Critical Surface Contamination in Clear Weather

Understanding and Dealing With Active Frost

Frost looks benign, but continues to claim lives

CL604 at Birmingham on 4 January 2002

– Hull loss

CRJ 200 at Baotou, China on 21 November 2004

– Hull loss

Numerous events where frost is suspected but obliterated prior to the investigation

Why is Frost still an Issue?
Some possibilities

- Complacency with what appears to be a benign level of contamination
- Insufficient understanding of the phenomenon itself and its effects
- Insufficient understanding of the limitations of de-icing and anti-icing strategies for frost
- Ease of removal is misinterpreted as an indication of low threat.

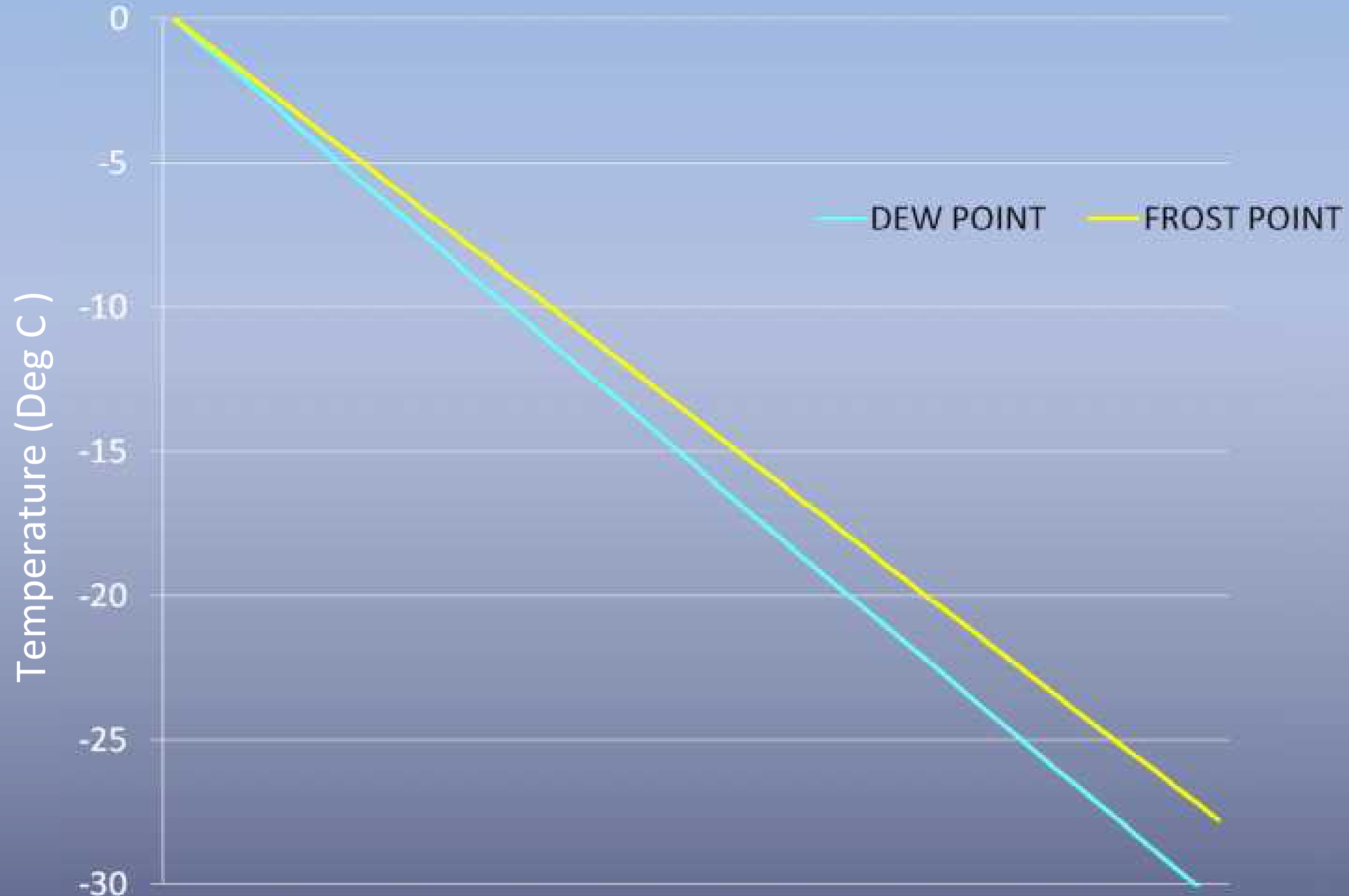
Over the Next Half Hour…

- What is Active Frost?
- What are the threat conditions?
- What mitigations work and for how long?
- What mitigation methods do not work?
- How does a flight crew identify the threat and assess the safety of the wing before flight?

What is Active Frost?

