GAIT

**Integrating Unmanned Aircraft into Non-Segregated Airspace – Discussion of a Special Purpose Code to Indicate Lost Link**

## GLOSSARY

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| ACAS | Airborne Collision Avoidance System |
| AIC | Aeronautical Information Circular |
| AIP | Aeronautical Information Publication |
| AIS | Aeronautical Information Service |
| ANSP | Air Navigation Service Provider |
| ATC | Air Traffic Control |
| ATCO | Air Traffic Control Officer |
| ATCRBS | Air Traffic Control Radar Beacon System |
| ATM | Air Traffic Management |
| C2 | Command and Control |
| CNS | Communications, Navigation and Surveillance |
| DHS | Department of Homeland Security |
| DoD | Department of Defense |
| EASA | European Aviation Safety Agency |
| EC | European Commission |
| EDA | European Defence Agency |
| EUROCAE | European Organization for Civil Aviation Equipment |
| FAA | Federal Aviation Administration |
| GAT | General Air Traffic |
| GCS | Ground Control Station |
| HALE | High Altitude Long Endurance |
| HITL | Human in the loop |
| ICAO | International Civil Aviation Organization |
| IFR | Instrument Flight Rules |
| ITU | International Telecommunication Union |
| LOS | Line of Sight |
| Mode S | Mode Select |
| NASA | National Aeronautics and Space Administration |
| NBCAP | National Beacon Code Allocation Plan |
| NMSU PSL TAAC | New Mexico State University, Physical Science Laboratory Technical Analysis and Applications Center |
| NORDO | No Radio |
| OJT | On Job Training |
| ORCAM | Originating Region Code Assignment Method |
| RLOS | Radio Line of Sight |
| RPA | Remotely Piloted Aircraft |
| RTCA | Radio Technical Commission for Aeronautics |
| SAA | Sense and Avoid |
| SARPs | (ICAO) Standards & Recommended Practices |
| SMS | Safety Management System |
| SSR | Secondary Surveillance Radar |
| UA | Unmanned Aircraft |
| UAS | Unmanned Aircraft System |
| UA-C | Unmanned Aircraft Commander |
| UAS-p | UAS Pilot |
| UAV | Unmanned Air Vehicle |
| VFR | Visual Flight Rules |
| WRC | World Radiocommunication Conference |

## EXECUTIVE SUMMARY


The Global Airspace Integration Team (GAIT) is an affiliation of individuals with extensive experience in the development and regulation of UAS. It has formed to independently assess operational airspace integration issues for the benefit for the wider UAS community. With demand for UAS access to non-segregated airspace growing, from the many challenges facing the integration of UA, this paper considers whether current Mode 3/A special purpose SSR codes make adequate provision for UA experiencing lost link.

Whilst in many respects UAS can successfully emulate the behaviour of manned aircraft, the unique nature of some UAS failure modes will require additional, or at least different, provisions by ATC. To date, much of the work on the integration of UA has focussed on the development of sense and avoid technologies and failure modes such as lost link have received less attention. When the C2 link between the UA and the UA-p is lost, the pilot is unable to maintain operational control over the aircraft until the link is regained. Currently, there are no internationally standardised procedures to address such a failure and procedures are developed on a case by case basis, including the selection of an appropriate SSR code to inform ATC of the situation.

When a manned aircraft suffers a failure such that the pilot considers there is imminent danger to the aircraft and its occupants, he declares an emergency and, as part of the internationally standardised procedure, selects the SSR special purpose code 7700. Similarly, when a manned aircraft experiences a radio communication failure and the pilot cannot communicate with ATC, as part of the internationally standardised procedure, he selects the SSR special purpose code 7600. In many situations, the response of a UA will mirror that of a manned aircraft. However, it is felt that there are occasions when a UA may experience a lost link and undertake a pre-determined manoeuvre, yet will not be in imminent danger and the pilot may still be able to communicate with ATC. In such circumstances, the selection of either SSR code 7700 or 7600 would not accurately convey the status of the UA to ATC. Instead, it is felt that the introduction of an additional special purpose code as part of a standardised procedure to indicate a UA experiencing lost link would more clearly indicate to ATC the nature of the problem. Armed with this more accurate information, ATC would then be better able to deal with the situation and safety would be enhanced.

It is recognised that SSR codes are a globally scarce resource and the difficulty of agreeing on the assignment of a new special purpose code for UA experiencing lost link, that will need to be implemented across international borders, is not underestimated. Whilst several studies, experiments and simulations have been conducted to investigate the integration of UA into non-segregated airspace, GAIT has been unable to find any that have focussed specifically on the potential benefits of the allocation of an additional special purpose code to indicate a UA experiencing lost link. To help build a body of evidence in support of the safety benefits of such an allocation, GAIT has undertaken a thorough academic analysis of existing special purpose SSR codes and the corresponding triggers.

GAIT concludes that a special purpose SSR code to provide rapid and unambiguous indication to ATC of a UA lost link may well improve future aviation safety. However, recognising the challenges of the universal adoption of such a measure, GAIT recommends that specific experimentation and simulation be undertaken to validate this finding. This evidence could then be used to help persuade and convince decision makers of the efficacy and safety benefits of the global introduction a new lost link special purpose code.

**CONTENTS**

# 1 INTRODUCTION

This paper has been prepared by the recently formed Global Airspace Integration Team (GAIT), which is described in more detail at Annex A. From the many challenges facing the integration of Unmanned Aircraft (UA[1]) into non-segregated airspace, this paper focuses on UA lost link behaviours and considers whether current Mode 3/A special purpose Secondary Surveillance Radar (SSR) codes[2] make adequate provision for such events. The paper first explains why the GAIT has focussed on lost link behaviours and the use of special purpose SSR codes. It then describes how special purpose SSR codes are currently employed in manned aviation and suggests that this allocation may not provide sufficient information to the Air Traffic Management (ATM) system of a UA experiencing a lost link. Whilst recognising the challenges, it then discusses how the introduction of a new special purpose code to indicate lost link would be beneficial to the integration of Unmanned Aircraft Systems (UAS[3]) into the ATM system.

# 2 BACKGROUND

The demand for UAS access to non-segregated airspace within national boundaries and across borders is already growing. For example in the USA, several public bodies already operate UA in the National Airspace System (NAS). These include the Department of Defense (DoD) for a variety of military missions, the National Aeronautics and Space Administration (NASA) for scientific missions and the Department of Homeland Security (DHS) for border patrol [1]. Similar activities are either planned or are already underway across the globe and, in addition, significant potential for the commercial exploitation of UAS has also been identified. Key to unlocking this potential will be safe, seamless integration of UA and manned aircraft in non-segregated airspace, where a recurrent theme is the need for a strategic, standardised approach and the development of a common, global, way forward.

## 2.1 Existing Initiatives

There are a raft of technical, operational and policy issues associated with enabling routine safe operations of UAS in non-segregated airspace. Foremost among these are:

- The lack of an on board capability in UA to sense and avoid (SAA) other aircraft;
- The availability of dedicated spectrum for UAS and vulnerabilities of the UAS Command and Control (C2) link;
- The need for UAS-specific procedures for ATM integration, where UAS systems and operations differ from manned aviation, or cannot comply with existing manned procedures.

Other issues will also have to be addressed such as [2]:

- Airworthiness certification;

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[1] A UA is an aircraft which is designed to operate with no human pilot on board, as part of a UAS.
[2] The term ‘SSR code’, widely employed in Europe, is synonymous with the term ‘Beacon Code’, used more widely in the USA.
[3] A UAS comprises individual 'system elements' consisting of the UA, the Ground Control Station and any other system elements necessary to enable flight, such as a communication link and launch and recovery element.

- Certification and associated training requirements for UA flight crews.

Solutions to these challenges are complex and likely to involve multiple interdependent factors and contributions from a wide range of stakeholders. These will include the development of new technology and accompanying operational procedures, with input from both UAS operators and those responsible for ATM, supported by appropriate policy and regulation.

