INTEGRATING UNMANNED AIRCRAFT INTO NEXTGEN AUTOMATION SYSTEMS

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Abstract

The routine integration of unmanned aircraft into non-segregated civil airspace is important to enable a number of current and proposed applications ranging from military and homeland security to a wide variety of research and eventually commercial purposes. The Federal Aviation Administration (FAA) is currently undertaking a comprehensive overhaul of the National Airspace System (NAS) known as Next Generation Air Transportation System (NextGen). NextGen will include increased automation systems for both terminal and en-route Air Traffic Control (ATC). Improvements in two-way data communication links between aircraft and ATC will facilitate the use of such automation systems. The robust integration of unmanned aircraft systems (UAS) into NextGen automation systems is an integral component to meeting the far-term (2018+) NextGen vision. By determining how UAS flight operations and protocols may be different than those of traditional manned aircraft, informed decisions can be made concerning the data and interfaces required to accommodate routine UAS operations by NextGen automation systems, ultimately leading to safer and more efficient integration of UAS into non-segregated civil airspace. This paper describes many of the challenges associated with such accommodation as well as proposed solutions to address these challenges based upon construction of prototype interfaces using established UAS communication standards and envisioned ATC automation interfaces. Enhanced data formats, communication protocols and algorithms are also researched and discussed.

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Introduction

Over the past decade, UAS have become an integral part of U.S. military and government operations [1] spanning the Departments of Defense (DoD), Homeland Security (DHS), Interior (DoI), and other agencies. UAS expenditures are expected to double over the next decade, largely driven by the U.S. military [3]. The U.S. Army anticipates that “with the proliferation of UAS and the eventual troop redeployment to home stations within CONUS, the demand for DoD training will quickly exceed the allotted volume for military aviation operations today” [4]. Additionally, UAS are increasingly being employed for non-military applications [4]. The Department of Homeland Security – Customs and Border Protection (DHS-CBP) operates a small fleet of MQ-9 Predator-B UAS that have been deployed around the country. In 2011, DHS-CBP used these aircraft to help seize more than 7,600 pounds of illegal narcotics [15]. UAS have also been used to support scientific studies relating to flooding impacts on erosion and crop damage, and in support of forest firefighting operations (e.g. the Monument Fire in Arizona) [15]. All these public-use UAS applications currently operate under Certificates of Waiver or Authorization (COA). There is also increasing demand for commercial use of UAS for a variety of applications. Commercial UAS operations currently are not permitted in the NAS.

The Next Generation Air Transportation System is a comprehensive overhaul of the U.S. national airspace system; the primary goals of NextGen are to “enhance the safety and reliability of air transportation, to improve efficiency in the NAS and to reduce aviation's impact on the environment.” [2]

Background

NextGen capabilities that could require special attention for integration of routine UAS operations include Data Communications and enhanced Automation Systems. Existing standards found in NATO STANAG 4586 may be useful for consideration in NextGen systems.

Data Communications

The mid and far-term NextGen vision includes enhancements in two-way data communication links between aircraft and ATC systems. Data communications “will provide routine and strategic information to flight crew and automate some routine tasks for both pilots and controllers” [2]. Such enhancements will impact every phase of flight including both terminal and en-route procedures.

Benefits include

- Greater capability for pilots via flight deck displays
- The use of sophisticated automation tools
- Improved coordination between pilots and air traffic controllers
- Reduced reliance on voice communications

Because UAS pilots are not physically onboard the aircraft, additional capabilities (such as a ground-based link) may be leveraged to achieve the same data link benefits. It is possible that the aircraft could serve as a communications relay point between ATC and flight crew; such a link, however, would likely be susceptible to the same link failures that occur on the vehicle Command and Control (C2) link and may not provide a robust data communications pathway between the flight crew and controllers in the event of a failure or other emergency situation. Current UAS operations are heavily reliant on voice communication with ATC; voice communication may not scale to the possible demand for UAS in the NAS nor is it an ideal protocol, due to the complexity and volume of UAS data (e.g. long endurance flight plans).

