The MROI Fast Tip-Tilt/ Narrow-field Acquisition System (FTT/NAS) project

FLC & FTT/NAS Camera
Thermal Control Issues

Environmental Requirements

- FTT/NAS
  - Operational Temp Range:-5°C to + 20°C(goal -10°C to +20°C)
  - Operational Humidity Range: 10% to 70% (goal 10% to 90%)
- FLC
  - Operational Temp Range:-15°C to + 20°C
  - Operational Humidity Range: 10% to 70% (goal 10% to 90%)
  - Check these with UT spec.
- Both
  - Surface temp any object ‘near’ beam to be within 2°C of ambient

Camera Thermal Operation Scenarios

- No enclosure
  - cooling fan running: not acceptable if the air temperature in the enclosure is lower than -5°C [0°C from camera spec]
  - No control over humidity – dew point problems
  - Start-up issues in cold weather
- Partial enclosure
  - allows some ventilation but otherwise allows the enclosure to warm up: not much better; no thermal or humidity control
- Camera is placed in a thermally controlled enclosure
  - temperature is maintained at a few degrees below ambient but not below -5°C and preferably not below 0°C
  - requires a camera enclosure cooling system that tracks a few degrees below ambient but with a low limit set point of ~0°C
  - Dew point considerations eased.

Basic Calculations 1

- **Heat dissipation and surface temp**
- If the cameras produce 10W convective heat dissipation in a passive enclosure the surface temperature would be approx:

$$\dot{Q} = hA(T_s - T_b)$$

$$T_s - T_b = 10W/(2*0.375m^2) = 13.3°C$$

- Assuming:
  - no forced cooling (wind)
  - an enclosure of outer dimensions 250 x 250 x 250 mm
  - a convective heat transfer coefficient of (average) 2 over the whole surface area.
  - Excluding radiative cooling
- May be OK for FLC (would need to check internal temperature) but is not OK for normal operations

Basic Calculations 2

- For convection cooling in no wind conditions the maximum amount of heat that can be allowed to escape the enclosure without the surface temperature increasing by more than 2°C is (very approximate):

$$Q' = 2*0.375*2 = 1.5W$$

- Therefore, at least for the FTT/NAS arrangement we would need to extract ~8.5W by some kind of internal heat exchanger.
- Best done with a substantial ΔT between the internal enclosure air and the cooling fluid to make heat exchange more efficient and to drive convection within.
- Coolant temperature of -5°C and an internal air temperature of +5°C would seem OK if the box insulation could be sufficient to allow a ΔT of up to 18°C between internal and external air - otherwise have cooling track ambient.

Test Results 1

- Results from simple tests on Andor camera
  - Peltier off: camera head dissipation produces $\Delta T = 2°C$ in air-stream from camera fan compared with ambient temperature.
  - Peltier on: set temperature of -85°C produces $\Delta T = 8°C$
  - camera has a 50mm silent fan. These typically give an airflow of 7 to 10 cu. ft. per minute (0.21 to $0.3 m^3 min^{-1}$)

- Heat dissipated by the camera (approx.):
  - Heat gained by the air is: $Q = m' \times c_p \times \Delta t$

Where

- Δt is the difference in temperature between the air-stream and ambient.
- The density of air is $\rho = 1.26\ kg.m^3$
- the mass flow rate for 10cu.ft/min is $m' = \frac{0.3m^3}{60s} \times 1.26 kg.m^{-3} = 0.006 kgs^{-1}$
- the specific heat of air at constant pressure $c_p = 1.006 \times 10^3 Jkg^{-1}K^{-1}$

Test Results 2

- Approximate camera head dissipation by convection to air:

  Then for a Δt of 2°C: $Q = 0.006 \times 1.006 \times 10^3 \times 2 \approx 12W$ (or 8.4W for 7cu.ft/min)

