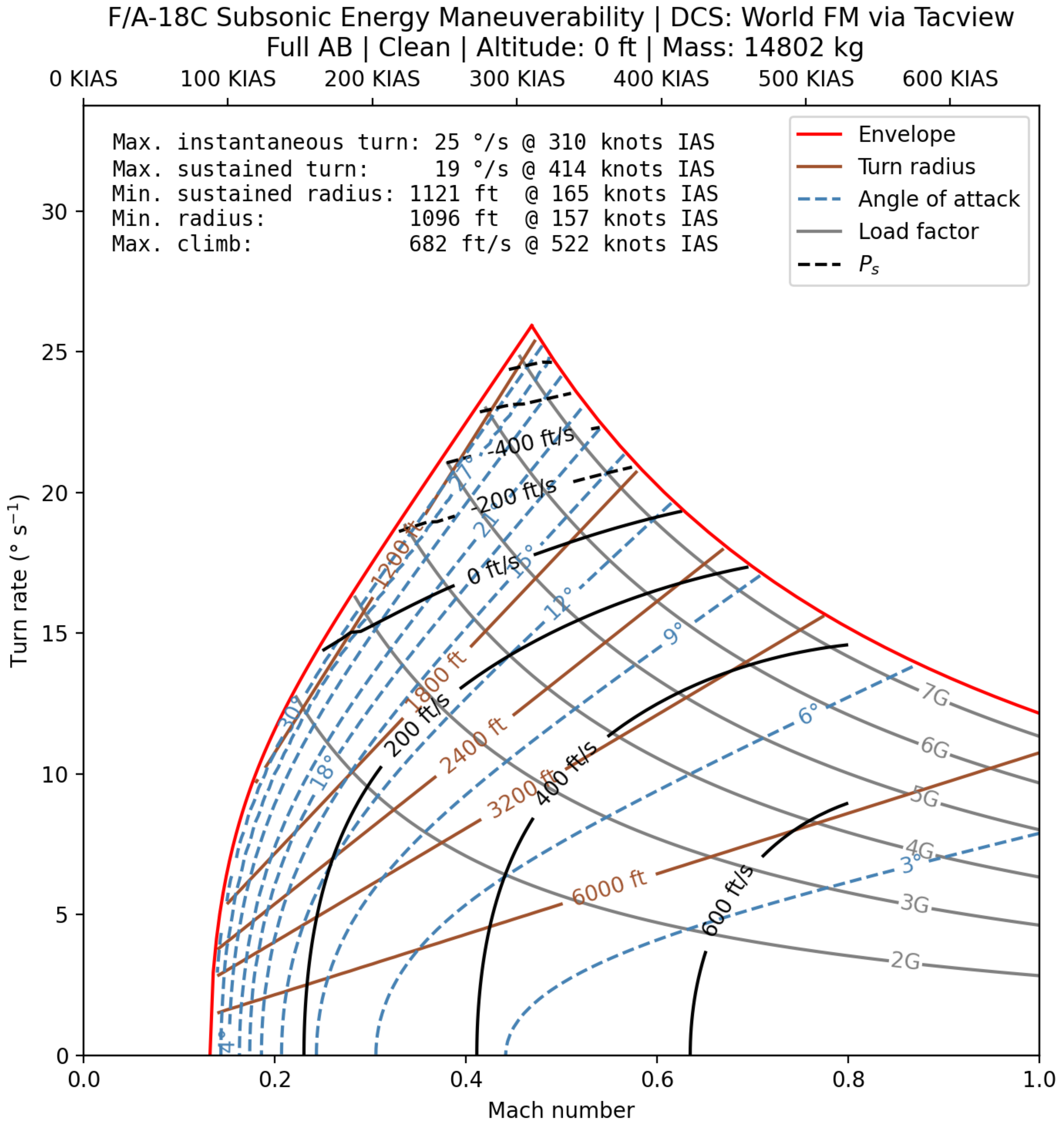
Subsonic Energy Maneuverability Diagrams for Selected *DCS: World* Aircraft

Contact Light **| Revised: September 2022**



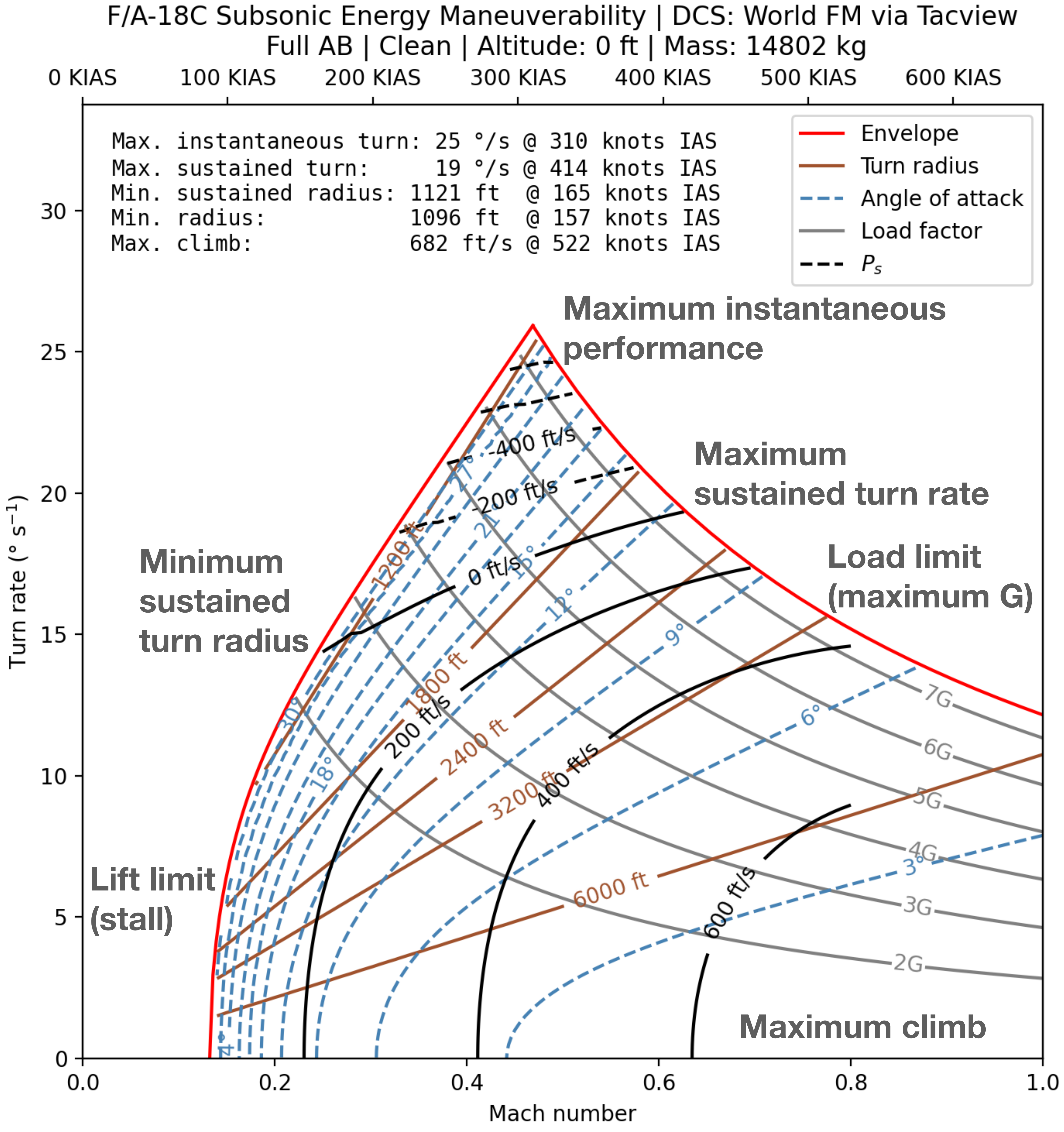
Energy Maneuverability Diagrams

An energy maneuverability (EM) diagram concisely summarizes how quickly an aircraft can change its speed, altitude, and heading throughout its performance envelope. It shows the following variables for a given combination of speed and horizontal turn rate:

- Angle of attack
- Turn radius
- Load factor (G)
- Specific excess power (P_s)

Specific excess power (P_s) is the rate of change of total mechanical energy per unit weight. It can be expressed in terms of equivalent climb rate and also reflects acceleration. P_s increases with thrust and speed and decreases with drag and weight.

In general, the more energy an aircraft has, the more options it has for maneuvering. An aircraft that can build a high energy margin relative to its opponent can cash in this energy in an attack.



How This Works

These diagrams are based on estimates of subsonic thrust, lift, and drag characteristics based on flight tests performed in DCS for a standard day and fixed fuel setting.

The flight data is saved to Tacview and exported to CSV, where it is analyzed in Python. Using the aircraft's normal and longitudinal acceleration at various speeds and angles of attack, I can estimate a model of the lift curve, drag polar, and thrust.

I can then use this model to predict the aircraft's lift and drag at different combinations of speed and horizontal turn rate. This is how the E-M diagram is generated.

Tests Performed

- Sustained turns at various speeds between powered stall and Mach 0.8 (or maximum speed) at 1,000 ft
- Level acceleration at maximum power from idle stall to Mach 0.8 (or maximum speed) at 1,000 ft. Follow with climb or Immelman to 10,000 ft or higher.
- Split-S at idle thrust at constant subsonic Mach number from 10,000 ft or higher
- Level deceleration to stall at 1,000 ft
- Maximum performance turn above corner speed until minimum sustained turn radius achieved

Caveats

- This document only focuses on *energy maneuverability*, or an aircraft's ability to change is velocity vector quickly. Other measures of fighter agility, such as pitch rate, roll rate, or combat cycle time are not explored.

- These diagrams are only applicable to the flight models in DCS. No comment is made on the real-world performance of these aircraft.

- The fuel/weight settings apply only to mobettameta's *DCS Dogfighters* server, which are optimized for about 6 minutes of fight time at maximum power based on user feedback.

- Variable geometry and automatic high-lift devices are generally handled by assuming a correlation between angle of attack and speed. However, even this approach does not work with models of certain aircraft. For example, the F-14B model is invalid above Mach 0.6.

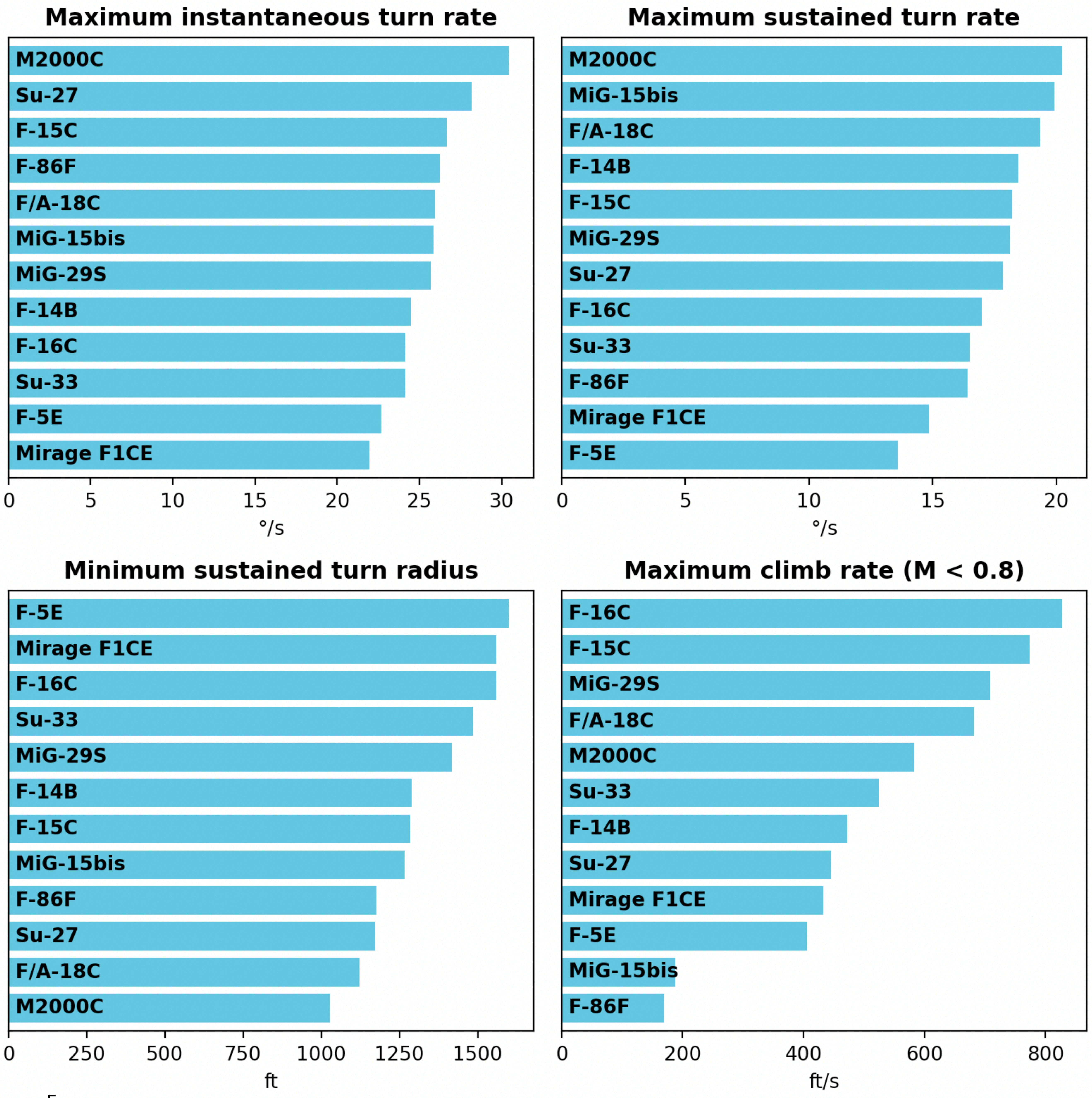
- Piston-engine aircraft are difficult to model with this approach due to propeller drag contributions at idle and the challenge of modeling propeller efficiency at different speeds. It's tough to separate thrust and drag for these.