- Frost actively forms when the temperature of the skin surface is below the **frost** point of the ambient air.
- Frost point is the temperature at which moisture from the air is deposited as frost on a surface.
- Frost point is different than Dew Point
  - State change from water vapour directly to frost
  - Always at or below 0 deg C
  - Frost point is equal to **or warmer than** Dew Point
- Normally skin surface is colder than ambient, otherwise fog is the result.

Dew Point versus Frost Point



Frost can form above the Dew Point!

Active Frost Conditions

- Need a mechanism to bring the wing skin temperature and frost point together
- Several possible scenarios
  - Conduction cooling due to cold soaked fuel
  - Radiation cooling below ambient to frost point (most common)
  - Advection cooling due to rapid rise in dewpoint to match skin temperature of wing (supercooled dew)
- Some or all scenarios can be active at the same time

Frost Phases

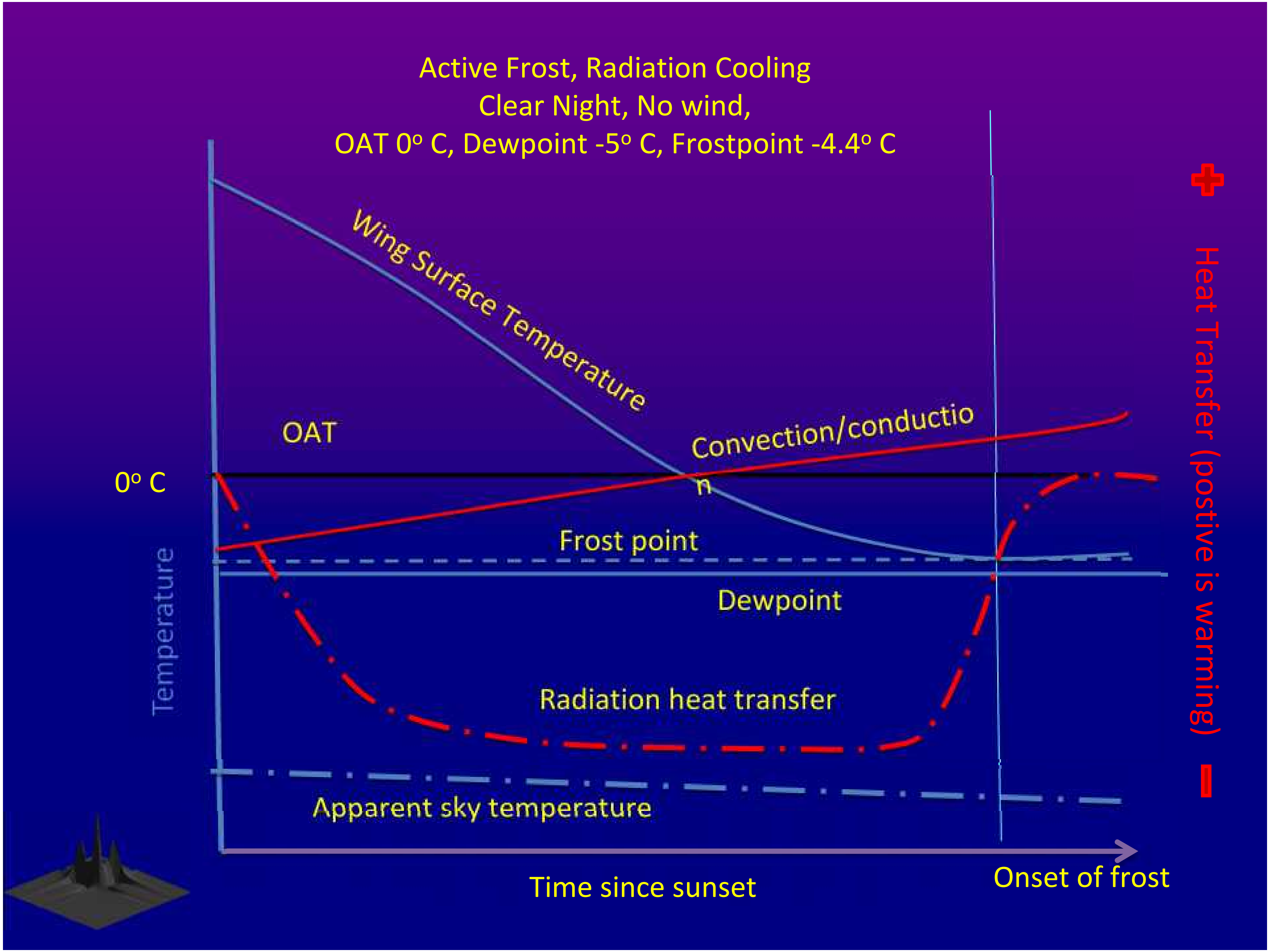
- Active phase – aka 'Active Frost'
  - Conditions are right for one or more of the frost accretion methods
  - It is a matter of when, not if
- Residual phase
  - Active frost accretion has ceased, but the surface is still below freezing and there is no opportunity for sublimation back to vapour

