Dynamic V_{NE}: A Proposal for Condition-Aware Velocity-Never-Exceed Indication in Light Helicopter Primary Flight Displays

Vojtech Knyttl
vne.knyt.tl

March 2026

Abstract

Velocity Never Exceed (V_{NE}) is the most critical airspeed limitation in rotorcraft operations. Exceeding V_{NE} risks retreating blade stall, loss of control, and catastrophic structural failure. Despite its importance, the majority of light helicopter cockpit displays—both analog airspeed indicators and modern glass-panel Primary Flight Displays (PFDs)—depict V_{NE} as a *static red line* fixed at a single airspeed value, typically the sea-level, minimum-weight, power-off limit. In reality, V_{NE} is a *dynamic function* of pressure altitude, outside air temperature, gross weight, and power state. This paper presents a real-time V_{NE} computation engine and a PFD that renders a dynamically adjusted V_{NE} barber pole, providing pilots with immediate, condition-aware overspeed awareness. During the course of this work, we discovered that the Bell 429 already incorporates a factory-integrated dynamic V_{NE} display that automatically adjusts the limit based on flight conditions—a pleasant validation of the concept that nearly obviated this paper. Nevertheless, the vast majority of light helicopters in service lack such capability, and we believe the tool remains valuable for the types addressed here. A live implementation is available at https://vne.knyt.tl.

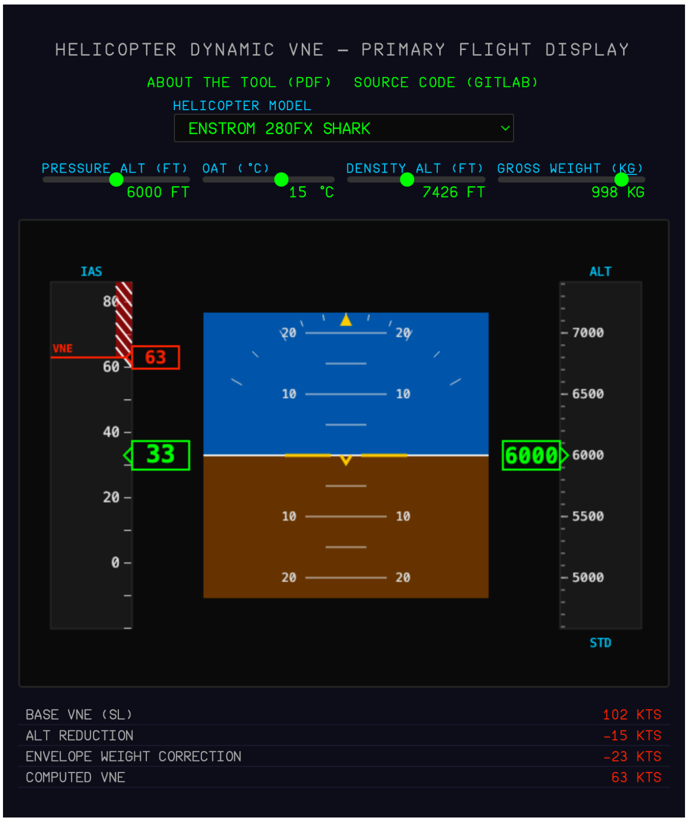

Figure 1: Dynamic V_{NE} display: Enstrom 280FX at 6,000 ft DA, Envelope D. Base 102 KIAS − 15 kts (altitude) − 23 kts (envelope) = 63 KIAS. Live at https://vne.knyt.tl.

1 Introduction and Motivation

1.1 The Problem of Static V_{NE} Display

The V_{NE} of a helicopter is not a single number. It decreases with altitude due to reduced air density, which lowers the retreating blade's effective tip speed and brings the onset of retreating blade stall to a lower forward airspeed. Temperature, weight, and power state further modulate this limit—yet the vast majority of cockpit airspeed indicators display V_{NE} as a single static red line.