The basic principles of the regulatory approach to the integration of UAS is that operations should be conducted at an equivalent level of safety to manned aircraft, should not increase risk to other airspace users and should not deny airspace to them. Furthermore, ATM procedures for UAS should, **wherever possible,** mirror those applicable to manned aircraft and provision of Air Traffic Services to UA should be transparent to ATC. Several studies[4,5] suggest that the integration of 'routine' UA operations in non-segregated airspace should not be problematic. However, it is also recognised that the absence of a pilot on board the aircraft and the unique nature of some UAS emergencies will require additional, or at least different, provisions by ATC[6]. Finally, UAS regulations should also be fair, in the sense that they should not impose requirements beyond reaching an equivalent level of safety, which are not in place for manned aviation[7], although it is recognised that this might not be possible in the short to mid-term or at least until regulators have the confidence that UAS platforms have achieved the same level of maturity as manned platforms.

To meet these challenges, widespread and diverse initiatives are already being undertaken, for example in Europe by EUROCONTROL, the European Aviation Safety Agency (EASA), together with European Commission (EC) and European Defence Agency (EDA). UAS manufacturers, users and regulators, both at an individual level and through collaborative efforts, are also engaged. These efforts range from those organized by industry and trade bodies, through regulators in individual States, to international and trans-Atlantic collaborative regulatory activities including:

- The International Civil Aviation Organization (ICAO) Unmanned Aircraft System Study Group (UASSG)
- EUROCAE WG-73
- RTCA SC-203

The ICAO UASSG has already identified that the introduction of UAS will introduce changes to a majority of the Annexes to the Chicago Convention and to many ICAO guidance documents. There are still many unknown factors concerning UAS certification and subsequent operational requirements that will impact ATM. Informal dialogue suggests that most stakeholders favour a coordinated and global approach to addressing the challenges of integrating UAS operations in non-segregated airspace, which would avoid fragmented regulation. Developing performance-based standards before the technologies are developed

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[4] B Korn, A Udovic* DLR, Germany; *DFS, Germany "File and Fly" – Procedures and Techniques for Integration of UAVs in Controlled Airspace, 25th Congress of International Council of the Aeronautical Sciences, 3 - 8 September 2006, Hamburg, Germany.

[5] Dörgeloh, Heinrich and Keck, Bernd and Klostermann, Elmar and Schmitt, Dirk-Roger (2009) Integration of UAV into civil ATC/ATM ATM-Simulation.

[6] EUROCONTROL specifications for the use of military UAVs as operational air traffic outside segregated airspace dated 26 July 2007.

[7] JAA/EUROCONTROL UAV Task Force Final Report "A Concept for European Regulations for Civil Unmanned Aerial Vehicles ", JAA, 11 May 2004.

could take the industry in the wrong direction, yet waiting until those technologies are in place before agreeing upon standards would be equally inappropriate.

To date, much of the work on the integration of UA has focussed on SAA, including projects that performed technical experimentation in flight. However, a key distinguishing feature of UAS is the radio Command and Control (C2) link between the pilot and the flight control systems of the aircraft. Work is underway in the International Telecommunication Union (ITU) to identify bandwidth requirements for protected spectral allocations for UA, which would reduce the vulnerability of the C2 link, and this is on the agenda of the World Radiocommunication Conference 2012 (WRC-12). The specific agenda item seeks to make provision for the required safety related air-ground and ground-air communication links for UAS, and any required regulatory actions. However, other issues around the Unmanned Aircraft pilot (UA-p) to UA C2 communications link have not yet been addressed in detail.

## 2.2 Initial Scope - Why is GAIT Looking at Lost Link?

As a key factor in the integration of UA into 'regular' controlled airspace, GAIT has initially focussed upon the actions taken following the loss of the C2 link between the Ground Control Station (GCS) and the UA. There is little empirical evidence available in the public domain relating specifically to lost link behaviours and UA do not yet operate outside segregated airspace on a regular basis. Therefore, the paper examines the existing aviation environment and develops arguments to stimulate discussion, and hopefully action, between the UA and ATM communities, specifically amongst Air Navigation Service Providers (ANSPs) and regulators, both civil and military. It is recognised that dealing with the challenges posed by lost link will require extensive policy changes from regulators and enhanced automation from manufacturers and operators, both of which have long-lead times. It is therefore essential that these issues are addressed as soon as possible.

UA face an additional challenge over manned aircraft in that vulnerabilities of the C2 link may mean that the pilot on the ground is unable to maintain operational control over the aircraft. Currently no standards exist and a variety of approaches to deal with the lost link event have evolved. A standardized approach would ensure that ATC knew what to expect when such a scenario occurred. Increasing the real-time predictability to ATC of UAS experiencing failure modes will address significant safety issues associated with their integration. Specifically, the GAIT decided to look at two inter-related topics that could enhance predictability and therefore overall safety: the need to develop standardized flight contingency procedures in the event of a lost link and, the focus of this paper, the potential need for a special purpose SSR code to indicate to ATC and other suitably equipped aircraft that a UA had experienced a lost link. Specific questions raised are:

- Do existing special purpose SSR codes adequately describe a UAS experiencing lost link and provide enough information transparently to ATC and other airspace users? And;

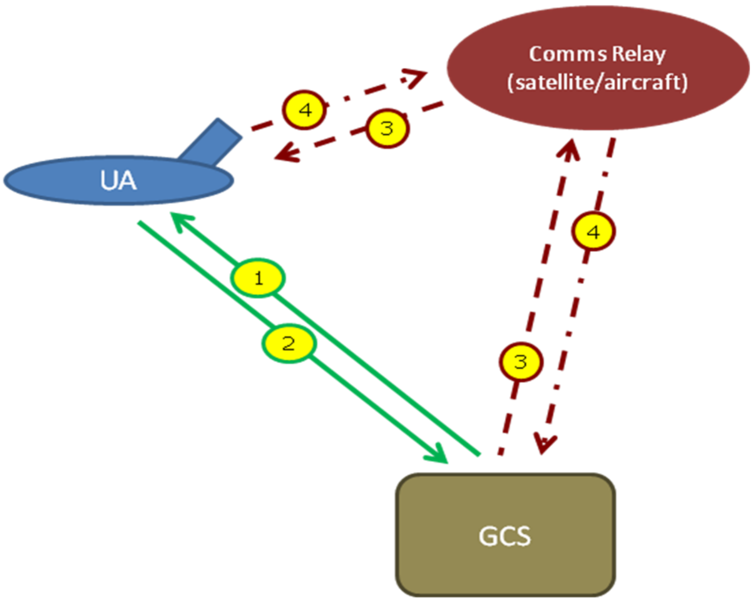
- If not, should a new special purpose SSR code be proposed for the Lost Link event, and what will the impact be of introducing a new code?

When a UAS experiences a lost link, the UA may, or may not, be able to maintain its flight clearance and may instead execute a pre-programmed manoeuvre. Furthermore, whilst the UA-p may not be able to control his aircraft, even though the aircraft itself may remain fully functional, he will most likely still be able to communicate with ATC. If the UA cannot maintain its flight clearance, a standardized approach to how the UA will react in such circumstances, if notified swiftly, would help ATC at a tactical level and this will require the development and validation of specific ATM procedures tailored to these unique UAS operational characteristics.

As discussed below, depending on the individual circumstances, the incident may or may not be considered an emergency, and currently much of this decision-making process is at the pilot in command's discretion and based on his airmanship skills. Nevertheless, the incident may be more than a radio (voice) communications failure as currently described for manned aircraft. GAIT has considered the rationale of applying the existing special purpose SSR codes of 7700 to indicate an aircraft in emergency and 7600 to indicate an aircraft that has experienced a radio (voice) communications failure and has determined that in some circumstances the current special purpose codes do not adequately address the issue of a UAS that has experienced a lost link. However, if new procedures are introduced to help ATC recognise the difference, this may have a positive impact on the safe management of the airspace in which the UA flies.

