4-6-2009

A Technology Survey of Emergency Recovery and Flight Termination Systems for UAS

Richard Stansbury
Embry-Riddle Aeronautical University, stansbur@erau.edu

Wesley Tanis
Embry-Riddle Aeronautical University

Timothy Wilson
Embry-Riddle Aeronautical University, wilsonti@erau.edu

Scholarly Commons Citation

Stansbury, R., Tanis, W., & Wilson, T. (2009). A Technology Survey of Emergency Recovery and Flight Termination Systems for UAS. , (). Retrieved from https://commons.erau.edu/publication/73

AIAA Infotech@Aerospace Conference
and
AIAA Unmanned...Unlimited Conference
6 - 9 April 2009, Seattle, Washington

AIAA 2009-2038

A Technology Survey of Emergency Recovery and Flight Termination Systems for UAS

Richard S. Stansbury,[*] Wesley Tanis, [†] and Timothy A. Wilson[‡]
Embry-Riddle Aeronautical University, Daytona Beach, FL 32114 USA

For safe flight in the National Airspace System (NAS), either under the current interim rules or under anticipated longer-term regulatory guidelines facilitating unmanned aircraft system (UAS) access to the NAS, the UAS must incorporate technologies and flight procedures to ensure that neither people nor property in the air, on the ground, or on or in the water are endangered by the failure of an onboard component, by inappropriate unmanned aircraft (UA) response to pilot commands, or by inadvertent entry by the UA into prohibited airspace. The aircraft must be equipped with emergency recovery (ER) procedures and technologies that ensure that in the event of such a failure that the UA is recovered intact with minimal risk to other aircraft, people, or property. Finally, should ER procedures prove ineffective and it is impossible to recover the UA, the pilot-in-command and/or the UAS may engage flight termination (FT) procedures-activities to ensure that the UA is safely destroyed (should the UA be so equipped) or immediately grounded. Together ER and FT are referred to as emergency recovery and flight termination (ERFT). This paper presents a technology survey of ERFT technologies and procedures as applied toward unmanned aircraft.

Nomenclature

COA	Certificate of Authorization
CMS	Contingency Management System
ER	Emergency Recovery
ERFT	Emergency Recovery and Flight Termination
FAA	Federal Aviation Administration
FDIR	Fault Detection, Identification, and Recovery
FT	Flight Termination
LL	Lost Link
LOS	Line of Sight
NAS	National Airspace System
PIC	Pilot in Command
RF	Radio Frequency
RFDL	Radio Frequency Data Link
TFR	Temporary Flight Restriction
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System

I. Introduction

This paper presents a technology survey emergency recovery and flight termination technologies and processes for unmanned aircraft systems (UAS). As currently defined by the FAA Air Safety Unmanned

---

[*] Assistant Professor, Department of Computer and Software Engineering, 600 S. Clyde Morris Blvd, Professional Member
[†] Graduate Research Assistant, Department of Computer and Software Engineering, 600 S. Clyde Morris Blvd
[‡] Professor, Department of Computer and Software Engineering, 600 S. Clyde Morris Blvd, Professional Member

Aircraft Program Office (AIR-160) in UAS Interim Operational Approval Guidance 08-01,[1] an Unmanned Aircraft (UA) is:

> A device used or intended to be used for flight in the air that has no onboard pilot. This includes all classes of airplanes, helicopters, airships, and translational lift aircraft that have no onboard pilot. Unmanned aircrafts are understood to include only those aircraft controllable in three axis and therefore, exclude traditional balloons.

The UA is remotely controlled by a pilot in command (PIC) from a ground control station (GCS) via radio frequency data links (RFDL) for command and control. Together, the UA and GCS make up the unmanned aircraft system (UAS).

For safe flight in the NAS, either under the current interim rules or under anticipated longer-term regulatory guidelines facilitating UAS access to the National Airspace System (NAS), the UAS must incorporate technologies and flight procedures to ensure that neither people nor property in the air, on the ground, or on or in the water are endangered by loss of the RFDL, by inappropriate UA response to pilot commands, or by inadvertent entry by the UA into prohibited airspace. In the event of lost link (LL), both the PIC and the UAS have to respond initially with lost link procedures-operations that increase the likelihood that the link is restored. If LL procedures are ineffective or if the UA is responding erratically, emergency recovery (ER) procedures—activities to ensure that the UA is recovered intact with minimal risk to other aircraft, people, or property-are necessary. Finally, should ER procedures prove ineffective and it is impossible to recover the UA intact, the PIC and/or the UAS may engage flight termination (FT) procedures—activities to ensure that the UA is safely destroyed (should the UA be so equipped) or immediately grounded. Together ER and FT are referred to as emergency recovery and flight termination (ERFT).

