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Multi-disciplinary simulations of stores in weapon bays using scale adaptive simulation

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ABSTRACT

This paper presents cavity flow calculations using the scale-adaptive simulation method involving door opening, store release and aeroelasticity. For established bay flows, the structural excitation showed a directional dependence, and the structures were responding to the flow frequency content. Maximum store deformations were of about 2% of the store diameter during store release. This is the first time where such effects are quantified for stores released from within bays. The store deformation, the role of the shear layer, and the store trajectory variability are also quantified.

1. Introduction

Weapon bays are used to enhance the stealth of modern military aircraft. Nevertheless, during store delivery, exposed bays generate a strong acoustic field produced by a complex interaction between the shear layer and reflected acoustic waves travelling in the bay (Rossiter, 1964; Loupy and Barakos, 2017a). During carriage and release, stores are subjected to this unsteady flow and may undergo elastic deformations. The aeroelasticity of stores inside cavities received substantial attention in the last five years both using CFD and experiments.

Flight tests were conducted by Probst et al. (2017) using an SUU-41 POD mounted on a F-16. A store model, with canards and fins was placed at different carriage positions inside the cavity. The store loads and accelerations were noticeably influenced by the tonal bay flow fluctuations. Wagner et al. (2015, 2016) obtained similar results in a wind tunnel, where the store was represented by a cylinder held on two support rods (Wagner et al., 2015), and had a tunable natural frequency (Wagner et al., 2016). The results showed an excitation of the store at its natural structural frequencies, and at cavity modes. Near mode matching, the store response varied with changes of the store vibration by a factor two for a variation of cavity tone frequencies by about 1%. Switching to a complex cavity geometry increased the span-wise vibrations due to further asymmetries in the cavity flow (Casper et al., 2017). Nevertheless, experiments were limited to low Reynolds numbers compared to in flight conditions, and the scaled structures were not representative of actual full scale stores.

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Latin

C_x, C_y, C_z	Axial, side and normal force coefficients (–)
C_l, C_m, C_n	Rolling, pitching and yawing moment coefficients (–)
D	Cavity depth (m)
d_{mis}	Store diameter (m)
d_{ref}	Reference length (m)
f	Frequency (Hz)
f_d	Door opening frequency (Hz)
f_m^s	Modal force on solid s for the mth mode (N/m·kg)
f_{tt}	Cavity travel time frequency (Hz)
I_x, I_y, I_z	Moment of inertia of the store ($kg \cdot m^2$)
k	Specific turbulent kinetic energy (m^2/s^2)
L	Cavity length (m)
L_s	Store length (m)
m_s	Mass of the store (kg)
M_∞	Free-stream Mach number (–)
N_i	Number of inner timesteps (–)
n_s	Number of CFD points on solid s (–)
n_{sp}	Number of shared points (–)
n_m^s	Number of modes for solid s (–)
p, q, r	Roll, pitch and yaw rates (deg/s)
p	Pressure (Pa)
$\mathbf{p}(p, t)$	Pressure vector at a point p, and at a time t (N/m^2)
$\mathbf{P}(p)$	Position of node p (m)
$\mathbf{R}$	Rotation matrix (–)
Re_L	Reynolds number based on cavity length (-)
S	Reference area (m^2)
u, v, w	Velocity components (m/s)
t	Time (s)
$\mathbf{t}$	Translation matrix
T	Temperature (K)
U_∞	Free-stream Velocity (m/s)
W	Cavity width (m)
W_e	Maximum envelope width
$w_i(\mathbf{x})$	Interpolation weight (–)
X, Y, Z	Earth reference coordinates (m)
X_b, Y_b, Z_b	Store reference coordinates (m)
X_{dp}, Y_{dp}, Z_{dp}	Port side door reference coordinates (m)
X_{ds}, Y_{ds}, Z_{ds}	Starboard side door reference coordinates (m)
X_f, Y_f, Z_f	Fins reference coordinates (m)

Greek

α_m^s	Model amplitude of mode m of solid s (–)
Δ_μ	Statistical convergence index (–)
$\mu(t, n)$	Average of n trajectories
ω_m	Pulsation (1/s)
ϕ, θ, ψ	Roll, pitch and yaw angles (deg)
ϕ_p, ϕ_s	Port side and starboard door angle (deg)
ϕ_m^s	Normalised mth mode displacement of solid s (m/kg)
ϕ^s	Normalised displacement of solid s (m/kg)
ρ	Density (kg/m^3)
ζ_m	Damping coefficient (–)

Acronyms

ADT	Alternate Digital Tree
AEDC	Arnold Engineering Development Center
CFD	Computational Fluid Dynamics