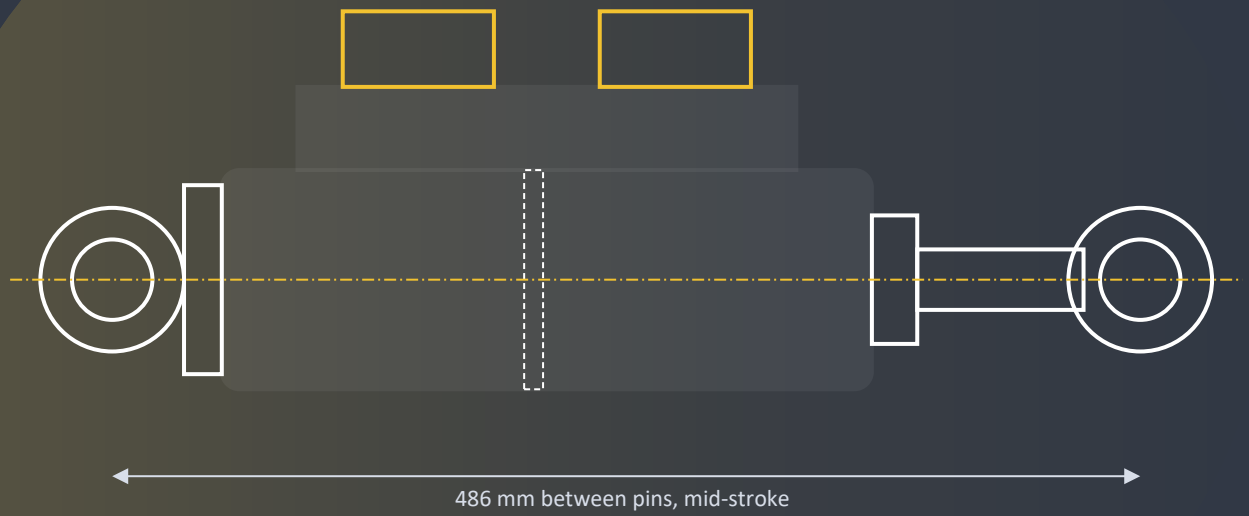
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# SHA-40 servo-hydraulic main rotor actuator

## Critical Design Review

Ostral OR-260 programme · Friedrichshafen

Presented by Dr Selin Aydın, Chief Engineer SHA-40




22–23 September 2026

# Agenda

## Day 1 · Tuesday 22 September

| | | |
|---|---|---|
| 09:00 | Opening, objectives, entry criteria<br>H. Vossberg | › |
| 09:45 | Requirements and compliance<br>S. Aydın | › |
| 10:45 | Architecture and design description<br>S. Aydın · P. Mertens | › |
| 13:30 | Structural and performance analysis<br>L. Brandner | › |
| 15:30 | Mass properties<br>P. Mertens | › |

## Day 2 · Wednesday 23 September

| | | |
|---|---|---|
| 09:00 | Verification and test campaign<br>K. Haug | › |
| 10:30 | Risks and open issues<br>T. Reischl | › |
| 13:30 | Review item disposition and actions<br>All | › |
| 15:00 | Board caucus and decision<br>Review board | › |

Venue: Aster Fluidtechnik, Building 7, review room "Bodensee" · Select a row to open the corresponding section.

# Review objectives, entry criteria and board

## Objectives

- Confirm that the detailed design meets the specification SHA-SPEC-001 Issue 4
- Confirm maturity for manufacture of qualification units P5–P8
  - Tooling, special processes and first article inspection plan
- Accept residual risks and the verification plan

## Entry criteria

- ← Design data package ASF-DDP-0418 Rev. B released 1 Sep 2026
- ← Stress, fatigue and thermal reports issued
- ← FMECA and fault tree analysis Rev. A
- ← Prototype P1: proof and frequency response tests
  - Proof 311 bar, leakage, frequency response at ±5%
- PDR actions closed: 37 of 38 (AI-PDR-29 transferred)

**Review board**

| Role | Name | Organisation |
|---|---|---|
| Chair | **Dr Henrike Vossberg** | Aster · Head of Engineering |
| Customer, flight controls | **Matteo Calvi** | Ostral Rotorcraft |
| Customer, airworthiness | **Jens Oltmann** | Ostral Rotorcraft |
| Quality | **Birgit Lanz** | Aster · Quality Assurance |
| Programme | **Tobias Reischl** | Aster · Programme Manager |
| Independent reviewer | **Dr Ulrike Sandmeier** | External, servo-hydraulics |
| Presenter | **Dr Selin Aydın** | Aster · Chief Engineer SHA-40 |

**Quorum and decision rule.** The board decides by consensus; the customer representatives hold a veto on airworthiness topics. 64 review item discrepancies (RIDs) were raised before the meeting.

# Programme status since PDR

Status at data cut-off, 4 September 2026

**TRL 6**
**Technology readiness**
Prototype P1 tested on HTR-2

**94%**
**Drawings released**
212 of 226 drawings

**9.74 kg**
**Dry mass**
Limit 9.80 kg · margin 0.6%

**41 / 52**
**Requirements compliant**
6 at risk · 4 open · 1 non-compliant

**€ 18,900**
**Recurring unit cost**
Target € 19,500 at rate 36/year




## Main design changes since PDR

Titanium pistons and pocketed manifold (−0.62 kg) · EHSV changed to dual-coil, single-stage jet-pipe design · LVDT moved inside the piston rod (quad redundant) · rod-end bearing upgraded to self-lubricating liner

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# 01

# Requirements and design

Compliance with SHA-SPEC-001 Issue 4, system architecture and the detailed mechanical design.