Cold Soak Frost

- Substantial load of cold fuel remaining on arrival
- Heat is conducted away from surface via wing structures that are immersed in fuel
- Fuel temperature readings in the Flight Deck may correlate on some aircraft types after landing and before fuelling
- Once fuelling has begun, fuel temperature no longer correlates with the surface
  - only direct surface reading or observation are useful

Radiation Cooling Frost

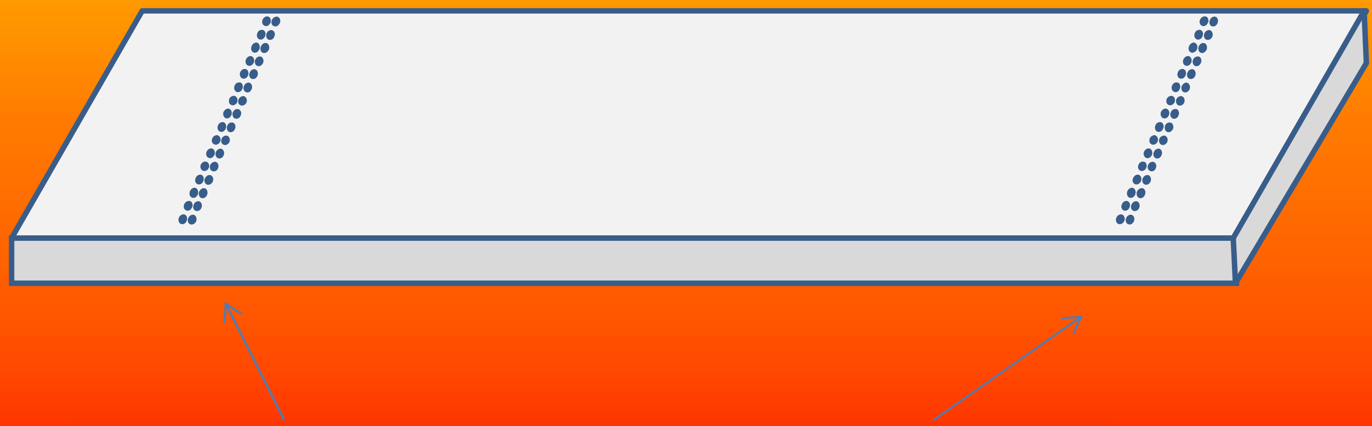
- Radiation exchange to cold sky is weak
- Accurate prediction relies on
  - Initial wing temperature
  - Relative Humidity
  - Air Quality
  - Wind Speed
  - Cloud cover
  - Sun angle



Active Frost, Radiation Cooling
Clear Night, No wind,
OAT 0° C, Dewpoint -5° C, Frostpoint -4.4° C
Wing Surface Temperature
OAT
0° C
Convection/conductio
n
Frost point
Dewpoint
Temperature
Radiation heat transfer
Apparent sky temperature
Time since sunset
Onset of frost
Heat Transfer (postive is warming)

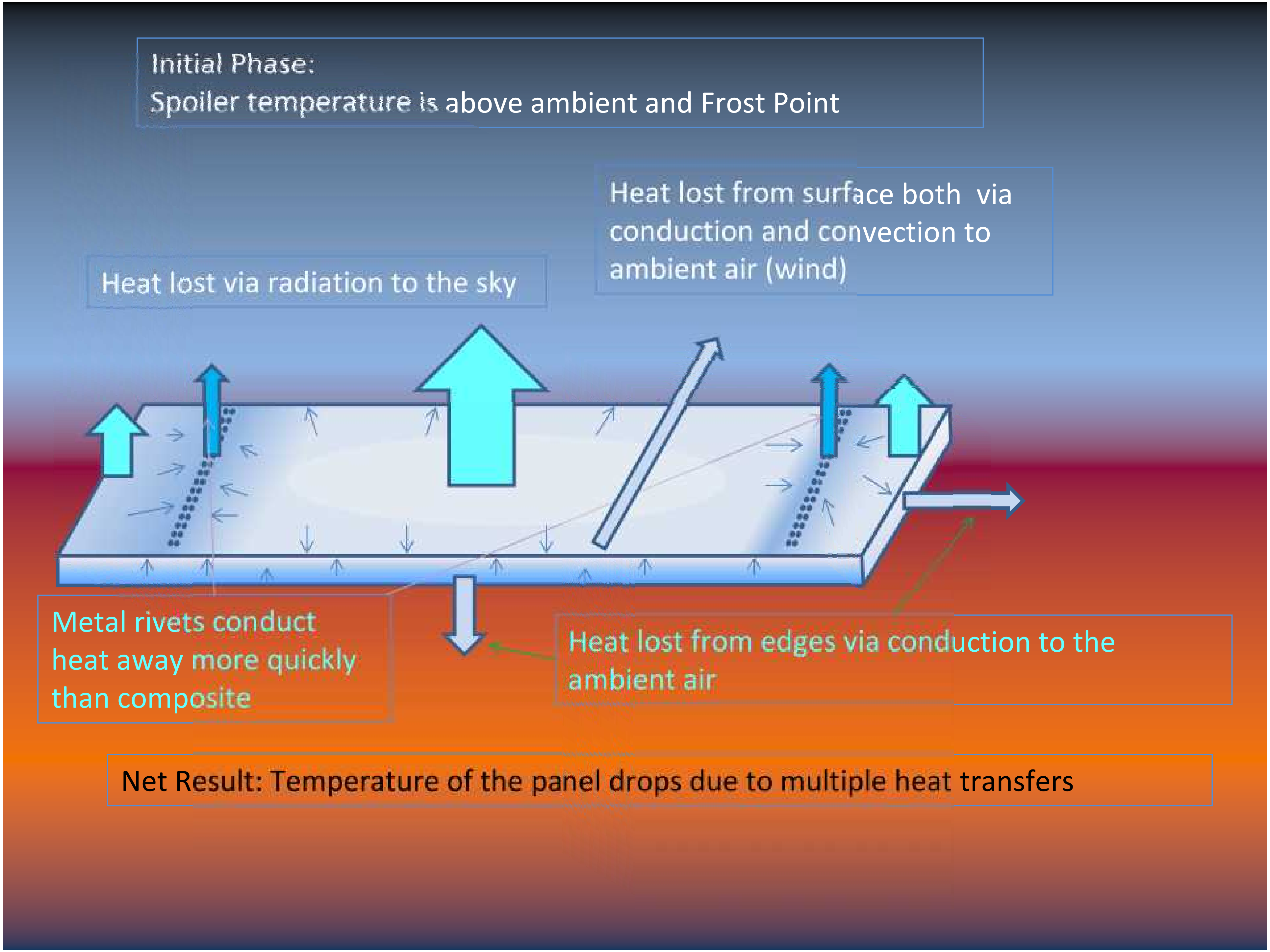
Frost forms at different rates on different aircraft materials and surfaces

