

# Fatigue design primer

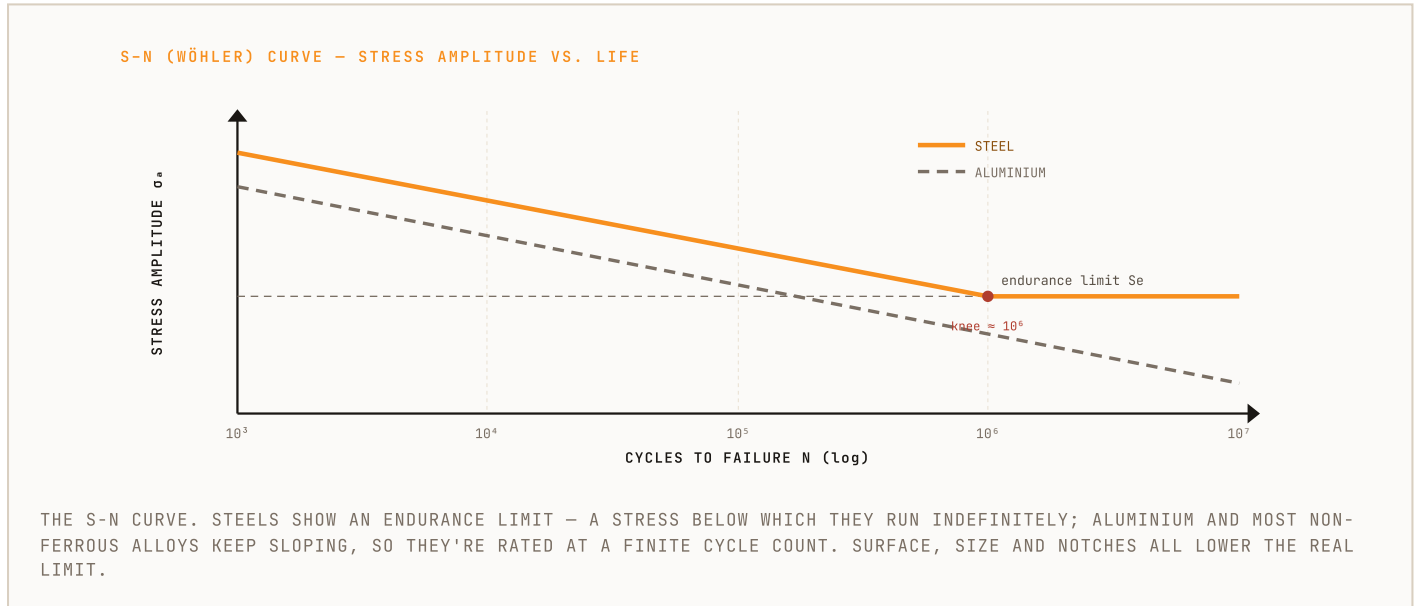
Designing against cyclic failure — the S-N curve and endurance limit, the Marin modifiers that knock it down, mean-stress (Goodman) correction, and the notches where cracks actually start.

REVISION	ISSUED	OWNER	COMPANION
1.0	June 2026	Ideambox engineering	PDF reference

## ABSTRACT

Most mechanical parts that break in service break by fatigue — cracking under cyclic stress well below the static strength. Fatigue is driven by the stress *amplitude* (and the mean stress), grows from stress raisers, and is hugely sensitive to surface finish. This primer is the high-cycle design workflow.

Section 1 covers what fatigue is. Section 2 is the S-N curve and endurance limit. Section 3 is the Marin modifiers that reduce the lab endurance limit to a real one. Section 4 is mean-stress correction (Goodman / Gerber / Soderberg). Section 5 is stress concentration and notch sensitivity. Section 6 is design rules and a checklist.



## CONTENTS

1.	What fatigue is	4.	Mean stress correction
2.	The S-N curve and endurance limit	5.	Stress concentration and notches
3.	Endurance-limit modifiers (Marin factors)	6.	Design rules and checklist

# 1. What fatigue is

---

A part loaded repeatedly can crack and fail at a stress far below its yield strength. A crack initiates at a stress raiser, grows a little with each cycle, and finally fractures the remaining section suddenly. The driver is the **alternating stress**, modified by the **mean stress**.

## 1.1 Terms

Stress amplitude $\sigma_a$	Half the stress range — $(\sigma_{\max} - \sigma_{\min})/2$ — the primary fatigue driver
Mean stress $\sigma_m$	$(\sigma_{\max} + \sigma_{\min})/2$ — a tensile mean shortens life
Stress ratio R	$\sigma_{\min} / \sigma_{\max}$ (R = -1 fully reversed, R = 0 repeated)
Endurance limit $S_e$	Stress amplitude a steel survives indefinitely ( $>10^6$ – $10^7$ cycles)
S-N curve	Stress amplitude vs cycles-to-failure (log-log), from rotating-beam tests
$K_t / K_f$	Geometric / fatigue stress-concentration factor at a notch

High-cycle fatigue ( $>10^3$  cycles, elastic) is handled with the S-N / endurance approach below. Very-low-cycle, plastic fatigue needs strain-life methods (out of scope here).

