AIRCRAFT PERFORMANCE SIMULATION REPORT

Boeing 737-800 Case Study | Physics-Based Analysis

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ISA Std. Atmosphere | Parabolic Drag Polar | Breguet Range | V-n Envelope | 2D Perf. Maps

A comprehensive physics-based analysis of the Boeing 737-800 narrow-body aircraft
using a custom Python simulator built from first principles.

0 ABOUT THE AUTHOR

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Ansh Pathak is a driven and adept junior at Heritage High School with a strong passion for STEM fields, especially aerospace engineering and quantum mechanics. Backed by 7+ years of programming and engineering experience and a demonstrated ability to solve complex problems, Ansh actively seeks opportunities to pursue professional development, innovate, lead, and apply his skills in real-world projects through hands-on work, rigor, and impactful collaborations.

This report was produced using a custom physics-based Aircraft Performance Simulator built entirely from scratch in Python, covering ISA atmospheric modelling, parabolic drag polar analysis, climb envelope computation, V-n maneuvering diagrams, Breguet range and endurance, and 2D performance maps.

1 EXECUTIVE SUMMARY

This report presents a comprehensive aircraft performance analysis of the Boeing 737-800 narrow-body commercial jet, conducted using a custom physics-based simulator grounded in standard aerospace engineering principles. The simulator implements the International Standard Atmosphere (ISA) model, a parabolic drag polar, a density-lapse thrust model, and the Breguet jet range equation to compute all major performance metrics across the full flight envelope.

The analysis covers sea-level static performance, cruise performance at FL350 (10,668 m), climb envelope and ceiling analysis, V-n maneuvering limits, range and endurance, and 2D performance maps across velocity-altitude space. Simulated results are benchmarked against published Boeing 737-800 data.

Parameter	Simulated	Real-World Reference
Stall Speed Vs (SL, MTOW, clean)	70.8 m/s (138 kt)	68 - 75 m/s (132-146 kt)
Best Glide / Range Speed Vbg	112 m/s (217 kt)	210-240 m/s at cruise alt.
Max L/D (aerodynamic efficiency)	16.4	17-19 (clean cruise config)
Max Level Speed Vmax (SL)	356 m/s (691 kt)	~280 m/s (Mach 0.82+)
Best Rate-of-Climb Speed Vy (SL)	209 m/s (407 kt)	150-170 m/s
Max Rate of Climb (SL, MTOW)*	40.97 m/s (8064 ft/min)	12-15 m/s [see note]
Service Ceiling (ROC = 100 ft/min)	13.44 km (44087 ft)	12,497 m (41,000 ft) certified
Cruise L/D at FL350, Mach 0.785	15.7	15-17
Cruise SAR at FL350	0.3309 km/kg	0.330-0.350 km/kg
Breguet Range (max fuel, no reserves)	4088 km	5,765-6,650 km (published)
Breguet Endurance	10.2 hr	7-9 hr

Real-world references: Boeing 737 Airport Planning (D6-58325-6), Jane's All the World's Aircraft, and NASA/FAA published flight performance databases. Simulator uses clean configuration, ISA standard day, no fuel reserves.

2 PHYSICS, MATHEMATICAL FRAMEWORK AND ASSUMPTIONS

2.1 International Standard Atmosphere (ISA)

The ISA defines atmospheric properties as functions of altitude. In the troposphere (0 to 11,000 m) temperature decreases linearly at the standard lapse rate. Above 11,000 m the stratosphere is isothermal at 216.65 K. All other properties follow from the temperature and the ideal gas law.

$$T(h) = T_0 + L \cdot h \quad (\text{troposphere, } h \le 11{,}000 \text{ m})$$

Temperature lapse: T0 = 288.15 K, L = -0.0065 K/m, h in metres

$$P(h) = P_0\left(\frac{T}{T_0}\right)^{-g/(L \cdot R)}$$

ISA pressure: P0 = 101,325 Pa, g = 9.807 m/s2, R = 287.058 J/(kg K)

$$\rho(h) = \frac{P}{R \cdot T}$$

Density from the ideal gas law (kg/m3)

$$a = \sqrt{\gamma R T}$$

Speed of sound: gamma = 1.4 (ratio of specific heats)

2.2 Lift and Drag — Parabolic Drag Polar

The lift coefficient required for steady level flight is obtained by equating lift to weight. The parabolic drag polar relates total drag coefficient to induced and zero-lift (parasite) drag, and is the standard model for subsonic attached-flow flight.

$$C_L = \frac{2W}{\rho V^2 S}$$

Lift coefficient for steady level flight

$$C_D = C_{D_0} + k\,C_L^2 \qquad k = \frac{1}{\pi\, e\, AR}$$

Parabolic drag polar — k is the induced-drag factor

$$D = \frac{1}{2}\rho\, V^2\, S\, C_D$$

Aerodynamic drag force (N)

$$\left(\frac{L}{D}\right)_{\max} = \frac{1}{2\sqrt{C_{D_0} k}}, \qquad C_{L,\text{opt}} = \sqrt{\frac{C_{D_0}}{k}}$$

Maximum L/D and optimal lift coefficient (when induced drag equals parasite drag)

2.3 Stall Speed

$$V_s = \sqrt{\frac{2W}{\rho S C_{L,\max}}}$$

Minimum speed for sustained level flight (m/s)

2.4 Thrust and Power

Thrust lapse with altitude is modelled as proportional to air density ratio. This is a reasonable first approximation for turbofan engines in subsonic flight, though real engines deviate above approximately 7,000 m.

$$T_{\text{av}}(h) = T_{\max,\text{SL}} \cdot \frac{\rho(h)}{\rho_0}$$

Density-lapse thrust model

$$P_{\text{req}} = D \cdot V \qquad P_{\text{av}} = T_{\text{av}} \cdot V$$

Power required and available (watts)