It is important that ERFT systems and procedures are evaluated as part of the airworthiness certification process for UAS. To develop guidance material and future regulations for ERFT, it is important to have a strong understanding of the current and near-term future technologies used to support UAS ERFT, and to identify the gaps of 14 CFR, FAA advisory circulars, FAA orders, and FAA technical standing orders between the state-of-the-art and existing regulations. Two similar studies have been conducted by the authors involving UAS propulsion systems[2] and UAS command, control, and communication (C3) systems[3] for the FAA Technical Center.

This paper discusses the first of these ERFT research tasks, a survey of current and future technologies for ERFT. The intent of the technology survey is to identify and articulate existing and near-future technologies and procedures used for ERFT, as well as to identify technologies used in determining when lost link occurs, when the UA is unresponsive or responding erratically to supplied commands, or when the UA is in violation of previously agreed to airspace restrictions. Coordination of ERFT procedures with ATC and other agencies is also examined. The technology survey involves searching journal and conference proceedings; web sites for UA manufacturers, operators, and interest groups, and for regulatory agencies; and public records. The goal of the technology survey is not simply to generate an exhaustive listing of every approach for every class of UAS, but is an attempt to be representatively inclusive with an emphasis on an appropriate organization. It will also look at ER technologies applied to manned aircraft such as ballistic recovery techniques (i.e. parachutes) that may be applied toward UA.

The paper is organized as follows. Background related to ERFT and existing regulatory efforts is provided. A systems level framework of UAS ERFT technologies is presented. Organized based on this framework, the technology survey results are presented. The paper concludes by defining a plan for the regulatory gap analysis that will be carried out as a follow-up to the reported research.

II. Background

The need for lost link procedures and/or flight termination systems has been indicated by a number of entities including domestic (USA) regulatory agencies,[1, 4–6] international regulatory agencies,[7] aerospace think tanks,[8] UAS manufacturers, and researchers. For instance, in the FAA Interim Operational Approval Guidance 08-01,[1] LL procedures are mandated such that in the event of a lost of data link the aircraft would act predictably. The aircraft must be equipped with a FT system to protect the public in the event that sufficient redundancy does not exist to ensure safe and predictable operation. The Australian Civil Aviation Safety Authority's AC 21-43(0)[7] also mandated LL and FT systems for experimental UA, and went further in requiring that flight termination be demonstrated by the UA landing within some area such that there

Table 1. Autopilot ERFT capabilities.

Autopilot	Lost Link	Flight Termination
Cloudcap Piccolo[9]	Return to waypoint	Mission selectable from close throttle, aerodynamic termination, and/or Deploy parachute
Procerus Kestrel[10]	Shallow bank until restored	Aerodynamic termination
Micropilot MP-2028g[11]	Mission selectable (see next column)	Mission selectable from fly-to, climb, descend, roll, eject chute, etc.

Table 2. Surveyed aircraft and ERFT capabilities.

Aircraft	Manufacturer	ERFT Capabilities
QH-50 Dash[12]	Gyrodyne Helicopters	None, expendable drone
ScanEagle[13, 14]	Insitu, Inc.	Link loss: Loiter at designated point Mission area departure - aerodynamic termination
Predator[15]	General Atomics	Lost link: Return home Optional parachute
Global Hawk[16, 17]	Northrup Grumman	Contingency flight paths FTS with extreme prejudice
Polecat[18]	Lockheed Martin	FTS with extreme prejudice
X-48B[19]	Boeing and Cranfield Aerospace	Parachute, airbags, and spin parachute (for stall testing).
Arrow[20]	Jordon Military	Parachute and floatation device for termination over water.

was only a 10^{-5} and no greater probability of the aircraft not landing within the specified landing area. In a report by MITRE,[8] the need for ERFT is considered essential to safe operation of civil UAS. This report goes further to also state the need for training air traffic controllers so that they have a better understanding of how unmanned aircraft will operate under lost link or failure conditions. The MITRE study also indicates the importance of exposure of such systems in order to improve understanding and gain acceptance of safe UAS operation. In these or other cited examples, no specific technologies or substantial requirements exist for ERFT.

