DEFINING RPAS EMERGENCY PROCEDURES FOR CONTROLLERS, REMOTE PILOTS AND AUTOMATIC ON-BOARD SYSTEMS

Dipl.-Ing. M. Finke,
Institute of Flight Guidance, German Aerospace Center (DLR),
Lilienthalplatz 7, 38108 Braunschweig, Germany

Abstract

Emergency handling procedures used in aviation involve well-considered countermeasures applied by the pilot while prepared checklists provide a step-by-step assistance. Most of these procedures also require a direct interaction with air traffic control (ATC); for example the controller needs to be informed about the nature and the level of urgency of the emergency situation, the kind of required assistance and intended manoeuvers. In return, the controller provides essential information, separates the aircraft from other traffic, allocates airspace (e.g. in case of fuel dumping) or directly assists otherwise. As a summary, emergency situations require efficient and coordinated teamwork as well as a clear communication between controller and pilot and – as far as possible – simple and standardized handling procedures for both.
Switching to unmanned aviation, safely integrating remotely piloted aircraft systems (RPAS) in non-segregated airspace will require corresponding standards and procedures, at least for the ‘certified’ UAS category defined by EASA, because it can be expected that the number of incidents in regard to the total number of flights will be in the same range compared to manned aviation. One of the main challenges will be the introduction of a third party to take part in the above mentioned relationship: automatic on-board routines of the unmanned aircraft, executed independently without external triggers. And moreover, the communication between these three ‘team players’ may be restricted, as the failure of air-ground data link is a very prominent issue for RPAS.
Following this holistic approach on the relationship between the remotely piloted aircraft, the remote pilot and ATC, this paper describes a bandwidth of common or RPAS specific emergency situations and derives corresponding contingency measures wherever feasible. The usability of existing procedures and standards of manned aviation is discussed (e.g. lost communication procedures, hydraulic failure, engine failure etc.); they are extended to unmanned aviation (e.g. electrical failure, navigational failure) or RPAS specific procedures are pointed out (e.g. loss of sense and avoid capability, loss of automatic / autonomous capabilities). Finally an outlook on next steps for research and implementation is given.

1. INTRODUCTION

Presently, the demand to use unmanned aircraft for several purposes is continuously increasing. According to the strategy of the European Commission, the civil use of unmanned aerial systems in the frame of exploration, inspection and cargo transport shall be possible until the end of 2019 by following certain research and development activities regarding airspace access, airport operations and contingency procedures for flights of Remotely Piloted Aircraft Systems (RPAS) under Visual Flight Rules (VFR) and Instrument Flight Rules (IFR) [1]. Up to now, only IFR flights with unmanned military aircraft or unmanned experimental aircraft have been realized and are still subject to effortful approvals by the responsible national aviation authority; often involving the establishment of restricted airspaces for the departure and approach phase [2] [3]. Usually, special contingency procedures for these extraordinary flights are developed in advance, which are very specific to the individual RPAS type and focus on the loss of radio communications, the loss of the control link, emergency landing and flight termination procedures [4]. These procedures introduce purpose-built aspects to be considered for the remote pilot and air traffic control (ATC) in contrast to common contingency procedures applicable for manned aviation. Additionally, as it can be expected that the number of different RPAS / Unmanned Aircraft Systems (UAS) types will also continuously increase, the application of type specific contingency procedures may become more challenging and more complex for all involved persons.

This paper contributes to a first guideline for the development of contingency procedures for RPAS flights under IFR and VFR. It describes an approach to standardize and harmonize these procedures to allow a broad application to different RPAS types and to enable air traffic control to handle those emergency situations without the need of extensive training and comprehensive special knowledge.

The paper starts with background information to the research activities behind the described work and summarizes today’s standards in handling emergency procedures for manned aviation. Further on a methodology guideline for developing RPAS emergency procedures is described including relevant constraints and specific conditions. Generic emergency procedures are then derived and described.

2. BACKGROUND

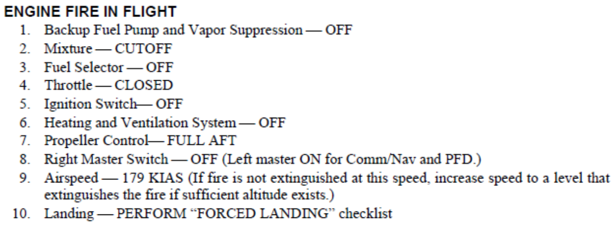
2.1. Project Overview / Research Activities

The results presented in this paper are an outcome of the internal project Unmanned Freight Operations (UFO) of the German Aerospace Center (DLR) [5]. Within this project, an interdisciplinary concept of operations (ConOps) [6] for the integration of freight RPAS into the existing aviation systems was developed. This ConOps has a wide scope, covers regular and abnormal RPAS operations under IFR and VFR and contains corresponding handling procedures for involved stakeholders.

2.2. Emergency Procedures in Manned Aviation

According to the International Civil Aviation Organization (ICAO), an emergency situation can be a distress or an urgency condition. Distress is defined as a condition of being threatened by serious and/or imminent danger and requiring immediate assistance. Urgency is defined as a condition of being concerned about safety and requiring timely but not immediate assistance [7]. Generally speaking, emergency situations are induced by a certain event (a failure, the encounter of dangerous situations, unlawful interference etc.) and involve a reduction of flight safety, which may cause a physical damage to or a complete loss of the aircraft or ground installations as well as injuries and casualties of humans on board or on ground.

