



Flight Trajectory Options to Mitigate the Impact of Unmanned Aircraft Systems (UAS) Contingency Trajectories – A Concept of Operations

Approved for Public Release. Distribution
Unlimited. Case Number 13-3449.

©2013 The MITRE Corporation.
All rights reserved.

McLean, VA

**John Bernard
Andrew R. Lacher**

September 2013

Executive Summary

No NextGen Air Transportation System (NextGen) mid-term automation capability is currently planned for storing and processing Unmanned Aircraft (UA) contingency trajectories. Contingency trajectories are plans that would be executed in case of a loss of the command and control (C2) link between the pilot's control station and the UA, or some other unexpected event. As a result, controllers have limited situational awareness and cannot depict an unmanned aircraft's flight trajectory on air traffic management displays during a contingency event.

This concept of operations proposes to re-purpose a Traffic Flow Management System (TFMS) capability, scheduled for implementation in 2014, to facilitate coordination of UA contingency trajectories between UA remote pilots and the air traffic management (ATM) system. A Trajectory Option Set (TOS) message could be leveraged by the remote pilot to communicate UA contingency trajectories. Optional to the concept, augmentations to existing TOS specifications are described, which could quickly communicate to ATC a UA's contingency trajectory based on UA problem type (e.g., lost C2 link or other type of emergency situation).

Leveraging a mid-term capability such as TOS, (with essentially no modifications other than Unmanned Aircraft System (UAS)-specific procedures) to handle UAS contingency trajectories would help address a critical integration issue for UAS (lost C2 link), while providing greater predictability, consistency, and situation awareness for controllers while enabling the use of ATM decision support systems.

Acknowledgments

The authors would like to thank Nathan Paczan, David Simenauer, and Steve Fabela for their input and guidance. The authors would like to acknowledge Mike Klinker and Dean Fulmer for their review of and advice regarding this document. Additionally, the authors thank Angela Signore and Sam Tungul for their support in editing and preparing the document for delivery.

Table of Contents

1	Introduction/Scope.....	1
1.1	Background	1
1.2	Problem Statement	2
1.3	Scope	3
1.4	Concept Relationship to UAS Integration into the NAS Concept of Operations	3
2	Current Operations and Capabilities.....	5
2.1	Description of Current Operation.....	5
2.2	Current Supporting Infrastructure	5
2.2.1	TFMS	5
2.2.1.1	Airborne Reroutes (ABRR) – Available in 2014	6
2.2.1.2	Trajectory Option Sets (TOS) – Available in 2014.....	7
2.2.2	ERAM – Currently Being Deployed, Deployment Completed in 2014	7
2.2.2.1	Conflict Probe – Currently Deployed in all 20 ARTCCs.....	7
2.2.2.2	Trial Planning – Currently Deployed in all 20 ARTCCs	7
2.2.2.3	ABRR – Available in 2014	7
2.2.2.4	System to Enable Flight Operator to File TOSs –Available in 2014	7
3	Flight Trajectory Options to Mitigate the Impact of Unmanned Aircraft Systems Contingency Trajectories Concept of Operations	8
3.1	Assumptions and Constraints	8
3.2	Existing Automation Capabilities – Today’s Operating Environment	9
3.3	Potential Operations	9
3.4	Benefits to be Realized.....	14
4	Summary of Impacts.....	15
4.1	Operational Impacts	15
4.2	System Impacts.....	15
5	References	17
	Appendix A Glossary	A-1

List of Figures

Figure 1. UAS Elements in the NAS	1
Figure 2. Route Segments of a UA Flight Plan and Contingency Trajectory.....	10
Figure 3. Example of UA Filed Flight Plan and Contingency Trajectories.....	11
Figure 4. TVST and TVET Updated to Reflect Actual Departure Time.....	11
Figure 5. Applicable Contingency Trajectory for Current Time of 1938.....	12
Figure 6. Notional TFMS Route Amendment Dialog Box.....	12
Figure 7. Notional ERAM Controller GPD without Conflict Detected.....	13
Figure 8. Notional ERAM Controller GPD with Conflict Detected.....	14
Figure 9. Contingency Operations Flow Chart – Example Use Case: Lost Link.....	14

List of Tables

Table 1. Strategic Traffic Management Improvements	3
Table 2. Manned, Unmanned Aircraft Contingency Comparison . Error! Bookmark not defined.	

1 Introduction/Scope

1.1 Background

Unlike with manned aircraft, the pilot in command (PIC) can lose connectivity (lost link) with an unmanned aircraft (UA); however UA have the capability to continue controlled flight along a pre-determined trajectory. This pre-determined trajectory may differ from the current Air Traffic Control (ATC)-known Instrument Flight Rules (IFR) flight plan due to needs of the Unmanned Aircraft System (UAS) to attempt to reestablish contact with the remote pilot or to satisfy other UAS mission objectives, e.g., make a precautionary landing. The UA has one or more programmed pre-determined trajectories to follow in the case of a lost command and control (C2) link or other emergency situation. These are referred to as *contingency trajectories*. Figure 1 depicts the UAS linkages and the communication paths between the UAS crew and ATC. Voice communications between the UAS crew and ATC are either via radio link through the UA and then to ATC or via alternate communications to ATC (e.g., telephone).