The **Enstrom 280FX** presents the most dramatic illustration of this problem. Unlike most light helicopters where the V_{NE} penalty from weight is modest or absent, the Enstrom RFM (Figure 5-1) defines *four* entirely separate V_{NE}/altitude envelopes (A–D), each corresponding to a different gross-weight and longitudinal-CG combination [1]:

Envelope	Weight range	V_{NE} at SL
A (light / fwd CG)	≤ 1,469 lb	102 KIAS
B (medium / mid CG)	1,470–1,762 lb	90 KIAS
C (heavy / aft CG)	1,763–2,056 lb	79 KIAS
D (max wt / aft CG)	≥ 2,057 lb	74 KIAS

The difference between the lightest and heaviest envelopes is **28 knots** at sea level—and this penalty compounds with altitude. At 6,000 ft density altitude, Envelope A yields 87 KIAS while Envelope D yields only 63 KIAS, a gap of **24 knots** on a much lower absolute limit. A cockpit display showing a single static V_{NE} of 102 KIAS (Envelope A) provides dangerously misleading guidance to a pilot flying at maximum gross weight in Envelope D, where the actual limit is nearly **40 knots lower**.

The cognitive burden this imposes is substantial: during flight, the pilot must first determine the aircraft's current gross weight and CG position, cross-reference these against the weight/CG envelope chart to identify which envelope (A–D) applies, then look up the corresponding V_{NE}/altitude graph to read off the speed limit for the current altitude. This multi-step process is poorly suited to high-workload phases of flight such as mountain operations or emergency descent.

The Enstrom F-28F exhibits the same four-envelope structure (with sea-level values of 112/104/91/85 MPH), confirming this is a systemic design characteristic of the Enstrom piston line, not an anomaly of a single model. The turbine Enstrom 480B also shows weight-dependent V_{NE}, though the variation is smaller (125 kt at 2,800 lb vs. 124 kt at 3,000 lb).

Other types exhibit different but equally significant variations. The **Guimbal Cabri G2** PFD shows a fixed red line at 110 KIAS—the power-off sea-level value—yet the power-on V_{NE} is 130 KIAS, and both decrease by 2 kt per 1,000 ft. At 5,000 ft in autorotation, the actual V_{NE} is only 100 KIAS while the display still shows 110. The **Bell 206B3** has two distinct V_{NE}/altitude schedules depending on whether gross weight exceeds 2,650 lb, and the **Bell 407** uses a full pressure-altitude × OAT lookup table.

1.2 The Consequence: Accidents and Near-Misses

The aviation safety record contains multiple incidents where V_{NE} exceedance or proximity to V_{NE} contributed to loss of control.

1.2.1 *Enstrom 480B OK-CLV — Slavoňov, Czech Republic (22 March 2019)*

An Enstrom 480B-G (registration OK-CLV) was conducting a training flight near Nové Město nad Metují with a foreign student pilot and a Czech instructor from DSA / Air Rescue Service. After approximately one hour of flight at 4,500 ft, the helicopter entered an unusual nose-down attitude during a right turn and descended rapidly into terrain. Both occupants were fatally injured and the helicopter was destroyed by impact and post-crash fire. The investigation by ÚZPLN (Czech Air Accident Investigation Institute) [2] examined the flight profile. Accounts from the helicopter community indicate the student may have applied collective input at or near V_{NE}, resulting in a sudden departure from controlled flight—consistent with the pitch-up and roll characteristic of retreating blade stall onset at excessive forward speed [3, 4].

1.2.2 *AS350 BA C-FBLW — Smithers, British Columbia (16 March 2016)*

An Airbus AS350 BA operated by TRK Helicopters on a heli-skiing flight with six passengers departed from a staging area at approximately 6,000 ft. Shortly after takeoff, the pilot initiated a descent into a ravine, during which airspeed increased rapidly. When the pilot attempted a corrective left turn, the helicopter *abruptly rolled right and pitched up*, striking a steep snow-covered slope. All occupants survived.

The Transportation Safety Board of Canada (Report A16P0045) [5] attributed the event to **servo transparency**—the hydraulic actuators being overwhelmed by aerodynamic forces. However, experienced rotary-wing pilots on professional forums [6] have raised an important alternative hypothesis: at 6,000 ft pressure altitude, the AS350's V_{NE} is reduced by approximately 18 KIAS from its sea-level value ($155 - 3 \times 6 = 137$ KIAS). The rapid descent would have increased airspeed well above cruise, potentially into the V_{NE} regime. The pitch-up/right-roll signature observed is consistent with **retreating blade stall** on the Écureuil's clockwise-rotating main rotor.

Whether the root cause was servo transparency, retreating blade stall, or a combination, the event underscores that V_{NE} **decreases significantly at altitude** and that a static ASI red line provides no warning of this reduction [7].