## 2.3 UAS C2 Overview

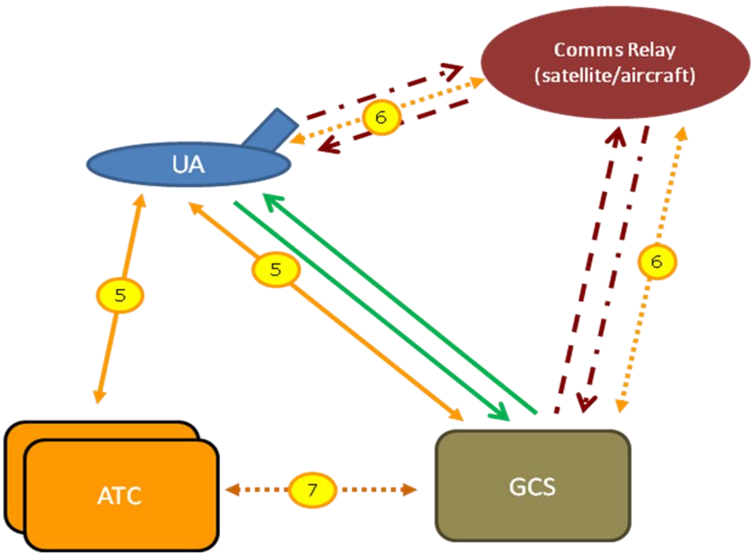
The UA-p controls the UA from a Ground Control Station (GCS)[8], linked by radio, which can either be in direct Radio (Frequency) Line of Sight (RLOS/FLOS[9]) of the UA, or Beyond (Frequency) Line of Sight (BLOS) using satellite or other relays (Figure 1). These links are used both for the C2 of the UA and for communications with ATC (Figure 2) and are potentially vulnerable to disruption. As radio communication is the critical mechanism for interaction between the UA and UA-p, their seamless operation in non-segregated airspace requires high availability of communication links for C2 between the UA and UA-p.




1. Uplink representing RLOS 'Command' in the C2 function
2. Downlink representing a RLOS report from the UA
3. Relay of C2 communications from the UA-p to the UA
4. Relay of C2 communications from the UA to the UA-p

**Figure 1: C2 radio communications in a UAS**

[8] It is recognised that the UAS Control Station could be in another aircraft, but for simplicity the term GCS is used here.
[9] EUROCAE tend to use the term RLOS, whereas RTCA tend to use FLOS.




5. ATC communications relayed between ATC, the UA and the UA-p

6. ATC communications relayed between ATC, the UA, a satellite and the UA-p

7. Alternative direct link between ATC and the UA-p

**Figure 2: UAS radio communications related to ATC**

## 2.4 Defining Lost Link - Is There a Problem?

There are several definitions of lost link employed within the UAS community including:

- Loss of command and / or control links between pilot and UA[10].
- Non-specific condition in which control, payload data, and/or communication links are broken[11].
- A situation where the control station has lost either or both of the uplink and downlink contacts with the unmanned aircraft and the pilot can no longer affect the aircraft's flight[12].

For the purposes of this paper lost link is defined as:

- The loss of command and/or control links between the UA-p and the UA, so that the pilot can longer maintain operational control.

However, there is currently no standard lost link procedure for UA and each manufacturer and operating agency employs a slightly different process. It has become normal practice for these processes to be discussed with ATC and agreed by regulators on a case by case basis before UA operations are authorised. To date, there is no formal agreement on whether a lost link should be defined as an emergency, a radio communications failure, or its own unique

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[10] RTCA SC-203 - Draft Guidance Document, dated 20 July 2006
[11] RTCA SC-203 Guidance Material and Considerations for Unmanned Aircraft Systems, dated 22 March 2007.
[12] ASTM Committee F38 on UAV Systems – Edition 1 Jul '04; Updated 1 Jan 2005

event. The sections that follow look at current provisions for 'State of Emergency' and 'Radio Communication Failure' for manned aircraft and discuss how these apply to UA and effect UA integration.

# 3 CURRENT PROVISIONS FOR AIRCRAFT IN 'STATE OF EMERGENCY'

## 3.1 Definition of State of Emergency

For manned aircraft, 'states of emergency' are typically defined as[13]:

Distress phase. A situation wherein there is reasonable certainty that an aircraft and its occupants are threatened by grave and imminent danger or require immediate assistance.

Uncertainty phase. A situation wherein uncertainty exists as to the safety of an aircraft and its occupants.

## 3.2 Recognition of a State of Emergency

Although the precise symptoms will be type-specific, the Skybrary aviation knowledge store identifies several emergency or abnormal situations which may develop as a result of one or more factors within or outside an aircraft. For manned aircraft, the recognition of these situations by the crew is more likely than for a remote UA-p who would miss the physical, on-board clues such as vibrations, noise and fumes often associated with emergency situations. For UA, there may well also be issues of latency, human factors, (loss of) system functionality and general lower situational awareness which will impair recognition, as elaborated in *italics* below[14].

- Fire on board the aircraft (*For UA, probably not recognised until a system warning or fault occurs, when it will be hard to determine the severity of the problem but which will not be directly life-threatening*);
- Aircraft component failure or malfunction (e.g. engine failure, landing gear malfunction or loss of pressurisation) (*Whilst a loss of pressurisation is not relevant to UA, others are comparable*);
- Shortage of fuel (*Identical for UA, although subsequent actions and considerations may differ – eg terminate flight rather than divert*);
- Worsening weather (*More difficult to detect for UA, more likely to experience this due to reduced local situational awareness*);
- Pilot incapacitation (*Probably easier to compensate for UA due to relative accessibility of GCS, flight control automation and likelihood of multiple cross-skilled operators*);
- Aircraft damage (*UA not well placed to avoid bird strike, otherwise comparable to manned aircraft, first indications will be of system fault or unusual control inputs*);

An emergency or abnormal situation may result in it being impossible to continue the flight to destination as planned, resulting in one or more of the following outcomes (*which are equally relevant to UA*):

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[13] ICAO Doc 4444 ATM/501 PANS ATM Dated 2 June 2007
[14] http://www.skybrary.aero/index.php/Emergency_or_Abnormal_Situation.

- Loss of altitude;
- Diversion to a nearby aerodrome;
- Forced landing.
- Uncontrolled crash

## 3.3 Action in a State of Emergency

For a manned aircraft, the relevant SSR action in a state of emergency is typically specified as follows (author's emphasis) [15]:

> The pilot of an aircraft in a state of emergency shall set the transponder to Mode A Code 7700 unless ATC has previously directed the pilot to operate the transponder on a specified code. In the latter case, the pilot shall continue to use the specified code unless otherwise advised by ATC. However, a pilot may select Mode A Code 7700 whenever there is a specific reason to believe that this would be the best course of action.

Whilst some guidance expresses the same intent slightly differently, as detailed in Annex B, most regulations describe similar actions. However, informal research in support of this paper revealed little substantive guidance of a specific trigger to help a pilot to judge when selecting SSR code 7700 'appears to be the most suitable course of action'. For example, the syllabi of two well known UK commercial aviation schools appear to treat 7700 as a digital 'MAYDAY' call to be used only when voice means have failed. In the absence of specific, detailed guidance pilots of manned aircraft rely upon their airmanship skills to judge when to declare an emergency. Airmanship can be defined as[16]:

> A sound acquaintance with the principles of flight, the ability to operate an airplane with competence and precision both on the ground and in the air, and the exercise of sound judgment that results in optimal operational safety and efficiency.

However, airmanship is a highly subjective concept that is difficult to define empirically, which has presented a significant challenge in interpretation for the UA community. The primary consideration of the crew of a manned aircraft in distress is the prevention of the loss of the aircraft because this inevitably engenders a high risk of harm to the crew and passengers. The protection of third parties on the ground becomes an additional consideration relevant only when the eventual landing is not at a recognised aviation location or in an otherwise suitable clear area. Thus 'protecting self' will usually mean that the pilot of a manned aircraft also protects second and third parties both in the air and on the ground. Although protecting a UA is likely also to protect third parties (through the avoidance of mid-air collision and/or executing a forced landing in appropriate circumstances), the UA-p's balance of risk is different because an increased risk to the UA itself may be warranted to reduce the overall risk to third parties on the ground or in the air. In circumstances where a UA is distant from any people (be they in other aircraft or on the ground), the notion that a fatal (to the UA) emergency constitutes a state of 'distress' in aviation terms is moot. Thus, in many ways, the judgement over protection of materiel versus protection of people may be different, with more options, for the UA-p than for the commander of a manned aircraft (especially one carrying passengers).

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[15] ICAO Doc 8168.
[16] FAA Airplane Flying Handbook FAA-H-8083-3A (http://www.faa.gov/library/manuals/aircraft/airplane_handbook/).