Due to the technical complexity of aircraft, the complexity of air traffic management (ATM) and local circumstances (airspace structure, sector capacity, usability of aerodromes, firefighting capacity of the fire brigade etc.), aircraft emergency situations can be very multifaceted. Hence the definition of detailed contingency procedures is not possible. Existing procedures are to be understood as a standardized guideline for the considered stakeholder; nevertheless it is always required that best judgement and common sense is used to solve the situation [8]. Additionally, emergency checklists are used to give concerned pilots a step-by-step assistance and to mitigate the risk of human errors in handling the aircraft under stress [9], see Figure 1 for an example.



ENGINE FIRE IN FLIGHT

1. Backup Fuel Pump and Vapor Suppression — OFF
2. Mixture — CUTOFF
3. Fuel Selector — OFF
4. Throttle — CLOSED
5. Ignition Switch— OFF
6. Heating and Ventilation System — OFF
7. Propeller Control— FULL AFT
8. Right Master Switch — OFF (Left master ON for Comm/Nav and PFD.)
9. Airspeed — 179 KIAS (If fire is not extinguished at this speed, increase speed to a level that extinguishes the fire if sufficient altitude exists.)
10. Landing — PERFORM “FORCED LANDING” checklist

Figure 1. Sample emergency checklist [10]

The large number of possible failures, events and circumstances makes it necessary that emergency situations and countermeasures are an essential part of ATC and flight training. Especially for ATC, regular refresher trainings are part of the continuing professional development [11]. The purpose is to enable controllers and pilots to immediately react according to the situation as time can be a critical factor. The continuous training makes pilots and controllers familiar with the basic aspects of emergency situations and helps to avoid shock effects. It also enables them to improvise if necessary.

An emergency situation usually starts with a distress call or any other distress signal of the pilot, such as:

- The word MAYDAY, preferably spoken three times,
- A datalink message containing a distress message,
- Transponder setting 7700,
- A Morse code containing the SOS group (…---…), given with any method,
- Red flares, fired within short time intervals,
- A parachute flare showing a red light.

Instead of using the mentioned distress signals, a pilot can also verbally declare an emergency situation via radio communication. Corresponding procedures can also be triggered by ATC without any distress signal if it is obvious that a situation exists where the safety of the considered aircraft is in doubt [8].

After the distress call to ATC, the pilots will [9]:

- (if time permits) assess the situation carefully according to their training,
- Initiate countermeasures according to their training, according to the flight preparation and (if time permits) according to the procedures developed and published by the aircraft manufacturer as operating manual / checklist (see [10] for an example),
- Communicate important information and intentions to ATC as soon as the situation permits; maintaining control of the airplane always has priority.

After receiving the distress call, ATC will [8]:

- Handle the considered aircraft with absolute priority,
- Collect information about the nature of the emergency and the intentions of the pilot,
- Inform responsible firefighting and rescue services,
- Inform all ATC units concerned,
- Separate other aircraft from the distress traffic,
- Support the pilot by all available means,
- Execute steps specific to the situation and according to the requests of the pilot,
- Inform the responsible watch supervisor, authorities etc.
- Track the flight path of the aircraft in case of a forthcoming forced landing.

EUROCONTROL provided a general guideline document for controller training in the handling of emergency situations, containing the ASSIST principle [12] (see also Figure 2) and additional procedures for special situations such as bird strike, hydraulic problems, engine failure, fuel problems, electrical failure, oxygen problems etc.

Further steps or details can be contained in local emergency procedures such as the aerodrome emergency plan [13].

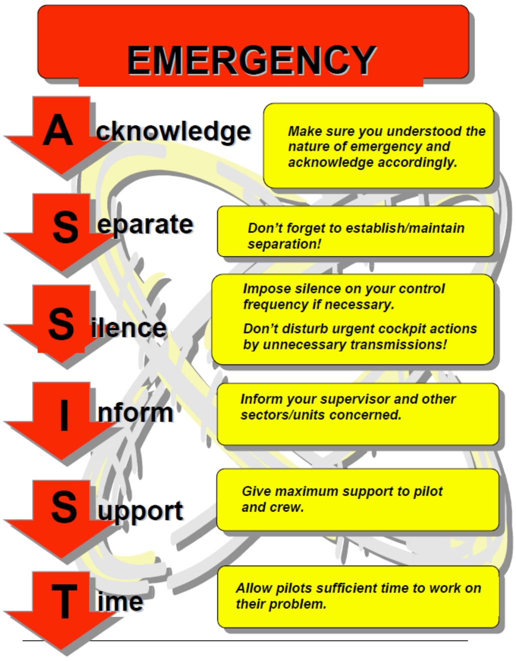


Figure 2. ASSIST principle [12]

In manned aviation, emergency situations can lead to:

- A precautionary landing: a premeditated landing on or off an airport, when further flight is possible but inadvisable [9].
- A forced landing: an immediate landing, on or off an airport, necessitated by the inability to continue further flight [9].
- An uncontrolled crash of the aircraft.

An emergency situation ends as soon as it is ensured that no further safety risk exists, e.g.

- The airplane landed safely on an aerodrome,
- The airplane landed (or crashed) outside of an airport and all persons in the vicinity of the landing / crash site are rescued; no risk of further damage to ground installations or further injuries / casualties exists.