Automation Systems

NextGen will expand the use of automation tools (e.g. En-Route Automation Modernization (ERAM)) to streamline routine operations of both controllers and flight crew. According to a MITRE study, controller workload is likely to remain the single greatest functional limitation on the capacity of the ATM system; workload is largely driven by airspace complexity [7][8][9]. Controller workload increases almost linearly as the ratio of UAS to manned aircraft increases [6]. As a result, it is important for UAS to be integrated into NextGen automation systems to meet potential capacity demands in the mid to far-term.

NATO STANAG 4586

NATO Standardization Agreement (STANAG) 4586 “defines the architectures, interfaces, communication protocols, data elements, message formats and identifies related STANAGs that compliance with is required to operate and manage multiple legacy and future UAVs [Unmanned Aerial Vehicles] in a complex NATO Combined/Joint Services Operational Environment” [5]. UAV is another term sometimes used for UAS. In this paper, we will use the term UAS. The standard consists of numerous messages representing the two-way data exchange between the vehicle and the control segment. These messages and their corresponding data elements cover a broad range of functions including vehicle and payload C2, route configuration (including contingencies), data link status, emergency states, and others. This research uses STANAG 4586 (ed. 3, 2012) as a reference for the types of data fields likely to be stored in a GCS and/or onboard a UAS that could potentially be shared with an external ATC system.

Integration Challenges

Flight Planning

Flight planning is an integral component of air traffic operations that enables controllers to efficiently manage complex airspaces. ATC systems that handle route information (e.g. Traffic Flow Management System (TFMS)) require routes to be specified in either the NAS Flight Plan (FP) or ICAO (FPL) format. Certain capabilities require the submission of the newer FPL route type. For example, ERAM requires an FPL for the assignment of RNAV arrival or departure routes. The DOD commonly submits flight plans using 2 forms: DD-1801[1] (DOD International Flight Plan) or DD-175[2] (Military Flight Plan). While both of these flight plan

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[1] DD-1801 is the same as the ICAO FPL form.

[2] DD-175 is the same as the batch NAS FP form.

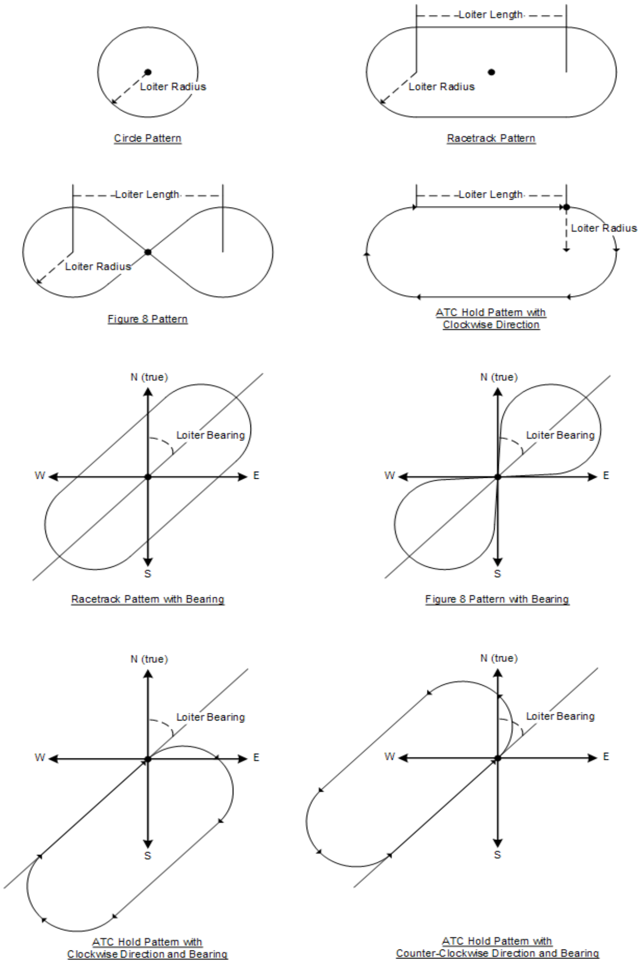
formats accommodate UAS differently, neither adequately handles all UAS route types.