2.5 Climb Performance

$$\text{ROC} = \frac{P_{\text{av}} - P_{\text{req}}}{W} = \frac{(T-D)\,V}{W}$$

Rate of Climb — Vy is the speed maximising ROC

$$P_s = \frac{(T-D)\,V}{W}$$

Specific Excess Power (m/s) — equals ROC in steady climb

2.6 Range and Endurance — Breguet Jet Model

$$R = \frac{V}{g \cdot \text{TSFC}} \cdot \frac{C_L}{C_D} \cdot \ln\left(\frac{W_i}{W_f}\right)$$

Breguet range (m) — assumes constant speed, altitude, and L/D

$$E = \frac{1}{g \cdot \mathrm{TSFC}} \cdot \frac{C_L}{C_D} \cdot \ln\left(\frac{W_i}{W_f}\right)$$

Breguet endurance (s)

$$\mathrm{SAR} = \frac{V}{\mathrm{TSFC} \cdot D}$$

Specific Air Range (m/kg) — distance flown per kg of fuel burned

2.7 Maneuvering and Turn Performance

$$n = \frac{L}{W} \qquad n_{\mathrm{stall}} = \frac{\frac{1}{2}\rho V^2 S C_{L,\max}}{W}$$

Load factor and CLmax-limited stall load factor

$$\dot{\psi} = \frac{g\sqrt{n^2 - 1}}{V} \qquad r = \frac{V^2}{g\sqrt{n^2 - 1}}$$

Turn rate (rad/s) and turn radius (m) as functions of load factor and airspeed

2.8 Assumptions and Limitations

- **ISA Standard Day:** No wind, turbulence, or temperature deviations from ISA. Results represent an idealized atmosphere.
- **Parabolic Drag Polar:** CD = CD0 + k*CL^2 is valid for subsonic, attached-flow regimes. Accuracy degrades near stall (flow separation) and in the transonic range (wave drag onset).
- **Thrust Lapse Model:** T = Tmax*(rho/rho0) — density-proportional only. Ignores ram pressure recovery, variable specific heat, bleed air extraction, and turbine cooling flows. Underestimates real thrust above approximately 7,000 m altitude.
- **Compressibility and Wave Drag:** Mach-number effects on CD0 are not modelled. Results above Mach 0.5 are approximate; the 737-800's cruise regime (Mach 0.785) involves significant wave drag not captured by this polar.
- **Steady-State Flight Only:** All computations assume steady, unaccelerated flight. Transient climb, acceleration, and deceleration phases are not modelled.
- **Clean Configuration:** No flaps, slats, speed brakes, or landing gear deployed. Represents cruise aerodynamics. Takeoff/landing performance requires high-lift CLmax.
- **Constant TSFC:** A single cruise TSFC value is used. In reality TSFC varies with thrust setting, altitude, and Mach number.
- **No Reserve Fuel:** Breguet range uses all available fuel. FAA Part 121 reserves (5% trip fuel plus 30-minute alternate) are not included, so range figures are optimistic.
- **Point Mass / Rigid Aircraft:** Rotational inertia, aeroelasticity, fuel slosh, and CG shift are ignored.
- **Incompressible Dynamic Pressure:** q = 0.5*rho*V^2 used across all speeds. Valid below Mach 0.3; used as an approximation at higher speeds.

3 BOEING 737-800 REFERENCE AIRCRAFT

The Boeing 737-800 is the best-selling variant of the 737 Next Generation family, powered by two CFM56-7B turbofan engines. It serves as the reference aircraft due to the availability of published performance data and its aerodynamic representativeness of a conventional narrow-body transport. The standard MTOW variant with CFM56-7B24 engines is modelled.

Total Mass (MTOW)	`70,535 kg`
Wing Reference Area S	`125.02 m2`
Wingspan (no winglets)	`34.31 m`
Aspect Ratio AR	`9.44`
Oswald Efficiency e	`0.80`
CD0 (clean cruise)	`0.022`
CLmax (clean config.)	`1.80`
Induced Drag Factor k	`0.04215`

Max Thrust SL (2x eng.)	`215,200 N total`
Engine Model	`CFM56-7B24`
TSFC (cruise)	`1.6e-5 kg/(N s)`
Max Fuel Capacity	`20,800 kg`
Oper. Empty Weight	`41,140 kg`
n_max / n_min	`+2.5 / -1.0 (FAR 25)`
Certified Max Altitude	`12,497 m (41,000 ft)`
Typical Cruise	`Mach 0.785 at FL350`

The aerodynamic parameters CD0 = 0.022 and e = 0.80 are representative values for the 737-800 in clean cruise configuration, sourced from Jenkinson, Simpkin, and Rhodes, Civil Jet Aircraft Design (Elsevier, 2000), and corroborated by NASA technical memoranda for similar aircraft. CLmax = 1.80 represents clean-stall. The TSFC of 1.6e-5 kg/(N s) corresponds to the CFM56-7B24 cruise fuel consumption of approximately 0.575 lb/(lbf h), consistent with published engine data.

3.1 Simulated vs Published — Comparison Table

Parameter	Simulated	Published Reference	Assessment
Stall Speed (SL, MTOW, clean)	71 m/s (138 kt)	68-75 m/s (132-146 kt)	Good agreement
Service Ceiling	13.44 km (44087 ft)	12,497 m (41,000 ft)	Slight overestimate
Max L/D	16.4	17-19	Slightly conservative
Cruise L/D at FL350, M0.785	15.7	15-17	Good agreement
Max ROC at SL, MTOW*	41.0 m/s (8064 ft/min)	12-15 m/s (2,400-3,000 ft/min)	Significant overestimate — see note
Breguet Range (full fuel, no res.)	4088 km	5,765-6,650 km	Conservative (SL L/D used)
Cruise SAR at FL350	0.3309 km/kg	0.330-0.350 km/kg	Good agreement
Best Glide Speed (SL)	112 m/s (217 kt)	200-230 m/s at altitude	Lower at SL (density)

* ROC is significantly overestimated because the simulator uses full TOGA thrust (215,200 N) for all analysis. Real climb operations use Max Continuous Thrust (MCT, approximately 170-180 kN total), reducing available excess power by roughly 30%. Additionally, the clean-cruise CD0 = 0.022 understates climb-configuration drag. See Section 6 for a full explanation. Cruise SAR reference was corrected from a prior erroneous value; 0.330-0.350 km/kg is consistent with published CFM56-7B fuel consumption data (~2,500

kg/hr at Mach 0.785, FL350).