- This document will be updated roughly quarterly with additional aircraft, including the MiG-21, MB-339, and F-4. Future iterations may include altitude-Mach diagrams exploring the full subsonic and supersonic envelope of these aircraft.

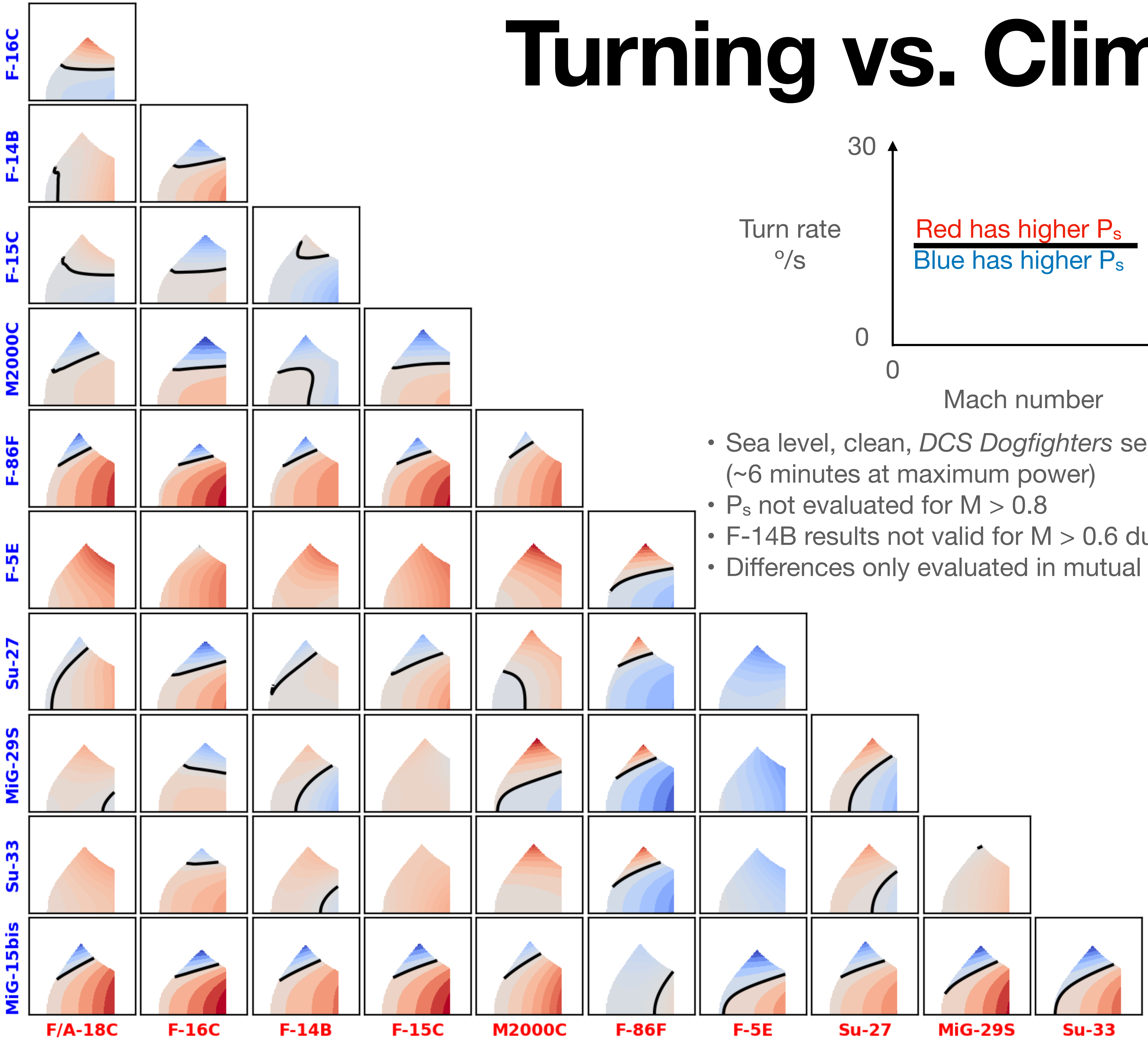
Summary Data

Definitions

- Maximum *instantaneous turn rate* is the highest turn rate achievable by an aircraft. It occurs at maximum G and normally can only be held in a dive.
- Maximum *sustained turn rate* is the highest turn rate an aircraft can attain without accelerating or changing altitude. This metric determines the winner of a two-circle flow. For many high-thrust jets, this turn rate is at the limit load (maximum G).
- Minimum *sustained turn radius* is the smallest horizontal turn radius that can be maintained at maximum power. This metric determines the winner of a one-circle flow. It is usually no more than 10% larger than minimum possible turn radius.
- Maximum *climb rate* is the maximum steady rate of climb available to an aircraft. It is closely related to longitudinal acceleration and reflects how well an aircraft can use the vertical plane in a fight.



Turning vs. Climbing in a Dogfight



- Sea level, clean, *DCS Dogfighters* server fuel settings (~6 minutes at maximum power)
- P_s not evaluated for $M > 0.8$
- F-14B results not valid for $M > 0.6$ due to wing sweep
- Differences only evaluated in mutual envelope overlap

Fights between aircraft with major performance differences often boil down to a contest of turn performance vs. climb performance. These are best captured by thrust-to-weight ratio (T/W) and wing loading (the ratio of weight to wing area).

The aircraft with a higher T/W should leverage its superior acceleration and climb performance. This means it should favor two-circle flows, climbs, dives, extensions, pitchbacks, and lag pursuit.

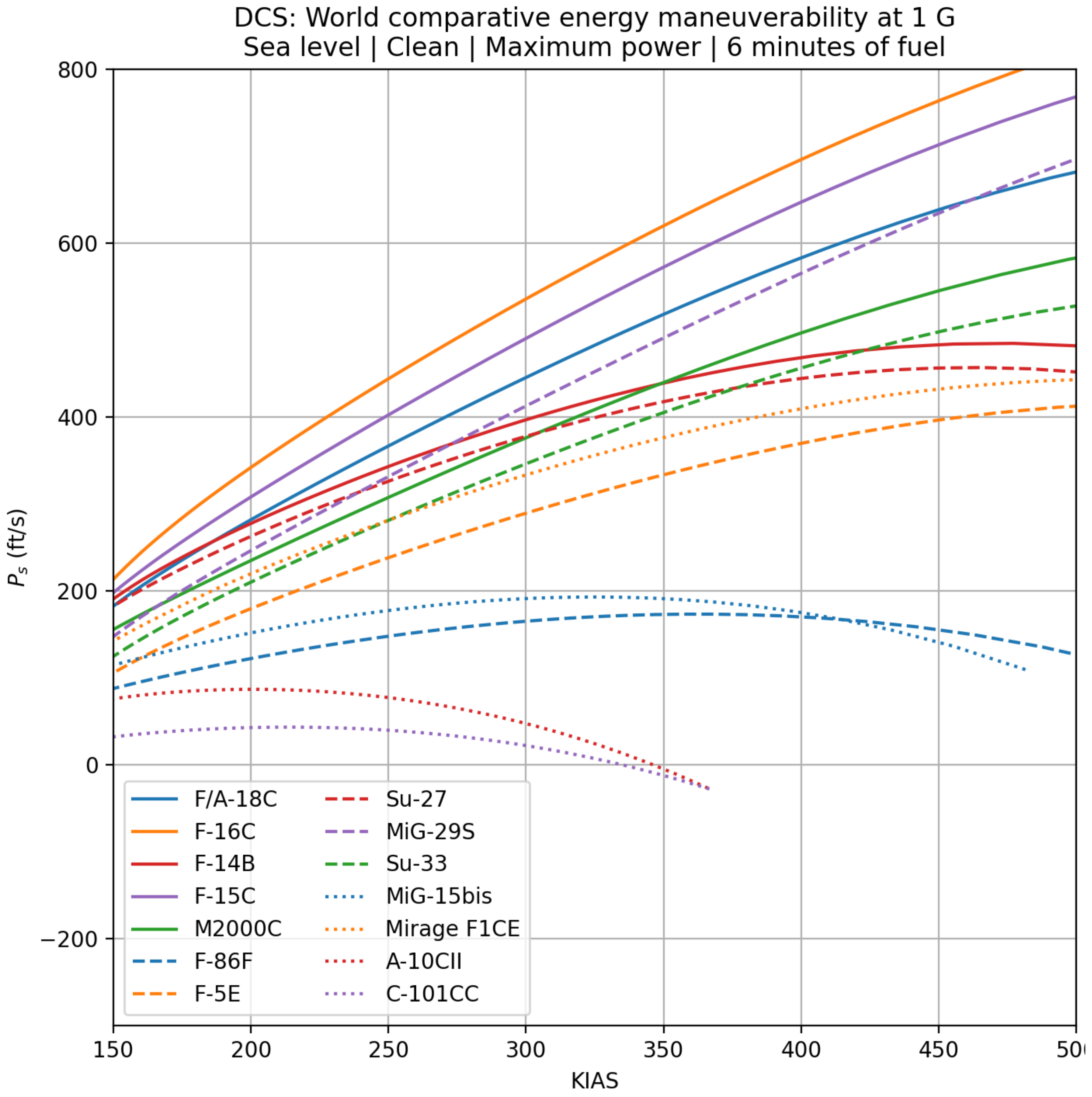
The aircraft with a wing loading advantage is assumed to be better in a horizontal turning fight at lower speed. It should favor one-circle flows, scissors, yo-yos, and lead pursuit.

This diagram illustrates the difference in specific energy rate between selected pairs of aircraft. It shows whether an aircraft can build energy margins in a turning fight or if it is more comfortable in the vertical plane.

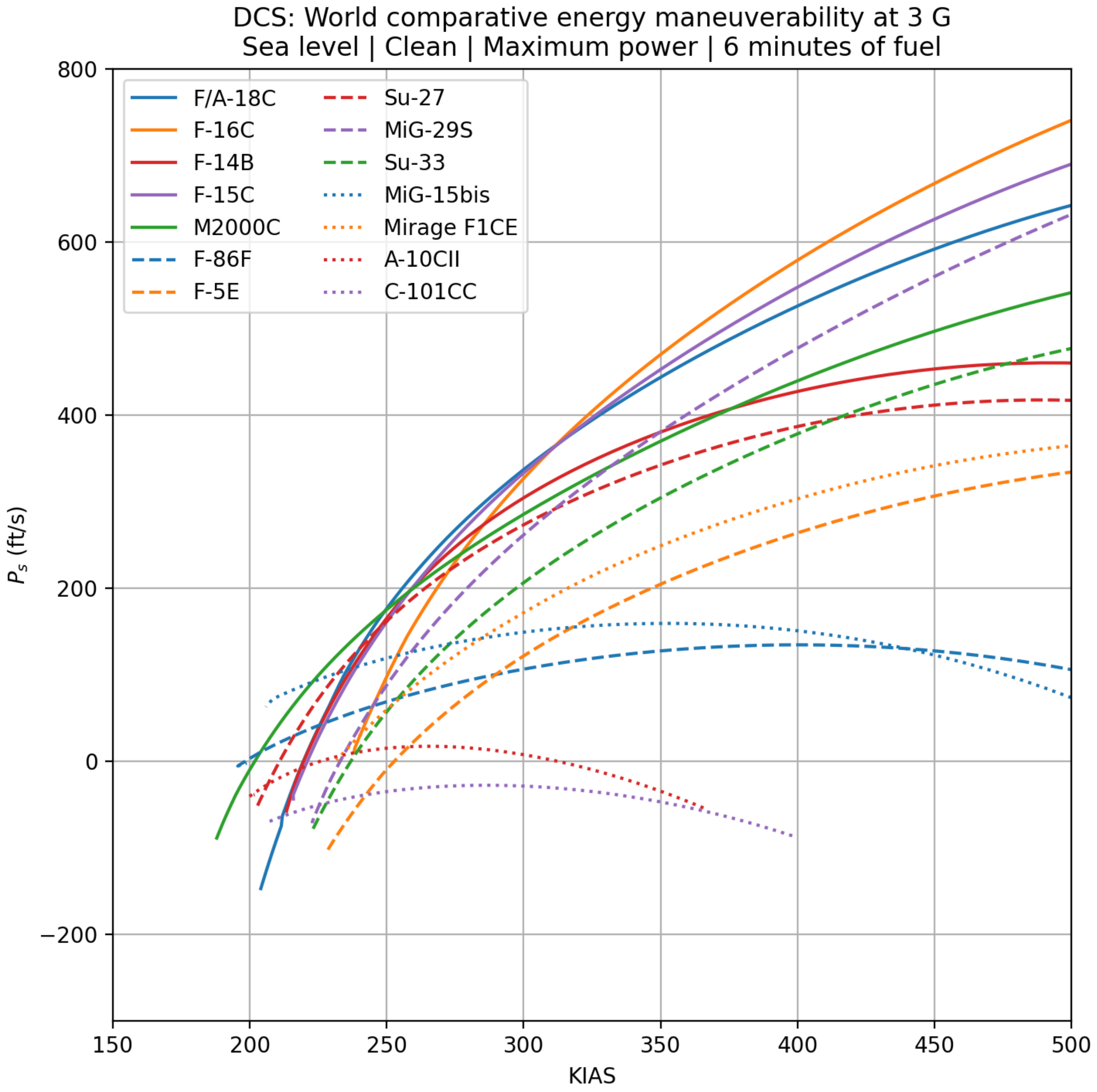
Relative Turn/Climb Tradeoff

These charts slice the EM diagrams along selected G contours. They illustrate how a bandit's energy may be drained or how its climb ability may be restricted by pulling moderate sustained G. For example, an F-86 will develop a maneuverability advantage over an F-16C if both aircraft are pulling 5 G below 350 knots, but an F-16 that stays above 350 knots can build an energy advantage over an F-86. Similarly, an F-15 pulling 5 G above 380 knots can build energy margins over a Mirage 2000 at the same speed and load factor.