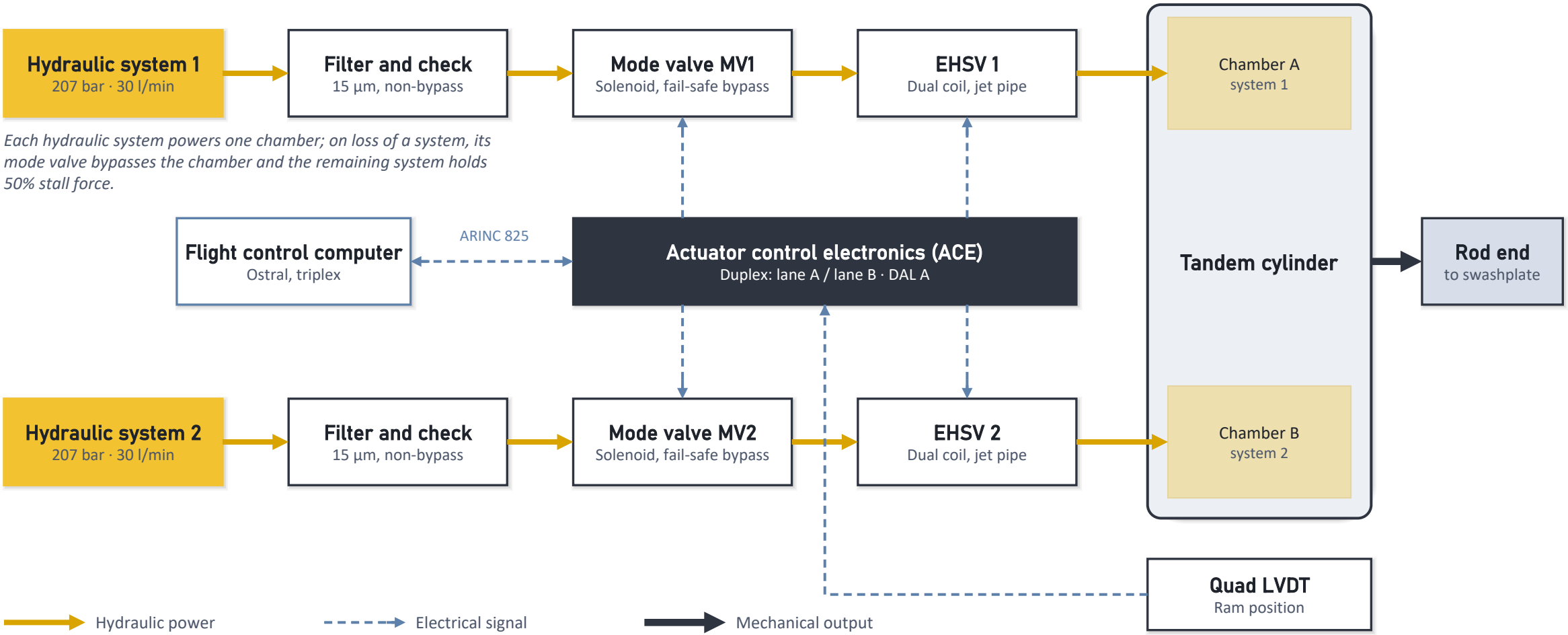
# Requirements compliance matrix (key requirements)

| | ID | Requirement | Target | Predicted / measured | Method | Status |
|---|---|---|---|---|---|---|
| Performance | SHA-R-001 | Stall force, both systems at 207 bar | ≥ 40.0 kN | 42.6 kN (P1 test) | T | Compliant |
| | SHA-R-004 | Stroke | 100 mm (±50 mm) | 100.4 mm | I | Compliant |
| | SHA-R-007 | No-load rate | ≥ 120 mm/s | 126 mm/s | A, T | Compliant |
| | SHA-R-011 | Rate at 26 kN opposing load | ≥ 75 mm/s | 79 mm/s | A | Compliant |
| | SHA-R-015 | Frequency response, −3 dB at ±5% amplitude | ≥ 8.0 Hz | **7.6 Hz (P1 test)** | T | At risk |
| Physical | SHA-R-019 | Dry mass | ≤ 9.80 kg | **9.74 kg** | A | At risk |
| | SHA-R-023 | Internal leakage at null, per system | ≤ 0.35 l/min | 0.28 l/min | T | Compliant |
| | SHA-R-027 | Proof and burst pressure | 1.5× / 2.5× 207 bar | MS +0.27 | A | Compliant |
| Environment | SHA-R-036 | Fluid temperature range | −54 to +135 °C | **Seal qualification pending** | T | Open |
| | SHA-R-048 | EMC and lightning, DO-160G | Categories per ICD | – | T | Not verified |
| Safety | SHA-R-031 | Fatigue life | 30,000 FH | MS +0.18 | A | Compliant |
| | SHA-R-040 | Position transient on system loss | ≤ 0.8 mm | 0.55 mm | S | Compliant |
| | SHA-R-044 | Jam probability | ≤ $1\times10^{-9}$ /FH | $3.2\times10^{-10}$ /FH | A | Compliant |
| | SHA-R-052 | Mean time between failures | ≥ 25,000 FH | **21,800 FH** | A | Non-compliant |