As a conclusion, the treatment of emergency situations is a collaboration of a considerable number of persons, while the pilot and the air traffic controller, who directly handle the incident, play the most important roles. The communication between these two participants needs to be effective and unambiguous; the actions that are taken by both parties need to be harmonized, coordinated and understandable. The air traffic controller also needs to use sensitiveness in his communication as the pilot may be directly threatened by the safety hazard and may be under immense psychological stress.

2.3. Applicability on Unmanned Aviation

2.3.1. Frame Conditions

Compared to manned aviation, the introduction of UAS / RPAS constitutes a change of several frame conditions, such as:

- It is likely that, due to the use of modern technology, the unmanned aircraft systems are even more complex; the variety of different situations that could arise is expected to increase,
- Unmanned aircraft systems might use a high level of automation for the flight itself; it can be expected that also for abnormal situations a high level of automation will be used on board of the aircraft,
- The remote pilot may not be able to influence the behavior of the aircraft during the situation,
- The remote pilot may not be able to fully assess the situation as this depends on a reliable connection between the remotely piloted aircraft (RPA) and the remote pilot station (RPS),
- The ability of the remote pilot to use best judgement and to improvise may be restricted therefore,
- Due to his remote location, the remote pilot is able to directly coordinate with other stakeholders (e.g. via phone coordination),
- The pilot himself is not directly affected by the safety hazard,
- The primary focus is on the reduction of injuries / casualties of persons on ground and on the safety of other air traffic,
- The secondary focus is on the reduction of physical damage to ground installations and finally to the aircraft itself,
- The involved RPA may have very different performance parameters, may be a very small system and may not be liable to the use of an aerodrome,
- Depending on the RPAS equipment, the RPA flight manoeuvers may not depend on certain weather conditions (e.g. visual meteorological conditions)
- The priority status of an RPA subject to an emergency situation is not yet regulated.

2.3.2. Conclusions and Resulting Constraints

The following conclusions can be drawn already as a basis for the development of RPAS emergency procedures:

- Due to the higher complexity and the expected number of different types of systems in the future, it is even more important to develop procedures which still can be handled by air traffic controllers or other emergency responders (e.g. firefighting, ground handling) without overwhelming them,
- A priority regulation needs to be in place. [14] suggests that the present priority regulation (see [8]) for manned aircraft is maintained while a manned aircraft shall on principle have priority over the unmanned aircraft of the same priority ranking,
- Automatic routines on board of the RPA must be considered as a ‘third main player’ beside the remote pilot and the air traffic controller,
- The responsibility to initiate countermeasures that are directly related to the aircraft is therefore shared between the remote pilot and the mentioned automatic on-board routines,
- The distinction between both areas of responsibility cannot be fully predicted or even pre-defined and can be variable during the emergency situation,
- The same applies for the situational awareness of the remote pilot and his possibilities to take influence on the aircraft,

- Response actions of all ‘three main players’ (including automatic on-board routines) must nevertheless be harmonized and coordinated,
- In case that the remote pilot experiences a lack of information or restricted / no possibilities to influence the RPA, ATC would suffer from these constraints in the same way; the only option to react would be to apply significantly increased separation to other traffic and to give the RPA the absolute priority, which would be neither proportionately nor according to the proposed priority regulation (see above); a possible simultaneous emergency of a manned aircraft would be endangered unnecessarily,
- The emergency situation itself can be caused by a (full or partial) failure on board of the RPA (while the RPS and the link are fully functional); by a (full or partial) failure at the RPS (while the RPA and the link are fully functional); by a (full or partial) failure of the link (while the RPS and the RPA are fully functional),
- In case the flight is continued automatically / autonomously, any means to take at least a very basic direct influence on the RPA and to upload important flight information (such as the runway in use, QNH, other weather information, holding instructions, airspace allocation for the purpose of fuel dumping) would therefore be very advantageous for ATC,
- As the focus is more on minimizing the risk for persons and installations on ground and other air traffic as well as minimizing the risk of further damages to or a loss of the RPA, a new risk assessment must stand behind RPAS emergency procedures,
- RPAS emergency procedures may also be specific to the size and weight of the aircraft.

3. METHODS OF APPROACH

As a general imperative, the above listed constraints are to be considered when developing emergency procedures for RPAS. Additionally, it has to be considered that RPAS system requirements may result from these procedures.

Within the UFO Project, the following three approaches to define RPAS emergency procedures were applied [6] [15].

3.1. Approach based on operational needs for regular RPAS operations

The operational needs for regular RPAS operations (no contingency) including those which are directly related to the controllability, communication and the information exchange between ATC, the remote pilot and the RPA, were identified and listed in [6]. Additionally, work around procedures were defined in case of operational needs are not given whenever realistic. Depending on the final way of integrating RPAS into air traffic, these workaround procedures can already be understood as contingency procedures, because emergency situations for RPAS always involve a loss of several technical capabilities, which means that operational needs for a safe integration into air traffic are no longer (fully) given.

3.2. Approach based on existing procedures for manned aviation

Additionally, existing emergency procedures are also analyzed and modified in [6] to be also applicable to RPAS; resulting operational needs are identified. These procedures are further supplemented by additional RPAS specific steps.