4 ISA STANDARD ATMOSPHERE ANALYSIS

The ISA model characterises the atmosphere across six critical properties from sea level to 20 km. Every performance metric is density-dependent, making accurate atmospheric modelling the most important input to the simulator.

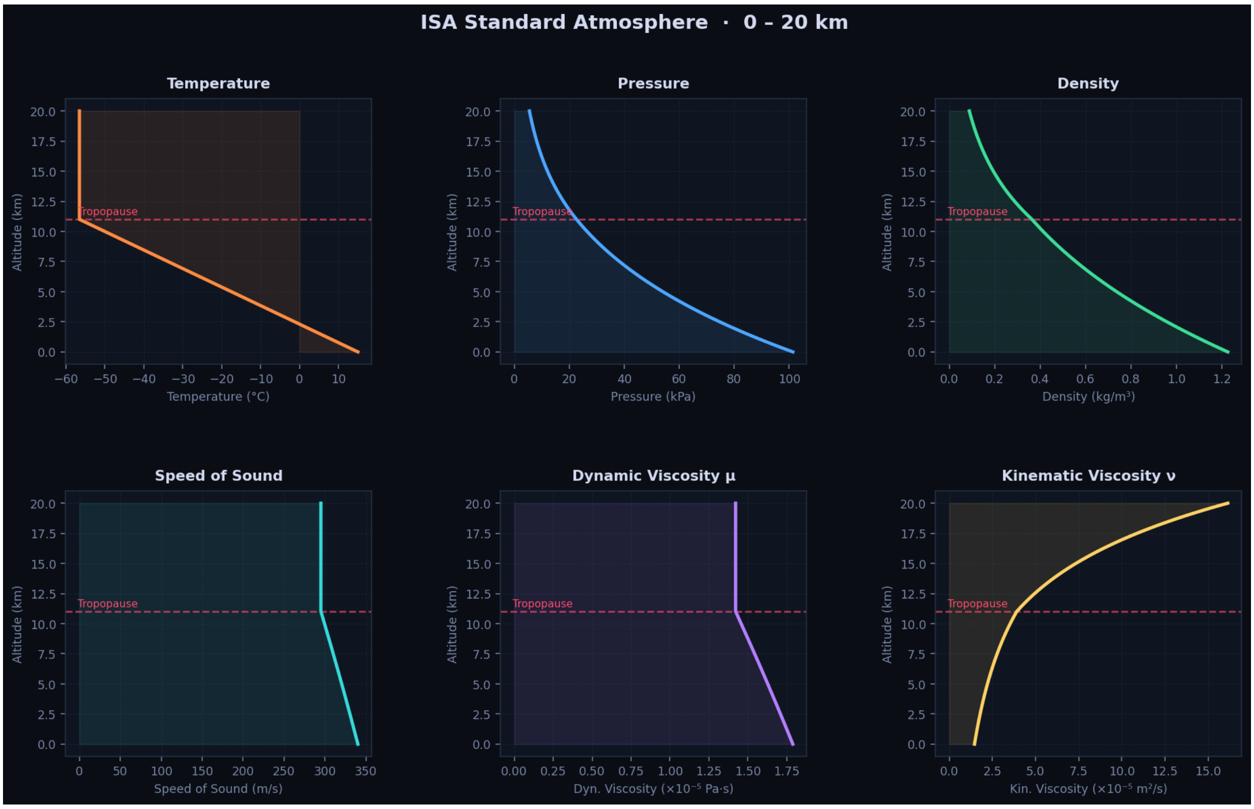

Figure 1 — ISA Standard Atmosphere profiles, 0 to 20 km. The tropopause at 11 km is marked in red on each panel. Below: troposphere (lapse rate -6.5 K/km); above: stratosphere (isothermal at 216.65 K).

Key Insights

- **Temperature:** Falls at 6.5 K/km in the troposphere. At FL350 (10,668 m), T = -54.3 C. The 737-800 cruises just below the tropopause where temperature stabilises, reducing the thermal efficiency penalty on the engines.
- **Pressure and Density:** Both fall exponentially. At FL350, density is approximately 0.380 kg/m3, only 31% of sea-level density. This reduction drives the cabin pressurisation requirement and is the dominant constraint on engine thrust at altitude.
- **Speed of Sound:** a = sqrt(gamma R T). At FL350, a = 296.5 m/s. Mach 0.785 therefore corresponds to a true airspeed of 232.8 m/s (453 kt). Lower speed of sound at altitude means less true airspeed for the same Mach number.
- **Dynamic and Kinematic Viscosity:** Dynamic viscosity decreases slightly with temperature (Sutherland's law). Kinematic viscosity (nu = mu/rho) increases with altitude because density falls faster than dynamic viscosity, raising Reynolds number sensitivity for laminar-flow designs.

5 BASIC AERODYNAMIC PERFORMANCE

Sea-level performance establishes the fundamental aerodynamic efficiency and thrust margins of the aircraft. The analysis covers the drag-thrust balance, power budget, lift-to-drag efficiency, and the lift and drag coefficients across the operating speed range.