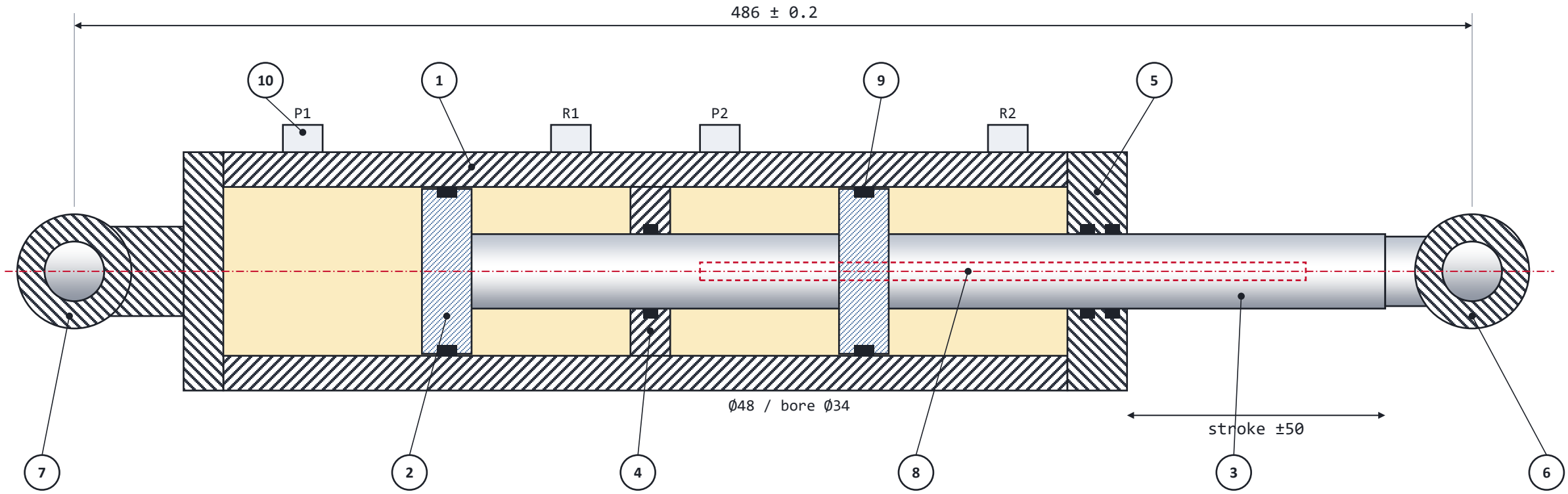
Compliant · At risk · Open · Not verified · Non-compliant

Methods: A analysis · T test · I inspection · S simulation. 14 of 52 requirements shown; full matrix in ASF-VCRM-0418.

# System architecture: dual tandem, duplex electronics



# Sectional view A–A (mid-stroke)




| Item | Description | Item | Description |
|---|---|---|---|
| 1 | Barrel, 17-4PH H1025 | 6 | Rod end, self-lubricating liner |
| 2 | Piston (2×), Ti-6Al-4V | 7 | Attachment eye |
| 3 | Piston rod, 15-5PH, HVOF WC-CoCr | 8 | Quad LVDT, core in rod |
| 4 | Centre bulkhead with rod seal | 9 | Piston seal, bronze-filled PTFE |
| 5 | Gland, step seal + wiper | 10 | Ports P/R, MS33649 bosses |

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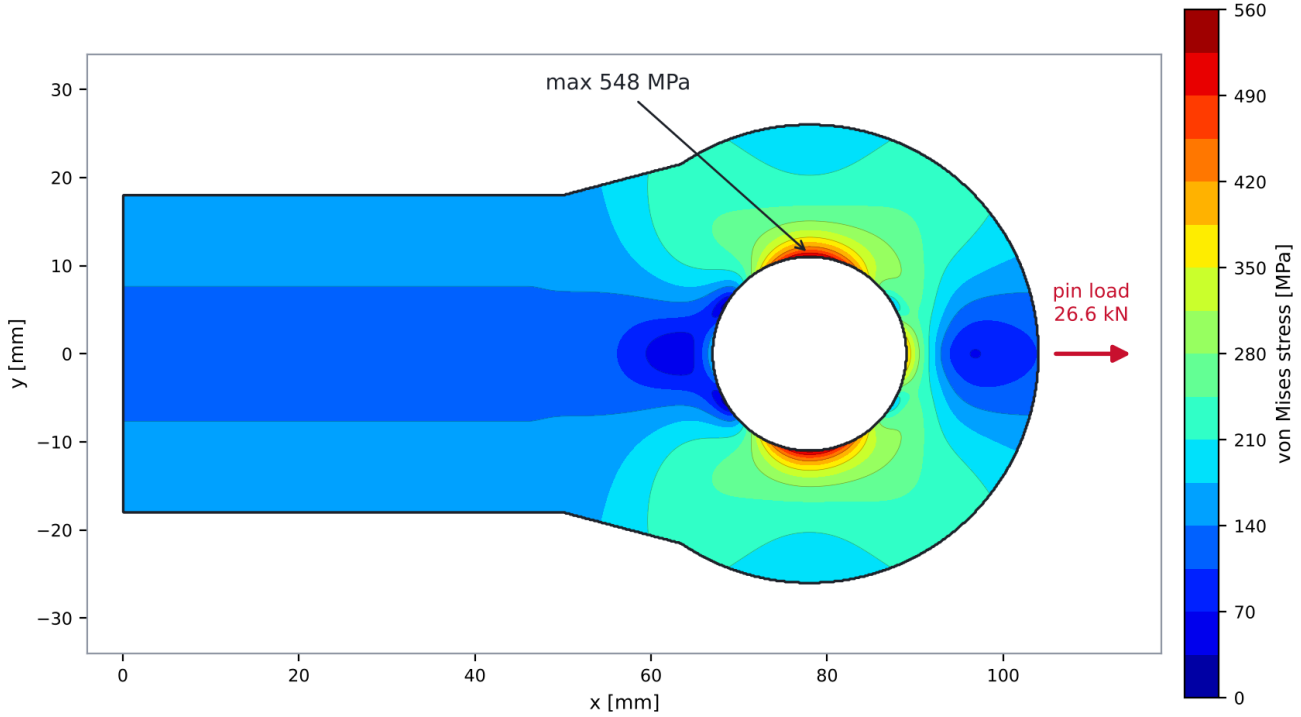
# 02

# Analysis

Structural margins, performance predictions and correlation with prototype P1, mass properties.