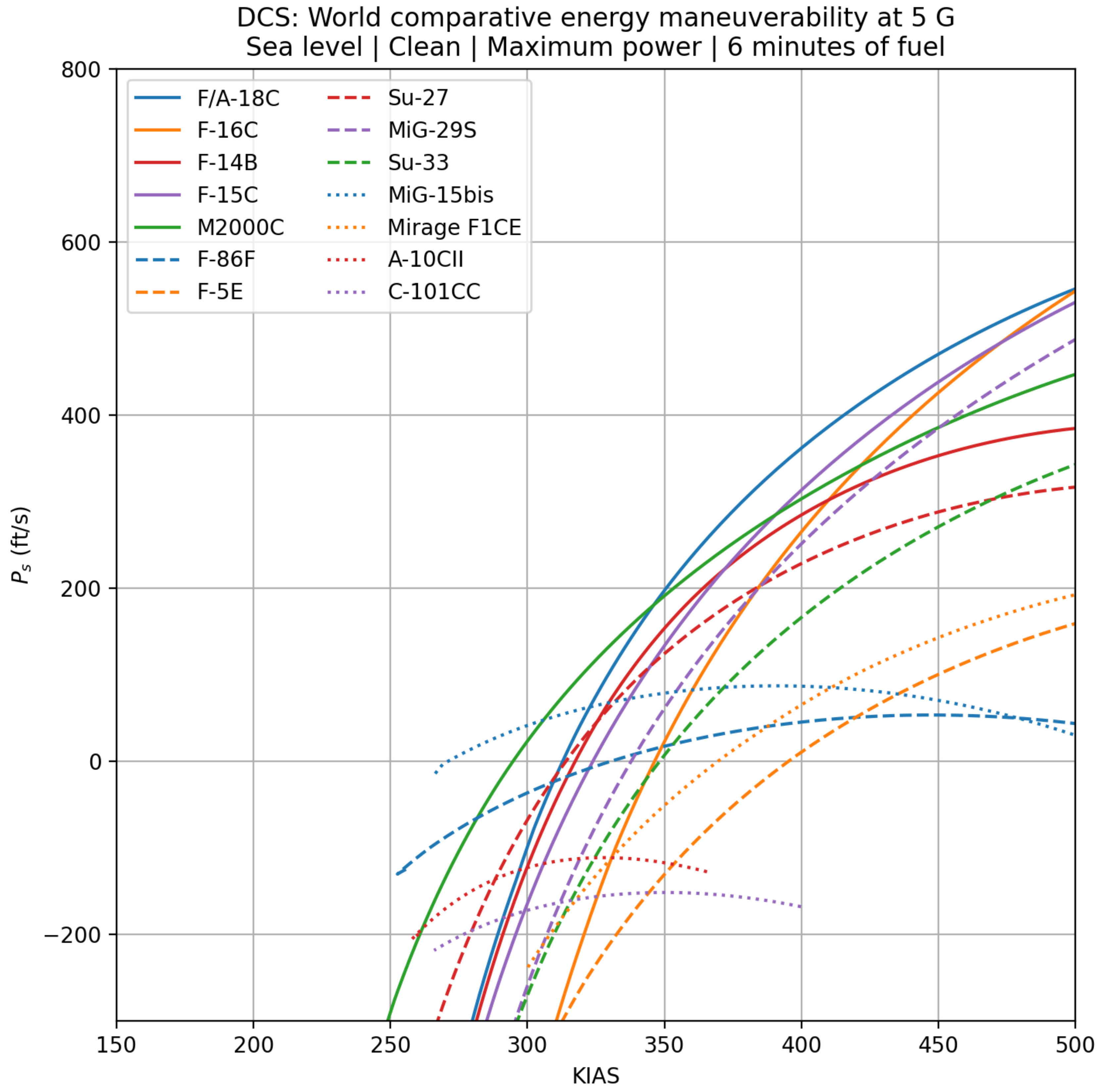
1 G



3 G



5 G



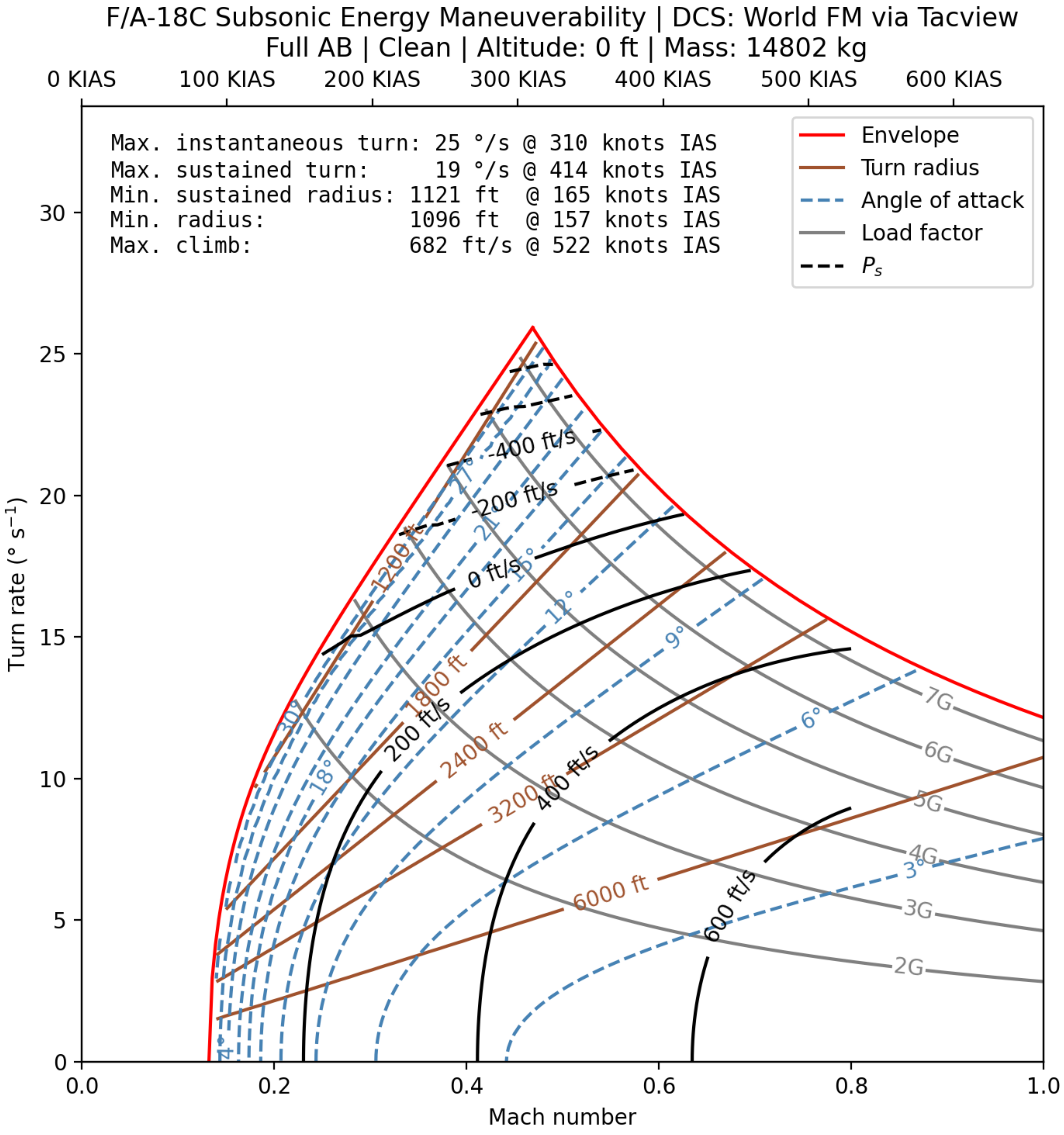
Fast Jets

F/A-18C

Wingspan	37 ft / 11 m
Thrust-to-Weight Ratio (M = 0.5)	1.1
Wing Loading	82 lb/sqft
Test Date	2022-08-29
Solution Confidence	High

Notes

Tight turn radius, high climb rates, and high sustained turn rate make this a versatile dogfighter.



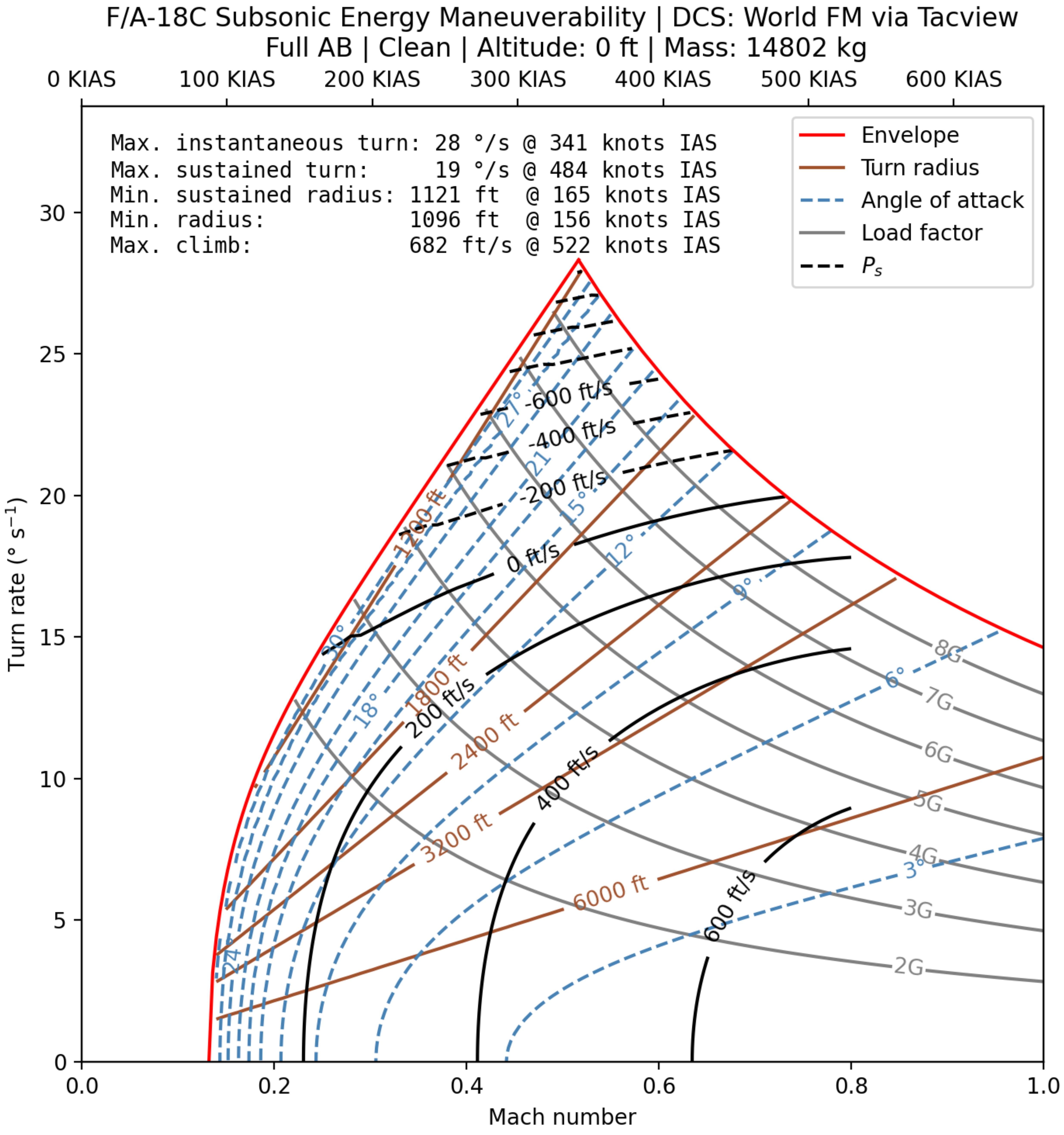
F/A-18C

G-limiter disengaged

Wingspan	37 ft / 11 m
Thrust-to-Weight Ratio (M = 0.5)	1.1
Wing Loading	82 lb/sqft
Test Date	2022-08-29
Solution Confidence	High

Notes

Tight turn radius, high climb rates, and high sustained turn rate make this a versatile dogfighter. This diagram assumes a 9 G limit with the paddle switch.

