Writing Tips for the AERO-CORE Lab

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The flying and handling qualities of a Small-scale Supersonic Uncrewed Aerial Vehicle (SSUAV) are analyzed to facilitate future SSUAV design and experimental testing. For this goal, the flying qualities of an experimental Multipurpose Uncrewed Fixed-wing Advanced Supersonic Aircraft (MUFASA) SSUAV are assessed. A continuous handling quality evaluation is proposed and implemented across the SSUAV's flight regime, providing a new flight trajectory optimization method. The results highlight that the mean handling qualities of the targeted SSUAV range from acceptable to controllable in the transonic flight regime and controllable in the subsonic regime. Finally, SSUAVs were compared to small-scale UAVs and full-scale supersonic aircraft, exhibiting much higher roll-rates. When attitude rates are normalized, SSUAVs exhibit roll behavior in line with small-scale UAVs but pitch behavior in line with full-scale supersonic aircraft. SSUAVs pose unique handling quality challenges that combine elements of small-scale UAVs and large-scale supersonic aircraft.

Nomenclature

b	=	wingspan, m
C_D, C_L, C_Y	=	drag, lift, and lateral force coefficient
C_F	=	skin friction coefficient
C_l, C_m, C_n	=	roll, pitch, and yaw moment coefficient
c_{mean}	=	mean aerodynamic chord, m
$\mathbf{F}_{\text{aero}}$	=	aerodynamic force vector along the body axes, N
$\mathbf{F}_g$	=	force of gravity vector, N
$\mathbf{F}_T$	=	force vector of engine thrust, N
$I_{\text{xx}}, I_{\text{yy}}, I_{\text{zz}}$	=	aircraft moments of inertia about the body axes, $\text{kg} \cdot \text{m}^2$
I_{xz}	=	aircraft product of inertia about the xz-axis, $\text{kg} \cdot \text{m}^2$
m	=	mass, kg
$\mathbf{M}_{\text{aero}}$	=	aerodynamic moment vector about the body axes, $\text{N} \cdot \text{m}$

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$\mathbf{M}_T$	=	moment vector due to engine thrust, $\mathrm{N} \cdot \mathrm{m}$
n	=	Froude scaling factor
P, Q, R	=	aircraft angular velocity about the body axes, $\frac{\mathrm{rad}}{\mathrm{s}^2}$
T	=	time constant, s
$T_{\square 2}$	=	time-to-double, s
U, V, W	=	aircraft translational velocity along the body axes, $\frac{\mathrm{m}}{\mathrm{s}}$
V_a	=	aircraft resultant velocity magnitude, $\frac{\mathrm{m}}{\mathrm{s}}$
x_b, y_b, z_b	=	body axes Cartesian coordinates
α	=	angle of attack, rad
β	=	angle of sideslip, rad
$\delta_a, \delta_e, \delta_r$	=	control surface deflections, rad
ξ	=	damping ratio
τ	=	time constant, s
ω	=	natural frequency, $\frac{\mathrm{rad}}{\mathrm{s}}$

Subscripts

0	=	nominal coefficient
dr	=	Dutch-Roll
ph	=	phugoid
r	=	roll subsidence
s	=	spiral
sp	=	short period

I. Introduction

SMALL-scale Supersonic Uncrewed Aerial Vehicles (SSUAVs) have the potential to revolutionize high-speed research and civil transportation. The next era in supersonic civil transportation is approaching, with multiple supersonic aircraft concepts proposed for development [1]. Unfortunately, supersonic prototype aircraft are costly, and the financial risk of development to companies is large [2]. An alternative to full-scale prototype aircraft development is an SSUAV. Small-scale UAVs are now increasingly used as low-cost technology testing platforms [3], and developing an SSUAV would significantly reduce the costs of supersonic aircraft development [4]. A handful of developmental research programs have investigated the feasibility of an SSUAV demonstrator [5–11], however, only six programs (Ohwashi, MUFASA, SCALOS, R-UAV, Project Boom, and The Mach Initiative) are ongoing according to recent publications

