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MITRE PRODUCT

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MITRE
Center for Advanced Aviation System Development
McLean, Virginia

MITRE Project Approval: Andrew R. Lacher

Abstract

This report provides a preliminary assessment and summary of the command, control, and communications (C^3) loading requirements of a generic future high-altitude, long-endurance unmanned aircraft (UA) operating in the National Airspace System. Two principal types of C^3 traffic are considered in our analysis: communications links providing air traffic services (ATS) to the UA and its human pilot, and the command and control data links enabling the pilot to operate the UA remotely. We have quantified the loading requirements of both types of traffic for two different assumed levels of UA autonomy. Our results indicate that the potential use of UA-borne relays for the ATS links, and the degree of autonomy exercised by the UA during the departure and arrival phases of its flight, will be among the key drivers of UA C^3 loading and bandwidth requirements.

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1 Introduction

1.1 Background

The role of high-altitude, long-endurance (HALE) unmanned aircraft systems (UAS) in military, scientific, and commercial applications has expanded steadily in recent years. Future growth in their numbers will exacerbate the strain on the already overloaded portions of the radio-frequency (RF) spectrum that are currently available for air/ground (A/G) communications in the National Airspace System (NAS). Each unmanned aircraft (UA) requires sensor downlinks, and a command and control (C^2) data link to a control station (CS) from which a human pilot remotely operates the UA. It may also have to relay voice and data messages between air traffic controllers and the CS, unless those messages can be reliably carried by other means such as land lines.

The growing bandwidth requirements of these new command, control, and communications (C^3) links will soon necessitate additional allocations of A/G radio spectrum. The need for additional spectrum is intensified by the fact that RF interference can propagate over very long distances to and from high-altitude aircraft. That impedes frequency reuse by HALE UAs in adjacent geographical areas and thus tends to increase the total amount of spectrum they will need to operate within the NAS.

Changes to existing spectral allocations can be requested at World Radiocommunication Conferences (WRCs). The next WRC occurs in 2007, with no others planned before 2010. A detailed analysis is needed before submittal of any reallocation request. Such an analysis will provide a basis for recommending acquisition of any additional spectrum needed to enable the safe and effective operation of this new class of vehicles throughout the upper reaches of U.S. airspace. The analysis should include the following steps:

1. Assessing the C^3 traffic loading requirements—including C^2 and air traffic services (ATS) communications, but excluding UA "payload" data downlinks—of individual UAs.
2. Defining priorities and latency requirements for each class of UAS data messages.
3. Forecasting the numbers of UAs likely to be aloft simultaneously in the NAS during the time frame of interest, and the probable distributions of their cruising altitudes and areas of operation.
4. Identifying candidate spectral bands where reallocation of spectrum to UAS A/G communications use may be feasible.
5. Determining technical parameters that would enable radio links to operate in each band while conforming to realistic UA size and power constraints, and identifying appropriate multiple-access and modulation methods for the links.
6. Using the results of steps 1–5 to estimate the aggregate bandwidth, in megahertz, that the predicted population of UAs would need in each candidate band in the time frame of interest.

7. Using the results of steps 4–6 to assess the relative suitability of each candidate band for supporting HALE UAS communications in the NAS.
8. Recommending specific candidate bands and, if appropriate, specific frequency ranges within those bands, whose reallocation for UAS purposes should be proposed at upcoming WRCs.

In September 2005 the Access 5 Project Office of the National Aeronautics and Space Administration (NASA) requested the MITRE Corporation to analyze the future C^3 spectrum/bandwidth requirements of HALE UAS in the NAS. Access 5 is a government/industry partnership that was established to enable routine, safe, and reliable operation of HALE UAS in en route airspace (with initial focus on operation at 45,000 feet above mean sea level), with launch and recovery at designated UA airports, by the year 2009. The NASA/MITRE Task Concurrence Document (TCD) for this effort essentially defined MITRE's role as comprising steps 1, 5, and 6 listed above. The TCD stipulated a completion date of 30 September 2006.

In January 2006 an overall reordering of NASA priorities resulted in the early termination of Access 5. The termination is effective in February. The Access 5 project office was directed to ensure a smooth transition of Access 5 knowledge to the Federal Aviation Administration (FAA) and to deliver a report to Congress no later than 15 February 2006. This premature closeout of Access 5 activities has made it necessary to scale back the MITRE effort to a preliminary execution of step 1, the assessment of C^3 traffic loading requirements. This document presents the results of our preliminary assessment.

1.2 Objective and Scope

The objective of this analysis is a preliminary assessment and summary of the C^3 traffic loading requirements of a generic HALE UA operating in the NAS. Payload-sensor data loading is explicitly excluded from the scope of this analysis.

1.3 Approach

The analysis has been performed as follows:

- Developing a generic scenario for HALE UAS operation, including timelines and assumed levels of UA autonomy.
- Identifying UAS functions that generate message transactions.
- Identifying message types that support each function.
- Investigating the protocols and overhead associated with the UAS messages.
- For each defined level of autonomy, estimating the likely message sizes and repetition rates associated with each message type for a single UA in the generic scenario.

2 Generic HALE UAS Scenario

Figure 1, adapted from [1], illustrates the principal C^3 interfaces of a HALE UAS in which a single CS exercises C^2 of two separate UAs: one via a line-of-sight (LOS) link, and the other by an over-the-horizon (OTH) link via satellite communications (SATCOM). Air traffic control (ATC) links—one to a departure airport, and the other to an Air Route Traffic Control Center (ARTCC)—are shown as well. Both UAs are receiving weather and runway information from the Automatic Terminal Information Service (ATIS). Also depicted are certain interfaces outside the scope of the present study: navigation signals from the Global Positioning System (GPS), and sense-and-avoid interactions (e.g., via transponders) with cooperative and non-cooperative aircraft in the vicinity.

