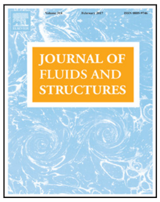
Journal of Fluids and Structures 81 (2018) 255–269

Contents lists available at ScienceDirect

Journal of Fluids and Structures

journal homepage: www.elsevier.com/locate/jfs



Influence of flexibility on the steady aeroelastic behavior of a swept wing in transonic flow

Günter Schewe [*], Holger Mai

DLR-Institute of Aeroelasticity, Göttingen, Germany

HIGHLIGHTS

- Influence of flexibility of a swept flexible wing compared to its rigid equivalent.
- Global forces, pressure distributions etc. were analyzed for $0.5 \leq Ma \leq 0.88$.
- In the transonic regime for the flexible wing there is a double shock system.
- By increasing of Mach or α, then both shocks are moving against each other.
- Structural wash-out (outer part) leads to an attenuation of the transonic effects.

ARTICLE INFO

Article history:
Received 6 December 2017
Accepted 24 April 2018

Keywords:
Transonic flow
Swept wing
Influence of flexibility
Aerostabil wing
Structural washout effect

ABSTRACT

The development in the last decades generally shows that large aircraft wings have become more light and flexible, thus the investigation of the effects of elasticity is suggested. If for example the flexible wing is also backward swept, then the situation becomes even more complex — the kinematic coupling between bending and torsion leads to a structural washout effect.

In order to investigate the influence of flexibility, in the project "Aerostabil" an aeroelastically scaled half-model was tested compared to its rigid equivalent. The flexible model was equipped with pressure transducers in three wing sections and accelerometers, while the rigid model had a reduced number of sensors. The experiments were performed in the adaptive test section of a transonic wind tunnel. Steady and unsteady pressure-, and force measurements were conducted for fixed and oscillating wings. Already Dietz et al. (2003) have reported about the special features of the wing models, their structural properties and preliminary results. The present paper is focused on the analysis of the global forces and pressure distributions for the range $0.5 \leq Ma \leq 0.88$. The angle of attack was varied from $-4°$ to $4°$ and also the quasistatic aeroelastic derivatives for lift and moment were obtained.

When the model is rigid in the transonic regime and at moderate angles of incidence the pressure distribution exhibits a single shock system, in contrast for the flexible wing there is a double shock system. For the flexible wing up to about $Ma = 0.82$ the curves of global lift, moment and their derivatives are rather smooth and are remaining on nearly the same level. Beyond there are moderate deviations up to the end of the transonic regime. However examining the corresponding curves of the rigid wing the changes are drastic,

---

[*] Corresponding author.
E-mail address: guenter.schewe@dlr.de (G. Schewe).

https://doi.org/10.1016/j.jfluidstructs.2018.04.021

particularly in the transonic range. Obviously the structural wash-out, particularly of the outer wing leads to an attenuation of the transonic effects.

1. Introduction

In the last decades the general trend shows that large aircraft wings have become more light and flexible, thus the investigation of the effects of elasticity is even more suggested. Particularly in the transonic regime the interaction between the shock dynamic, the boundary layer and its separation is a significant source of complex behavior. If the wing is flexible and in addition backward swept, as in case of a real transport aircraft then the kinematic coupling between bending and torsion leads to a washout-effect i.e. a reduction of the streamwise local angle of attack when the bending of the wing is increased. Hence the static bending and torsional deformations depending on the airloads can have drastic consequences on the global aerodynamic behavior and therefore on the aeroelastic stability.

The aerodynamic foundations of the swept wing concept were laid by Busemann (1935). He predicted that the compressibility effects are shifted to higher values of the Mach number when the wing is backward swept. The fundamental aeroelastic properties of the swept wing were investigated theoretically by Jordan (1946) in Götingen. He described the occurrence of the mentioned kinematic coupling effects between bending and torsion (washout) and he already predicted the possibility of one degree of freedom flutter of a backward swept wing (see also Försching, 2010; Meier, 2010). The field of steady and unsteady transonic aerodynamics and aeroelasticity are reviewed by Tijdeman and Seebass (1980) and Bendiksen (2011).

An early wind tunnel test with flexible models was performed in a German/French cooperation called "Aeroelastic Model Program (AMP)", (Zingel et al., 1991). Two models were applied; a scaled flexible swept wing with 300 pressure transducers and a dynamically scaled model for flutter tests. Apart from the steady and unsteady pressures also the static wing deformations were measured optically as well as the global steady and unsteady forces using a rigid piezoelectric balance. Only a few results are accessible in Zingel et al. (1991) and Arnold et al. (2009). Fig. 1 shows the AMP-wing in the French transonic wind tunnel S2 in Modane.

The present experiments were performed in the framework of the project "Aerostabil" and the features and details of the wing models and their structural properties are already described by Dietz et al. (2003). In that paper there are also a few results presented concerning static aeroelasticity.

In Bendiksen (2009) several investigations of an Aerostabil-similar wing with an identical planform but different airfoil shape and an Euler CFD-solver are presented. In this paper Bendiksen pointed out that the above mentioned wash-out effect is responsible for a special type of flutter, which he called "High-Altitude Limit Cycle Flutter". An example for this phenomenon will be presented in Schewe and Mai (2017). Neumann and Mai (2013) investigated experimentally and numerically the dynamic response problem using the same elastic Aerostabil model. Upstream of our elastic swept wing a generic gust was produced by a moving 2D wing, which acted as gust generator. The experiments were compared with numerical simulations leading to result concerning steady and unsteady deflections of the elastic wing and pressure distributions. Finally, the results of simulated transfer functions of the gust generator to the elastic wing are presented in comparison to the measurements. Stickan et al. (2014) used the Aerostabil data as test cases for their numerical simulation. A Navier Stokes solver (DLR-Tau code) and a linear structural shell model were applied. It turned out that the application of a shell-FE-model is necessary for the correct simulation of the Aerostabil experiments.

Based on the experience gained in the AMP-Program, the Aerostabil-Project was planned. Hence the main aim was to study the steady aeroelastic effects and the LCO-flutter behavior of a generic elastic swept wing. Thus a geometry of low complexity was selected. Nevertheless the aerodynamic shape is close to the geometry of the outer part of a modern transport aircraft wing. The model had a supercritical airfoil and was equipped with pressure transducers in three wing sections. In addition accelerometers were installed and steady and unsteady pressure measurements were taken. A very stiff mount at the root is a prerequisite for wind tunnel test with flexible wings, thus a rigid piezo balance was applied for the measurement of the steady and unsteady global forces. In order to see directly the influence of elasticity a second but rigid wing-model with the same geometry was applied.

Contrary to the mentioned paper by Dietz et al. (2003) the present investigation is concentrated on the description of the procedures during the Aerostabil-experiments and the evaluation of the data. The time functions of global forces, pressure distributions and accelerations were measured, thus steady and unsteady data for the Mach No range $0.5 \leq Ma \leq 0.88$ are available. The angle of attack was varied between $-4^\circ \leq \alpha \leq 4^\circ$ and also quasistatic aeroelastic derivatives were obtained, which reflect partly the behavior of both different wings regarding special effects in the transonic flow regime.

Flutter experiments were analyzed systematically in the transonic Mach number range and the results are presented in Schewe and Mai (2017).

2. Test set-up

As mentioned in the introduction, the features and details of the elastic wing model and their structural properties are described in Dietz et al. (2003) and Stickan et al. (2014). The sketch of the test-setup in Fig. 2 shows that the swept wing