3.3. Approach based on failure / malfunction analysis

Alternately also the following approach can be applied to identify relevant conditions and to define corresponding RPAS specific emergency procedures:

1) Identify any hardware component, software component or connection component which can be subject to a failure or a malfunction,
2) Identify the effects on controllability, communication, airworthiness and integration into air traffic (including manageability by ATC),
3) Identify possible measures individually for all actors (remote pilot, ATC, automatic on-board routines) to either mitigate or compensate the effects while considering the above mentioned frame conditions,
4) Filter and harmonize these measures,
5) Define a standardized contingency procedure which involves the measures that are most acceptable and reasonable for all actors (remote pilot, ATC, automatic on-board routines); if possible combine with already existing procedures; measures to recover the usability of (aerodrome) infrastructure shall be included,
6) Define system requirements for the RPAS (RPA, RPS, Link) and ATC equipment,
7) Define airspace and ground infrastructure requirements,
8) Define training requirements for air traffic controllers and remote pilots.

If applied, this approach must be repeated for all hardware and software components and corresponding sub-systems / sub-routines of the RPAS which may be subject to failures or malfunctions.

4. GENERIC PROCEDURES FOR UNMANNED FLIGHTS

Within the UFO project, a set of generic RPAS emergency procedures were derived using the above mentioned methods of approach. These procedures are described in [6] and are based as much as possible on existing procedures for manned aviation. One complete procedure consists of the distress call (chapter 4.1), one or more recovery procedures (chapter 4.2) and additional aspects, depending on the situation (chapter 4.3 and 4.4).

Whenever appropriate, the conditions and actions for the remote pilot, for ATC and for automatic on-board routines will be stated; depending on if the procedure is executed manually, automatically or autonomously.

Within the UFO project, the term ‘manual flight control’ is used as synonymously to ‘direct control’ defined by ICAO [16]; ‘automatic flight control’ involves a planned on-board trajectory which can only be influenced by the remote pilot (equally to ‘autopilot control’ / ‘waypoint control’ defined by ICAO); ‘autonomous flight control’ involves a planned on-board trajectory which is changed by the aircraft itself.

The procedures listed below are based on the assumption that any communication channel between the three active instances – remote pilot, RPA, ATC – is in place without examining the distinct technical implementation (see Figure 3).

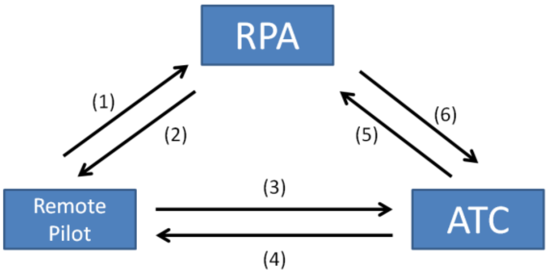


Figure 3. Communication channels between Remote pilot, RPA, ATC

Channel (1) and (2) form the Command and Control (C2)-Uplink / Downlink or parts thereof. Channel (3) and (4) can be established via landline phone coordination, datalink, AFTN, etc. Channel (5) and (6) can for example be based on existing transponder / broadcasting technology such as ATIS (5) or Mode S / ADS-B / ADS-C (6).

4.1. Distress Call to ATC

As the responsibility to assess the situation and to initiate countermeasures cannot be clearly allocated to either the remote pilot or automatic routines of the RPA, there should be means in place allowing both instances to report the distress situation direct to ATC.

4.1.1. Remote Pilot Induced Distress Call

On principle, this distress report can be done by using the following means based on [8], communicated via channel (3) or (1) + (6):

- A vocal message containing a distress report,
- A datalink message containing a distress report,
- A command to set transponder code 7700.

The following measures should additionally be taken by the **remote pilot**:

- Send information of the distress call to the RPA to avoid further RPA induced distress calls in parallel.

The following measures should be taken by the **RPA**:

- Suspend all distress calls as long as the C2-link is fully functional.

The following measures should be taken by **ATC**:

- Acknowledge the receipt of the call either by voice or by datalink message (channel (4) or channel (5) + (2)).

4.1.2. RPA Induced Distress Call

On principle, this distress report can be done by using the following means, based on [8], and communicated via channel (6):

- Automatic datalink message containing a distress report,
- Automatic transponder setting to code 7700.

The following measures should be taken by the **remote pilot**:

- Assess the situation by all available means,
- Provide ATC with further details,
- Provide ATC with information about the further intention / the further RPA behavior.

The following measures should be taken by the **RPA**:

- In case the C2-link is fully functional: execute only these countermeasures which are absolutely necessary to avoid a further deterioration; send any useful information about the reason for the distress call to RPS, no execution of a recovery procedure,
- In case the C2-link is lost: execute all countermeasures including recovery procedure, try to regain the C2-link
- In case the C2-link is partially lost: currently under investigation [15].

The following measures should be taken by **ATC**:

- Contact remote pilot either by voice or by datalink message to obtain further details (channel (4) or channel (5) + (2)).

4.2. General Recovery Procedures

Recovery as it is used in this chapter means to reach and maintain a situation where the safety of persons and property as well as other air traffic is no more directly endangered by the presence of the considered RPAS subject to an abnormal situation. The general procedures in the following sections, which are based on the ones listed for manned aviation, are also likely to resolve a contingency situation of an RPAS.

