Supplementary Material: Full Nomenclature
Effect of Carbon Black and Aluminum Additives on Combustion Instability in Paraffin/GOX Hybrid Rockets: Experiments and a Classification Framework

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Nomenclature

Latin Symbols	
a	Power-law coefficient (mm/s / (kg/m^{2}s)^n)
A_s	Fuel surface area (m^2)
c	Speed of sound in combustion chamber (m/s)
D	Port diameter (m)
D_0	Initial port diameter (m)
D_f	Final port diameter (m)
f	Frequency (Hz)
f_1	Fundamental acoustic frequency (Hz)
G	Oxidizer mass flux (kg/m^{2}s)
G_{avg}	Average oxidizer mass flux over burn (kg/m^{2}s)
h	Step height (pre-chamber to port) (m)
L	Fuel grain length (m)
L_{pre}	Pre-combustion chamber length (m)
$\dot{m}_f$	Fuel mass flow rate (kg/s)
$\dot{m}_{ox}$	Oxidizer mass flow rate (kg/s)
n	Power-law exponent (dimensionless)
p	Chamber pressure (Pa)
p'	Pressure oscillation amplitude (Pa)
p'/p	Relative pressure oscillation amplitude (dimensionless)
q'	Heat release oscillation amplitude (W/m^3)
$\dot{r}$	Regression rate (mm/s)
$r_{0.7}$	Regression rate at 70% of burn time (mm/s)
Re	Reynolds number (dimensionless)
St	Strouhal number (dimensionless)
t	Time (s)
t_{burn}	Burn duration (s)
u	Local flow velocity (m/s)
u_{pre}	Mean oxidizer velocity in pre-combustion chamber (m/s)
Greek Symbols	
Δm	Fuel mass loss (kg)
Δt	Time interval (s)
ϕ	Equivalence ratio (dimensionless)
ρ_f	Fuel density (kg/m^3)
Subscripts	

0	Initial condition
f	Final condition; fuel
ox	Oxidizer
pre	Pre-combustion chamber
stoich	Stoichiometric
Acronyms and Abbreviations	
AP	Ammonium perchlorate
GOX	Gaseous oxygen
HFI	High-frequency instability
HTPB	Hydroxy-terminated polybutadiene
HYPRO	Hybrid Propulsion Analysis and Optimization
IFI	Intermediate-frequency instability
LFI	Low-frequency instability
PA	Paraffin + micron-aluminum (14 wt%)
PAA	Paraffin + activated nano-aluminum (14 wt%)
PC	Paraffin + carbon black (1 wt%)
PSD	Power spectral density
RSS	Root-sum-square
STFT	Short-time Fourier transform
TOST	Two one-sided test
VMD	Variational mode decomposition
Other Constants and Parameters	
R^2	Coefficient of determination (fit quality)
95% CI	95% confidence interval
p	p-value (statistical significance)

Note: All symbols follow standard rocket propulsion notation. Additional details on measurement uncertainties can be found in Section **??** of the main paper.