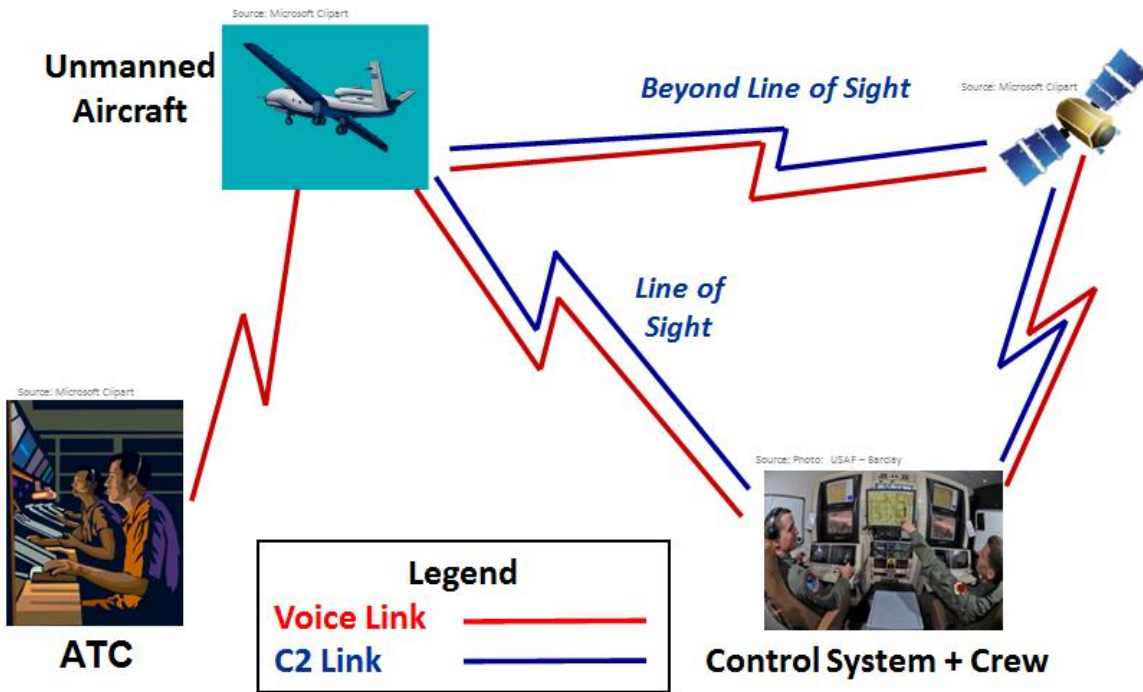


Figure 1. UAS Elements in the NAS

Currently, capabilities are not planned for ATC and Traffic Flow Management (TFM) to store, retrieve, and process UA contingency trajectories. UA contingency route information, when available, may be stored, in written form in ATC facilities, in hard copy form and/or on the En Route Information Display System (ERIDS) located in Air Route Traffic Control Centers (ARTCCs). As a result, when a contingency trajectory is being flown that differs from the ATC clearance, there is less predictability and a lack of situational awareness for radar air traffic controllers (controllers). The contingency trajectory must be manually accessed and interpreted

by the controller. Therefore, there can be a significant delay in accessing this information – the UAS may begin maneuvering before ATC has the information and has assessed the new trajectory. There is only limited consistency among UA contingency trajectories, even with similar UA flights, making it difficult for controllers to remember or become familiar with the contingency trajectories.

The Traffic Flow Management System (TFMS) has evolved a capability for flight operators to express not only a filed route of flight but a set of flight operator-provided trajectory options to be used by TFM in the event the filed route is unavailable (e.g., due to weather or excess air traffic volume). This concept of operations describes a capability that builds upon the Trajectory Options Set (TOS) function already within the TFMS to enable ATC and TFM to store, retrieve, and process UA contingency trajectories. The TFMS is described in Section 2.2.1. UAS flight operators will have the capability to file and amend contingency trajectories with ATC in advance of and during UAS operations.

1.2 Problem Statement

This section will first describe nominal aircraft and ATC operations, i.e., when aircraft are following expected trajectories. ATC-cleared trajectories, more commonly referred to as ATC clearances, are used by controllers and ATC automation to help predict future aircraft paths for manual and automated problem identification and resolution. For example, if two aircraft, on intersecting paths, are each assigned an altitude clearance that keeps the two aircraft safely separated vertically, the controller working these two aircraft and the ATC automation will predict both aircraft will comply with their altitude clearances and will predict they are safely separated. Similarly, controllers and ATC automation will predict two aircraft at the same altitude that are cleared via routings that keep the two aircraft safely separated horizontally, will follow their ATC clearances and will remain safely separated.¹

When UA encounter off-nominal situations (e.g., lost C2 link with the PIC, engine problems, or other aircraft problems) they are pre-programmed to fly a contingency trajectory to help the UA recover from the off-nominal situation and/or navigate to a pre-determined destination to land in a safe manner.² Contingency trajectories often differ from the UA's ATC clearance. Therefore, when a UA departs from its ATC clearance and follows a contingency trajectory, the controller and the ATC automation lack the correct trajectory information needed to predict and solve conflicts between the UA and other aircraft.

Replacing the last-assigned (and automation-stored) ATC clearance with the UA contingency trajectory will correct the trajectory discrepancy; however, the current method of making this correction is a manual and time-consuming process. To replace the current ATC clearance with the UA contingency trajectory, controllers must first manually look up and interpret contingency routes or they may interact verbally with the PIC via alternate communications paths (e.g., via telephone service). In either case, controllers then need to manually enter the contingency trajectory in ATC automation. Due to variances in the time and location, as well as the cause, of

¹ Generally, FAA separation standards require controllers to separated aircraft (including UAs) on IFR flight plans by 1,000 feet vertically or 5 statute miles laterally up to and including Flight Level 410 (FL410 or 41,000 feet pressure altitude) and 2,000 feet vertically or 5 miles above FL410 up to FL600. Additional separation rules apply to altitudes above FL600 and to other situations. UAs and other aircraft discussed in the research proposal are those on IFR flight plans.

² In some instances, the UA will navigate to a hold location where it has be pre-determined that if the C2 link is not reestablished prior to fuel exhaustion, a crash will pose minimal risks. Currently, contingency procedures are contained in the UA flight operator's FAA-approved Certificate of Authorization (COA).

the contingency trajectory, there is only limited consistency among UA contingency trajectories, even with similar UA flights. This makes it difficult for controllers to remember or become familiar with the contingency trajectories. Furthermore, contingency routes are often in a latitude/longitude or fixed radial distance format increasing the entry time and potential for input error.

Most UAS have multiple contingency trajectory characteristics, which must be coordinated with ATC, including:

- Contingency trajectory definition, which may vary based on
 - Problem Type (e.g., lost C2 link, engine problems, other aircraft problems)
 - The segment of the UA’s filed route of flight upon which the UA is currently located
- Contingency Activation Time: Lag between start times of problems to the time the UA activates its contingency
- Manual Restore Time (MRT): If the time a UA has been on a contingency trajectory exceeds a specified time duration (or MRT), then the UAS requires a manual restore by the PIC to return to the previous trajectory

1.3 Scope

This paper documents a potential concept of operations which discusses how specific contingency trajectories could be communicated between UAS flight operators and ATC. It is beyond the scope of this paper to propose specifics associated with the contingency trajectory path or other characteristics. It is also beyond the scope of this paper to explore systems UAS operators would need in order to develop and submit contingency trajectories to the FAA via the concept presented.