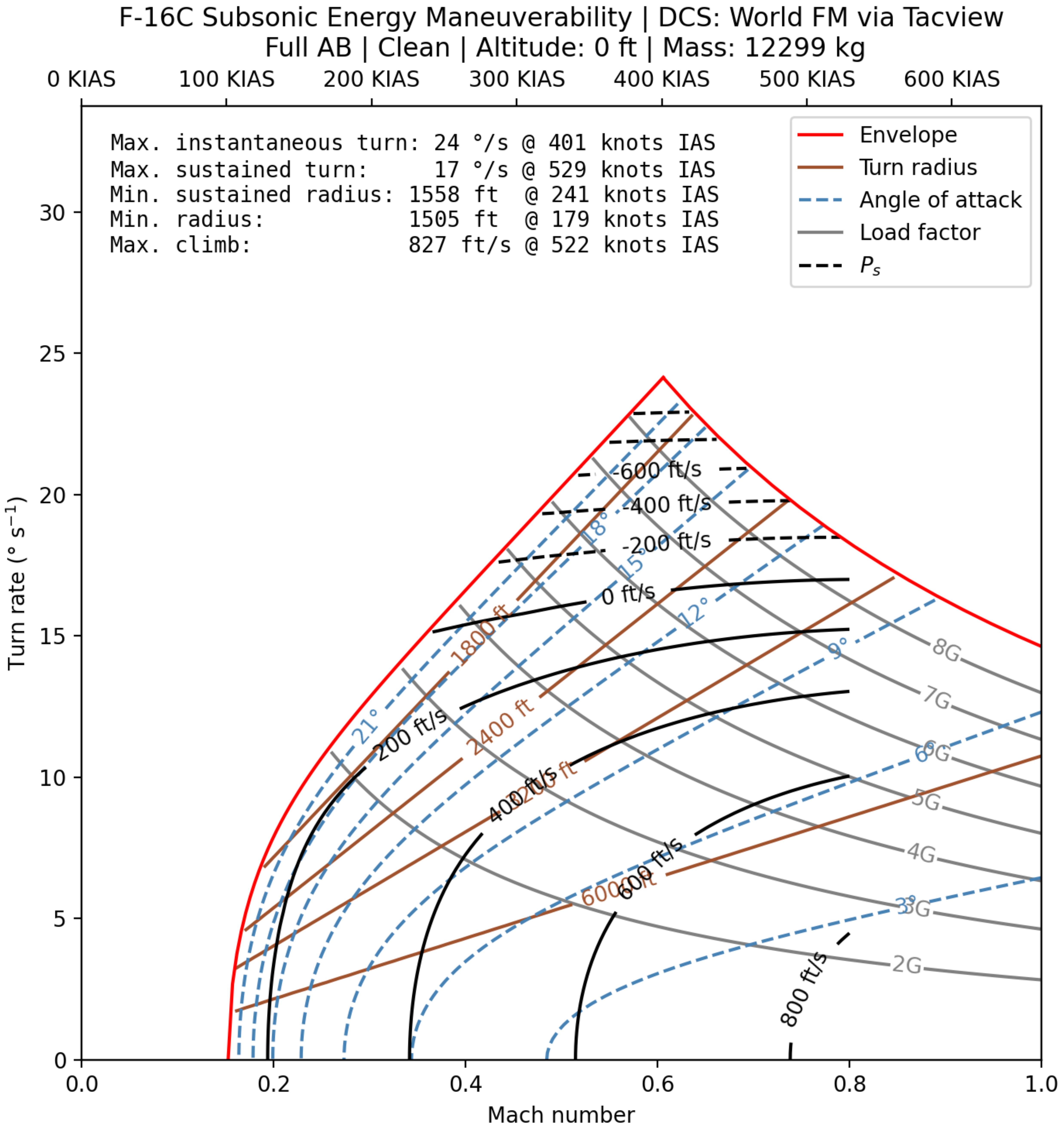


F-16C

Wingspan	33 ft / 10 m
Thrust-to-Weight Ratio (M = 0.5)	1.2
Wing Loading	90 lb/sqft
Test Date	2022-08-24
Solution Confidence	High

Notes

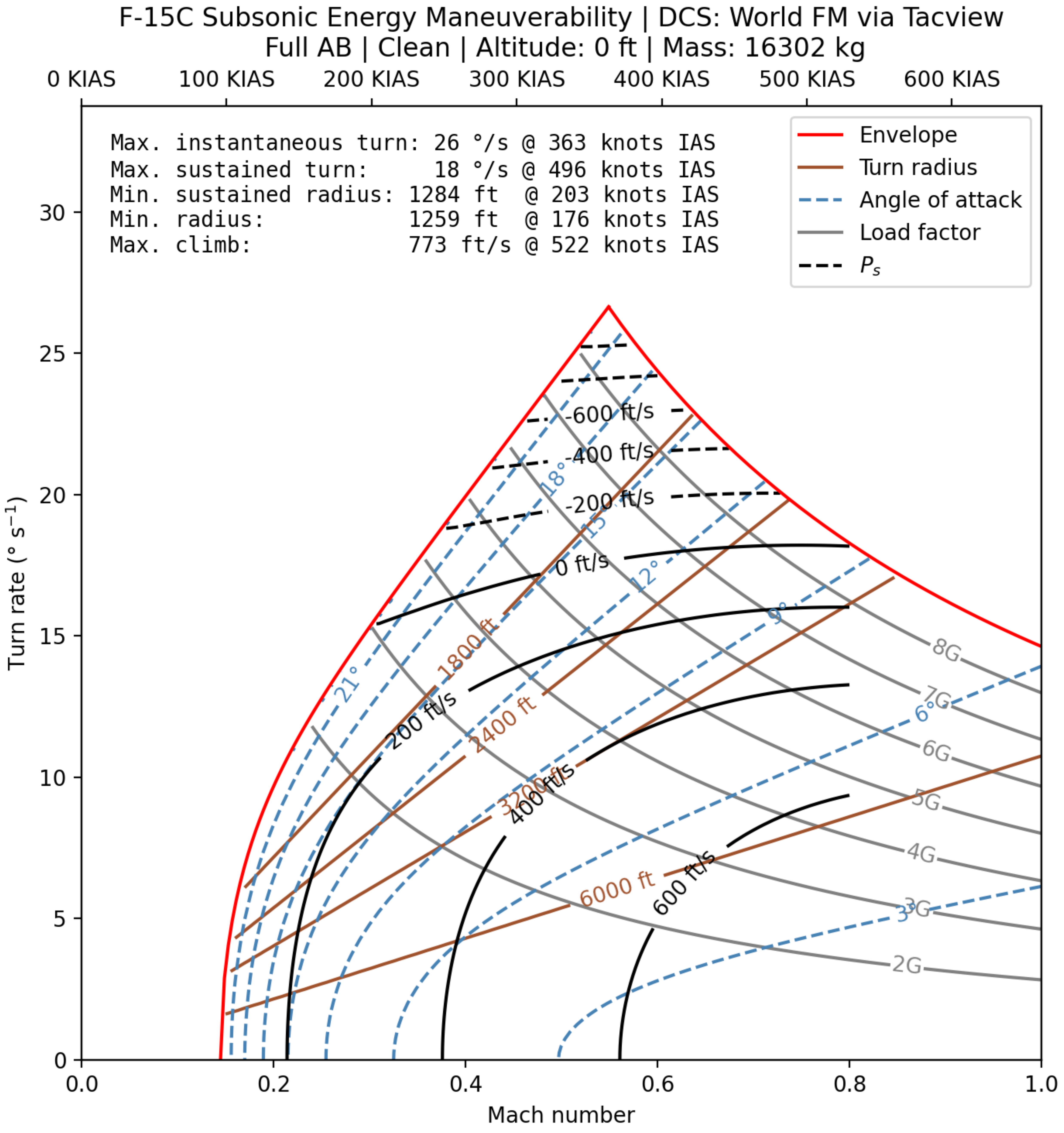
Dominant energy fighter, but generally disadvantaged in horizontal turns. High fuel fraction may mean better relative turn performance later in the fight. G-limiter schedule is not reflected in the upper part of this diagram and maximum performance may be somewhat lower than indicated.



F-15C

Wingspan	43 ft / 13 m
Thrust-to-Weight Ratio (M = 0.5)	1.2
Wing Loading	59 lb/sqft
Test Date	2022-08-03
Solution Confidence	High

Notes

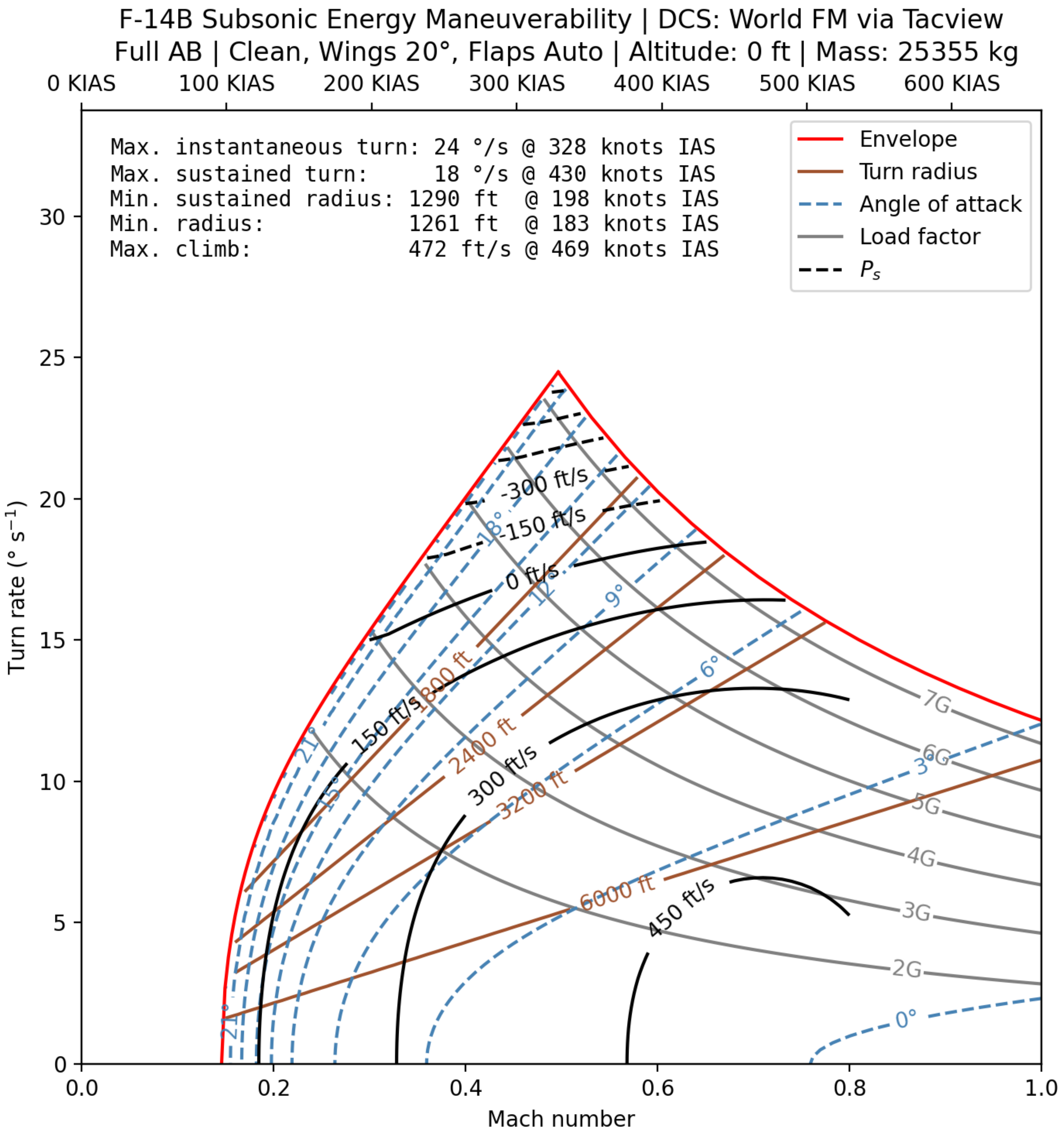


F-14B

Wingspan (upswept)	64 ft / 20 m
Thrust-to-Weight Ratio (M = 0.5)	0.9
Wing Loading	95 lb/sqft
Test Date	2022-07-02
Solution Confidence	Medium

Notes

Flight model only valid below Mach 0.6 due to wing sweep schedule. Multiple issues with fit dampen confidence in flight model solution. Future versions will resolve these issues.