III. Technology Survey

In this section, the initial results of the technology survey are presented. Table 1 summarizes the ERFT capabilities of several surveyed autopilots for UA. Table 2 presents the ERFT capabililities of several of the surveyed aircraft.

Figure 1 presents the initial framework as it is used within this paper. From left-to-right, the criticality of a vehicle loss (as well as the ramifications of such a vehicle loss) increase. When the criticality is low, health-based recovery systems attempt to diagnose and correct the problem so that the vehicle may continue onward. With greater criticality, it becomes necessary for mission-level contingency systems handle an emergency recovery. At this level, it is expected that the aircraft's mission must be terminated. The final and most extreme emergency response system is a flight termination system. With each category, there will always be shades of gray. This framework captures the majority of technologies surveyed.

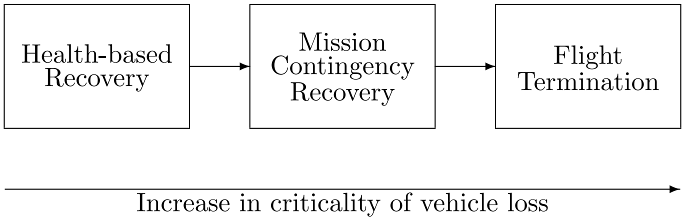

Figure 1. A framework for guidance of ERFT technology survey.

III.A. Health-based Recovery

Health-based recovery systems handle less extreme aircraft system faults and failures in which given an adjustment of the vehicle's control system it should be possible to continue with the aircraft's mission. Under this category, fault detection, identification, and recovery is a common example of control's technology for health-based recovery.

FDIR represents a body of controls research that includes both manned and unmaned aircrafts. For fault detection, residuals, which represent the error between the actual response of the craft using its control system versus what was expected, are calculated. Fault identification analyzes the residuals to identify the cause of the problem so that it may be addressed. This could be used to identify a parameter within the control system's transfer function, or it could identify the failure of a particular component such as a control surface. Fault recovery adjusts the control system dynamically to reduce the impact of the residuals and restore nominal operation. Ideally, the recovery system would reconfigure the control system such that it continues on its mission. However, if it is unable to do so, then either a mission contingency plan or a flight termination system may be activated.[21] A number of papers exist discussing FDIR systems that may be used for unmanned aircraft.[22, 23]

Redundancy may be another approach for addressing a health related issue. Given sufficient redundancy, if a component becomes non-functional, it is possible for the control system to transition to a backup system and continue nominal operation. A Eruopean UAS research commission has recently funded the development of a medium altitude unmanned aircraft equipped with a redundant engine.[24] Redundancy is not uncommon in the aviation industry in which dual or triple redundancy is used for safety critical electrical components within commercial aircraft.

III.B. Mission Contingency Recovery

Under mission contingency recovery, when a component or aircraft failure occurs, the aircraft shifts away from its current mission and into one of several possible emergency-recovery modes. Unlike the health-based recovery techniques discussed above, under these situations, the aircraft does not attempt to adapt to the situation, but rather alters its flight path in order to mitigate risk due to the failure and/or safely recover the aircraft. This section will first present the contingency management used by Global Hawk. Next, link loss procedures are discussed, which represent a specific case requiring contingency management.

The Global Hawk UAS possesses a sophisticated contingency management system (CMS). As reported by Lt. Col. J. Scott Winstead,[16] a number of recovery modes are enumerated including lost link recovery, return-to-base command, abort landing command, and land now command. For each of these and other potential modes, the CMS redirects the aircraft to a flight path appropriate for the current mode. In order for this to work over an entire mission, it is necessary at all points along the route that contingency routes are branched off for each respective contingency mode. Likewise, on these contingency routes, additional contingency routes may be branched off in order to handle additional failures should they occur. Figure 2 presents a primary flight path and a number of contingency branches. In this figure, only three contingency modes are considered and abstractly defined as $C1$, $C2$, and $C3$. The purpose for such an elaborate contingency plan is that all ATC whose airspace the aircraft may enter are aware of the aircraft's potential presence and the potential circumstances for that presence. This awareness will help ATC to respond when a contingency situation occurs in order to safely re-route air traffic and alert ground crews.

