Aircraft Thermal Management
Systems Architectures

Mark F. Ahlers

Aircraft Thermal Management (ATM) is increasingly important to the safe and efficient design and operation of commercial and military aircraft due to the steadily rising heat loads. These now come from expanded electronic functionality, more electric systems, and the greater temperature sensitivity of composite material systems relative to traditional metallic designs (for commercial aircraft). Military aircraft designers also face the added challenges of removing the waste heat from advanced weapon systems and countermeasures. More recently, commercial-off-the-shelf (COTS) electronic components, which typically have more stringent cooling requirements than their military grade counterparts, are also contributors.

Improved aircraft thermal management system architectures are being developed to meet these growing aircraft cooling needs, while minimizing the engine fuel consumption associated with removing waste heat from an aircraft. Fuel consumption occurs due to electrical power, weight, ram air drag, and/or external aerodynamic drag caused by cooling system installations designed to transfer waste heat to the outside ambient environment.

For years, military aircraft design, especially stealth fighters, has been the primary driver for the search for more efficient ATM architectures due to their higher heat generation rates in absolute terms, and relative to available heat sinks. Ram air cooling systems which provide an efficient means for removing large amounts of waste heat on a commercial aircraft reduce the stealth of military aircraft due to the heat signature, driving the search for alternative cooling techniques.

The papers contained in this book describe aircraft thermal management system architectures designed to minimize airplane performance impacts, which could be applied to commercial or military aircraft.

Additional information on Aircraft Thermal Management System Architectures is available from SAE AIR 5744 issued by the AC-9 Aircraft Environmental System Committee and the SAE book Aircraft Thermal Management: Integrated Energy System Analysis (IESA) (PT-178).

Mark F. Ahlers
Mark F. Ahlers is a Technical Fellow in thermal and fluid flow network analytical tool and process development at the Boeing Company. He has spent more than 25 years developing the analytical tools and process, which form the basis for Aircraft Thermal Management (ATM) technologies. In addition to supporting thermal design efforts for the International Space Station, launch vehicle proposals, and commercial and research satellite programs. As BCA’s first Thermal Marshal, Mark was responsible for the technical oversight of thermal analysis activities on the 787 program.
# Table of Contents

Introduction ................................................................................................................. 1

   Dooley, M., Lui, N., Newman, R., and Lui, C.

2. Integrated Aircraft Thermal Management & Power Generation:  
   Reconfiguration of a Closed Loop Air Cycle System as a Brayton  
   Cycle Gas Generator to Support Auxiliary Electric Power Generation  
   (2014-01-2192) ......................................................................................................... 9  
   Abolmoali, P., Parrilla, J., and Hamed, A.

3. Aircraft Integration Challenges and Opportunities for Distributed  
   Intelligent Control, Power, Thermal Management, Diagnostic and  
   Prognostic Systems  
   (2014-01-2161) ....................................................................................................... 13  
   Behbahani, A., Von Moll, A., Zeller, R., and Ordo, J.

   Commercial Aircraft (2013-01-2274)................................................................. 23  
   Vredenborg, E., and Thielecke, F.

   Ganev, E., and Koerner, M.

6. A Highly Stable Two-Phase Thermal Management System for Aircraft  
   (2012-01-2186) ....................................................................................................... 51  
   Chen, W., Fogg, D., Izenson, M., and Kurwitz, C.

7. Thermal Management and Power Generation for Directed Energy  
   Weapons (2010-01-1781) ...................................................................................... 61  
   Patel, V. P., Koerner, M., Loeffelholz, D.

8. Comparative Analysis of Thermal Management Architectures to Address  
   Evolving Thermal Requirements of Aircraft Systems (2008-01-2905) ............ 69  

   Simulation of High Acceleration Environments Using the Centrifuge Table  
   Test Bed (2006-01-3066) ...................................................................................... 77  
Homitz, J., Scaringe, R., and Cole, G.

About the Editor ........................................................................................................ 99
Aircraft Thermal Management
Integrated Energy Systems Analysis

Mark F. Ahlers

Aircraft Thermal Management: Integrated Energy System Analysis (IESA)

The simultaneous operation of all systems generating, moving, or removing heat on an aircraft is simulated using integrated analysis, which is called Integrated Energy System Analysis (IESA) for this book. The purpose of this analytical modeling is to understand, optimize, and validate more efficient system architectures for removing or harvesting the increasing amounts of waste heat generated in commercial and military aircraft.

In the commercial aircraft industry, IESA is driven by the desire to minimize airplane operating costs associated with increased system weight, power consumption, drag, and lost revenue as cargo space is devoted to expanded cooling systems.

In military aircraft thermal IESA is also considered to be a key enabler for the successful implementation of the next-generation jet fighter weapons systems and countermeasures.

This book contains a selection of papers relevant to aircraft thermal management IESA published by SAE International. The papers cover both recently developed government and industry-funded thermal management IESA, such as the Integrated Vehicle Energy Technology (INVENT) program, and older published papers still relevant today which address modeling approaches. While the modeling discussed primarily refers to military aircraft, the same tools and methods may be adapted for commercial aircraft simulations following minor modifications.

Additional information on the closely related topic of Aircraft Thermal Management is available from SAE AIR 5744 issued by the AC-9 Aircraft Environmental System Committee and the book Aircraft Thermal Management: System Architectures (PT-177).

Aircraft Thermal Management: Integrated Energy System Analysis is an excellent source of technical information on a subject that is becoming increasingly important in addressing aircraft overall performance.

Mark F. Ahlers

Mark F. Ahlers is a Technical Fellow in thermal and fluid flow network analytical tool and process development at the Boeing Company. He has spent more than 25 years developing the analytical tools and process, which form the basis for Aircraft Thermal Management on Boeing commercial airplane programs. In addition to supporting thermal design efforts for the International Space Station, launch vehicle proposals, and commercial and research satellite programs. As BCA’s first Thermal Marshal, Mark was responsible for the technical oversight of thermal analysis activities on the 787 program.
Table of Contents

Introduction ................................................................................................................. 1

1. An Exergy-Based Methodology for Decision-Based Design of Integrated Aircraft Thermal Systems (2000-01-5527) .......................................................... 3
   Figliola, R., and Tipton, R.


   Maser, A., Garcia, E., and Mavris, D.

   Bodie, M.

5. Integrated Electrical and Thermal Management Sub-system Optimization (2010-01-1812) .............................................................................. 45
   Bodden, D., Eller, B., and Clements, S.

   Vredenborg, E., and Thielecke, F.

   Del Valle, P., and Blazquez Munoz, P.

8. A Thermal Management Assessment Tool for Advanced Hypersonic Aircraft (921941) ................................................................................................... 71

   Schlabe, D., and Lienig, J.