Spoiler Panel or control surface
Composite Material (Thickness exaggerated)



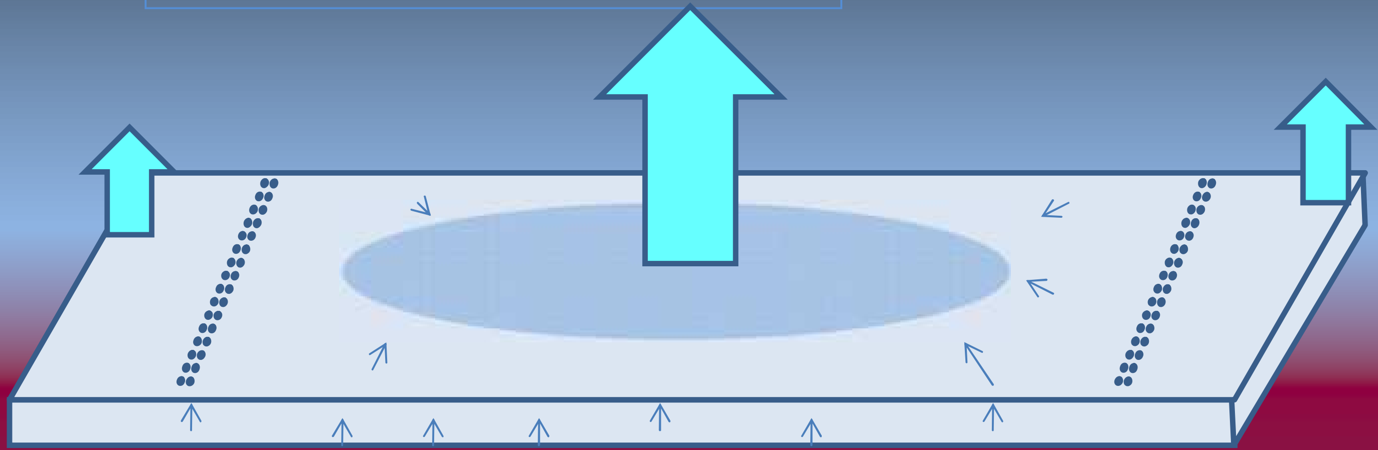
Metal Rivets to supports and actuators

Metal is more thermally conductive than composite


Initial Phase:
Spoiler temperature is above ambient and Frost Point
Heat lost from surface both via conduction and convection to ambient air (wind)
Heat lost via radiation to the sky
Metal rivets conduct heat away more quickly than composite
Heat lost from edges via conduction to the ambient air
Net Result: Temperature of the panel drops due to multiple heat transfers

Secondary Phase:
Spoiler temperature is at ambient temp but still above Frost Point

