

LHP TECHNOLOGY FOR AIRCRAFT ANTI-ICING APPLICATIONS

Carmen Gregori
Donatas Mishkinis
Paula Prado
Alejandro Torres
Ramón Pérez
Tarik Kaya

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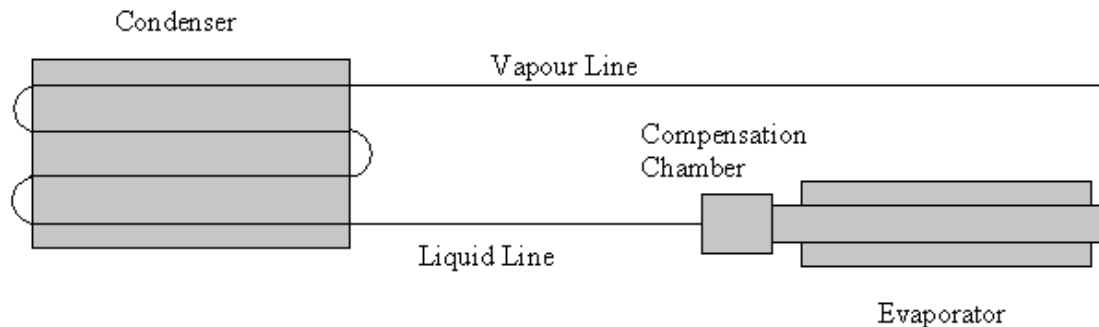
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- LHP Modeling and Results
 - High Temperature Working Fluid Trade-off
- Conclusions

INTRODUCTION

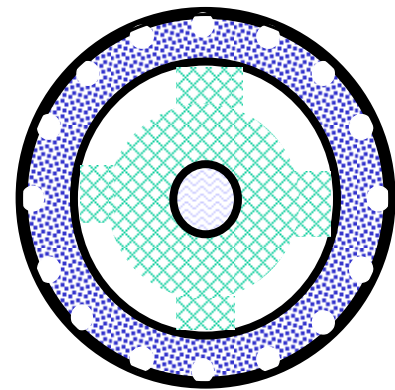
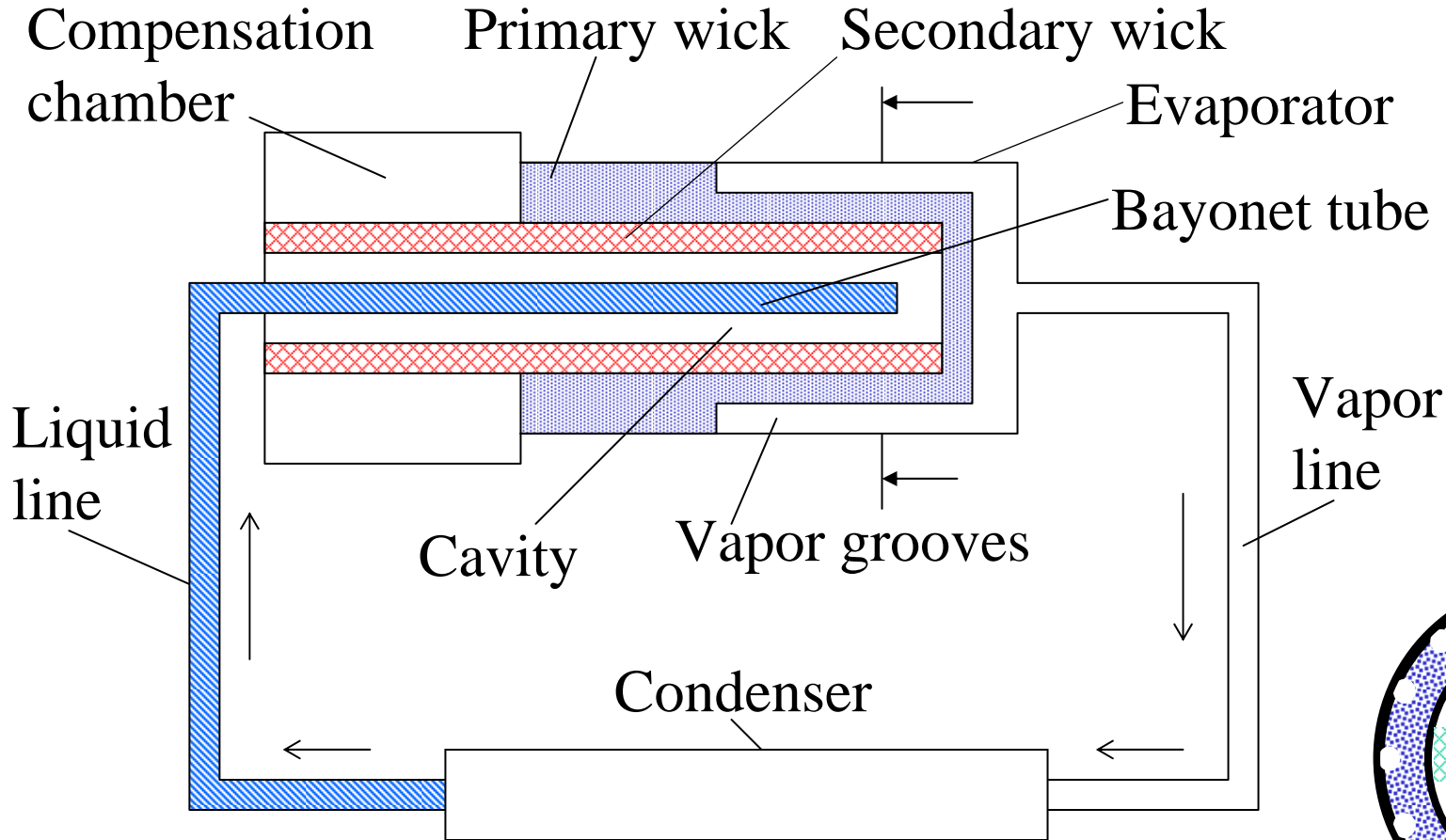
INTRODUCTION (1)