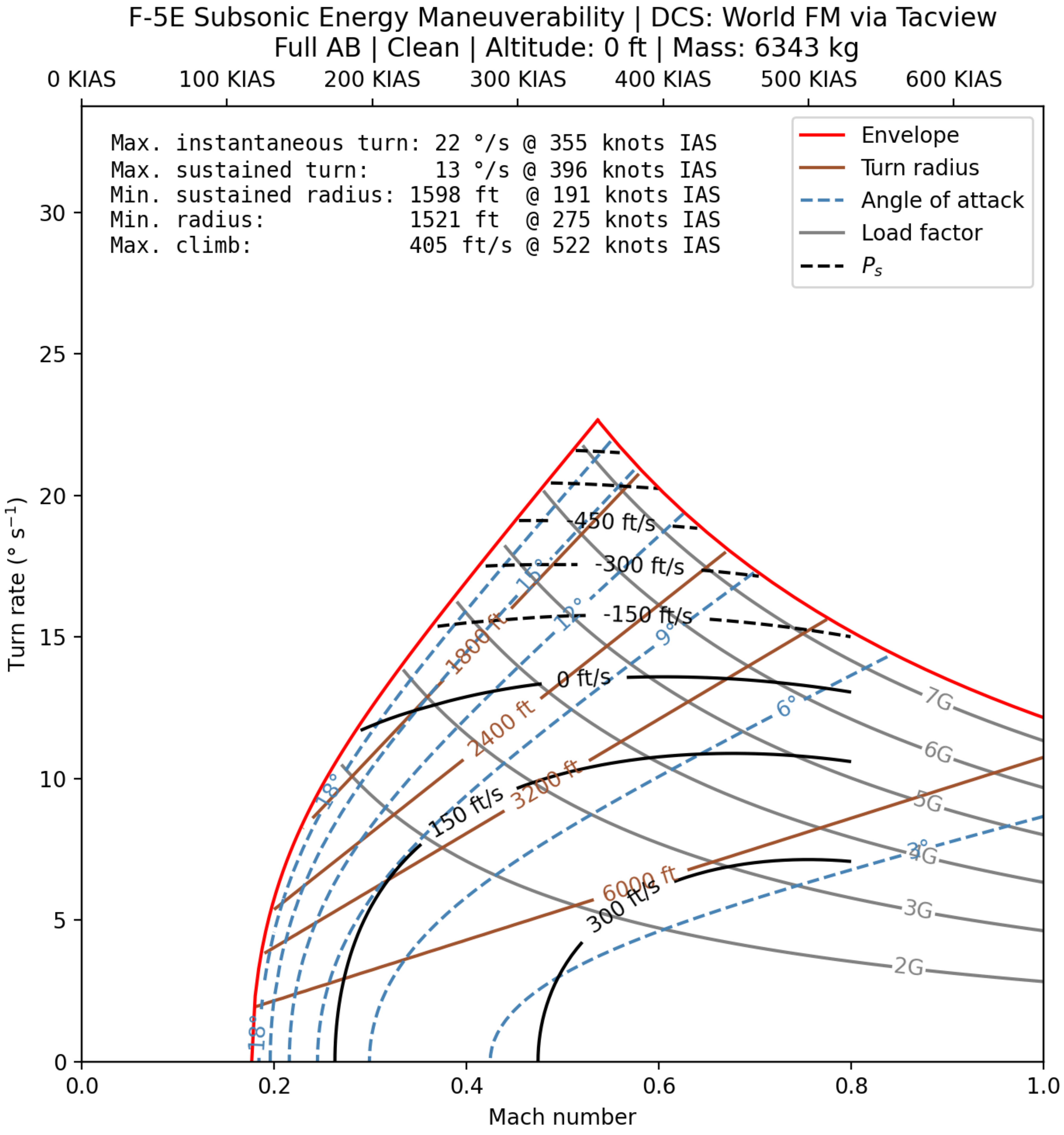


F-5E

Wingspan	27 ft / 8 m
Thrust-to-Weight Ratio (M = 0.5)	0.7
Wing Loading	65 lb/sqft
Test Date	2022-07-05
Solution Confidence	High

Notes

Disadvantaged throughout entire envelope when compared with most fighters in DCS.

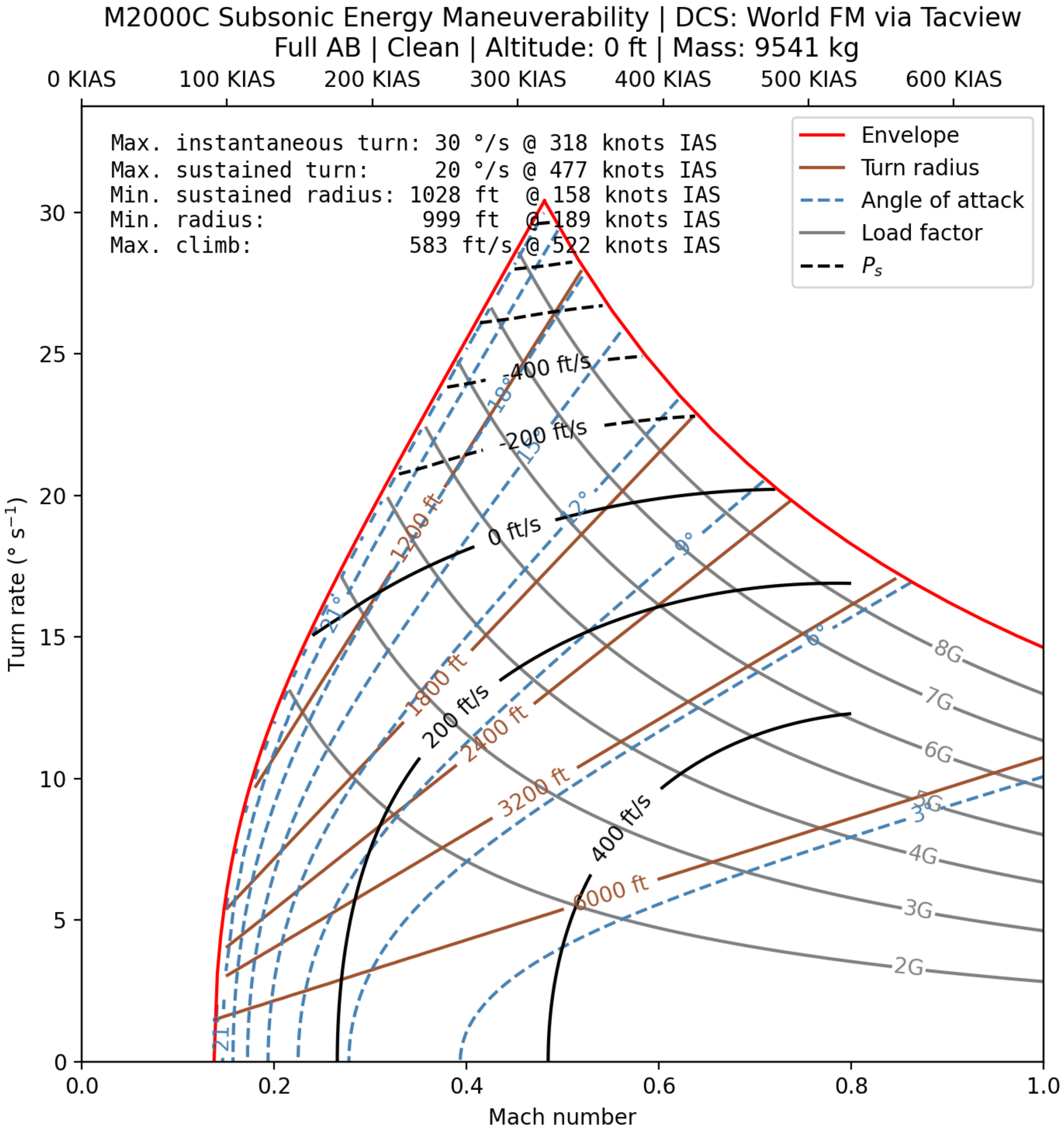


M2000C

Wingspan	30 ft / 9 m
Thrust-to-Weight Ratio (M = 0.5)	0.9
Wing Loading	47 lb/sqft
Test Date	2022-08-06
Solution Confidence	High

Notes

Dominant turn fighter due to low wing loading and high thrust-to-weight ratio.

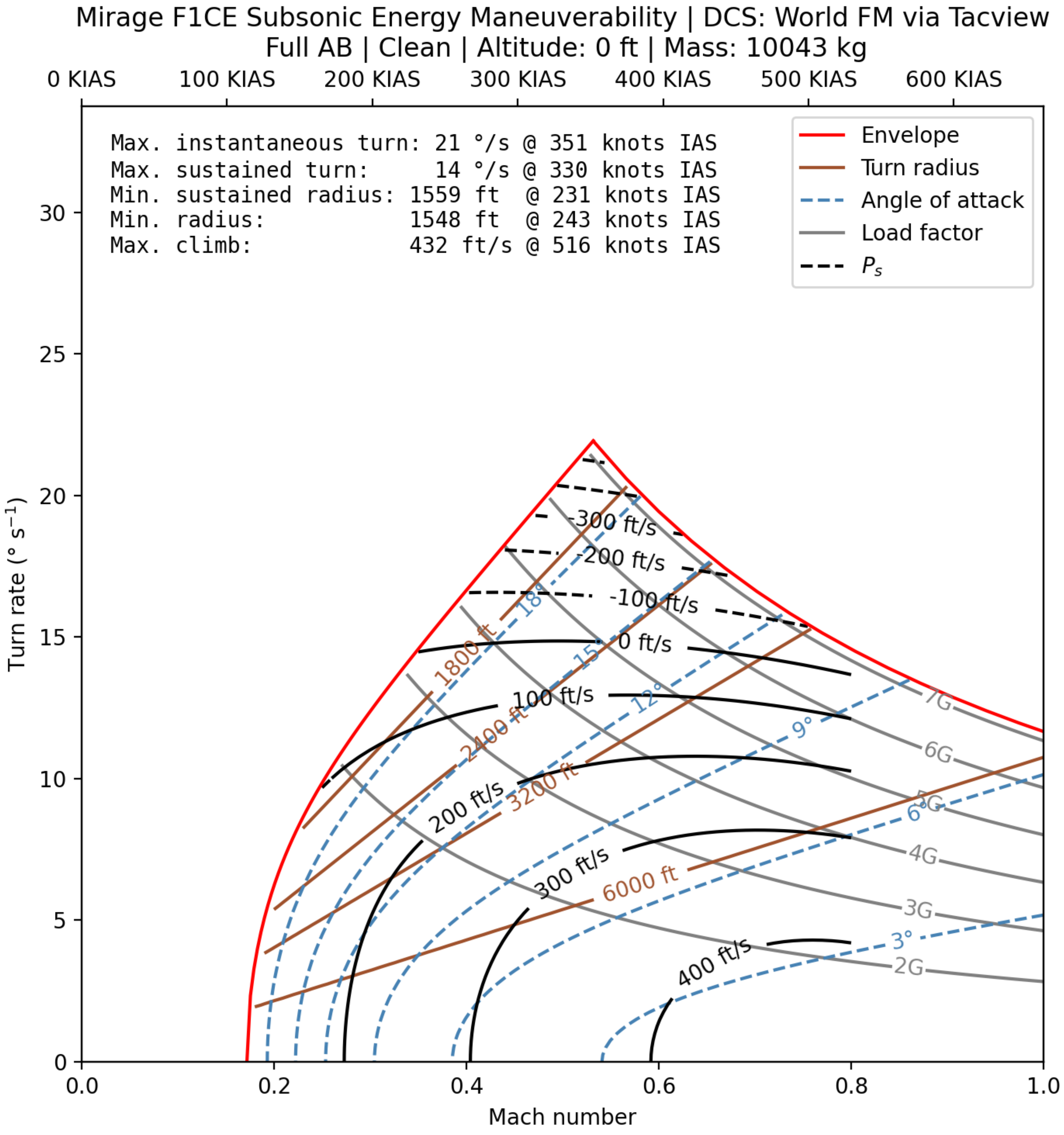


Mirage F1CE

Wingspan	28 ft / 9 m
Thrust-to-Weight Ratio (M = 0.5)	0.8
Wing Loading	82 lb/sqft
Test Date	2022-08-12
Solution Confidence	High

Notes

Poor instantaneous turn performance and unexceptional sustained turn and climb performance.

