Preliminary Piloted Flight-Simulation Evaluation of Autogyro Operations in the Presence of a Wind-Turbine Wake

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Background

Due to the increasing imperative of slowing, halting or even reversing climate change, there continues to be significant investment in renewable energy sources. One source of renewable energy comes in the form of wind turbine-generated electricity. Europe installed 15.4GW of new wind power capacity in 2019, taking total European capacity to 205GW. Three-quarters of this capacity was installed onshore, with the remainder in offshore wind farms. Interestingly for that year, the UK installed the most capacity with an increase of 2.4GW of energy-generation capacity and, perhaps because it is an island, 74% of that was offshore. Of course, as with any other man-made structure, particularly those in harsh, exposed environments, they must be subject to a rigorous planned maintenance routine, which will include regular inspection requirements.

Wind-turbine inspection has traditionally been carried out by teams of expert rope climbers. This process is slow, relatively expensive and requires significant Health & Safety management. More recently, unmanned aerial system (UAS or 'drone') services companies offer a replacement to this, whereby a manually-flown drone takes high-resolution images of, for example, turbine blades. These can be used to allow the operator to direct manned teams only to any areas of concern. This latter solution still requires a small team to operate the drone and for that team to be in the vicinity of the wind-farm. For offshore farms in particular, this is clearly a significant logistical task.

Rotorcraft have long been associated with the offshore energy sector. Helicopters are used to move personnel and freight to and from energy fields (both fossil fuel and renewable). It is possible that a UAS solution could be used to provide some of these functions e.g. an initial inspection capability before deploying manpower, but this has yet to be fully explored. However, in the drive to reduce costs, the use of an alternative to the helicopter would be an obvious place to start.

The situation above hints at a requirement for a low cost but useable shore-to-wind-farm range aerial wind-turbine inspection solution for the UK. One potential candidate would be the autogyro. However, in the UK, the autogyro has long been confined to the fringes of sports aviation. This is, in part at least, due to a poor safety record gained throughout the 1980's and 90's. More recently, however, a small number of manufacturers have been able to produce factory-built autogyro airframes that have been granted a Certificate of Airworthiness (CofA). These aircraft provide a relatively low cost (compared to helicopters), but safer platform that has (very) short take-off and landing capability, useful range and endurance as well as the ability to fly at sufficiently low speed to aid sensor data acquisition.

There are, however, a number of elements of uncertainty for this proposed inspection solution. The first, which is beyond the scope of this paper, is that autogyros tend to be single engine craft and the safety case for operating a significant distance from shore would need to be argued strongly. The second, and the subject of this paper, is the likely response of an autogyro to the wake of an operating wind turbine. A traditional aerospace approach to reduce this uncertainty before attempting to fly any hardware in such a wake would be to try to assess the response of the aircraft in a simulation environment. This paper reports upon a preliminary study to examine the effect of a wind turbine air wake on the handling qualities of an autogyro aircraft. On- and offline simulation has been used to provide an initial look at the feasibility of using an autogyro as a sensor platform for a wind-turbine inspection role.

Method

A handling qualities approach has been adopted to perform the required assessment. This necessitates the definition of at least one mission task element (MTE). The ‘Wind-Turbine Inspection’ Mission was divided into a number of phases that were both typical and atypical of a conventional aircraft flight (take-off, cruise to inspection site and so on). The HQ-critical mission phase for the purposes of this paper was the ‘Inspect Site’ phase. The MTE to emulate a downwind inspection pass of a wind turbine is shown in plan-view in Figure 1. Its instantiation in the simulation environment is shown in Figure 2. It was assumed that the collection of inspection data would be performed automatically by a sensor package mounted on the aircraft but that the aircraft would be manually piloted. As such, the pilot’s task would be to fly the aircraft along a trajectory through wind turbine wakes to facilitate the data collection process. The pilot was asked to fly inspection passes in both directions along three different North/South flight lines, with a 20-knot wind blowing from West to East normal to the wind turbine.

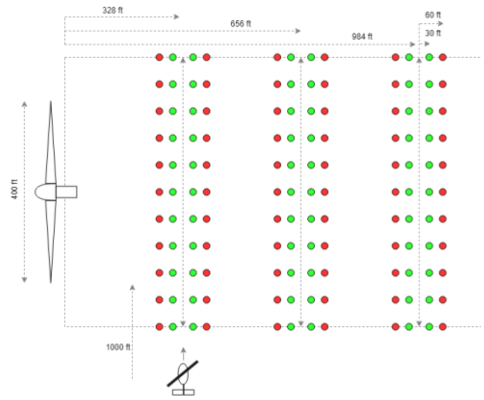

Figure 1: Wind turbine downwind inspection pass MTE course

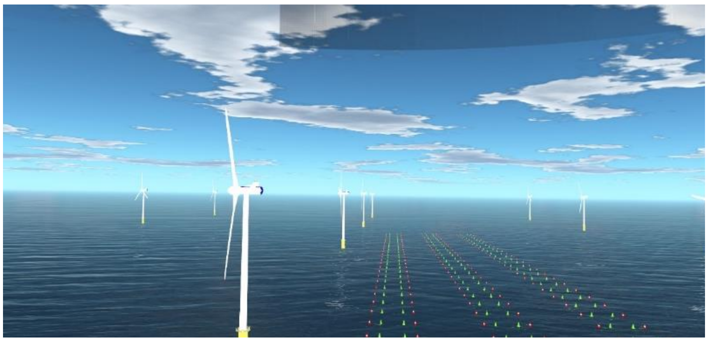

Figure 2: Pilot eye point view of wind turbine downwind inspection pass MTE course