LOOP HEAT PIPES (LHP)

- Two phase capillary pumped heat transfer devices for rejecting excess heat
- Characteristics
 - High power transport capability
 - Design flexibility
 - Operation against gravity
 - Robustness
 - High temperature stability
 - Reliability



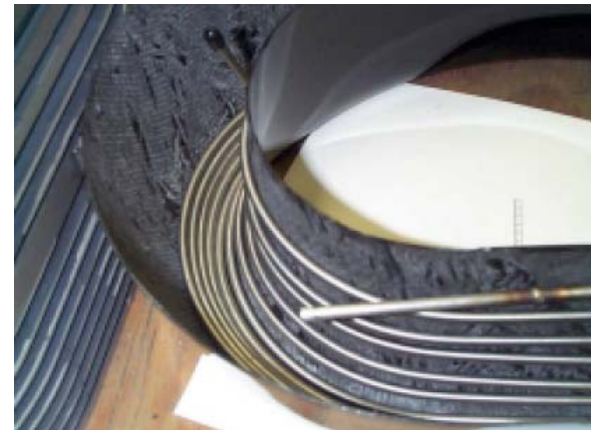
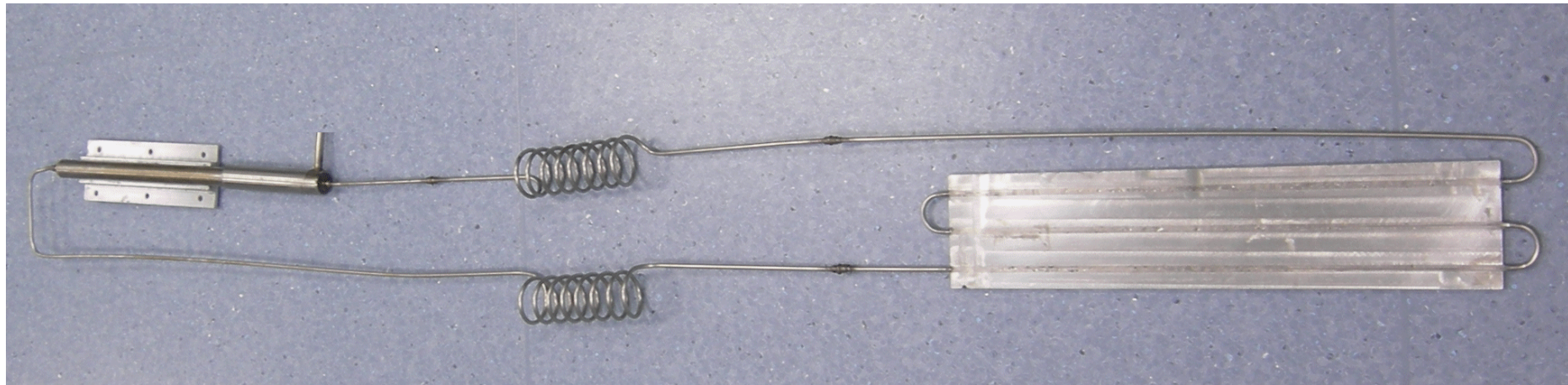
INTRODUCTION (2)



(not drawn to scale)

INTRODUCTION (3)

LHP PROTOTYPE

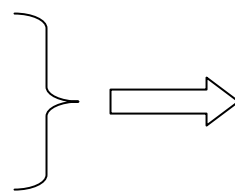


INTRODUCTION (4)

ANTI-ICING APPLICATIONS

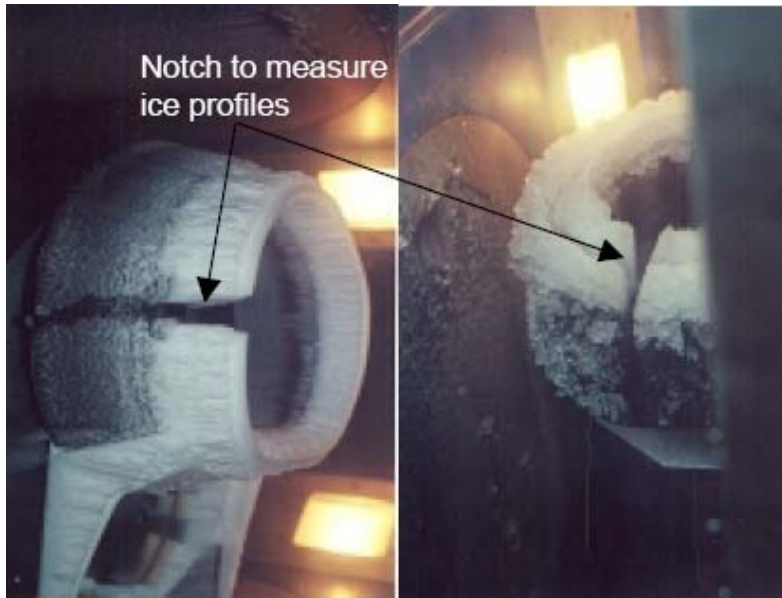
- Anderson and Chow (1995) \Rightarrow Conceptual design. Heat extracted from the air-oil cooler and transported to the engine inlet
- Philips and Wert (2000) \Rightarrow Passive aircraft anti-icing system. 5 LHPs to transport ~ 4 kW from the hydraulic system to the engine inlet

