Experiences with coastal and maritime UAS BLOS operation with phased-array antenna digital payload data link

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***Abstract*—This paper describes recent experiences with operating an unmanned aerial vehicle (UAV) in a coastal and maritime environment beyond line of sight (BLOS) in controlled airspace (class D) where separation from other air traffic is provided by the Air Traffic Control (ATC). The UAV operation followed normal ATC procedures with two-way VHF communication between the UAS Operator and ATC in order to provide separation vertically and horizontally by operation within pre-defined areas according to specific operational procedures made by ATC. Tests were conducted using direct 2.4 GHz radio and GPRS mobile network control links at a distance up to 20 km from the ground control station when operating at 1500 ft altitude. A new low-weight and small size experimental phased-array antenna providing a digital high capacity payload data link was tested and found to give stable real-time HD video at a distance of 50 km under line of sight conditions at 2500 ft altitude.**

***Index Terms*—Beyond line of sight; unmanned aerial vehicle; remotely piloted aircraft systems; air traffic control; phased array antenna; digital data link.**

I. INTRODUCTION

Unmanned aerial vehicles (UAVs) and systems (UASs) are being developed at an increasing pace. These developments are motivated by numerous potential benefits such as

- Increased safety and reduced risk of unmanned systems (e.g. hazardous operations such as power line inspection, search and rescue in harsh weather, operations with high risk for icing, etc.).
- The opportunity to use small light-weight payloads for remote sensing and surveillance in a small UAV that allows efficient deployment, operation and recovery compared to manned aircraft or surface vehicles.
- Potentially long endurance of unmanned systems that are not limited by the fatigue of pilots on-board manned aircraft.

We are in particularly interested in the use of UAVs in order to support a wide range of remote sensing applications in coastal and maritime environments, an area with considerable attention and importance [9], [10]. Such operations will require operation over large areas and distances, beyond visual line of sight (BLOS), and sometimes beyond the line of sight of direct radio links. In such cases communication redundancy may be needed, and communication may need support from infrastructure such as satellites, cellular/mobile networks, dedicated relay nodes, or other cooperative networking strategies, e.g. [1], [3], [5]–[7]. For operations far from the coasts or in remote areas such as the arctic, the availability of such infrastructure might be very limited.

The safety and reliability of BLOS UAS operations are challenging since visual observation of the UAV is not possible, and manual emergency operation is not feasible. This imposes both technical and operational requirements to ensure fault-tolerance in the event of faults in communication and navigation equipment. This is in particular the case if the UAV is operating in an air space together with other air traffic, since see-and-avoid is not available, and separation from other air traffic must still be guaranteed.

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Integration of UAS with conventional air traffic is considered by many to be a significant regulatory and technical challenge that is a key enabler for the commercial UAS market. Detect-and-avoid systems are required, and many conclude that the use of ADS-B transponders in an important step towards such integration [12]. Online sensors such as radar may still be required.

This paper describes recent experiences with operating UAS in controlled airspace (class D) from Ørland airport out over the ocean with separation from other air traffic provided by the Air Traffic Control (ATC). The UAV operation followed normal ATC procedures with two-way VHF communication between the UAS Operator and ATC in order to provide separation vertically and by operation within pre-defined areas according to specific operational procedures made by ATC. No transponder was required or installed. Civilian BLOS UAS operations in controlled airspace over the ocean provides useful experience towards integration of UAS with other air traffic.

Beyond the testing of the UAS itself, the main purpose of the UAV flights were to test new technology and collect data for ongoing research project, in particular

- Testing of Radionor Communication's phased array antenna system to provide a long-distance high-capacity digital payload data link from UAV to ground payload operator. The system consists of a very small and low-weight antenna array integrated into the UAV, and a larger array at the ground station.
- Collection of navigation data for research on robust navigation, supporting fault-tolerant sensor fusion based on camera, inertial, magnetometer, GPS, airspeed, altitude and other sensors. Quite interestingly, the phased array antenna may also be used to provide heading and attitude measurements, [2].

Phased-array antenna technology enables electronic beam-forming by signal processing software and hardware, [4], [8], [11]. Compared to mechanically stabilized tracking antennas it has the benefits of significantly smaller size and weight, and it allows efficient multi-point communication since the beam direction can be changed much more quickly electronically than mechanically, and multiple beams can be formed simultaneously.

