# Reliability Based Design Optimization of a Long-Range eVTOL Aircraft under Uncertain Mission Parameters

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## Shortened Abstract

This research quantifies operational uncertainty in Urban Air Mobility (UAM) and integrates it into the Multidisciplinary Analysis and Design Optimization (MADO) of a long-range eVTOL aircraft. The study utilized the existing design process of the Wigeon aircraft as a basis. The stochastic MADO approach employed a Monte Carlo Simulation to estimate energy requirements for various missions. The results indicate that the deterministic design outperforms in scenarios with frequent longer flights, while the RBDO (Reliability-Based Design Optimization) approach is expected to yield better solutions in non-conforming design spaces such as for the Lift+Cruise eVTOL's.

## What is UAM?

Urban Air Mobility (UAM) is an emerging concept of utilizing aerial technologies, such as electric vertical takeoff and landing (eVTOL) aircraft and Distributed Electric Propulsion (DEP), to enable efficient transportation within urban environments. An example of such an UAM vehicles can be seen in Figure 2.

Figure 1. Wigeon: A long range tandem tilt wing eVTOL [1]

Figure 2. Volocopter: A drone like UAM vehicle designed for short intracity trips.

### The Wigeon

The UAM vehicle which is analyzed and optimized for is a Tandem Tilt Wing eVTOL called the Wigeon, which was the result of one of the Design Synthesis Exercises (DSE) of 2021. The Wigeon is a long range eVTOL focusing on the intercity travel segment. See Figure 1.

### Operational Uncertainty within UAM

The UAM mission space is extremely dynamic with unconventional landing and take off procedure causing a great amount of uncertainty which affect the fidelity of the MADO scheme [1]. Additionally, the absence of an established market further complicates the task of estimating the appropriate range and loitering times to consider [2, 3].

## Design methodology and Assumptions

The deterministic elements in the existing framework have been transformed into random variables, taking into account information from the literature, existing regulations, and market expectations. To determine the most influential mission parameter, range, an analysis was conducted on the 50 wealthiest cities in Europe. Figure 3 provides an illustration of this analysis. For a comprehensive summary of all parameters, refer to Table 1.

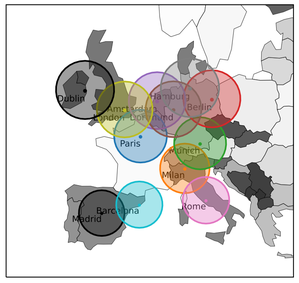


Figure 3. Visualization of the range analysis showing all Europeaan cities with a GDP greater than €159 billion.

Table 1. Comprehensive Overview of Random Variables in Mathematical Notation for Uncertainty Quantification

| Parameter | PDF |
|---|---|
| $Range$ | $\sim genextreme\{0.94\}$ |
| $Loiter_{cruise}$ | $\sim U\{0, 600\}$ |
| $h_{trans}$ | $\sim halfnorm\{95, 50\}$ |
| $Loiter_{hov}$ | $\sim 1.4\frac{h_{trans}}{v_{descent}} \cdot Ber\{0.01\}$ |
| $H_{HHD}$ | $\sim h_{trans} - 80$ |
| $H_{loiter}$ | $\sim 1.2h_{trans}$ |

The distributions shown in Table 1 were sampled, and a Monte Carlo Simulation was performed to assess their effect on various output parameters, with particular emphasis on energy consumption.

## Results

The range parameter dictates the general shape of the energy distribution as seen in Figure 4. The design of the RBDO uses a different method in minimizing the energy. It tries to find a balance between wing weight and induced drag (Aspect Ratio). This can be seen from Figure 5 and Figure 6.

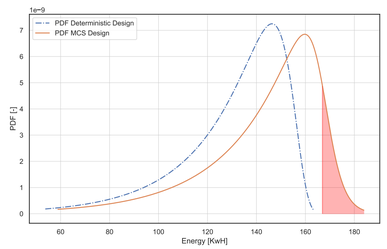


Figure 4. The energy distribution of the deterministic design and RBDO design.

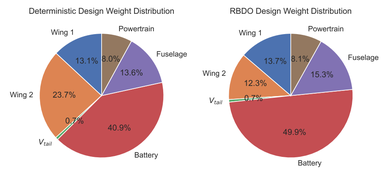


Figure 5. The weight distribution of the deterministic and RBDO design.

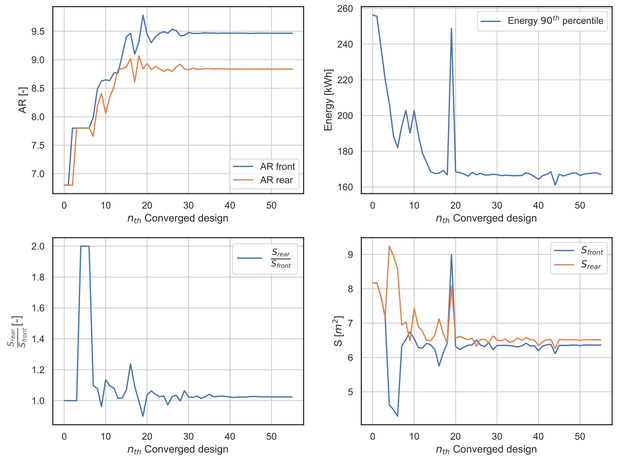


Figure 6. Convergence of various design parameters of the RBDO optimization.

## Preliminary Conclusion and Final Steps

The cruising phase of long range eVTOL dominates the energy consumption and is by far the most influential parameter. Due to larger distances occurring more frequently in intercity travel, the deterministic design fares better as the optimizer finds a global optimum more easily. The final step in my research is to compare the two methods for Lift+Cruise eVTOL whose mission is more ambiguous as they often fly a mix of medium to short range. Take for example Archer, RBDO seems to have great potential for finding an optimal solution with a larger variance in mission range. Finally, the cruise height will also be added as an additional stochastic parameter.

## References

[1] S. C. E. Beyne, "Preliminary performance assessment of a long-range evtol aircraft,", 2021. DOI: https://doi.org/10.2514/6.2022-1030.

[2] K. Song, H. Yeo, and J.-H. Moon, "Approach control concepts and optimal vertiport airspace design for urban air mobility (uam) operation," *International Journal of Aeronautical and Space Sciences*, vol. 22, pp. 1–13, Mar. 2021. DOI: 10.1007/s42405-020-00345-9.

[3] P. Pradeep, "Arrival management for evtol aircraft in on-demand air mobility," Ph.D. dissertation, Iowa State University, 2019.