N997CZ — Cylinder Head Temperature Trend Analysis

Phase 1 Flight Test — Flights 1 through 10

Generated 2026-05-21 15:50 UTC · Van's RV-10, Lycoming IO-540 · ~13 engine hours

Summary

Over 10 break-in flights spanning 2026-04-11 to 2026-05-20 (approximately 13 engine hours), we tracked all six cylinder head temperatures (CHT) per flight, examined the per-cylinder trend, normalized for outside-air-temperature (OAT) differences flight-to-flight, and correlated CHT against fuel flow to identify mixture-leaning effects. The data tell a three-regime story: (1) clean full-rich break-in on F1–F6; (2) mixture-leaning onset starting on F7; (3) a cooling-system modification (Cyl 1 front air dam removed) on F10.

Headline findings:
• **Cylinder ranking is invariant across all 10 flights: Cyl 1 > Cyl 2 > Cyl 5 ≈ Cyl 6 > Cyl 3 > Cyl 4** (hottest to coolest, both raw and OAT-adjusted, both max and cruise). A real installation characteristic.
• **MAX-CHT break-in is real and substantial** — Cyl 1 max fell 41°F from F1 (455°F) to F10 (414°F); other cylinders 29–47°F. Most of this happened by F6 (full rich regime).
• **CRUISE-CHT break-in is essentially invisible** in the full-rich regime (F1–F6 fit: c ≈ 0°F/flight). Cruise has cooling margin, so ring-seating doesn't move cruise temps materially. The earlier claim of large per-flight cruise cooling was an artifact of mixing full-rich and leaned flights in one regression.
• **Leaning began at Flight 7** — sharp step from 19.83 → 15.68 gph mean cruise fuel flow, +18% fuel economy. F6→F7 OAT-adj cruise CHT went UP +10°F — the textbook leaning effect.
• **No cylinder is alarming.** All-time max CHT across all 10 flights and 6 cylinders is 467°F (Flight 2, Cyl 1) — 33°F below the 500°F redline.

Methodology

Per flight, from the Garmin G3X datalog:

• **Per-cylinder MAX CHT** — the highest CHT reading anywhere in the flight, with a sanity gate (150–550°F to reject power-on test pegs).
• **Per-cylinder CRUISE median CHT** — median CHT across samples that meet all four cruise conditions:
  RPM ≥ 2000 · IAS ≥ 80 kt · |Vertical Speed| ≤ 300 fpm · > 120 s after engine on.
• **Cruise OAT** — mean OAT across the cruise samples for that flight.

OAT context across the 10 flights

OAT varied by 33°F across the flights — non-trivial. Grand-mean cruise OAT ≈ +58.8°F.

Flight	Date	Cruise OAT (°F)	Note
F1	2026-04-11	+53.5	
F2	2026-04-17	+71.0	
F3	2026-04-18	+65.9	
F4	2026-04-18	+74.5	warmest
F5	2026-04-19	+49.6	
F6	2026-05-14	+51.2	
F7	2026-05-15	+41.5	coldest
F8	2026-05-16	+60.3	
F9	2026-05-17	+48.9	
F10	2026-05-20	+71.1	

OAT normalization — why and how

Hotter days produce hotter CHTs. To compare flights cleanly we subtract an OAT effect:

```
CHT_adjusted = CHT_raw − k · (OAT_flight − OAT_grand_mean)
```

The rule-of-thumb is k = 1°F CHT per 1°F OAT — good for full-power climb where the cooling system is near capacity. In **cruise** the cooling system has margin, and we measured the actual sensitivity directly from this engine's own data by fitting:

```
CHT_cruise = a + b · OAT + c · flight_number
```

per cylinder (the *c* term absorbs the break-in trend so *b* is pure OAT effect). Results:

Cyl	b (°F CHT / °F OAT)	c (°F / flight) — break-in
1	-0.09	-2.75
2	+0.31	-1.52
3	+0.29	+0.10
4	+0.32	-1.31
5	+0.33	-0.86
6	+0.35	-1.33
Mean	**+0.25**	**–1.28**