Lost link procedures also fall under this category as it is currently deemed unsafe to operate a UAS with a loss of the control datalink between the aircraft and the ground control operator, and must be

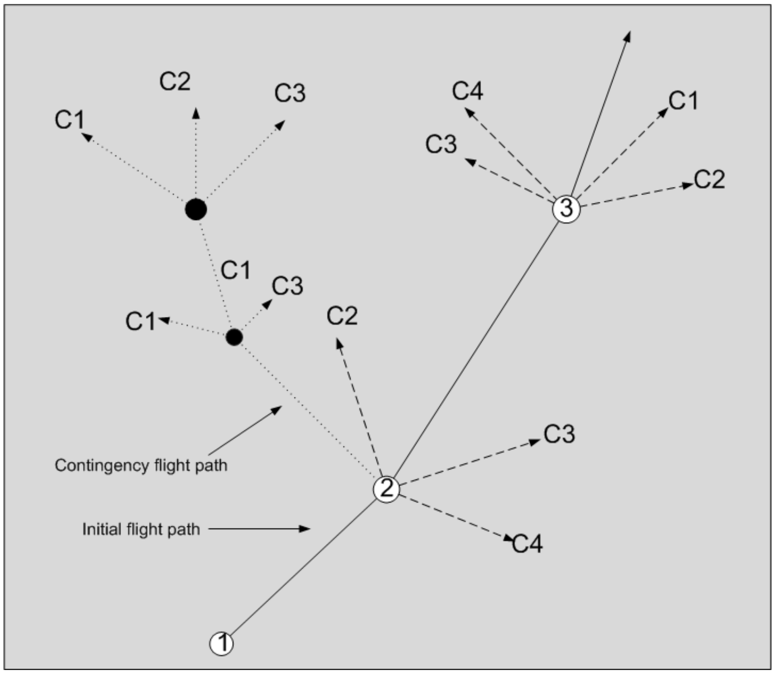

Figure 2. An example Global Hawk flight path with contingency routes.[16]

addressed by a LL contingency procedure. It is important that the aircraft always operates in a predictable manner. From the survey, it was revealed that the most common LL procedure is for the aircraft to fly to a predefined location. Once at the predefined location, the UAS can either loiter until the link is restored, it can autonomously land, or it can be remotely piloted via secondary data link.[25–28] The BAT III UA's LL procedure involves a simple return home functionality, where it turns to the last known location of the GCS and flies directly toward it.[28] Once within sufficient range to the base, a remote pilot will control the aircraft to land. NASA and Boeing's PhantomWorks X-36 follows a similar method of returning to base and loitering.[25] Rather than simply return to the base directly, the aircraft follows a pre-defined return path.

For small UAS, many of the commercial aircraft have contingency management features for link loss procedures. The Piccolo Autopilot[9] is capable of defining a timeout for lost communication in seconds. If after so many seconds a message from the base station is not received, the aircraft will fly to a LL waypoint. The Procerus Kestrel lost link procedure returns the aircraft either to base or an alternate "rally point".[10] Micropilot's various autopilots[11] allow users to define the response to the lost link procedure and the criteria for diagnosing the lost link. The lost link procedure could support the return to any waypoint, or alternatively to trigger a flight termination system.

Officials at Fort Carson have drafted a document for Unmanned Aerial Vehicle Flight Regulations. The military base includes two potential flight areas, one is restricted airspace, and the other is non-restricted airspace requiring either a COA or Temporary Flight Restriction (TFR) from the FAA.[29] They defined their classes of UA as Tactical UAV (TUAV) for operation beyond visual line-of-sight or over 1000 ft; and Small UAV (SUAV) for flight under 1000 ft or within visual LOS. For the restricted airspace, if a TUAV loses link, it returns to a predefined grid location and loiters at 8000 ft. If the SUAV loses link in the restricted airspace, it returns to the center of mass of the restricted airspace and lands. In both cases, necessary military authorities are contacted. When operating under a certificate of authorization (COA) or temporary flight restriction (TFR), the procedures modified in that FAA or other civilian authorities will be notified. If in either case the aircraft is likely to leave its restricted airspace, the flight will be terminated by some undisclosed means.