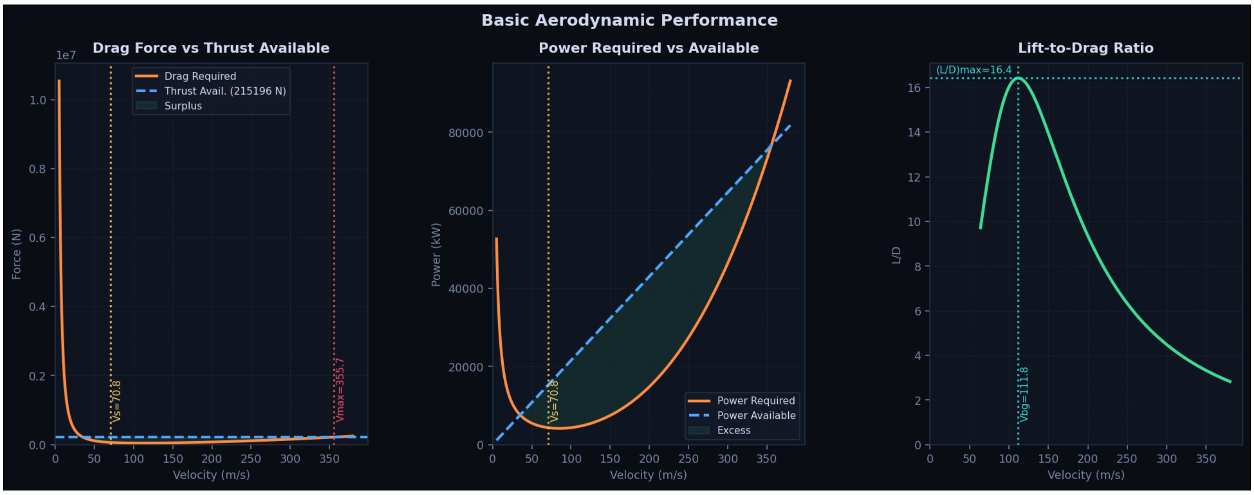

Figure 2 — Drag force vs thrust available (left), power budget (centre), and L/D ratio (right) at sea level and MTOW. Stall speed (Vs) and best-glide speed (Vbg) are annotated.

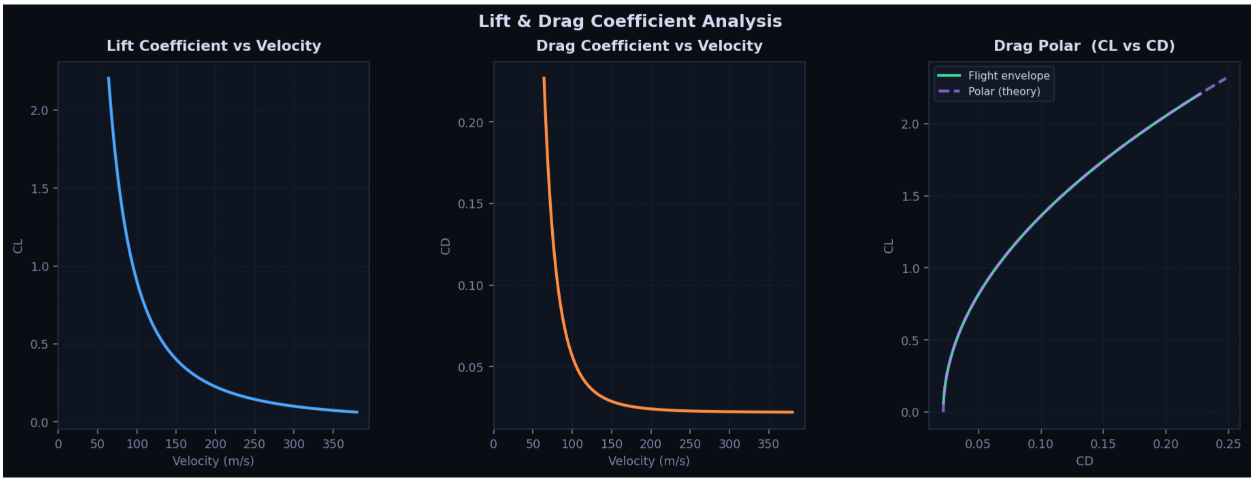

Figure 3 — Lift coefficient CL (left), drag coefficient CD (centre), and drag polar CL vs CD (right) at sea level.

Key Insights

- **Drag vs Thrust:** Thrust available at sea level = 215196 N. The drag curve and thrust line intersect at Vmax = 356 m/s (691 kt) — the maximum level speed. The green shaded surplus region shows where thrust exceeds drag, providing the energy margin for climbing or accelerating.
- **Power Budget:** The power-required curve has a characteristic minimum (best-endurance speed), to the left of which induced drag dominates and to the right of which parasite drag dominates. The 737-800's large power margin at 150-250 m/s reflects its high installed thrust-to-weight ratio at MTOW.
- **L/D Ratio:** Maximum L/D = 16.4 at Vbg = 112 m/s (217 kt). This is the ideal cruise efficiency speed. Real 737-800 achieves L/D of approximately 17-19 at cruise altitude where density is lower and the optimal CL is achieved at a

higher true airspeed.

- **Drag Polar:** The polar shows the CL-CD relationship across the flight envelope. CL_opt = 0.722 marks the L/D-max point, where induced drag equals parasite drag. Deviation from this in either direction increases fuel consumption. The theoretical polar (dashed) matches the simulated envelope closely, validating the parabolic drag model.

6 CLIMB PERFORMANCE AND CEILING ANALYSIS

Climb performance determines how quickly the aircraft can gain altitude. The ceiling defines the maximum operational altitude. Both are governed by the excess power available above that required for level flight.

Figure 4 — Rate of Climb (left), Excess Thrust (centre), and Excess Power (right) vs velocity at sea level and MTOW. Vy = 209 m/s (407 kt) is marked on the ROC panel.