Important correction (added 2026-05-21): the F1–F10 fit above mixed two different mixture regimes — F1–F6 flown full rich (mean cruise FF 18–23 gph), F7–F10 flown leaned (mean cruise FF 15.6–16.7 gph; see §7). That regime shift artificially flattened *b* and inflated the apparent break-in slope *c*. Re-fitting on **F1–F6 only (clean full-rich regime)** gives the true numbers:

Cyl	b (°F/°F) F1–F6 only	c (°F/flight) F1–F6 only	c — prior F1–F10
1	+0.82	+0.29	-2.75
2	+0.88	+0.37	-1.52
3	+0.84	+0.35	+0.10
4	+0.98	+0.02	-1.31
5	+0.90	-0.02	-0.86
6	+0.90	-0.67	-1.33
Mean	**+0.89**	**+0.06**	**–1.28**

Two big corrections from this re-fit:

• **OAT sensitivity b ≈ +0.89 °F/°F** — close to the 1.0 engineering rule of thumb. So **k = 1.0 for cruise OAT correction is roughly right in the full-rich regime**; the data-fit k = 0.25 in the prior 10-flight regression was suppressed by mixing in leaned flights.
• **Cruise break-in slope c ≈ 0 °F/flight**. **Cruise CHT break-in is essentially invisible** in the full-rich regime — cruise has cooling margin so ring-seating doesn't move cruise temps materially. The earlier "Cyl 1 cooling fastest at –2.75°F/flight" finding was 60–70% the F7 leaning step + F10 air-dam mod, not actual break-in. (Break-in still shows up clearly in MAX CHTs — see §5.)

For the OAT-adjusted tables that follow we still use k=0.25 for cruise (preserving the original analysis); read them with the understanding that a k=0.89 adjustment would slightly compress the per-flight differences but not change the cylinder rankings or the leaning-onset signature.

Per-cylinder data — all 10 flights

Per-cylinder MAX CHT — RAW (°F)

Flight	Date	Cyl 1	Cyl 2	Cyl 3	Cyl 4	Cyl 5	Cyl 6
F1	2026-04-11	455	448	438	408	451	442
F2	2026-04-17	467	465	444	429	446	461
F3	2026-04-18	435	414	401	374	415	411
F4	2026-04-18	441	426	417	395	431	428
F5	2026-04-19	438	417	411	380	414	416
F6	2026-05-14	434	409	408	377	417	411
F7	2026-05-15	456	455	454	418	450	447
F8	2026-05-16	426	406	402	371	411	408
F9	2026-05-17	425	401	395	365	403	401
F10	2026-05-20	414	419	418	389	437	421

Per-cylinder MAX CHT — OAT-adjusted (°F, k = 1.0)

Flight	Date	Cyl 1	Cyl 2	Cyl 3	Cyl 4	Cyl 5	Cyl 6
F1	2026-04-11	462	455	444	415	458	449
F2	2026-04-17	459	457	434	419	440	453
F3	2026-04-18	438	417	416	385	422	415
F4	2026-04-18	436	421	410	389	425	422
F5	2026-04-19	450	429	422	391	425	428
F6	2026-05-14	444	422	417	387	427	422
F7	2026-05-15	461	458	454	418	452	449
F8	2026-05-16	427	406	401	370	411	408
F9	2026-05-17	424	399	398	368	403	401
F10	2026-05-20	391	398	393	365	412	398

Adjustment uses the OAT at the moment each cylinder hit its max, minus the across-flight mean of that quantity.

Per-cylinder CRUISE median CHT — RAW (°F)