## 2. The S-N curve and endurance limit

---

Plotting stress amplitude against cycles-to-failure gives the S-N (Wöhler) curve:

- **Steels have an endurance limit**

a knee near  $10^6$  cycles below which life is effectively infinite. The lab estimate is  $Se' \approx 0.5 \cdot Sut$  (capped at  $\sim 700$  MPa for  $Sut > \sim 1400$  MPa).

- **Aluminium and most non-ferrous alloys have no true endurance limit**

the curve keeps sloping, so they're rated at a finite life (e.g. fatigue strength at  $5 \times 10^8$  cycles).

- **The finite-life region between  $\sim 10^3$  and  $10^6$  cycles is roughly log-linear; interpolate there for a target life.**

$Se'$  is a polished lab specimen. The real part is always weaker — that's what the Marin factors are for.

### 3. Endurance-limit modifiers (Marin factors)

Reduce the lab limit to a design value:  $S_e = k_a \cdot k_b \cdot k_c \cdot k_d \cdot k_e \cdot S_e'$ .

FACTOR	ACCOUNTS FOR	TYPICAL VALUE
<b>ka — surface</b>	finish (cracks start at the surface)	ground ~0.9, machined ~0.7–0.8, hot-rolled ~0.5–0.7, as-forged ~0.3–0.5
<b>kb — size</b>	larger sections fail sooner (bending/torsion)	~1.0 ( $d \leq 8$ mm) down to ~0.75 (large); axial = 1.0
<b>kc — load type</b>	bending vs axial vs torsion	bending 1.0, axial 0.85, torsion 0.59
<b>kd — temperature</b>	strength change with temp	~1.0 near room temperature
<b>ke — reliability</b>	scatter for higher survival %	50% 1.00, 90% 0.90, 99% 0.81, 99.9% 0.75

Surface finish ( $k_a$ ) is usually the biggest single knock-down — a forged or corroded surface can halve the endurance limit. This is why fatigue-critical parts are ground, polished, or shot-peened. The standard surface factor is  $k_a = a \cdot S_{ut}^b$  ( $a, b$  per finish;  $S_{ut}$  in MPa).

## 4. Mean stress correction

---

A tensile mean stress lowers the allowable amplitude. Combine  $\sigma_a$  and  $\sigma_m$  with one of:

CRITERION	EQUATION	USE
<b>Goodman (modified)</b>	$\sigma_a/Se + \sigma_m/Sut = 1/n$	Default for brittle-ish / conservative design
<b>Gerber</b>	$\sigma_a/Se + (\sigma_m/Sut)^2 = 1/n$	Ductile steels, less conservative (fits data)
<b>Soderberg</b>	$\sigma_a/Se + \sigma_m/Sy = 1/n$	Most conservative; guards against yield too

Here **n** is the fatigue factor of safety. Goodman is the usual default. Always also check static yield at the peak stress ( $\sigma_{max} \leq Sy/n$ ).

## 5. Stress concentration and notches

---

Fatigue cracks start at **stress raisers** — fillets, holes, keyways, threads, shoulders, tool marks. The geometric factor  **$K_t$**  multiplies nominal stress; the *fatigue* effect is  $K_f = 1 + q(K_t - 1)$ , where  **$q$**  (notch sensitivity, 0–1) rises with material strength and notch radius.

- **Apply  $K_f$  to the alternating stress (and often the mean) in the Goodman check.**
- **A generous fillet radius is the cheapest fatigue improvement**  
sharp internal corners are crack factories.
- **Threads, keyways and press-fit edges are classic initiation sites**  
keep them out of the highest-stress regions or detail them carefully (rolled threads, undercut radii).

## 6. Design rules and checklist

---

- **Round every internal corner**  
maximise fillet radii at shoulders and section changes.

---

- **Improve the surface where stress is high**  
fine finish, and shot-peening / surface rolling to induce compressive residual stress (raises fatigue strength markedly).

---

- **Avoid stacking stress raisers**  
don't put a hole in a fillet in a high-stress zone.

---

- **Keep the mean stress down**  
preload, residual compression, and symmetric loading help.

---

- **Use the right detail for welds**  
weld toes are severe notches; grind/peen toes and use fatigue-classified joint details.

---

- **Design checklist: find  $\sigma_a$  and  $\sigma_m$  at the critical section → apply  $K_f$  → estimate  $S_e = k_a \cdot k_b \cdot k_c \cdot k_d \cdot k_e \cdot S_e'$  → apply Goodman for fatigue  $n$  → check static yield at  $\sigma_{max}$  → if marginal, attack surface finish, fillets and residual stress first.**

Pair this with the Ideabox spring and bolted-joint tools, whose fatigue factors use exactly this Goodman approach.