Generic Thrust Model for F-18 Aircraft Simulation

1   Introduction

In six-degrees-of-freedom (6-DOF) aircraft simulations, the propulsion system provides forces and moments that strongly influence the translational and rotational motion of the vehicle. For high-fidelity aircraft such as the F/A-18 Hornet, real propulsion models involve nonlinear engine dynamics, inlet effects, afterburner scheduling, and extensive lookup tables. However, for **control-oriented modeling, trimming, linearization, and academic simulations**, simplified thrust models are commonly employed.

This document explains a **generic thrust model** used in Simulink, evaluates its applicability to an F-18 simulation, and derives the **force and moment contributions** from first principles of rigid-body dynamics.

2   Generic Thrust Model Formulation

The thrust magnitude is modeled as:

$$T = \delta_T \, T_{\max} \left(\frac{V}{V_{ref}} \right)^{n_V} \left(\frac{\rho}{\rho_{ref}} \right)^{n_\rho} \tag{1}$$

where:

- T : Engine thrust magnitude (N)

- δ_T : Throttle command (0–1)

- $T_{\max}$: Maximum thrust at reference conditions (N)

- V : True airspeed (m/s)

- V_{ref} : Reference airspeed (m/s)

- ρ : Air density (kg/m^3)

- ρ_{ref} : Reference density (kg/m^3)

- n_V : Velocity exponent

- n_ρ : Density exponent

This formulation captures the **first-order dependence of thrust on flight condition** while remaining computationally simple.

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3 Physical Interpretation of Model Parameters

3.1 Throttle Scaling (δ_T)

The throttle command linearly scales thrust:

$$0 \leq \delta_T \leq 1 \tag{2}$$

The engine is assumed to respond instantaneously to throttle changes, meaning **engine spool dynamics are neglected**. This assumption is valid for trim analysis and basic flight control design but not for transient propulsion studies.

3.2 Velocity Scaling Term

$$\left(\frac{V}{V_{ref}}\right)^{n_V} \tag{3}$$

Typical values:

- Turbofan engines: $n_V = 0$

- Turboprop engines: $n_V = -1$

For the F/A-18, which uses twin F404 turbofan engines, $n_V = 0$ implies thrust is **independent of airspeed**. This is a reasonable approximation at subsonic speeds where inlet pressure recovery effects are not explicitly modeled.

3.3 Density Scaling Term

$$\left(\frac{\rho}{\rho_{ref}}\right)^{n_\rho} \tag{4}$$

Typical values are:

$$0.7 \leq n_\rho \leq 1.0 \tag{5}$$

Physically, reduced air density leads to lower mass flow through the engine, resulting in reduced thrust.

4 Applicability to F-18 Simulation

The model is suitable for:

- Control law development

- Aircraft trimming and linearization

- Educational 6-DOF simulations

- Placeholder propulsion modeling

However, it does not capture:

- Afterburner operation

- Mach-dependent thrust variation

- Engine spool dynamics

- Inlet pressure recovery

Thus, it should be regarded as a **control-oriented propulsion approximation**, not a performance-accurate engine model.

5   Thrust Vector Resolution in Body Axes

Assuming the engine axis is aligned with the body x-axis and tilted by the angle of attack α, the thrust vector is resolved as:

$$X_{eng} = T \cos \alpha \tag{6}$$
$$Z_{eng} = T \sin \alpha \tag{7}$$
$$Y_{eng} = 0 \tag{8}$$

where:

- X_{eng} : Body-axis longitudinal force

- Z_{eng} : Body-axis vertical force

- Y_{eng} : Body-axis lateral force

This decomposition is required for correct inclusion of thrust in the rigid-body equations of motion.

6   Rigid-Body Moment Generation from Thrust

6.1   Fundamental Principle

The moment generated by engine thrust is:

$$\mathbf{M}_{eng} = \mathbf{r}_{eng} \times \mathbf{F}_{eng} \tag{9}$$

where:

- $\mathbf{r}_{eng} = (x_f,\, 0,\, z_f)$: Engine position relative to CG

- $\mathbf{F}_{eng} = (X_{eng},\, 0,\, Z_{eng})$: Engine force vector

6.2   Pitching Moment

Evaluating the cross product yields:

$$M_{eng} = x_f Z_{eng} - z_f X_{eng} \tag{10}$$

This pitching moment represents:

- Nose-up moment if thrust acts below CG

- Nose-down moment if thrust acts above CG

- Pitch-down tendency if thrust line is ahead of CG

6.3   Roll and Yaw Moments

For a symmetric twin-engine configuration without thrust vectoring:

$$L_{eng} = 0 \tag{11}$$
$$N_{eng} = 0 \tag{12}$$

7   Conclusions

This generic thrust model:

- Correctly represents thrust-induced forces and moments

- Is suitable for F-18 trim and control simulations

- Is not intended for high-fidelity propulsion modeling

Note: The simplicity of this model is a feature when the objective is flight dynamics and control analysis rather than propulsion system design.