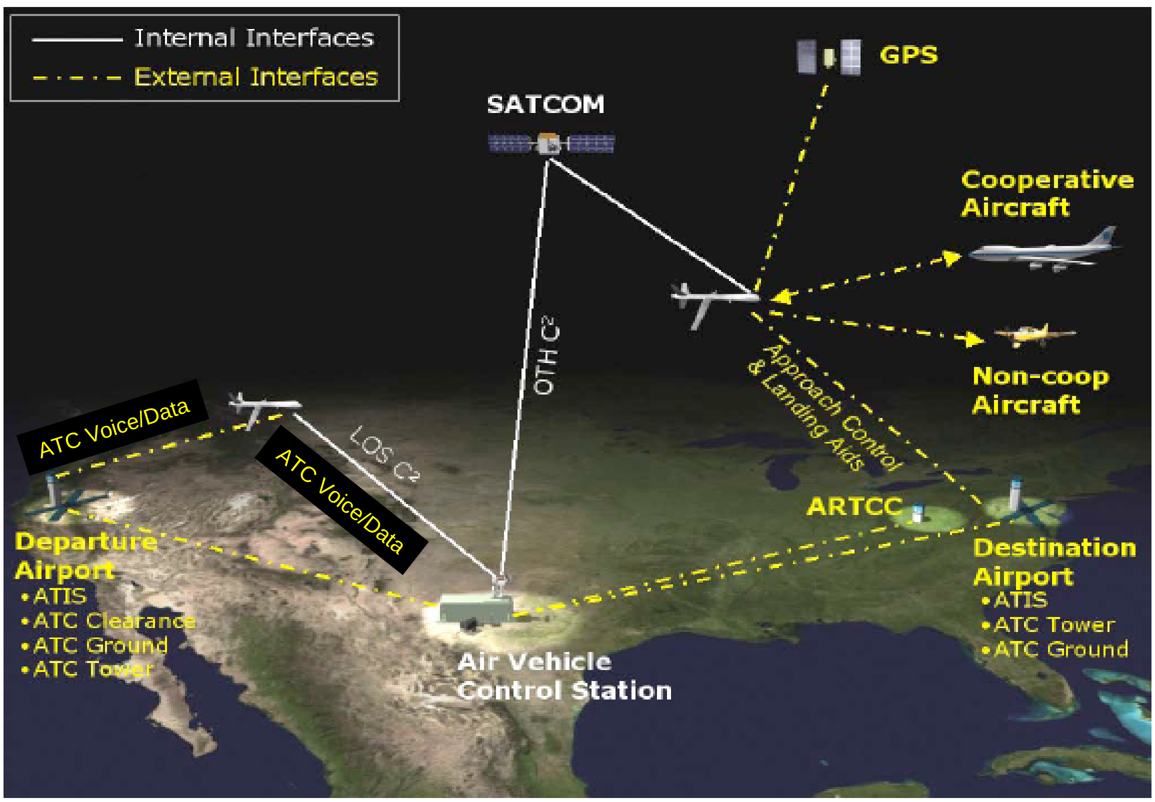

Figure 1. HALE UAS Interfaces

To develop a generic scenario for use in our analysis, we extracted features of relevant UAS scenarios in [2] and adapted them as appropriate to conform to the constraints of the HALE UAS environment. A UA mission [3] comprises five flight phases:

- *Taxi-out*: UA operations between engine start and takeoff. (For our present analysis, we have assumed that before the taxi-out begins, the pre-flight and pre-takeoff checks are conducted and passed, and the UA engine is started.)
- *Departure*: Operations during takeoff and the TRACON control stage.
- *En route*: The phase between departure and arrival. It includes the actual UA mission, as well as travel within en route airspace to and from the mission area.
- *Arrival*: Approach, landing, and exiting the active runway.
- *Post-flight*: This phase begins when the UA has safely cleared the active runway at its destination airport, and ends when the UA is parked in its designated area.

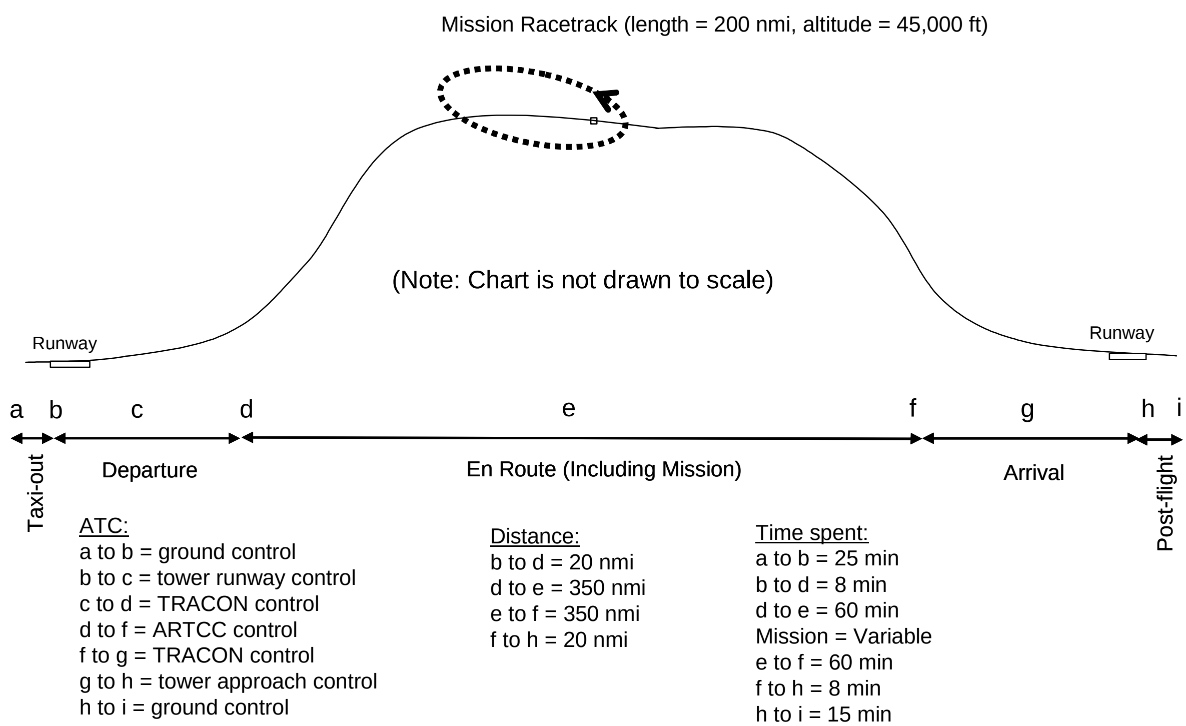

Figure 2. Generic HALE UA Mission Scenario Used in Analysis

Figure 2 depicts the generic mission scenario that we have developed for use in our analysis. The UA spends 25 minutes in taxi-out, 8 minutes in the departure phase, and 60 minutes traveling in en route airspace toward the mission area. The actual mission is assumed to occur at a cruising altitude of 45,000 feet within a mission racetrack 200 nautical miles (nmi) long. Its duration may range from a few hours to several days. After the mission, travel toward the destination airport (which is typically the same as the departure airport) consumes another 60 minutes. The arrival phase lasts 8 minutes and is followed by a 15-minute post-flight phase.

Eight ATC handovers occur during the flight: at points b, c, d, f, g, and h, as indicated in Figure 2; and also at ARTCC boundaries (not shown), halfway between points d and e and also halfway between e and f. CS responsibility is handed over twice during the en route phase (once before the mission, and once after). Mission maneuvering is directed by a CS near point e. The other CS(s) are at the departure and destination airport(s).

The level of autonomy exercised by a given UA significantly affects its C^2 traffic loading and its resultant consumption of spectral resources. An operation performed automatically by a UA generally requires less-detailed guidance from its CS, and thus a lower uplink data rate and less need for spectrum, than would be the case if the CS had to exercise manual control of the same operation. For example, directing an autonomous UA to fly in a predefined orbit is likely to require far fewer bytes of data than manually operating the UA's ailerons and other control devices. For the purpose of analyzing traffic loading in our generic scenario, we have defined two general levels of UA autonomy—"medium" and "high"—which are explained in Table 1. These are believed to be representative of UA operations in the future NAS.

Table 1. Levels of UA Autonomy Considered in Study

UA Activity	Medium Autonomy	High Autonomy
Taxi-out	Manual	Manual
Departure	Manual	Automatic
En Route Maneuvering	Automatic	Automatic
Arrival	Manual	Automatic
Post/flight	Manual	Manual

It must be kept in mind that even the most autonomous UA may have its automatic functions manually overridden by its CS in some circumstances. However, those circumstances are unlikely to affect a large number of HALE UAs at once, at least not at times of good flying weather when the largest numbers of UAs are likely to be aloft. The medium and high autonomy levels are believed to be realistic assumptions for forecasting future loading requirements.

3 Message-Generating Functions

3.1 UAS Communications Taxonomy

Figure 3 provides a high-level taxonomy of UAS communications. The present analysis deals with UAS functions that generate C^3 messages between the CS and the UA. UA "payload" sensor output data are not part of C^3 and thus are specifically excluded from consideration here. The message-generating C^3 functions considered in this analysis fall into two principal classes: ATS and C^2. As Figure 3 indicates, two particular subsets of the C^2 communications traffic have been omitted from our detailed quantitative assessment, for reasons discussed in Section 3.3.2.