1.4 Concept Relationship to UAS Integration into the NAS Concept of Operations

This concept of operations supports the FAA’s *Integration of Unmanned Aircraft Systems into the National Airspace System Concept of Operations*, (version 2.0) by proposing a mitigation for controllers and ATC automation diminished awareness of UAS flight contingency trajectories. The relationship between this Federal Aviation Administration (FAA) concept of operations and the concept of operations described in this paper is depicted in Table 1, which is an excerpt from the former concept of operations. [1]

Table 1. Strategic Traffic Management Improvements [1]

Past Practice	Change with Integration	Improvements
The COA/SAC-EC ³ process addressed contingency operations as part of the approval process, but they	UAS contingency procedures are predetermined in most cases, and are otherwise described in the flight object	Contingency procedures are known and available to controllers in real time.

³ Special Airworthiness Certificate – Experimental Category

were not easily accessible to
ATC.

by flight segment.

2 Current Operations and Capabilities

2.1 Description of Current Operation

In today's operation, controllers depend on each aircraft under their control to follow an assigned route and altitude (and under certain ATC situations, airspeed). This gives each flight's trajectory predictable characteristics upon which a controller can depend to provide safe and efficient ATC services.

One airborne aircraft problem that may lead to following a contingency trajectory situation is a loss of the C2 link between the PIC and the UA, referred to as lost link. During a lost link event, the PIC can no longer exert operational control over the path of the unmanned aircraft. While ATC may be able to communicate with the PIC verbally, ATC will not be able to issue clearances or instructions since the PIC can no longer control the aircraft and thus will not be able to adhere to them. In this situation, after a pre-defined wait period, the UA will start to execute a pre-defined contingency trajectory. This contingency trajectory may be for the purpose of the UA attempting to reestablish link with the PIC, returning to base to land, transiting to a loiter point to await fuel exhaustion and crash, or a combination of attempting to reestablish link and one of the latter two. It is important for ATC and the ATC automation system to be cognizant of the lost link contingency trajectory being flown by the UA to provide the controller and the automated problem detection conflict probe with the information needed to continue to provide effective ATC services.

Today, contingency trajectories stored in ARTCCs are stored either on paper or in systems that are not connected to the systems ARTCC controllers use for ATC.⁴ When a controller recognizes or is advised by the UA PIC of a lost link or other contingency situation that would result in the UA following a contingency trajectory, the appropriate trajectory must be located for that UA. Looking up and determining the correct contingency trajectory that the UA will follow requires locating the COA and the contingency plans within it and then reading through the list to determine the contingency trajectory that would apply at the current point in the flight plan. Then, a controller must type the correct trajectory amendment into the UA's flight plan contained within HOST or En Route Automation Modernization (ERAM). Depending on the length of the trajectory amendment and character lengths of the fixes (Latitude/Longitude/Altitude/Speed or Navigational Aid [NAVAID]/fix) in the contingency trajectory, this could be a time-consuming process for a controller.

2.2 Current Supporting Infrastructure

2.2.1 TFMS

TFMS is a system used by TFM personnel and managers in FAA ATC facilities to conduct TFM activities. TFMS consists of the following functions. The Traffic Situation Display (TSD) provides a plan view map display of flight and weather data and is a primary graphical interface for accessing TFMS functions and data. Flight Schedule Monitor (FSM) provides a display of airport flight data and the capability to model and implement ground stop, ground delays

⁴ The legacy ARTCC ATC system still in use in some ARTCCs is called the Host Computer System (HOST) and the newer ARTCC ATC system in use in some ARTCCs and planned for all ARTCCs is called En Route Automation Modernization (ERAM).

program, and airspace flow program Traffic Management Initiatives (TMIs). The National Traffic Management Log (NTML) provides the capability to record TFM activities and coordinate TFM-related information between ATC facilities. Below are the existing or planned TFMS capabilities, which will help enable the TOS capabilities to mitigate the impact of UAS contingency trajectories.

2.2.1.1 Airborne Reroutes (ABRR) – Available in 2014

The ABRR capability within TFMS and ERAM provides TFM personnel in ARTCCs with the ability to electronically send aircraft-specific assigned reroutes to ARTCC controllers, so the controllers do not have to type the reroutes into the flight plan. Capabilities to support an initial implementation of flight-specific reroute execution for airborne flights are planned to be implemented in 2014 as part of the FAA’s Collaborative Air Traffic Management Technologies (CATMT) Work Package (WP) 2, in coordination with complementary enhancements in a future ERAM release.

2.2.1.2 Trajectory Option Sets (TOS) – Available in 2014

TOS was developed to allow flight operators (e.g., airlines) to submit multiple trajectory options to the ATM systems in addition to the trajectory in an aircraft's filed flight plan. This provides TFM with trajectories that would be acceptable to the flight operator if the primary trajectory in the filed flight plan was unavailable (e.g., due to convective weather activity) or would result in an undesirable amount of delay.⁵ A trajectory option includes data that defines the relative preferences (e.g., tolerable delay) and usability of the trajectories. The list of trajectory options for each flight is referred to as a TOS. Each trajectory in a TOS has parameters assigned by the flight operator, which provide TFM with information about each trajectory, including: which trajectory is most preferred, how much delay the flight can accept to wait for it, the time period within which the flight can depart on the trajectory, and the minimum amount of notification time for the flight to accept a change to that trajectory (this may be due to the need for additional fuel at the departure gate or other factors).

2.2.2 ERAM – Currently Being Deployed, Deployment Completed in 2014

ERAM is a system used by controllers, front line managers, and TFM personnel in FAA ARTCCs for air traffic control. ERAM provides a display of and interface for accessing flight and weather data.

2.2.2.1 Conflict Probe – Currently Deployed in all 20 ARTCCs

The Conflict Probe capability can detect future problems, which can assist controllers with problem detection and resolution. This capability is available to all ARTCC controllers, either through ERAM or the User Request Evaluation Tool (URET) in ARTCCs that have not yet deployed ERAM.

