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Adaptive support for aircraft panel testing: New method and its experimental verification on a beam structure

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ABSTRACT

Acoustic transmissibility of aircraft panels is measured in full-scale test rigs. The panels are supported at their frames. These boundary conditions do not take into account the dynamic influence of the fuselage, which is significant in the frequency range below 300 Hz. This paper introduces a new adaptive boundary system (ABS). It combines accelerometers and electrodynamic shakers with real-time signal processing. The ABS considers the dynamic effect of the fuselage on the panel. The frames are dominating the dynamic behaviour of a fuselage in the low-frequency range. Therefore, the new method is applied to a beam representing a frame of the aircraft structure. The experimental results are evaluated and the precision of the ABS is discussed. The theoretical apparent mass representing the cut-off part of a frame is calculated and compared with the apparent mass, as provided by the ABS. It is explained how the experimental set-up limits the precision of the ABS.

1. Introduction

Both a fuselage made from carbon fibre reinforced plastics and a counter-rotating open rotor engine are regarded as key technologies to reduce the fuel consumption of future aircraft. Both technologies lead to higher noise levels in the aircraft cabin [1]. Therefore, measures to reduce the noise transmission through the lightweight structure must be developed and tested in the future [2,3]. In comparison with jet engines, open rotors will probably have a greater significance in the future due to their reduced fuel consumption. Their acoustical challenge is the multi-tonal noise with high pressure amplitudes [4]. The fuselage dynamics exerts a major influence on the sound transmission [5].

Fig. 1 shows an aircraft panel mounted in a breakthrough of a wall. The three vertical grey stiffening elements are the so-called *frames*. They are bolted to other frame segments to form a closed circle in the fuselage. The 15 horizontal green stiffening elements are the stringers. In the so-called *low-frequency range* the eigenmodes of the lightweight fuselage are characterized by global deformations of the entire structure [6,7]. The bending stiffness of the frame has a significant influence, while in the so-called high-frequency range the local eigenmodes are dominated by stringer and skin stiffness. Only a few bays of the stiffened panel vibrate, whereas the frames remain nearly undeformed [8].

The most realistic way to investigate cabin noise is, of course, by **testing** the original **full-scale aircraft** fuselage [10,11]. Active noise reduction systems have been ground tested for example with a fuselage section of a Dornier 328 [12] and a

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Nomenclature

Latin characters

a	Vertical acceleration
A, B, C, D	Coefficients of $w(x)$
e	Error
E	Modulus of elasticity
F	Force
I	Areal moment of inertia
l	Length
L	Cutting moment
$\boldsymbol{M}$	Apparent mass
n	Discrete time step
Q	Cutting lateral force
$\boldsymbol{S}(n)$	Secondary path
$\hat{\boldsymbol{S}}(n)$	Secondary path model
t	Time
$w(x, t)$	Deflection of beam axis
$\boldsymbol{w}(n)$	Adaptive filter coefficients
x	Coordinate
$x(n)$	Reference signal
$\boldsymbol{X}'(n)$	Filtered reference signal

Greek characters

α	Angular acceleration
γ	Leakage factor
δ	Lever arm
κ	Parameter
μ	Mass per unit length
φ	Bending angle
ω	Angular frequency
ξ	Coordinate substructure

Indices

A, B	Cut-point
p	primary force
R	Reference structure
S	Substructure
s	secondary force

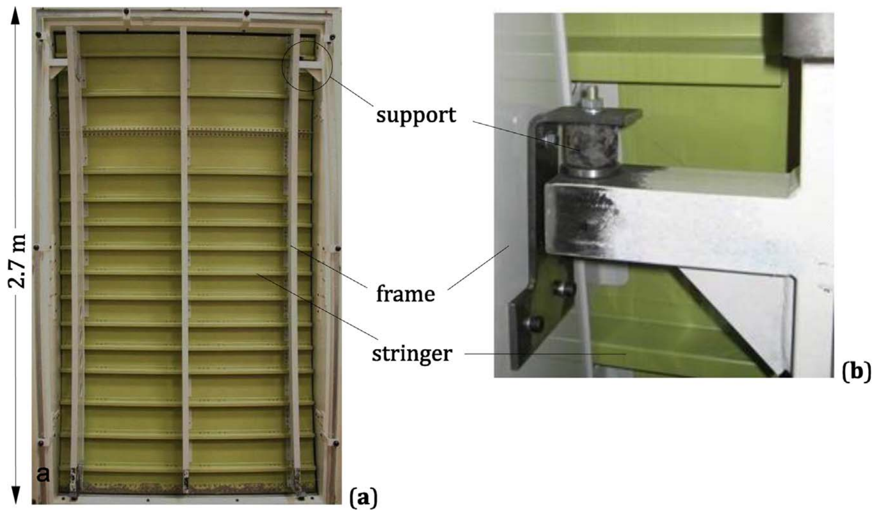

Fig. 1. Aircraft panel test bed, adapted from [9].

Boeing 767 [13], with an Airbus A400M preseries fuselage [14] and with a fully equipped Dornier 328 [15]. In-flight experiments have been carried out with a BAe 748 twin turboprop [16,17]. Full-scale aircraft testing is expensive and test conditions may vary.

Acoustic transmission laboratories with **full-scale aircraft panels** work under steady and in the high-frequency range realistic conditions. Due to the fact that the frames of the panel are clamped or mounted, the local eigenmodes of the structure stay nearly unchanged [9,18,19] and [20], compare Fig. 1. Thus, active and passive means for reduction of noise transmission through the aircraft fuselage can be tested [21–31].

At low frequencies, the vibration of the whole fuselage (global modes) has to be considered. This leads to the new concept of adaptive boundary conditions for the panel under investigation. The boundary conditions must behave dynamically like the part of the fuselage to which the panel is connected in the aircraft.

This paper is related to both research areas *Real-Time Hybrid Substructuring* (RTHS) and *Active Vibration Control* (AVC).

Real-Time Hybrid Substructuring is an active area of research, see [32–36]. This method cuts up a structure into two (or more) substructures. Mostly one substructure exists physically, whereas the other is calculated. Both are coupled in real-time. In the numerical substructure displacements are calculated. They are applied via actuators to the physical substructure. These displacements lead to measurable reaction forces that are input to the numerical substructure.