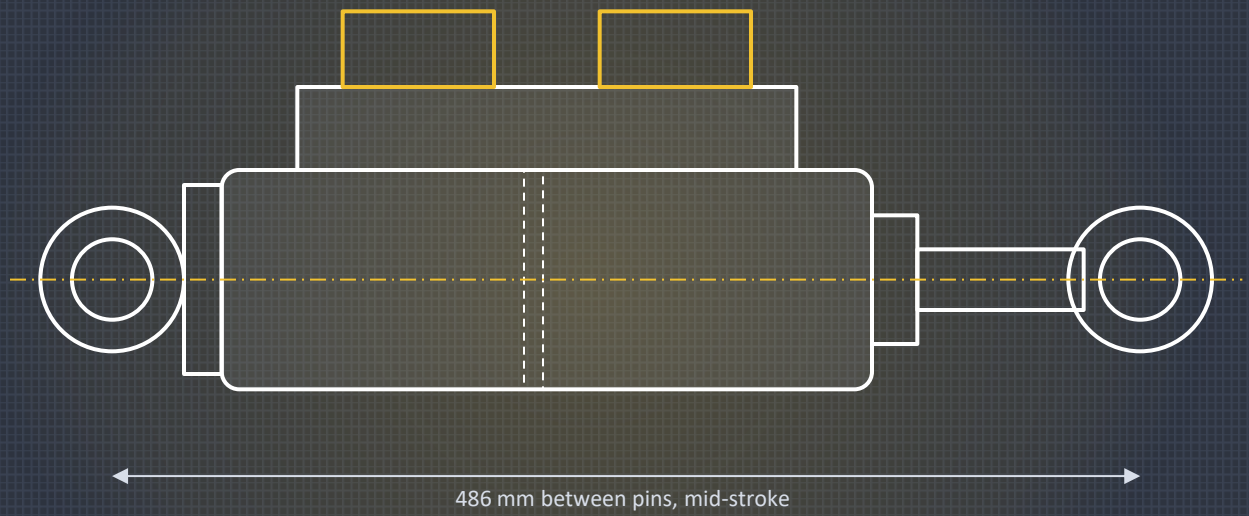
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SHA-40 servo-hydraulic main rotor actuator

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 H. Vossberg	›
09:45	Requirements and compliance S. Aydın	›
10:45	Architecture and design description S. Aydın · P. Mertens	›
13:30	Structural and performance analysis L. Brandner	›
15:30	Mass properties P. Mertens	›