2.2.2.2 Trial Planning – Currently Deployed in all 20 ARTCCs

The trial planning capability provides controllers with the capability to check proposed trajectory changes for potential problems, which assists controllers with resolving conflicts. This capability is available to all ARTCC controllers, either through ERAM or URET in ARTCCs that have not yet deployed ERAM.

2.2.2.3 ABRR – Available in 2014

See description in Section 2.2.1.1 above.

2.2.2.4 System to Enable Flight Operator to File TOSs – Available in 2014

Flight operators can submit TOSs and, as needed for changing conditions, submit new TOSs to TFMS. [2] The TOS provides a flight's user-preferred, ranked trajectory options to TFMS. [3]

⁵ Flow Evaluation Areas (FEAs) or Flow Constrained Areas (FCAs) capabilities within TFMS are often used to identify flights that are projected to pass through potential areas of traffic congestion (e.g., due to excess traffic volume, convective weather, or degraded ATC equipment). TFM personnel in ATC facilities define FEAs and FCAs by location, spatial dimensions, start and end times, and multiple flight filters (e.g., origin, destination, type aircraft, and flight path direction).

3 Flight Trajectory Options to Mitigate the Impact of Unmanned Aircraft Systems Contingency Trajectories Concept of Operations

3.1 Assumptions and Constraints

For this paper, several assumptions, which are listed below, are made concerning UA contingency trajectories:

- UA contingency situations often involve a lateral and/or vertical trajectory change
- Manned aircraft depend on an intelligent decision maker on board
- UA have multiple pre-programmed trajectories that vary according to location and triggering event, such as⁶:
 - Interrupted or lost C2 link
 - Engine problems
 - Other aircraft problems (other than engine problems)
- UA contingency trajectories are set prior to departure and may change once the UA has departed and is airborne.

Additionally, there are constraints/conditions that must be considered for contingency trajectories:

- In the event that a UA switches to a contingency trajectory, a means of quickly updating ATC systems with the new trajectory is needed to
 - Keep the controller and ATC systems updated with the correct flight profile that the UA is actually flying
 - Support air traffic control specialists' (ATCS) problem identification and problem solving
 - Maintain ATC conflict probe accuracy
- Multiple contingency trajectory characteristics must be coordinated with ATC
 - Contingency trajectory definition, which may be based on:
 - Problem type (e.g., lost link, engine problems, other aircraft problems)
 - UA current position in correlation to appropriate contingency filed route (e.g., the contingency route segment will be activated when UA encounters problem)
 - Contingency Activation Time: Lag between start time of problem to the time the UA activates its contingency

⁶ Except for lost C2 link, these situations affect manned aircraft as well

- Manual Restore Time: If time on contingency is longer than the duration of this parameter, then UAS requires manual restore to return to the previous trajectory

Finally, a number of assumptions were made concerning planned TFMS functionality based on available information [2] [4]:

- After a flight departs, TFMS will continue to accept and store TOS submitted for that flight.
- Traffic managers will be able to view the latest TOS for airborne flights.

These assumptions will need further review as TFMS capabilities are developed.

3.2 Existing Automation Capabilities – Today’s Operating Environment

TOSs are electronic messages sent to TFMS by flight operators to convey to the FAA the trajectory options they are willing to fly and their preferences for each trajectory option in the event that a TMI may be needed to delay and/or reroute the flight due to a traffic demand/capacity imbalance. TOS messages contain one or more trajectory options for a given flight, ranked by route, altitude, speed, and applicable start and end times. TFMS algorithms assign a route option to aircraft when needed to mitigate air traffic system demand/capacity imbalances. The TFMS algorithm may also assign a required delay through the issuance of an Expect Departure Clearance Time (EDCT). The flight operator then files a flight plan matching the TFM-assigned route and plans for a departure time at the EDCT. Each trajectory in a TOS contains the following fields:

- Route
- Altitude
- Speed
- Relative Trajectory Cost (RTC) – preference, in terms of minutes of ground delay
- Trajectory Valid Start Time (TVST) – the earliest acceptable take-off time for this option
- Trajectory Valid End Time (TVET) – the latest acceptable take-off time for this option
- Required Minimum Notification Time (RMNT) – time needed to prepare for this trajectory (e.g., ordering and taking on more fuel) [4]

3.3 Potential Operations

This concept is to provide an automated capability to electronically coordinate UA contingency trajectories with en route ATCS. This is accomplished by leveraging existing or planned functionalities of the TOS within the TFMS and TFMS/ERAM ABRR. Providing ATCSs with the most correct flight plan information allows more accurate tracking and conflict detection during UA contingency operations.

In this concept, UA flight operators send TOSs to TFMS in the same manner as do manned flight operators; however the purpose of the TOS is not for communicating flight operator’s preferred alternate trajectories in the event of a TMI. Instead, the UA TOS represents pre-planned

contingency trajectories the UA will follow in the event of lost link, engine problems, or other aircraft problems.

In a generic example, a UA flight operator files a flight plan for a planned UA flight. The UA flight operator also submits the contingency trajectories for the flight within a TOS message sent to TFMS. The UA PIC receives the flight plan clearance (based on the filed flight plan) from ATC prior to taxiing for departure. After being cleared to taxi and takeoff, if the UA flight operator needs to amend any or all of the contingency trajectories, the UA flight operator submits a new TOS message to TFMS.

A UA’s TOS consists of multiple end-to-end route strings. Each string consists of a combination of route segments that define the route changes necessary in the event of a problem with the UA once en route. Figure 2 gives an example of how route segments are defined.