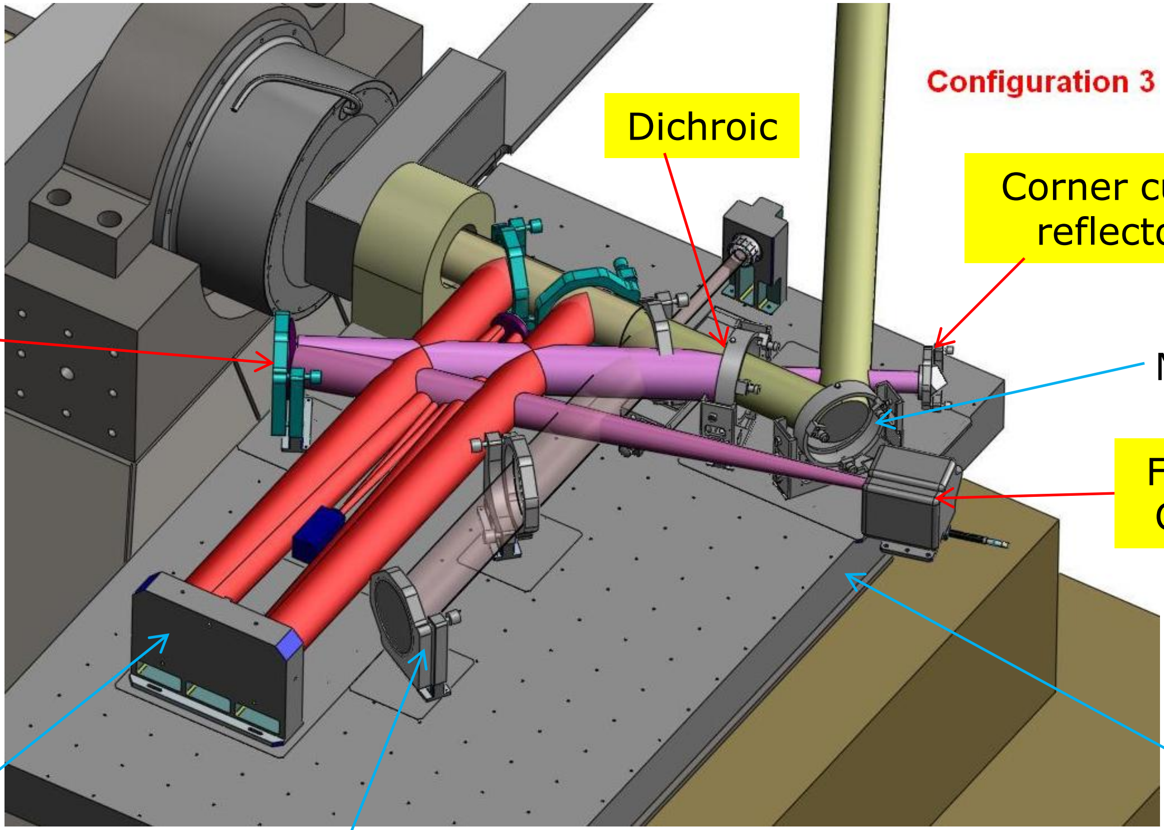
  For a Δt of 8°C, Q increases to 48W (34W)

- Peltier Operation

  Peltier efficiency (CoP) for a 3-stage device with cold side temperature -85°C and a hot side temperature of 35°C is about 1% but this increases to about 5% if the hot side temperature is maintained at about 10°C. For room temperature ~20°C and fan operation giving an air-stream temperature of 8°C above ambient the hot-side temperature is likely to be ~35°C so the efficiency of the Andor unit is about 1%. The maximum power that the Andor unit delivers for the Peltier is 3A x 5V = 15W and so the maximum power removed at the cold side is about 0.15W which is composed of the detector dissipation and the thermal leakage to the assembly from the environment. Chip power is dominated by the output amplifiers (typically 30mW for the LS and 40mW for the HR amplifiers). Assuming both amplifiers are active this means ~50% of the heat removed is from the chip and the rest is heat transfer from the surroundings.