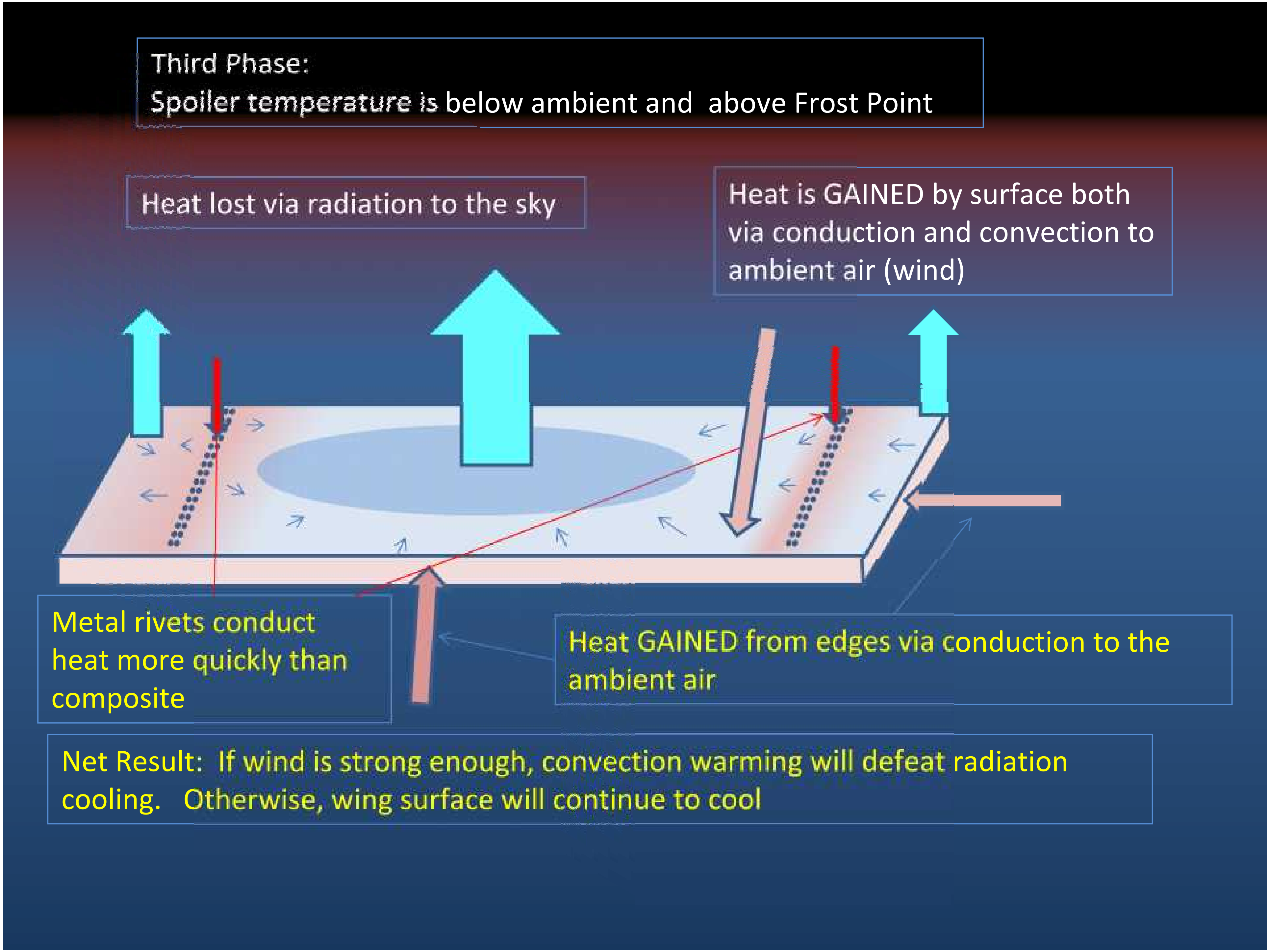
Heat lost via radiation to the sky



No heat transfer to the air (no temperature differential)

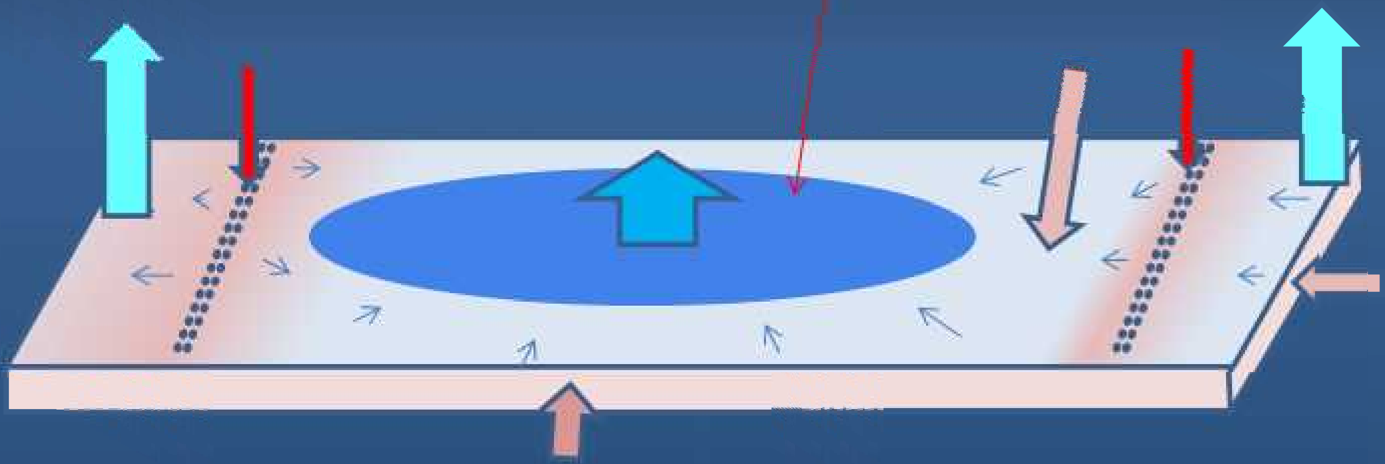
Net Result: Radiation Cooling depends on amount of cloud cover , air quality and sun exposure.