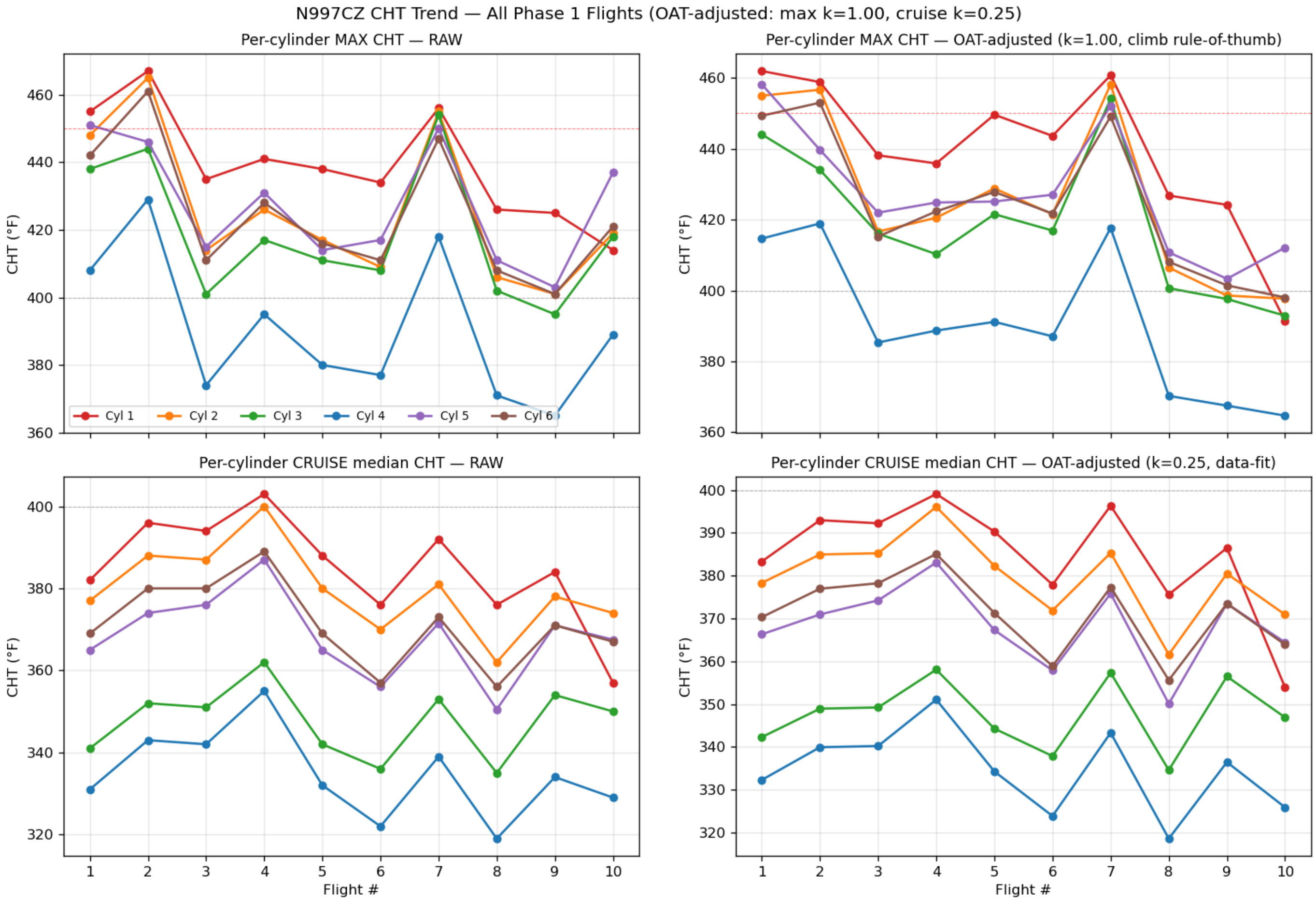
Flight	Date	Cruise OAT	Cyl 1	Cyl 2	Cyl 3	Cyl 4	Cyl 5	Cyl 6
F1	2026-04-11	+53.5°F	382	377	341	331	365	369
F2	2026-04-17	+71.0°F	396	388	352	343	374	380
F3	2026-04-18	+65.9°F	394	387	351	342	376	380
F4	2026-04-18	+74.5°F	403	400	362	355	387	389
F5	2026-04-19	+49.6°F	388	380	342	332	365	369
F6	2026-05-14	+51.2°F	376	370	336	322	356	357
F7	2026-05-15	+41.5°F	392	381	353	339	372	373
F8	2026-05-16	+60.3°F	376	362	335	319	350	356
F9	2026-05-17	+48.9°F	384	378	354	334	371	371
F10	2026-05-20	+71.1°F	357	374	350	329	368	367

Per-cylinder CRUISE median CHT — OAT-adjusted (°F, k = 0.25 from data fit)