Day 2 · Wednesday 23 September

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

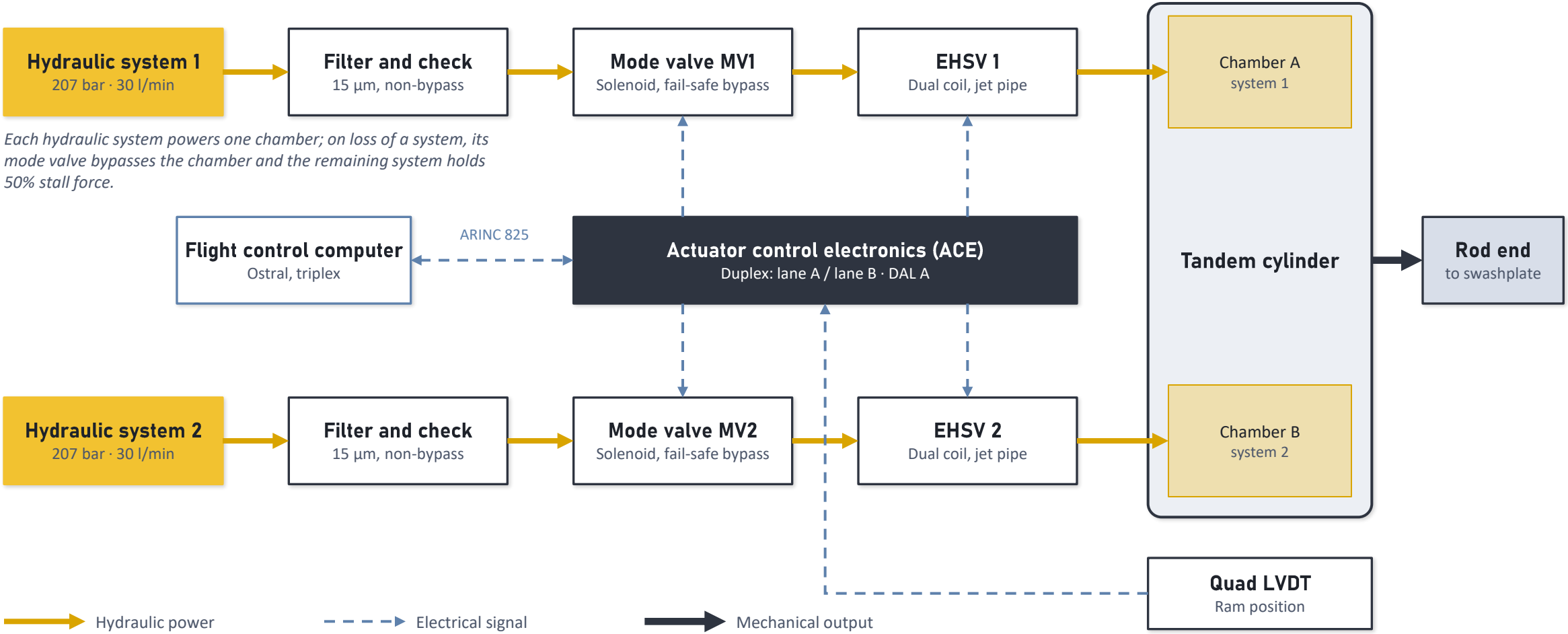
Requirements compliance matrix (key requirements)

	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	≤ 1×10^{-9} /FH	3.2×10^{-10} /FH	A	Compliant
	SHA-R-052	Mean time between failures	≥ 25,000 FH	**21,800 FH**	A	Non-compliant

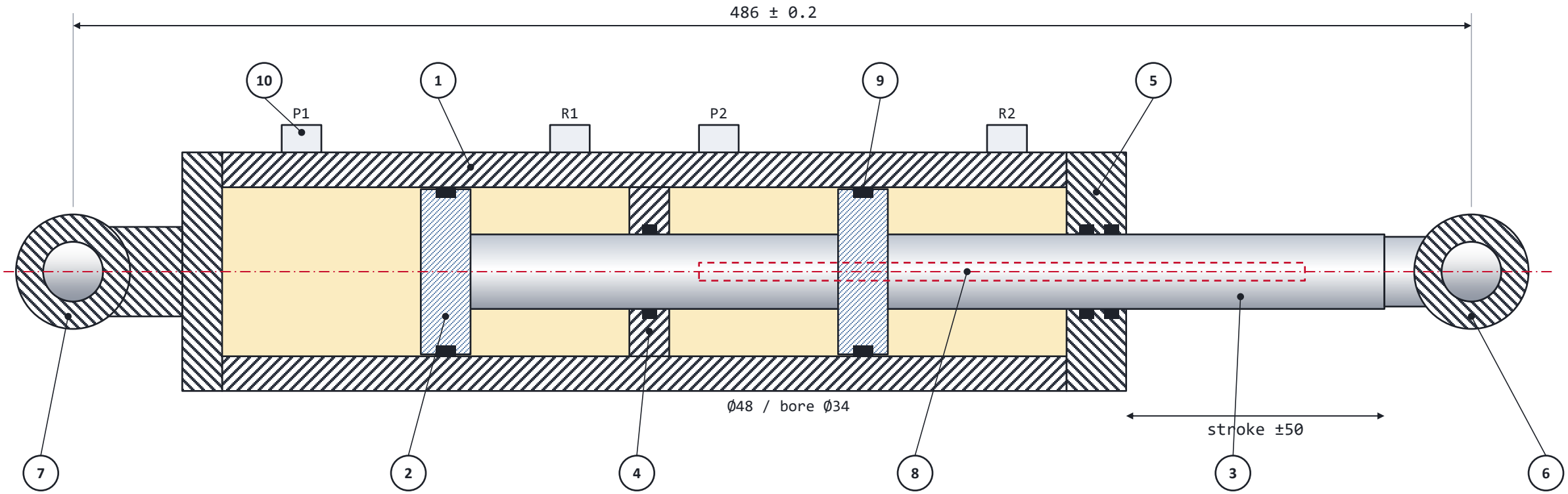
Compliant · At risk · Open · Not verified · Non-compliant