## 3.4 Case Study - Aircraft in Distress

The key differences between the use of SSR code 7700 for manned aircraft and UA are summarised at Columns 1 and 2 of the Table at Section 7. A useful case study for manned aircraft is an emergency descent when flying IFR caused, for example, by a rapid decompression. This scenario represents an unexpected deviation from the planned flight path and an inability to comply with ATC instructions engendering an increased workload. In general terms, it is equally descriptive of the behaviour of an unmanned and manned aircraft in distress. As summarised in UK AIC: P 052/2009 (Emergency Descents in UK Controlled Airspace)[17], ICAO Doc. 7030/EUR states that:

> When an aircraft receiving an ATC service experiences sudden decompression or a malfunction requiring an emergency descent, the aircraft shall, if able:
>
> a. Initiate a turn away from the assigned route or track before commencing the emergency descent (although the AIC goes on to say that this may not be advisable in crowded UK airspace);
>
> b. advise the appropriate air traffic control unit as soon as possible of the emergency descent;
>
> c. set transponder to Code 7700 and select the Emergency Mode on the automatic dependent surveillance/controller-pilot data link communications (ADS/CPDLC) system, if applicable;
>
> d. turn on aircraft exterior lights;
>
> e. watch for conflicting traffic both visually and by reference to ACAS (if equipped); and
>
> f. co-ordinate its further intentions with the appropriate ATC unit.

AIC: P 052/2009 goes on to explain the significance of the selection of an emergency transponder code:

> 2.5.1 In busy, highly sectorised airspace, controllers may adjust their situation displays to filter out aircraft in adjacent sectors, which will be separated vertically or horizontally from aircraft in their own sector. This is done to prevent clutter on the controller's display. Selection of the emergency code 7700 will override the display filter and highlight to all controllers the emergency state of the aircraft, whether or not the aircraft is in their sector (including vertically). This function allows controllers to act quickly in providing separation from an aircraft in emergency descent as it passes through their sector. The prompt selection of 7700 is of paramount importance.

All of the preceding provisions are equally applicable to manned or unmanned aircraft with the exception of the UA pilot's inability to "watch for conflicting traffic ... visually". For IFR flight (analogous to UA operation), the expectation would be that ATC (and, possibly, ACAS) will continue to provide separation (albeit at increased workload) during manoeuvres following an emergency and that standard rules of the air (including 'see and avoid') remain applicable. Thus, for a UA, avoiding a mid-air collision during an emergency will be heavily dependent upon ATC's provision of separation. Furthermore, any FLOS C2 link will fail when the aircraft descends below the radio horizon, further complicating the situation. Selecting an appropriate

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[17] www.nats-**uk**.ead-it.com/aip/.../**aic**/EG_Circ_2009_**P**_052_en.pdf.

SSR code to make all relevant controllers aware of the need to avoid a UA which has an emergency and which may manoeuvre unusually would appear to be a critical element in the immediate actions of the UA-p.

Irrespective of the decision on which code to assign, it will remain crucial to ATC situational awareness that the UA continues to transmit an SSR code. This has not always been the case following a UA system failure[18].

As with manned aviation, the commander of a UA in distress will be faced with a complex scenario which may well entail 'life or death' decisions; nevertheless, in most circumstances, those skill-based airmanship decisions will involve UA-specific considerations rather than rule-based deterministic actions. It is reasonable to assume, for the purposes of this paper on special-use SSR codes, that the crew of a future UA flying in controlled airspace will be versed in UA airmanship and well aware of their duty to protect to third parties by working closely with ATC and by carefully planning the UA flight path. Thus, from the perspective of the UA crew, existing requirements and guidelines for the use of emergency SSR code 7700 are considered to be sufficient. Furthermore, no change in wording would be warranted because the terms 'aircraft', 'pilot' or 'pilot-in-command' are equally applicable to both manned aircraft and UA.

FAA Contingency Guidelines[19] suggest that the impact of a UA 'Emergency' on ATC will be moderate or high due to the additional onus on them to compensate as far as possible for the lack of a UA SAA capability. Nevertheless, the Guidelines do not suggest that the elemental actions of ATC are different for UA. This would be consistent with the principles of (UA) transparency to ATC in that any differences between the behaviours of the crews of manned and unmanned aircraft should be minimised[20]. However, there is a counter argument, developed in Section 5 of this paper, that whilst in 'Emergency' situations, such as those illustrated above, it would be wholly justifiable for a UA to select code 7700, in other specific lost link situations a different code selection, which would provide additional information to ATC, would be more appropriate.

To conclude, it is felt that fundamentally, the current extant provisions to indicate an aircraft in 'distress', including the selection of code 7700, are appropriate for UA, but that this may not be appropriate for an event that only involves a lost link.

# 4 EXISTING PROVISIONS FOR 'RADIO COMMUNICATION FAILURE'

## 4.1 Meaning and Definitions of 'Radio Communication Failure'

A loss of communications that would result in a pilot selecting SSR code 7600 is variously defined as 'an aircraft radio receiver failure'[21] or 'two-way radio communications failure'[22]. There are a number of causes for a loss of voice communications including human factors (eg inaccurate frequency selection), environmental factors (eg radio propagation), external influence (eg blocked transmissions) or technical failures both in the air and on the ground. Some communications 'drop-outs' may be temporary whereas others, typically caused by a

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[18] NTSB, Safety recommendation A-07-70 through -86: Loss of a Type—B Predator 10 nautical miles northwest of Nogales International Airport, Nogales, Arizona, April 25, 2006. Washington DC, USA, October 2007.
[19] FAA, Contingency Guidelines for Extended Range Unmanned Aircraft System Operations in Class A Airspace.
[20] CAP 722.
[21] Belgium eAIS.
[22] FAR 91.185 - IFR operations.

fundamental equipment failure, may be permanent until repair can be effected. For the purpose of this paper, a 'Radio Communication Failure' is taken to mean:

> The permanent loss of ability to exchange verbal information between the pilot of an aircraft and ATC in one or both directions.

The main indicator of radio failure is self-evident. Normal practice for the pilot is to check all selections and equipment and attempt to communicate with ATC using alternatives. When convinced his radio has failed and he cannot communicate with ATC, the pilot should select the 'radio failure' SSR code of 7600. Compliance by the pilot with one-way instructions from ATC (eg "squawk ident") may elicit that the aircraft can receive but not transmit voice.

### 4.2 Actions on 'Radio Communication Failure'

The action to be taken by the pilot of a manned aircraft experiencing loss of communications through Radio Failure is well defined and common to most environments. In essence, the flight should be continued under visual flight rules if possible to alleviate the reduced ability to derive separation information from ATC instructions. If this is not possible, then the flight is continued under instrument flight rules following a predictable flight path compliant with a set of rules as typified by 14 CFR 91.185. Observing the no radio aircraft's SSR code, ATC can reasonably predict the likely flight path and provide separation if necessary by taking action on other aircraft. Furthermore, in the event of a partial loss of voice communications, various actions can be taken to assure co-operation, and hence separation, such as blind transmissions (where receiver failure is suspected), manoeuvres to confirm receipt of instructions (where transmitter failure is suspected) or the use of alternative means such as voice-capable navigation aids. All of these measures increase pilot and/or ATCO workload and may contribute to an erosion of safety margins.

For UAS, it is important to distinguish between the loss of voice communications between the UAS crew and ATC and the loss of the UA C2 link. The discussion below highlights the fundamental differences between these two scenarios in support of an analysis of how appropriate, or otherwise, it would be to employ the standard manned aircraft SSR code of 7600 for a UA with a C2 link loss.

### 4.3 Key Differences for UA Experiencing Only Loss of Voice Communications

At its simplest, the loss of voice communications between a UAS crew in the GCS and ATC is broadly analogous to such a scenario in a manned aircraft in that co-ordination and information exchange are impaired but the control of the aircraft is unaffected. Depending upon system architecture and the voice communication route, alternative non-radio means (eg telephone) may be available and would be exercised in the same way as alternative radios in a manned aircraft. Assuming that any UAS certificated to operate in controlled airspace will incorporate robust voice communications; and, noting that UA control is, in principle, unimpaired by the loss of voice communications, there is no fundamental reason why a UA should not behave like a manned aircraft under IFR in the event of a loss of voice communications, including selection of SSR code 7600 and conforming to standard procedures. However, in the absence of a certificated SAA capability, the option to continue flight under VFR is not available to a UA, hence there will be an increase in ATCO workload in certain situations.

As concluded by the FAA[23], the overall impact for ATC, other aircraft and the UA crew of a 'simple' Radio Failure on a UA is low and in the event of a loss of voice communications only, it is concluded that the meaning to ATC of the 7600 transponder code is similar for both manned and unmanned aircraft.

