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# Manipulator-aircraft dynamical system dedicated for wind tunnel testing

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**Abstract:** This paper describes work focused on the development of a new conceptual design of a directly controlled manipulator placed in the working section of a wind tunnel, with the goal of expanding and diversifying the type of dynamic experiments performed in the tunnel. In this research, our main objective is to develop a model and controllers to simulate a manipulator with an aircraft test model attached to its end. The final model will be fully geometrically qualified to operate in confined spaces and to rigorously evaluate the nonlinear simulation for the determination of stability derivatives with high precision that relates to the *longitudinal flight* and control characteristics of the aircraft. Various simulation tests help to understand how close the calculated values are to reality, which can improve the determination of aircraft control in the *pitch plane*.

**Keywords:** wind tunnel tests, aircraft flight model, aircraft feedback control

## 1. Introduction – wind tunnel test challenges

Wind tunnel testing is long established experimental approach for aircraft design and analysis as well as fundamental flight physics and aerodynamics. Most wind tunnel studies involve static models, but dynamic wind tunnel studies are important for both the investigation of non-steady aerodynamics and for flight dynamics, particularly for non-linear flight regimes involving high angles of attack, unsteady aerodynamics, spin and upset recovery. Dynamic wind tunnel testing thus plays an important role in the determination of aerodynamic and flight dynamic parameter identification.

One longstanding ambition of wind tunnel testing has been to ‘fly’ an aircraft inside the wind tunnel [1]. This is clearly an expensive thing to do and is fraught with difficulties which has limited the experience to a few very large facilities and to specific flight regimes such as spin test. However, recent advances in measurement technologies have extended the possibilities and 3 degrees of rotational freedom ‘flight’ is now fairly common [2, for example], with 4 and 5 degrees of freedom (dof) having success in relatively small and low-cost facilities [3, 4]. An extensive review of dynamic wind tunnel testing can be found in [5].

The control of the aircraft in [3] was enacted by the classical elevator, rudder, aileron moving surfaces. However, energy is injected into the dynamic system through the propulsion system, and this affects the dynamics, particularly the longitudinal motion. Whilst the 4-dof rig used in [3] includes the heave motion, the surge motion is constrained, thus limiting the ‘flight’. Mechatronics technologies have also advanced enormously in recent years, so possibilities of mounting the aircraft on a manipulated sting now exist [1, for example]. In this work, the possibilities for full 6-dof flight in a wind tunnel with the ‘propulsion’ enacted by a robotic manipulator are investigated. In order to simplify the problem, 3-dof longitudinal flight only will be initially considered. Decoupling of longitudinal and lateral motion is a standard assumption in flight dynamics analysis and is valid for many flight regimes. A schematic of the proposed configuration is shown in Figure 1.

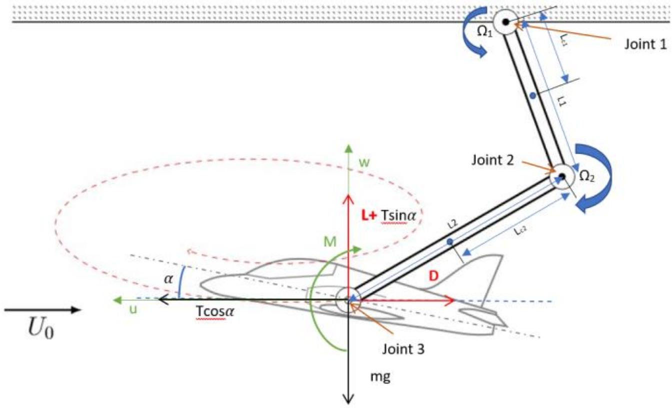


**Fig. 1.** Schematic diagram of a manipulator with an aircraft test model attached at the end intended for wind tunnel testing. The aircraft can freely rotate or manoeuvre in the x-z plane along the y-axis at joint 3. The pitch of the aircraft can be controlled by the elevator of the test aircraft model, which is assumed to be actuated. The manipulator arm joints, joint 1 and joint 2, are driven by servomotors (the best choice for systems requiring high accuracy) provide control of the aircraft thrust, denoted by T.

## 2. Results and discussion

The full paper will include the analysis of the system dynamics, including the aerodynamic forces. The 2-R manipulator consists of stiff links connected by mechanical joints and control torques that move the links so that the aircraft model at the end can make its longitudinal flight. The majority of this research is concerned with the design of the feedback loops of the position controllers applied to the joints, which should be properly synchronized to characterize the dynamics of the model being tested in its planar motion. Introducing a reduction in the required power by analyzing different ways to minimize support interference and deflection error correction, which can also lead to a reduction in the reaction transmitted to the tunnel structure.

The research presented here includes modeling the dynamics of a coupled manipulator and aircraft model and controller designs, and various simulations in MATLAB to design the control dynamics with a robust feedback loop.

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