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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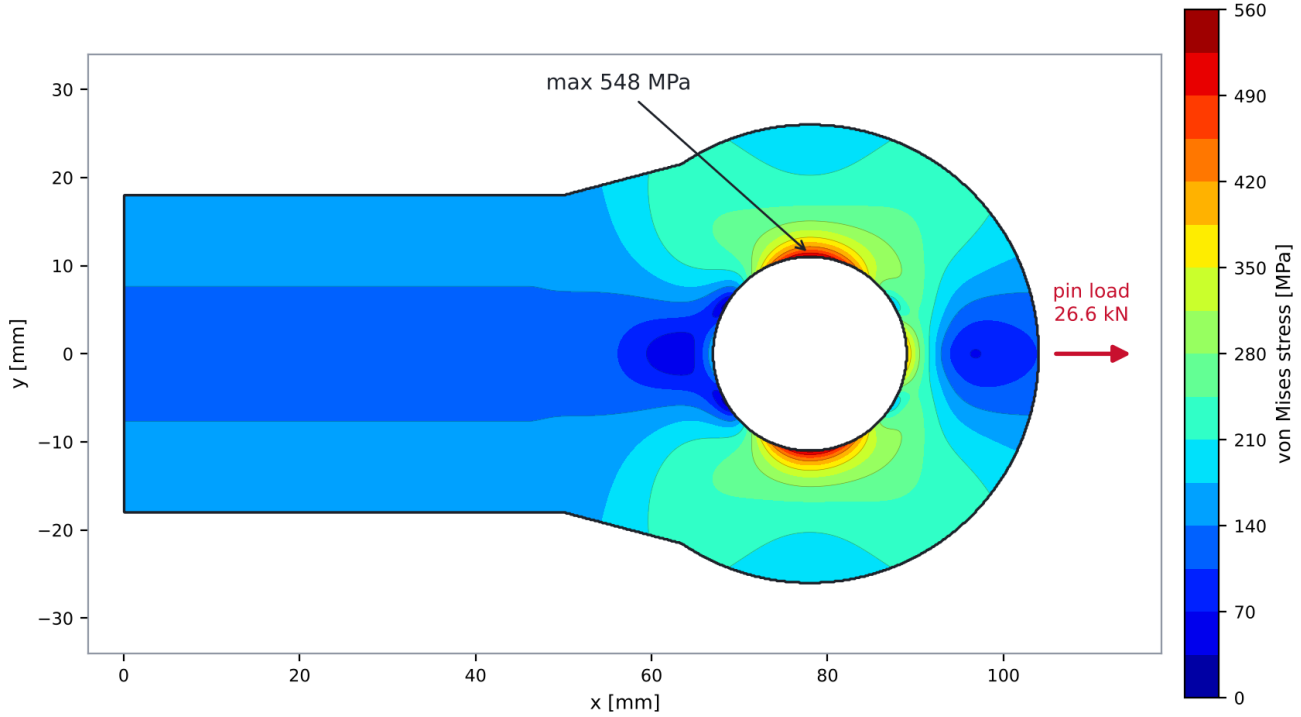
02

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.