- Anti-icing sources > 100 °C
- Ammonia LHP ≤ 80 °C



HIGH TEMPERATURE
WORKING FLUIDS

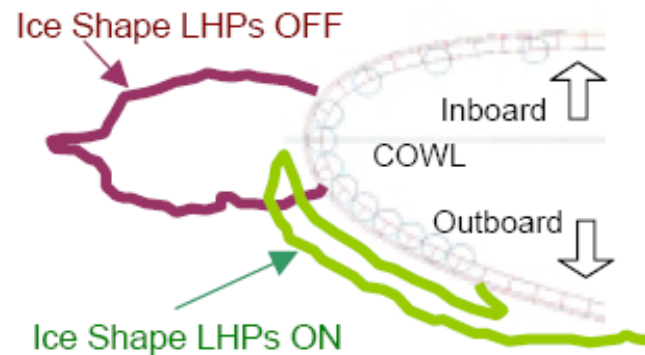
LHP BASED ANTI-ICING SYSTEM



LHP off



LHP on



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LHP ANTI-ICING

LHP ANTI-ICING (1)

ICE FORMATION AT THE ENGINE INLET

- Conventional IPS \Rightarrow Use of engine bleed to heat the engine cowl
- Advantages of an optimized LHP system:
 - Improvement of the available power from the engine
 - Slight reduction of the fuel consumption

WING ANTI-ICING SYSTEMS

- Conventional IPS \Rightarrow Rubber boots, hot air and electro-thermal systems

LHP ANTI-ICING (2)

PNEUMATIC BOOT

- Main drawbacks: Complex and heavy systems, continuous maintenance, air pumps failure
- Advantages of an LHP system: Maintenance not required and mass saving

HOT AIR

- Main drawbacks: Large performance penalty
- Advantages of an LHP system: Power and mass saving

ELECTRO-THERMAL SYSTEMS

- Main drawbacks: Reliability
- Advantages of an LHP system: Power and mass savings, and passive operation

LHP ANTI-ICING (3)

AIRCRAFT LHP INTEGRATION

- Evaporator and condenser tubes embedded into aluminum saddles (to improve the contact with the hot and cold sources)

LHP SWITCH-OFF

- Disconnecting hot and cold sides. Several options:
 - Pressure regulator valve
 - Heater
 - Coupling of the transport lines

LHP ANTI-ICING (4)

LHP WORKING FLUID

- Available anti-icing heat sources:

Air/Oil Cooler	130 °C
LP Bleed Air	100 °C
HP Bleed Air	260 °C
LP Turbine Case	430 °C
Exhaust Nozzle	415 °C

Ref: "LHPs for Anti-Icing of Gas Turbine Inlets" Anderson and Chow

ALTERNATIVE WORKING FLUIDS (1)

WORKING FLUID PROPERTIES

- Freezing/Boiling/Critical points in accordance with the operating temperature range
- Advantageous transport properties:
 - High liquid and vapor densities
 - High latent heat of vaporization } ⇒ ↑ HEAT TRANSPORT
- High surface tension ⇒ ↑ HEAT TRANSPORT, dPcap
- Low liquid and vapor viscosities ⇒ ↓ RESISTANCE
- Good wettability (small contact angle)

ALTERNATIVE WORKING FLUIDS (2)

- Compatibility with common engineering materials
- Chemical stability
- Environmental consistency (Non CFC)
- Availability
- Inexpensive in high purity state

ALTERNATIVE WORKING FLUIDS (3)

SELECTION CRITERIA

- Melting and critical temperatures
- Figures of merit
- Variation of pressure with temperature: dP/dT
- Saturated vapor pressure values
- Safety and environmental issues
- Chemical stability
- Compatibility

ALTERNATIVE WORKING FLUIDS (4)

CANDIDATE WORKING FLUIDS (over 100 °C)

- Water
- Alcohols: methanol, ethanol, isopropanol, 1-butanol
- Alkanes: n-heptane
- Ketones: Acetone
- Chlorofluorocarbons (freons): freon 11, freon 113
- Aromatics: benzene, toluene, naphthalene, Dowtherm A, Dowtherm E
- Organochlorides: Perchloroethylene

ALTERNATIVE WORKING FLUIDS (5)

PRELIMINARY HIGH TEMP. FLUID SELECTION

WATER

- Highest figures of merit
- Non-toxic, not flammable, easy to handle, not expensive and chemically stable
- Drawback: Freezing point at 0 °C

ALCOHOLS (METHANOL AND ETHANOL)

- In terms of physical properties, water is followed by alcohols
- High figures of merit and good vapor pressure values

ALTERNATIVE WORKING FLUIDS (6)

ACETONE

- Suitable fluid
- Drawback: Its figure of merit of liquid decrease significantly over 80 °C

ALKANES AND AROMATICS

- Suitable fluids but physical properties worse than the alcohols
- Freezing points (in the cases of benzene and naphthalene, the freezing point is higher than that of the water.)