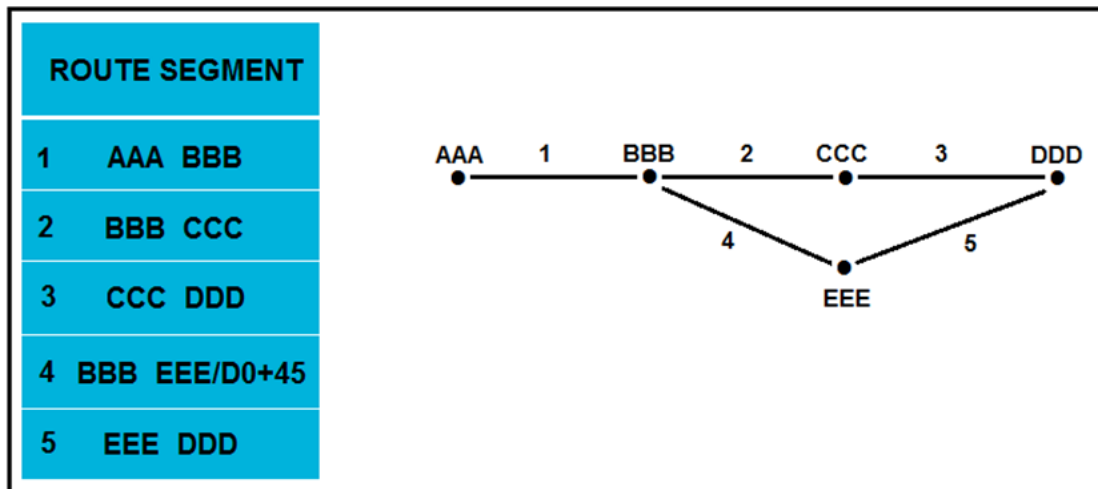


Figure 2. Route Segments of a UA Flight Plan and Contingency Trajectory

Route segments are portions of a route that make up the aircraft’s entire route of flight

- In the above diagram, the aircraft filed a primary flight plan of AAA direct to BBB direct to CCC direct to DDD (Segments 1, 2 and 3)
- A contingency (alternate) trajectory is planned that includes a change in trajectory after BBB direct to EEE then direct to DDD (Segments 1, 4 and 5)
- In NAS flight plans, a “/D” with a plus sign “+” next to a fix means that when the aircraft reaches that fix, it will delay (holding pattern) at that fix for the amount of hours/minutes specified in the segment. For the example above, the aircraft will delay at Fix EEE for 45 minutes before proceeding to DDD

The UA flight operator is required to submit contingency trajectories as a TOS. Trajectories for each of the UA’s filed flight plan segment are defined by segment start and end times. This leverages the existing TOS format using TVST/TVET data fields. It is beyond the scope of this paper to address how the UA flight operator would generate the appropriate TOS messages.

At some point in the future, additional trajectory characteristics could also be submitted with the introduction of three new TOS fields: Problem Type (PT), e.g., LLINK or ENG, Contingency

Activation Time (CAT), and MRT. Figure 3 shows an example of a filed flight plan as well as associated TOSs associated with the filed flight plan (the new required fields are outlined in red).

EDGY14 RQ4A/Q 400 KSYR P1720 340 KSYR..DJB..ROD..VHP..STL..RZC..FSM..MLC..TTT..DYS

Route	Altitude	Speed	RTC	TVST	TVET	RMNT	PT	CAT	MRT
KSYR DJB ROD VHP/D0+45 IND	340	460	-	1800	1845	-	LLINK	+05	+02
KSYR DJB ROD VHP IND	120	320	-	1800	1845	-	ENG	+00	+02
KSYR DJB ROD VHP STL/D1+00 MCI	340	460	-	1845	1930	-	LLINK	+02	+05
KSYR DJB ROD VHP STL	120	320	-	1845	1930	-	ENG	+00	+05
KSYR DJB ROD VHP STL BUM PER SYO/D1+32 SPS	340	460	-	1930	1955	-	LLINK	+08	+10
KSYR DJB ROD VHP STL BUM PER AFW	120	320	-	1930	1955	-	ENG	+00	+05
KSYR DJB ROD VHP STL RZC FSM MLC/D0+30 TTT DYS	340	460	-	1955	2110	-	LLINK	+05	+08
KSYR DJB ROD VHP STL RZC FSM MLC	120	320	-	1955	2110	-	ENG	+00	+05

Figure 3. Example of UA Filed Flight Plan and Contingency Trajectories

The UA flight operator can submit an updated TOS to TFMS to update the TVST and TVET for each flight segment to reflect any changes due to revised estimates due to departing later than proposed, winds aloft different from forecast, or ATC-issued clearances. Changing the TVST and TVET to reflect the actual departure time could be an automated process for UA aircraft types, by adjusting these values by actual departure time minus the proposed time of departure. Figure 4 shows the updated TOS TVST/TVET times based on the UA departing 7 minutes after proposed time of departure.

Route	Altitude	Speed	RTC	TVST	TVET	RMNT	PT	CAT	MRT
KSYR DJB ROD VHP/D0+45 IND	340	460	-	1807	1852	-	LLINK	+05	+02
KSYR DJB ROD VHP IND	120	320	-	1807	1852	-	ENG	+00	+02
KSYR DJB ROD VHP STL/D1+00 MCI	340	460	-	1852	1937	-	LLINK	+02	+05
KSYR DJB ROD VHP STL	120	320	-	1852	1937	-	ENG	+00	+05
KSYR DJB ROD VHP STL BUM PER SYO/D1+32 SPS	340	460	-	1937	2002	-	LLINK	+08	+10
KSYR DJB ROD VHP STL BUM PER AFW	120	320	-	1937	2002	-	ENG	+00	+05
KSYR DJB ROD VHP STL RZC FSM MLC/D0+30 TTT DYS	340	460	-	2002	2117	-	LLINK	+05	+08
KSYR DJB ROD VHP STL RZC FSM MLC	120	320	-	2002	2117	-	ENG	+00	+05

Figure 4. TVST and TVET Updated to Reflect Actual Departure Time

When a UA senses C2 link is lost with the PIC or other contingency situation requiring the execution of a contingency trajectory, the UA could set its transponder to a special-purpose beacon code.⁷ The lost link beacon code would cause a prominent indication in the UA data block on the controller display,⁸ informing ATC of the contingency situation. Other special-purpose emergency beacon codes could also be defined or the UA might be able to make use of the three existing emergency beacon codes, so UAs could inform ATC of other problem types. When an en route controller notices a lost link or other problem beacon code in a UA datablock, the controller notifies the front line manager (FLM) of the UA contingency situation.

⁷ Today unmanned aircraft would squawk 7600, the special purpose beacon code signifying a loss of ATC communications. It is expected that a new special purpose emergency beacon code will be defined to specifically indicate a loss of a UAS command and C2 link. The beacon code of 7400 is being explored. If an unmanned aircraft is experiencing a contingency other than a loss of a command and C2 link it would most likely squawk either 7600 or 7700 (emergency).

