

Correlation of Hand Book Method Results with Wind Tunnel Data for a Subsonic UAV Design

Stefan von Bergen and Jürg Müller
RUAG Aerospace

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ABSTRACT

In the preliminary design phase of an aircraft, handbook methods are used to size the aircraft and to predict its aerodynamic characteristics and flight performances. For a new twin-boom pusher UAV a systematic comparison of theoretical predictions and wind tunnel test data is performed. It is shown that although performance and stability parameters are generally well predicted important deviations can occur if the specific airplane configuration is not taken into account in a sufficiently accurate manner. This is illustrated using results from pitching moment estimates for different tail configurations.

INTRODUCTION

For the initial sizing and design of a new aircraft handbook methods are heavily used. With these, performance and stability data can be quickly estimated and parameter studies performed. Smaller development projects often go directly from this preliminary design to a flying prototype without the benefit of extensive CFD analysis or wind tunnel tests to validate the data and to reduce the corresponding uncertainties.

The present paper aims to illustrate, quantify and explain the differences between the results from handbook methods and wind tunnel measurements through the example of an UAV development program. The twin-boom aircraft (figure 1) is powered by a piston engine driven pusher propeller and has a span of 9.5 meters (31 ft). Handbook methods as described in Roskam [1] and implemented in a computer program [2] are used for the preliminary design. Wind tunnel tests were then performed on a 40% scale model in the Large Subsonic Wind Tunnel Emmen (LWTE). In addition to the internal 6-component balance, the model was equipped with strain gauges for hinge moment measurements on all control surfaces. The accurate and very complete aerodynamic database thus allows not only an exhaustive comparison of the global aerodynamic coefficients and, stability and control derivatives but also of hinge moments. In the discussion of the results

special attention is paid to the pitching moment for different configurations and the indirect power effects.



Figure 1: UAV development project

METHODS

HAND BOOK METHODS

The hand book methods are mainly based on superposition principles. For instance the lift of the entire aircraft with extended flaps is a sum of the lift of all lifting surfaces and the extra lift due to the flaps. Interference effects between different lifting surfaces are considered to a certain extent. For instance the methods account for the change in downwash angle on the horizontal tail plane due to the extended (wing fixed) flaps. Other interference effects, for instance the interferences between horizontal and vertical tail, are not accounted for.

WIND TUNNEL TESTS

The wind tunnel tests were performed in RUAG's Large Wind Tunnel Emmen (LWTE). In its closed test section of 7x5 meters (21x15 ft) a maximum speed of 70 m/s (157 mph) can be reached.

Based on the original aircraft external geometry definition a 40% scale model of the aircraft is built for wind tunnel testing. The model is designed for fast configuration changes and high modularity to facilitate efficient testing in the wind tunnel. The lifting surfaces, central fuselage and booms are machined out of aluminum, the forward fuselage from polyurethane. Engine cowling, undercarriage as well as the dummies for the external payloads are manufactured using rapid prototyping methods (STL and SLS). The wind tunnel model is equipped with an internal 6-component balance measuring the integral forces and moments. In addition all control surfaces were instrumented with strain gauge hinge moments balances so that the actuator loads could be determined.

The model is mounted in the wind tunnel through a dorsal mono-strut (figure 2). This setup is expected to cause only very small support interference effects, which remain uncorrected. The results are corrected for wind tunnel wall interference effects (blockage, induced flow angle even though these corrections are significantly smaller than the effects investigated in the present paper.

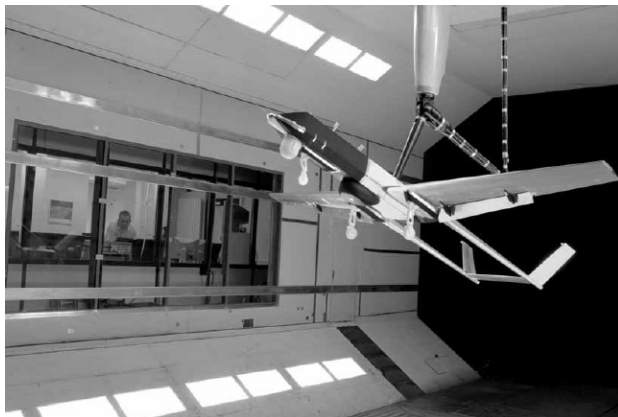


Figure 2: 40% model of the UAV in the LWTE wind tunnel

The current wind tunnel model is not powered and therefore propeller effects could not be investigated in this case. However the wind tunnel model of a predecessor UAV with at very similar layout was equipped with an engine and this data is used for comparison with the hand book method results.