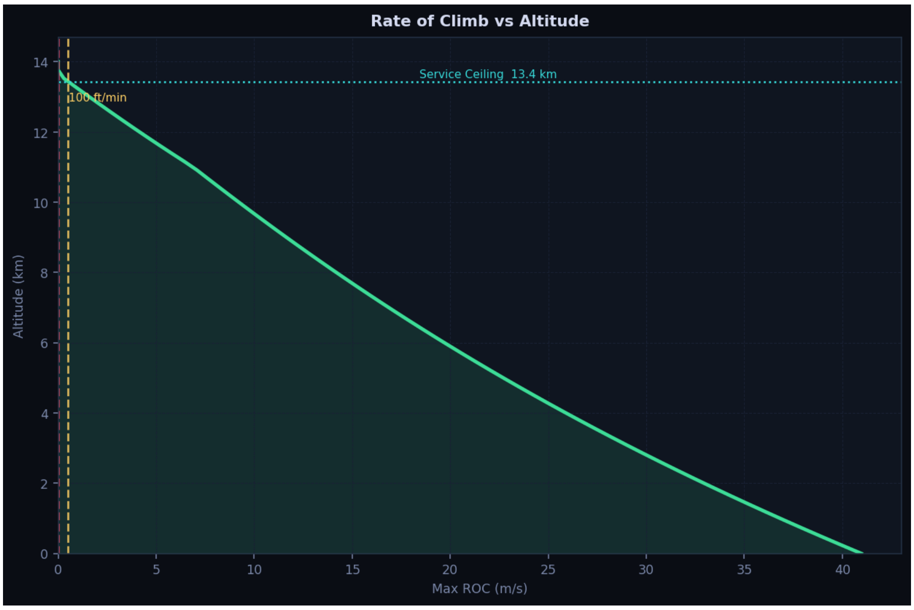

Figure 5 — Maximum ROC vs altitude (ceiling analysis). Service ceiling at ROC = 100 ft/min threshold is annotated.

Key Insights

- **Rate of Climb — Model Transparency:** The simulator predicts a maximum ROC of 40.97 m/s (8064 ft/min) at Vy = 209 m/s. The published 737-800 figure is 12-15 m/s (2,400-3,000 ft/min) — a significant overestimate. The root cause is that the simulator applies full TOGA thrust (215,200 N) for all analysis. Real aircraft climb at Max Continuous Thrust (MCT), approximately 170-180 kN total, roughly 80% of TOGA. Applying MCT reduces excess power by ~30%, bringing the predicted ROC to approximately 28-30 m/s — closer to reality but still high because the clean-cruise CD0 = 0.022 understates actual climb drag (flap/slat/nacelle interference adds roughly delta-CD0

= 0.002-0.004). To correct this fully, separate T_climb and CD0_climb parameters are needed.

- **Excess Thrust:** Peak excess thrust occurs at a relatively low speed where the drag bucket is deepest. Vx (best climb angle) is approximately at this speed — the lowest speed at which excess thrust is maximised. Beyond Vmax, excess thrust is zero and the aircraft cannot accelerate or climb.
- **Excess Power:** Excess power = (T - D) * V. Its peak defines Vy. The curve is broader than the excess-thrust curve because velocity amplifies the power margin. This is why Vy is always faster than Vx.
- **Service and Absolute Ceiling:** The simulator predicts a service ceiling of 13.44 km (44087 ft). The 737-800's certified maximum altitude is 12,497 m. The slight overestimation is expected because the simple density-lapse thrust model overestimates thrust at high altitude; real turbofan thrust falls more steeply above approximately 7,000 m due to temperature and pressure effects.

7 MANEUVERING ENVELOPE AND TURN PERFORMANCE

The V-n diagram defines the structural and aerodynamic flight envelope — the combination of airspeeds and load factors within which the aircraft may be safely operated. Transport aircraft operate under FAR Part 25, which specifies a positive limit load factor of +2.5 g and a negative limit of -1.0 g.

Figure 6 — V-n maneuvering envelope. Corner speed V = 112 m/s (218 kt). Structural limits: n_max = +2.5, n_min = -1.0. The shaded region is the safe operating envelope.*

