tanker Modification,” Approved October 27, 2006.
21. Interagency Aerial Supervision Guide 2008.
22. Fisher, S., “Continued Airworthiness Program – CAP,” U.S. Forest Service Presentation.
23. Payne, B., “DC-10 Supertanker Operating Plan,” CAL FIRE, Revision 5, August 2, 2007.
24. “Summary of Comments Received in Response to USFS Proposed Continued Airworthiness Program (CAP),” In Fedbizzops (SN-2007-07), July 10, 2007.
25. “Very Large Airtanker Drop Height Considerations”
26. “USDA Forest Service Airtanker Drop Test Report - Evergreen Supertanker - Tanker 947”
27. Nelson, J., “US Forest Service Operational Loads Monitoring Program,” PowerPoint Presentation, 11th Joint FAA/DoD/NASA Aging Aircraft Conference, Phoenix, AZ, April 22, 2008.
28. Manson, A. L Lt and Traskos, R. L.; “Final Report - Flying Qualities and Performance Technical Evaluation of the P-3B Airplane,” Naval Air Test Center, FT-98R-68. 31 Dec 1968.
29. “Combined Stability and Control and Aircraft and Engine Performance Trials of the P3V-1 Airplane,” Naval Air Test Center Technical Report, FT2122-020, May 6, 1963.

30. “Turbulence Researchers Working on Detection Systems,” 30 November 1999 http://www.usatoday.com/weather/wturb497.htm

31. Atmospheric Properties Calculator based on US Standard Atmosphere 1976. http://www.aerospaceweb.org/design/scripts/atmosphere/