RPAS-ATM Integration Demonstration

Final Workshop

Flight Trial Results: Safety Aspects

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Safety Objectives

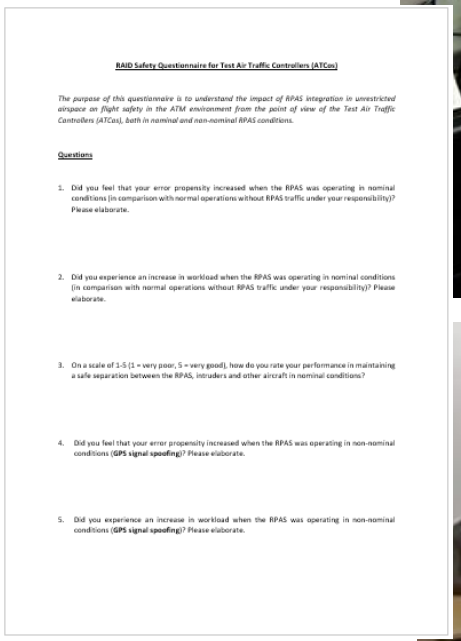
Obj. Identifier	Objective	Exercises#/ Flight ID	Success Criteria
OBJ-RPAS.03-SAF001	Effect of detect-and-avoid system failure on operational safety	Flight #9 - Flight #12	The implications of detect-and-avoid system failure on safety are estimated within acceptable margins and no major limitations are identified.
OBJ-RPAS.03-SAF002	Effect of C2L failure on operational safety	Flight #3, Flight #7, Flight #8	The impact of C2L failure on safety is estimated within acceptable margins and no major limitations are identified.
OBJ-RPAS.03-SAF003	Effect of limitations in human performance on safety	All flights	The effect of the limitations of human performance on safety is assessed, focussing on the 4 identified areas (i.e. operator tasks and roles, HMI^2, organisational issues, skills and training needs) and no major risks to safety are identified.
OBJ-RPAS.03-SAF004	Effect of weather and terrain on DAA and C2L	Flight #3, Flight #7 - Flight #12	The implications of weather and terrain on C2L and detect-and-avoid system loss of integrity/availability and their effect on safety are assessed and evaluated as within acceptable margins. No major limitations that can preclude operations in certain conditions are identified.
OBJ-RPAS.03-SAF005	Effect of the loss of integrity and availability of the C2L link, the GNSS system and detect-and-avoid system	Flight #3, Flight #7-Flight #12	The implications of cyber-attacks on safety are assessed and evaluated as acceptable. No major limitations that can compromise safety are identified.

Metrics and Indicators for Results Analysis

Obj. Identifier	Objective	Indicators/metrics
OBJ-RPAS.03-SAF001	Effect of detect-and-avoid system failure on operational safety	Stakeholder workload, risk of error, risk of accident resulting from expected response to D&A function outputs
OBJ-RPAS.03-SAF002	Effect of C2L failure on operational safety	Stakeholder workload, risk of continued traffic conflict, risk of error
OBJ-RPAS.03-SAF003	Effect of limitations in human performance on safety	Stakeholder workload, risk of error
OBJ-RPAS.03-SAF004	Effect of weather and terrain on DAA and C2L	Impact of emergency / recovery procedures & manoeuvres on continued safety, including effects of stakeholder workload and impact of resulting vehicle manoeuvre
OBJ-RPAS.03-SAF005	Effect of the loss of integrity and availability of the C2L link, the GNSS system and detect-and-avoid system	The impact of the resulting RPAS manoeuvre and stakeholder workload on continued safety

Data Collection

- Video recordings of the CWP and the RFO
- Questionnaires (completed by test ATCOs and RFO at the end of the flight test campaign)
- Discussions with test ATCOs and RFO after each flight
- Direct observations
- Pre- and post-flight briefings



RAID Safety Questionnaire for Test Air Traffic Controllers (ATCos)

The purpose of this questionnaire is to understand the impact of RPAS integration in unrestricted airspace on flight safety in the ATM environment from the point of view of the Test Air Traffic Controllers (ATCos), both in nominal and non-nominal RPAS conditions.

Questions

1. Did you feel that your error propensity increased when the RPAS was operating in nominal conditions (in comparison with normal operations without RPAS traffic under your responsibility)? Please elaborate.

2. Did you experience an increase in workload when the RPAS was operating in nominal conditions (in comparison with normal operations without RPAS traffic under your responsibility)? Please elaborate.

3. On a scale of 1-5 (1 = very poor, 5 = very good), how do you rate your performance in maintaining a safe separation between the RPAS, intruders and other aircraft in nominal conditions?