Pilot-in-the-loop HQ assessments are typically made up of two parts. The first is an objective assessment of performance using recorded flight test data. These will be covered in more detail in the presentation. The second is a subjective assessment using rating scales that the pilot interrogates and gives scores for immediately after the test point (where possible). Two ratings scales were used to assess how the wind turbine air wake affected the autogyro during the downwind inspection pass MTE. The Wake Vortex Encounter (WVE) Severity rating scale was used to quantify both the effect of the wake on the aircraft and the ability of the pilot to recover from that effect. The second criteria used to assess the wind turbine inspection MTE was the ‘Transient Following a Failure (TFF)’ criteria, described in ADS-33E. This states that any ‘transient following a failure or combination of flight control system failures shall be recoverable to a safe steady flight condition without exceptional piloting skill’

The aircraft simulation model used in this investigation was based on the G-UNIV Montgomerie-Parsons research autogyro owned by Glasgow University. This model was originally developed during a PhD project at the University of Liverpool[1], which made design recommendations for future autogyro aircraft via simulation techniques using FLIGHTLAB software.

Indicative Results

Two pilots were used to evaluate the MTE. Pilot 1 flew all 9 test points flying both North and South, and a summary of the ratings he gave on the WVE and TFF scales for each point is given in Table 1. The Table shows the pilot’s ratings as well as the actual performance of the aircraft against each requirement of the TFF scale. It can be seen that the pilot consistently rated the aircraft’s response more benignly than the actual response from the aircraft and seemed to struggle to judge its linear accelerations. This is perhaps to be expected, since no instrumentation of linear acceleration was provided, and simulator motion cueing is limited in its ability to provide accelerative cues like this. However, the pilot also tended to underestimate excursions in attitude, which were more clearly instrumented by a heading indicator and artificial horizon. The pilot was able to avoid corrective action

[1] Robinson, S., Taming the autogyro, will the autogyro ever be truly domesticated?

for over 5 seconds in every wake encounter, and for 10 seconds in all but two cases. This better-than-expected performance for this aspect of the TFF criteria perhaps influenced his overall ratings more than the large excursions in attitude and transient accelerations. All WVE ratings by the pilot were Level 2 or better, again at odds with the performance indicated by the TFF scale. The pilot gave improved ratings on both scales as the aircraft moved away from the wind turbine as expected. Though there was some variation in ratings given for different test altitudes, there does not seem to be any discernible pattern in this variation for pilot 1.

Table 1: Pilot 1 Wake Vortex Encounter Severity Ratings and Transients Following a Failure Criteria Ratings (WVE: A → H = increasing Severity of encounter; TFF: 1 = best, 4 = worst)

Direction	Distance from Wind Turbine (m)	Altitude (ft)	WVE Severity Rating	TFF Rating			
				Pilot	Actual		
					Time	Attitude	Acceleration
North i.e. 'Up' Fig. 1	100	250	C, H	3, 2	1, 2	4, 3	4, 2
		350	C, G	3, 2	2, 1	4, 3	4, 2
		450	C, A	2, 2	1, 1	4, 3	4, 2
	200	250	C, A	2, 1	1, 1	2, 2	3, 2
		350	C, A	2, 2	1, 1	3, 2	3, 2
		450	C, A	2, 2	1, 1	3, 2	3, 2
	300	250	B, A	1, 1	1, 1	2, 2	2, 2
		350	B, A	2, 1	1, 1	3, 2	3, 2
		450	A, A	1, 1	1, 1	2, 2	2, 2
South i.e. 'Down' Fig. 1	100	250	C	2	1	3	4
		350	D	2	1	3	4
		450	C	2	2	4	4
	200	250	C	2	1	2	3
		350	C	2	1	3	4
		450	B	2	1	3	3
	300	250	A	1	1	3	3
		350	B	1	1	2	2
		450	B	1	1	2	2

Conclusions

Based upon the analyses of all of the results data, which will be presented in the full paper, the following can be concluded:

1. Pilots reported that the poor handling qualities of the aircraft in a crosswind created the bulk of the workload for the task. Obtaining and maintaining a useable trim before entering the air wake volume was reported to be particularly difficult. The autogyro model exhibited certain handling qualities deficiencies that led to rapid loss of control if a PIO was excited, but this was independent of the effect of the wake. However, the aircraft did have sufficient control power to overcome any excursions in attitude.
2. Once a trimmed flight condition was achieved, it was possible to pass through the air wake without the need for any corrective action to be applied at all.
3. Although it was possible to fly through the wake, the resultant transient angular rates and linear accelerations were large. So, whilst it was possible to traverse the wake without pilot input, the resulting excursions in attitude and accelerations are considered hazardous. This behaviour was observed even at test points far downstream of the wind turbine. It was only possible to achieve a successful flight by not interacting with the controls. This is unlikely to be a natural or comfortable behaviour for the pilot.
4. The direction that the aircraft passed the wind turbine did mildly affect the performance of the aircraft in the wake.