III.C. Flight Termination

A flight termination system is utilized as a last resort to bring down an aircraft expeditiously in order to maintain some level of safety to the public or property. Given sufficient redundancy, a flight termination system may not be necessary. However, two motivating factors for having a flight termination system include not having sufficient redundancy, which is very often the case for smaller UAS, or that the FTS is mandated as per the restricted airspace for which the aircraft is flying (i.e. range safety). In this section, a variety of flight termination systems will be discussed. For each, representative aircraft will be discussed.

Aerodynamic termination is one approach to flight termination. Under these cases, the aircraft's control surfaces are set at a state that will result in the vehicle crashing into the ground or a body of water in a somewhat controlled manner. One form of aerodynamic termination is to set the control surfaces such that the vehicle performs a slow downward spiral. Under this termination technique, some aircraft damage may be mitigated depending upon the speed of the descent. Likewise, under a spiral descent, the aircraft's final position may be well estimated and somewhat controlled. This mechanism is ideal under airspace violation events as it will prevent further violation of the restricted airspace. This technique is used by the Insitu ScanEagle[14] and is also provided as a common feature for a number of autopilots including the Cloudcap Piccolo,[9] Micropilot autopilots,[11] and the Kestrel autopilot.[10]

Glide-path descents are another alternative aerodynamic termination technique. For this termination technique, the aircraft glides from its current altitude to a landing site without engine power. Under a glide-path termination, if possible, a suitable landing site may be designated. Under the surveyed literature, it was found that this could be done by the UA PIC[22] or autonomously.[22,30] Glide-path descents for high altitude UAS provide the potential for the aircraft to fly toward and terminate within a region in which the risk is somewhat mitigated. For instance, the aircraft could glide out over the ocean before impacting with the surface. This is not as feasible for lower altitude platform that are likely unable to maintain altitude long enough to significantly mitigate risk.

Several ballistic recovery systems are available to handle flight termination of an unmanned aircraft. Parachutes are one of the most common ballistic recovery systems for unmanned aircraft, and have a history of use in manned aircraft including existing technical standard orders.[31] Autopilots such as the Piccolo[9] and Kestrel[10] allow for a parachute deployment to be part of the flight termination system if the target aircraft is appropriately equipped. While not a standard feature, parachutes have been installed on the Predator UAS.[15] A number of other UAS are parachute equipped.[9–11,20,24] Parafoil parachutes provide additional loft permitting greater control for the aircraft such that it is possible to achieve a glide-path approach,[30] which is used on the BAE SkyEye[20] and the IAI I-View.[20] Some aircraft such as the X-48B also include spin parachutes, which aid in recovery of an aircraft caught in a spin. Airbags or flotation devices may accompany parachute-based FTS. The X-48b is equipped with airbags to reduce the forces at impact.[19] The Jordon Arrow is equipped with a foam body in order to remain buoyant if the aircraft is terminated in the water.[20]

Flight termination systems are a common requirement for operation of UAS within a test range. New Mexico State University's Flight Test Range does not explicitly require a flight termination system to maintain the integrity of the range. Only enough fuel is provided to the aircrafts to allow successful performance of flight tests, but not so much to allow an out-of-control aircraft to reach and fly over a populated area. Other flight test ranges including the White Sands Missile Range[32] and Wallops Air Force Base[33] explicitly require the inclusion of FTS that meets the commonality specifications of the Range Control Council, Document 319-07.[34]

For Wallops AFB, a risk assessment plan is required for an aircraft to be approved for flight tests.[33] Under this plan, the FTS is necessary if the craft posses major risk to persons or property. Contingency management systems may be added under the risk plan; however, they are not sufficient to reasonabily exclude the need of an FTS.

IV. Conclusion

Emergency recovery and flight termination technologies and procedures have been partitioned into a framework from relatively low risk recovery to high-risk flight termination. Under health-based recovery, the vehicle adapts to a failure condition in order to continue on with its mission even if under some diminished capability set. Contingency management recovery is responsible for handling situations in which the health-based recovery is not available or not sufficient to safely respond to the failure condition. In this case, the aircraft performs some pre-defined sequence of actions in order to safely land the aircraft. If the failure is more critical and a greater risk to the public exists, flight termination systems may be utilized to terminate the aircraft's flight rapidly, and possibly with extreme prejudice. For each of these categories, surveyed technology has been developed or is being developed.