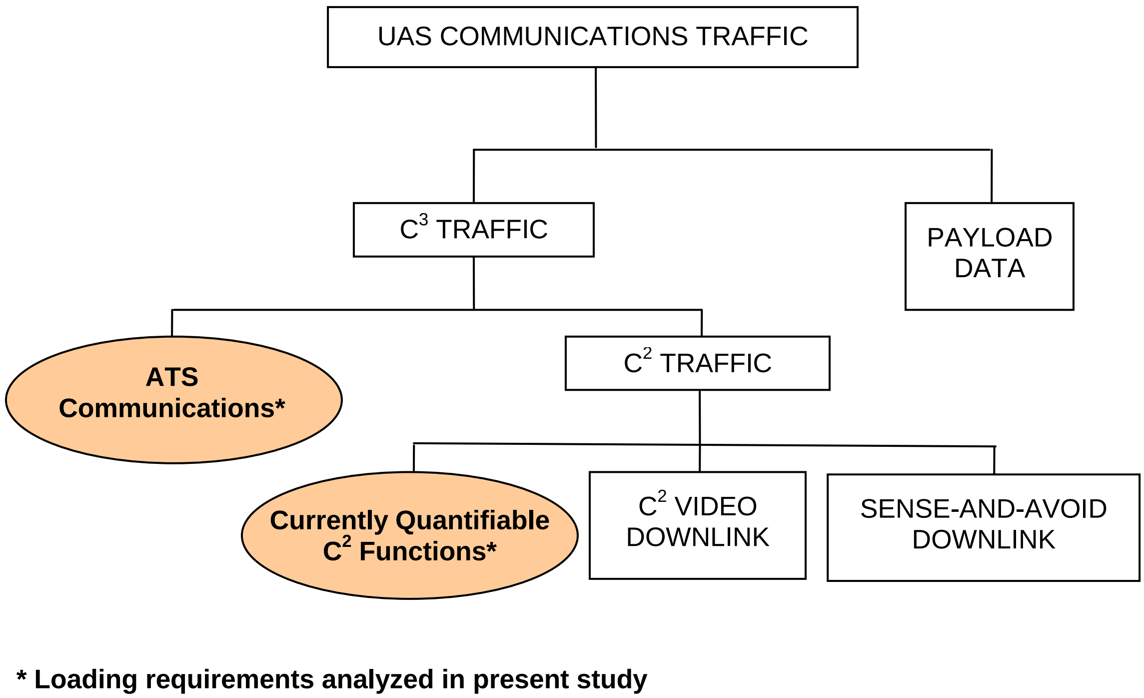

Figure 3. Classes of UAS Communications Traffic

3.2 ATS Functions

ATS functions may require the use of voice/data relay links to transfer ATS messages between air traffic controllers (or uplink-broadcast stations) and the CS, using the UA as a relay platform, as in the example on the left side of Figure 1. The RF path from a ground ATS facility to the UA requires no bandwidth or spectrum beyond that required for manned aircraft, and thus is not considered in our analysis. The relay links will not be needed if all UA ATS communications are carried exclusively via land lines directly to and from the CS, but the need for UA-borne ATS relays cannot be ruled out at present and so must be considered here. We have assumed that, when the UA is used as a relay for either voice or data traffic between air traffic controllers and the CS, the message requirements and characteristics will be essentially equivalent to those of ATC communications involving manned aircraft.

3.2.1 ATS Data Communications

The following list of ATS data-communications functions, jointly developed by EUROCONTROL and the FAA for the Future Communications Study, is believed to be applicable to relayed UAS ATS communications as well [4]:

ATC functions:

- ATC clearance (ACL)
- ATC microphone check (AMC)
- Data-link taxi clearance delivery (D-TAXI)
- Departure clearance (DCL)
- Pilot preferences downlink (PPD)

Automated downlinking of airborne parameters:

- Flight plan consistency (FLIPCY)
- Flight path intent (FLIPINT)
- System access parameters (SAP)

Flight information functions:

- Data-link operational en-route information service (D-ORIS)
- Data-link significant meteorological information (D-SIGMET)
- Data-link ATIS (D-ATIS)
- Data-link surface information and guidance (D-SIG)

Communications management functions:

- Data-link logon (DLL)
- ATC communication management, mainly for control handover (ACM)
- Sequencing and merging (SM)

3.2.2 ATS Voice Communications

Voice ATC communications with UA CSs are currently set up to mimic traditional ATC controller-pilot communications. The voice traffic per UA, to a first approximation, can be estimated using the same survey results and guidelines described in Section 6.3 of [4]. Regardless of whether relays or land lines are used for ATS communications to and from the CS, the voice messages provided to the CS should include not only those from air traffic controllers but also (for the sake of situational awareness at the CS) the messages from other manned-aircraft pilots and UAS CSs using the same ATS circuit. This "party line" capability is an important feature of the present 25-kHz AM A/G radio system for ATS. Guaranteed immediate access is another feature of the present A/G radio system that must be preserved by the UA/CS relay links.

The present voice A/G radio system for ATS currently uses about 13 MHz of spectrum in the 117.975–137 MHz band to support about 6800 ATS circuits in the NAS. Conversion to an 8.33-kHz AM system or other new architecture could roughly triple the supportable number of circuits. Some of this additional capacity might be used for UA/CS ATS relay links, but at the expense of the ATS data-link applications already being envisioned for future placement in the same band. In the worst case, if all UAS ATS voice traffic were carried via UA-borne relay radios, the UA/CS ATS voice links could eventually become as numerous (and consume as much additional A/G radio spectrum) as the non-relayed ATS voice circuits in the NAS today. The spectral efficiency of future UAS C^3 in the NAS depends heavily on finding a way to minimize the role of UA-borne relays in carrying UAS ATS traffic.

3.3 C^2 Functions

C^2 functions require the use of data links between the CS and the UA. Uplink functions enable direct control of the UA by the CS. Primarily, these are functions that a pilot would perform on a manned aircraft, such as changing the flight level, retuning a communications radio or navigation receiver, turning landing lights on or off, and raising or lowering landing gear. Downlinks carry sensor/telemetry data regarding UA "health" and other system status parameters, including vehicle pitch, altimeter readout, airspeed indicators, and outputs of onboard weather radars. Uplinks and downlinks must all meet aviation requirements for reliability and integrity.

3.3.1 C^2 Functions Considered in Quantitative Assessment

The following C^2 functions, identified on the basis of information in North Atlantic Treaty Organization (NATO) Standardization Agreement (STANAG) 4586 [5] and related documents, have relatively well-defined requirements and thus are considered in our quantitative assessment of loading requirements:

- Authorization and configuration setup
- Mission plan upload
- Report-back of mission plan upload
- UA flight-path control mode selection
- UA steering command – flight vector, manual
- UA lighting control

- UA landing-gear control
- Transponder activation switching
- GPS activation switching
- UA engine-throttle command
- UA engine-mixture command
- UA gear break command
- UA position/speed/attitude report downlink
- UA body-relative sensed states download
- UA operating status download
- UA engine operating status download
- Communications relay radio control
- Navigational-aid (navaid) radio control
- CS responsibility handover
- UA subsystem status summary

Several of the commands listed above are not described in [5], but sufficient background information existed to allow us to specify them as part of our analysis. Appendix A identifies those commands and describes the message formats that we have created to enable quantification of their contributions to overall traffic loading.

Appendix B summarizes the data lengths of the messages described in [5], as well as the user-specified messages discussed in Appendix A.