1.2.3 *AS350 LN-OFU — Alta, Norway (31 August 2019)*

An AS350 B3 operated by Helitrans AS on a sightseeing flight crashed near Alta, killing all six occupants. The Norwegian Safety Investigation Authority (NSIA Report 2022-02) [8] found that the pilot, with only 17 hours on type, exceeded bank and pitch limits with descent rates exceeding 3,000 fpm. The report documented *eleven prior AS350 accidents* attributed to servo transparency, where the actuators max out at 193 kg (425 lbs) of force, causing the helicopter to "roll right and pitch up while the flight controls seem to have locked." The boundary between servo transparency and retreating blade stall onset remains a subject of active debate in the rotorcraft engineering community [9, 10].

1.2.4 *BK117B2 VH-VSA — Queensland, Australia (15 February 2013)*

A Kawasaki BK117B2 air ambulance was cruising at 115 KIAS—only 5 knots below V_{NE} for its conditions—at a density altitude of approximately 7,000 ft, near maximum weight, in light to moderate turbulence. The helicopter experienced a *violent uncommanded nose-up pitch and left roll*. The pilot applied full forward cyclic with both hands but could not arrest the pitch-up. The aircraft reached approximately 70° nose-up and 120° left roll before the pilot recovered at approximately 1,000 ft (800 ft AGL). The Australian Transport Safety Bureau determined the cause to be **retreating blade stall**, induced by the combination of high airspeed close to V_{NE}, high density altitude, high weight, and turbulence [11].

1.3 Why Dynamic V_{NE} Display Matters

These events share a common thread: the actual safe V_{NE} at the time of the event was significantly lower than the published sea-level value, and pilots had no cockpit instrument providing real-time awareness of the reduced limit. A dynamic V_{NE} display that adjusts the barber pole position based on current pressure altitude, OAT, weight, and power state would:

1. **Eliminate mental arithmetic**—pilots would no longer need to cross-reference altitude with V_{NE} charts during flight.
2. **Provide visual margin awareness**—the closing gap between current IAS and the moving V_{NE} barber pole would trigger natural pilot attention.
3. **Account for all relevant variables**—weight corrections, temperature corrections, and power state would be computed automatically.
4. **Enhance safety during critical phases**—mountain flying, autorotation practice, and heli-skiing operations where altitude changes rapidly.

Some modern EFIS systems (Garmin G500H, Dynon) allow configurable speed bugs, but none currently compute and display a fully dynamic V_{NE} based on real-time flight conditions for the helicopter types addressed in this paper. A notable exception is the **Bell 429**, whose integrated digital airspeed indicator automatically adjusts the displayed V_{NE} limit based on altitude and temperature—precisely the concept this project implements as a standalone tool for older and simpler helicopter types that lack such factory-integrated capability.

2 Supported Helicopter Types

Table 1 summarizes the nine helicopter types currently supported by the system.

Each helicopter type is defined as a typed data object conforming to a common `HelicopterType` interface. All helicopter data and the V_{NE} computation engine are embedded directly in the client-side JavaScript, requiring no server-side processing.

3 Implementation

3.1 Architecture

The application runs as a Cloudflare Worker at https://vne.knyt.tl, serving a self-contained single-page application. All helicopter data and V_{NE} computation logic run entirely in the browser—no server-side API calls are required.

- **Computation engine:** Client-side JavaScript computing V_{NE} for arbitrary flight conditions using bilinear interpolation, piecewise-linear interpolation, or linear formulas depending on helicopter type.
- **Display:** Canvas-based PFD rendering using the **ECAMFont** typeface—a monoline geometric sans-serif recreation of the actual Thales EIS/ECAM display font (sourced from the FlyByWire A32NX open-source project [22]).
- **Data model:** Each helicopter's V_{NE} limitations are encoded as typed schedule objects (linear, piecewise, or table) with optional temperature and weight corrections, embedded directly in the page.

Table 1: Supported helicopter types and their V_{NE} schedule characteristics.