This paper is organized as follows: Section II describes UAS operating procedures applied for BLOS operations in class D airspace. Section III describes the UAS, while section IV contains a description of the experimental payload data link and results.

II. AIR SPACE AND OPERATING PROCEDURES

UAS tests were conducted in September and October 2013 at Ørland airport (IATA: OLA, ICAO: ENOL) in Norway. The airport hosts a major Norwegian air force base and some civial activities. It was chosen for our tests because it is located in a coastal and maritime environment. The Norwegian RPAS (Remotely Piloted Aircraft System) requirements AIC-N 14/13 from June 2013 opens for UAS BLOS operations in controlled airspace subject to coordination with the ATC.

The flight operations were carried out in Class D airspace, which means that the UAS operator communicates with ATC using two-way VHF radio for takeoff and landing, when requesting a change in altitude, as well as when requesting to enter or leave any of the areas illustrated in Figure 1. ATC provides separation from other air traffic by vertical separation when more than one aircraft is within the same area. Class D airspace requires ATC clearance to enter, so one knows about the whole traffic inside.

The main operational procedures decided by the ATC for our operations are given by the following:

- UAV takeoff and landing uses the runway. Until the UAV is established in Fosna area, no other traffic is allowed near the runway.
- The UAV shall wait in Fosna area until cleared for landing. If UAV is not established in Fosna area before landing, 5 minutes notice before return shall be given.
- Other air traffic can take off and land turning east of the runway when the UAV is established in the Fosna area.
- Other air traffic can take off and land turning east of the runway when the UAV is established in the Kraakvaag area and Fosna area is not active.
- UAV emergency landing area is at a field west of the runway.