3.3.2 Other C^2 Functions

Two important types of message-generating UAS C^2 functions have *not* been quantitatively analyzed in this study, because the UAS community has not yet defined the associated operational requirements in sufficient detail to permit a detailed loading analysis. The first of these is the UA-to-CS C^2 video downlink, which is probably the more important in terms of potential bandwidth and spectrum impact. Its operational importance will be greatest when it is used in approach and landing. Its bandwidth will be largely dependent on the minimum acceptable frame-update rate, which is highly mission-dependent. An update rate as low as one frame per second might, depending on required image quality, result in a necessary video downlink data rate on the order of 100 kilobits (12.5 kilobytes) per second per UA. However, since the requirements for such downlinks have not yet been defined sufficiently for a reasonably accurate assessment of the data rate, the C^2 video downlink has not been included in the traffic-loading tables that appear below.

The second important C^2 function that is insufficiently defined at present for quantitative assessment is the sense-and-avoid alert function by which the CS will be informed of potential collision risks by the sense-and-avoid surveillance equipment on the UA. That function will generate downlink messages in response to such threats, but the requirements have not yet been defined well enough to allow a quantitative loading analysis.

4 C^3 Traffic Loading

The tables in this section show the published [4], [5] and calculated values of transaction sizes of each of the ATS and C^2 data-link functions identified above. The transaction sizes are presented first without, and then (in parentheses) with, the transport- and network-layer protocol overheads stipulated in the Space Communications Protocol Standards (SCPS) recommended for UAS use in [6] and documented in [7] and [8]. The User Datagram Protocol (UDP) option was employed in calculating overhead values for the SCPS transport layer. Using this option, the SCPS transport protocol (SCPS-TP) has a header length of 8 bytes. The SCPS network protocol (SCPS-NP) has a maximum header size of 46 bytes. Thus the combined transport- and network-protocol overhead was found to be 54 bytes per message. (Many transactions comprise multiple messages, as stipulated in [4], [5], and [6].) The tables also show how often each transaction would be likely to occur during each phase of flight in the HALE UAS scenario described in Section 2.

Table 2 describes the estimated ATS data loading requirements for a single UA operating with medium autonomy in the generic scenario. Table 3 lists the estimated C^2 data loading requirements for the same UA. The sources for establishing the numbers and durations for each C^2 operational function or maneuver included consultation with UA experts, the discussion of specific message types in [6], and nominal manned-aircraft pilot maneuvering procedures. The footnotes of Table 3 illustrate some basic assumptions employed to derive certain loading numbers. Tables 4 and 5 provide corresponding numbers for a UA operating at a high autonomy level.

A comparison of Tables 2 and 4 reveals that, as expected, the level of autonomy has very little impact on ATS data loading. Tables 3 and 5 demonstrate that the effect of autonomy on C^2 loading is much larger.

Table 2. ATS Data Loading for Single Medium-Autonomy UA in Generic Scenario

Functions	Transaction Size in Bytes*		Average Number of Occurrences During Each Phase of Flight				
	CS to UA	UA to CS	Taxi-out	Departure	En Route	Arrival	Post-flight
Data-link logon (DLL)	33 (87)	96 (150)	1	0	0	0	0
ATC communications management (ACM)	22 (130)	60 (168)	2	2	5	2	1
Sequencing and merging (SM)	173 (227)	183 (237)	0	0	0	1	0
ATC clearance (ACL)	52 (268)	52 (268)	1	2	5	2	1
ATC microphone check (AMC)	0 (0)	183 (237)	1 per week	1 per week	1 per week	1 per week	1 per week
Data-link taxi clearance delivery(D-TAXI)	0 (0)	323 (377)	2	0	0	1	0
Departure clearance service (DCL)	33 (195)	63 (225)	1	0	0	0	0
Pilot preferences downlink (PPD)	823 (877)	223 (277)	1	1	0	1	0
Flight plan consistency (FLIPCY)	104 (212)	34 (142)	1	1	3	1	0
Flight path intent (FLIPINT)	923 (977)	923 (977)	0	1	3	1	0
System access parameters (SAP)	240 (780)	40 (148)	0	1 every 10 seconds	1 every 10 seconds	1 every 10 seconds	0
Data-link operational en route info service (D-ORIS)	48 (210)	3609 (4095)	0	0	1	0	0
Data-link significant meteor-ological info (D-SIGMET)	156 (318)	212 (428)	0.3	0	0.3	0.3	0
Data-link automatic terminal info service (D-ATIS)	48 (210)	115 (385)	1	0	0	1	0
Data-link surface info and guidance (D-SIG)	156 (318)	5052 (5268)	1	0	0	1	0

* Transaction sizes without parentheses exclude protocol overhead. (Values in parentheses include the overhead.)

Table 3. C^2 Data Loading for Single Medium-Autonomy UA in Generic Scenario (Page 1 of 2)

Functions	Transaction Size in Bytes[1]		Average Number of Occurrences During Each Phase of Flight				
	CS to UA	UA to CS	Taxi-out	Departure	En Route	Arrival	Post-flight
Authorization and configuration setup	10333 (18433)	21245 (29291)	1	0	0	0	0
Mission plan upload	1158 (1860)	0 (0)	1	0	0	0	0
Report-back of mission plan upload	73 (127)	1012 (1606)	1	0	0	0	0
UA flight-path control mode selection	51 (105)	51 (105)	1	0	1	1	0
UA steering command – flight vector, manual	58 (112)	0 (0)	0	1380[2]	0	1380[2]	0
UA lighting control	52 (106)	52 (106)	1	2	0	2	1
UA landing-gear control	52 (106)	51 (105)	10 per sec for 30 sec[3]	1[3]	0	1 + 10 per sec for 10 sec[3]	10 per sec for 30 sec[3]
Transponder activation switching	51 (105)	51 (105)	1	0	0	0	1
GPS activation switching	51 (105)	51 (105)	1	0	0	0	1
UA engine-throttle command	58 (112)	0 (0)	90[4]	90[4]	0	90[4]	30[4]
UA engine-mixture command	58 (112)	0 (0)	90[5]	30[5]	0	90[5]	30[5]
UA gear break command	54 (108)	0 (0)	2	1	0	0	1
UA position/speed/attitude report downlink	0 (0)	216 (324)	10 per sec	10 per sec	10 per sec	10 per sec	10 per sec
UA body-relative sensed states download	0 (0)	74 (128)	0	50 per sec[6]	0	50 per sec[6]	0
UA operating status download	0 (0)	179 (233)	1 per sec	1 per sec	1 per sec	1 per sec	0
UA engine operating status download	0 (0)	78 (132)	1 per sec	1 per sec	1 per sec	1 per sec	1 per sec
Communications relay radio control	69 (123)	69 (123)	2	2	3	1	1

Table 3. C^2 Data Loading for Single Medium-Autonomy UA in Generic Scenario (Page 2 of 2)

Functions	Transaction Size in Bytes[(1)]		Average Number of Occurrences During Each Phase of Flight				
	CS to UA	UA to CS	Taxi-out	Departure	En Route	Arrival	Post-flight
Navaid radio control	74 (128)	74 (128)	0	2	6	2	0
CS responsibility handover	557 (989)	124 (232)	0	0	2	0	0
UA subsystem status summary	0 (0)	197 (305)	1 per sec	1 per sec	1 per sec	1 per sec	1 per sec

(1) Transaction sizes without parentheses exclude protocol overhead. (Values in parentheses include the overhead.)