# Rod-end lug: static strength and fatigue

Linear static FE, load case LC-03 (limit load 26.6 kN), material 17-4PH H1025




Peak at the hole edge, perpendicular to the load (Kt = 3.0, net section). Mesh: 186,000 second-order tetrahedra, 0.4 mm at the bore; converged within 2% of the previous refinement.

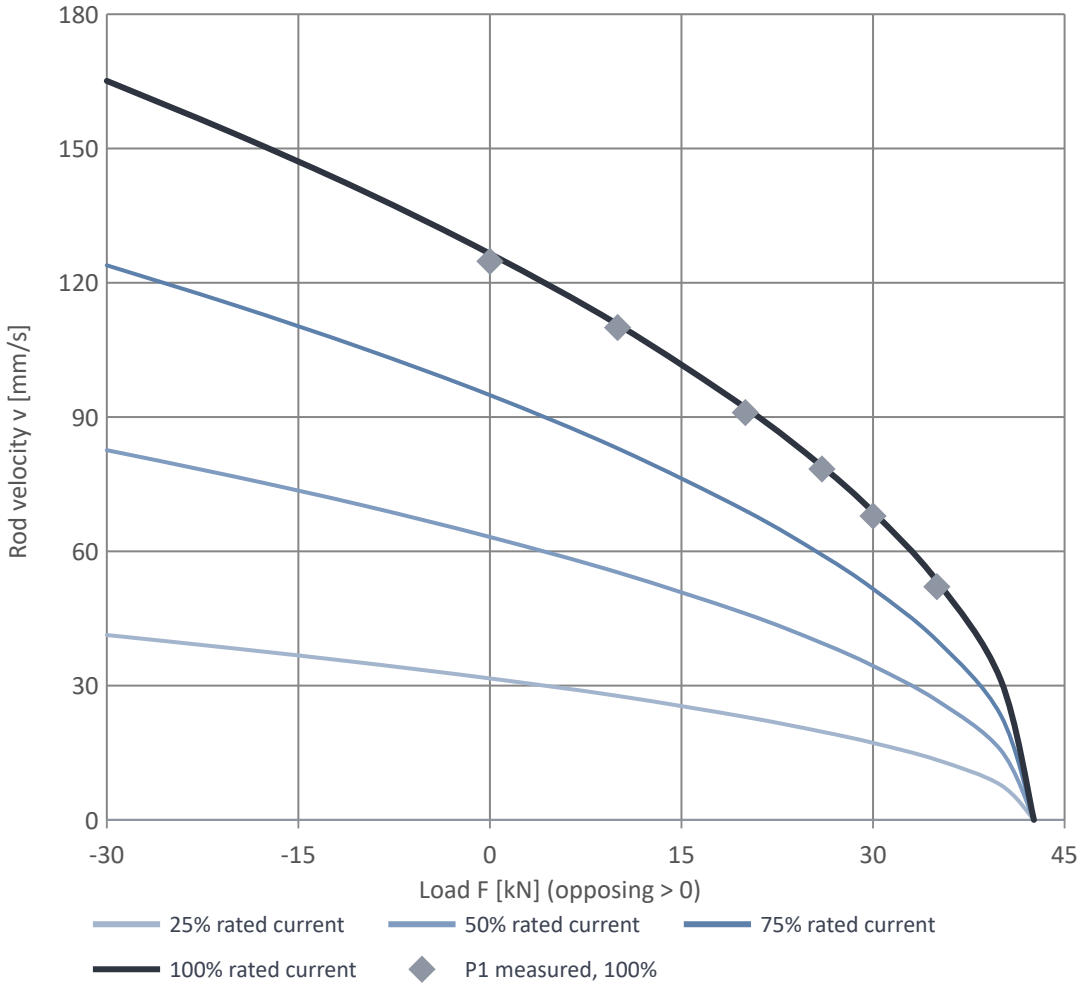
| Location | Case | Allowable | Applied | MS |
|---|---|---|---|---|
| **Rod-end lug, net section** | LC-03 × 1.5 | 1,069 MPa | 822 MPa | **+0.30** |
| **Piston rod, column buckling** | Stall × 1.5 | 90.7 kN | 63.9 kN | **+0.42** |
| **Barrel hoop, proof 311 bar** | Proof | 1,000 MPa | 787 MPa | **+0.27** |
| **Gland thread shear** | Stall × 1.5 | 74.6 kN | 62.7 kN | **+0.19** |
| **End-cap bolts, 8 × M6** | Burst | 52.2 kN | 46.6 kN | **+0.12** |
| **Rod-end fatigue, $5\times10^7$ cycles** | Spectrum SP-2 | D = 1.0 | D = 0.85 | **+0.18** |