As a general requirement, ATC needs to know which of these manoeuvers is executed when, where, how and under which mode of flight control. As it cannot be predefined, which instance (remote pilot or automatic routines on board of the RPA) initiates these procedures, both shall be able to communicate this information directly to ATC (see Figure 3). Either the remote pilot or automatic routines on board of the RPA should be the instance of control while the other instance provides all relevant information that is needed and available.

Alternately, these recovery procedures can be predefined / negotiated and programmed prior to the flight as part of the flight preparation which constitutes a large effort in terms of coordination, airspace management and the definition of fixed flight routes and reduces flexibility in the handling of the situation. Additionally this would mean that these procedures should be – if possible – not executed immediately but after certain time delay to enable ATC to prepare this maneuver.

4.2.1. Manual, Automatic or Autonomous Precautionary Landing

Like for manned aviation, a precautionary landing is done when the flight safety is (at the moment) guaranteed; further flight is possible but inadvisable. The safety risk for the RPA itself, other traffic and persons and installations on ground is at a minimum. A precautionary landing with an RPA can be done on any suitable aerodrome and, depending on the weight of the aircraft as well as legal issues, at any place that facilitates a take-off after the problems have been solved again.

The following measures should be taken by the **remote pilot** and/or the **RPA**, depending on the mode of control:

- Choose a suitable aerodrome / landing site to land (if an off-field landing is intended, the instance of control (remote pilot or RPA) must be able to scan the terrain below for such a place),
- Consider latest weather / aerodrome information,
- Choose a suitable approach procedure,
- Communicate this intention to ATC,
- Communicate the position and this intention with the Rescue Coordination Center (RCC) (if an off-field landing is intended),
- Expect to fly one or several holdings prior to land in case of manned priority traffic.

The following measures should be taken by **ATC**:

- Provide latest weather / aerodrome information,
- Separate other traffic with no priority,
- Segregate the RPA in case of automatic flight as far as possible (allocate segregated airspace, broadcast the establishment of such an airspace)
- Inform the landing aerodrome and other concerned Air Traffic Services (ATS) units,
- Use holding procedures in case of manned priority traffic.

4.2.2. Manual, Automatic or Autonomous Forced Landing

Like for manned aviation, a forced landing is done when the flight safety is not guaranteed; further flight is not possible. The safety risk for the RPA itself, other traffic and persons and installations on ground is considerable. A forced landing with an RPA can be done on any suitable aerodrome and at any place which facilitates a (relatively) safe landing. To avoid unnecessary damage to the environment, this landing site should easily be reachable by rescue and firefighting units.

A landing on a busy aerodrome may not be advisable; in order to reduce the risk, a landing on a low frequented airport or an emergency landing field should be preferred, even if this may require additional distance to fly. Especially for light aircraft, an off-field landing (probably by using a parachute or other equipment, see [16]) can also be considered.

The following measures should be taken by the **remote pilot** and/or the **RPA**, depending on the mode of control:

- Choose a suitable aerodrome / landing site to land (if an off-field landing is intended, the instance of control (remote pilot or RPA) must be able to scan the terrain below for such a place),
- Consider latest weather / aerodrome information,
- Choose a suitable approach procedure,
- Communicate this intention to ATC,
- Communicate the position and this intention with RCC (if an off-field landing is intended),
- Expect to fly one or several holdings prior to land in case of manned priority traffic,
- (Prepare an off-field forced landing at any time in case of a landing on an aerodrome is not possible anymore).

The following measures should be taken by **ATC**:

- Provide latest weather / aerodrome information,
- Separate other traffic with no priority,
- Segregate the RPA in case of automatic flight as far as possible (allocate segregated airspace, broadcast the establishment of such an airspace)
- Inform the landing aerodrome and other concerned ATS units,
- Use holding procedures in case of manned priority traffic,
- Ensure a landing as soon as the approach procedure is commenced.

4.2.3. Manual, Automatic or Autonomous Flight Termination

An RPAS flight termination as it is also announced by [16] is an option specific to unmanned aviation in case of flight safety is not guaranteed; further flight is not possible (due to the malfunction or due to the unavailability of a suitable landing site). The safety risk for the RPA itself, other traffic and persons and installations on ground is considerable. As already practiced [4], this manoeuver should be done either on designated flight termination areas or at any suitable off-field site, which should easily be reachable by rescue and fire fighting units to avoid unnecessary damage to the environment.

The following measures should be taken by the **remote pilot** and/or the **RPA**, depending on the mode of control:

- Choose a suitable flight termination area / off-field site (if an off-field site is chosen, the instance of control (remote pilot or RPA) must be able to scan the terrain below for such a place),
- Consider latest weather information,
- Choose a suitable approach procedure,
- Communicate this intention to ATC,
- Communicate the position and this intention with RCC (if an off-field landing is intended).

The following measures should be taken by **ATC**:

- Provide latest weather information,
- Separate other traffic with no priority,
- Segregate the RPA in case of automatic flight as far as possible (allocate segregated airspace, broadcast the establishment of such an airspace)
- Confirm the flight termination to RCC including a position update.

4.2.4. Manual, Automatic or Autonomous Fuel Dumping

Depending on the propulsion of the RPA, fuel dumping may also be necessary prior landing (to reduce weight) or prior flight termination (reduce the damage / the needed firefighting capacity afterwards). Fuel dumping can only be done in accordance with regulations in the airspace that is allocated by ATC [8].