(2) Transaction rate = 10 per second. Turn rate = 3 degrees (deg) per second (sec) and total angle of turn = 360 deg in both departure and arrival phases. Six non-turning maneuvers (on flaps, elevator, etc.) in each of departure and arrival phases. Each maneuver lasts 3 seconds.

(3) One gear retraction in departure phase and one “gear down” occurrence in arrival phase. The other occurrences are for taxiing gear turn control.

(4) Three occurrences of manual throttle adjustment in each of taxi-out, departure, and arrival phases and one occurrence in post-flight phase. Each maneuver lasts 3 seconds. Transaction rate = 10 per second.

(5) Three occurrences of manual mixture adjustment in each of taxi-out and arrival phases and one occurrence in each of departure and post-flight phases. Each occurrence lasts 3 seconds. Transaction rate = 10 per second.

(6) Based on information from UAS experts and [5].

Table 4. ATC Data Loading for Single High-Autonomy UA in Generic Scenario

Functions	Transaction Size in Bytes*		Average Number of Occurrences During Each Phase of Flight				
	CS to UA	UA to CS	Taxi-out	Departure	En Route	Arrival	Post-flight
Data-link logon (DLL)	33 (87)	96 (150)	1	0	0	0	0
ATC communications management (ACM)	22 (130)	60 (168)	2	2	5	2	1
Sequencing and merging (SM)	173 (227)	183 (237)	0	0	0	1	0
ATC clearance (ACL)	52 (268)	52 (268)	1	2	5	2	1
ATC microphone check (AMC)	0 (0)	183 (237)	1 per week	1 per week	1 per week	1 per week	1 per week
Data-link taxi clearance delivery(D-TAXI)	0 (0)	323 (377)	2	0	0	1	0
Departure clearance service (DCL)	33 (195)	63 (225)	1	0	0	0	0
Pilot preferences downlink (PPD)	823 (877)	223 (277)	1	0	0	0	0
Flight plan consistency (FLIPCY)	104 (212)	34 (142)	1	1	3	1	0
Flight path intent (FLIPINT)	923 (977)	923 (977)	0	1	3	1	0
System access parameters (SAP)	240 (780)	40 (148)	0	1 every 10 seconds	1 every 10 seconds	1 every 10 seconds	0
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Data-link significant meteor-ological info (D-SIGMET)	156 (318)	212 (428)	0.3	0	0.3	0.3	0
Data-link automatic terminal info service (D-ATIS)	48 (210)	115 (385)	1	0	0	0	0
Data-link surface info and guidance (D-SIG)	156 (318)	5052 (5268)	1	0	0	1	0

* Transaction sizes without parentheses exclude protocol overhead. (Values in parentheses include the overhead.)

Table 5. C^2 Data Loading for Single High-Autonomy UA in Generic Scenario (Page 1 of 2)

Functions	Transaction Size in Bytes*		Average Number of Occurrences During Each Phase of Flight				
	CS to UA	UA to CS	Taxi-out	Departure	En Route	Arrival	Post-flight
Authorization and configuration setup	10333 (18433)	21245 (29291)	1	0	0	0	0
Mission plan upload	1158 (1860)	0 (0)	1	0	0	0	0
Report-back of mission plan upload	73 (127)	1012 (1606)	1	0	0	0	0
UA flight-path control mode selection	51 (105)	51 (105)	1	1	0	0	1
UA steering command – flight vector, manual	58 (112)	0 (0)	0	0	0	0	0
UA lighting control	52 (106)	52 (106)	1	0	0	0	1
UA landing-gear control	52 (106)	51 (105)	10 per sec for 30 sec	0	0	0	10 per sec for 30 sec
Transponder activation switching	51 (105)	51 (105)	1	0	0	0	1
GPS activation switching	51 (105)	51 (105)	1	0	0	0	1
UA engine-throttle command	58 (112)	0 (0)	90	0	0	0	30
UA engine-mixture command	58 (112)	0 (0)	90	0	0	0	30
UA gear break command	54 (108)	0 (0)	2	0	0	0	1
UA position/speed/attitude report downlink	0 (0)	216 (324)	10 per sec	10 per sec	10 per sec	10 per sec	10 per sec
UA body-relative sensed states download	0 (0)	74 (128)	0	0	0	0	0
UA operating status download	0 (0)	179 (233)	1 per sec	1 per sec	1 per sec	1 per sec	0
UA engine operating status download	0 (0)	78 (132)	1 per sec	1 per sec	1 per sec	1 per sec	1 per sec
Communications relay radio control	69 (123)	69 (123)	2	2	3	1	1

Table 5. C^2 Data Loading for Single High-Autonomy UA in Generic Scenario (Page 2 of 2)

Functions	Transaction Size in Bytes*		Average Number of Occurrences During Each Phase of Flight				
	CS to UA	UA to CS	Taxi-out	Departure	En Route	Arrival	Post-flight
Navaid radio control	74 (128)	74 (128)	0	2	6	2	0
CS responsibility handover	557 (989)	124 (232)	0	0	2	0	0
UA subsystem status summary	0 (0)	197 (305)	1 per sec	1 per sec	1 per sec	1 per sec	1 per sec

* Transaction sizes without parentheses exclude protocol overhead. (Values in parentheses include the overhead.)

5 Findings

5.1 Observations

- The unrestricted use of UA-borne relays to carry ATS voice and data traffic to and from UAS CSs in the NAS could eventually double the number of ATS frequency assignments in the A/G radio bands. That would impose severe and probably unacceptable strains on ATS spectral assets in those bands.
- Under conditions of manual operation, UAS C^2 loading requirements are most demanding in the departure and arrival phases, and the C^2 bandwidth requirements of UAS will be primarily determined by the traffic in those two phases of flight.
- If the departure and arrival phases are both automated, UAS C^2 traffic loading and required bandwidth can be greatly reduced. However, automating either the departure or the arrival phase alone would not reduce the peak bandwidth requirement of a single UA, because the traffic loadings associated with those two phases are about the same.
- The impact of UA autonomy on UAS ATS traffic loading requirements is very small.

5.2 Recommendations

- To conserve scarce ATS spectral assets in the A/G radio bands, a strategy should be developed for minimizing the future role of UA-borne relays in providing ATS communications to UAS.
- To minimize UAS C^2 bandwidth and spectrum requirements, UA arrival and departure operations should be automated as much as possible.

5.3 Next Steps

The loading analysis documented in this report is a first step toward defining the future C^3 bandwidth and spectrum requirements of HALE UAS in the NAS. The following additional activities are needed to allow that larger effort to be completed:

- A more thorough assessment of the applicability of the military UAS C^3 requirements in [5] and [6] to the largely civilian environment of the NAS should be performed, and appropriate changes made as necessary to the loading tables presented in this report.
- When operational requirements for the C^2 video downlinks and sense-and-avoid downlinks of HALE UAS in the NAS are better defined, their data-loading requirements should be assessed and incorporated into these tables.
- Steps 2–8 (outlined in Section 1.1) of the overall HALE UAS C^3 bandwidth and spectrum analysis should be performed and completed in time to affect the decisions of WRC 2007 when it sets the agenda for the subsequent WRC that will be held in 2010 or later.