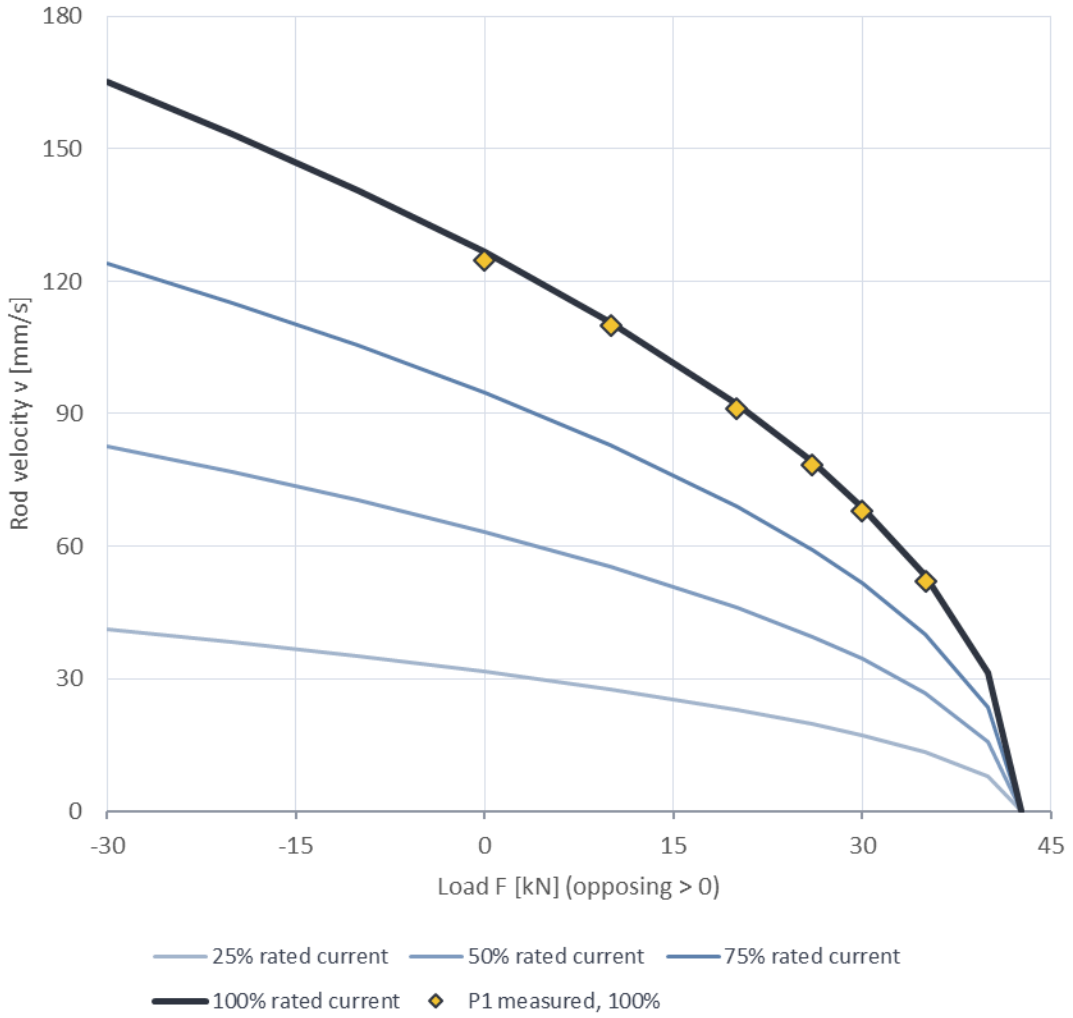
Location	Case	Allowable	Applied	MS
Rod-end lug, net section	LC-03 × 1.5	1,069 MPa	822 MPa	**+0.30**
Piston rod, column buckling	Stall × 1.5	90.7 kN	63.9 kN	**+0.42**
Barrel hoop, proof 311 bar	Proof	1,000 MPa	787 MPa	**+0.27**
Gland thread shear	Stall × 1.5	74.6 kN	62.7 kN	**+0.19**
End-cap bolts, 8 × M6	Burst	52.2 kN	46.6 kN	**+0.12**
Rod-end fatigue, 5×10^7 cycles	Spectrum SP-2	D = 1.0	D = 0.85	**+0.18**