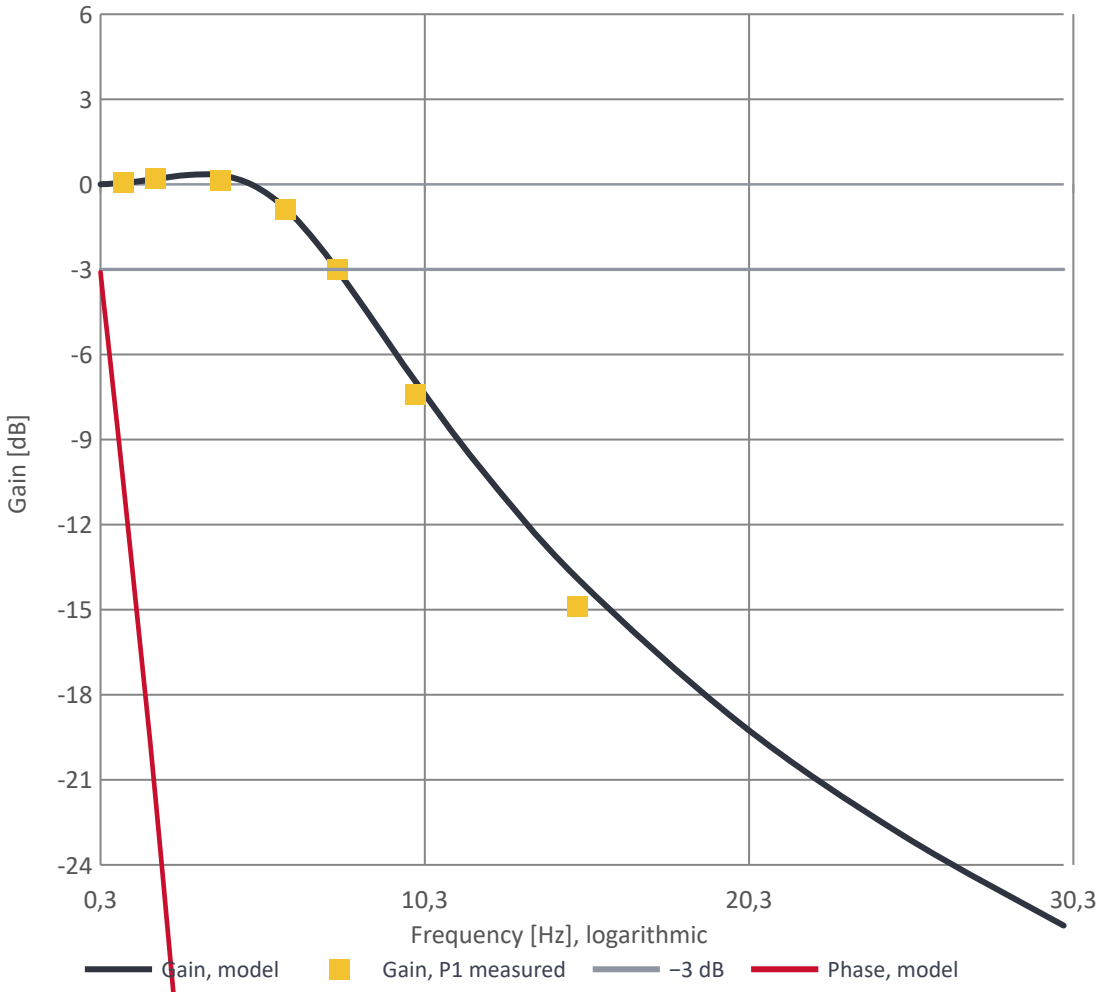
$$\mathrm{MS} = \frac{\sigma_{\mathrm{allow}}}{\mathrm{FS}\cdot\sigma_{\mathrm{limit}}} - 1$$

FS = 1.5 ultimate. All margins positive; lowest +0.12 at the end-cap bolts (burst case).

Allowables: 17-4PH H1025 Ftu 1,069 MPa, Fty 1,000 MPa (A-basis). Report ASF-STR-0418-07 Rev. A.

# Performance: velocity–load and frequency response




Left: model $v = v_0 \cdot i \cdot \sqrt{(1 - F/F_s)}$, $F_s = 42.6$ kN. Right: ±5% amplitude, both systems. Measured −3 dB bandwidth 7.6 Hz vs 8.0 Hz required (risk R-03).

# Servo-valve flow equation and rate check

$$Q_L = C_d w x_v \sqrt{\frac{P_s - \mathrm{sgn}(x_v) P_L}{\rho}}$$

$$v = \frac{Q_L}{A_p}, \quad P_L = \frac{F}{2A_p}$$

| Symbol | Meaning | Value |
|---|---|---|
| $Q_L$ | Load flow per system | **7.82 l/min (no load)** |
| $C_d$ | Discharge coefficient | **0.61** |
| $w$ | Orifice area gradient | **3.6 mm** |
| $x_v$ | Spool / jet displacement, rated | **0.38 mm** |
| $P_s$ | Supply pressure | **207 bar** |
| $P_L$ | Load pressure | **F / 2A$_p$** |
| $\rho$ | Fluid density at 40 °C | **850 kg/m³** |
| $A_p$ | Effective piston area per chamber | **10.3 cm²** |