References

1. *HALE ROA Concept of Operations*, Version 2.0, Access 5 Systems Engineering and Integration Team, March 2005.
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3. *UAS NAS Operational Handbook*, Draft, W1-S2-A-003-J-HAND, RTCA SC-203, December 6, 2005.
4. *Communications Operating Concept and Requirements for the Future Radio System*, COCR Draft 0.9, EUROCONTROL/FAA, 2005.
5. *Standard Interface of the Unmanned Control System (UCS) for NATO UAV Interoperability*, STANAG 4586, Edition 2, NATO, March 2005.
6. *STANAG 4586 Implementation Guideline Document*, AEP-57 Volume 1, NATO, March 2005.
7. *Space Communications Protocol Specification - Transport Protocol (SCPS-TP),* CCSDS 714.0-B-1, May 1999, http://public.ccsds.org/publications/archive/714x0b1c1.pdf
8. *Space Communications Protocol Specification - Network Protocol (SCPS-NP),* CCSDS 713.0-B-1, May 1999, http://public.ccsds.org/publications/archive/713x0b1.pdf

Appendix A User-Specified C^2 Messages

STANAG 4586 [5] is a living document, and its message set is continually being revised and expanded. Numerous commands required for UA maneuvering and control have not yet been specified in [5]. Implementers of the standard are required to augment the existing message set with their own user-specified messages. The messages that we have added to the set of STANAG 4586 common messages for use in the present Access 5 traffic loading analysis are described below. The format agrees with the requirements set forth for the existing STANAG 4586 messages. Note that the terms "Core UAV Control System" (CUCS) and "Vehicle," as used in the STANAG, have the same meaning as CS and UA used in the present study. The number of bytes associated with each data type is shown in the Type column of each table, except for Float and Double, which require 4 and 8 bytes, respectively.

Message #43A: UA Steering Command – Flight Vector, Manual

This message shall be used to provide the ability to command a new flight vector to the UA through maneuvering the rudder, ailerons, flaps, and elevator (or specifying the angle of attack).

Field	Data Element Name & Description	Type	Units	Range
1	**Time Stamp**	Double	Seconds	See Section 1.7.2 of [5]
2	**Vehicle Identifier (ID)**	Integer 4	None	See Section 1.7.5 of [5]
3	**CUCS ID**	Integer 4	None	See Section 1.7.5 of [5]
4	**Angle of Attack**	Float	Radians	$-\pi/2 \le x \le \pi/2$
5	**Elevator**	Integer 1	0.02 Radians	$-\pi/2 \le x \le \pi/2$
6	**Rudder**	Integer 1	0.02 Radians	$-\pi/2 \le x \le \pi/2$
7	**Ailerons**	Integer 1	0.02 Radians	$-\pi/2 \le x \le \pi/2$
8	**Flaps**	Integer 1	0.02 Radians	$-\pi/2 \le x \le \pi/2$

Message #44A: UA Gears

This message shall be used by the CS to control the UA landing gears.

Field	Data Element Name & Description	Type	Units	Range
1	**Time Stamp**	Double	Seconds	See Section 1.7.2 of [5]
2	**Vehicle ID**	Integer 4	None	See Section 1.7.5 of [5]
3	**CUCS ID**	Integer 4	None	See Section 1.7.5 of [5]
4	**Set Landing Gears State**	Unsigned 1	Enumerated	0 = No Value 1 = Stowed 2 = Cycling 3 = Down
5	**Gear Turn**	Integer 1	0.02 Radians	$-\pi/2 \le x \le \pi/2$

Message #44B: UA Transponder Activation Switching

This message shall be used by the CS to control the activation switch of the UA transponder.

Field	Data Element Name & Description	Type	Units	Range
1	**Time Stamp**	Double	Seconds	See Section 1.7.2 of [5]
2	**Vehicle ID**	Integer 4	None	See Section 1.7.5 of [5]
3	**CUCS ID**	Integer 4	None	See Section 1.7.5 of [5]
4	**Set Transponder State**	Unsigned 1	Enumerated	0 = Off 1 = On

Message #44C: UA GPS Activation Switching

This message shall be used by the CS to control the activation switch of the UA GPS receiver.

Field	Data Element Name & Description	Type	Units	Range
1	**Time Stamp**	Double	Seconds	See Section 1.7.2 of [5]
2	**Vehicle ID**	Integer 4	None	See Section 1.7.5 of [5]
3	**CUCS ID**	Integer 4	None	See Section 1.7.5 of [5]
4	**Set GPS State**	Unsigned 1	Enumerated	0 = Off 1 = On

Message #45A: Engine Command - Throttle

This message shall be used by the CUCS to control the UA engine-throttle.

Field	Data Element Name & Description	Type	Units	Range
1	**Time Stamp**	Double	Seconds	See Section 1.7.2 of [5]
2	**Vehicle ID**	Integer 4	None	See Section 1.7.5 of [5]
3	**CUCS ID**	Integer 4	None	See Section 1.7.5 of [5]
4	**Engine Number** ID of engine currently being reported	Integer 4	None	Specified by Configuration
5	**Throttle Level Command**	Float	%	$0 \leq x \leq 100$

Message #45B: Engine Command - Mixture

This message shall be used by the CUCS to control the UA engine-mixture.

Field	Data Element Name & Description	Type	Units	Range
1	**Time Stamp**	Double	Seconds	See Section 1.7.2 of [5]
2	**Vehicle ID**	Integer 4	None	See Section 1.7.5 of [5]
3	**CUCS ID**	Integer 4	None	See Section 1.7.5 of [5]
4	**Engine Number** ID of engine currently being reported	Integer 4	None	Specified by Configuration
5	**Mixture Level Command**	Float	% RICH	$0 \leq x \leq 100$

Message #45C: Gear Break Command

This message shall be used by the CS to control the break of the UA landing gears.

Field	Data Element Name & Description	Type	Units	Range
1	**Time Stamp**	Double	Seconds	See Section 1.7.2 of [5]
2	**Vehicle ID**	Integer 4	None	See Section 1.7.5 of [5]
3	**CUCS ID**	Integer 4	None	See Section 1.7.5 of [5]
4	**Break Command**	Float	% BREAK	$0 \leq x \leq 100$

Message #107A: UA Gear State

This message shall be used by the UA to report the state of the gears.

Field	Data Element Name & Description	Type	Units	Range
1	**Time Stamp**	Double	Seconds	See Section 1.7.2 of [5]
2	**Vehicle ID**	Integer 4	None	See Section 1.7.5 of [5]
3	**CUCS ID**	Integer 4	None	See Section 1.7.5 of [5]
4	**Landing Gear State**	Unsigned 1	Enumerated	0 = No Value 1 = Stowed 2 = Cycling 3 = Down 4 = Inoperable

Message #107B: UA Transponder State

This message shall be used by the UA to report the state of the transponder.

Field	Data Element Name & Description	Type	Units	Range
1	**Time Stamp**	Double	Seconds	See Section 1.7.2 of [5]
2	**Vehicle ID**	Integer 4	None	See Section 1.7.5 of [5]
3	**CUCS ID**	Integer 4	None	See Section 1.7.5 of [5]
4	**Transponder State**	Unsigned 1	Enumerated	0 = Off 1 = On

Message #107C: UA GPS State

This message shall be used by the UA to report the state of the GPS receiver.

Field	Data Element Name & Description	Type	Units	Range
1	**Time Stamp**	Double	Seconds	See Section 1.7.2 of [5]
2	**Vehicle ID**	Integer 4	None	See Section 1.7.5 of [5]
3	**CUCS ID**	Integer 4	None	See Section 1.7.5 of [5]
4	**GPS Receiver State**	Unsigned 1	Enumerated	0 = Off 1 = On

Message #204A: Communications Relay Radio Command

This message shall be used to command the communications relay radios and is sent from the CS. This message accommodates three ATC communications relay radios: COMM1, COMM2, and COMM3.