ICAO FPL 2012

The ICAO 2012 standard is a step towards compatibility with STANAG 4586-like routes, but falls short in several key areas. With STANAG 4586, routes essentially consist of waypoints, which may or may not exactly match existing known fixes (and their constraints), loops, and various loiter patterns. The ICAO 2012 standard can support (a possibly limited number of) the STANAG 4586 waypoints, but can only partially support the loops in the route and specified loiter patterns.

The primary method to transmit routes to the aircraft with STANAG 4586 is with the “AV Route” message (13001), and a series of “AV Position Waypoint” messages (13002) or “AV Loiter Waypoint” messages (13003). A route may contain up to 65,535 waypoints; and some of those waypoints can be part of a loop or be the significant point of a loiter pattern. The loops can be limited by time, fuel, or number of laps. A loiter waypoint may exist that specifies a certain pattern to follow: a circle, racetrack, figure 8, figure 8 with a bearing, racetrack with a bearing, etc. Additionally with STANAG 4586, contingency routes may be specified. Contingency routes are not explicitly part of the ICAO message set.

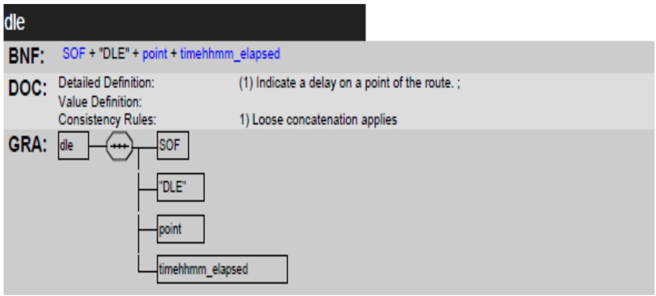
The ICAO route specification makes it easy to specify waypoints. The user creating the flight plan for ICAO 2012 may specify latitude and longitude pairs with altitude and airspeed constraints directly in the route definition. ICAO uses the concept of a “significant point,” defined as “a specified geographical location used in defining an ATS route or the flight path of an aircraft and for other navigation and ATS purposes” [10]. The significant point may be an arbitrary latitude/longitude pair, not necessarily a known fix, and if a change of speed or flight level is planned, it may be specified at that point in the route definition. For instance, a point at 46°2’N 78°5’W changing to 500knots and 35000ft, would be represented as “4602N07805W/N0500F350”. This is something that is currently not possible with current NAS flight plans unless using a pre-stored SID/STAR or other procedure where those constraints are part of the procedure. TFMS accepts the FPL route string with altitude and speed changes in the route text, but strips them out. TFMS models routes as if flying the initial cruising speed and altitude for the entire length of the route, until the start of descent [11]. STANAG 4586 allows a pilot to specify a unique speed/altitude for every waypoint.



Circle Pattern
Racetrack Pattern
Figure 8 Pattern
ATC Hold Pattern with Clockwise Direction
Racetrack Pattern with Bearing
Figure 8 Pattern with Bearing
ATC Hold Pattern with Clockwise Direction and Bearing
ATC Hold Pattern with Counter-Clockwise Direction and Bearing

Figure 1. Example loiter configurations in STANAG 4586

Using the new ICAO FPL also provides the user some capability to specify a loiter procedure on the route. One of the new additions to the ICAO flight plan format is the ability to specify a delay point on a route using the “DLE” (Figure 2) flag. Previously, this was done in the Integrated Initial Flight Plan Processing System (IFPS) Zone (IFPZ) with the “STAY” indicator (Figure 3), which allows the user creating the flight plan to specify a period of special activity with an entry and exit point, and duration in the area. STAY may be used a maximum of nine times in any given route. With DLE, the user may specify any number of locations on the route where a delay will be applied (limited by the number of points specified on the route). In addition, DLE can handle only a time-based duration; it cannot specify some number of loops, or until fuel reaches some point, etc., all of which are possible with STANAG 4586. DLE and STAY also do not allow the user to specify a pattern to fly or give an airspace boundary to be used, just the point (or 2 points for STAY). DLE is being added to the official ICAO 2012 spec, while STAY is a custom addition in the IFPZ area only. The most likely use of DLE, and possibly STAY, is to indicate a standard ATC hold (racetrack) pattern, and not to fly any custom loiter routes as specified by STANAG 4586.