ALTERNATIVE WORKING FLUIDS (7)

FREONS

- Drawback: Safety and environmental issues

PERCHLOROETHYLENE

- Suitable fluid with physical properties close to those of Toluene

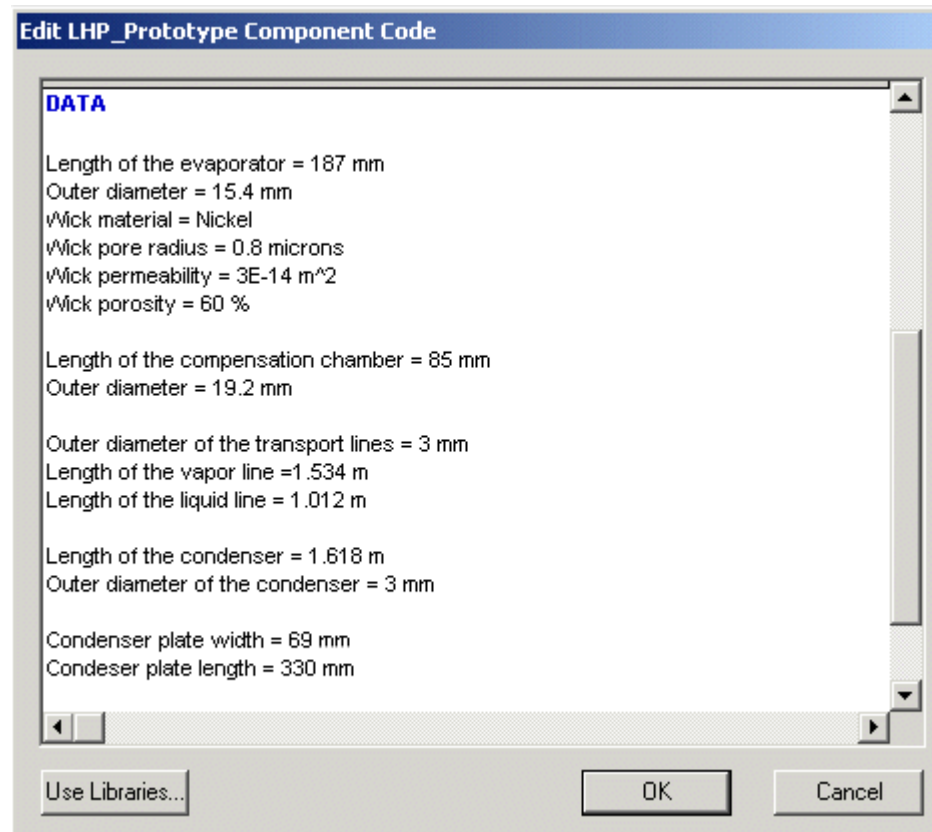
TRADE-OFF CONCLUSION

METHANOL,
ACETONE, TOLUENE AND
WATER (As a reference fluid)

LHP MODELING AND RESULTS

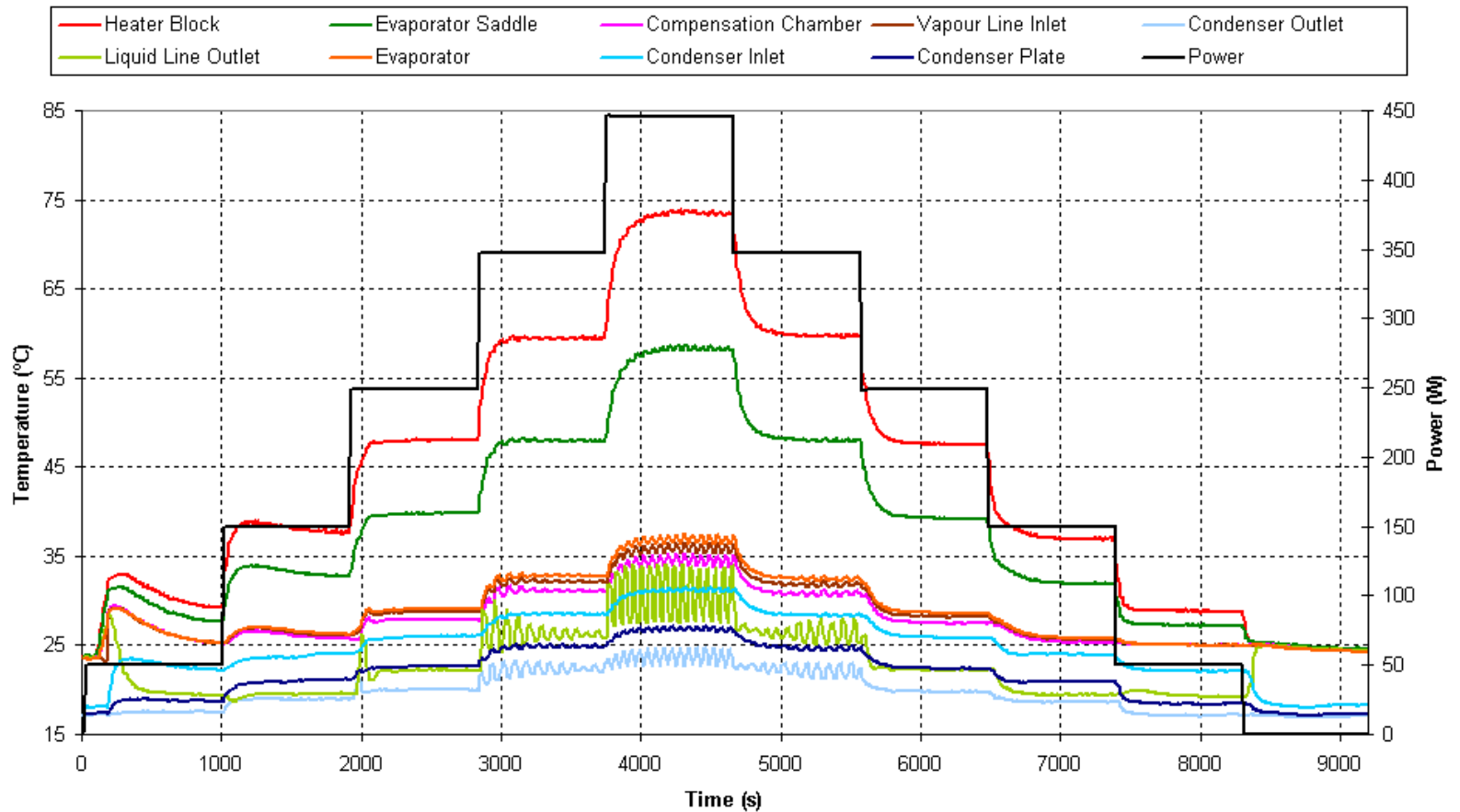
LHP MODELING AND RESULTS (3)