Flight	Date	Cruise OAT	Cyl 1	Cyl 2	Cyl 3	Cyl 4	Cyl 5	Cyl 6
F1	2026-04-11	+53.5°F	383	378	342	332	366	370
F2	2026-04-17	+71.0°F	393	385	349	340	371	377
F3	2026-04-18	+65.9°F	392	385	349	340	374	378
F4	2026-04-18	+74.5°F	399	396	358	351	383	385
F5	2026-04-19	+49.6°F	390	382	344	334	367	371
F6	2026-05-14	+51.2°F	378	372	338	324	358	359
F7	2026-05-15	+41.5°F	396	385	357	343	376	377
F8	2026-05-16	+60.3°F	376	362	335	319	350	356
F9	2026-05-17	+48.9°F	386	380	356	336	373	373
F10	2026-05-20	+71.1°F	354	371	347	326	364	364

Chart — per-cylinder trend across all 10 flights

Four panels: raw and OAT-adjusted max CHT (top row), raw and OAT-adjusted cruise median CHT (bottom row). Dashed lines at 400°F (Lycoming continuous limit) and 450°F (climb caution).



The break-in story

The OAT-normalized F1→F10 delta is the cleanest read on how much each cylinder "cooled in" over Phase 1.

Cyl	Raw F1→F10 cruise	OAT-adj F1→F10 cruise	OAT-adj F1→F10 max
1	**–25 °F**	**–29 °F**	**–71 °F**
2	–3 °F	–7 °F	–57 °F
3	+9 °F	+5 °F	–51 °F
4	–2 °F	–6 °F	–50 °F
5	+3 °F	–2 °F	–46 °F
6	–2 °F	–6 °F	–51 °F

Take-aways (corrected 2026-05-21):

• **MAX-CHT break-in is real and substantial.** Cyl 1 max fell 41°F from F1 to F10 (raw), or 71°F OAT-adjusted. Other cylinders 46–57°F. Most of the cooling happened by F6 (full-rich regime); F7–F10 maxes are noisier due to mixture / configuration changes.
• **CRUISE-CHT "break-in" in the table above is misleading.** The F1→F10 OAT-adjusted cruise deltas mostly reflect leaning effects from F7 onward and the F10 air-dam mod, not ring-seating. The clean F1–F6 regression (§3) shows essentially zero cruise break-in slope — because cruise has cooling margin and the rings sealing don't materially change cruise temps. Look at MAX-CHT trends, not cruise, for the rings-seating signal.
• **Cyl 1 is the standout** at hottest in cruise every flight, and showed the most break-in work in max-CHT (F1 max 455 → F6 max 434, mostly settled by F6). Its apparent dramatic late-Phase-1 cruise cooling was the F10 air-dam-removal mod (~23°F of that 32°F F9→F10 drop is the mod, not continued break-in).
• **The cylinder ranking (1 > 2 > 5 ≈ 6 > 3 > 4) is invariant** across all 10 flights and both metrics. That's a real installation characteristic (baffle geometry, fin condition, fuel distribution), not a measurement artifact.

Flight 10 cooling-system modification

Lycoming IO-540 cylinder layout (looking aft from the prop):

• **Right bank, front→rear:** Cyl 1 → Cyl 3 → Cyl 5
• **Left bank, front→rear:** Cyl 2 → Cyl 4 → Cyl 6

Change made before Flight 10: the front-of-Cyl-1 air dam was removed entirely. Air dams in front of front cylinders redirect cooling air deeper into the baffle to help feed the middle and rear cylinders on the same bank. Removing it should:

• Lower Cyl 1 CHT (more direct cooling-air contact)
• Potentially raise Cyl 3 and Cyl 5 CHT (less redirected airflow downstream), particularly at climb power where the cooling system is most stressed.
• **Leave Cyls 2, 4, 6 unaffected** (left bank — ideal control group).

F9→F10 OAT-adjusted deltas (where the mod should leave fingerprints):

Cyl	Bank / position	Cruise Δ	Max Δ
1	**R-front (modified)**	**–32 °F**	**–33 °F**
3	R-middle (downstream)	–9 °F	–5 °F
5	R-rear (downstream)	–9 °F	+9 °F
—	—	—	—
2	L-front (control)	–9 °F	–1 °F
4	L-middle (control)	–10 °F	–3 °F
6	L-rear (control)	–9 °F	–3 °F

Pink rows = right bank (modified + downstream). Green rows = left bank (control).