dle

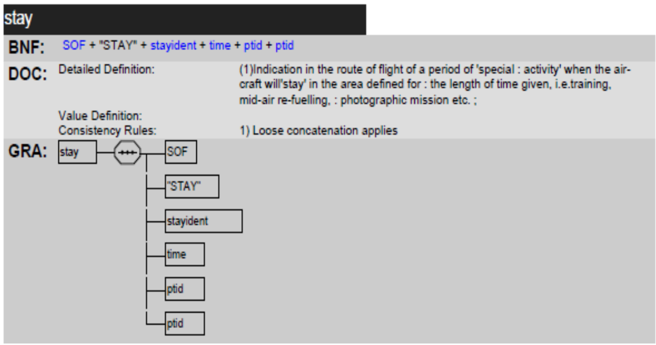
BNF: SOF + "DLE" + point + timehhmm_elapsed

DOC:

Detailed Definition:	(1) Indicate a delay on a point of the route. ;
Value Definition:	
Consistency Rules:	1) Loose concatenation applies

GRA:

Figure 2. DLE specification in IFPS message set [12].



stay

BNF: SOF + "STAY" + stayident + time + ptid + ptid

DOC:

Detailed Definition:	(1)Indication in the route of flight of a period of 'special : activity' when the aircraft will'stay' in the area defined for : the length of time given, i.e.training, mid-air re-fuelling, : photographic mission etc. ;
Value Definition:	
Consistency Rules:	1) Loose concatenation applies

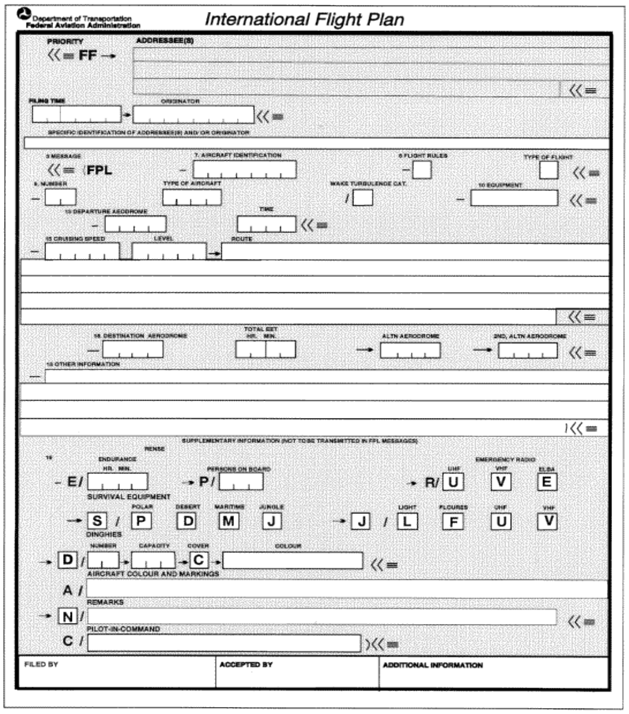
GRA:

Figure 3. STAY specification in IFPS message set [12].

Another possible issue with ICAO is the maximum length of the route transmitted. The route length is often specified by the size of the paper forms to be filled out (X lines, with Y characters max per line). The form is shown in Figure 4 below. For instance, the ICAO 4444 document specifies in the transmission instructions for the FPL (flight plan) message a requirement to not include "more than 69 characters in any line of Items 15 or 18".[10] In the "IFPS and RPL Dictionary of Messages; ICAO 2012 Special edition", an unlimited number of POINT_ROUTE_ITEM's are possible in the FIELD_TYPE_15C_ICAO field in the ICAO_FPL_MESSAGE, so there should theoretically be no limit to the size of the route depending on the implementation; at least in the IFPZ [12]. One of the additions to the ICAO 4444 format, shown in Appendix 2 of the amendment 1 document, is the following additional requirement:

> Note 2. Air traffic services data systems may impose communications or processing constraints on information in filed flight plans. Possible constraints may, for example, be limits with regard to item length, number of elements in the route item or total flight plan length. Significant constraints are documented in the relevant Aeronautical Information Publication [17].