## Rate check against SHA-R-007 and SHA-R-011

**No load**

$P_L$ = 0 → $Q_L$ = 7.82 l/min

v = 126 mm/s

req. ≥ 120 mm/s

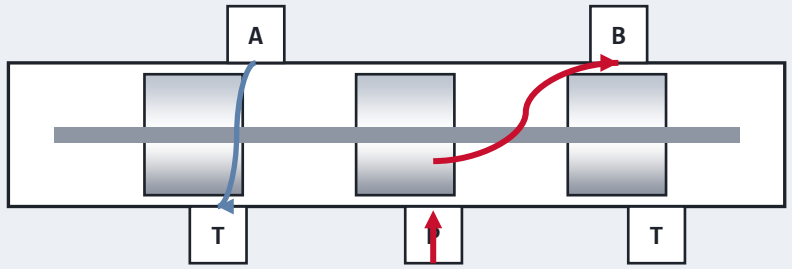
**26 kN opposing**

$P_L$ = 126 bar → $Q_L$ = 4.89 l/min

v = 79 mm/s

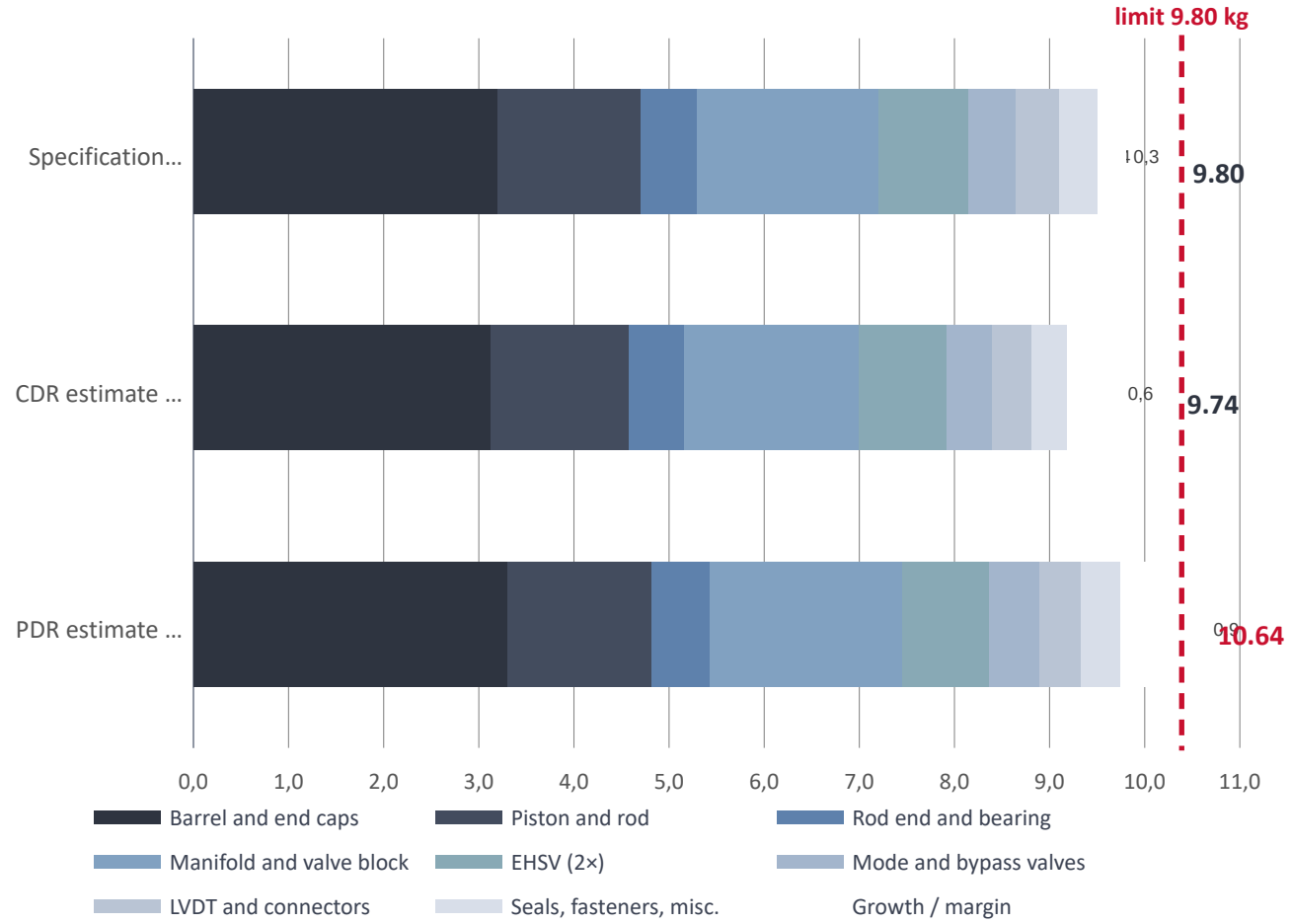
req. ≥ 75 mm/s

Four-way metering, spool displaced by +$x_v$




Red: supply to cylinder port B · blue: return from port A to tank

# Mass budget: 60 g of margin at CDR




| kg | PDR | CDR | Δ | Basis |
|---|---|---|---|---|
| Barrel and end caps | 3.30 | **3.12** | −0.18 | Weighed P1 |
| Piston and rod | 1.52 | **1.46** | −0.06 | Calculated |
| Rod end and bearing | 0.61 | **0.58** | −0.03 | Weighed P1 |
| Manifold and valve block | 2.02 | **1.84** | −0.18 | Calculated |
| EHSV (2×) | 0.92 | **0.92** | – | Supplier data |
| Mode and bypass valves | 0.52 | **0.48** | −0.04 | Weighed P1 |
| LVDT and connectors | 0.44 | **0.41** | −0.03 | Supplier data |
| Seals, fasteners, misc. | 0.41 | **0.38** | −0.03 | Estimated |
| Growth / margin | 0.90 | **0.55** | −0.35 | Maturity-weighted |
| **Total dry mass** | **10.64** | **9.74** | **−0.90** | **Limit 9.80** |

52% of the CDR mass is weighed on P1 hardware. Growth allowance by maturity: weighed 1%, calculated 4%, estimated 10%.



