

ON THE MODELLING AND SIMULATION OF BODY-FREEDOM AEROELASTICITY OF MORPHING AIR-LAUNCHED UAVS

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ABSTRACT

Tube-launched unmanned aerial systems (UAS) are novel systems that have been developed by various aerospace companies in recent years. They are morphing systems, where the lifting surfaces can rotate inwards such that the system fits within a narrow launch tube. The UAS is then launched from the tube, akin to a missile. Briefly after leaving the tube, its lifting surfaces unfold, and it takes the form of a fixed wing UAS.

Such systems can also be launched in-air, from another aircraft, also known as the carrier aircraft. As these aircraft are much larger than the UAS, the flight envelopes of both systems are unlikely to overlap. Moreover, such launches are accompanied by a strong coupling between the aerodynamics, structural dynamics and flight dynamics. This results in highly unsteady loading during the launch phase.

Thus, there is a clear interest in developing models that can be used to numerically simulate such launch procedures for different flight conditions. This can help determine whether structural limits are exceeded during launch, whether the UAS is controllable after launch, and whether the UAS can be safely launched from the carrier aircraft without risk of collision.

Literature review

The analysis of the dynamics of such systems is not new [1]. However, usually at least one of the physical domains is ignored. For example, Cheng et al. [2] consider the aerodynamic modelling of a tandem wing in straight flight with rigid wings. Selitrennik et al. [3] do include structural models for the wings, but assume the fuselage to be clamped. Cheng et al. [4] do include the flight dynamics, but do not include a structural model.

The overall objective of the research is to study the characteristics of the flight dynamics and structural dynamics of air-launched UASs during the launch phase. To achieve this objective, a new software framework for the numerical simulation of air launched morphing UASs is developed. This framework has been used to implement a body-freedom aeroelastic model of such UASs; that is, the aerodynamics, flight dynamics and structural dynamics are included.

Modelling

The aerodynamic and flight dynamic models have been discussed previously in [5] but are mentioned here for completeness' sake. The aerodynamics are modelled through a custom unsteady vortex lattice model (UVLM), combined with a vortex particle method (VPM). The VPM offers multiple benefits over classical wake treatments in the UVLM. By converting wake panels into vortex particles, risk of collision with downstream geometry is minimized. Furthermore, it allows for use of the Fast Multipole Method (FMM), improving the scaling of the computational cost of the wake interactions from $\mathcal{O}(N^2)$ for N wake panels to $\mathcal{O}(N)$ for N

vortex particles. The FastMultipole.jl-library has been used to implement the FMM in our model [6].

The flight dynamic model is constructed by applying the Newton-Euler equations to the UAS as a whole, including terms that account for the relative motion of the lifting surfaces relative to the fuselage. The motion of the connecting hinges is prescribed, resulting in a closed system of equations.

The structural model is created by assuming the fuselage to be rigid, and the lifting surfaces to be 1D-beams in 3D space. The beams are modelled as Timoshenko beams, using the PyFe3D library [7]. The beam equations are formulated in a reference frame that co-rotates with the wing deployment.

These models are coupled through a custom co-simulation framework. This framework, written in C++, allows the user to define simulation units (SU) consisting of custom model, input, state and output classes. Each SU can also contain a number of child SUs, resulting in a hierarchical structure that allows the user to intuitively represent a multi-physics multi-body problem. This framework will be discussed in more detail in the forthcoming conference paper.

Results

The aeroelastic model has been verified using the Goland wing [8]. Figure 1 shows the vertical deflection at the tip of the wing for the first second of a simulation, for different free stream velocities. It is evident that the flutter speed is approximately 160 m/s with a flutter frequency of approximately 10.81 Hz, in line with values found in literature. Figure 2 shows a snapshot of the output of the solver when simulating a Goland wing at a freestream velocity above the flutter speed.

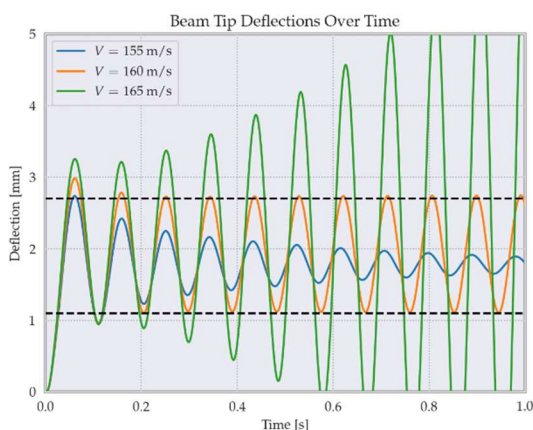


Figure 1 - Tip deflections of a Goland wing for different free stream velocities.