Field	Data Element Name & Description	Type	Units	Range
1	**Time Stamp**	Double	Seconds	See Section 1.7.2 of [5]
2	**Vehicle ID**	Integer 4	None	See Section 1.7.5 of [5]
3	**CUCS ID**	Integer 4	None	See Section 1.7.5 of [5]
4	**Station Number**	Unsigned 4	None	0x0001 = Stn #1 0x0002 = Stn #2 0x0004 = Stn #3 0x0008 = Stn #4 etc.
5	**Set COMM1 Relay Radio State**	Unsigned 1	None	0 = Turn Off 1 = Turn On 2 = Go To Standby 3 = Deploy 4 = Activate 5 = Deactivate 6 = Stow
6	**Set COMM1 Relay Radio Frequency**	Float	Hz	Link Dependent
7	**Set COMM2 Relay Radio State**	Unsigned 1	None	0 = Turn Off 1 = Turn On 2 = Go To Standby 3 = Deploy 4 = Activate 5 = Deactivate 6 = Stow
8	**Set COMM2 Relay Radio Frequency**	Float	Hz	Link Dependent
9	**Set COMM3 Relay Radio State**	Unsigned 1	None	0 = Turn Off 1 = Turn On 2 = Go To Standby 3 = Deploy 4 = Activate 5 = Deactivate 6 = Stow
10	**Set COMM3 Relay Radio Frequency**	Float	Hz	Link Dependent

Message #204B: Navaid Radio Command

This message shall be used to command the navaid radios and is sent from the CS. This message accommodates radios serving up to four types of navaids: VHF Omnidirectional Range (VOR), localizer (LOC), glide slope (GLI), and marker beacon (BEA).

Field	Data Element Name & Description	Type	Units	Range
1	**Time Stamp**	Double	Seconds	See Section 1.7.2 of [5]
2	**Vehicle ID**	Integer 4	None	See Section 1.7.5 of [5]
3	**CUCS ID**	Integer 4	None	See Section 1.7.5 of [5]
4	**Station Number**	Unsigned 4	None	0x0001 = Stn #1 0x0002 = Stn #2 0x0004 = Stn #3 0x0008 = Stn #4 etc.
5	**Set VOR Radio State**	Unsigned 1	None	0 = Turn Off 1 = Turn On 2 = Go To Standby 3 = Deploy 4 = Activate 5 = Deactivate 6 = Stow
6	**Set VOR Radio Frequency**	Float	Hz	Link Dependent
7	**Set LOC Radio State**	Unsigned 1	None	0 = Turn Off 1 = Turn On 2 = Go To Standby 3 = Deploy 4 = Activate 5 = Deactivate 6 = Stow
8	**Set LOC Radio Frequency**	Float	Hz	Link Dependent
9	**Set GLI Radio State**	Unsigned 1	None	0 = Turn Off 1 = Turn On 2 = Go To Standby 3 = Deploy 4 = Activate 5 = Deactivate 6 = Stow
10	**Set GLI Radio Frequency**	Float	Hz	Link Dependent
11	**Set BEA Radio State**	Unsigned 1	None	0 = Turn Off 1 = Turn On 2 = Go To Standby 3 = Deploy 4 = Activate 5 = Deactivate 6 = Stow
12	**Set BEA Radio Frequency**	Float	Hz	Link Dependent

Message #305A: Communications Relay Radio Status

This message shall be used to report the status of the communications relay radio(s) to the CS.

Field	Data Element Name & Description	Type	Units	Range
1	**Time Stamp**	Double	Seconds	See Section 1.7.2 of [5]
2	**Vehicle ID**	Integer 4	None	See Section 1.7.5 of [5]
3	**CUCS ID**	Integer 4	None	See Section 1.7.5 of [5]
4	**Station Number**	Unsigned 4	None	0x0001 = Stn #1 0x0002 = Stn #2 0x0004 = Stn #3 0x0008 = Stn #4 etc.
5	**Report COMM1 Relay Radio State**	Unsigned 1	Enumer-ated	0 = Turn Off 1 = Turn On 2 = Go To Standby 3 = Deploy 4 = Activate 5 = Deactivate 6 = Stow
6	**Report COMM1 Relay Radio Frequency**	Float	Hz	Link Dependent
7	**Report COMM2 Relay Radio State**	Unsigned 1	Enumer-ated	0 = Turn Off 1 = Turn On 2 = Go To Standby 3 = Deploy 4 = Activate 5 = Deactivate 6 = Stow
8	**Report COMM2 Relay Radio Frequency**	Float	Hz	Link Dependent
9	**Report COMM3 Relay Radio State**	Unsigned 1	Enumer-ated	0 = Turn Off 1 = Turn On 2 = Go To Standby 3 = Deploy 4 = Activate 5 = Deactivate 6 = Stow
10	**Report COMM3 Relay Radio Frequency**	Float	Hz	Link Dependent

Message #305B: Navaid Radio Status

This message shall be used to report the status of navaid radios to the CS.

Field	Data Element Name & Description	Type	Units	Range
1	**Time Stamp**	Double	Seconds	See Section 1.7.2 of [5]
2	**Vehicle ID**	Integer 4	None	See Section 1.7.5 of [5]
3	**CUCS ID**	Integer 4	None	See Section 1.7.5 of [5]
4	**Station Number**	Unsigned 4	None	0x0001 = Stn #1 0x0002 = Stn #2 0x0004 = Stn #3 0x0008 = Stn #4 etc.
5	**Report VOR Radio State**	Unsigned 1	Enumer-ated	0 = Turn Off 1 = Turn On 2 = Go To Standby 3 = Deploy 4 = Activate 5 = Deactivate 6 = Stow
6	**Report VOR Radio Frequency**	Float	Hz	Link Dependent
7	**Report LOC Radio State**	Unsigned 1	Enumer-ated	0 = Turn Off 1 = Turn On 2 = Go To Standby 3 = Deploy 4 = Activate 5 = Deactivate 6 = Stow
8	**Report LOC Radio Frequency**	Float	Hz	Link Dependent
9	**Report GLI Radio State**	Unsigned 1	Enumer-ated	0 = Turn Off 1 = Turn On 2 = Go To Standby 3 = Deploy 4 = Activate 5 = Deactivate 6 = Stow
10	**Report GLI Radio Frequency**	Float	Hz	Link Dependent
11	**Report BEA Radio State**	Unsigned 1	Enumer-ated	0 = Turn Off 1 = Turn On 2 = Go To Standby 3 = Deploy 4 = Activate 5 = Deactivate 6 = Stow
12	**Report BEA Radio Frequency**	Float	Hz	Link Dependent

Changes to Existing STANAG 4586 Messages

We have supplied certain additional details, needed to support our analysis, to the following messages.

In Message #1301 (Field Configuration Double Response), we have added the following items to the list of message fields to be supported:

- Message #204A, Set COMM1 Relay Radio Frequency
- Message #204A, Set COMM2 Relay Radio Frequency
- Message #204A, Set COMM3 Relay Radio Frequency
- Message #204B, Set VOR Radio Frequency
- Message #204B, Set LOC Radio Frequency
- Message #204B, Set GLI Radio Frequency
- Message #204B, Set BEA Radio Frequency

In Message #1303 (Field Configuration Command), we have added the following items to the list of message fields:

- Message #204A, Set COMM1 Relay Radio State
- Message #204A, Set COMM2 Relay Radio State
- Message #204A, Set COMM3 Relay Radio State
- Message #204B, Set VOR Radio State
- Message #204B, Set LOC Radio State
- Message #204B, Set GLI Radio State
- Message #204B, Set BEA Radio State
- Message #107A, Landing Gear State
- Message #107B, Transponder State
- Message #107C, GPS Receiver State

Appendix B C^2 Message Lengths

The following table describes the STANAG 4586 [5] messages, together with the user-specified messages described in Appendix A, that have been considered in our loading analysis. No STANAG 4586 message sizes have been changed. "Vehicle Specific Module" (VSM), as used in [5], means the same thing as "UA" elsewhere in our present report. As noted in Appendix A, the term "CUCS" in [5] is equivalent to "CS" as used in our report. The length of each message listed below consists of its data length plus the length of its 34-byte wrapper. No other protocol overhead is included in this table.