The following measures should be taken by the **remote pilot** and/or the **RPA**, depending on the mode of control:

- Communicate fuel dumping intention to ATC,
- Perform fuel dumping only within the airspace allocated by ATC,
- Maintain the prescribed safety distance to the dumped fuel,
- Communicate further intentions after fuel dumping to ATC as soon as possible.

The following measures should be taken by **ATC**:

- Allocate an airspace for fuel dumping,
- Separate other traffic,
- Prepare next maneuver after the fuel dumping.

4.2.5. Manual, Automatic or Autonomous Take-off Abort

Like for manned aviation, a take-off may be rejected if malfunctions are detected during the departure. As this is a very time-critical process, it is likely that this maneuver is executed autonomously.

The following measures should be taken by the **remote pilot** and/or the **RPA**, depending on the mode of control:

- Communicate the take-off abort immediately to ATC,
- Communicate the intention to ATC,
- Stop on the runway unless cleared otherwise,
- Wait for further clearance (remote pilot only).

The following measures should be taken by **ATC**:

- Consider the take-off abort,
- Issue taxi clearance to the remote pilot,
- Perform a runway check if deemed necessary.

4.3. Conventional Emergencies

In the sense of this paper, the term ‘conventional emergencies’ refers to emergency situations which are on principle already known from manned aviation (see [12]), but which nevertheless may need to be supplemented or redefined for RPAS.

The next sections are to be understood as a list of aspects that have to be considered in addition to the steps directly related to the recovery procedures listed above.

4.3.1. Partial / Complete Engine Failure

Similar to a partial engine failure in manned aviation, the following situation can be expected:

- Reduced aircraft performance and maneuverability,
- Inability to maintain the current level or to continue the climb.

The following RPA behavior can result:

- Deviation from the planned / cleared route of flight (especially when turns are necessary),
- Deviation from the planned / cleared altitude profile
- Failure of automatic / autonomous flight control,
- Turn / Vertical Movement restrictions / constraints,
- Go-around is not possible,
- Electrical or Hydraulic Failure as secondary failures.

The following measures should additionally be taken by the **remote pilot** and/or the **RPA**, depending on the mode of control:

- Try to regain full engine power,
- Prepare to switch to manual flight control as soon as it becomes necessary,
- Consider turn / vertical movement restrictions during the planning of the respective recovery procedure (e.g. choose an appropriate approach procedure if done automatically / autonomously).

The following measures should be taken by **ATC**:

- Consider turn / vertical movement restrictions.

4.3.2. Electrical Failure

Electrical failure usually means a loss of power supply; just the battery power supply is still available. Similar to an electrical failure in manned aviation, the following situation can be expected:

- Deactivation of all electrical systems which are not necessary to maintain a basic flight control (including flight management systems, C2-link, transponder, detect and avoid etc.),
- RPA is only able to fly until the battery power is consumed.

The following RPA behavior can result:

- Height loss,
- No further information of any kind is transmitted after the distress call,
- Automatic forced landing (off-field landing is likely).

The following measures should additionally be taken by the **RPA**:

- Communicate the failure directly to ATC,
- Reduce the power consumption so that a controlled landing can be performed,
- Initiate an automatic forced landing.

The following measures should be taken by **ATC**:

- Increase separation (especially below the RPA),
- Expect the flight to be continued automatically,
- Segregate the RPA as far as possible (allocate segregated airspace; broadcast the establishment of such airspace).

4.3.3. Loss of Navigation

This emergency situation can be caused by hardware or software errors / failures on board of the RPA or due to a general non-availability of a distinct air navigation method, which would affect also all other aircraft using this method, e.g. due to a Global Positioning System (GPS) failure.

Similar to a navigation failure in manned aviation, the following situation can be expected:

- Unavailability to proceed along a cleared route or along a planned trajectory,
- Unavailability to proceed to a certain position, e.g. to an aerodrome,
- Especially for RPA also a safe landing or taxi operations may be impossible.

The following RPA behavior can result:

- Uncontrolled deviation from the cleared or intended route,
- Uncontrolled deviation from the cleared or intended level,
- Failure of automatic / autonomous flight control.

The following measures should additionally be taken by the **remote pilot**:

- Switch to manual flight control,
- Communicate the situation to ATC and ask for navigational assistance,
- Use all remaining means to navigate (e.g. visual sensors to locate landmarks),
- Perform a manual landing.

The following measures should be taken by **ATC**:

- Increase separation,
- Provide navigational assistance,
- Expect a high workload of the remote pilot.

4.3.4. Loss of Communication

In case of an RPAS this emergency situation means a loss of communication between the remote pilot and ATC by using the RPA as a relay. It can be caused by hardware or software errors / failures on board of the RPA, at the RPS or due to link problems.

In case of a communication failure, the following situation can be expected:

- Unavailability to immediately report status information or communicate requests,
- If caused by link problems, other link-dependent functionalities may be affected,
- Light signals as used for manned aircraft in lost communication situations may be not useable for RPAS,
- RPAS suffering a loss of communication under VFR may not be visually recognized by Tower controllers when approaching in bad visibility conditions.

As one of the basic assumptions of this paper is the availability of direct communication channels between all three instances (RPA, remote pilot, ATC), a communication failure as described above can easily be compensated (by using channel (3) + (4)). This solution is identical to the procedure already published and practiced in several cases (e.g. [4]).