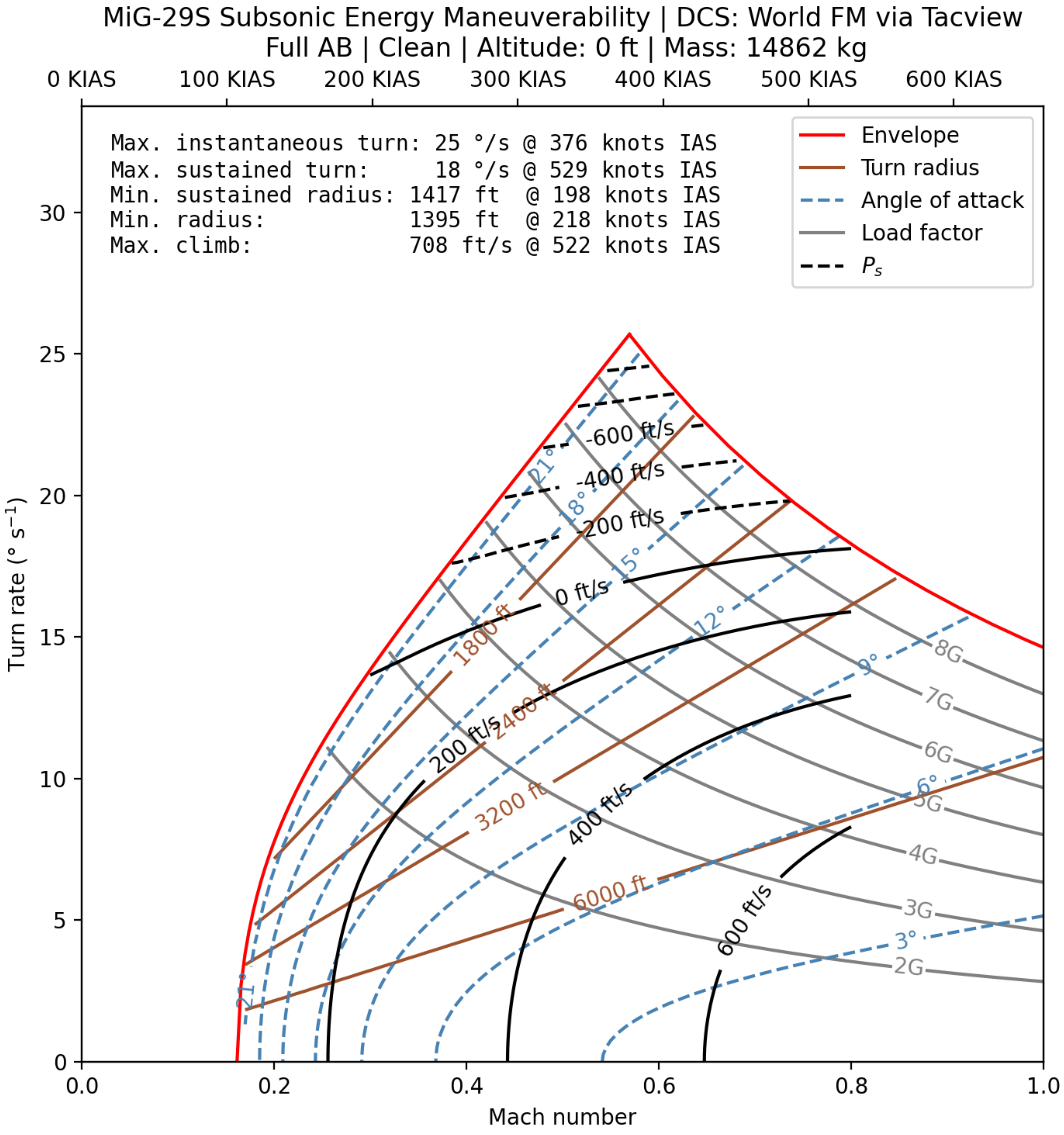


MiG-29S

Wingspan	37 ft / 11 m
Thrust-to-Weight Ratio (M = 0.5)	1.0
Wing Loading	80 lb/sqft
Test Date	2022-07-24
Solution Confidence	High

Notes

Similar to F-16C, but better sustained turn performance at high speed. Vulnerable in one-circle flows.

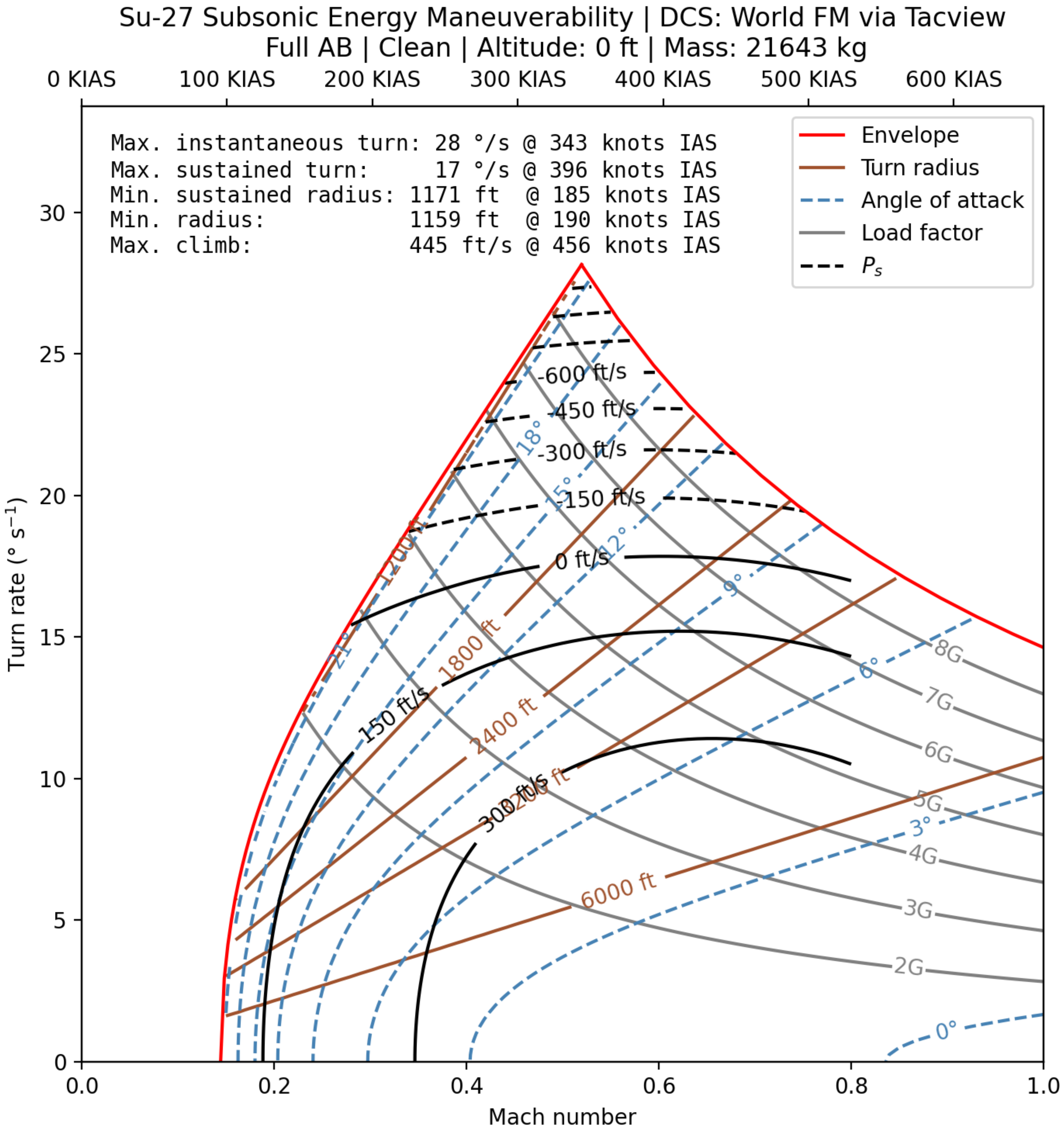


Su-27

Wingspan	48 ft / 15 m
Thrust-to-Weight Ratio (M = 0.5)	0.9
Wing Loading	71 lb/sqft
Test Date	2022-07-26
Solution Confidence	High

Notes

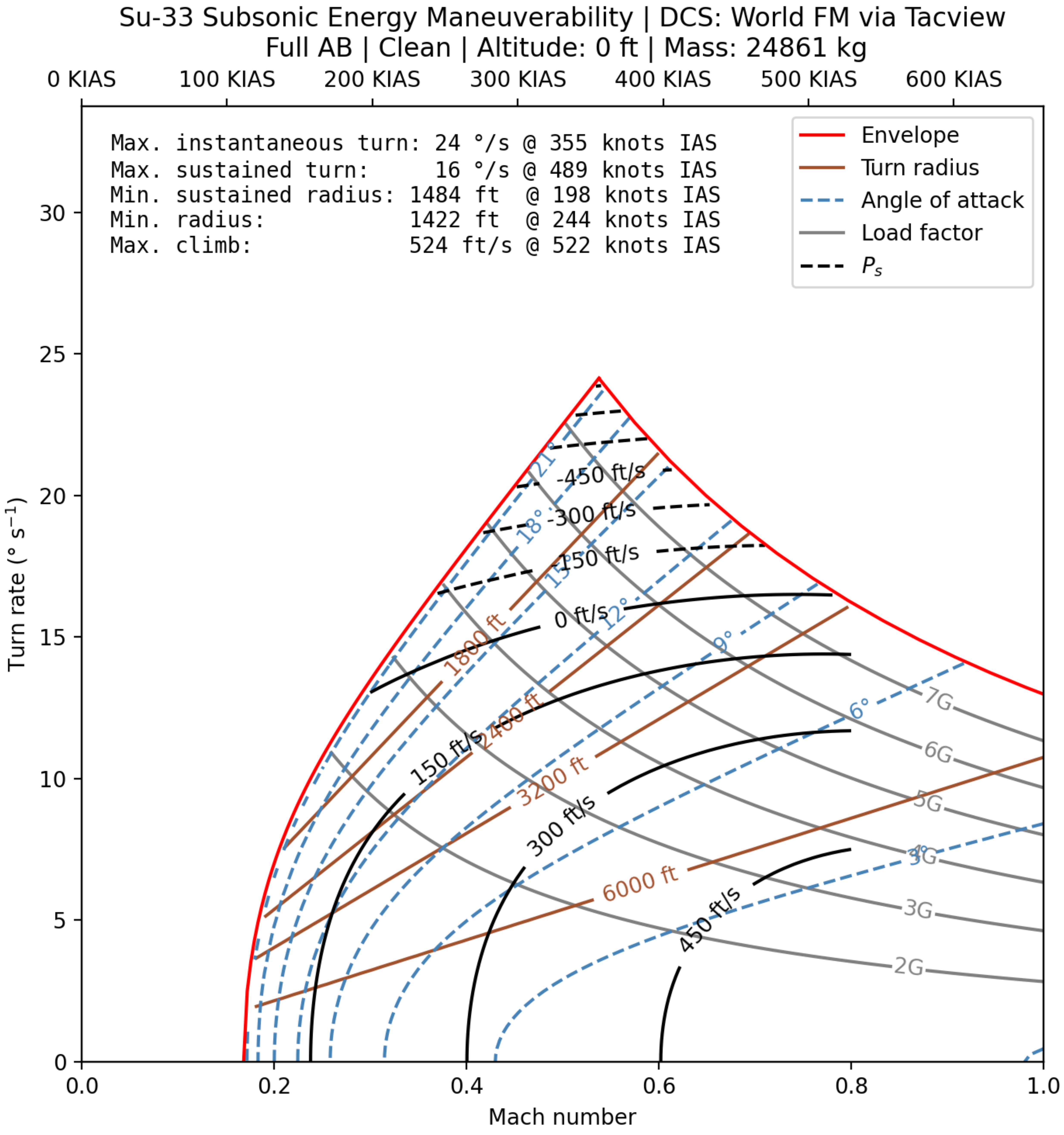
Excellent turn performance



Su-33

Wingspan	48 ft / 15 m
Thrust-to-Weight Ratio (M = 0.5)	0.9
Wing Loading	75 lb/sqft
Test Date	2022-07-26
Solution Confidence	High

Notes



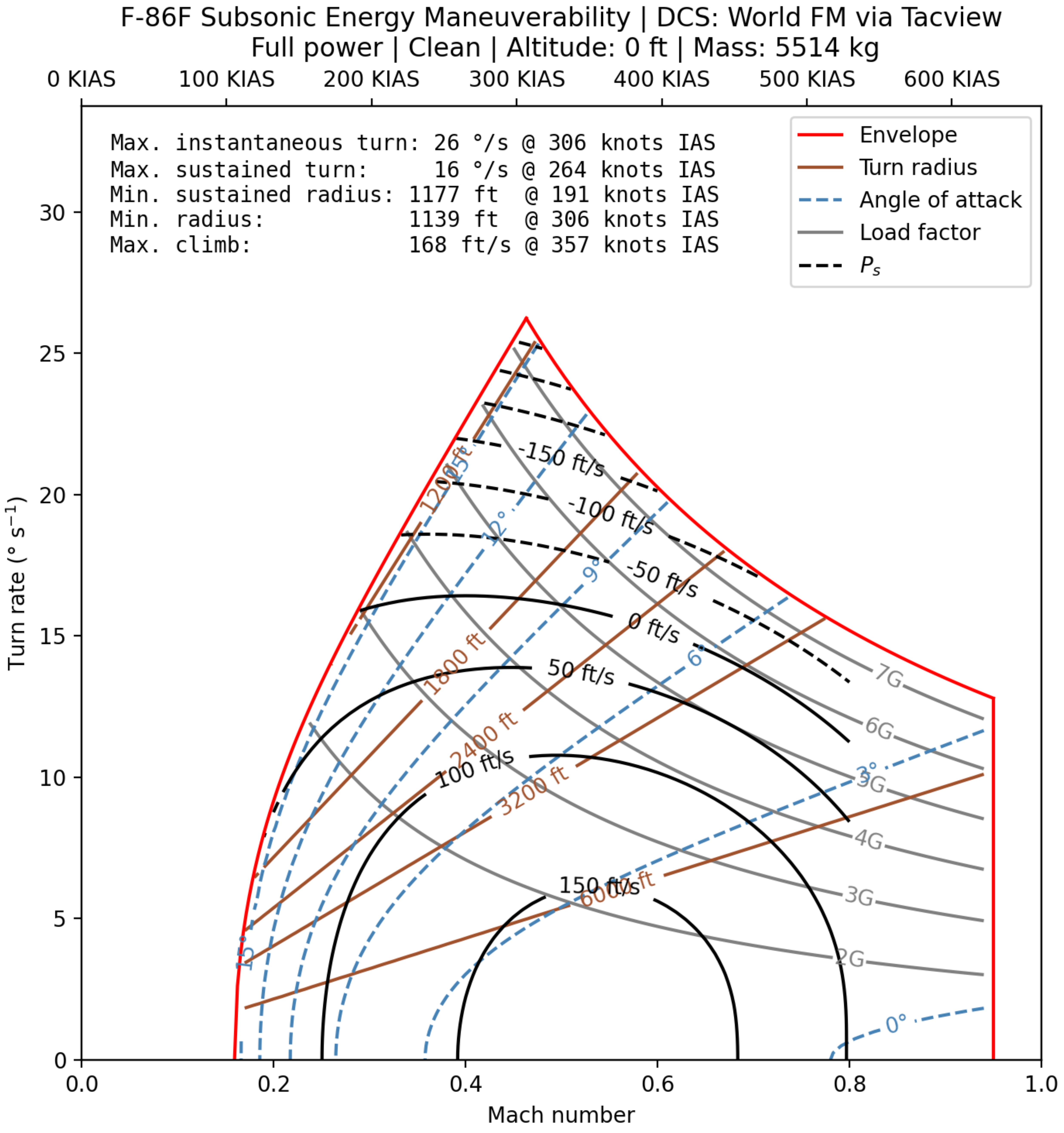
Subsonic Jets

F-86F

Wingspan	37 ft / 11 m
Thrust-to-Weight Ratio (M = 0.5)	0.4
Wing Loading	39 lb/sqft
Test Date	2022-08-10
Solution Confidence	High

Notes

Low thrust-to-weight ratio is compensated by low wing loading and superlatively high lift-to-drag ratio ($(L/D)_{max} \approx 14$) throughout its envelope. Maximum-performance turns come with a minimum loss of energy.