Radiation Cooling is not just a night time phenomenon!


Third Phase:
Spoiler temperature is below ambient and above Frost Point
Heat lost via radiation to the sky
Heat is GAINED by surface both via conduction and convection to ambient air (wind)
Metal rivets conduct heat more quickly than composite
Heat GAINED from edges via conduction to the ambient air
Net Result: If wind is strong enough, convection warming will defeat radiation cooling. Otherwise, wing surface will continue to cool

Fourth Phase:
Frost Point reached for central area

Frost disrupts weak radiation cooling, but also insulates against convective warming of the wing . Frosted areas serve as a heat sink for the warmer areas of the wing

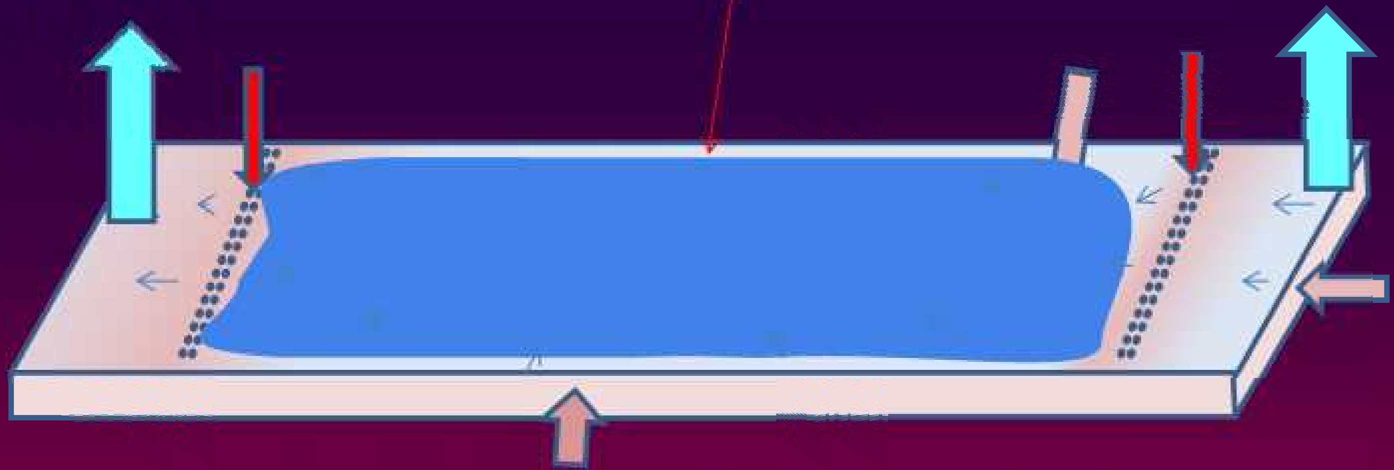


Remaining heat transfers continue

Net Result: degree of frost coverage will depend on ambient conditions, but generally will spread outward from central areas as cooling continues.

Frost Propagation outward from coldest area

Cold central area drains heat from periphery
At higher rate than ambient air can replace

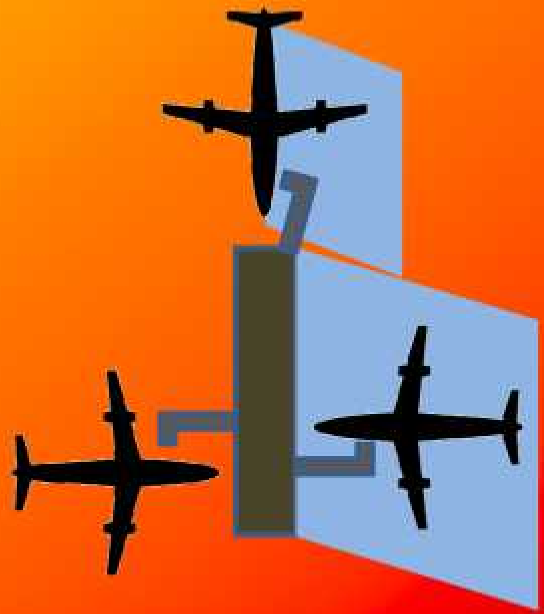


Net Result: frost pattern spreads outward, eventually involving the entire surface
Radiation heat transfer is disrupted by the frost layer and the surface temperature stabilizes near the frost point.
Edges and areas joined to higher conductivity materials generally frost later