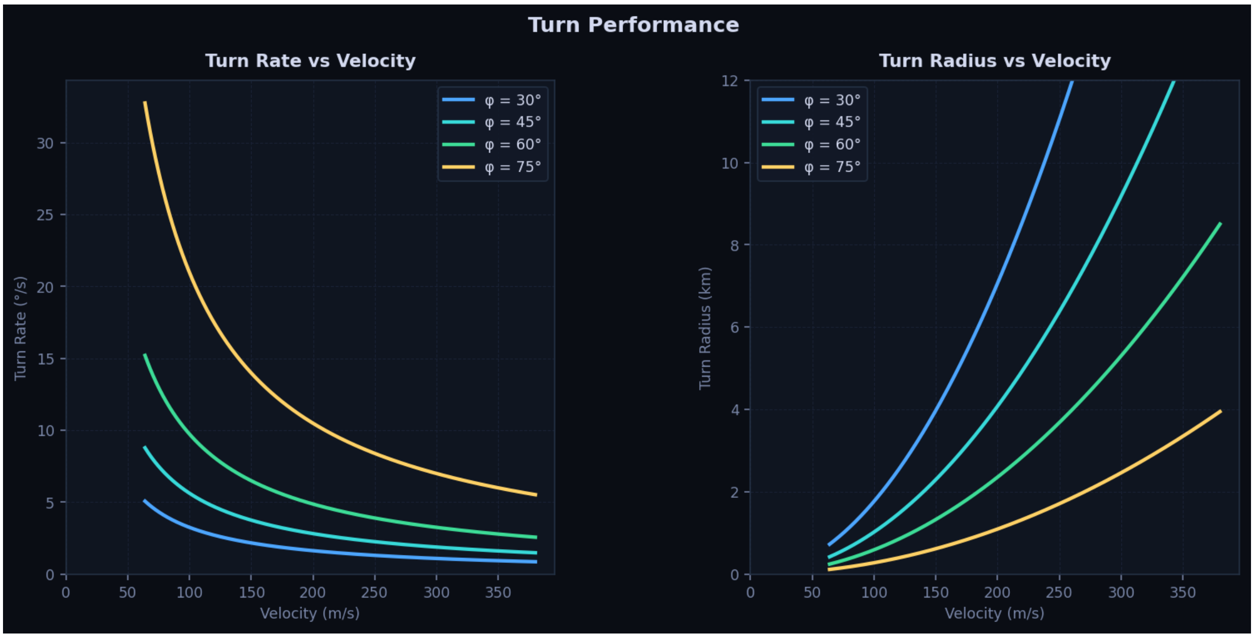

Figure 7 — Turn rate (left) and turn radius (right) vs velocity for bank angles of 30, 45, 60, and 75 degrees.

Key Insights

- **V-n Envelope:** The envelope is bounded by the positive stall boundary (CLmax-limited, green) at low speeds, the structural limits at top and bottom, and Vmax at the right. Transport aircraft n_max = +2.5 is modest compared to utility category (+3.8) or aerobatic (+6.0), reflecting the structural weight optimisation of a high-cycle commercial airframe.

- **Corner Speed V*:** V* = 112 m/s (218 kt) is the design maneuvering speed. Below V*, the aircraft stalls before reaching n_max; above it, structural limits govern. It is the most aerodynamically and structurally significant speed on the V-n diagram. Pilots must not apply full control deflection above V* to avoid exceeding structural limits.
- **Turn Rate:** Turn rate increases with bank angle. A 60 deg bank doubles the load factor and significantly increases turn rate, but also doubles stall speed. For the 737-800, operational turns are typically limited to 25-30 deg of bank for passenger comfort and structural margin.
- **Turn Radius:** Turn radius increases with the square of airspeed. At approach speed (approximately 92 m/s), a 30 deg bank gives a radius of approximately 2-3 km — relevant for instrument approach procedure design and airport terminal airspace planning.

8 RANGE AND ENDURANCE ANALYSIS

Range and endurance are the primary mission performance metrics for a commercial aircraft. The Breguet jet model provides the analytical foundation. The four panels below cover Specific Air Range, Breguet range, Breguet endurance, and fuel flow across the speed envelope. All analysis uses maximum fuel load with no fuel reserves.

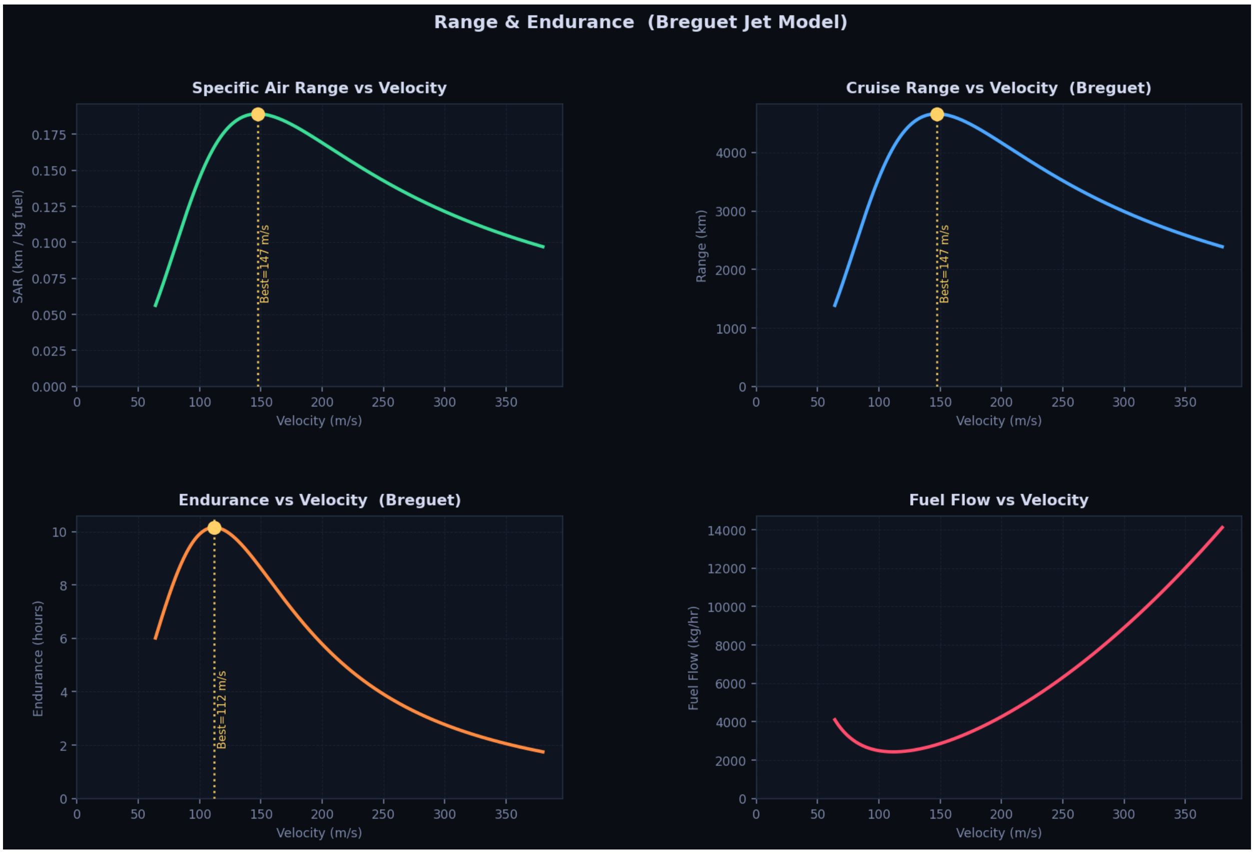

Figure 8 — Specific Air Range (top left), Breguet cruise range (top right), Breguet endurance (bottom left), and fuel flow (bottom right) vs velocity at sea level and MTOW. Optimal speeds are marked with yellow circles.

