International Civil Aviation Organization

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Agenda Item 14: Innovation and New Technologies

TRIALS OF USING TWO-PHASE IMMERSION COOLING TO ENHANCE AIR NAVIGATION SERVICES SYSTEMS PERFORMANCE AND ENERGY EFFICIENCY

(Presented by Hong Kong China)

SUMMARY

This paper outlines the pioneer application of Two-phase Immersion Cooling System (ICS) for Air Navigation Services (ANS) systems. Hong Kong China has successfully completed trials of ICS in 2024 for a High-Performance Control Tower Simulator (CTS) image generator workstation. This innovation technology offers superb heat transfer rate compared to traditional forced-air cooling approach, with significant energy saving in system cooling, stable system operation and extended equipment operational life. This solution aligns with the ICAO's sustainability and operational resilience goals. The paper proposes broader adoption of the ICS technology in global aviation infrastructure. This paper aims to share experience of Hong Kong China in conducting trials and applying this technology to enhance ANS systems performance and energy efficiency, and encourages States/Administrations to consider its applications and share relevant experience.

1. INTRODUCTION

1.1 With the ever-increasing air traffic growth, increasing application of digital transformation and modernization of the ANS systems is necessary to sustain this continuous growth. These ANS systems are built on high performance computers, which dissipates substantial heat and in turn requires substantial and elaborate cooling system to remove. Forced air-cooling is still the mainstream system cooling approach. This conventional approach has relatively less effective heat transfer rate and requires a large-scale air-conditioning system, which consumes a significant electricity to operate and in turn generates heat on top of the heat generated by the computer systems that the cooling system is designed to remove. Large-scale chiller plants and ducting take up substantial space, including valuable equipment room space while also necessitating complex raised-floor systems and vent hole designs to support heat dissipation. Furthermore, dust accumulation and thermal throttling, a phenomenon where hardware performance degrades due to overheating, can impact operational stability and equipment life.

1.2 The ICAO's long-term Strategic Plan 2026 – 2050 includes the goal of achieving net-zero carbon emissions by 2050 for international civil aviation operations. The ICAO has encouraged States/Administrations to explore feasibility of making use of innovation and emerging technology for sustainable development and reduced environmental impact on the aviation sector.

1.3 The Civil Aviation Department (CAD) of Hong Kong China pioneered the development of a dedicated Two-phase Immersion Cooling technology to explore the benefits of the technology. In 2024, CAD successfully implemented a Two-phase Immersion Cooling System (ICS) in the CAD's high-performance CTS Image Generator. This technology immerses the complete system such as motherboard and high-performance graphic card, with the exception of the power supply and computer case, in a non-conductive dielectric coolant formulated with a low boiling point. By leveraging phase-change principle, i.e. latent heat of vaporization, the ICS dissipates heat much more effectively than air-cooling systems while eliminating dependency on traditional air conditioning and its associated high-energy consumption. The ICS' success has been demonstrated through extensive trials and recognized internationally, underscoring its potential to redefine thermal management plan for ANS equipment.

2. DISCUSSION

2.1 The ICS features a sealed container filled with a non-conductive, non-flammable and non-toxic dielectric coolant, which is specially formulated with a low boiling point (50°C). With the CTS Image Generator immersed in this liquid bath, the coolant, on contact with the heat-generating computer component, vaporises and thereby removes heat from the image generator in the process. The heated coolant vapour rises to the metal plate at the top of the container which is cooled through an external water-cooling system. The coolant vapour then returns to liquid state as it dissipates its heat to the metal plate, thus completing one two-phase (liquid-gas-liquid) change cycle. This Two-phase Immersion Cooling application provides direct and highly efficient heat transfer in a sealed enclosure. With on-the-spot and direct cooling, Two-phase Immersion Cooling can reduce or even replace traditional forced air conditioning and significant energy savings can be achieved. Further, as the equipment operates in a sealed, dust free and noise free environment at a low and evenly distributed temperature, its operation is stable, operating life is extended and therefore less electronic waste.

Fig. 1: The CAD's 360-Degree Control Tower Simulator

Fig. 2: Two-phase ICS for high-performance CTS's IG workstation

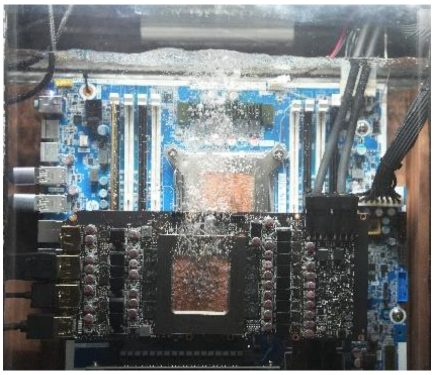

Fig. 3: Efficient heat transfer at CPU and GPU of the workstation through vaporisation of dielectronic coolant in ICS

2.2 From an environmental perspective, the ICS directly addresses the aviation sector's growing imperative to reduce carbon emissions and natural resource consumption. The dielectric coolant used in the system is engineered with a low Global Warming Potential (GWP), zero Ozone Depletion Potential (ODP) and recyclable, significantly mitigating its environmental footprint compared to other conventional cooling technology. The closed-loop design of the ICS ensures negligible coolant loss and enables full recyclability of the dielectric fluid, further enhancing its sustainability profile.