With that additional requirement, each AIP must specify those constraints explicitly, and they may vary by country or location. Depending on how the flight plan is filed, and what online services are used (if any), there may be other limitations that may not be expected. For instance, GA pilots can file online using www.homebriefing.com, www.eurofpl.eu, etc., which may each have different limitations.



Department of Transportation
Federal Aviation Administration

International Flight Plan

PRIORITY
ADDRESSEE(S)
<<≡ FF →
FILING TIME
ORIGINATOR
SPECIFIC IDENTIFICATION OF ADDRESSEE(S) AND/OR ORIGINATOR
3 MESSAGE TYPE
<<≡ (FPL
7 AIRCRAFT IDENTIFICATION
8 FLIGHT RULES
TYPE OF FLIGHT
9 NUMBER
TYPE OF AIRCRAFT
WAKE TURBULENCE CAT.
10 EQUIPMENT
13 DEPARTURE AERODROME
TIME
15 CRUISING SPEED
LEVEL
ROUTE
16 DESTINATION AERODROME
TOTAL EET HR. MIN.
ALTN AERODROME
2ND. ALTN AERODROME
18 OTHER INFORMATION
SUPPLEMENTARY INFORMATION (NOT TO BE TRANSMITTED IN FPL MESSAGES)
19 ENDURANCE HR. MIN.
PERSONS ON BOARD
EMERGENCY RADIO UHF VHF ELBA
– E/ → P/ → R/ U V E
SURVIVAL EQUIPMENT
POLAR DESERT MARITIME JUNGLE
→ S / P D M J
JACKETS LIGHT FLOURES UHF VHF
→ J / L F U V
DINGHIES
NUMBER CAPACITY COVER COLOUR
→ D / → → C →
AIRCRAFT COLOUR AND MARKINGS
A /
REMARKS
→ N /
PILOT-IN-COMMAND
C /
FILED BY
ACCEPTED BY
ADDITIONAL INFORMATION

Figure 4. ICAO FPL Paper Form

When transiting out of the NAS into international airspace, the ICAO fields are stored and transmitted along with other NAS fields, and there are additional limitations currently in place for those messages. For instance, the NAS will return an error of: “RTE TOO MANY ELEMENTS” if “an FPL message contains more than the maximum number of elements (46); or after Field 10 is constructed, Field 10 contains more than 48 elements.” It goes on to say that “A future ERAM enhancement will expand the route capacity to 1000 characters”.[16] Other rules exist for using ICAO for aircraft that operate at least partially in the NAS.

Looping, or reusing the same point on the route more than once, may also be a possible issue with ICAO (or at least some implementations). In the IFPS, specifying the same point twice in field 15 is not allowed, and the point must be renamed or an error code will be returned when attempting to file. There is a rename capability in IFPS to enable the same point to be used in the route more than once; however, the “renid”, or id of the renamed point has a 2 digit limitation, so there can be no more than 100 instances of any reused points in an ICAO route with IFPS. If the user attempts to create loops in the route, it is uncertain how different implementations of the ICAO flight plan processing systems will handle it, and whether other automation systems similar to conflict probe would be capable of processing those routes.

When not using loops, each unique STANAG 4586 waypoint may be translated to an ICAO route that specifies an absolute latitude, longitude, altitude and speed, however. Any relative waypoint locations in STANAG 4586 will need to be converted to absolute lat/lon positions when translating to the ICAO flight plan format, and any speed or altitude fields may need to be translated into the format expected by ICAO, as well. Additionally, certain systems will reject a flight plan with a duration of greater than 24 hours; a rejection message “FLYING TIME GR 24 HRS” is returned [13]. This would be a significant limiting factor for medium-altitude long endurance (MALE) and high-altitude long endurance (HALE) aircraft.