Camera Enclosure

- Minimum size of enclosure is probably 250x250x250mm



Derived requirements candidates

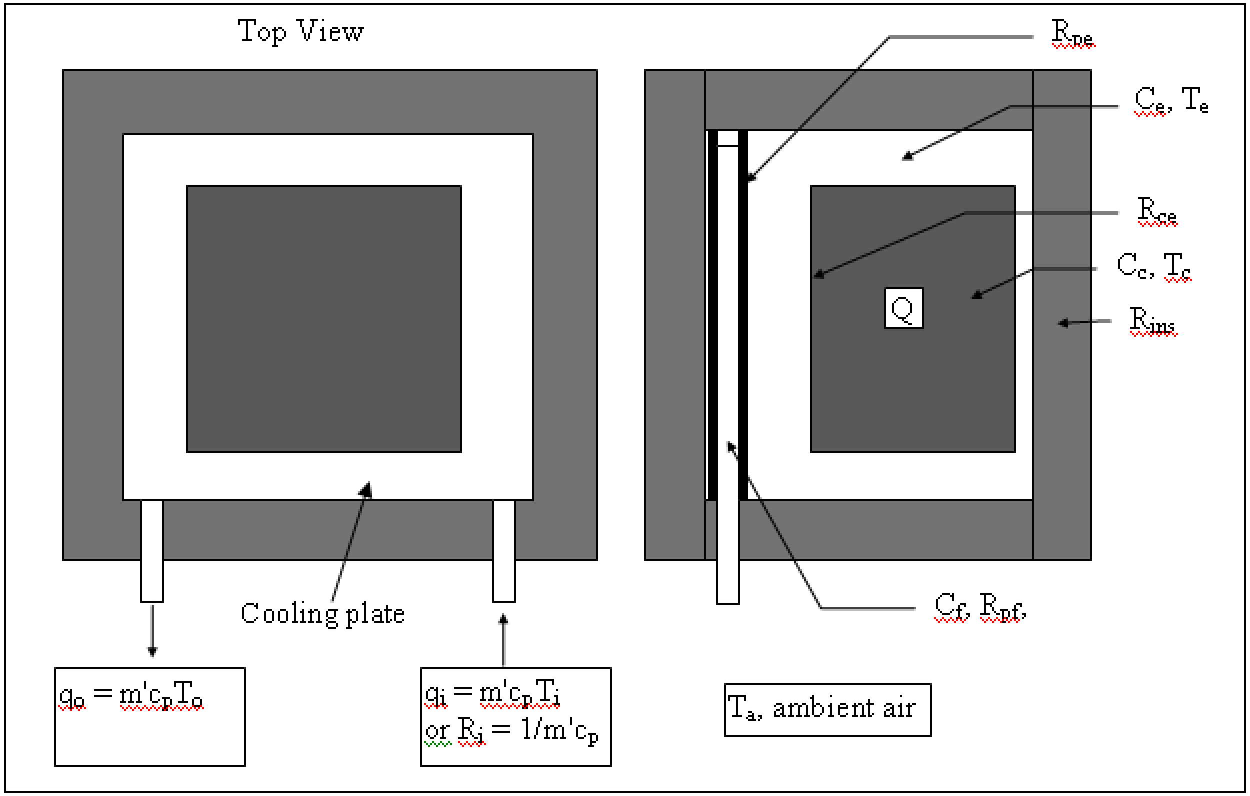
- Camera Head
  - Camera must be enclosed
  - At least 8W (TBC) to be removed by a fluid cooling system
  - Cooling system to track -5°C (TBC) below ambient but to no less than -5°C.
  - Camera must conduct no more than TBC W to optical table
  - A maximum size of enclosure may be defined by other requirements/space envelope
- Electronics
  - Dissipation in electronics rack
    - Computer (100W TBC)
    - Other electronics we may need (25W TBC)
    - Peltier/camera head enclosure chiller if located here (125W TBC)

Potential Design

- Place camera in sealed, insulated enclosure.
- Use Peltier chiller circuit to extract heat from enclosure.
  - Pass chilled fluid through enclosure first and then into camera head
  - Mount chiller in electronics rack (no more than 250W allowed to be dissipated so apportion this between chiller and computer plus any electronics.
  - Otherwise need additional fluid/fluid heat exchanger and use telescope coolant.
- Avoid heat being conducted to optical table.
- Mount as far away from beam as possible?
  - Helps with cable length issues
  - May be able to allow $\Delta T > 2°C$ surface temperature?
  - Limit influence of any heat conducted into table