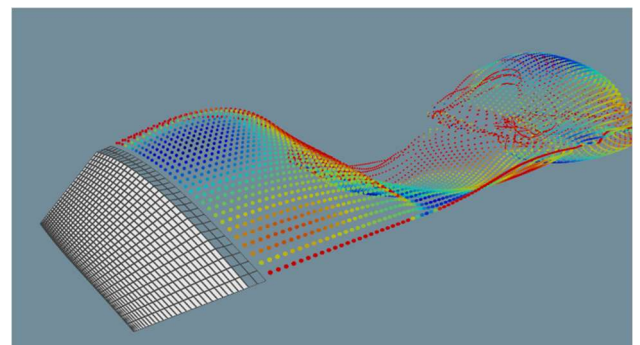


Figure 2 - Snapshot of the displacement of and flow around a fluttering Goland wing.

The body-freedom aeroelastic model has been applied to a sample tube-launched UAS. Figure 3 & 4 show snapshots of the output of the solver during this operation. The results of these simulations will be elaborated in more detail in the upcoming conference paper.

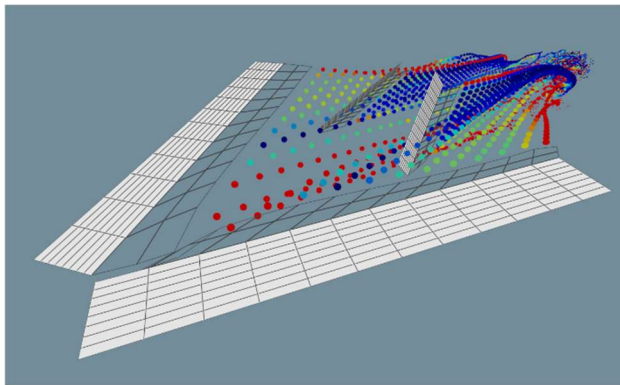


Figure 3 – Morphing UAS during the beginning of the launch phase, with its wings still mostly folded in.

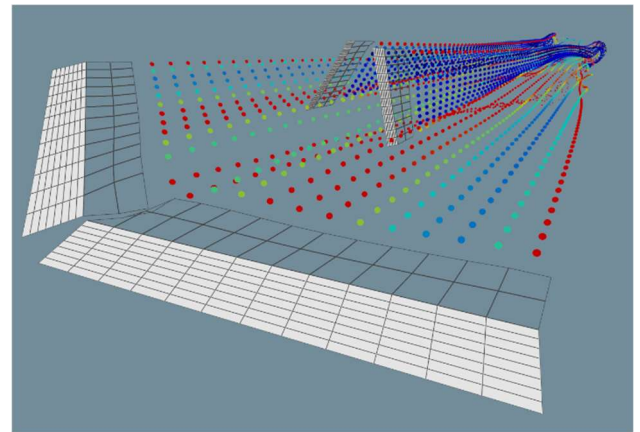


Figure 4 – Morphing UAS towards the end of the launch phase, with its wings almost fully deployed.

References

- [1] Chu, L., Li, Q., Gu, F., Du, X., He, Y., and Deng, Y., Design, modeling, and control of morphing aircraft: A review, *Chinese Journal of Acoustics*, 2022, vol 35, no. 5, pp. 220-246.
- [2] Cheng, H., Wang, H., Shi, Q., et al., Unsteady aerodynamics investigation of deploying tandem-wing with different methods, *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*, 2019, vol. 233, pp. 3714– 3733.
- [3] Selitrennik, E., Karpel, M., and Levy, Y., Computational Aeroelastic Simulation of Rapidly Morphing Air Vehicles, *Journal of Aircraft*, 2012, vol. 49, no. 6, pp. 1675–1686.
- [4] Cheng, H., Shi, Q., Wang, H., et al., Flight dynamics modeling and stability analysis of a tube-launched tandemwingaerial vehicle during the deploying process, *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*, 2022, vol. 236, pp. 262– 280.
- [5] van Elsloo, S.J., van Rooij, M., Hamraz, A. De Breuker, R., Voskuijl, M., *Multibody Dynamic and Aerodynamic Modeling of a Tube-Launched Sweep Morphing Unmanned Aerial System*, 2025.
- [6] Anderson, R. *FastMultipole.jl*, GitHub repository, 2026.
<https://github.com/byuflowlab/FastMultipole.jl>
- [7] Castro , Saullo G. P., *General-purpose finite element solver based on Python and Cython (Version 0.6.2)*, Zenodo, 2025.
- [8] Goland, M., The Flutter of a Uniform Cantilever Wing, *Journal of Applied Mechanics*, 1945, vol. 12, no. 4, A197-A208.