LHP PROTOTYPE - CHARACTERISTICS



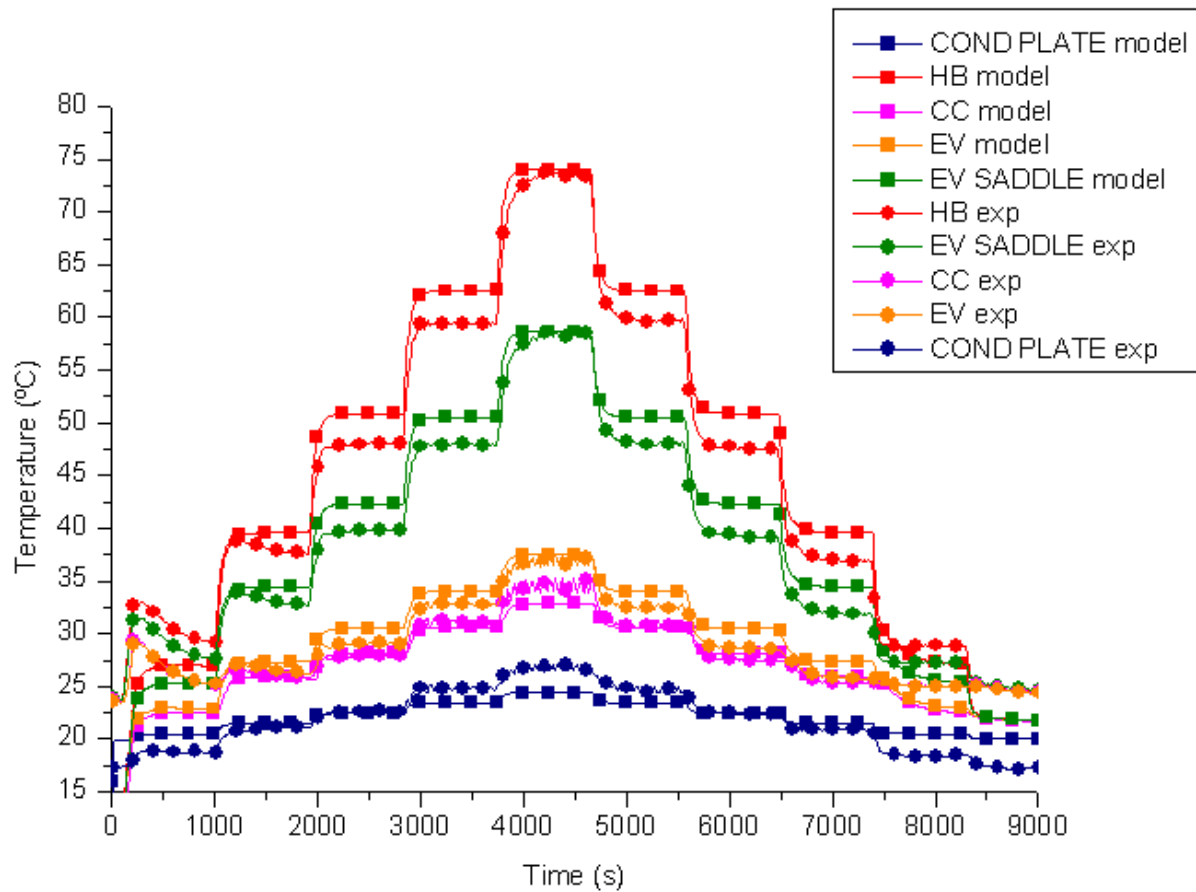
LHP MODELING AND RESULTS (4)

LHP PROTOTYPE – EXPERIMENTAL RESULTS



LHP MODELING AND RESULTS (5)