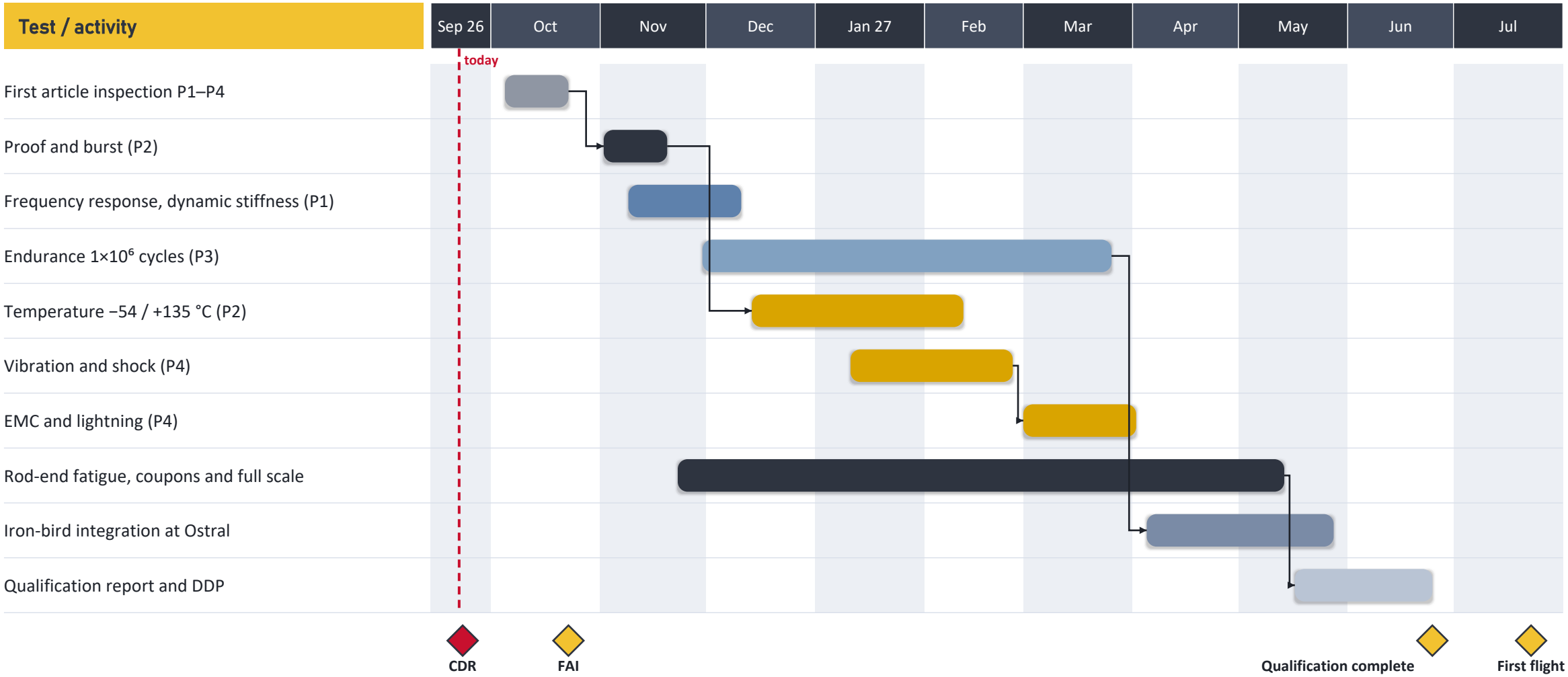

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# 03

# Verification and risk

Qualification test campaign on the HTR-2 rig, risk register and the CDR action plan.

# Qualification test campaign



# Test facility: HTR-2 hydraulic rig, Friedrichshafen

## Rig capabilities

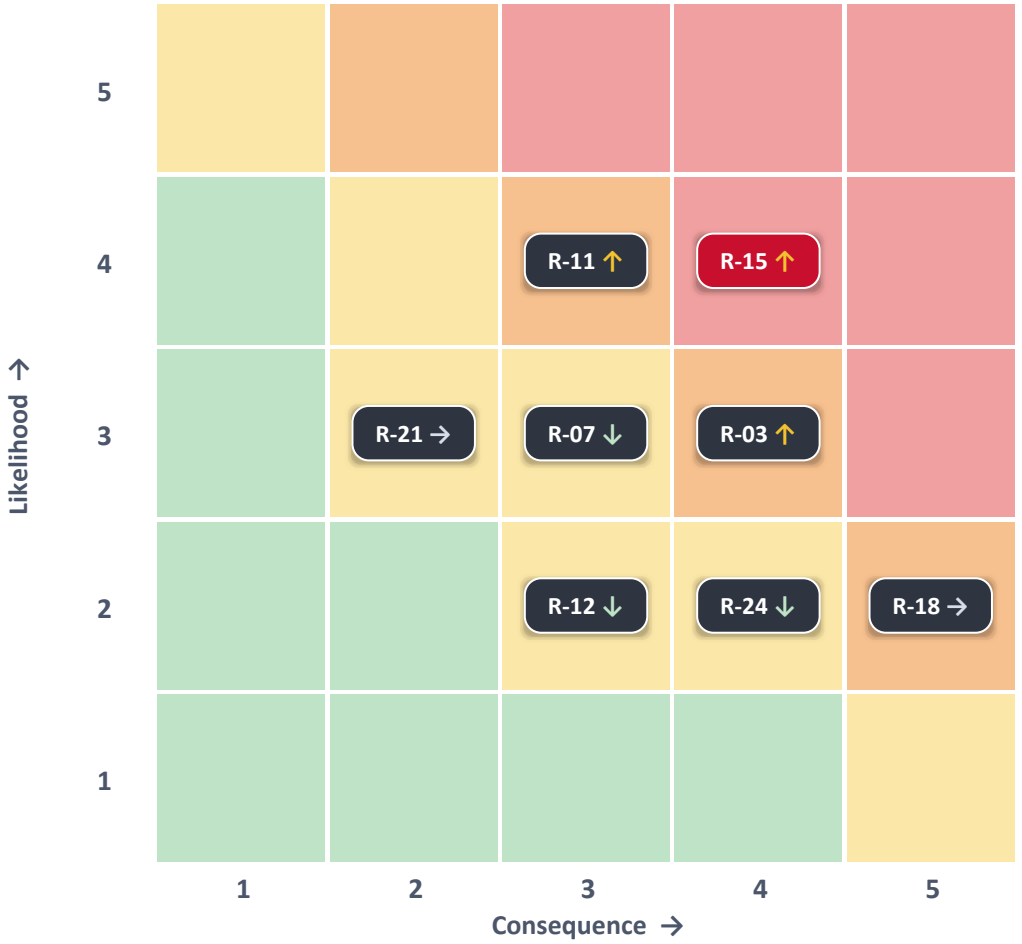
- Two independent 280 bar supplies, 120 l/min each
  - Fluid cleanliness monitored online, ISO 4406 15/13/10
- Load actuator 100 kN, 0–50 Hz, inertia simulator
- Climatic chamber −60 to +150 °C around the specimen
  - Ramp rate 3 K/min; dew-point controlled
- 24 channels at 10 kHz, synchronised with ACE data