4.3.5. Unlawful interference

This emergency situation can involve bomb threats (if the RPAS is used as a cargo airplane), scenarios related to cybersecurity (e.g. hacking the RPA or the C2-link) or unlawful acts at or against the remote pilot / the RPS. A more detailed analysis of such threat scenarios has already been done in [17].

4.3.6. Other situations with identical handling compared to manned aviation

Some of the typical procedures applicable to manned aviation can be applied also to unmanned aviation with no or only minor modifications, especially:

- Bird strike and icing: may cause a physical impairment to the aircraft structure (suitable sensors are needed to be able to assess this impairment) and may result in secondary emergency situations,
- Hydraulic failure: reduced maneuverability,
- Brake problems: a runway excursion is likely,
- Fuel problems: an off-field landing is more likely for RPAS and should be considered as an option at an earlier stage compared to manned aviation,
- Gear problems: require an intense interaction with ATC and / or other aircraft and cannot be solved under automatic / autonomous flight control.

4.4. Specific Emergencies

In the sense of this paper, the term ‘specific emergencies’ refers to emergency situations which are not typical for manned aviation (see [12]) and which result from RPAS specific aspects.

4.4.1. Partial / Complete Loss of C2-Link

A complete loss of the C2-link is the most prominent RPAS specific emergency situation; first regulations are already laid down in [16]. As the functionality and the performance of the C2-Link contains plenty of information flows and depends on many factors, a partial loss of the link is also likely, which is currently subject to research in the frame of the UFO project [15].

This emergency situation can be caused by hardware or software errors / failures in the RPS as well as on board of the RPA, in relay stations, due to the physics of wave propagation or due to interference [16].

One or more of the following conditions can be expected:

- Delayed transmission of information or commands between RPS and RPA,
- (partial) Loss of telemetry data at the RPS,
- (partial) Loss of manual control,
- (partial) Loss of communication between remote pilot and ATC if relayed via the RPA.

The following RPA behavior can result:

- Switching to automatic / autonomous flight control,
- Turn around / Climb to regain the C2-link [16].

The following measures should additionally be taken by the **remote pilot** and/or the **RPA**, depending on the mode of control:

- Continuously communicate the situation directly to ATC (extent of the failure, current mode of control, expected transmission delay),
- Try to re-establish the C2-link without changing the present route of flight (e.g. by using backup systems),
- Try to re-establish the C2-link including changes in the present route of flight after a certain period of time if applicable (only useful in case of Radio-Line-of-Sight (RLOS) connections or Beyond-Radio-Line-of-Sight (BRLOS) connections via a ground based relay station),
- Continuously monitor which link-dependent functionalities are still available and to which extent.

The following measures should be taken by **ATC**:

- Increase separation,
- Expect the flight to be continued automatically or autonomously,
- Segregate the RPA in case of automatic flight as far as possible (allocate segregated airspace; broadcast the establishment of such airspace).

4.4.2. Loss of Control

As there are different modes of control, a loss of a single control capability (e.g. autonomous control) needs compensation by switching to another available mode of control (e.g. manual control). If no other control mode is available or can be re-established, then the total loss of the RPA is unavoidable.

This emergency situation can be caused by hardware or software errors / failures in the RPS as well as on board of the RPA, due to C2 link problems or due to stall situations.

One or more of the following conditions can be expected:

- Uncontrolled manoeuvers can be possible at any time,
- Further malfunctions / damage due to a structural overload are possible at any time.

The following measures should additionally be taken by the **remote pilot** and/or the **RPA**, depending on the mode of control:

- Communicate the situation to ATC,
- Try to identify the reason for the loss of control,
- Try to recover full control by all means necessary.

The following measures should be taken by **ATC**:

- Increase separation (especially below the RPA),
- Make an aeronautical broadcast if uncontrolled traffic may be affected,
- Expect a high workload of the remote pilot.

4.4.3. Loss of Automatic / Autonomous Capabilities

This emergency situation comprises the loss of any automatic / autonomous functionality which is essential to conduct the flight. It can be caused by hardware or software errors / failures in the RPA.

One or more of the following conditions can be expected:

- Restricted capability to maintain the heading / level / speed or to fly certain manoeuevers,
- Restricted capability to navigate,
- Restricted / delayed transmission of information via the C2-link which are of less priority (e.g. Pilot-ATC voice communication).

The following measures should additionally be taken by the **remote pilot**, depending on the mode of control:

- Communicate the situation to ATC,
- Perform all actions manually, restrict all actions to those which are absolutely necessary,
- Avoid all conditions that might reduce the performance of the C2-link.

The following measures should be taken by **ATC**:

- Increase separation,
- Expect a high workload of the remote pilot.

4.4.4. Loss of Detect & Avoid Capability

A complete loss of the Detect & Avoid Capability is a critical event especially for RPAS flights under VFR.

This emergency situation can be caused by hardware or software errors / failures in the RPA, especially in the sensor components. Additionally, this kind of situation can also be caused by circumstances which degrade the performance of the used sensors (environmental conditions, jamming etc.).

One or more of the following conditions can be expected:

- Loss of autonomous control,
- Encounters of weather hazards or other environmental hazards,
- Encounters of obstacles during low level flight.

The following RPA behavior can result:

- Switching to automatic / manual flight control.