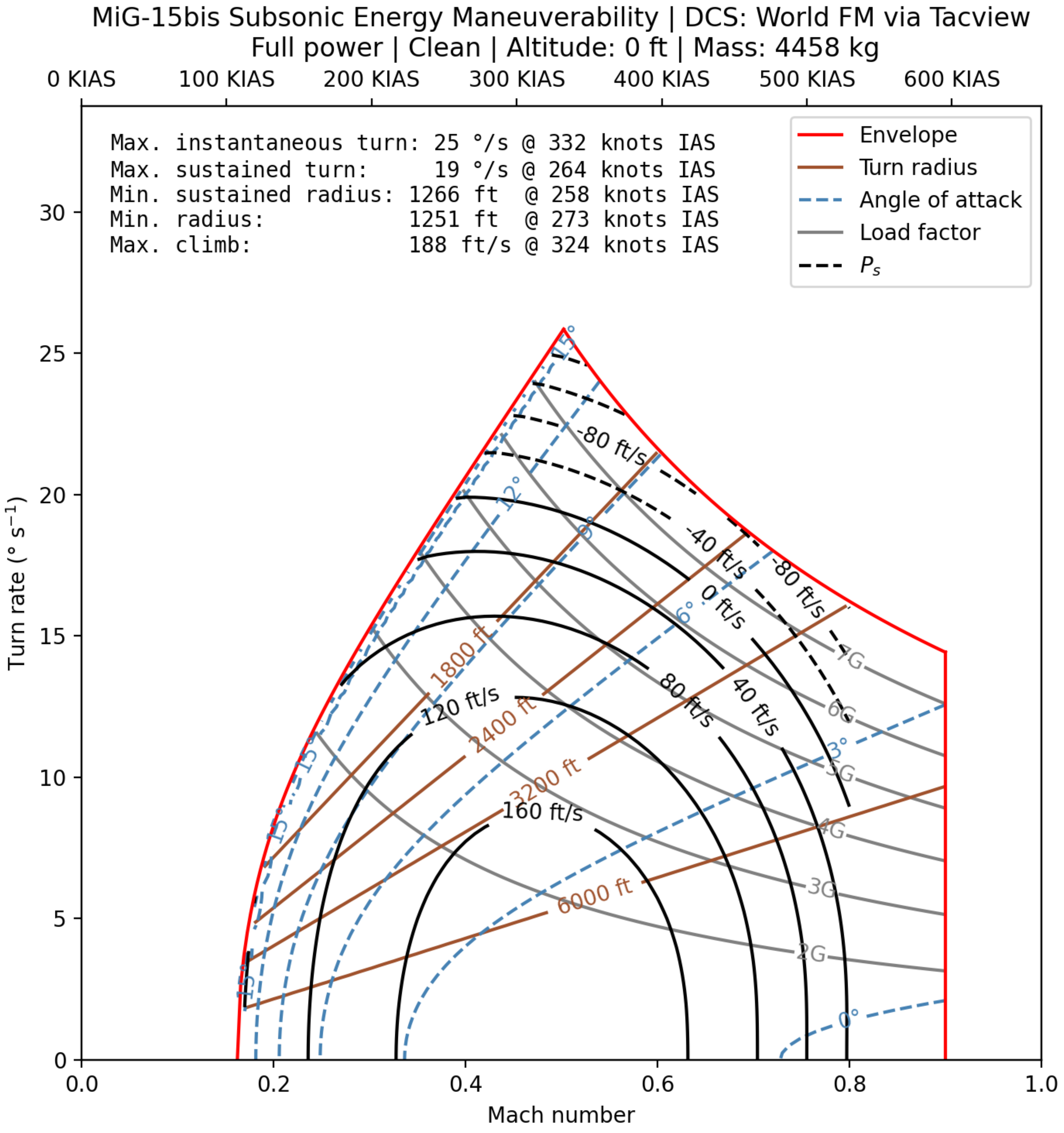


MiG-15bis

Wingspan	33 ft / 10 m
Thrust-to-Weight Ratio (M = 0.5)	0.5
Wing Loading	44 lb/sqft
Test Date	2022-08-12
Solution Confidence	High

Notes

Low wing loading and high lift-to-drag ratio give exceptional sustained turn performance at low speed. G-LOC onset at 7 G. Sluggish roll rate due to mechanical aileron linkages.

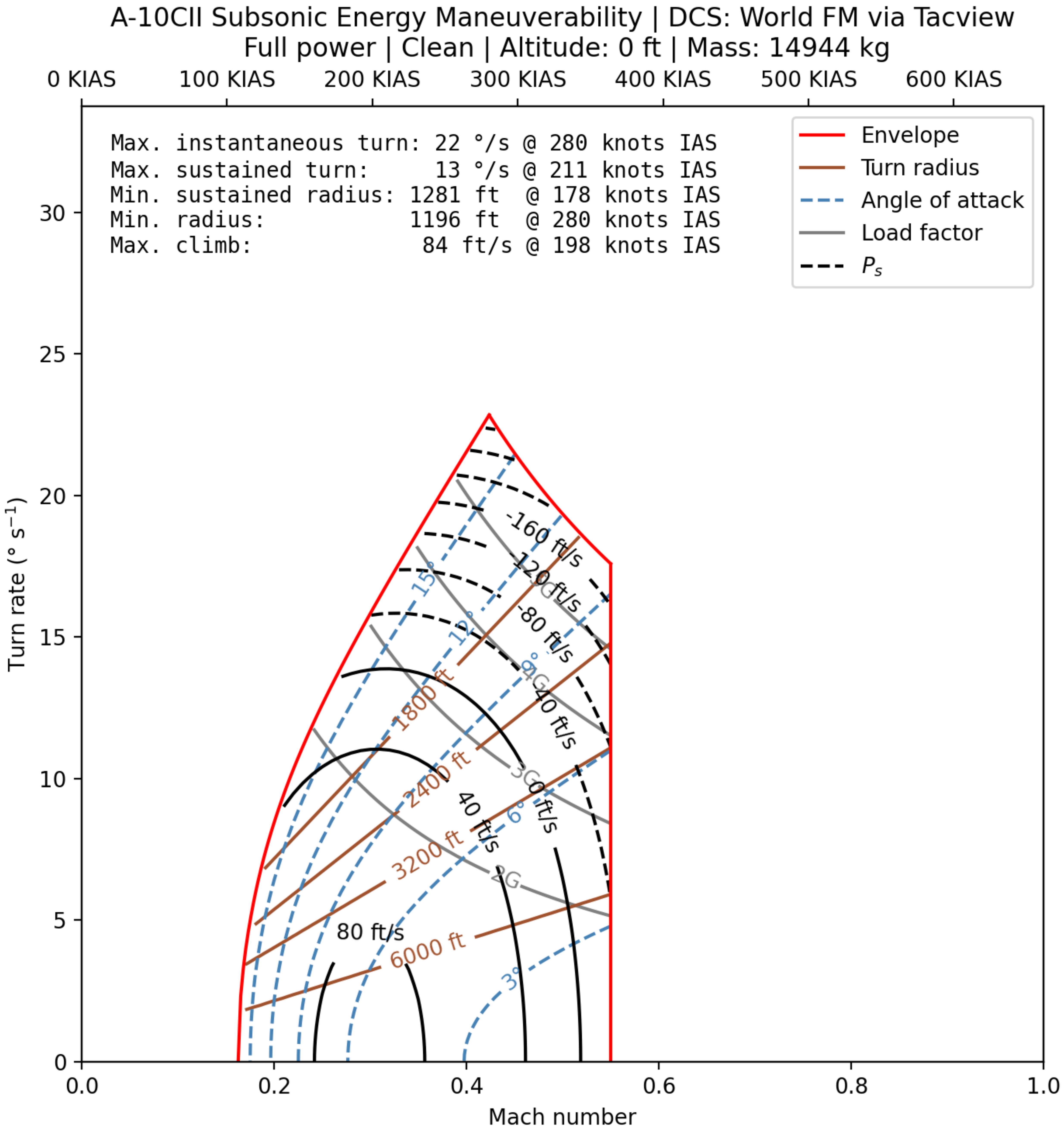


A-10CII

Wingspan	57 ft / 18 m
Thrust-to-Weight Ratio (M = 0.5)	0.3
Wing Loading	65 lb/sqft
Test Date	2022-07-05
Solution Confidence	Medium

Notes

Poor climb performance and unexceptional turn performance. A fun novelty in a dogfight, particularly against opponents with wider turn radii.

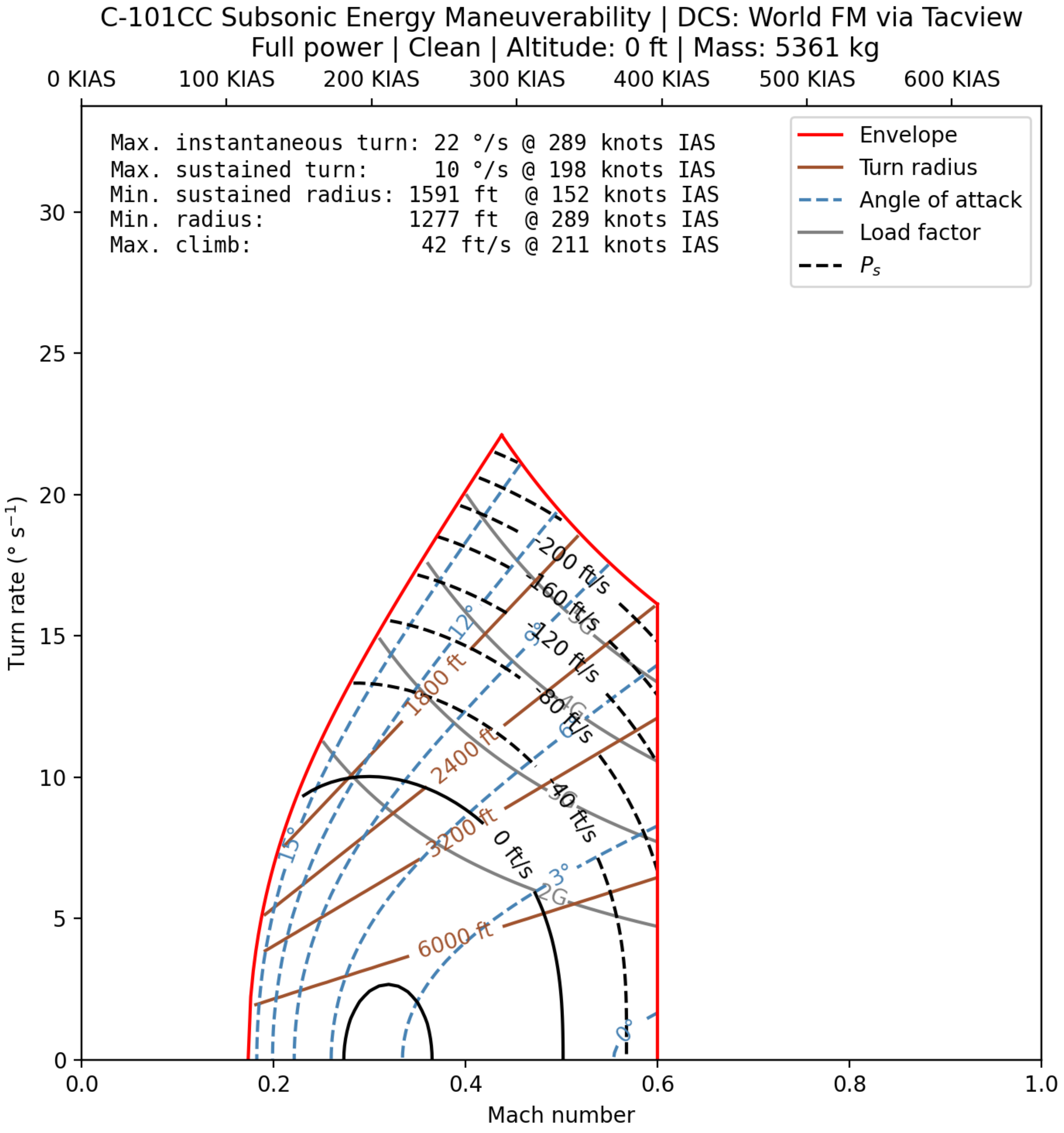


C-101CC

Wingspan	34 ft / 11 m
Thrust-to-Weight Ratio (M = 0.5)	0.2
Wing Loading	55 lb/sqft
Test Date	2022-07-05
Solution Confidence	Medium

Notes

Surprisingly poor turn performance for its airframe.
Compressor stalls at moderate angles of attack.