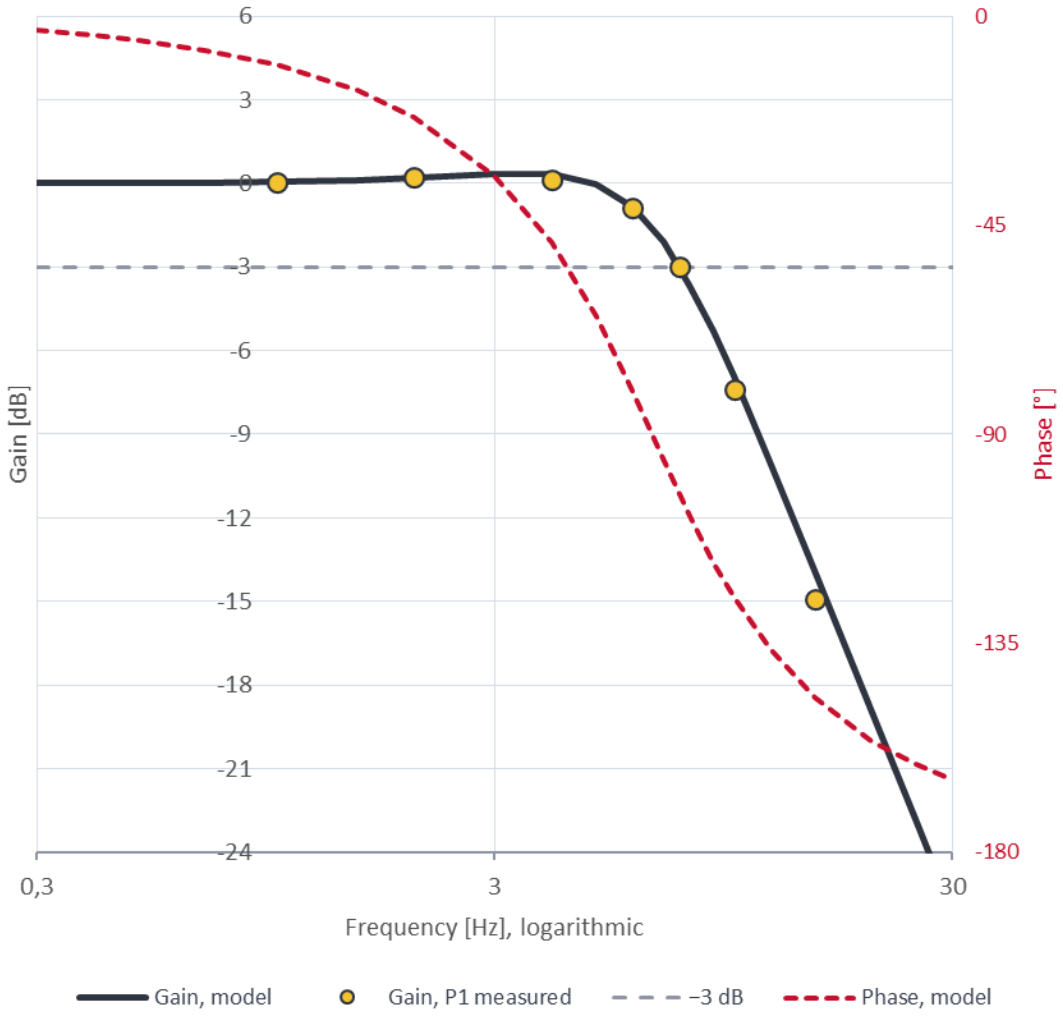
$$\mathrm{MS} = \frac{\sigma_{\mathrm{allow}}}{\mathrm{FS} \cdot \sigma_{\mathrm{limit}}} - 1$$