[8–12]. Of the aforementioned projects, none have undergone high-speed flight testing, and the fastest small-scale aerial vehicle flown remains the Trance remote piloted UAV [13]. One reason for the lack of a functioning SSUAV is that the aerodynamic conditions experienced by an SSUAV and the control required remain undetermined [11]. Whether SSUAVs pose unique handling quality challenges is an open research question that requires further study. Different SSUAV control strategies have been implemented [14–17]; however, due to the absence of standardized performance criteria, none of the control laws can be deemed reliably satisfactory [18]. Unfortunately, fixed-wing UAV flying quality performance standards are nonexistent [19], with UAV flying quality research still in its infancy [19, 20]. To facilitate UAV flying quality standard development, flying quality data from multiple aircraft types must be generated [21, 22]. To facilitate the inclusion of SSUAVs in future UAV flying quality standards, SSUAV flying quality and perturbation response data must be generated.

II. Conclusions

This paper obtained SSUAV aerodynamic and flying quality data by modeling the MUFASA and GOJETT SSUAV concepts. The MUFASA SSUAV flying quality parameters were evaluated against a proposed continuous modification of the MIL-STD-1797A standard for full-scale aircraft via Froude scaling. MUFASA exhibited mostly acceptable (level 2) performance at the analyzed cruise conditions of 4km altitude and $350\frac{m}{s}$. This evaluation was then performed across MUFASA's flight regime to generate a handling quality level surface, a new tool for flying quality based flight trajectory optimization. Though the proposed modification to MIL-STD-1797A was designed to yield a continuous handling quality evaluation, abrupt transitions were still present. These abrupt handling quality level transitions are attributed to slight aerodynamic coefficient changes occurring where data was collected and a lack of specifications to quantify instability.

When comparing each aircraft at its cruise conditions, MUFASA and GOJETT achieved a roll-rate at least twice as fast as small-scale UAVs and an order of magnitude faster than full-scale supersonic aircraft. Regarding pitch-rate, MUFASA and GOJETTS's performance was in line with full-scale supersonic aircraft. When normalized, SSUAVs exhibit roll behavior in line with small-scale UAVs but pitch behavior in line with full-scale supersonic aircraft. Taken together, the MUFASA and GOJETT SSUAVs pose unique handling quality challenges that combine elements of small-scale UAVs and large-scale supersonic aircraft.

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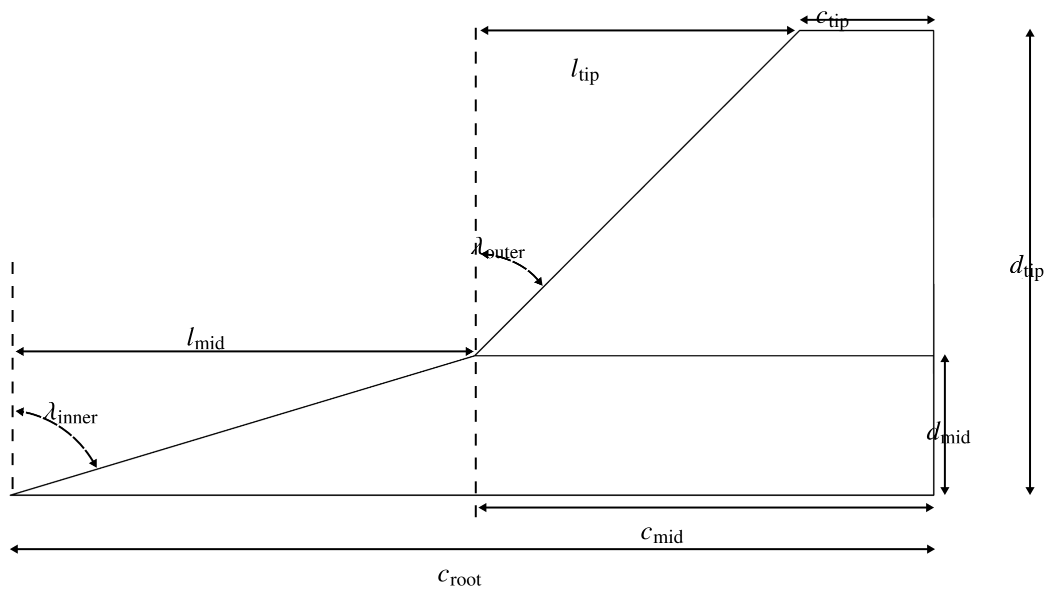

Fig. 1 MUFASA B aerodynamic design and coordinate system.

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