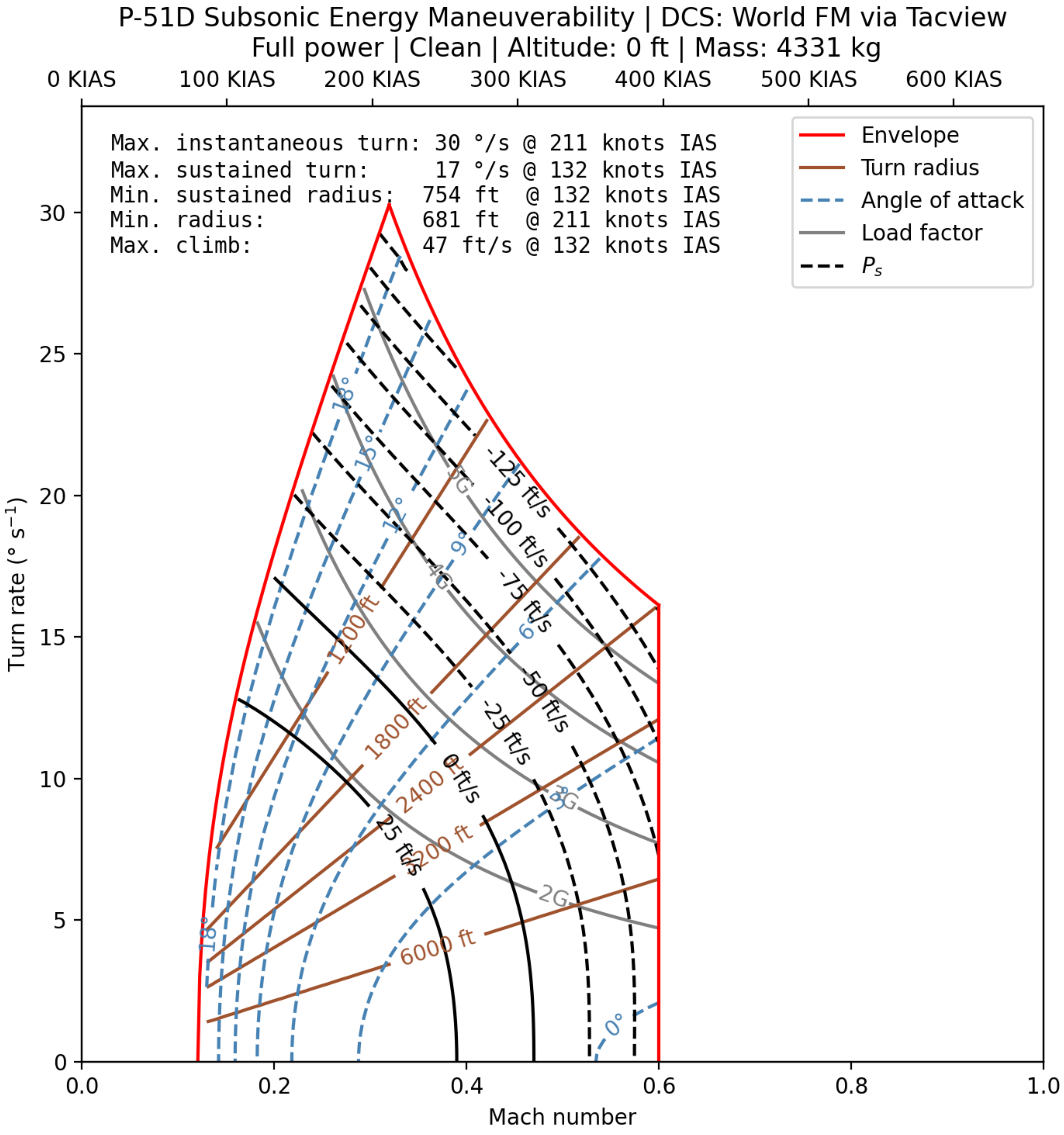


Piston-Engine Aircraft

P-51D

Wingspan	36 ft / 11 m
Wing Loading	41 lb/sqft
Test Date	2022-07-05
Solution Confidence	Low

Notes

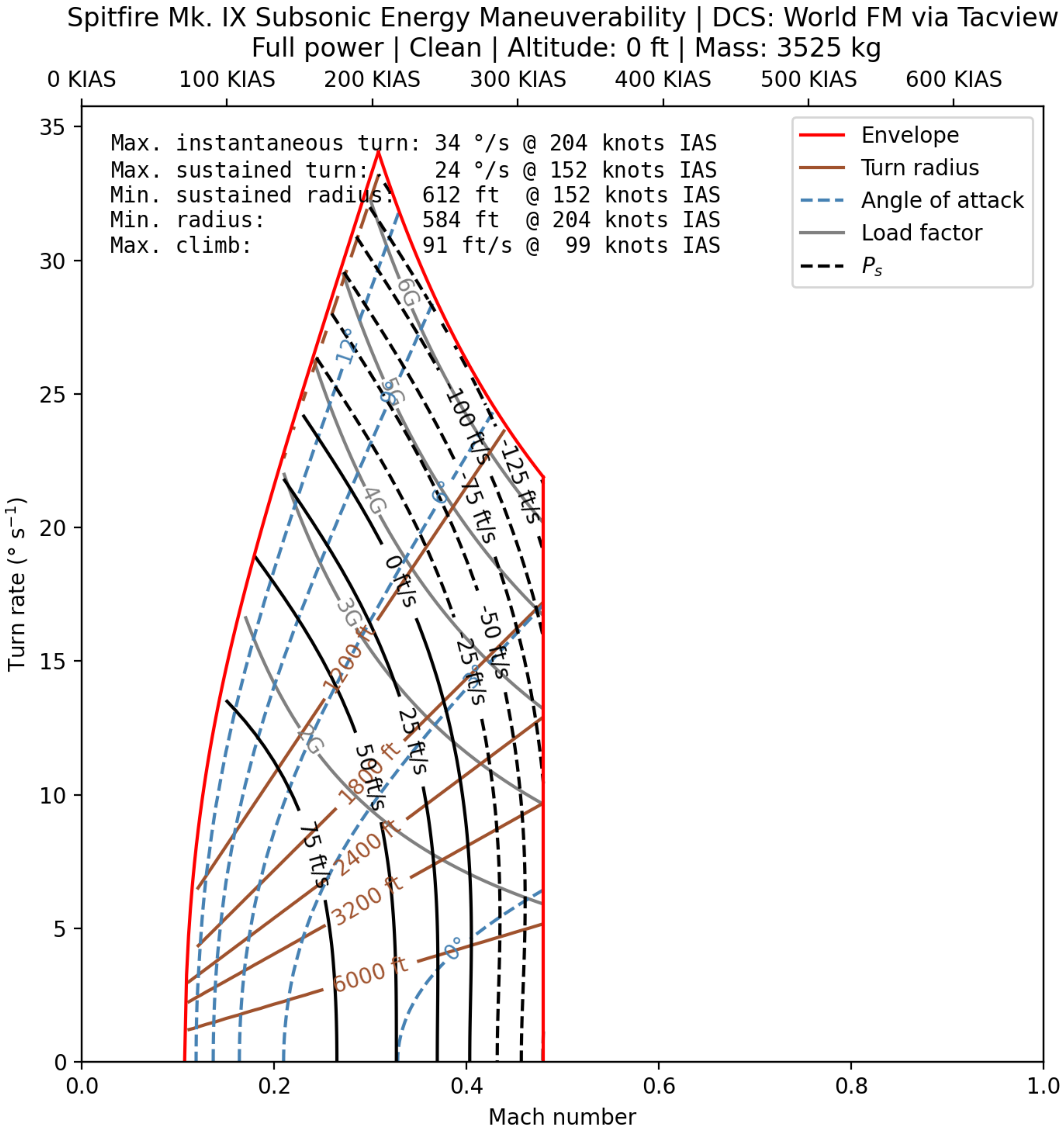


Spitfire Mk IX

Wingspan	36 ft / 11 m
Wing Loading	33 lb/sqft
Test Date	2022-07-05
Solution Confidence	Low

Notes

Arguably the best turn fighter in DCS

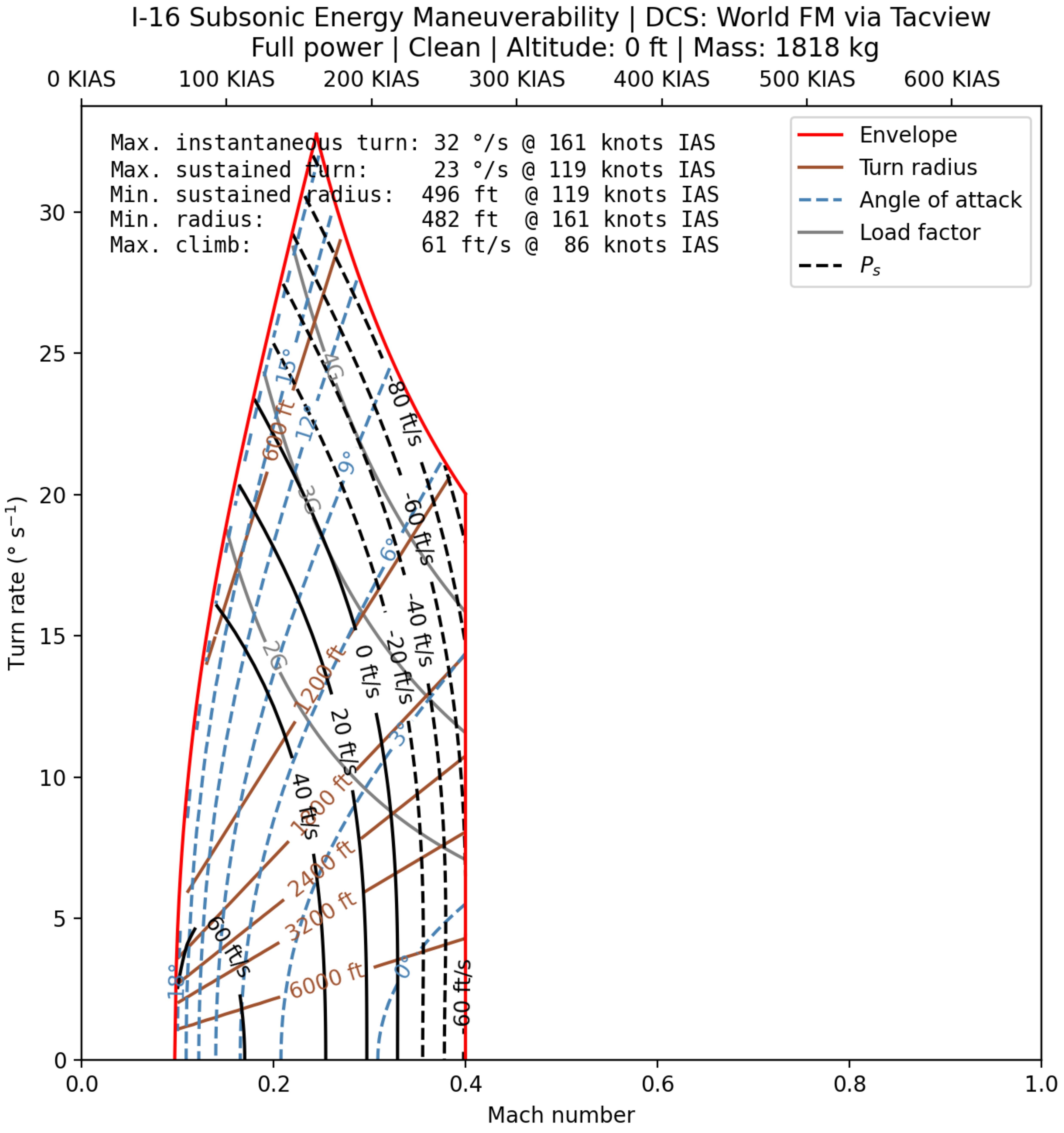


I-16

Wingspan	30 ft / 9 m
Wing Loading	25 lb/sqft
Test Date	2022-07-05
Solution Confidence	Low

Notes

Tightest turn radius for an armed aircraft in DCS



Mosquito FB VI

Wingspan	54 ft / 16 m
Wing Loading	44 lb/sqft
Test Date	2022-07-02
Solution Confidence	Low

Notes

Poor dogfight performance, but suitable opponent for the A-10 and trainer aircraft.