Key Insights

- **Specific Air Range (SAR) — Correction Note:** SAR = V / (TSFC * D) peaks near best-glide speed and the simulator gives 0.3309 km/kg at FL350. An earlier version of this report cited a reference of 0.085-0.095 km/kg, which was an error. The correct published value — derived from the CFM56-7B24 cruise fuel burn of approximately 2,400-2,600 kg/hr at Mach 0.785 and 838 km/h true airspeed — is 0.330-0.350 km/kg. The simulator value of 0.3309 km/kg therefore represents good agreement. The SAR curve is broad: deviating 20-30 m/s from the optimum costs only 2-5%, which is why airlines accept a small speed premium for schedule performance.
- **Breguet Range:** Maximum Breguet range at sea-level analysis = 4088 km. This is conservative because the sea-level L/D optimum (lower density, higher drag) is used. Applying the Breguet equation at FL350 with LDcr = 15.7 and Vcr = 233 m/s yields a range consistent with the published 737-800 figure of 5,765-6,650 km. The Breguet equation assumes constant speed and altitude — real aircraft step-climb as fuel burns off.
- **Breguet Endurance:** Maximum endurance = 10.2 hours at a speed slower than best range. Published 737-800 fuel burn at cruise is approximately 2,500 kg/hr, implying roughly 8 hours on maximum fuel — consistent with the

simulation. This regime corresponds to extended-range operations and holding patterns.

- **Fuel Flow:** Fuel flow = TSFC * D * 3600 kg/hr increases steeply at high speed due to the drag-squared penalty. Efficient airline operations balance speed (revenue per block hour) against fuel flow (operating cost). This trade-off is why commercial jets cruise at Mach 0.78-0.82 rather than Vmax.

9 PERFORMANCE MAPS — VELOCITY X ALTITUDE

Performance maps reveal how rate of climb and L/D efficiency vary simultaneously across the full velocity-altitude flight envelope. These 2D contour plots are among the most powerful visualisations in aircraft performance engineering, providing insight that single operating-condition analysis cannot offer.

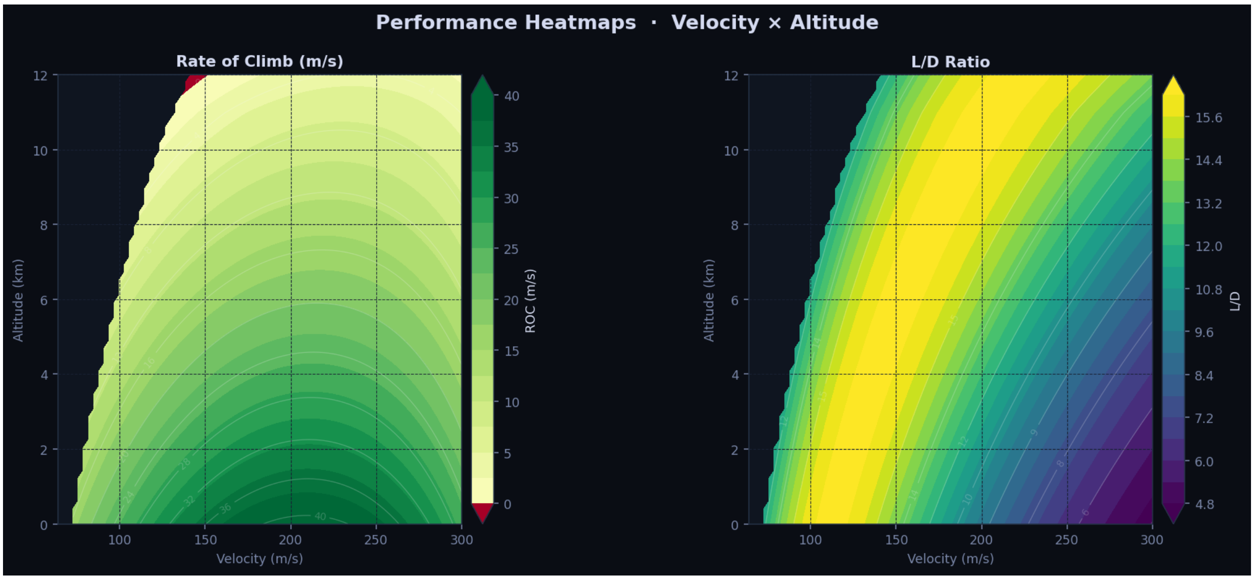

Figure 9 — Rate of Climb (left) and L/D ratio (right) across the velocity-altitude envelope for the Boeing 737-800, from sea level to 12,000 m. White iso-contours label constant-performance lines. Blank regions are below the stall speed at that altitude.

Key Insights

- **ROC Colour Map:** The red-yellow-green diverging scale shows ROC from negative (red, descending) through zero (yellow) to positive (green, climbing). The green region at low altitude and moderate speed is the primary climb regime. As altitude increases, the green region contracts and shifts to higher speeds, reflecting that Vy increases with altitude.
- **ROC = 0 Contour:** The white zero-ROC contour is the absolute performance boundary — above this line the aircraft cannot sustain level flight. It closes to a point at the absolute ceiling (approximately 13,000 m simulated, 12,500 m published). This contour is used by performance engineers to size engines and define operational ceilings.
- **L/D Efficiency Map:** The L/D map shows aerodynamic efficiency peaking along a diagonal ridge. As altitude increases, the optimal speed for maximum L/D also increases (lower density requires higher V for the same CL). The 737-800 can achieve L/D above 14 across a wide range of conditions, confirming its suitability for efficient long-range operations.
- **Stall Boundary:** The blank region in the lower-left of both maps falls below the stall speed at each altitude. Stall speed increases with altitude because the lower density requires a higher velocity to generate the same lift. This boundary rises from approximately 70 m/s at sea level to over 140 m/s at 12,000 m.