The ICAO route format has advantages over the NAS route specification, since it allows specifying altitude and speed changes in line with the rest of the route definition. However, loiter patterns and waypoint loops may not be practically applicable in ICAO routes. Although with ICAO, you may use the DLE and/or STAY (STAY only if in the IFPZ) to specify where a loiter pattern or special activity may take place (as long as the duration of the activity is known), DLE or STAY specifies only the point to loiter about, but nothing about the loiter radius or area/shape of the flight path. This lack of ability to define specific flight paths is a key limitation that must be addressed for more detailed UAS routes.

Contingency Routes

Contingency routes, one of the key differences in flight/mission planning between manned and unmanned aircraft, are flight plans to be flown in the event that an emergency, failure, or other off-nominal set of conditions are met. Contingency routes are typically pre-programmed into an aircraft’s flight management computer. Example conditions include loss of C2 communication link, loss of critical avionics, engine out, and missed approach. A particular contingency route may be assigned to a specific waypoint, route, mission or area; a contingency route may additionally be assigned based on a specific type of emergency or failure. For example, contingency route alpha may be activated if and only if there is a loss of critical avionics and the most recent waypoint crossed was 4602N07805W. As a result, a given UAS flight may have dozens or hundreds of contingency routes assigned to it. Contingency routes are defined in STANAG 4586 using the Define Contingency (13007) message. This raises several challenges for ATC systems, as there are currently no existing or planned mechanisms for storing and/or processing contingency routes.

For controller situational awareness and to make use of certain automation (e.g. conflict probe), a storage mechanism must be in place for (at least a subset of) a UAS’s contingency routes. Each of these routes would have the same data requirements as the primary route (FP or FPL). Additionally, each contingency route would have to carry with it all of the specific activation conditions and other necessary meta-data. If a contingency were based on an Area, the ATC system would have to understand that Area definition (see Figure 5).

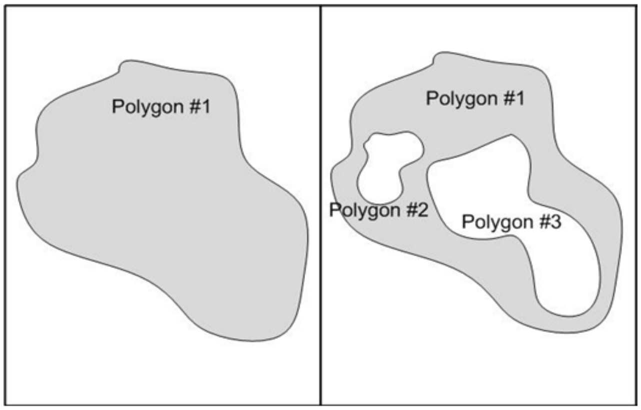


Figure 5. Area Polygon Definition in STANAG 4586

Area polygons are defined in STANAG 4586 using the Area Transmission Command (2011) and Area Polygon Loop Segment (2012) messages. A polygon Area is defined as a set of vertices, accompanied by min/max altitudes and temporal information (start/end time). Each Area may contain up to 255 "segments"; each segment may contain between 3 and 50 vertices. Each vertex requires an 8-byte latitude/longitude pair.

Area ID	Unsigned 1	1 ≤ x
Polygon ID	Unsigned 1	1 < x
Polygon Start Time	Unsigned 5	
Polygon End Time	Unsigned 5	
Number of Segments in this polygon (Loop)	Unsigned 1	1 < x
Loop segment number	Unsigned 1	1 < x
Number of Vertices in this Segment (n)	Unsigned 1	3 < x ≤ 50
Latitude #<n>	Integer 4	-π/2 ≤ x ≤ π/2
Longitude #<n>	Integer 4	No Restrictions

Figure 6. Area Polygon Data Requirements

Similarly if a waypoint, route, or mission specifies the contingency route, relevant ATC automation must have the information required to determine which contingency route will become active under certain conditions. Emergency, failure, or other vehicle specific conditions for contingency activation would also have to be stored with each route. Certain contingency routes may be configured with both a Delay Time – the time between when contingency conditions are met, and the contingency procedure is activated, and a Required Manual Restore Time – "Time prior to AV executing loss link maneuver where restoration of the link will not result in automatic recovery of Core UAV Control System (CUCS) control" [5].