4. Did you feel that your error propensity increased when the RPAS was operating in non-nominal conditions (**GPS signal spoofing**)? Please elaborate.

5. Did you experience an increase in workload when the RPAS was operating in non-nominal conditions (**GPS signal spoofing**)? Please elaborate.

Safety-related Assumptions (1/2)

- RF communication between RFO and ATCO
  - The communication by different means (not RF) may impact on the workload and operating methods of the Controller
- VMC are met and wind conditions are compatible with performance limitations of the RPAS and intruder aircraft
  - The Safety Pilot has to be able to keep control of the aircraft and maintain separation with traffic and terrain by visual means. Weather conditions also need to be adequate to enable intruder aircraft to participate in the flight tests.
- Availability of ADS-B (cooperative traffic)
  - DAA technology is based on the ADS-B communication protocol

Safety-related Assumptions (2/2)

- Departure and arrival operations performed by the Safety Pilot
  - Automatic take-off and landing operations are not covered by the demonstration. The presence of the on-board pilot for terminal operations also facilitated the application for the permit to fly.
- Tests are carried out within a defined Flight Test Area (FTA)
  - An FTA is required in order to be able to conduct the necessary flight tests
- Exercise participants aware of flight test objectives
  - Exercise participants need to be aware of the purpose of a test flight in order to be prepared in the event that something unexpected occurs. This is especially important for the on-board Safety Pilot

Analysis of Exercise Results

Effect of DAA system failure on operational safety

- DAA with RFO in the loop
  - The system informs the RFO of loss of separation on the GCS HMI and suggests an avoidance manoeuver. It is up to the RFO to activate the avoidance manoeuver while informing the test ATCOs of the intended manoeuver.
- Override of DAA by RFO
  - There were some instances where the DAA system did not operate as expected or where the suggested avoidance manoeuver was not accepted by the RFO. In these cases the RFO was able to take over control of the RPAS and separation was handled by the ATCO who treated the RPAS as normal traffic.
- RPAS self-separation and safety
  - RFO said that RPAS self-separation can improve safety because it occurs at an early stage, thus giving the RFO more peace of mind and comfort, and there is little risk of dependence on automation.
  - ATCOs said that safety can be improved if the RPAS can initiate an avoidance manoeuver before ATC issue an instruction. However, the ATCOs prefer to be involved (to give authorisation) unless a collision is imminent.

Analysis of Exercise Results
Effect of C2L failure on operational safety (1/2)

- Pilot identification of C2L failure
  - Whenever a communication (data-link) failure occurred in the flight test campaign, all telemetry data was lost from the remote pilot's displays and crosses appeared instead of telemetry data. The remote pilots said that they could easily identify such a failure and quickly report it to the test ATCOs. The test ATCOs were then able to ensure that no traffic approached the RPAS.
- Link lost procedure
  - In the event of link loss, the RPAS is programmed to automatically follow a predefined route. The test ATCOs were aware of this procedure and could therefore anticipate the next manoeuvers of the RPAS, give instructions to surrounding aircraft and keeping the RFO informed of the current aircraft position. However, the test ATCOs stressed that the procedure should be published and not be defined for a particular area or flight. The importance of a good voice communication link between the ATCOs, RFO and intruder aircraft was also emphasised as the controllers relied on it to be able to manage safe aircraft separation.

Analysis of Exercise Results
Effect of C2L failure on operational safety (2/2)

- Restoration of communication link
  - When the communication link was restored, the remote pilot quickly identified this because the telemetry data reappeared on the ground station HMI. Furthermore, since the test ATCOs kept the remote pilot informed of the RPAS position when the communication link was not operational, the remote pilot could immediately take over the RPAS once the data link was restored.
- Error propensity and workload
  - From the RFO's point of view, a C2L failure does not increase error propensity or workload because the RFO has no control over the RPAS and can do little to fix the situation. On the other hand, two of the test ATCOs said that their workload increased due to the situation being non-nominal (as in the case of a manned aircraft operating in a non-nominal condition). The workload could increase further if the failure occurred close to a SID or STAR where other traffic was present.