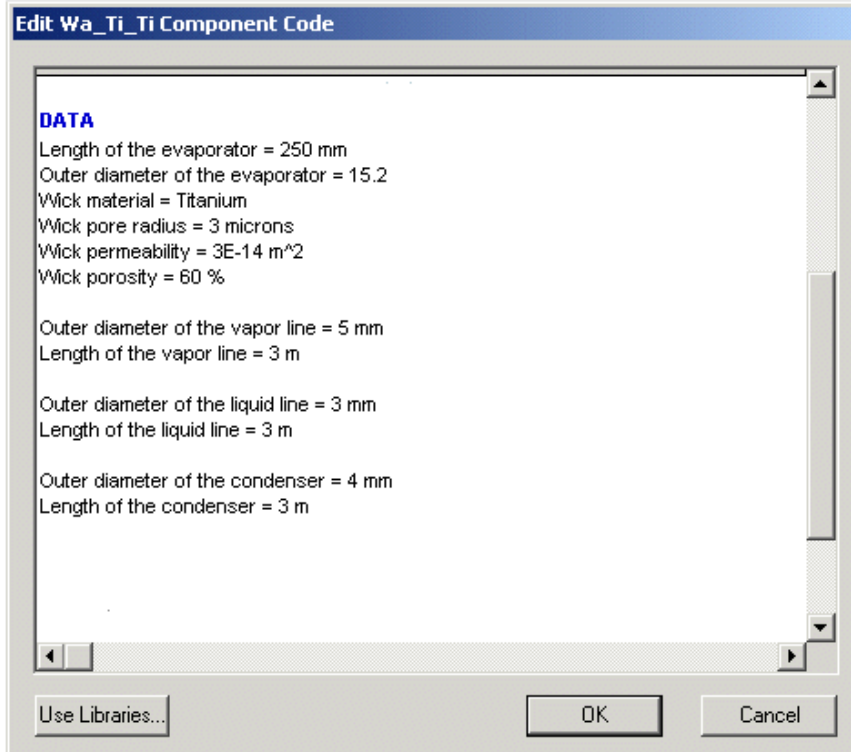
LHP PROTOTYPE – COMPARISON



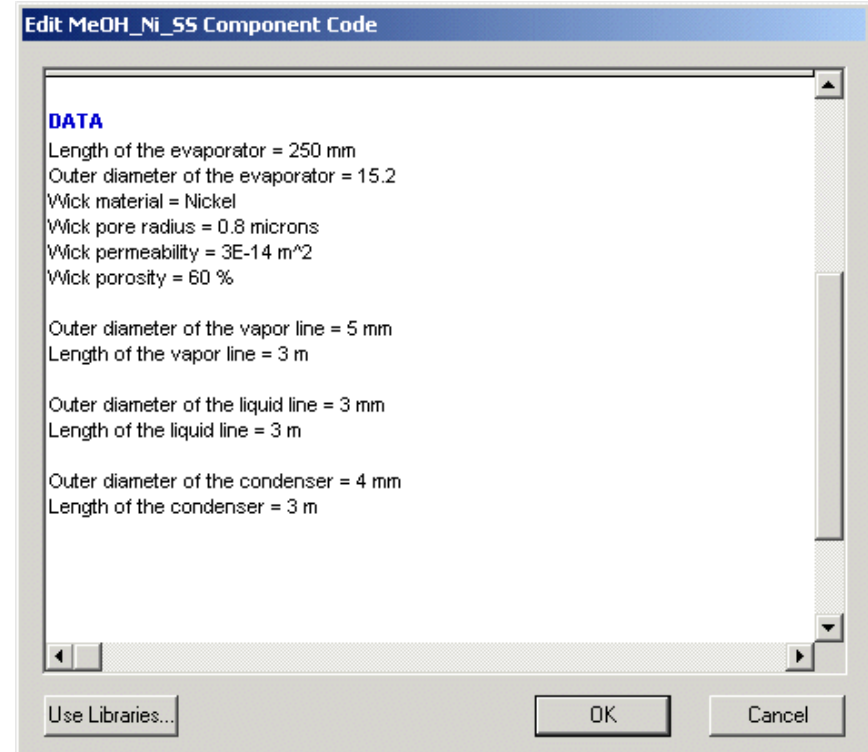
LHP MODELING AND RESULTS (6)