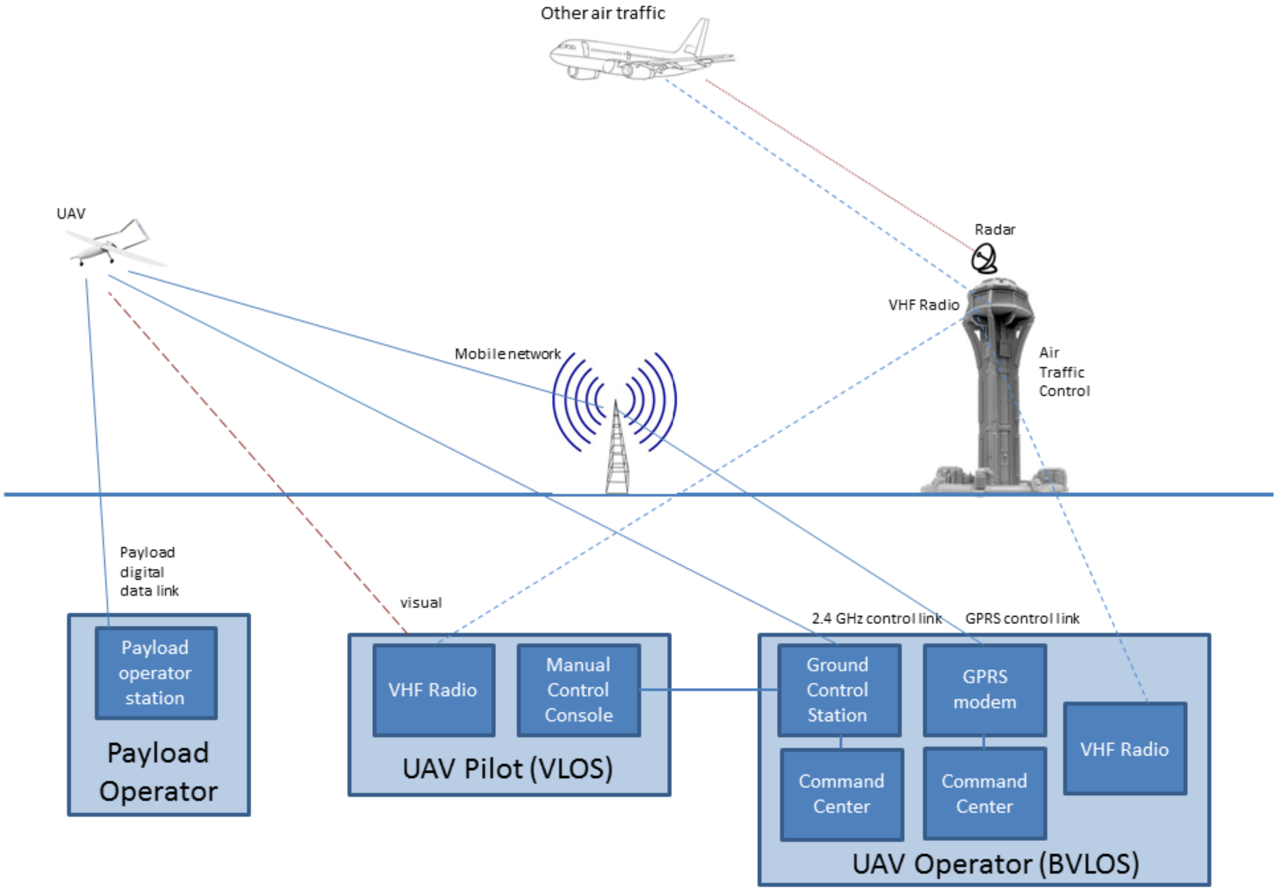

Fig. 2. Unmanned aerial system overview - concept of operation.

III. UNMANNED AERIAL SYSTEM

The UAS is set up to manage flights that are both beyond visual line of sight (BVLOS) as well as beyond radio line of sight (BRLOS). While a Mode C transponder might have been desirable to assist ATC in separation of the UAS from other traffic, it was not required and not installed.

An overview of the UAS is provided in Figure 2. It consists of the following systems and functions:

- The UAV is a Penguin B fixed-wing aircraft with MTOW at about 21 kg operating at about 28 m/s airspeed.
- The UAV has a Piccolo SL autopilot with the capability to track way-points and commands provided from the ground command center. The autopilot has GPS, pressure-based altimeter, inertial sensors, a 2.4 GHz digital control link, and a GPRS modem as a second digital control link.
- The ground operations center operated by the UAS Operator has two computers running separate instances of the Piccolo Command Center software operating independently on the 2.4 GHz data link and GPRS mobile network, see Figure 3. The dual computer and communication setup provides redundancy that is in particular useful when one of the control data links is lost. All critical components are power by an uninterruptible power supply (UPS) that would ensure safe return and landing of the UAV upon power failure.
- Takeoff and landing was done under manual control of the UAV Pilot using the console and

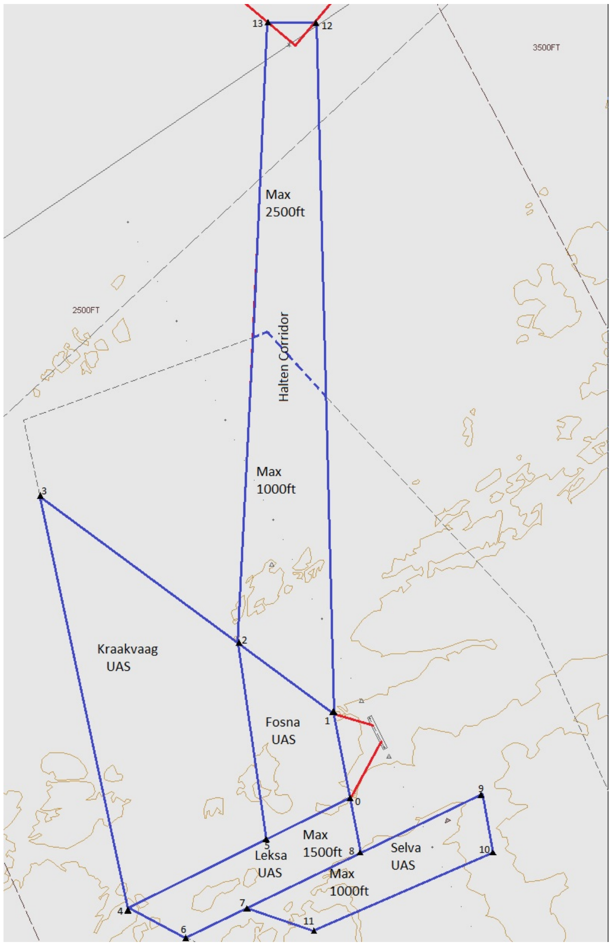

Fig. 1. Airspace near Ørland airport assigned for UAS operations by ATC during our tests (areas enclosed by blue lines). Most of the UAS areas are inside CTR (dashed grey lines).

visual feedback, see Figure 4.