LIFT AND PICHING MOMENT CHARACTERISTICS

The fundamental parameters defining the lift polare in the linear lift regime are the lift derivative $dc_L/d\alpha$ and the zero lift angle of attack α_0 .

A measure of the longitudinal stability is given by the variation of the pitching moment as a function of the

angle of attack or lift. For a given center of gravity location a larger value of the derivative $-dc_m/d\alpha$ indicates a higher longitudinal stability. It also influences the controllability: the more stable the airplane the more difficult it is to change its attitude. The range in which the stability derivative must lay is bound on side by a minimum stability requirement for the most rearward center of gravity (CG) location and on the other side by a minimal control authority requirement at the must forward CG location (usually the ability to flare upon landing).

The main influence factor on the longitudinal stability is the tail volume – the product of the horizontal tail surface and the distance between the wing and the horizontal tail.

In addition to the stability requirements other factors influence the layout and the sizing of the tail surfaces and finally the stability of the airplane. In this particular case these include the following:

- The twin boom pusher configuration puts the horizontal tail in the wake of the propeller and the fuselage.
- The vertical tail surfaces are tilted outward by 32 degrees in an attempt to reduce the radar cross section (RCS) of the airplane. This causes a coupling of the lateral and the longitudinal dynamics.
- The vertical fins are located at the end of the horizontal tail and thus function as endplates
- There are only flaps on the wing outboard of the booms. This influences the downwash generated at the tail by the extended flaps.

AIRCRAFT CONFIGURATIONS

The above effects and their influence on the longitudinal stability are discussed in further details for the configurations shown in table 1.

Table 1: Investigated aircraft configurations

Case #	Configuration	Flaps	(additional) relevant effects
1	Wing-Fuselage-Tailbooms	up	Wing and Fuselage Pitching moment
2	Wing-Fuselage-Tailbooms	40 deg	Flap Pitching moment
3	Wing-Fuselage-Tailbooms -HTP-tVTP	up	Empennage Effect
4	Wing-Fuselage-Tailbooms -HTP-tVTP	40 deg	Flap downwash

The starting point for all the calculations are the unmodified methods as described in [1] and implemented in [2]. Comparisons to the corresponding wind tunnel data indicates whether the theoretical model must be improved. This adjustment is performed if the physical reason for the discrepancy is understood and can be traced to the specific peculiarities of the aircraft configuration.

WING-FUSELAGE CLEAN (CASE 1)

For the first configuration only the contributions from the wing, the fuselage and the tail booms are considered.

Figure 4 shows the lift curves for the wing fuselage configuration. The theoretical slope is smaller than the one measured in the wind tunnel. This could be due to the hexagonal shape of the fuselage. The sharp edge along the fuselage forebody generates a strong vortex. The circulation and fuselage lift related to this vortex is not predicted by the hand book methods. Additionally the fuselage thus acts as a leading edge extension, the vortex introduces additional energy into flow in the area of the inner wing, delaying flow separation at high angle of attacks. This vortex was visualized by oil paint. Figure 3 shows the flow pattern on fuselage side in the area between the nose and the wing root.

The estimate for the zero lift angle is too negative. The method does not consider any influence of the fuselage on the zero lift angle of attack $\alpha_{0_{wf}}$. This value is calculated as the zero angle of attack of the wing, which is derived from the airfoil zero angle of attack and the wing twist, and the wing angle of incidence. It is assumed that the difference to the wind tunnel is a result of the neglected (negative) lift contribution of the fuselage. But since there are no wind tunnel tests for the fuselage alone it is not possible to substantiate this claim further.

The corrections applied on the wing fuselage lift curves are given in table 2.