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 $v = v_0 \cdot i \cdot V(1 - F/F_s)$, $F_s = 42.6$ 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

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

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

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$_p$**
ρ	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

$P_L = 0 \rightarrow Q_L = 7.82$ l/min

v = 126 mm/s

req. ≥ 120 mm/s

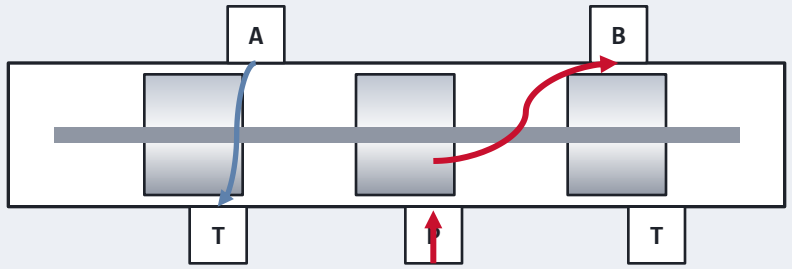
26 kN opposing

$P_L = 126$ bar $\rightarrow Q_L = 4.89$ l/min

v = 79 mm/s

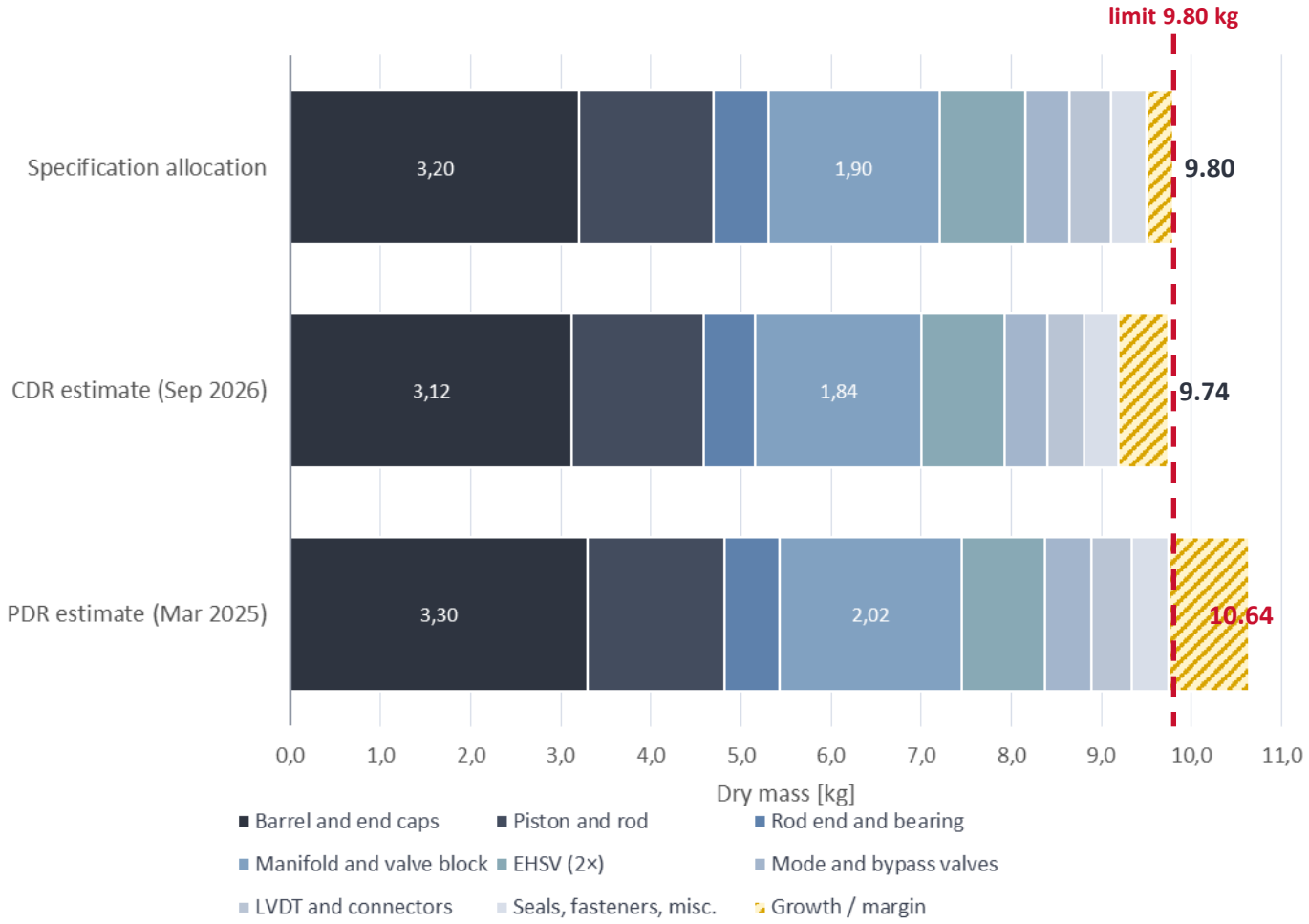
req. ≥ 75 mm/s

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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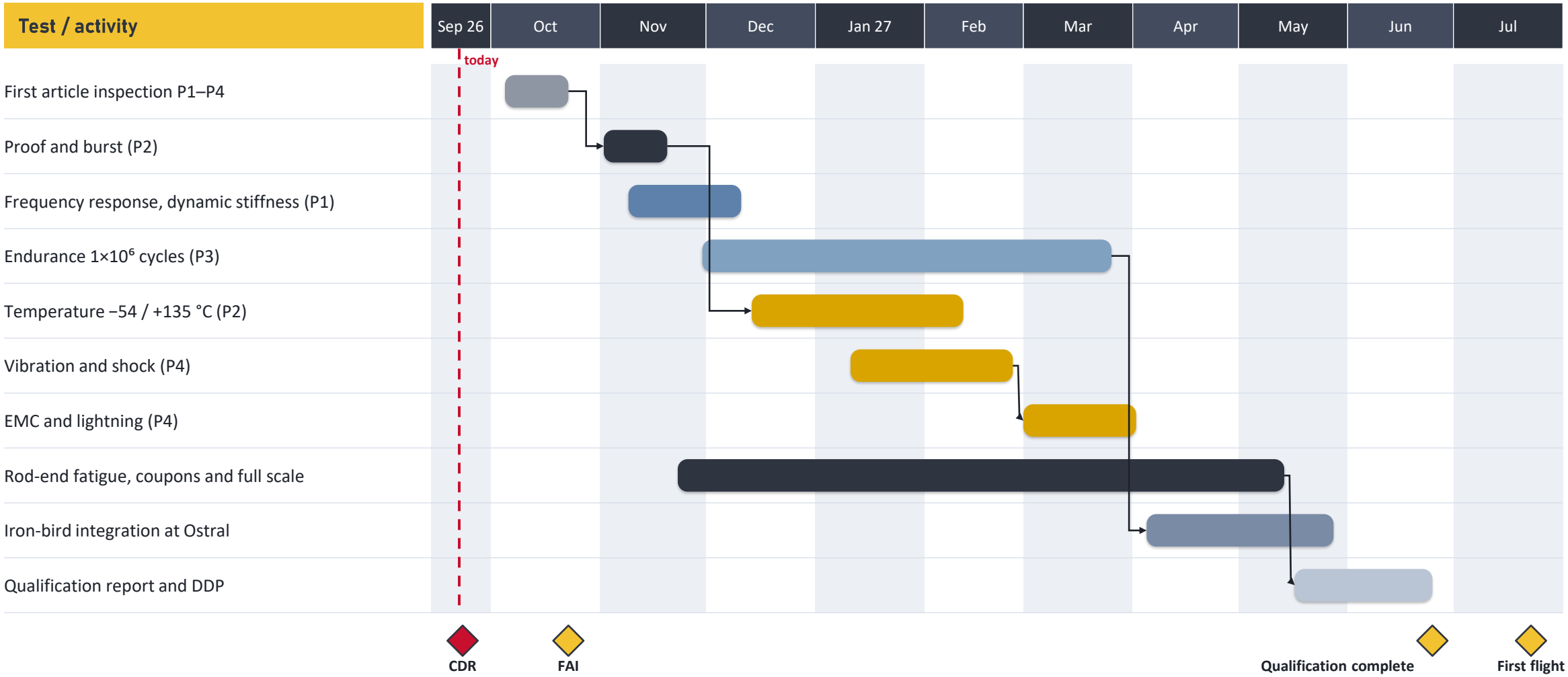
03