# 5 ANALYSIS AND RECOMMENDATIONS: NOTIFYING ATC WHEN UA EXPERIENCE LOST LINK

## 5.1 Lost Link – A Unique Event

There is no equivalent in manned aviation to the UA scenario where the C2 link is lost such that the ground-based crew can no longer influence the flight of the aircraft. Whilst the loss of the C2 link has a potentially high impact on ATC, other air traffic and the UAS crew, it may not necessarily warrant the declaration of an emergency because, as long as separation is maintained, there is no 'grave and imminent danger' to life. Similarly, as the UA-p may still be able to communicate with ATC, the event may not develop in the same way as a loss of voice communications. This poses the question: does selection of either the transponder code 7700 or 7600 adequately capture the loss of a UAS C2 link, or should there be an exclusive SSR code assigned for this unique event, such that the alternative could quickly present ATC with more specific information on the nature of the event and how the UA will react? It is important to stress that the selection of a new special purpose code to indicate lost link would not in itself provide a complete solution, but would indicate in the first instance to ATC that the event was underway.

In the event of the loss of a UAS C2 link, the internal (system) and external (ATM environment) impacts are almost the opposite of the preceding loss of voice communications scenario. Assuming that all back-up systems and contingencies have been exhausted, the UA-p is no longer able to exercise control of the aircraft and the UA should execute a pre-determined, automatic, lost-link behaviour. In most cases voice communications with ATC will be retained, for example via land line, the pilot will be able to explain to ATC what will happen and ATC will remain able to 'see' the transponder code of the UA[24].

## 5.2 Responses to a Lost Link Event

For most UA potentially capable of operating in controlled airspace, lost-C2 link behaviour typically involves the execution of a pre-programmed flight behaviour with a variety of, currently, non-standardised attributes which may include:

- The ability to update the lost-C2 link behaviour according to flight segment, location, pilot preference or ATC instructions
- The short-term maintenance of the current flight conditions
- An initial manoeuvre (eg a climb, spiral and/or turn-back) intended to increase the chances of regaining link in the absence of a technical failure
- Changing the aircraft configuration (eg switching on external lights, changing transponder code)

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[23] FAA, Contingency Guidelines for Extended Range Unmanned Aircraft System Operations in Class A Airspace.
[24] Note that changing the transponder code from the ground will likely be impossible without a C2 link hence any special purpose code will need to be selected by an on-board system.

- Transit to a pre-determined location, either direct or via a pre-programmed route with or without altitude changes

- Holding at a safe location to attempt re-acquisition of link

- Executing a pre-programmed recovery manoeuvre (eg parachute deployment or even automatic landing to a suitable aviation location)

- Ditching or cut-down on fuel exhaustion if link is not restored

This pre-programmed automatic response from the UA is not standardised and will often vary depending on the nature of the UA mission and its phase of flight; for example it may be different in the vicinity of the aerodrome of arrival/departure, when in climb or descent, in the en route/cruise phase, or when on-task in the mission area. The implications for ATC and the safety of other airspace users will be different in each case and the actions taken could vary significantly.

For example, the GlobalHawk UA typically flies missions in excess of 24 hours and operates above Flight Level (FL) 500. At such altitudes and endurances, if GlobalHawk were to experience a lost link event while en-route or conducting a mission profile, then the event would have little or no impact on the ATM system. In such circumstances, the selection of 7700 would likely trigger a disproportionate response (at least initially). Without a compounding problem, the simple fact of lost C2 link is not intrinsically dangerous and would not warrant such a distress signal which would be likely both to disrupt other airspace users and increase ATC workload.

On the other hand, if the aircraft were in a transition phase (e.g. climbing or descending to/from its destination/arrival aerodrome) then the scenario becomes more serious due to the likely density of traffic and rapidity of control instructions. Unless ATC is quickly able to recognise the situation and take action on other aircraft, a potential loss of separation could quickly develop. Without very sophisticated on-board functionality, it seems unlikely that there will be a guarantee that a UA with a lost C2 link will be able to maintain its assigned, expected or planned flight path (including autonomous diversion and landing at an alternate airfield) with sufficient integrity. A much more realistic medium-term expectation is that the UA will automatically execute a pre-programmed lost-link manoeuvre intended to restore link and/or to place the UA in a safe holding pattern. Unless the UA's lost C2 link behaviour is identical to that for lost voice communications, any misinterpretation of a 7600 SSR code could be hazardous in such a scenario, since ATC's ability to predict the UA behaviour would be compromised.

## 5.3 The Criticality of Notifying ATC

It could be argued that ATC might be notified (eg via the flight plan or other means) of the nature of a lost C2 link event and the intended behaviour of the UA (see Table at 7.1). However, something would need to trigger the rapid search for, and acquisition of, such information to avoid ambiguity. Without a dedicated SSR code, it is not obvious how this would occur quickly in a high-pressure ATC environment, unless direct radio communications were in place because:

- There is no guarantee that the UA-p will be immediately aware of the link loss

- If voice communications are routed through the C2 link then a call to ATC may also be inhibited.

- If voice communications are via a land line there may well be some latency and, for long-range operations, immediate GCS connectivity to all of the appropriate sector controllers may not be assured.

Thus, a means of rapidly and unambiguously appraising ATC of the loss of a UA C2 link would appear to be a critical factor in safely containing such a situation. In the absence of such a process, the safety of air navigation when a UA is in busy terminal airspace may not be assured. Indeed, the current position of the FAA is to prohibit UA from operating in the Class B airspace environment, due both to the lack of system maturity, but also due to the lack of standards and procedures specifically for UAS. In other words, **the lack of UA predictability is hampering their access to airspace**.

Thus, discussion on the need for a dedicated lost-link SSR code centres on the immediate recognition of the situation by ATC and thereafter their selection of the best course of action. In earlier work conducted by EUROCONTROL[25] the actions required are summarised as follows:

- UAVs should be pre-programmed with an appropriate contingency plan in the event that the pilot-in-command is no longer in control of the UAV.

- A UAV System should provide a prompt indication to its pilot-in-command in the event of loss of control data-link.

- When a UAV is not operating under the control of its pilot-in-command, the latter should inform the relevant ATC authority as soon as possible, including details of the contingency plan which the UAV will be executing. In addition, the UAV System should indicate such loss of control to ATC.

The MITRE Study of the impact of UAS on ATC reveals the criticality of the unambiguous and prompt recognition by controllers of a lost C2 link, especially where separation from other (manned) aircraft is predicated upon a predictable UA response to controller instructions. Although limited in scope, this study suggests that recognition of lost C2 link within one minute should be normal and that a further minute only should elapse before the UA takes contingency action. In the study, UA experiencing lost link selected the radio failure transponder code of 7600, but GAIT considers that there is justification for an additional, alternative code to avoid ambiguity with the potentially more benign loss of voice communications scenario.

The importance of UA trajectory predictability following a datalink failure is highlighted in the German UAV demonstration project, WASLA-HALE (Weitreichendes Abbildendes Signalerfassendes Luftgestütztes Aufklärungssystem – High Altitude Long Endurance[26]). In addition, the project report states that:

*Controllers would prefer that a UAV specific squawk for the datalink loss is introduced. A datalink failure does not correspond exactly to the Loss Com case (Squawk 7600) neither to the Emergency Squawk 7700 because the UAV is still in a stabilized situation due to the autonomous airborne systems. An additional UAV specific squawk for datalink loss would*

[25] Op. cit.
[26] B Korn, A Udovic* DLR, Germany; *DFS, Germany "File and Fly" – Procedures and Techniques for Integration of UAVs in Controlled Airspace, 25th Congress of International Council of the Aeronautical Sciences, 3 - 8 September 2006, Hamburg, Germany.

*give as well the possibility to indicate further deterioration of the UAV in case of e.g. an engine failure.*

Elsewhere, a USICO evaluation of an ATC/ATM integration concept for civil UAV operations[27] raises an interesting issue. In this case, after simulations using alternative codes to indicate UA lost-link, controllers came to the conclusion that the standard codes 7600 and 7700 are appropriate for UA. However, the report states that additional codes would be a 'nice idea' but were dismissed due to perceived difficulties in their allocation worldwide. Furthermore, informal discussions suggest that both the FAA and US DoD are collaborating on preliminary activities to standardise UA lost link procedures, including considering the potential benefits of the introduction of a new special purpose SSR code to indicate lost link.