Helicopter	V_{NE} (SL, PwrOn)	Schedule	Alt. Ref.	Key Feature
Robinson R22 Beta	102 KCAS	Piecewise	DA	CAS-based; non-linear DA reduction [12]
Robinson R44 Raven II	130 KIAS	PA×OAT Table	PA	2D lookup with weight correction [13, 14]
Guimbal Cabri G2	130 KIAS	Linear	PA	Static PFD shows 110 (power-off only) [15, 16]
Enstrom 280FX Shark	74–102 KIAS	Piecewise	DA	4 envelopes by weight/CG [1, 17]
Enstrom 480B	125 KIAS	Piecewise	DA	Weight correction above 2,800 lb [17]
EC120B Colibri	150 KIAS	Linear	PA	−3 kt / 1,000 ft [18]
H125 / AS350 B3	155 KIAS	Linear	PA	Temp correction below −30 °C [19]
Bell 206B3 JetRanger	130 KIAS	Piecewise	DA	Dual rate by weight: −3.5/−7.0 kt / 1,000 ft [20]
Bell 407	140 KIAS	PA×OAT Table	PA	Full 2D lookup; 100 kt at takeoff power [20, 21]

3.2 V_{NE} Computation

The computation pipeline proceeds as follows:

1. Determine effective altitude (pressure altitude or density altitude, per helicopter type). For density-altitude referenced types:

$$DA = PA + 120 \times (OAT - T_{ISA}), \qquad T_{ISA} = 15 - 1.98 \times \frac{PA}{1000} \tag{1}$$

2. Select the applicable V_{NE} schedule. For most types this is determined by power state (power-on vs. power-off). The Enstrom 280FX and F-28F use a different paradigm: four V_{NE}/altitude envelopes (A–D), each defined by a gross-weight and longitudinal-CG combination per RFM Figure 5-1 [1]. Envelope A (lightest, forward CG) yields 102 KIAS at sea level, while Envelope D (heaviest, aft CG) yields only 74 KIAS—a 28-knot difference at the same altitude.

3. Evaluate the selected V_{NE} schedule:
   - *Linear:* $V_{NE} = V_{NE,\text{base}} - r \times h/1000$
   - *Piecewise:* Linear interpolation between altitude breakpoints.
   - *Table:* Bilinear interpolation in a PA × OAT matrix.

4. Apply temperature corrections (e.g., H125: −10 KIAS below −30 °C).

5. Apply weight corrections (e.g., R44: −10 KIAS above 2,200 lb; Enstrom 480B: −1 KIAS above 2,800 lb).

6. Return computed V_{NE} with full correction breakdown.

3.3 Primary Flight Display

The PFD renders the following elements (see Figure 1):

- **Speed tape** (left) with a dynamic V_{NE} barber pole that moves in real time as flight conditions change.
- **Altitude tape** (right) with interactive drag-to-scroll altitude adjustment.
- **Attitude indicator** (center) with pitch ladder and bank scale.
- **Flight mode annunciator** showing V_{NE} status, margin, and exceedance warnings.
- **Info panel** (below) with base V_{NE}, altitude reduction, temperature correction, envelope weight correction, and computed V_{NE} breakdown.

4 Disclaimer

This application is a **research prototype** and educational tool. It is **not certified** for use in actual flight operations. V_{NE} values are derived from publicly available EASA Type Certificate Data Sheets and Pilot Operating Handbooks but may contain errors or omissions. Always refer to the approved Rotorcraft Flight Manual for your specific aircraft serial number. The authors accept no liability for any use of this software in flight planning or in-flight decision making.

Acknowledgments

This project was inspired in large part by my flight instructor, **Petr Dolejšek**, whose attention to the finer details of helicopter safety and handling has profoundly influenced the way I think about flight operations. Although I had known about the Enstrom accident [2] even before I started flying, I was not familiar with the explanation behind it. Petr later walked me through the accident and pointed out an important limitation: the V_{NE} displayed on the PFD is only a static value. That realization became one of the main motivations for developing this tool.

References

[1] *Enstrom 280FX Rotorcraft Flight Manual, Section 5 — Performance, Figure 5-1: V_{NE} Envelopes A–D*. Enstrom Helicopter Corporation, 2020. Four V_{NE}/altitude envelopes defined by gross weight and longitudinal CG.

[2] ÚZPLN. Final Report: Enstrom 480B-G, OK-CLV, 22 March 2019, Slavoňov. Technical report, Czech Air Accident Investigation Institute (ÚZPLN), 2020. URL https://uzpln.gov.cz/pdf/20200601155243.pdf.

[3] Aviation Safety Network. Accident Record: Enstrom 480B OK-CLV, 2019. URL https://aviation-safety.net/wikibase/223282.

