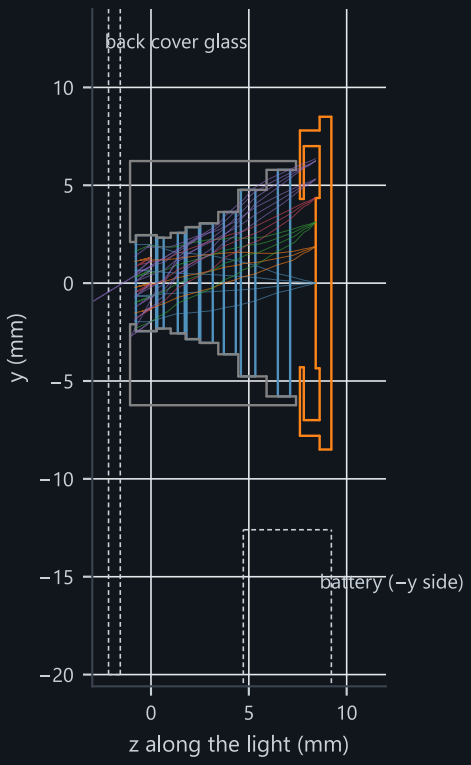
CASE STUDY 4 · MECHANICAL AND THERMAL · ENVIRONMENT

Temperature moves focus 129 µm; the battery adds only 0.33 pixel

The plastic main camera of case study 1 defocuses by 1.19 µm per kelvin, so it needs its autofocus at every temperature from −20 to +70 °C: 129 µm of travel, well inside the voice-coil stroke. A battery heating one side tilts the lens and the sensor together, so the image moves by a fraction of a pixel. Vibration and shock are a different story: the soft suspension that makes autofocus possible lets the lens swing millimetres, far beyond its stroke.



Section through the module model with the battery block and back cover.

129 µm
AF travel, −20 to +70 °C

0.33 px
image shift, 60 °C battery side

45 Hz
first suspension mode

1.03 mm
RMS lens swing at 8.9 g random — on the end stops

BACKGROUND 01

A phone camera lives next to a battery, in a pocket, on a handlebar

A phone's main camera is an eight-element plastic lens on a spring-suspended carrier, a few millimetres from the battery and the processor. Plastic optics change focus several times faster with temperature than glass, the battery and processor heat the module from one side, and the springs that let the autofocus move the lens also let it swing when the phone vibrates or is dropped.

The question this study answers: does the case-study-1 camera stay in focus and intact next to a hot battery, at −20 and +70 °C, and through vibration and a drop?

Case study 1 designed the lens; this study puts it in its module and environment. The lens prescription here is case study 1's, unchanged.

THE JOB 02

Six environmental cases from public phone and component data

WHAT THE JOB NEEDS	SPECIFICATION	WHY
Cold soak	−20 °C	storage minimum / module tests (research 04 §1.1)
Hot soak	+70 °C (+60 °C sensor limit marked)	module test limit; image-sensor stable-image limit
Battery side	35 °C ambient, battery 45 °C, sensor 0.37 W, VCM 0.1 W	charge-throttle temperature; sensor datasheet
Battery abuse	battery 60 °C	vendor stop-charging threshold
Random vibration	0.04 g²/Hz, 20–2000 Hz	MIL-STD-810G general minimum integrity
Shock	1500 g, 0.5 ms half-sine	JESD22-B110/B111 cond. B (≈ 1.1–1.5 m drop)

WHY IT IS HARD 03

Four tensions set the problem

- **Plastic against temperature.** the lens plastics change index by -100 and -109 ×10⁻⁶ per kelvin, against a depth of focus of only ±3.8 µm.
- **One hot side against symmetry.** a battery on one side bends the module, which can tilt the lens against the sensor.
- **A soft suspension against vibration.** autofocus needs a carrier on springs of about 100 N/m; the same springs resonate near 40–150 Hz.
- **Light parts against a hard landing.** a 1500 g pulse turns the 1.26 g lens carrier into a 18 N load on its end stop.

UNIFORM SOAKS 04

Plastic lenses move focus by more than a micron per kelvin

The lens was rebuilt and traced at each temperature by the API's thermal analysis, with the plastics' index change and expansion and with the spacers (55 ×10⁻⁶/K) and liquid-crystal-polymer holder setting the air gaps. Focus moves 1.19 µm per kelvin between 25 and 60 °C: 41.7 µm, against 22–26 µm quoted for a typical all-plastic lens of 1.57 mm focal length over the same range (a 4.5× longer focal length here). The holder's flow or cross-flow expansion changes the +70 °C focus by only 0.7 µm.

> **Decision.** the autofocus tracks temperature. The 129 µm of thermal travel fits inside a 250–500 µm voice-coil stroke, next to the travel macro focusing needs.

> **Finding.** refocus does not restore the field: 0.75F contrast at 102 lp/mm drops by 41 % at −20 °C. The plastics' index change rebalances the field curvature, which a single focus move cannot undo.