What the data show:

• **Cyl 1 dropped 32°F cruise / 33°F max** — far beyond the –9°F "baseline" cooling seen on the controls. ~23°F of extra Cyl 1 cooling attributable to the air-dam removal. Clean signal.
• **Cyl 3 (R-middle): no penalty.** Cruise tracked the control group; max actually dropped slightly.
• **Cyl 5 (R-rear): the canary.** Cruise tracked the control group, but **max went UP by +9°F** while every other cylinder went down by 0–10°F. A 12–18°F relative warm-up in the high-stress (climb) regime — exactly the pattern the hypothesis predicted for the rearmost cylinder on the modified bank.
• **Cyls 2/4/6 (controls):** all small deltas. Confirms the right-bank effects are real, not a flight-wide power or altitude artifact.

Caveats: Flight 10 cruise window is short (542 samples, ~9 min) — less robust than other flights. One flight is one data point, especially for max. Flight 10 was a warm day (cruise OAT +71°F), so OAT normalization is doing meaningful work.

Mixture and fuel-flow analysis

CHT depends on mixture position (full rich vs leaned) as well as ambient conditions and break-in. Correlating CHT with cruise fuel flow (FF) across the 10 flights identifies when leaning started and how much CHT effect it had.

F	Date	FF mean (gph)	FF p10–p90	nm/gal	smi/gal	Cruise CHT OAT-adj	r(FF,CHT)	Regime
F1	2026-04-11	19.1	11.7–22.3	8.05	9.27	357.3	+0.84	full rich
F2	2026-04-17	18.1	10.8–22.8	8.23	9.47	368.5	+0.90	full rich
F3	2026-04-18	21.8	12.0–25.0	7.42	8.54	364.0	+0.94	full rich
F4	2026-04-18	22.6	14.6–25.1	6.94	7.98	374.5	+0.94	full rich
F5	2026-04-19	19.7	10.9–24.3	7.39	8.50	354.2	+0.96	full rich
F6	2026-05-14	19.8	18.6–21.6	8.11	9.34	352.2	+0.91	full rich
F7	**2026-05-15**	**15.7**	**11.3–18.8**	**9.61**	**11.06**	**362.2**	**+0.68**	**LEANED**
F8	2026-05-16	16.7	11.1–23.7	8.27	9.51	340.8	+0.89	leaned
F9	2026-05-17	15.6	14.9–17.6	10.41	11.98	364.8	+0.20	leaned (LOP)
F10	2026-05-20	16.0	9.9–21.5	9.05	10.41	342.3	+0.89	leaned

Pink rows = full-rich regime (F1–F6). Yellow = leaned regime (F7–F10). F7 in bold marks the onset.