[4] HeliHub. 22 Mar 19: OK-CLV Enstrom 480 — Slavonov, Czech Republic, 2019. URL https://helihub.com/2019/03/22/22-mar-19-ok-clv-enstrom-480-slavonov-czech-republic-2f/.

[5] Transportation Safety Board of Canada. Aviation Investigation Report A16P0045: AS350 BA, C-FBLW, 16 March 2016. Technical report, TSB Canada, 2018. URL https://www.tsb.gc.ca/eng/rapports-reports/aviation/2016/a16p0045/a16p0045.html.

[6] PPRuNe Rotorheads. AS350 Crash Due to Jack Stall (Forum Discussion), 2019. URL https://www.pprune.org/rotorheads/655990-as350-crash-due-jack-stall.html.

[7] Vertical Magazine. Limitations of Hydraulic System, Pilot Control Input Led to 2016 Helicopter Collision, 2018. URL https://verticalmag.com/press-releases/limitations-hydraulic-system-pilot-control-input-led-2016-helicopter-collision/.

[8] Norwegian Safety Investigation Authority. Report 2022-02: AS350 B3, LN-OFU, 31 August 2019, Alta. Technical report, NSIA, 2022. URL https://nsia.no/Aviation/Aviation/Published-reports/2022-02.

[9] ROTOR Media. Past the Limits: AS350 Servo Transparency History, 2022. URL https://rotormedia.com/past-the-limits/.

[10] Missi Pyle Aviation. Servo Transparency — Understanding the AS350/H125 Phenomenon, 2023. URL https://www.youtube.com/watch?v=P44VxgI20H8. YouTube video.

[11] Aerossurance. Retreating Blade Stall: BK117B2 VH-VSA, 15 February 2013, 2014. URL https://aerossurance.com/helicopters/retreating-blade-stall/.

[12] EASA Type Certificate Data Sheet EASA.IM.R.120 — Robinson R22. Technical report, European Union Aviation Safety Agency, 2024. URL https://www.easa.europa.eu/en/document-library/type-certificates/rotorcraft-cs-27/easa-im-r120.

[13] *Robinson R44 Raven II Pilot's Operating Handbook, Section 2 — Limitations*. Robinson Helicopter Company, 2023. Not publicly available online.

[14] EASA Type Certificate Data Sheet EASA.IM.R.116 — Robinson R44. Technical report, European Union Aviation Safety Agency, 2024. URL https://www.easa.europa.eu/en/document-library/type-certificates/rotorcraft-cs-27/easa-im-r116.

[15] EASA Type Certificate Data Sheet EASA.R.145 — Guimbal Cabri G2. Technical report, European Union Aviation Safety Agency, 2024. URL https://www.easa.europa.eu/en/document-library/type-certificates/rotorcraft-cs-27/easa-r145.

[16] *Guimbal Cabri G2 Flight Manual (J40-001, Issue 10.1)*. Hélicoptères Guimbal, 2018. URL https://cabri-usa.com/wp-content/uploads/2018/03/J40-001-Issue-10.1-Cabri-G2-Flight-Manual.pdf.

[17] EASA Type Certificate Data Sheet EASA.IM.R.122 — Enstrom 280FX / 480B. Technical report, European Union Aviation Safety Agency, 2024. URL https://www.easa.europa.eu/en/document-library/type-certificates/rotorcraft-cs-27/easa-im-r122.

[18] EASA Type Certificate Data Sheet EASA.R.508 — EC120B Colibri. Technical report, European Union Aviation Safety Agency, 2024. URL https://www.easa.europa.eu/en/document-library/type-certificates/rotorcraft-cs-27/easa-r508.

[19] EASA Type Certificate Data Sheet EASA.R.008 — AS350 / H125. Technical report, European Union Aviation Safety Agency, 2024. URL https://www.easa.europa.eu/en/document-library/type-certificates/rotorcraft-cs-27/easa-r008.

[20] EASA Type Certificate Data Sheet EASA.IM.R.512 — Bell 206/407 Series. Technical report, European Union Aviation Safety Agency, 2024. URL https://www.easa.europa.eu/en/downloads/7909/en.

[21] *Bell 407 Rotorcraft Flight Manual (BHT-407-FM-1), Section 5 — Limitations, Figure 1-3*. Bell Textron Inc., 2023.

[22] FlyByWire Simulations. FlyByWire A32NX Open-Source Aircraft Project, 2024. URL https://github.com/flybywiresim/aircraft.