The Table that follows provides a summary of how special purpose SSR codes are currently employed and how these could be further developed to meet the specific requirement of UAS:

[27] Evaluation of ATC/ATM Integration Concept for Civil UAV Operations, D4.1 Report, A Lemmers et al, USICO, April 2009.

## 5.4 Summary of Special Purpose SSR Codes and UAS

NB: Text in **bold** highlights the differences between manned and unmanned aircraft

| **SS Code** | **7700 (or distress call)** | | **7600** | | **7X00 (note 2)** |
|---|---|---|---|---|---|
| **Class of aircraft (1)** | **Manned (2)** | **Unmanned (3)** | **Manned (4)** | **Unmanned (5)** | **Unmanned (6)** |
| Code selection | Manual at pilot's discretion | Manual at pilot's discretion | Manual on loss of radio comms (if IMC) | Manual at Pilot's discretion | System dependent, on-board algorithm |
| Current meaning for manned aircraft<br>Likely meaning for UA | Distress, crew requires immediate assistance to minimise risk | Distress, crew requires immediate assistance to minimise risk | Loss of radio voice communications between ATC and crew in the aircraft | **Total** loss of voice communications between ATC and crew in the **GCS** | Inability to interact with UA due to system fault (ie lost C2 link). |
| Crew priority | Minimise risk to aircraft and thus occupants | Minimise risk to third parties (in other aircraft and on the ground) | Minimise risk to aircraft and thus occupants | Minimise risk to third parties (in other aircraft and on the ground) | Minimise risk to third parties (in other aircraft and on the ground) |
| Other crew considerations | Minimise risk to third parties (in other aircraft and on the ground) | Minimise risk to **UA** | Minimise risk to third parties (in other aircraft and on the ground) | Minimise risk to **UA** | Minimise risk to UA |
| Direct aircraft control | May be impaired depending upon nature of emergency | May be impaired depending upon nature of emergency | Unaffected | Unaffected | Not available.<br>Reversion to pre-programmed 'lost-link' behaviour |
| ATC-crew communication | Available, but may be impaired depending upon nature of emergency | Available, but may be impaired depending upon nature of emergency | Not available | Not available | Likely to be available, but may be impaired depending upon nature of event |

| SS Code | 7700 (or distress call) | | 7600 | | 7X00 (note 2) |
|---|---|---|---|---|---|
| **Class of aircraft**<br><br>**(1)** | **Manned**<br><br>**(2)** | **Unmanned**<br><br>**(3)** | **Manned**<br><br>**(4)** | **Unmanned**<br><br>**(5)** | **Unmanned**<br><br>**(6)** |
| Expected manned aircraft behaviour.<br><br>Possible unmanned aircraft behaviour | Manoeuvre as required (climb, turn, descend, land).Diverge from planned/cleared flight path if pilot considers necessary | Manoeuvre as required (climb, turn, descend, land or **ditch**).<br><br>Diverge from planned/cleared flight path if UA-p considers necessary | Follow ICAO or national procedures.<br><br>Achieve visual flight conditions if possible.<br><br>Otherwise, follow assigned, expected or planned route.<br><br>Land at destination (or alternate) at ETA. | To be determined.<br><br>May not be as per manned aircraft – this would require a very sophisticated UAS.<br><br>Likely to be predictable but may diverge from planned/cleared flight path if so-programmed.<br><br>Remain IFR (unless SAA certified equivalent to VFR is available) | Reversion to pre-programmed 'lost-link' behaviour.<br><br>Manoeuvre as required (climb, turn, descend, land or ditch).<br><br>Diverge from planned/cleared flight path if so-programmed |
| ATC response | Assist crew to recover aircraft safely.<br><br>Provide separation through action on other aircraft.<br><br>Alert other agencies. | Assist crew to recover aircraft safely.<br><br>Provide separation through action on other aircraft.<br><br>Alert other agencies. | Provide separation through action on other aircraft.<br><br>Alert other agencies. | Provide separation through action on other aircraft.<br><br>Alert other agencies. | Provide separation through action on other aircraft.<br><br>Alert other agencies. |

| SS Code | 7700 (or distress call) | | 7600 | | 7X00 (note 2) |
|---|---|---|---|---|---|
| **Class of aircraft**<br><br>**(1)** | **Manned**<br><br>**(2)** | **Unmanned**<br><br>**(3)** | **Manned**<br><br>**(4)** | **Unmanned**<br><br>**(5)** | **Unmanned**<br><br>**(6)** |
| Source of ATC knowledge of future flight path (for separation provision) | Voice communication of crew intentions | Voice communication of crew intentions | Knowledge of ICAO or national procedures and of assigned, expected or planned route | Prior knowledge of crew intent (eg via flight plan)<br>Or<br>Communication of crew intent via data transmission<br>Or<br>Knowledge of ICAO or national procedures and of assigned, expected or planned route (if UAS capable of compliance) | Voice communication of expected aircraft behaviour<br>Or<br>Prior knowledge of expected aircraft behaviour (eg via flight plan, standard manoeuvres, or pre-planned lost link manoeuvre) |
| Source of on-board traffic separation or collision avoidance | Crew lookout, augmented by ACAS (if fitted) | SAA system if fitted, otherwise none | Crew lookout | SAA system if fitted, otherwise none | SAA system if fitted, otherwise none |
| Ability to manoeuvre in response to ATC instructions (eg for separation) | Limited depending upon nature of emergency | Limited depending upon nature of emergency | None unless ‘receive’ capability still working | None unless ‘receive’ capability still working | None |

Note 1: Code 7500 (illegal interference) is not covered in this paper. However, the principles of alerting ATC to illegal interference appear to be comparable between manned and unmanned aircraft (albeit that follow-on actions by other agencies may differ significantly).

Note 2: 7X00 is a hypothetical special-use code indicating the loss of the C2 Link only for a UA.

## 5.5 Recommendation

GAIT considers that significant value would be gained by conducting a Human in the Loop (HITL) simulation, using current air traffic controllers in an experimental environment, similar to that already conducted by MITRE, but employing a new discrete special purpose code specifically to indicate a UA experiencing lost link. The aim of such a study would be to assess the impact for ATC of observing such a code and understanding the actions that the UA would then take. If the selection of a specific SSR code indicated that the UA had experienced a lost link, not an emergency or a voice communications failure, and was about to conduct a pre-arranged and standardised lost-link manoeuvre, then this predictability could enhance ATC's overall situational awareness and safety. The experimental design of such a simulation is described below:

### 5.5.1 Research Goals

The goal of this HITL experiment would be to quantify the need for a new special purpose SSR code to indicate that a UAS has lost its C2 link. The experiment would also help evaluate what changes are needed in ATC automation to give controllers sufficient awareness of the lost link event.

### 5.5.2 Hypothesis

If a new special purpose SSR code (e.g. 7400) is introduced for UAS lost link events and the ATC automation uniquely responds to that code, then controllers will be better able to manage those situations.

### 5.5.3 Independent Variables

The two independent variables are the use of new special purpose SSR code and the automation response to the lost link situation.

### 5.5.4 Dependent Variables

The results would be based on several variables, which may include but are not limited to:

- Workload (both subjective ratings and objective measurements)
- Loss of separation events
- Detection times for lost link events
- Manoeuvring of UAS versus other aircraft during non-lost link events
- Efficiency metrics
- Participant comments

### 5.5.5 Scenarios

There would be *at least* four distinct situations experimented with over the HITL experiment:

1. The current operation with a lost link SSR code of 7600.
2. The current operation with a lost link SSR code of 7700.
3. A new SSR code of 7400 which displays a different character string in the data block, in place of 'RDOF'.

4. A new SSR code of 7400 which causes the automation to respond differently, with the possible alternatives of:

    a) Changing the data block colour/brightness

    b) Inclusion of an auditory alert

    c) Offer a pop-up on the controller's display with a warning of the lost link

    d) Offer a pop-up display with more information about the contingency procedures (such as route and altitude – or other "binder" information that could be programmed in)

### 5.5.6 Explanatory Notes

The HITL would be most effective if current en route controllers could be used as subjects.

The airspace selected should be based on airspace with which participating controllers are familiar.

The options for scenario(s) 4 will depend on the capabilities and limitations of the HITL laboratory environment.

Recognising that 'learning effects' occur when testing rare events in a HITL simulation, emphasis should be placed on participant comments and subjective ratings over the objective data. The problem that occurs is that as participants run several scenarios they begin to expect the lost link situation, and watch more closely for it. The more controllers that participate, the stronger the objective data will be; however, this limitation will remain to some extent.