⁸ This would require additional ERAM modifications.

The FLM then notifies a traffic management coordinator (TMC) or looks up the UA flight plan in TFMS to read the TOS. The FLM or TMC identifies appropriate trajectory option from the UA's current TOS in TFMS by matching the current time with the TVST/TVET and the PT.

Figure 5 shows the correct contingency option that the FLM or TMC would select, based on the current time being 1938 at the time of the lost link.

Current time: 1938

Route	Altitude	Speed	RTC	TVST	TVET	RMNT	PT	CAT	MRT
KSYR DJB ROD VHP/D0+45 IND	340	460	-	1807	1852	-	LLINK	+05	+02
KSYR DJB ROD VHP IND	120	320	-	1807	1852	-	ENG	+00	+02
KSYR DJB ROD VHP STL/D1+00 MCI	340	460	-	1852	1937	-	LLINK	+02	+05
KSYR DJB ROD VHP STL	120	320	-	1852	1937	-	ENG	+00	+05
KSYR DJB ROD VHP STL BUM PER SYO/D1+32 SPS	340	460	-	1937	2002	-	LLINK	+08	+10
KSYR DJB ROD VHP STL BUM PER AFW	120	320	-	1937	2002	-	ENG	+00	+05
KSYR DJB ROD VHP STL RZC FSM MLC/D0+30 TTT DYS	340	460	-	2002	2117	-	LLINK	+05	+08
KSYR DJB ROD VHP STL RZC FSM MLC	120	320	-	2002	2117	-	ENG	+00	+05

Figure 5. Applicable Contingency Trajectory for Current Time of 1938

Next, the FLM or TMC enters selected trajectory option (current contingency trajectory) into the TFMS ABRR Route Amendment dialog box and sends the contingency trajectory to the controller through TFMS to ERAM ABRR reroute functionality. Figure 6 gives a notional view of the TFMS route amendment dialog box with the FLM/TMC inserted selected contingency route.

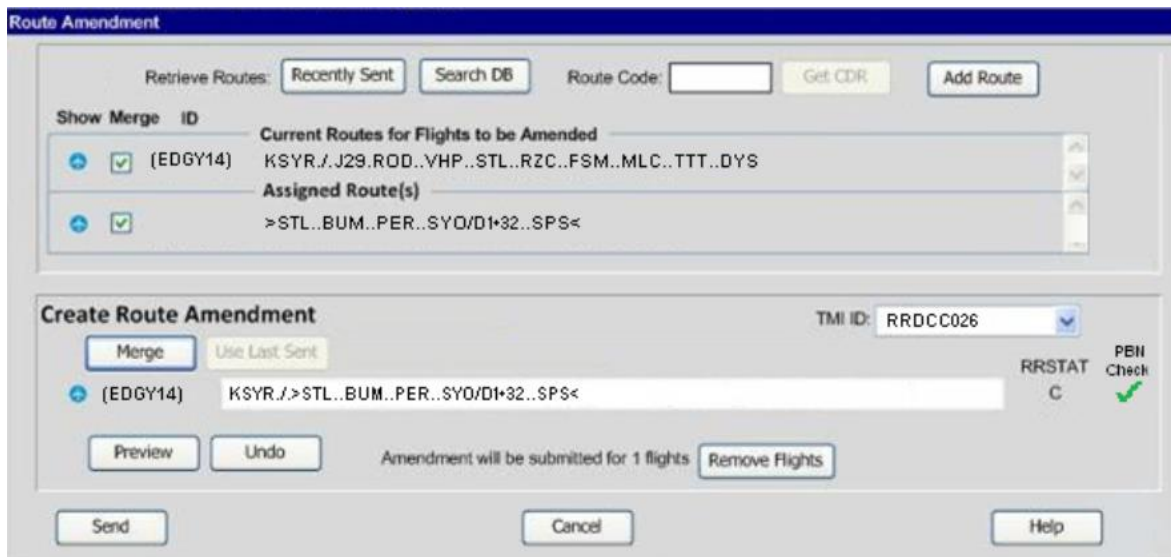


Figure 6. Notional TFMS Route Amendment Dialog Box (Modified from [5])

When the controller receives the UA contingency route amendment in ERAM, the route is not yet incorporated into the ERAM flight plan route of flight. The controller can trial-plan (see Section 2.2.2.2) the UA contingency trajectory route and altitude for potential conflicts and then

enter the amended route and altitude into the ERAM flight plan. After that, the controller monitors the actual UA track for future conflicts (aircraft-to-aircraft and SAA probe) and to ensure it follows the pre-coordinated, expected contingency trajectory. Figure 7 shows a notional example of what the en route controller's D-side Graphic Plan Display (GPD) and plans display may look like when no conflict is detected.

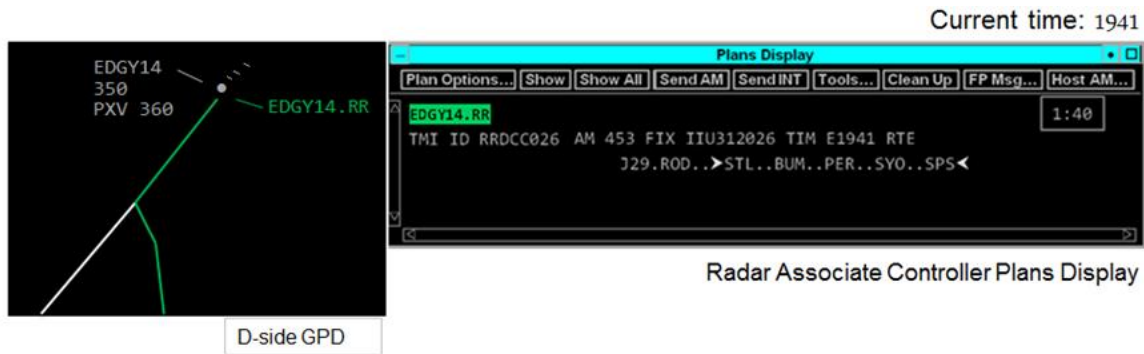


Figure 7. Notional ERAM Controller GPD without Conflict Detected (Modified from [5])

