

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:

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

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/m³)
- ρ_{ref} : Reference density (kg/m³)
- n_V : Velocity exponent
- n_ρ : Density exponent

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

3 Physical Interpretation of Model Parameters

3.1 Throttle Scaling (δ_T)

The throttle command linearly scales thrust:

$$0 \leq \delta_T \leq 1 \quad (2)$$

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

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

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

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

Typical values are:

$$0.7 \leq n_\rho \leq 1.0 \quad (5)$$

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 thrust axis is aligned with the body x -axis and inclined by a thrust vector angle α_T relative to the body x -axis

$$X_{eng} = T \cos \alpha_T \quad (6)$$

$$Z_{eng} = T \sin \alpha_T \quad (7)$$

$$Y_{eng} = 0 \quad (8)$$

where:

- X_{eng} : Body-axis longitudinal force
- Z_{eng} : Body-axis vertical force
- Y_{eng} : Body-axis lateral force

Here α_T denotes the *thrust vector inclination angle*, defined as the angle between the engine thrust axis and the body x -axis. This angle is a propulsion installation or thrust-vectoring parameter and must not be confused with the aerodynamic angle of attack, which is defined by the direction of the relative wind.

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:

$$\mathbf{M}_{eng} = \mathbf{r}_{eng} \times \mathbf{F}_{eng} \quad (9)$$

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:

$$M_{eng} = x_f Z_{eng} - z_f X_{eng} \quad (10)$$

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:

$$L_{eng} = 0 \quad (11)$$

$$N_{eng} = 0 \quad (12)$$

7 Numerical Constants for F/A-18 Engine Modeling

This section specifies the numerical values of the constants used in the generic thrust and moment model when applied to the F/A-18 aircraft. The intent is to provide a control-oriented yet physically meaningful propulsion representation suitable for trimming, linearization, and flight control design.

7.1 Reference Flight Conditions

The thrust model is normalized using standard sea-level reference conditions:

$$V_{\text{ref}} = 200 \text{ m/s} \quad (13)$$

$$\rho_{\text{ref}} = 1.225 \text{ kg/m}^3 \quad (14)$$

These reference values are chosen to lie close to typical subsonic cruise and maneuvering speeds of the F/A-18, ensuring numerical robustness during trimming and simulation.

7.2 Maximum Engine Thrust

The F/A-18 is powered by two General Electric F404-GE-402 turbofan engines. Representative thrust levels per engine are:

- Dry (military) thrust: 48–50 kN
- Afterburner thrust: 78–80 kN

Since afterburner dynamics are not modeled, the dry thrust value is used. The total equivalent thrust for a twin-engine configuration is therefore:

$$T_{\max} = 96,000 \text{ N} \quad (15)$$

In the Simulink model, this thrust is treated as a single equivalent force acting along the body x -axis.

7.3 Velocity Scaling Exponent

The thrust variation with airspeed is governed by the exponent n_V :

$$n_V = 0 \quad (16)$$

This reflects the approximately constant thrust behavior of low-bypass turbofan engines in subsonic flight. Effects such as inlet pressure recovery and Mach-dependent thrust lapse are neglected for control-oriented modeling.

7.4 Density Scaling Exponent

The reduction of thrust with altitude is modeled using a density exponent:

$$n_\rho = 0.8 \quad (17)$$

Physically, thrust is proportional to engine mass flow, which scales approximately with air density. Empirical data for turbofan engines suggest n_ρ typically lies between 0.7 and 1.0. The chosen value provides a reasonable compromise between realism and simplicity.

7.5 Engine Location Relative to Center of Gravity

Thrust-induced moments arise because the engine thrust line does not pass through the aircraft center of gravity. The engine position vector in body axes is defined as:

$$\mathbf{r}_{\text{eng}} = \begin{bmatrix} x_f \\ 0 \\ z_f \end{bmatrix} \quad (18)$$

Representative values for the F/A-18 are:

$$x_f = -4.5 \text{ m}, \quad z_f = 0.5 \text{ m} \quad (19)$$

The negative x_f indicates that the engines are located aft of the center of gravity, while the positive z_f indicates that the thrust line lies below the center of gravity.

7.6 Derivation of the Engine Pitching Moment

The engine-induced moment is given by the rigid-body relation:

$$\mathbf{M}_{\text{eng}} = \mathbf{r}_{\text{eng}} \times \mathbf{F}_{\text{eng}} \quad (20)$$

where the thrust force vector in body axes is:

$$\mathbf{F}_{\text{eng}} = \begin{bmatrix} T \cos \alpha \\ 0 \\ T \sin \alpha \end{bmatrix} \quad (21)$$

Evaluating the cross product yields the pitching moment:

$$M_{\text{eng}} = x_f Z_{\text{eng}} - z_f X_{\text{eng}} \quad (22)$$

Substituting for the force components:

$$M_{\text{eng}} = x_f T \sin \alpha - z_f T \cos \alpha \quad (23)$$

The first term represents a pitch-down contribution due to the aft engine location, while the second term represents a pitch-up contribution due to the thrust line lying below the center of gravity. The net pitching moment is the balance of these two geometric effects.

7.7 Summary of Constants

$$V_{\text{ref}} = 200 \text{ m/s} \quad (24)$$

$$\rho_{\text{ref}} = 1.225 \text{ kg/m}^3 \quad (25)$$

$$T_{\text{max}} = 96,000 \text{ N} \quad (26)$$

$$n_V = 0 \quad (27)$$

$$n_\rho = 0.8 \quad (28)$$

$$x_f = -4.5 \text{ m} \quad (29)$$

$$z_f = 0.5 \text{ m} \quad (30)$$

$$\alpha_T = 0 \quad (31)$$

These constants are appropriate for trimming, linearization, and control-law development of the F/A-18 within a six-degrees-of-freedom rigid-body simulation framework.

8 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.