The experiment described above focuses on the en route environment. Similar experiments should also be conducted that focus on the terminal manoeuvring area and approach control.

Each air navigation service provider (ANSP) has a different automation system to support provision of air traffic control services. The experimental design discussed above is primarily influenced by the United States automation systems. Similar experiments that focus on the automation systems of other ANSP might be warranted.

# 6 THE SSR CODE ALLOCATION PROCESS

## 6.1 Overview

As part of a standardised contingency procedure for a UA experiencing lost link, consideration is being given to a new SSR Mode 3/A special purpose code. It is recognised that across the globe SSR codes are a scarce resource. Therefore, before identifying such a code, it is important to understand how codes are currently managed and allocated. In Europe, demand for Mode 3/A codes is very high and the complex Originating Region Code Assignment Method (ORCAM) has been developed by Eurocontrol on behalf of ICAO. Similar processes are in place in other regions, as described in Annex D. Codes are only allocated on the basis of duly justified operational requirements. If it is decided that an additional special purpose code to indicate lost link is required, this too will have to be on the basis of duly justified requirements. Therefore, even if compelling evidence can be developed that shows the benefits of a new special purpose code to indicate a UA with a lost link, then the challenges of identifying such a code for global implementation are not underestimated. If such an outcome is decided as the best way forward, then it is recommended that an implementation strategy is developed through the offices of ICAO, initially through the UASSG. This strategy should include, but is not limited to the following:

- The Impact of CNS technology changes globally, ie the Mode S/ADS-B debate[28]
- The process for global (or regional) implementation
- A timescale for implementation
- Likely amendments to ICAO SARP's and Annexes
- The implications of and for SESAR and NextGen

Before investigating the specifics of the introduction of an additional special purpose code, it is helpful to understand how SSR code allocation is currently managed. ICAO document 4444-RAC/501, Procedures for Air Navigation Services Rules of the Air and Air Traffic Services, states the principles of how SSR codes should be allocated and utilised. The assignment and management of SSR codes is an integral part of the global ATM system as, once a flight is detected by SSR, its SSR code is used to correlate the flight with a corresponding flight plan through a Flight Data Processing System (FDPS). 'Classical' Mode 3/A SSR is based on 4 octal digits, meaning that there are only 4096 codes available for use throughout the world, making them a scarce resource. In areas of high traffic density their allocation becomes a significant challenge. Unambiguous aircraft identification is a cornerstone of modern air traffic management and UA will have to meet the same conditions as their manned counterparts.

These challenges have initially been addressed by complex code assignment methods that mitigate against code conflicts by ensuring adequate geographical distribution and separation in the allocation of codes. In addition, the introduction of technology such as Mode Select (Mode S) and Automatic Dependent Surveillance-Broadcast (ADS-B), aim to address the fundamental shortage of classical Mode 3/A SSR codes.

## 6.2 Challenges in Identifying a New Special Purpose Code

SSR codes are universally acknowledged as a scarce resource in ATM and, whilst all States and Regions follow basic ICAO principles in their allocation and assignment, variations have inevitably developed over time to address particular regional issues. Furthermore, with devolved responsibility for allocation and a variety of specific needs, different solutions to the same problems, such as the allocation of conspicuity codes have emerged.

In all cases, the assignment of a new purpose to an individual code would have to be fully justified operationally.

Re-emphasising that safety is the paramount consideration in ATM, the safety benefits of the introduction of a new special purpose code to identify a UA experiencing a lost link will have to be proven. This will require a convincing, empirically-based argument to be developed that could then be taken to the code allocation decision makers in each region.

[28] Irrespective of the future CNS solution implemented, current Mode 3/A special purpose SSR codes (7700, 7600, 7500) are expected to be employed for the foreseeable future.

The challenges and difficulties in seeking a global solution should not be under-estimated, nor should the length of time needed for a robust, global implementation of a new SSR Code.

# 7 CONCLUSION

The GAIT has reviewed existing procedures for the use of special purpose SSR codes by manned aircraft and considers that these procedures do not adequately address the unique UA event termed lost link – ie loss of command and/or control links between the UA-p and the UA, so that the pilot can longer maintain operational control. The emergency special purpose SSR code, 7700, indicates an aircraft or life-threatening event and few UA lost link events are likely to immediately threaten either an aircraft or to human life. The radio communications failure SSR code, 7600, indicates the failure of a voice communication link between a pilot and ATC. If the UA-p were to lose the communication link between the GCS and ATC, it would be entirely appropriate for the UA to select code 7600. However, a lost link is “a loss of command and/or control links between the UA-p and the UA.” In a lost link event, the pilot and ATC may still be able to communicate, but the UA may not follow the same procedure as a manned aircraft experiencing a ‘standard’ radio failure procedure. Instead, the UA is likely to follow a pre-determined lost-link behaviour that may vary according to the aircraft’s stage of flight. Therefore, a SSR code selection of 7600 does not accurately indicate the intentions of the UA, could cause confusion to ATC and other airspace users, which in turn could degrade safety. These conclusions are summarised in the Table at Section 7.1.

Several studies researching the integration of UA into non-segregated airspace have commented positively on the impact that would accrue from the introduction of an additional special purpose SSR code to indicate UA lost link. However, none of these studies focussed specifically on the potential benefits, or otherwise, of the allocation of a new special purpose code. In each case, the conclusions supporting a new code were ancillary to the primary objectives of the study, did not present empirical evidence to support these conclusions, and are not considered sufficiently detailed to be decisive.

Nevertheless, having examined current procedures and triggers for SSR codes 7700 and 7600, taking into account the different behaviour of UA that experience lost link, and having reviewed the available evidence, GAIT concludes that there is a strong case to consider the introduction of a new special purpose SSR code for the lost link event. To help confirm the benefits of such a code, GAIT recommends that a detailed HITL simulation is undertaken to develop empirical data to quantify such benefits.

Recognising that SSR codes are a globally scarce resource and that any new allocation would be a significant challenge, such a study would provide the analytical support and evidence to help confirm the case for such a significant change. It is felt that such a change would enhance predictability, transparency and safety, and could assist in the seamless integration of UA into non-segregated airspace.

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# Annex A

## A.1 What is GAIT?

GAIT is an informal affiliation of individuals from organizations with extensive experience in the development and operation of UAS and in the development of UAS regulation. GAIT was established in spring 2010 and, although in its infancy, has a global footprint with membership comprising individuals from the following organizations (alphabetically): The MITRE Corporation [US], NASA [US], National Aerospace Laboratory (NLR) [NL], New Mexico State University, Physical Science Laboratory Technical Analysis and Applications Center NMSU PSL TAAC [US], QinetiQ [UK], Siluri Integration Ltd [UK] and the Welsh Assembly Government [UK].

The GAIT Mission is to facilitate the integration of UAS into non-segregated airspace to enable safe and routine operations, by providing potential solutions to stakeholders and decision-making bodies, with a focus on operational issues. The team has formed to independently assess operational airspace integration issues for the benefit for the wider UAS community. It has no specific allegiance and, initially, each participating organization has provided in-kind resources for its activities.

The Chairs for the team are Doug Davis and Paul Cremin. Their contact information is as follows:

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## Annex B

### EXTRACTS FROM EXTANT REGULATIONS ON EMERGENCY PROCEDURES

### B 1 Federal Aviation Administration Aeronautical Information Manual Official Guide to Basic Flight Information and ATC Procedures, Chapter 6 (Includes Change 1 dated August 26, 2010)

**2.** If equipped with a radar beacon transponder (civil) or IFF/SIF (military):

**(a)** Continue squawking assigned Mode A/3 discrete code/VFR code and Mode C altitude encoding when in radio contact with an air traffic facility or other agency providing air traffic services, <u>unless instructed to do otherwise</u>.

**(b)** If unable to <u>immediately</u> establish communications with an air traffic facility/agency, squawk Mode A/3, Code 7700/Emergency and Mode C.