HTWF (High Temperature Working Fluid) –

LHP CHARACTERISTICS



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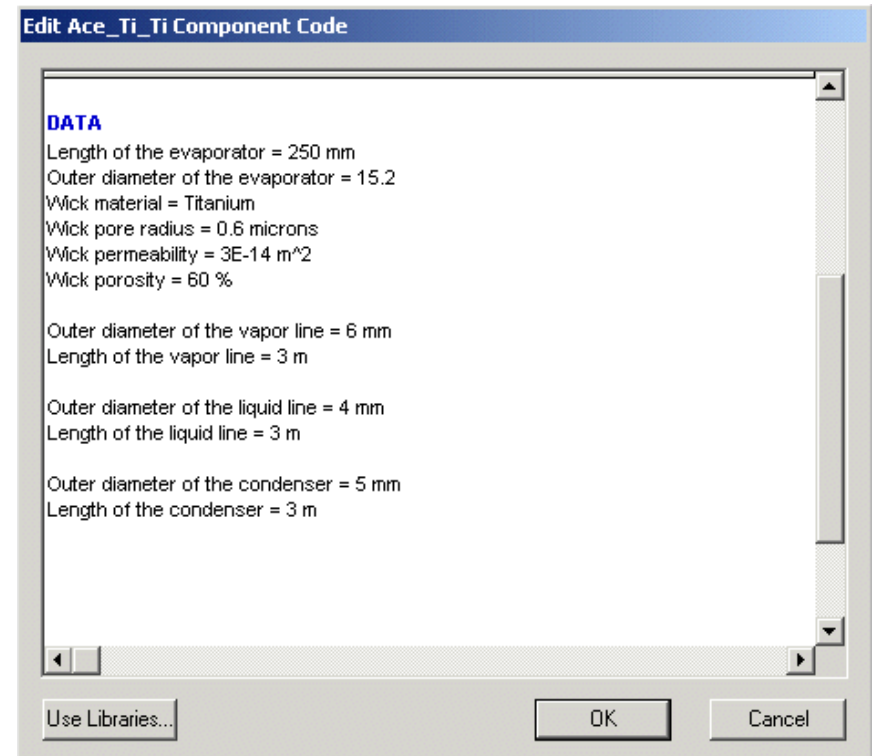
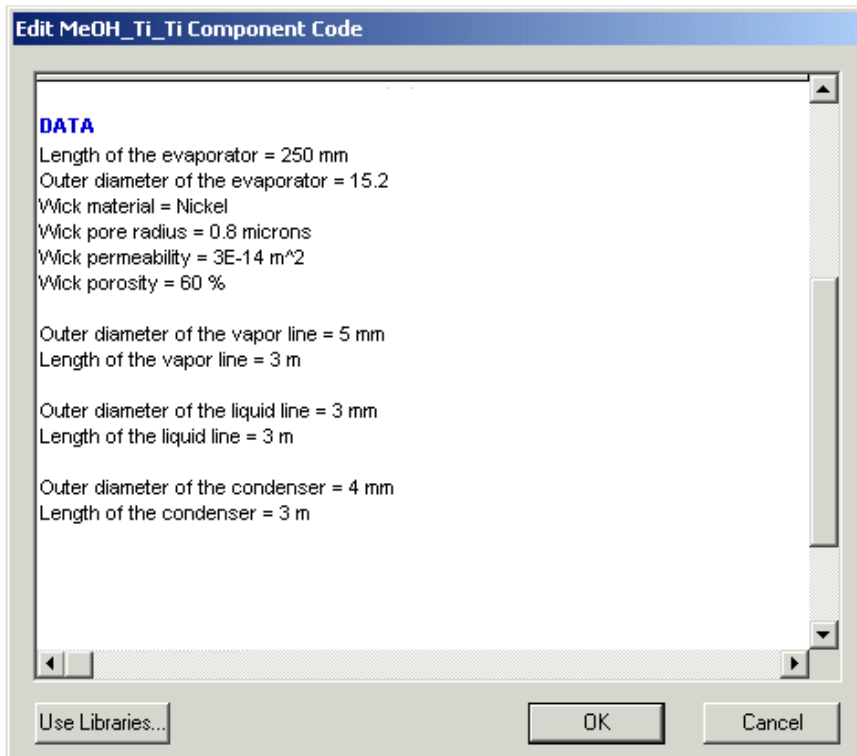


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LHP MODELING AND RESULTS (7)

HTWF (High Temperature Working Fluid) –

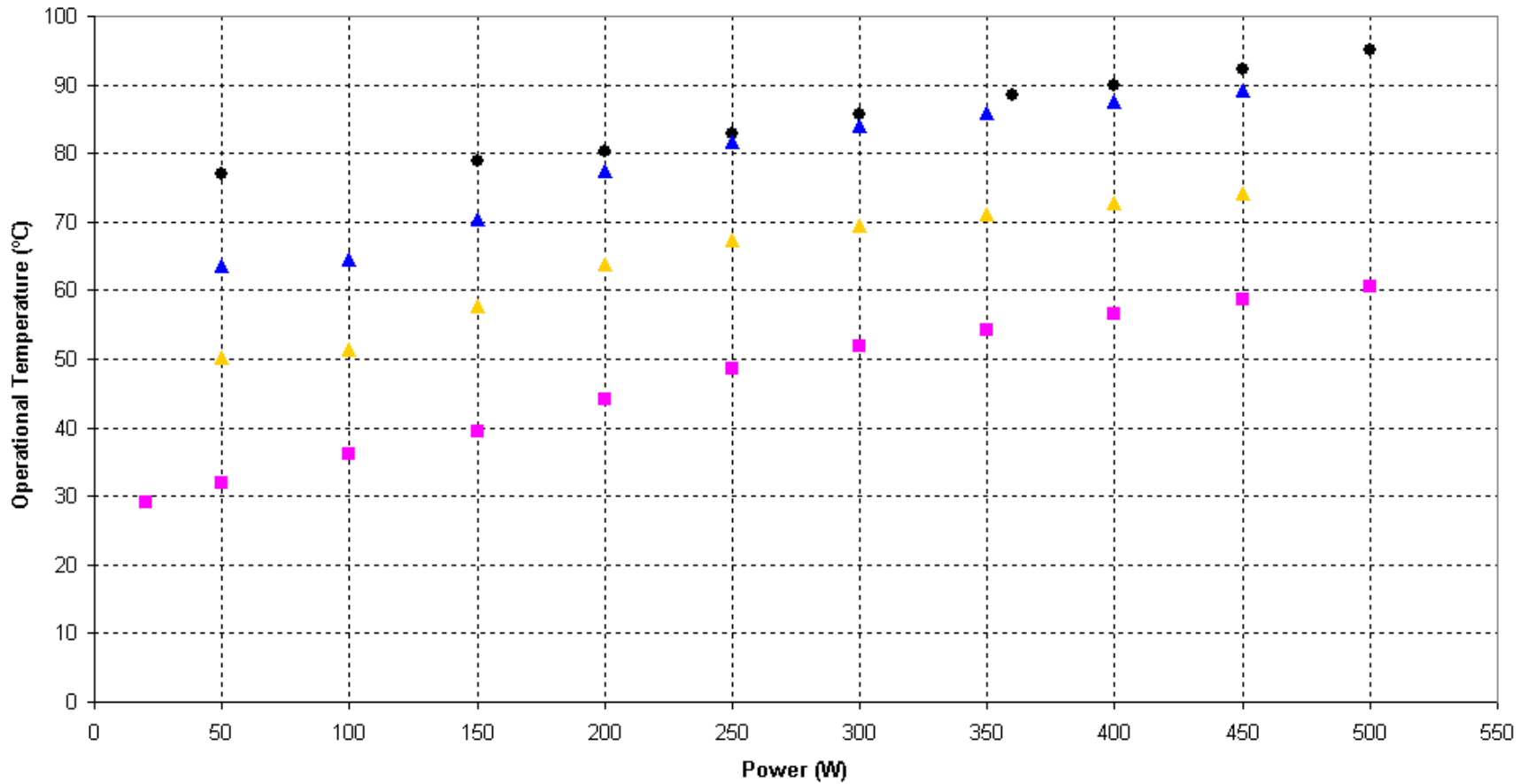
LHP CHARACTERISTICS



LHP MODELING AND RESULTS (8)