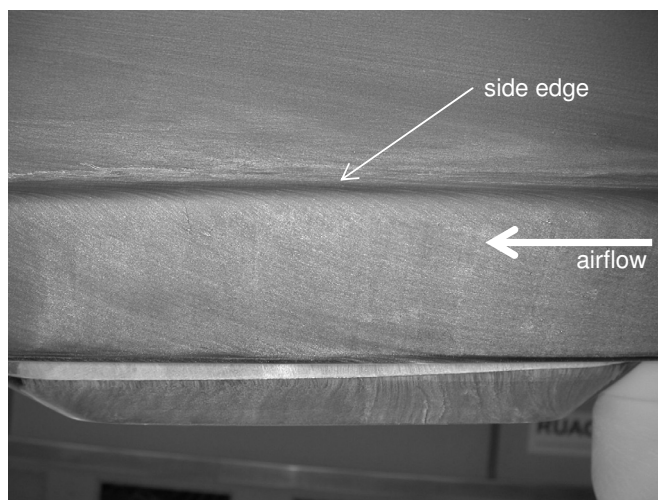


Figure 3: flow visualization on the fuselage forebody at 5 degree AoA

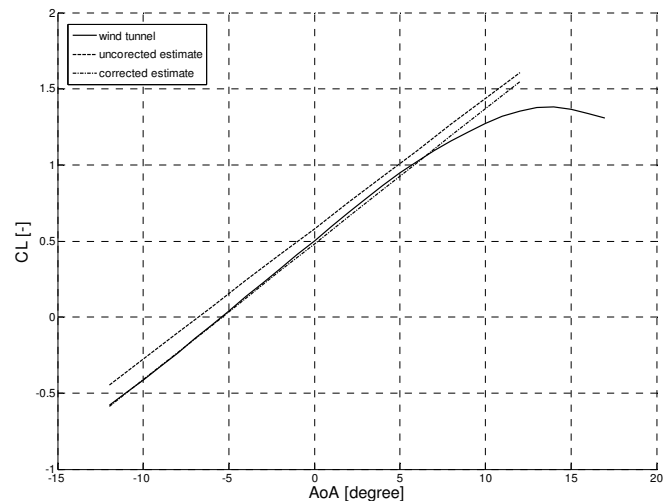


Figure 4: lift versus angle of attack for wing-fuselage-tail boom configuration

Figure 5 shows the pitching moment around the nominal CG position versus the angle of attack for this case. The calculation of the pitching moment derivative is based on the lift derivative. Note that for the *uncorrected* pitching moment curve the corrections made on the lift curve are considered.

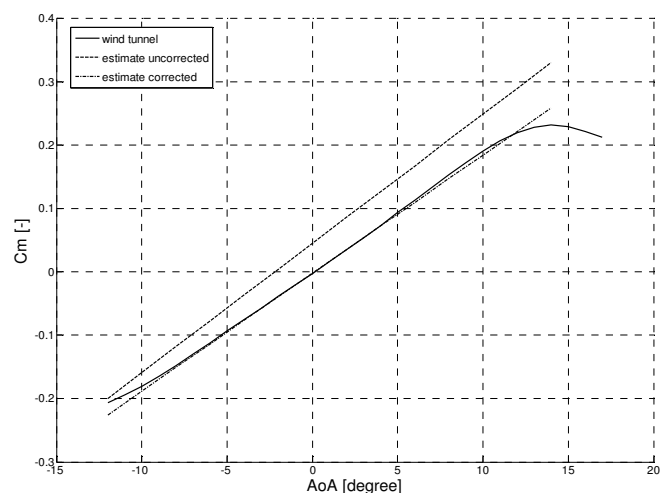


Figure 5: pitching moment versus angle of attack for wing-fuselage-tail boom configuration

Thus the residual difference to the wind tunnel curve is solely based on estimation errors in the zero-lift pitching moment and in the position of the aerodynamic center.

The zero-lift pitching moment of the wing is derived from the airfoil's value, for which wind tunnel data is available. Again the difference between the theory and the wind tunnel data is assumed to be due to the fuselage contribution. The fuselage zero lift pitching depends on the fuselage camber line. Due to the special faceted shape of the fuselage it is conceivable that the standard