Active Frost conditions can persist long after sunrise or commence prior to sunset

Azimuth and elevation of sun directly determines where frost forms

Some areas are prone to late morning frost while others are prone to early evening effects



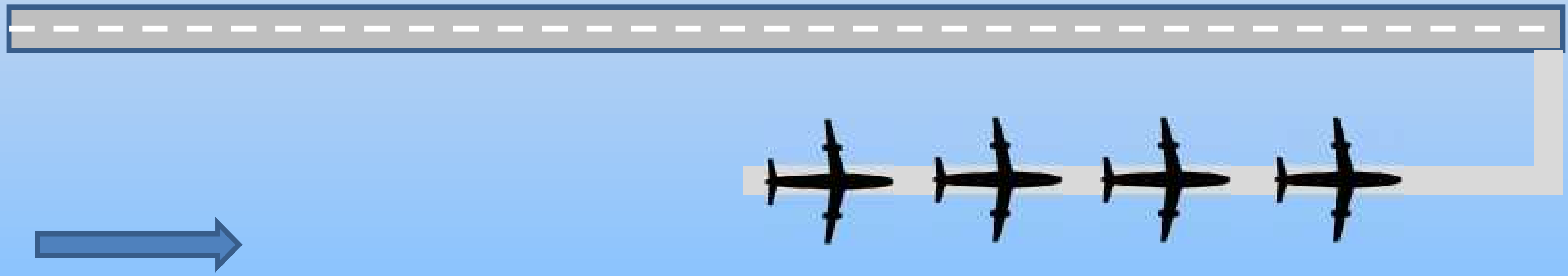
Active Frost After Sunrise

Sun is visible and shining on wing (note winglet shadows) as wing begins to develop haze at 08:47 am (left picture)
Crystaline frost observed by 08:55 a.m.
RH Picture taken 9:01 a.m.

Frost formation during daylight

- Sunrise was at 8:31
- Aircraft was a turn (short range, minor cold soak)
- OAT-9, Dewpoint -10, Frost Point -8.93
- Sun angle very low - insufficient to overcome radiant cooling
- High overcast reduced strength of sun but directly overhead the aircraft was clear enough for strong radiation cooling

Active Frost conditions can persist after treatment



Wind ≈Taxi Speed

Taxi speed in light tailwind zeros out airflow
Insufficient convective heating to overcome radiation cooling

Calm Wind

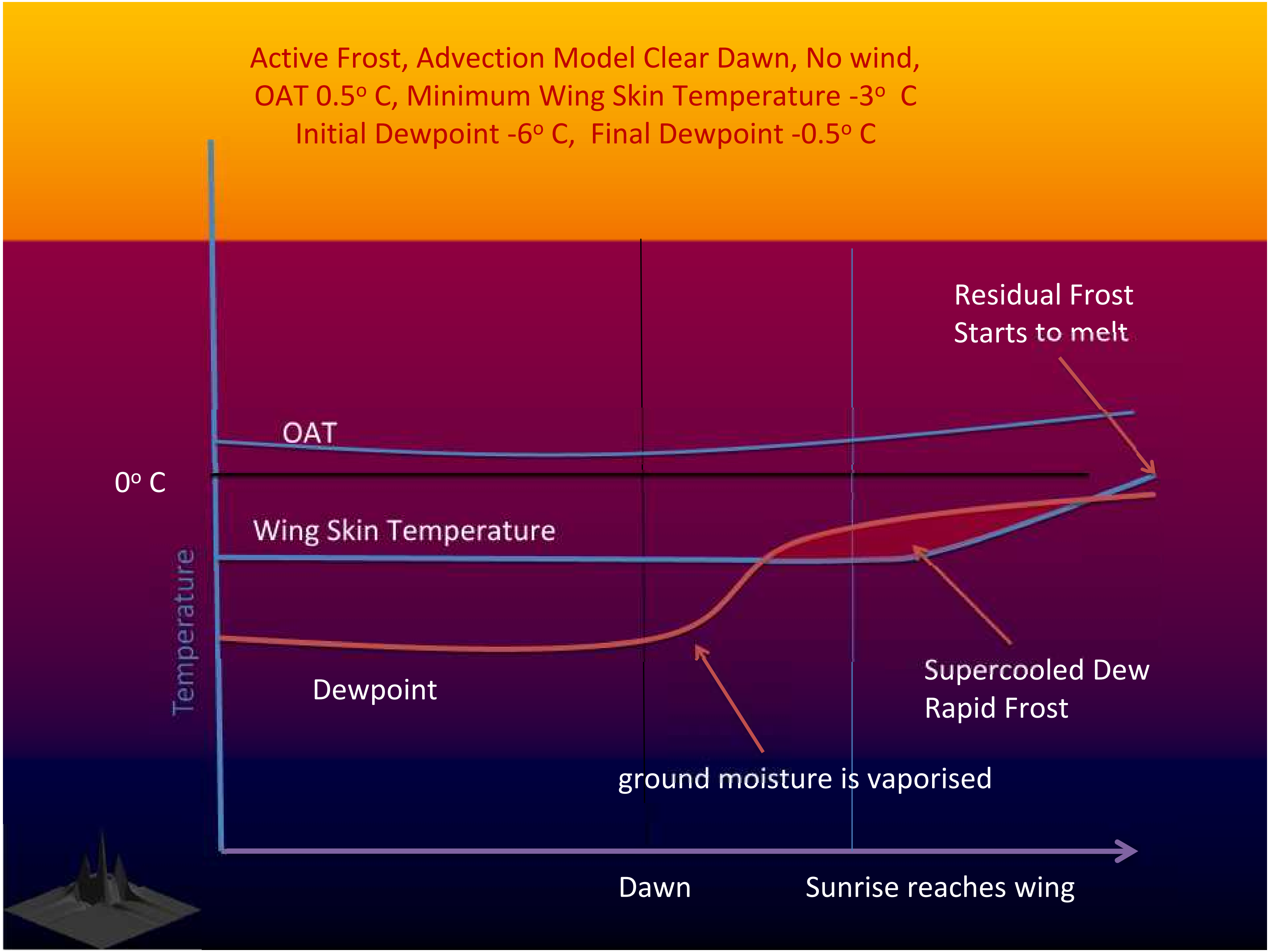
Holding in position with little airflow
Insufficient convective heating to overcome radiation cooling