## Booked for SHA-40

- Two shifts from November 2026 to May 2027
- Backup: Aster site Ravensburg, rig HTR-1 (60 kN)

HTR-2 power unit and manifold skid

# Risk register: 8 open risks, 2 red




| ID | Risk | L×C | Trend | Mitigation | Owner |
|---|---|---|---|---|---|
| R-15 | EHSV supplier lead time | 4×4 = 16 | ↑ | Qualify second source, buffer of 12 units | TR |
| R-03 | Frequency response shortfall | 3×4 = 12 | ↑ | Increase EHSV flow 8%, retune ACE notch filter | SA |
| R-11 | MTBF below 25,000 FH | 4×3 = 12 | ↑ | LVDT redundancy redesign, supplier field data | SA |
| R-18 | Rod-end fatigue | 2×5 = 10 | → | Shot peening, full-scale fatigue test | LB |
| R-07 | Seal low-temperature qualification | 3×3 = 9 | ↓ | Second-source compound, qualification Dec 2026 | KH |
| R-24 | ACE software DAL A certification | 2×4 = 8 | ↓ | Early SOI-2 audit passed in July | SA |
| R-12 | Mass growth | 2×3 = 6 | ↓ | Titanium pistons, pocketed manifold (done) | PM |
| R-21 | Test rig availability | 3×2 = 6 | → | Second shift on HTR-2, HTR-1 backup | KH |

Arrows: trend since PDR (March 2025). Score = likelihood × consequence; red ≥ 15, orange 10–14, yellow 5–9.

# CDR action items

| Area | ID | Action | Owner | Due | Risk | Status |
|---|---|---|---|---|---|---|
| Design | AI-CDR-01 | Increase EHSV rated flow from 7.8 to 8.5 l/min; update performance analysis | S. Aydın | 30 Oct 2026 | R-03 | Open |
| | AI-CDR-02 | Release LVDT redundancy redesign (ECR-0217) and update FMECA | S. Aydın | 15 Nov 2026 | R-11 | Open |
| | AI-CDR-03 | Complete drawing release (14 drawings remaining) | P. Mertens | 9 Oct 2026 | – | In progress |
| Analysis | AI-CDR-04 | Re-run rod-end fatigue with measured spectrum SP-2 Rev. C | L. Brandner | 30 Oct 2026 | R-18 | In progress |
| | AI-CDR-05 | Update MTBF prediction with supplier field data | S. Aydın | 30 Nov 2026 | R-11 | Open |
| Test | AI-CDR-06 | Add dynamic stiffness at −40 °C to the qualification test plan | K. Haug | 16 Oct 2026 | R-07 | Open |
| | AI-CDR-07 | Book EMC chamber slot, weeks 9–13 2027, external laboratory | K. Haug | 2 Oct 2026 | – | Closed |
| Programme | AI-CDR-08 | Qualify second EHSV source; deliver supplier plan | T. Reischl | 20 Nov 2026 | R-15 | Open |
| | AI-CDR-09 | Update ICD with Ostral for revised connector pin-out | T. Reischl / M. Calvi | 23 Oct 2026 | – | Open |

9 actions: 6 open, 2 in progress, 1 closed. AI-CDR-01, -02 and -05 must be closed before first article inspection.

# Board decision and sign-off

- ☐ CDR passed
- ☑ **CDR passed with actions**
- ☐ CDR not passed: delta review required




Decision recorded in minutes ASF-MOM-4011-02. Open RIDs: 11 of 64.

## Conditions

- Close AI-CDR-01, -02 and -05 before first article inspection
- Delta review of frequency response with P1 retest by 15 December 2026
- Monthly mass status to Ostral until qualification

**Dr Henrike Vossberg** · Chair, Aster — 23 Sep 2026

**Matteo Calvi** · Ostral Rotorcraft — 23 Sep 2026

**Jens Oltmann** · Ostral Rotorcraft — 23 Sep 2026

**Birgit Lanz** · Quality, Aster — 23 Sep 2026

**Tobias Reischl** · Programme, Aster — 23 Sep 2026

**Dr Selin Aydın** · Chief Engineer — 23 Sep 2026