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

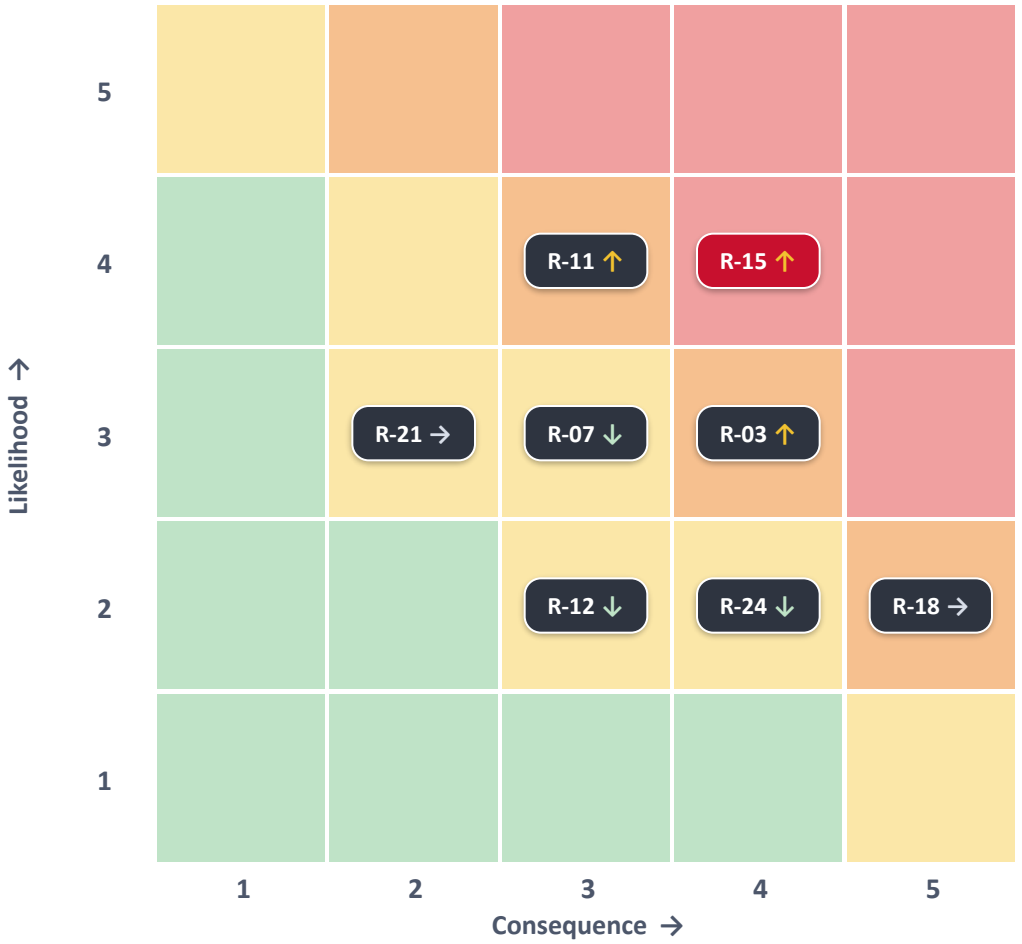
Booked for SHA-40

- 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