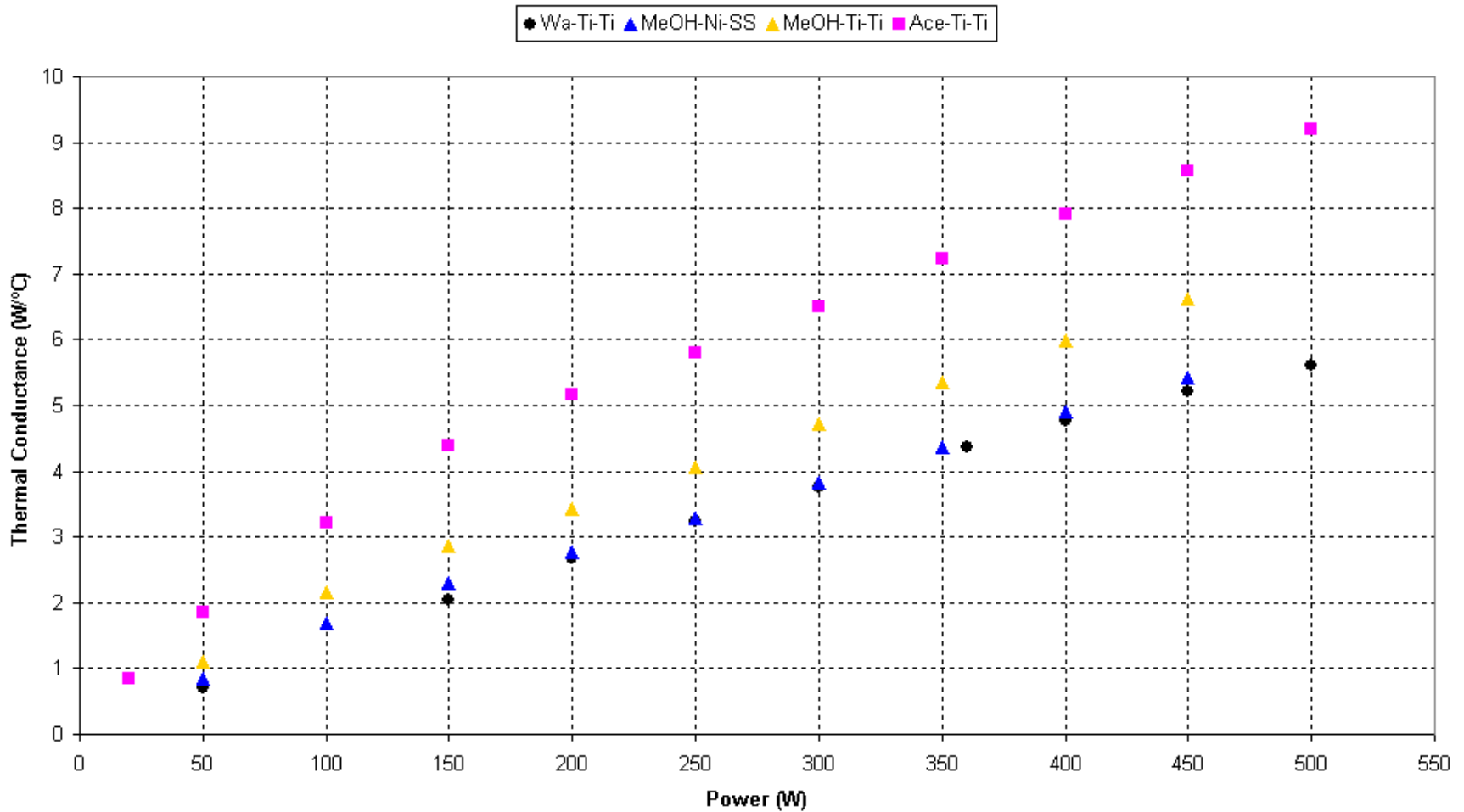
Trad = 5 °C - PERFORMANCE COMPARISON

● Wa-Ti-Ti ▲ MeOH-Ni-SS ▲ MeOH-Ti-Ti ■ Ace-Ti-Ti



LHP MODELING AND RESULTS (9)

Trad = 5 °C - THERMAL CONDUCTANCE COMPARISON



LHP MODELING AND RESULTS (10)

HTWF – RESULTS

- The best LHP performances are obtained for the acetone:
 - Higher thermal conductances
 - Lower operational temperatures
- For temperatures higher than 80 °C, methanol would present better performance.
- The worst LHP performance is obtained for the water for the temperature range studied.

CONCLUSIONS

CONCLUSIONS

- LHP technology has been identified as a solution for aircraft anti-icing problems.
- Because of the high temperatures involved in the application, alternative high temperature working fluids are needed. For this purpose, a trade off has been performed.
- Based on the numerical simulation results, acetone and methanol seem to be suitable fluids for anti-icing applications.