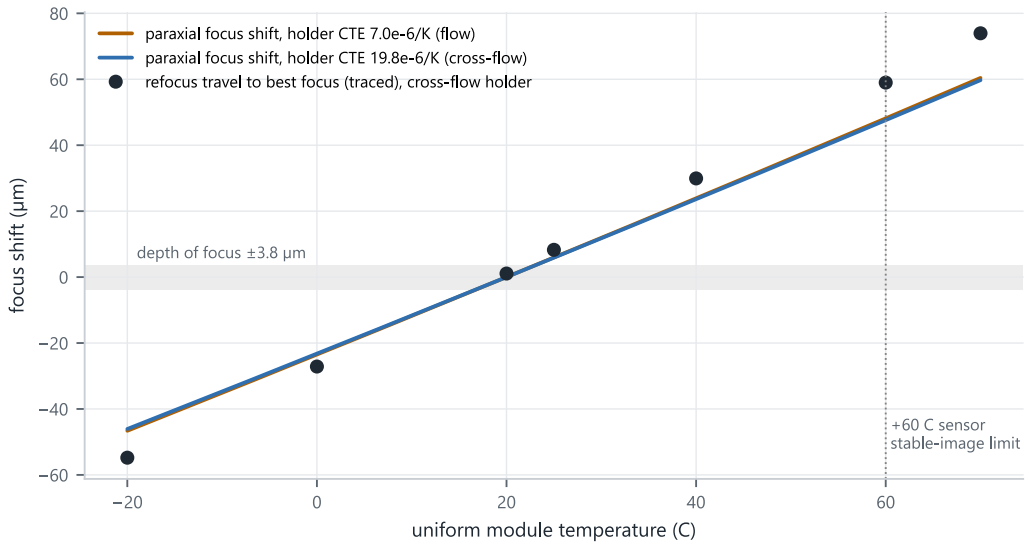


Figure 1. Paraxial focus shift (curves, 37 temperatures) and the traced refocus travel to best focus (dots) for uniform temperatures; shaded: depth of focus $\pm 2\lambda N^2 = \pm 3.8$ µm at f/1.84, 555 nm. The two holder expansions bracket the LCP flow and cross-flow CTE.

BATTERY SIDE 05

A hot battery tilts lens and sensor together

A lumped thermal network of the module (board, holder, barrel and lens stack, each split into a battery side and a far side) was solved by the API's thermal engine. With the battery face at 45 °C the rear lenses differ by 2.5 K across their width; at 60 °C by 6.1 K. The node temperatures were mapped onto the finite-element model, solved, and every lens's and the sensor's motion was fitted and traced (/analysis/stop) on the lens rebuilt at its mean temperature.

> **Finding.** the one-sided heating matters mainly through the mean temperature it raises (37 µm of refocus at 60 °C); its asymmetric part adds +0.57 µm of focus and 0.33 pixel of image shift.

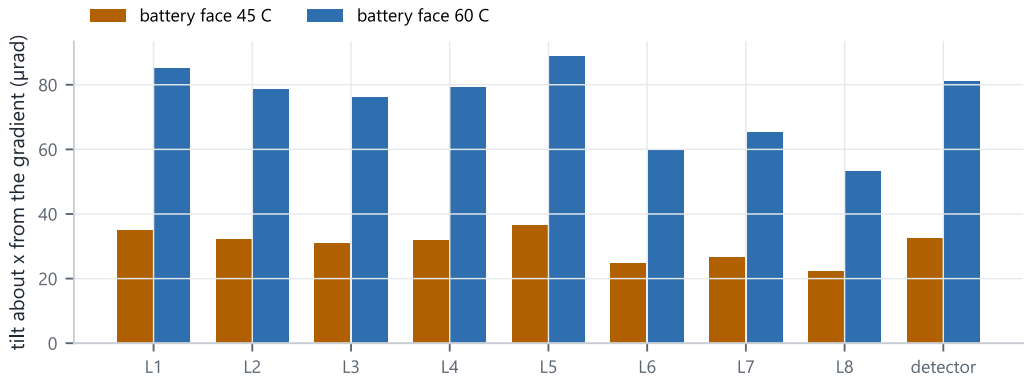


Figure 2. Tilt about x of each lens and the sensor caused by the one-sided heating (the uniform part at the mean lens temperature removed). Lens and sensor tilt together: the largest lens-to-sensor difference is 27.9 µrad at 60 °C.

VIBRATION 06

The autofocus springs make the lens a 45 Hz pendulum

The lens carrier (1.26 g, barrel and lenses) on the suspension (100 N/m per direction) has its first modes at 44.6 Hz (translations) and 59.4 Hz (rocking), inside the cited 40–150 Hz. Under the 8.9 g RMS random test it swings 1.03 mm RMS along the axis and 1.03 mm sideways at 2 % damping: far beyond a 500 µm stroke, so in the test the carrier rides its end stops. One micron of sideways carrier motion moves the image 1.015 µm; one micron along the axis moves focus 1.002 µm.