The following measures should additionally be taken by the **remote pilot** and/or the **RPA**, depending on the mode of control:

- Communicate the situation to ATC,
- Request a change to IFR if possible,
- Consider latest flight information, especially weather warnings and navigational warnings.

The following measures should be taken by **ATC**:

- Support a change to IFR; guide the traffic through airspace class A, B, C or D or a Transponder Mandatory Zone (TMZ),
- If this is not possible, segregate the RPA as far as possible (allocate segregated airspace; broadcast the establishment of such airspace).

4.4.5. Software failures

ICAO's Manual on Remotely Piloted Aircraft Systems mentions the possibility of software failures as a possible cause for emergency situations [16]. As it can be expected that all kinds of software is extensively used in all RPAS components, the resulting variety of possible consequences does not allow a generic classification or this case is already covered by other procedures. It is also possible that a significant number of software failures does not necessarily lead to an emergency situation. Therefore this kind of failures is not considered in detail in the UFO project [6].

4.4.6. Complete RPS failure

ICAO's Manual on Remotely Piloted Aircraft Systems mentions the possibility of a complete RPS failure as a possible cause for emergency situations [16]. From the RPA point of view there is no difference to a complete loss of the C2-link, so the RPA will follow corresponding procedures while the remote pilot will try to use backup systems. Therefore this kind of failure is also not considered in detail in the UFO project [6].

5. DISCUSSION AND OUTLOOK

The methods in chapter 3, together with the frame conditions and constraints in chapter 2, can serve as a guideline for RPAS manufacturers, pilots and controllers as well as for training purposes. They represent the basics that are resulting from the nature of unmanned aircraft, especially the transition from a pure pilot-ATC relationship to a trilateral relationship between ATC, the remote pilot and the RPA. Depending on how much RPAS differ from comparable manned aircraft, it will not always be possible to define generic procedures, but keeping those procedures uniform and as simple as possible will prevent human errors caused by misunderstandings, misinterpretations and mix-ups.

The generic procedures described in chapter 4 are not entitled to be complete as on one hand the analysis in the UFO project according to method 3.3 is not yet complete, on the other hand comprehensive knowledge about specific technical components of an RPAS is needed to cover all possibilities.

The contingency procedures described in this paper are also not yet verified and validated, which can and is planned to be done to a certain extent within validation activities of the UFO project, foreseen in 2017, by using human-in-the-loop real time simulations.

Nevertheless, it will not be possible to investigate all aspects and factors that can influence a real RPAS emergency. Therefore, similar to the procedures applicable in manned aviation, any RPAS contingency procedure can only be a guideline. It will be unavoidable to gather experience with RPAS flight operations, intense and continuous training of remote pilots and controllers will still be necessary.

REFERENCES

[1] European Commission: Roadmap for the integration of civil Remotely-Piloted Aircraft Systems into European Aviation System, Final Report from the European RPAS Steering Group, June 2013

[2] International Civil Aviation Organization (ICAO): German Activities Related to Remotely Piloted Aircraft Systems (RPAS), 12th Air Navigation Conference, Montreal, 2012

[3] https://artes-apps.esa.int/projects/desire

[4] EUROCONTROL: EUROCONTROL Air Traffic Management Guidelines for Global Hawk in European Airspace, Edition 1.0, 2010

[5] A. Temme: "UFO – Phase 1: an internal DLR project", Deutscher Luft- und Raumfahrtkongress 2016, Braunschweig, 2016

[6] M. Finke, M. Uebbing-Rumke, P. Sinapius, H. Braßel, J. N. Okuniek and L. Christoffels: "ConOps for the Tactical Guidance of RPAS by ATC", internal report. DLR-IB-FL-BS-2016-26, Braunschweig, 2016

[7] International Civil Aviation Organization (ICAO): Aeronautical Telecommunications, Annex 10, Volume II, 6th Edition, 2001

[8] DFS Deutsche Flugsicherung: Manual of Operations Air Traffic Services, 11th supplementary delivery, 26th May 2016

[9] Federal Aviation Administration: Airplane Flying Handbook, FAA-H-8083-3A, 2004

[10] Cessna Aircraft Company: Pilot's Operating Handbook and FAA Approved Airplane Flight Manual, Cessna 350 (LC42-550FG) with Garmin Integrated Flight Display, 2008

[11] EUROCONTROL: ATC Refresher Training Manual, Edition 1.0, 2015

[12] EUROCONTROL: Guidelines for Controller Training in the Handling of Unusual / Emergency Situations, Edition 2.0, 2003

[13] International Civil Aviation Organization (ICAO): Airport Emergency Planning, Doc 9137 Part 7, 2nd Edition, 1991

[14] M. Finke, P. Sinapius: "Application of Visual and Instrument Flight Rules to Remotely Piloted Aircraft Systems", submitted to 35th Digital Avionics System Conference, Sacramento, USA, 2016

[15] H. Braßel: „Investigation of implications of remotely piloted aircraft systems suffering a partial loss of information transfer of the C3-link on its airworthiness, airspace integration and air traffic control", Technical University of Dresden, 2016, not yet published

[16] International Civil Aviation Organization (ICAO): Manual on Remotely Piloted Aircraft Systems (RPAS), Doc 10019, 1st Edition, 2015

[17] GAMMA Consortium, Deliverable 2.1 "Threat analysis and evaluation report", 2015