- The UAV pilot, UAV operator and ATC use two-way VHF radios as primary communication.

The autopilot is set up to autonomously follow a flight plan with automatic landing upon simultaneous loss of both control links. If both communication links and GPS fails simultaneously, or other critical failures such as loss of engine occurs, the autopilot triggers a flight termination procedure.

The payload system used consisted of

- Additional inertial measurement unit logging data for navigation research.
- High-definition video camera with digital encoder mounted on passive vibration damped platform, logging data and feeding the experimental payload data link.
- High-capacity long-distance payload data link with a radio receiver and experimental phase-array antenna as described in section IV.

Fig. 3. UAS Operator with the command center.

Fig. 4. UAS Pilot besides the UAV and the ground operator center.

Figure 3 also indicates the flight path visualized in the command center. In this case the UAV was at 1500 ft altitude at 20 km away from the ground control station. This specific flight was conducted in Fosna, Kraakvaag and Leksa areas marked in Figure 1.

IV. LONG RANGE BROADBAND PAYLOAD DATA LINK

A critical factor for the operative value of a UAS is in some operations the ability to provide real-time sensor information from the UAS. The test

Fig. 5. Broadband payload data link: 4 small antennas are integrated in the Penguin B UAV fuselage.

flights carried a new type of broadband payload data link on-board. The experimental payload data link (by Radionor Communications) for the UAS had the following characteristics:

- Long range operation (more than 30 km).
- Broadband capability (more than 2 Mbps).
- IP based data network system.
- Point-to-multi-point capability.
- Phased array antenna system on-board the UAV.
- Small antennas on the UAV fuselage, cf. Figure 5.
- Compact size and weight for small UAV operations.
- Phased array antenna panel technology for the ground station.
- Separate logical channels for quality of service for sensor data, video stream data and for bidirectional control data.

During tests, the UAV was flown to 2500 feet above sea level altitude to clear the mountains between the UAV and the payload ground station as shown in the landscape profile for the link in Figure 6. A stable data stream from the UAV to the payload ground station in Trondheim at a distance of 50 km was established. A live HD video stream was sent over the digital data link, and a sample picture of the received video stream is shown in Figure 7. The main loss of image quality is due to camera vibrations that were not fully isolated or damped.

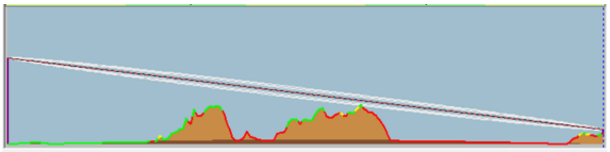

Fig. 6. Terrain altitude profile between the UAV at 2500 feet and the payload ground station. Note that the horizontal and vertical axes have different scales in the figure.

Fig. 7. HD video stream received at the payload ground station at 50 km distance.

V. CONCLUSIONS

Successful BLOS tests were conducted using direct 2.4 GHz radio and GPRS mobile network control data links at a distance up to 20 km from the ground control station when operating at 1500 ft altitude. A new experimental phased-array antenna providing a digital high capacity line-of-sight data link was tested and found to give stable live HD video at a distance of 50 km at 2500 ft altitude. Its low weight and size makes it an interesting alternative to satellite communication in small UAS operating in maritime and coastal regions without the availability of broadband mobile/cellular networks or other suitable communication infrastructure. Embedding the antenna array into the wing or fuselage design may further improve the efficiency of the approach, [8], [11].

The tests provides important experiences on the steps towards integration of UAS in controlled airspace, in particular towards operations in coastal and maritime environments that are characterized by limited infrastructure, relatively low risk for third parties (sparse population and traffic), and large distances.

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