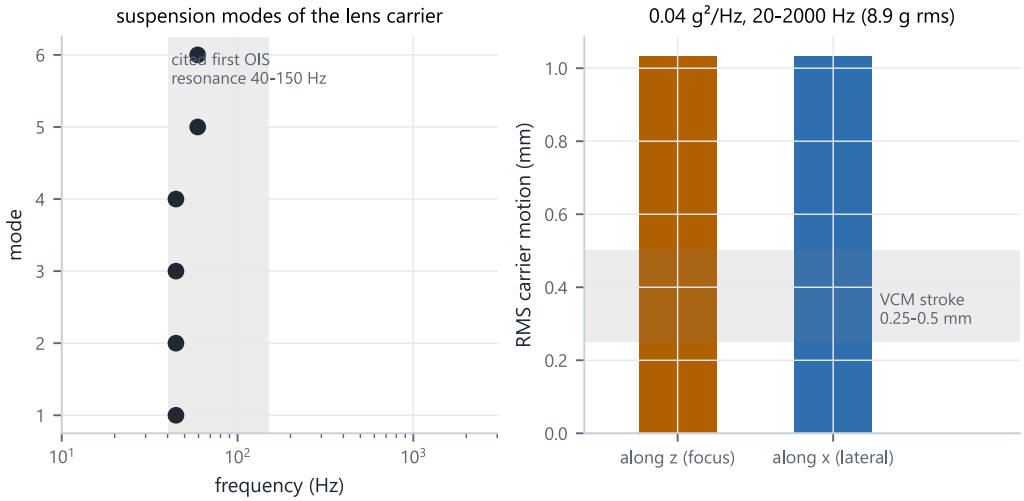


Figure 3. Left: suspension modes against the cited first-resonance band. Right: RMS carrier motion under the random test, against the VCM stroke (shaded).

> **Finding.** the 0.04 g^2/Hz level is a survival test, not an imaging condition: the passive suspension amplifies vibration near its 45 Hz resonance, which is the mechanism behind the cited phone-maker warning against mounting on high-power motorcycles. Sharp images under vibration need the closed-loop OIS and AF and a short exposure.

SHOCK 07

A drop sends the lens onto its end stop; the parts are not stressed

The 1500 g, 0.5 ms pulse would carry a free carrier 16.7 mm (transient analysis): it lands on its end stop. With the carrier held at its glue joint and the full 1500 g applied, the largest stress is 4.1 MPa (barrel, sideways pulse) and the largest lens stress 2.2 MPa, against 79 MPa tensile strength for the OKP4HT flint.

> **Finding.** the limits in a drop are the suspension springs and the end stops, which a linear model cannot judge (permanent set of the 30 µm leaf springs is the documented failure); the optics and barrel carry the deceleration with a large margin.

THE RESULT 08

6 of 9 checks met; the misses are by design

REQUIREMENT	TARGET	RESULT	STATUS
Thermal AF travel, −20…+70 °C	≤ 250 µm (smallest cited VCM stroke)	129 µm	✓ Met
Focus held without AF over −20…+70 °C	within ±3.8 µm	-46 … +60 µm	✗ Not met
Extra focus from the 60 °C battery side	≤ ±3.8 µm	+0.57 µm	✓ Met
Image shift from the 60 °C battery side	≤ 1 pixel	0.33 px	✓ Met
Sensor die, 60 °C battery case	≤ 60 °C stable-image limit	52.1 °C	✓ Met
First suspension mode	40–150 Hz (cited OIS first resonance)	44.6 Hz	✓ Met
Carrier motion, 0.04 g²/Hz random	≤ 125 µm RMS (stays off the end stops)	1034 µm RMS	✗ Not met
Carrier travel, 1500 g / 0.5 ms	≤ 500 µm (largest cited stroke)	16678 µm	✗ Not met
Lens stress on the end stop, 1500 g	≤ 79 MPa (OKP4HT tensile)	2.2 MPa	✓ Met

Next steps.

- Model the suspension springs and end stops on a deployment that runs spring connections in static and transient studies, with the measured suspension damping.
- Use separate lens and barrel materials when the mesher keeps one element block per body.
- Confirm the barrel and lens-stack modes (assumed above 2 kHz): the structural modal of the 53k-node module did not finish within the solver's 900 s limit.
- Compensate the field rebalancing at −20 °C: one molded-glass element or a low-dn/dT flint.
- Run the operating vibration case (car mount, motorcycle) with OIS in the loop.

METHOD 09

How the numbers were made

Every number in this summary is a saved Paraxial API response or simple arithmetic on one, and every status is computed from it. The lens is case study 1's, with the two plastics entered as catalogue materials carrying their cited dn/dT and expansion. Uniform soaks used the API's thermal analysis with refocus; the battery cases chained the API thermal network, a static finite-element solve and a traced lens with each element and the sensor moved by its fitted motion. Vibration and shock used modal, random-vibration and transient studies of the suspended lens carrier.

Limits. The lenses were modelled as discs of their true mass, one material covers every body in the finite-element model, and the springs and end stops are linear, so the stresses are indicative and the swing beyond the stroke shows contact rather than predicting it.

The full report adds further figures and tables, the cross-checks, the scripts and the model set-up.