### B 2 eAIS Package, Belgium and Grand Duchy of Luxembourg

2.2.2 Emergency procedure

a. If the pilot of an aircraft encountering a state of emergency has previously been directed by ATC to operate the transponder on a specific code, this code setting shall be maintained until otherwise advised.

b. In all other circumstances, the transponder shall be set to Mode A and C, Code 7700. Notwithstanding the "standard procedure" (see above), a pilot may select Mode A and C, Code 7700 <u>whenever the nature of the emergency is such that this appears to be the most suitable course of action.</u>

### B 3 Skybary Emergency Transponder Codes[29]

Aircraft already receiving an air traffic service, and transmitting a code, <u>should retain the code in use</u>. Aircraft in an emergency, who are not receiving an air traffic service should set the transponder to EMERGENCY (Mode 3A Code 7700) as part of their initial actions.

"A pilot may select Mode 3A Code 7700 whenever he has specific reason to believe that this would be the best course of action" [ ICAO Doc 8168 Vol 1.]

All regulation and guidance affords the pilot in command discretion to deviate from recognised procedures should the emergency situation dictate. For example[30]:

a. The pilot-in-command of an aircraft is directly responsible for and is the final authority as to the operation of that aircraft. In an emergency requiring immediate action, the <u>pilot-in-command may deviate from any rule in 14 CFR Part 91</u> …… to the extent required to meet that emergency.

### B 4 ICAO North Atlantic MNPS Manual Chapter 11: Special Procedures for In-Flight Contingencies

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[29] http://www.skybrary.aero/index.php/Emergency_Transponder_Codes

[30] Chapter 6 of the FAA Aeronautical Information Manual Official Guide to Basic Flight Information and ATC Procedures states at Paragraph 6-1-1 (Pilot Responsibility and Authority):

A specific example of guidance regarding when to make a distress call (and, possibly, to select SSR code 7700) is provided in the:

11.1.1 The following procedures are intended for guidance only. Although all possible contingencies cannot be covered, they provide for such cases as:

- inability to maintain assigned level due to weather (for example severe turbulence);
- aircraft performance problems; or
- pressurisation failure.

11.1.2 They are applicable primarily when rapid descent, turn-back, or diversion to an alternate aerodrome is required. The pilot's judgement will determine the specific sequence of actions taken, having regard to the prevailing circumstances.

11.2.1 If an aircraft is unable to continue its flight in accordance with its ATC clearance, a revised clearance should be obtained whenever possible, prior to initiating any action, using the radio telephony distress (MAYDAY) signal or urgency (PAN PAN) signal as appropriate

## Annex C

## ICAO SSR CODE MANAGEMENT PRINCIPLES AND SSR CODE MANAGEMENT IN SELECTED STATES

### C 1 ICAO SSR CODE MANAGEMENT PRINCIPLES

ICAO states that SSR Codes should be allocated and assigned in accordance with the following principles[31]:

- Codes should be allocated to States or areas in accordance with regional air navigation agreements, taking into account overlapping radar coverage over adjacent airspaces.
- The appropriate ATS authority shall establish a plan and procedures for the allocation of codes to ATS units.
- The plan and procedures should be compatible with those practised in adjacent States.
- The allocation of a code should preclude the use of this code for any other function within the area of coverage of the same SSR for a prescribed time period.
- To reduce pilot and controller workload and the need for controller/pilot communications, the number of code changes required of the pilot should be kept to the minimum.
- Codes shall be assigned to aircraft in accordance with the plan and procedures laid down by the appropriate ATS authority.
- Where there is a need for individual aircraft identification, each aircraft shall be assigned a discrete code which should, whenever possible, be retained throughout the flight.
- SSR Codes shall be reserved, as necessary, for exclusive use by medical aircraft operating in areas of international armed conflict.
- SSR Codes shall be allocated by ICAO through its Regional Offices in co-ordination with States concerned, and should be assigned to aircraft for use within the area of conflict.
- Codes 7700, 7600 and 7500 shall be reserved internationally for use by pilots encountering a state of emergency, radio communication failure or unlawful interference respectively.

All States allocate SSR Codes in accordance with these ICAO principles, together with international agreements and instructions contained within local ATM manuals. The main difference between States is how codes are allocated locally, which could be an issue if trying to allocate a new universal code. In addition to the three international special purpose codes of 7700, 7600 and 7500, States also employ a range of general ‘Conspicuity’ codes to indicate that an aircraft is undertaking a particular activity, but may not be in receipt of an ATS.

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[31] ICAO 4444

## C 2 Europe

In Europe, the agreed allocation of SSR codes to States and ATC units, as well as the principles and associated procedures, are detailed in the EUR Regional Air Navigation Plan – Facilities and Services Implementation Document (FASID), Part IV Communications, Navigation and Surveillance (CNS) – Supplement SSR Code Allocation List for the EUR Region[32]. The allocation process is particularly complex. At the request of the ICAO European Air Navigation Planning Group (EANPG), the SSR Code Management Plan (CMP) for the ICAO European (EUR) Region has been developed by the EUROCONTROL Originating Region Code Assignment Method (ORCAM) SSR Code Steering Group (SCSG), who work in close co-ordination with ICAO. Codes in Europe are allocated to ATS units on the basis of duly justified operational requirements.

## C 3 USA

In the USA, the National Beacon Code Allocation Plan (NBCAP) US Department of Transportation FAA Air Traffic Organization Policy Order JO 7110.66D[33] describes the procedures and responsibilities for the use of Mode 3/A SSR Codes and assigns codes to minimize the possibility of an aircraft having to change codes in flight. Beacon codes are assigned to proposed flight plans at specific parameter time prior to the proposed departure time. Each Air Route Traffic Control Center (ARTCC) is free to adapt the proposal parameter to any value between 5 and 60 minutes. Most facilities adapt this parameter to 30 minutes. For active flights, the beacon code is assigned when the flight plan is initially processed by the host.

Each facility has primary, secondary and tertiary code blocks in two categories:

- **Internal Codes** – the flight plan originates in this facility's airspace and will never exit this facility's airspace.

- **External Codes** – the flight plan will exit this facility's airspace.

For example, each aircraft is given a unique discrete code which is not duplicated and the intent would allow all aircraft to proceed from departure to destination using the same discrete code wherever possible. Like Europe, SSR codes in the USA are a scarce resource and their allocation remains a consistent challenge [3].

## C 4 Canada

In Canada, the Director, Air Traffic Services, Transport Canada, is responsible for the implementation of the SSR Code Employment Plan and the Superintendent, Rules and Procedures, is responsible for the allocation of codes and development of procedures for their use. In turn, the manager, ATC Operational Requirements, is responsible for the allocation of codes with an FIR.

The Canadian Authorities would ideally like each transponder-equipped aircraft should be assigned a discrete code that would identify it for the duration of its flight, anywhere within Canada and the USA. This could be accomplished by providing each centre with a unique set of codes for assignment to flights that either originate in that FIR, or first enter radar coverage there. Thus, each aircrafts code would be unique and could be retained for the

[32] Available at: http://www.paris.icao.int/documents_open/show_file.php?id=111
[33] Available at: http://www.faa.gov/regulations_policies/orders_notices/index.cfm/go/document.information/documentID/99913

duration of its flight. As elsewhere, this ideal cannot currently be met because there are not enough discrete Mode 3/A codes to provide each Canadian and US centre with a unique set of codes adequate for its traffic volume and the use of discrete codes by units equipped with analogue display systems is restricted by the limited decoding capability of these systems.

### C 5 India

All aircraft carrying a serviceable transponder shall operate the transponder at all times during flight within Chennai, Delhi, Guwahati, Kolkata, and Mumbai FIRs regardless of whether the aircraft is within or outside airspace where SSR is used for ATS. Operating procedures: Aircraft departing from an aerodrome located in Chennai, Delhi, Guwahati, Kolkata, and Mumbai FIR shall be assigned an appropriate SSR code on departure, which will continue until instructed otherwise. Aircraft engaged in international flight, entering Chennai, Delhi, Guwahati, Kolkata, and Mumbai FIR shall continue to maintain the SSR code allocated in the adjacent FIR. This SSR Code shall be included in the first position report entering the FIR.

### C 6 New Zealand

SSR codes are allocated by radar equipped ATS facilities to controlled flights operating within their area of responsibility, and to controlled flights entering the New Zealand FIR from the Auckland Oceanic FIR. Like all other States and regions, in New Zealand, a range of individual codes are used to indicate that an aircraft is conducting a particular activity under Visual Flight Rules (VFR), but may not be in receipt of an ATS, for example, SSR code 0111 is allocated for Fire suppression and reconnaissance, SSR code 1300 for gliders and balloons and 6000 for defence aircraft operating VFR.