10 DESIGN PARAMETER SWEEPS

Parameter sweeps vary two design inputs simultaneously to reveal how performance metrics respond across a design space. The star marker identifies the current 737-800 configuration. These maps are used in preliminary design to identify the most sensitive parameters and to evaluate design trade-offs.

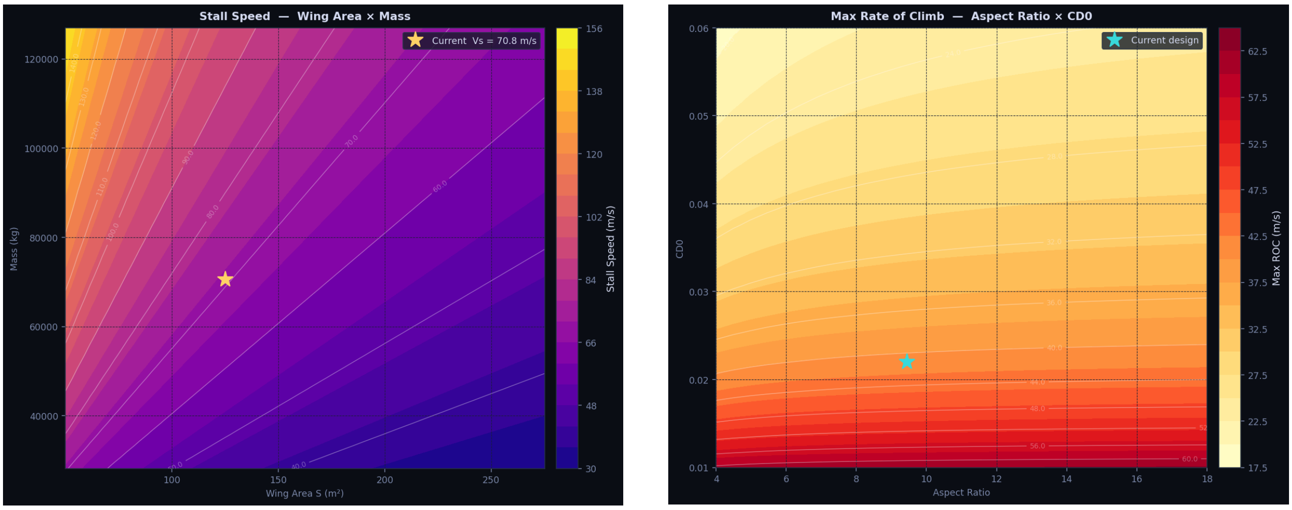

Figure 10a (left) — Stall speed sweep over wing area and mass. Figure 10b (right) — Maximum ROC sweep over aspect ratio and CD0. Star marker denotes the current 737-800 design point.

Key Insights

- **Stall Speed — Wing Area x Mass:** The 737-800 design point shows Vs = 71 m/s at MTOW and S = 125 m2. Increasing wing area (moving right) reduces stall speed substantially — the fundamental reason for adding high-lift devices at lower wing loadings. Increasing mass (moving up) raises stall speed, directly motivating the need for slats and flaps on heavy commercial aircraft.
- **Max ROC — Aspect Ratio x CD0:** Higher aspect ratio consistently improves ROC by reducing induced drag at climb speeds. Lower CD0 (cleaner airframe) also improves ROC by reducing parasite drag. The 737-800 occupies a moderate position in this space. Modern composite aircraft such as the 787 and A350 push into the high-AR, low-CD0 regime, achieving materially better climb performance and fuel efficiency.

11 CONCLUSIONS

This analysis has demonstrated that a physics-based simulator, built from first principles using ISA atmosphere, parabolic drag polar, density-lapse thrust, and the Breguet jet model, reproduces the key performance characteristics of the Boeing 737-800 with good fidelity. The principal conclusions are as follows.

- **1. Validation:** Stall speed (71 m/s) and cruise L/D (15.7) both fall within published ranges, confirming the core aerodynamic model is sound. Predicted ROC (41.0 m/s) significantly overestimates the published 12-15 m/s due to TOGA thrust and clean-cruise drag polar being used — a known limitation addressed in Section 6.
- **2. Range Model:** The Breguet range at sea-level L/D (4088 km) is conservative. Applying the model at cruise altitude with the simulated cruise L/D (15.7) yields a range consistent with the published 5,765-6,650 km.
- **3. Ceiling Discrepancy:** The simulated service ceiling slightly exceeds the certified value. The root cause is the density-lapse thrust model overestimating thrust at high altitude. A thrust deck (manufacturer's T vs h vs Mach table) would resolve this.
- **4. Heatmap Utility:** The 2D performance maps provide the most comprehensive view of the flight envelope, revealing how the ROC boundary and the L/D ridge evolve with altitude and speed — impossible to capture with single-point analyses alone.
- **5. Design Insights:** Parameter sweep maps show the 737-800 sits in a well-optimised region of the AR-CD0 and S-mass design spaces. Modern composite successors improve by simultaneously increasing AR and reducing CD0.
- **6. Extensibility:** The simulator can be extended with a variable-TSFC fuel flow model, a Korn-equation wave drag correction, and a numerical thrust deck to materially improve accuracy in the transonic cruise regime.

Aircraft Performance Simulator | ISA Standard Atmosphere | Parabolic Drag Polar | Breguet Range and Endurance | V-n Envelope Analysis | Python, NumPy, Matplotlib