Thermal Model 1

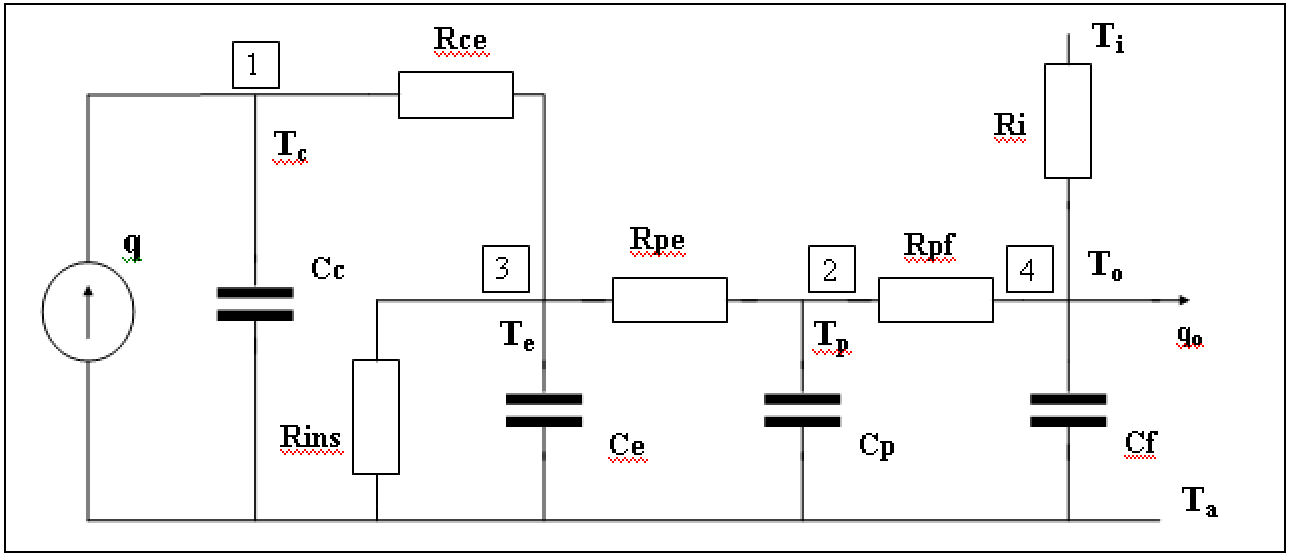
- Schematic of simple cooling arrangement



Schematic of Heat Exchanger annotated with lumped parameters.

Thermal Model 2

- Equivalent circuit



Thermal Model 3

Thermal Capacitances:

$Cc = \rho_{al} c_{pal} V_c$	Thermal capacitance of camera components of volume V_c and material aluminium.
$Ce = \rho_{air} c_{pair} V_{enc}$	Thermal capacitance of air in enclosure of volume V_{enc}.
$Cp = \rho_{al} c_{pal} V_p$	Thermal capacitance of aluminium plate assembly of equivalent volume V_p.
$Cf = \rho_f c_{pf} V_f$	Thermal capacitance of cooling fluid, say 50% water/glycol mixture, in volume V_f.

Thermal Resistances:

$Rce = 1/h_{cce} A_p$	Thermal Resistance of camera to enclosure air, camera area A_p and convection heat transfer coefficient h_{cce}.
$Rpe = 1/h_{cpa} A_p$	Thermal Resistance of plate to enclosure air, plate area A_p and convection heat transfer coefficient h_{cpa}.
$Rpf = 1/h_{cpf} A_f$	Thermal Resistance of plate to fluid under forced convection, effective area A_f and convection heat transfer coefficient h_{cpf}.
$Rins = L_{ins}/k_{ins} A_s$	Thermal Resistance of insulation, thickness L_{ins}, surface area A_s, conductivity k_{ins}.
$Ri = 1/m'_f c_{pf}$	Equivalent Thermal Resistance representing heat loss due to temperature difference and mass flow rate m'_f and specific heat of fluid c_{pf}.

$$
\begin{bmatrix} T_c \\ T_p \\ T_o \\ T_e \end{bmatrix} =
\begin{bmatrix}
\frac{-1}{C_c R_{ce}} & 0 & 0 & \frac{1}{C_c R_{ce}} \\
0 & -\left(\frac{1}{C_p R_{pe}} + \frac{1}{C_p R_{pf}}\right) & \frac{1}{C_p R_{pf}} & \frac{1}{C_p R_{pe}} \\
0 & \frac{1}{C_f R_{pf}} & -\left(\frac{1}{C_f R_{pf}} + \frac{1}{C_f R_i}\right) & 0 \\
\frac{1}{C_e R_{ce}} & \frac{1}{C_e R_{pe}} & 0 & -\left(\frac{1}{C_e R_{ce}} + \frac{1}{C_e R_{pe}} + \frac{1}{C_e R_{ins}}\right)
\end{bmatrix}
\begin{bmatrix} Tc \\ T_p \\ T_o \\ T_e \end{bmatrix} +
\begin{bmatrix}
\frac{-1}{C_c} & 0 \\
0 & 0 \\
0 & \frac{1}{C_f R_i} \\
0 & 0
\end{bmatrix}
\begin{bmatrix} q & \theta_i \end{bmatrix}
$$

$$q_o = m' c_p T_o$$