Analysis of Exercise Results

Effect of limitations in human performance on safety (1/2)

- Error propensity and workload in nominal conditions
  - In nominal conditions, the test controllers said that their error propensity and workload did not increase (when compared to normal operations without RPAS traffic), as long as the RPAS was cooperative and complied with ATC instructions. This was because they treated the RPAS and RFO like normal traffic. Furthermore, no communication lag was experienced and therefore there was no need for any sort of anticipation. As a result, the test controllers rated their performance in maintaining a safe separation between the RPAS and other aircraft as 'very good'.
- Error propensity and workload in non-nominal conditions due to C2L jamming
  - In non-nominal conditions due to C2L jamming, the remote pilot did not feel an increase in error propensity or workload because he had no control over the RPAS in those conditions. On the other hand, two of the controllers reported an increase in workload. This could be due to the fact that the controllers had to steer other aircraft away from the RPAS while keeping the remote pilot informed of current RPAS position.

Analysis of Exercise Results

Effect of limitations in human performance on safety (2/2)

- Error propensity and workload in non-nominal conditions due to GPS spoofing
  - ATCOs said that they did not feel an increase in error propensity, but said that it is normal for the error probability to increase when failures occur. The controllers reported an increase in workload in the presence of GPS signal spoofing but said that this increase is the same as any additional workload experienced when a similar failure occurs on a manned aircraft.
  - ATCO ability to maintain separation between the RPAS and surrounding traffic was not affected by spoofing because they could still see the actual RPAS position. ATCO reported 'very good' performance in this case.
  - RFO reported no increase in error propensity and no significant change in workload in non-nominal conditions due to GPS signal spoofing. This was because the controller provided all the necessary information and instructions. The RFO reported that it was easy to identify spoofing because of a sudden and large shift in RPAS position. Communication with ATC was reported as being very good since the ATC indications of actual RPAS position were very accurate. Also, the remote pilot found it easy to follow ATC instructions.

Analysis of Exercise Results

Effect of weather and terrain on DAA and C2L

- The effect of weather and terrain on DAA and C2L was not investigated directly in the RAID flight test campaign. This was mainly due to logistical complications and additional risks involved when conducting tests in hazardous weather and in the vicinity of terrain. For this flight test campaign, it was necessary to conduct the flights in VMC; therefore, the effect of weather and terrain on DAA and C2L was investigated indirectly by analysing the impact of DAA and C2L failures on operational safety .

Analysis of Exercise Results

Effect of the loss of integrity and availability of the C2L link, the GNSS system and DAA system (1/2)

- C2L failure
  - When a C2L failure occurs, the RPAS is programmed to follow a pre-defined set of waypoints (in an attempt to restore the communication link) before flying to a 'Home' waypoint. As soon as the RFO detects a link failure, he informs the ATCO who gives instructions to other traffic in order to prevent conflicts with the RPAS. The ATCO also keeps the RFO regularly informed of the current RPAS position. When the C2L is restored, the RFO informs the ATCO and the RPAS resumes its original flight.
- GNSS signal spoofing
  - The RFO notices a sudden significant change in RPAS position as indicated on the ground station HMI. This anomaly is communicated to the ATCO who can inform the RFO of the actual position of the RPAS, thus enabling the RPAS to continue with its flight.

Analysis of Exercise Results

Effect of the loss of integrity and availability of the C2L link, the GNSS system and DAA system (2/2)

- DAA failure
  - Self-separation has the potential of increasing operational safety by detecting loss of separation conflicts between the RPAS and other (cooperative) aircraft before ATC issue instructions to resolve such conflicts. In addition, the DAA system tested in RAID has the ability to propose separation manoeuvers to the remote pilot and execute them automatically upon confirmation by the pilot. However, if the DAA system is not working as expected (or not at all e.g. due to ADS-B signal loss), the remote pilot can easily override the system to resolve conflicts, and aircraft separation can be managed by the ATCO

Analysis of Exercise Results

Importance of different factors to safety of RPAS operations

Factor	ATCO #1	ATCO #2	ATCO #3	RFO
RPAS procedures	3	5	3	1
Voice communications between RFO and ATCO	1	1	2	2
Reliability of C2L link	4	3	4	3
Reliability of GPS receiver	6	6	5	4
ADS-B based self-separation	5	4	6	5
ATCO-based separation assurance	2	2	1	6

- ATC: Voice communications and ATCO-based separation assurance constitute a big part of ATC responsibility
- RFO: Procedures are considered to be the 'Bible' for RFO. ATCO presence/authority is taken for granted in IFR conditions and is not questioned

Conclusions and Recommendations

- RAID safety objectives have been met
- Flight trials have demonstrated safety of RPAS operations and procedures in controlled airspace and in the presence of manned/unmanned intruders
- Workload and error propensity of ATCO and RFO due to RPAS operations are considered to be acceptable
- Future studies should incorporate more realistic scenarios with multiple intruders in a bigger FTA