The results of this study will be utilized as part of an overall study that seeks to enumerate the regulatory gaps that exist between the emergency recovery technologies used for unmanned aircraft and the existing regulations as defined by Title 14, Code of Federal Regulations. With this technology survey complete, the next task is to perform a cursory review of existing regulations and enumerating potential regulatory issues that must exist. Given these potential issues, the regulations will be studied in greater detail to determine where gaps exist. Given these gaps, recommendations may be provided that may be used to develop guidance material such that UAS operators and manufacturers can ensure that the aircraft meets an equivalent level of safety.

Acknowledgments

This project was sponsored by the Federal Aviation Administration through the Air Transportation Center of Excellence for General Aviation, and was conducted by the members indicated. The Center of Excellence for General Aviation Research is comprised of the following universities: Embry-Riddle Aeronautical University, Florida A&M University, University of Alaska, University of North Dakota and Wichita State University. However, the Agency neither endorses nor rejects the findings of this research. The presentation of this information is made available in the interest of invoking technical community comment on the results and conclusions of the research.

References

[1] FAA Aviation Safety Unmanned Aircraft Program Office (AIR-160), "Interim Operational Approval Guidance 08-01: Unmanned Aircraft Systems Operations in the U. S. National Airspace System," 2008.

[2] Griffis, C. L., Wilson, T. A., Schneider, J. A., and Pierpont, P. S., "Framework for the Conceptual Decomposition of Unmanned Aircraft Propulsion Systems," *Proceedings of the 2008 IEEE Aerospace Conference.*, 2008.

[3] Stansbury, R. S., Vyas, M. A., and Wilson, T. A., "A Survey Of UAS Technologies For Command, Control, and Communication (C3)," *Proceedings of the UAV'08 Conference.*, 2008.

[4] European Aviation Safety Authority, "Advance Notice of Proposed Amendment 16/2005: Policy for Unmanned Aerial Vehicle Certification," 2005.

[5] FAA Production and Airworthiness Division (AIR-200), "FAA Order 8130.34: Airworthiness Certification of Unmanned Aircraft Systems," 2008.

[6] Transport Canada, "UAV Working Group Final Report," Online at: http://www.tc.gc.ca/civilaviation/general/recavi/uavworkinggroup.htm, 2007.

[7] Australian Civil Aviation Safety Authority, "Advisory Circular AC 21-43: Experimental Certificate for Large Unmanned Aerial Vehicle (UAV)." Tech. rep., 2006.

[8] DeGarmo, M. T., "Issues Concerning Integration of Unmanned Aerial Vehicles in Civil Airspace," Tech. rep., MITRE Center for Advanced Aviation System Development, 2004.

[9] Vaglienti, B., Hoag, R., and Niculescu, M., *Piccolo System User's Guide*, Cloud Cap Technology, Hood River, OR, 2008.

[10] Procerus Technologies, *Kestrel User Guide*, Procerus Technologies, Vineyard, UT, 2008.

[11] MicroPilot Inc., *MP2028g Installation and Operation*, MicroPilot Inc., Stony Mountain, Manitoba, 2005.

[12] Gyrodyne, "DASH Flight School," Gyrodyne Helicopter Historical Foundation. Online at: http://www.gyrodynehelicopters.com/dash_flight_school.htm, 2009.

[13] Heppe, S., "Insitu inc. Personal Communications," 2008.

[14] McDuffy, P., "Insitu inc. Personal Communications," 2008.

[15] Butler., M. C. and Loney, T., "Design, Development and Testing of a Recovery System for the Predator UAV," *13th AIAA Aerodynamic Decelerator Systems Technology Conference*, No. AIAA 95-1573, 15–19 May 1995.

[16] Winstead, J. S., "Transformational ISR (RQ-4 GlobalHawk)," *TAAC Conference Proceedings 2009 [cd-rom]*, Albuquerque, NM, November 2008.