Performance and Operational Outcomes

2.3 By eliminating dependency on energy-intensive air conditioning, the ICS reduces the operational carbon footprint of high-performance ANS systems/equipment. For instance, in the CAD's CTS, the system achieved a significant total energy consumption reduction at 24.4% on the ICS applied equipment compared to the conventional air-cooled unit in and hence lower electricity cost. It achieves an excellent Power Usage Effectiveness (PUE) at 1.03 - far surpassing the efficiency of traditional cooling infrastructure. The sealed and enclosed design eliminates dust ingress, reducing maintenance costs and downtime, while the absence of cooling fans also creates a noise-free operational environment.

2.4 A trial conducted under normal and extreme ambient temperatures (26°C to 43°C) demonstrated the ICS' superior thermal stability and energy efficiency. Under full system load operation scenario, the system maintained a stable computational performance (i.e. CPU clock speed), while the air-cooled identical control unit went into automatic thermal throttling as the ambient temperature increased from 30°C to 43°C. ICS offers excellent heat transfer capability, the CPU/GPU of the equipment inside the ICS maintained their across-the-board temperature close the dielectric boiling point with no hotspots compared to the conventional air-cooling case. Such an advantage slows hardware degradation and extends operational lifespan, ensuring consistent performance and provides more headroom to throttle up computer processing if needed.

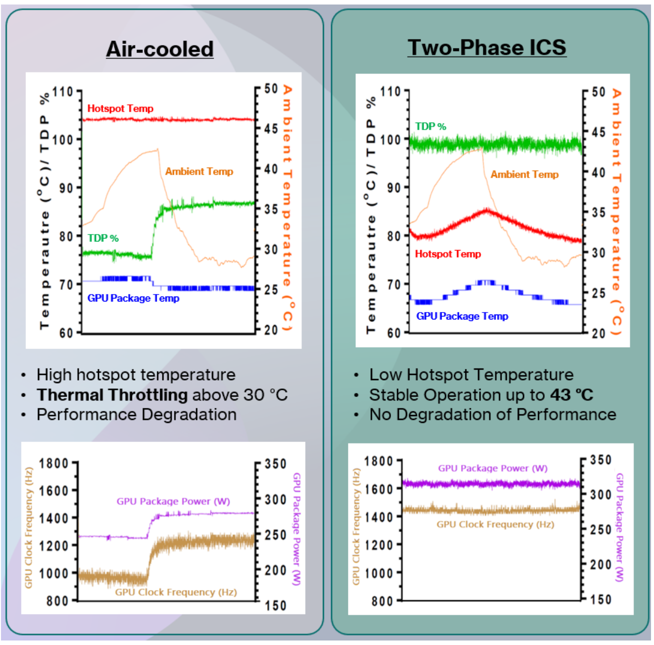

Fig. 4 Performance comparison between the equipment performance under Two-phase ICS and conventional air-cooling

Global Recognition and Future Applications

2.5 From a strategic perspective, the ICS has good scalability and adaptability. Its successful trial use on the CAD's CTS has provided a replicable framework for other systems facing high ambient temperatures in their operation or for organisations with ambitious energy reduction goals to meet. Experience gained from developing this new technology could be a valuable reference for broader applications and promotions across various fields. CAD will continue to conduct further studies on further scaling up or expanding utilization of this technology on other ANS systems.

2.6 The ICS' technical excellence was internationally recognized at the recent 50th International Exhibition of Inventions of Geneva, which was held between 9 and 13 April 2025 in Geneva, Switzerland, where it received the prestigious Prize of the Republic and Canton of Geneva and a Gold Medal. This is a special award presented by the Government of the Canton of Geneva, which represents the governmental level of honour and recognition, marking the first time for departments of the Hong Kong Special Administrative Region Government to receive this prestigious award. This special honour highlights the ICS' high potential for broader adoption, in aviation applications, meteorological modelling and other applications with high data processing demand.

3. ACTION BY THE MEETING

3.1 The meeting is invited to:

a) note the initiatives taken by Hong Kong China in carrying out trials of the ICS in ANS systems to enhance ANS systems performance and energy efficiency;

b) note the international recognitions on the technical excellence of the ICS, highlighting the ICS' high potential for broader adoption, in aviation applications, meteorological modelling and other applications with high data processing demand;

c) encourage CAAs/ANSPs, who have undertaken similar feasibility studies and trials, to share their experience and lessons learnt; and

d) discuss any relevant matters as appropriate.

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