When the controller is notified by the UA PIC (via air-ground or ground-ground communication) that the contingency situation is resolved, the controller can receive the updated route request directly from UA flight operator. Alternatively, the UA PIC can coordinate with the controller that the PIC is updating the TOS to reflect the new, revised, route with the route start time. If the UA flight operator has updated the TOS with this new nominal route, the controller informs the FLM, the FLM either advises the TMC or retrieves the new, revised, nominal route from UA updated TOS. The FLM or the TMC enters the selected trajectory option (revised nominal trajectory) into the TFMS ABRR reroute dialog box. The FLM or TMC then sends new nominal trajectory to ATCS through TFMS to ERAM ABRR reroute functionality. The controller observes the UA contingency route amendment received in ERAM from TFMS, selects the received contingency route to amend UA flight plan, and trial-plans the UA contingency route for conflicts. If ground to ground PIC/ATC communications are available or when 2-way voice communications are re-established, if there is a conflict, the controller has the option to revise the UA's trajectory to resolve the conflict. The controller then issues the UA PIC an ATC clearance for the new route, enters the amended route into the UA's ERAM flight plan and monitors the actual UA track the same as with other flights.

In the case where there is a conflict detected, when the en route controller conducts a trial-plan of the UA PIC's requested new nominal route, the controller would observe that the reroute problem status indicates the conflict. For example, if this is due to a predicted aircraft-to-aircraft problem, the controller may choose to either amend the UA clearance or adjust the trajectory (clearance) of the other aircraft. Figure 8 shows a notional example of what the en route controller's plans display may look like when there is a conflict detected. Figure 9 is a flow chart of the entire process once the UA encounters a problem and will be flying a contingency route.

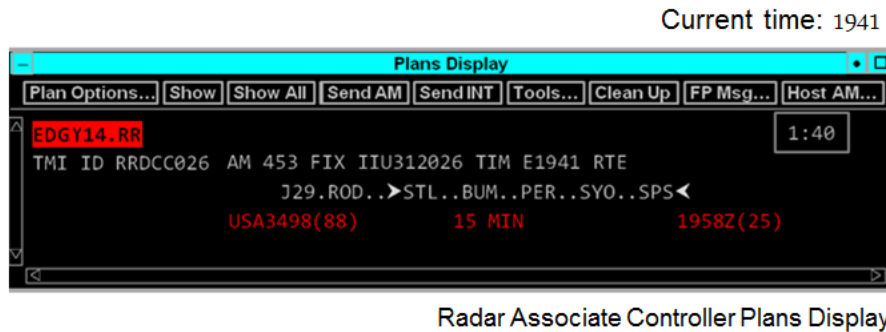


Figure 8. Notional ERAM Controller GPD with Conflict Detected (Modified from [5])

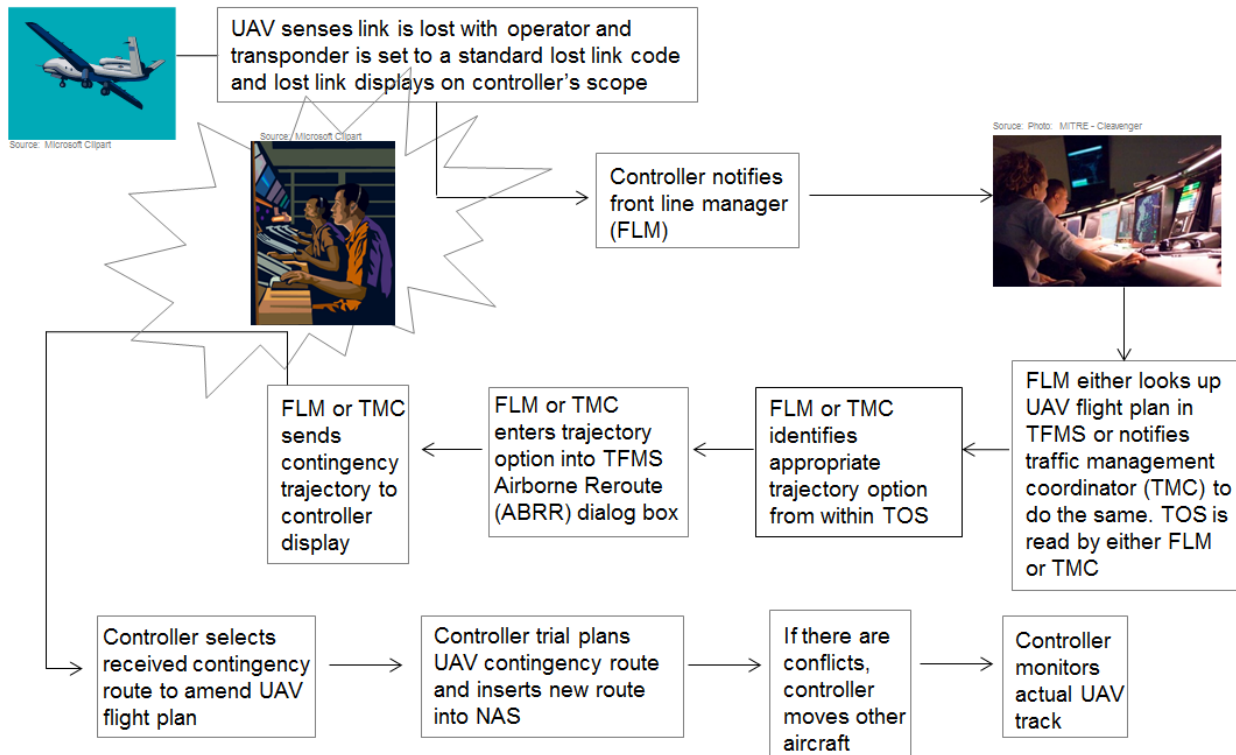


Figure 9. Contingency Operations Flow Chart – Example Use Case: Lost Link

3.4 Benefits to be Realized

The capability to electronically obtain, coordinate, and update active UA flight plans with correct trajectory information during UA contingency operations will more fully utilize existing and planned ATC automation capabilities and may enhance safety. This improvement in safety may be realized by providing controllers with earlier UA contingency-related flight plan updates, providing accurate trajectory and conflict detection information, less distraction from other high-priority ATC duties, and less chance for input errors than with currently used manual methods. This capability will allow UA contingency procedures to be both known and predictable. These capabilities will help make UA operations more routine and less of an exception to normal operations, which will reduce controller workload.