Supercooled Dew
Rapid Frost formation

Similar to Active Frost, but with some unique characteristics

Rapid Frost

- Occurs with OAT near freezing (0 to +5C)
- Cooling mechanisms as in Active Frost, but with humidity initially too low for accretion
- Skin temperature is cooled to just below freezing
- At dawn, dewpoint rises rapidly with little change in skin temp, causing formation of ‘supercooled dew’
- First disturbance of wing (e.g. jolt from pushback) triggers state conversion from liquid to frost.
- State conversion extremely rapid (under 2 seconds)



Active Frost, Advection Model Clear Dawn, No wind,
OAT 0.5° C, Minimum Wing Skin Temperature -3° C
Initial Dewpoint -6° C, Final Dewpoint -0.5° C
Residual Frost
Starts to melt
OAT
0° C
Wing Skin Temperature
Temperature
Dewpoint
Supercooled Dew
Rapid Frost
ground moisture is vaporised
Dawn
Sunrise reaches wing

Mitigation

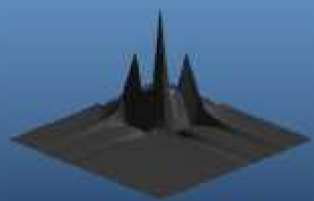
- Type I fluid is among the most common methods of removing frost. There are others.
- How long is Type I effective for?
  - Unless the minimum fluid thickness of the holdover time table is applied, active frost can re-accrete within minutes of Type I application
  - As Type I has no thickeners, even proper application will result in exposure roughly 45 minutes after application

End of Active Frost Conditions?

- Following active frost conditions, residual frost will remain as long as the skin temperature is below freezing.
- Residual frost conditions do not pose a threat of re-accretion, so holdover times do not apply. Removal is sufficient.
- If frost re-forms, it's still Active!
- Operationally, we must apply practical guidelines to identify active frost conditions

Active Frost Threat conditions

- SKC, high FEW or SCT cloud
- Nil to light winds (> 10 KTS)
- Critical surface in shade, at night or in low angle/obscured sun
- OAT - Frost point is less than
- 5C (metal, bare or smooth light paint)
- 7C (composite, metal with matte light paint)
- 10C(matte black, e.g. ‘representative strip’)
- Tighter spread = faster frost



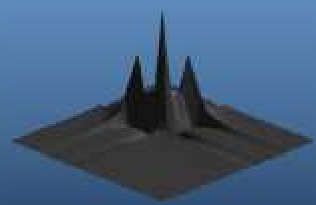
Apply Active Frost HOT

- When Active Frost conditions are anticipated prior to **takeoff** (not posted departure time)
- Expect aircraft variations due to cold soak, fuel load, surface materials, paint treatments and exposure to sun, shade or wind.
- Remember that cooling takes time. Frost may form in minutes to hours. Inspect as close to departure as practical.

Assessing the wing

- Frost often looks like dew or thin fluid film.
  - If it looks like dew and dewpoint is < 0 C, it is a threat.
- A visual inspection from inside the aircraft is inaccurate in these conditions.
- Proper application methods and adherence to HOT recommendations are best
- An external inspection cannot predict fluid performance beyond the longer of 5 minutes or the end of the HOT.
- If longer than 45 minutes from treatment to takeoff in continuous active frost conditions, consider Type 4.

Questions?




Thank You!