Mes-sage Type	Link Type	CS to UA		UA to CS	
	Message Description	**Data Length (bytes)**	**Message Length (bytes)**	**Data Length (bytes)**	**Message Length (bytes)**
	System ID Messages (#1, #20, #21)				
1	CUCS Authorization Request	31	65		
20	Vehicle ID			73	107
21	VSM Authorization Response			31	65
	Flight Vehicle Command and Status Messages (#40 to #47, #100 to #108)				
40	Vehicle Configuration Command	20	54		
41	Loiter Configuration	42	76		
42	Vehicle Operating Mode Command	17	51		
43	Vehicle Steering Command	66	100		
44	Air Vehicle Lights	18	52		
45	Engine Command	21	55		
46	Flight Termination Command	18	52		
47	Relative Route/Waypoint Absolute Reference Message	61	95		
100	Vehicle Configuration			53	87
101	Inertial States			84	118
102	Air and Ground Relative States			64	98
103	Body-Relative Sensed States			40	74
104	Vehicle Operating States			145	179
105	Engine Operating States			44	78
106	Vehicle Operating Mode Report			17	51
107	Vehicle Lights State			18	52
108	Flight Termination Mode Report			18	52
	Payload Command and Status Messages (#200 to #207, #300 to #308)				
200	Payload Steering Command	66	100		
201	Electrooptical (EO)/Infrared (IR)/Laser Payload Command	32	66		

202	Synthetic-Aperture Radar (SAR) Payload Command	29	63		
203	Stores Management System Command	58	92		
204	Communications Relay Command	21	55		
205	Payload Data Recorder Control Command	36	70		
206	Payload Bay Command	21	55		
207	Terrain Data Update	36	70		
300	Payload Configuration			28	62
301	EO/IR - Configuration State			59	93
302	EO/IR/Laser Operating State			77	111
303	SAR Operating State			60	94
304	Stores Management System Status			35	69
305	Communications Relay Status			21	55
306	Payload Data Recorder Status			46	80
307	Vehicle Payload/Recorder Configuration			21	55
308	Payload Bay Status			21	55
	Data Link Command and Status Messages (#400 to #404, #500 to #503)				
400	Data Link Set Up Message	33	67		
401	Data Link Control Command	25	59		
402	Pedestal Configuration Message	40	74		
403	Pedestal Control Command	46	80		
404	Data Link Assignment Request	25	59		
500	Data Link Configuration/Assignment Message			28	62
501	Data Link Status Report			38	72
502	Data Link Control Command Status			24	58
503	Pedestal Status Report			58	92
	Data Link Transition Messages (#600, #700)				
600	Vehicle Data Link Transition Coordination	61	95		
700	Handover Status Report			25	59
	Mission Messages (#800 to #806, #900)				
800	Mission Upload Command	39	73		
801	Air Vehicle (AV) Route	39	73		
801	AV Route			39	73
802	AV Position Waypoint	60	94		
802	AV Position Waypoint			60	94
803	AV Loiter Waypoint	38	72		
803	AV Loiter Waypoint			38	72
804	Payload Action Waypoint	58	92		
804	Payload Action Waypoint			58	92
805	Airframe Action Waypoint	20	54		
805	Airframe Action Waypoint			20	54
806	Vehicle Specific Waypoint	39	73		
806	Vehicle Specific Waypoint			39	73
900	Mission Upload/Download Status			18	52

	Subsystem Status Messages (#1000, #1001, #1100, #1101)				
1000	Subsystem Status Request	20	54		
1001	Subsystem Status Detail Request	20	54		
1100	Subsystem Status Alert			107	141
1101	Subsystem Status Report			22	56
	General Configuration Messages (#1200 to #1203, #1300 to #1303)				
1200	Field Configuration Request	35	69		
1201	Display Unit Request	25	59		
1202	CUCS Resource Report	34	68		
1203	Configuration Complete	28	62		
1203	Configuration Complete			28	62
1300	Field Configuration Integer Response			146	180
1301	Field Configuration Double Response			182	216
1302	Field Configuration Enumerated Response			128	162
1303	Field Configuration Command			32	66
	Miscellaneous Message Types (#1400 to #1403)				
1400	Message Acknowledgment	32	66		
1400	Message Acknowledgment			32	66
1401	Message Acknowledge Configuration	20	54		
1401	Message Acknowledge Configuration			20	54
1402	Schedule Message Update Command	24	58		
1403	Generic Information Request	20	54		
	Miscellaneous Message Types (#1500, #1501, #1600)				
1500	IFF Code Command	30	64		
1501	IFF Ident (Squawk) Command	19	53		
1600	IFF Status Report			27	61
	New (User-Specified) Flight Vehicle Command and Status Messages				
43A	UA Steering Command - Flight Vector Manual	24	58		
44A	UA Gears	18	52		
44B	UA Transponder Activation Switching	17	51		
44C	UA GPS Activation Switching	17	51		
45A	Engine Command - Throttle	24	58		
45B	Engine Command - Mixture	24	58		
45C	Gear Break Command	20	54		
107A	UA Gear State			17	51
107B	UA Transponder State			17	51
107C	UA GPS State			17	51
	New (User-Specified) Payload Command and Status Messages				
204A	Communications Relay Radio Command	35	69		
204B	Navaid Radio Command	40	74		
305A	Communications Relay Radio Status			35	69
305B	Navaid Radio Status			40	74

Glossary

ACL	ATC clearance
ACM	ATC communication management
A/G	air/ground
AMC	ATC microphone check
ARTCC	Air Route Traffic Control Center
ATIS	Automatic Terminal Information Service
ATS	air traffic services
AV	air vehicle
BEA	beacon
COCR	Communications Operating Concept and Requirements
COMM1	ATC communications relay radio #1
COMM2	ATC communications relay radio #2
COMM3	ATC communications relay radio #3
CS	control station
CUCS	Core UAV Control System
C^2	command and control
C^3	command, control, and communications
D-ATIS	data-link ATIS
DCL	departure clearance
deg	degree(s)
DLL	data-link logon
D-ORIS	data-link operational en route information service
D-SIG	data-link surface information and guidance
D-SIGMET	data-link significant meteorological information
D-TAXI	data-link taxi clearance delivery
EO	electrooptical
FAA	Federal Aviation Administration
FLIPCY	flight plan consistency
FLIPINT	flight path intent
GLI	glide slope
HALE	high-altitude, long-endurance
ID	identifier
IR	infrared
LOC	localizer
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
navaid	navigational aid
PPD	pilot preferences downlink

ROA	remotely operated aircraft
SAP	system access parameters
SAR	synthetic-aperture radar
SCPS	Space Communications Protocol Standards
SCPS-NP	SCPS network protocol
SCPS-TP	SCPS transport protocol
sec	second(s)
SM	sequencing and merging
STANAG	Standardization Agreement
TCD	Task Concurrence Document
UA	unmanned aircraft
UAS	unmanned aircraft system
UAV	unmanned aerial vehicle
UDP	User Datagram Protocol
VOR	VHF Omnidirectional Range
VSM	Vehicle Specific Module
WRC	World Radiocommunication Conference