4 Summary of Impacts

4.1 Operational Impacts

The capability to electronically obtain, coordinate, and update active UA flight plans with correct trajectory information during UA contingency operations may enhance safety. This improvement in safety may be realized by providing controllers with earlier UA contingency-related flight plan updates, providing accurate trajectory and conflict detection information, less distraction from other high-priority ATC duties, and less chance for input errors than with currently used manual methods. This capability will allow UA contingency procedures to be both known and predictable.

There will also be a sharing of tactical, operational responsibility between the controller, FLM and TMC whereas prior to this capability, most or all of the tactical operational responsibility belongs to the controller. There will also be a change of responsibility of UA flight operators to file and update TOSs to reflect current contingency trajectories whereas prior to the capability, UA flight operators relied on more manual methods of coordinating contingency trajectories with ATC as defined in UA flight operators' FAA-approved COAs.

Finally, while this paper presents a detailed concept of operations and speculates on the potential operational benefits from ATM perspectives, analysis was not conducted on how these benefits might impact UAS operators in terms of relaxation of operational limitations, flexibility in COA approvals, etc.

4.2 System Impacts

The capability described in this concept of operations could be realized with limited or no changes to TFMS, ERAM, or other FAA automation systems. This assessment is based on the included references for FAA automation [2] [3] [4] [5] and the assumptions previously outlined. This concept will need to be reviewed as more detailed FAA automation plans are developed. Additionally, if three additional fields could be added to the definition of the TOS (as optional fields), more refined information could be available to provide ATC with trajectory characteristics regarding: PT, e.g., LLINK or ENG, CAT, and MRT. These three additional fields are not necessary to achieve the majority of the capabilities described in this concept of operations.

A potential negative impact is that if a UA with contingency trajectories in its TOS became subject to a TMI, which was using TOSs to assign reroutes and EDCTs, the UA could potentially be assigned a reroute or EDCT, when the trajectories in the TOS were not designed for this purpose. This potentially negative impact could be mitigated through procedures that require UA flight operators to be aware of and avoid locations in the NAS where TMIs using TOSs are occurring or are expected to occur. A second potential mitigation option could be to introduce requirements for TFMS automation to ignore the TOS in UAs when analyzing and computing these types of TMIs and instead assign UAs reroutes and/or EDCTs that are not generated from use of the UA TOS. A third potential mitigation strategy for precluding the use of UA TOSs for TMI-related purposes would be to filter out UAs out of FEAs and FCAs upon which TOS-related TMIs are based. To avoid being issued a reroute by CTOP, UA operators could also submit TOS with the maximum RTC allowable for each contingency route. This would significantly decrease the likelihood that CTOP assigns a submitted contingency route as a reroute.

Finally, as previously mentioned, UAS operators will likely need to develop automation changes in order to generate contingency TOS messages from the stored contingency routes in mission planning and other flight control systems. Analysis of the automation changes required was beyond the scope of this research, but will likely be critical to this concept.

5 References

- [1] FAA, *Integration of Unmanned Aircraft Systems into the National Airspace System Concept of Operations*, V2.0, September 28, 2012.
- [2] Traffic Flow Management-Modernization (TFM-M) Program, *Traffic Flow Management System (TFMS) Collaborative Trajectory Options Program (CTOP) Interface Control Document (ICD) for the Traffic Flow Management-Modernization (TFM-M) Program*, Version 3.0, November 2012.
- [3] CSC, *Collaborative Trajectory Options Program (CTOP) Interface Control Document (ICD) for the Traffic Flow Management System (TFMS)*, Version 2.3, October 18, 2011, Prepared for U.S. Federal Aviation Administration by CSC, North American Public Sector – Civil Group, Rockville, MD.
- [4] Volpe, CACR Industry Day Technical Briefing, CTOP Assignment Algorithm and Substitutions, Cambridge, MA, November 2011.
- [5] Bowen, K. C. et al., *Concept of Operations for Executing Initial TFM-Initiated Airborne Reroutes in the 2014 Timeframe*, MTR110155R3, McLean, VA, September 2012.

Appendix A Glossary

Acronym	Definition
ABRR	Airborne Reroutes
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
ATCS	Air Traffic Control Specialist
ATM	Air Traffic Management
C2	Command and Control
CAT	Category
CATMT	Collaborative Air Traffic Management Technologies
COA	Certificate of Authorization
EDCT	Expect Departure Clearance Time
ERAM	En Route Automation Modernization
ERIDS	En Route Information Display System
FAA	Federal Aviation Administration
FCA	Flow Constrained Area
FEA	Flow Evaluation Area
FL	Flight Level
FLM	Front Line Manager
FSM	Flight Schedule Monitor
GPD	Graphic Plan Display
IFR	Instrument Flight Rules
MRT	Manual Restore Time
NAVAID	Navigational Aid
NextGen	NextGen Air Transportation System
NTML	National Traffic Management Log
PIC	Pilot in Command
PT	Problem Type
RMNT	Required Minimum Notification Time
RTC	Relative Trajectory Cost
SAC-EC	Special Airworthiness Certificates – Experimental Category
TFM	Traffic Flow Management
TFMS	Traffic Flow Management System

Acronym	Definition
TMC	Traffic Management Coordinator
TMI	Traffic Management Initiative
TOS	Trajectory Option Set
TSD	The Traffic Situation Display
TVET	Trajectory Valid End Time
TVST	Trajectory Valid Start Time
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
URET	User Request Evaluation Tool
WP	Work Package

Disclaimer

Approved for Public Release. Distribution Unlimited. Case Number 13-3449.

The contents of this material reflect the views of the author and/or the Director of the Center for Advanced Aviation System Development (CAASD), and do not necessarily reflect the views of the Federal Aviation Administration (FAA) or the Department of Transportation (DOT). Neither the FAA nor the DOT makes any warranty or guarantee, or promise, expressed or implied, concerning the content or accuracy of the views expressed herein.

©2013 The MITRE Corporation. All Rights Reserved. The Government retains a nonexclusive, royalty-free right to publish or reproduce this document, or to allow others to do so, for "Government Purposes Only." For further information, please contact The MITRE Corporation, Contract Office, 7515 Colshire Drive, McLean, VA 22102 (703) 983-6000.