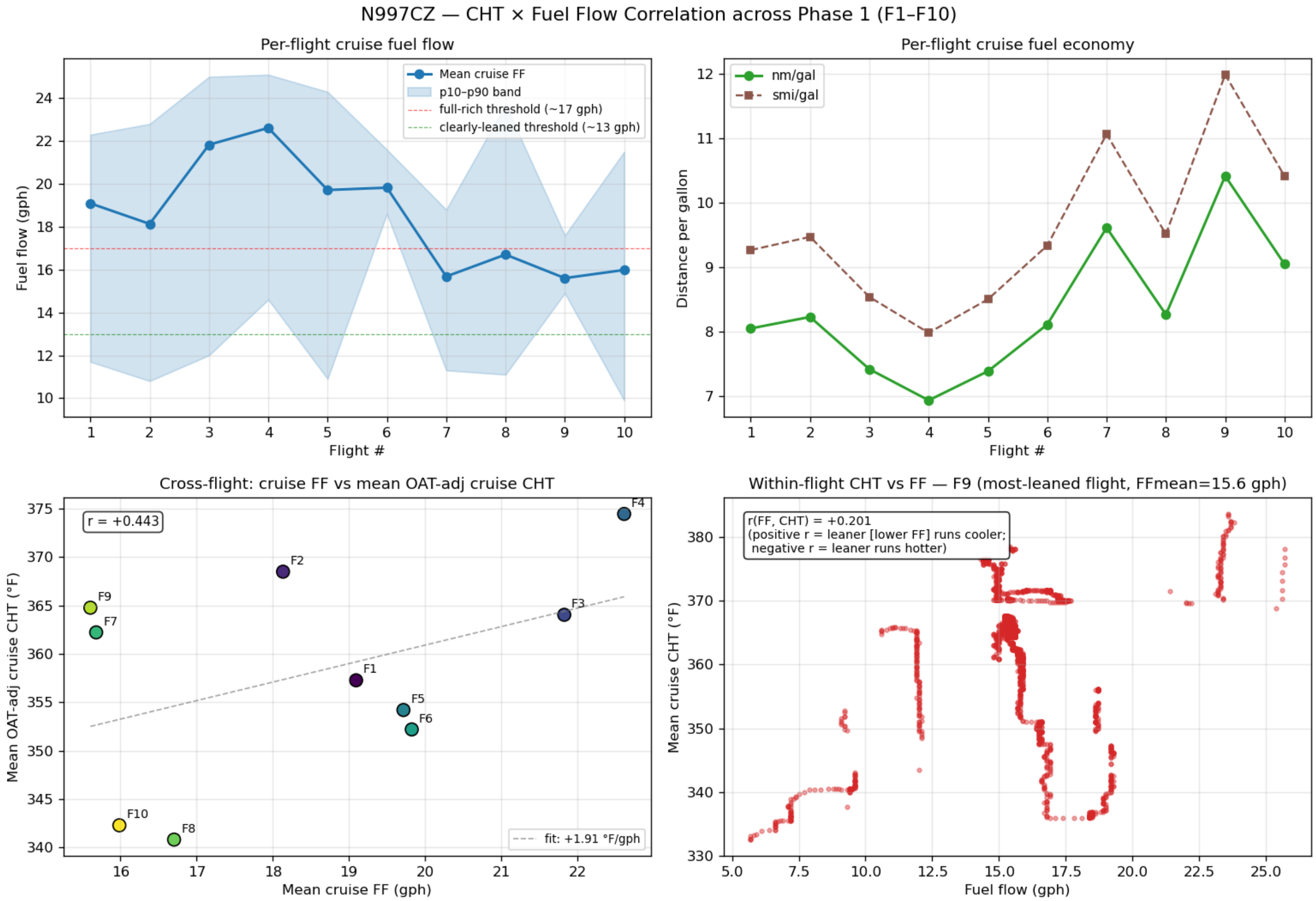
Key observations

1. Leaning onset is sharp and clean at Flight 7. Mean cruise FF stepped from 19.83 to 15.68 gph between F6 and F7 — a single-flight ~4 gph drop. Fuel economy improved from 8.11 to 9.61 nm/gal at the same step (+18%). Every F7+ flight runs leaner than every F1–F6 flight.

2. F6→F7 transition isolates the leaning effect: cruise CHT went UP +10°F (OAT-adjusted: 352.2 → 362.2 °F). That's the textbook leaning effect — reducing fuel cooling moves CHT toward peak EGT. Two adjacent flights, similar conditions, the only major change was mixture — clean signal.

3. Within-flight r(FF, CHT) is mostly >+0.7 — but that's a throttle/power signature, not mixture. When you pull power, FF and CHT both drop together (positive correlation) regardless of mixture position. The interesting flight is F9: r = +0.20 (almost no correlation), with FF tightly held in 14.9–17.6 gph. That's consistent with operating **lean of peak (LOP)** — far enough leaned that going leaner cools you off rather than heating you. F7/F8/F10 are murkier, possibly peak-EGT-ish.

4. Lycoming SI 1427C notice. The service instruction explicitly says *do not lean during break-in* — leaning reduces oil-mist in the combustion chamber, which helps rings wear in evenly. Leaning at F7 (~10 engine hr) is earlier than recommended. F8/F10 CHT data show no distress signature, so probably fine, but the cleanest path for the remaining ~12–15 hr of break-in is back to full rich at high power until oil consumption is stable.