Data Comm Integration

Due to the volume, length and complexity of UAS flight plans and contingency routes, the desire for dynamic operations (e.g. en-route flight amendment; adverse weather conditions) and to facilitate coordination between controllers and UAS pilots, a two-way data communications link between ATC and UAS control stations will be necessary in the far-term (2018+). Such a link could be ground based leading to increase resiliency and robustness.

In the event of a failure, emergency, or set of other off-nominal conditions, the flight crew would communicate via data-communications information relating to the incident. ATC automation would then update the controller scope with the necessary information. Via the same communication channel, ATC would be updated with the most up-to-date contingency procedures. ATC would need to be updated with the time of failure, type of failure (failure conditions met) and any applicable contingency route changes. For dynamic operations, data such as a pilot request for an en-route flight amendment, or updated meteorological data would be exchanged via data comm. This will enable the transmission of long and/or complex UAS route information and the use of ATC automation (e.g. conflict probe). Figure 7 shows an example controller display being updated after receiving a pilot request via data comm for an amended flight plan. The proposed route information is displayed in an "Alert List", which is not currently part of the standard ATC scope.

FLIGHT ID	ALERT		TIME
DAL1715◣	AC	DAL2293(unk)	7
REAP99◣	PR	FL150	

```
CLRD 351001N/835244W 351800N/823730W 353954N/823810W 353940N/844529W 355353N/844550W
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Figure 7. Pilot Request for Flight Plan Amendment on Controller Scope

Once received, the proposed route data would be processed by relevant automation. This will enable controllers to accept, reject, or further amend the proposed route update directly from their scope using data comm. Figure 9 and 10 show a notional controller scope displaying a propose UAS route amendment received via data comm. In Figure 9, the route has passed through conflict probe automation and is displayed in green, indicating that no conflicts were detected. In Figure 10, automation detected a conflict, causing the proposed route to appear in red. Figure 11 shows the controller scope providing the option to send data via data comm to a UAS in the controller's sector.

Figure 8. LOST Indicator on Controller Scope After Receiving Lost Link Activation via Data Comm from GCS

Figure 9. Proposed Route Amendment Approved by Conflict Probe Automation

Figure 10. Proposed Route Amendment Rejected by Conflict Probe Automation

Figure 11. Controller Using DATACOM Option to Accept, Reject or Amend Pilot Request

For initial flight planning and submission of primary and contingency routes, it is impractical for a flight crew to submit individual FP/FPL forms for every contingency route. In addition, the FP/FPL form in its current state is not sufficient to capture the length and necessary meta-data associated with each route. A preferred mechanism would be to leverage data communications to transmit all route and necessary related information. This would allow for the submission of an arbitrary number of routes, each of arbitrary length and complexity.

As both military and non-military UAS flights in the NAS become routine, data comm will be able to provide UAS flight crew with much of the same information that is provided to manned flight crews. Available data includes (but is not limited to): the position of other aircraft and surface vehicles at an airport; climb and merge instructions; bad weather; homeland security interventions; route and runway assignments; assigned taxi path, parking space and gate; departure clearances; and the position of other aircraft in en-route airspace [2].

Summary

Lack of sufficient data comm and automation system integration for UAS has the potential to create artificial capacity limits and inhibit their use in certain airspaces or for certain mission types. The same motivations for the development of these capabilities for manned aviation similarly apply to UAS. Current infrastructure and procedures may not scale to the potential demand for UAS, nor, due to the volume and complexity of UAS data, are they ideal for communication and the exchange of information. In order to achieve many of the stated far-term (2018+) NextGen objectives, a robust integration plan must be developed for UAS into these automation systems. Additionally, existing and planned systems must be augmented to support the unique elements of UAS data not present in current architectures.

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