[17] Flightglobal, "Global Hawk Downed by Rouge Abort Signal," Flightglobal. Online at: http://www.flightglobal.com/articles/1999/10/06/56882/global-hawk-downed-by-rogue-abort-signal.html, 2009.

[18] Flightglobal, "Lockheed Confirms P-175 Polecat UAV Crash," Flightglobal. Online at: http://www.flightglobal.com/articles/2007/03/20/212700/lockheed-confirms-p-175-polecat-uav-crash.html, 2009.

[19] Flightglobal, "British blend: UAV x-planes help Boeing with blended wing concept," Online at: http://www.flightglobal.com/articles/2006/05/30/206893/british-blend-uav-x-planes-help-boeing-with-blended-wing.html, 2009.

[20] Donaldson, P. and Lake, D., editors, *Unmanned Vehicles Handbook 2008*, Shephard Press, Ltd., Berkshire, UK, December 2007.

[21] Rotstein, H. P., Ingvalson, R., Keviczky, T., and Balas, G. J., "Fault-Detection Design for Uninhabited Aerial Vehicles," *Journal of Guidance, Control, and Dynamics*, Vol. 29, No. 5, September–October 2006.

[22] Atkins, E. M., "Dynamic Waypoint Generation Given Reduced Flight Performance." *Proceedings of the 42nd AIAA Aerospace Sciences Meeting and Exhibit*, No. AIAA 2004-779, Reno, Nevada, 5–8 January 2004.

[23] Heredia, G., Remu, V., Ollero, A., Mahtani, R., and Musal, M., "Actuator Fault Detection in Autonomous Helicopters," *Proceedings of the 5th IFAX Symposium on Intelligent Autonomous Vehicles (IAV 2004)*, Lisbon, Portugal, July 2004.

[24] Flightglobal, "Grand Designs," Flightglobal. Online at: http://www.flightglobal.com/articles/2005/06/07/198916/grand-designs.html, 2009.

[25] Walker, L. A., "Flight Testing the X-36 - the Test Pilot's Perspective," Tech. Rep. Technical Report NASA Contractor Report no. 198058, NASA - Dryden Flight Research Center, Edwards, California, 1997.

[26] McMinn, J. D. and Jackson, E. B., "Autoreturn Function for a Remotely Piloted Vehicle," *AIAA Guidance, Navigation, and Control Conference and Exhibit*, No. AIAA 2002-4673, Monterey, California, 5–8 August 2002.

[27] NTSB, "NTSB Incident CHI06MA121 - Full Narrative," National Transportation Safety Board. Online at: http://www.ntsb.gov/ntsb/brief.asp?ev_id=20060509X00531&key=%201, 2009.

[28] Ro, K., Oh, J.-S., and Dong, L., "Lessons Learned: Application of Small UAV for Urban Highway Traffic Monitoring," *45th AIAA Aerospace Sciences Meeting and Exhibit*, No. AIAA 2007-596, Reno, Nevada, 8–11 January 2007.

[29] United States Army, "Unmanned Aerial Vehicle - Flight Regulations 95-23," Tech. Rep. Technical Report AR 95-23, The Army Headquarters, Fort Carson, Colorado, 2005.

[30] Fitzgerald, D., Walker, R., and Campbell, D., "Vision Based Emergency Forced Landing System for an Autonomous UAV," *Proceedings of the Australian International Aerospace Congress Conference*, Melbourne, Australia, 2005 2005, pp. 397–402.

[31] FAA, "TSO-C23d: Personnel Parachute Assemblies," Online at: http://rgl.faa.gov/Regulatory_and_Guidance_Library/rgTSO.nsf/0/00493ac675eda12e86256da500600ef7/$FILE/C23d.pdf.

[32] RCC, "User Guide for UAS Operations on the National Ranges," Tech. Rep. Document 555-07, Range Control Council, November 2007.

[33] NASA, "Range Safety Manual (RSM-2002 Rev. A) For Goddard Space Flight Center (GSFC) / Wallops Flight Facility (WFF)," Tech. Rep. RSM-2002 Rev. A, NASA Goddard Space Flight Center, 3 November 2006.

[34] RCC, "Flight Termination Systems Commonality Standard 319-07," Tech. Rep. Document 319-07, Range Control Council - RANGE SAFETY GROUP, August 2007.