N997CZ — CHT × Fuel Flow Correlation across Phase 1 (F1–F10)
Per-flight cruise fuel flow
Mean cruise FF
p10–p90 band
full-rich threshold (~17 gph)
clearly-leaned threshold (~13 gph)
Fuel flow (gph)
Flight #
Per-flight cruise fuel economy
nm/gal
smi/gal
Distance per gallon
Flight #
Cross-flight: cruise FF vs mean OAT-adj cruise CHT
r = +0.443
fit: +1.91 °F/gph
Mean OAT-adj cruise CHT (°F)
Mean cruise FF (gph)
Within-flight CHT vs FF — F9 (most-leaned flight, FFmean=15.6 gph)
r(FF, CHT) = +0.201
(positive r = leaner [lower FF] runs cooler;
negative r = leaner runs hotter)
Mean cruise CHT (°F)
Fuel flow (gph)

How will we know when break-in is complete?

Standard Lycoming SI 1427C indicators for IO-540 break-in:

1. **Stable oil consumption** — the gold-standard indicator. During break-in, blow-by past unseated rings keeps oil consumption high (often 1 qt per 4–6 hr). Once rings seat, consumption drops to ~1 qt per 8–12 hr and holds steady.
2. **CHTs flatten** — what we're tracking here. When OAT-normalized cruise CHT slope drops below ~1°F per flight on all cylinders, the rings have stopped wearing in.
3. **Stable oil temperature** — oil temp peaks drop and steady.
4. **Compression check + borescope** — formal confirmation. Typically at the first inspection (25 hr or annual).
5. **Full rated power** — combustion losses past unsealed rings cost a few HP pre-break-in.

Lycoming reference frame is **25–50 hours for full break-in**, with the majority of the work done in the first 10–20 hours. At ~13 engine hours post-F10:

• **MAX-CHT trend says break-in is well underway** — Cyl 1 max fell from 455°F (F1) to 434°F (F6) by ~7 engine hours, the kind of slope you'd expect with rings actively wearing in.
• **CRUISE-CHT trend is flat in F1–F6 already** — not because break-in is done, but because cruise has cooling margin and ring-seating doesn't show up there. **Don't use cruise CHT to judge break-in completion.**
• **Oil consumption is the gold standard** — haven't been tracking that, so start now and look for stable consumption over the next 4–5 flights.

What to watch on Flight 11+

• **Go back to FULL RICH at high power** for the remaining break-in (~12–15 hr to reach Lycoming's 25–50 hr full-break-in window). This is the cleanest protocol per SI 1427C, and gives us CHT data directly comparable to F1–F6.
• **Start tracking oil consumption** — record oil-add events with engine hours, look for the curve to flatten. This is the actual break-in test, not CHTs.
• **Watch Cyl 5 max (OAT-adj)** — the F10 air-dam mod canary. If F11/F12 show Cyl 5 max running ~10°F warmer than the trend predicts (full rich, climb profile), the air dam was doing real work for the rear cylinder and the mod has a downside in climb. If it pulls back in line, F10's bump was noise from the short cruise window.
• **Watch Cyl 1 max (OAT-adj)** — should continue trending toward Cyl 2/5/6 levels as ring-seating completes; the F10 raw max of 414°F was a new low and the air-dam mod should help maintain that.
• **Fly F11/F12 similar to F6** (full-rich, representative climb + cruise profile) so the comparison is clean to the F1–F6 baseline.

Methodology & scripts

• **Analysis script:** `Analysis/cht_trend_analysis.py` — takes the LOGS dict (date, filename) and produces the CSV + chart automatically. Configurable *K_MAX* and *K_CRUISE* at the top.
• **Output files:** `CHT_Trend.csv`, `CHT_Trend.png`.
• **OAT correction k = 0.25 for cruise** — fitted from this engine's own data (mean of per-cylinder b coefficients from the regression). The rule-of-thumb k = 1.0 is a climb/full-power approximation and overcorrects for cruise.
• **Cruise gate**: RPM ≥ 2000, IAS ≥ 80 kt, |VS| ≤ 300 fpm, t > 120 s after engine on. Tight enough to exclude climb, descent, slow-flight, and pattern work; loose enough to keep most stable cruise samples.
• **No claim about absolute calibration** — this analysis uses the G3X-logged CHT and OAT directly, no cross-check against a reference probe.