



AEROSPACE INFORMATION REPORT

AIR5744™

Issued 2020-10
Reaffirmed 2026-01

Aircraft Thermal Management System Engineering

RATIONALE

This SAE Aerospace Information Report is intended to provide reference and background information pertaining to Aircraft Thermal Management System Engineering. This AIR will provide a standard definition for the subject area and provide critical insight to the requirements engineering activities required for execution.

This document provides guidance encouraging platform design and procurement be pursued from a system level perspective to optimize the capabilities of aircraft for mission performance and vehicle operational goals with thermal management as an objective.

AIR5744 has been reaffirmed to comply with the SAE Five-Year Review policy.

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1. SCOPE

The intent of this report is to encourage that the thermal management system architecture be designed from a global platform perspective. Separate procurements for air vehicle, propulsion system, and avionics have contributed to the development of aircraft that are sub-optimized from a thermal management viewpoint. In order to maximize the capabilities of the aircraft for mission performance and desired growth capability, overall system efficiency and effectiveness should be considered. This document provides general information about aircraft Thermal Management System Engineering (TMSE). The document also discusses approaches to processes and methodologies for validation and verification of thermal management system engineering.

Thermal integration between the air vehicle, propulsion system, and avionics can be particularly important from a thermal management standpoint. Due to these factors, this report is written to encourage the development of a more comprehensive system engineering approach to help eliminate and/or reduce mission limitations as a result of materials and components nearing temperature limits.

1.1 Purpose

The purpose of this document is to provide definition for aircraft thermal management system engineering and provide insight to generic design and verification requirements associated with this system engineering activity.

In the past, each subsystem was specified and designed with a thermal management system strictly centered on the heat loads of the specific subsystem. As a result, thermal conditioning and heat sink resources of the aircraft were often inefficiently used, resulting in a larger than necessary penalty associated with cooling on the aircraft.

2. REFERENCES

2.1 Applicable Documents

The following standards and publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Telephone: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

Iya, S., Trikha, A., and Ladd, M., "Thermal Management and Environmental Control of Hypersonic Vehicles," SAE Technical Paper 891440, 1989, <https://doi.org/10.4271/891440>.

Van Griethuysen, V.J., Glickstein, Marvin, M.R., Petley, D.H. Gladden, H.J., and Kubik, D.L., "High-Speed Flight Thermal Management." Chapter Developments in High Speed Vehicle Propulsion Systems, AIAA Progress in Astronautics and Aeronautics, Volume 165, 1996, pp 517-579.

2.2 Related Publications

The following publications form a source of reference for readers seeking greater understanding of the thermal system engineering approach being pursued in this aerospace information report. These publications give insight to the second law of thermodynamics role in the advancement of aircraft thermal management system engineering.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Telephone: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR64	Electrical and Electronic Equipment Cooling in Commercial Transports
AIR1168/3	SAE Aerospace Applied Thermodynamics Manual, Aerothermodynamic Systems Engineering and Design
AIR1168/8	Aircraft Fuel Weight Penalty Due to Air Conditioning
AIR1277	Cooling of Military Avionic Equipment
AIR1957	Heat Sinks for Airborne Vehicles

2.2.2 Other Publications

Bejan, Adrian, 1996, *Entropy Generation Minimization*, CRC Press, Boca Raton, Florida

Lazzaretto, A. and Tsatsaronis, G., 1997, "On the Quest for Objective Equations in Exergy Costing," Proceedings of the ASME Advanced Energy Systems Division, Edited by Ramalingam, M.L. Lage, Mei, V.C. and Chapman, J.N., AES-Vol.37, pp. 197-210

Gambill, J.M., D.E., Claeys, H.M. Matulich, D.S. and Weiss, C.F., 1993, "Integrated Aircraft Thermal Management and Power Generation," SAE Paper No. 932055, 23rd International Conference on Environmental Systems, Colorado Springs, CO, July 12-15

Krane, R.J., edition 1995, *Thermodynamics and the Design Analysis, and Improvement of Energy Systems* 1995, AES-Vol. 35, ASME, New York

Bejan, A., 1999, "A Role for Exergy Analysis and Optimization in Aircraft Energy-System Design," Presented at the ASME International Mechanical Engineering Congress, Nashville, Tenn., Nov. 14-19, 1999

Figliola, R.S. and Tipton, R. "An Exergy-Based Methodology for Decision-Based Design of Integrated Aircraft Thermal Systems" SAE Technical Paper 2000-01-5527, 2000, doi:10.4271/2000-01-5527

2.3 Definitions

ECS: Environmental Control System

ETOPS: Extended Operations (Federal Aviation Administration) and Extended Range Operations for Two-Engine Aeroplanes (European Aviation Safety Agency)

IFE: In-Flight Entertainment

LRU: Line Replacable Unit (known as Weapons Replacable Assembly (WRA) on Navy aircraft)

TMSE: Thermal Management System Engineering

USAF: United States Air Force

WRA: Weapons Replaceable Assembly

3. AIRCRAFT THERMAL MANAGEMENT SYSTEM ENGINEERING

An examination of thermodynamic processes are suggested for new aircraft design. This examination should cover all loads and their operational profiles, available coolant sinks, and coolant media to be used across the aircraft operational envelope. Optimize the cooling system on the aircraft will generally require detailed transient analysis to balance performance requirements and cooling capacity. This level of integrated analysis requires a system engineering approach.

3.1 Definition

Aircraft Thermal Management System Engineering is the systematic approach used to establish the thermal energy and mass interaction requirements for the most efficient and effective means for processing work and sustaining the balance between heat source and sink to insure that mission or flight profile, safety of flight, and life cycle cost requirements can be achieved for the aircraft.

3.2 Integrated Activities

Perform a thermal survey of the air vehicle to determine the basis of integration and provide a thermal assessment of a proposed thermal management solution:

- a. Establish temperature profile targets for the air vehicle and all the system drivers
- b. Perform heat load and heat sink management analysis (Q Balance)
- c. Identify duty cycles for the individual system LRU or WRA and subsystems (standby versus transmit, etc.)
- d. Perform trade study on cooling method versus impact on air vehicle and other systems (i.e., types of heat sink to use in the thermal management solution)
- e. Integrate electrical load analysis to thermal management assessment
- f. Define the manufacturing and installation impacts on air vehicle
- g. Define needs for separation and isolation of equipment for safety

Define the operational environment for integrated system and subsystem components:

- a. Define ambient temperature environment for the air vehicle
- b. Define induced environment for individual system and subsystem components
- c. Differentiate between ground, flight, and emergency operations

Fully characterize customer requirements and intended use of integrated solution:

- a. Define operation cycles and mission profiles for desired capabilities
- b. Define customer transient requirements (e.g., capabilities of pull-up and pull-down)
- c. Trade flexibility of operations versus technical performance

In general once the vehicle configuration and mission requirements are defined, the first step in thermal management system optimization consists of evaluation of the thermal environment encountered by the vehicle and all of its subsystems during the various mission phases. The next step is to define candidate thermal management concepts and conduct a detailed performance evaluation. It is recommended that the design requirements are satisfied by each candidate concept. Selection of the preferred thermal management concept should be based on a trade study that results in a concept that meets all the requirements with least air vehicle penalties and optimized for selected vehicle capabilities or parameters (payload, cost per seat mile, etc.). With the above information mission analysis can be accomplished using either steady state and/or dynamic models as appropriate. An example of this is presented in Iya, S.K. Trikha, A.K. and others, as well as in Van Griethuysen, V.J., Glickstein, Marvin, M.R., Petley, D.H. Gladden, H.J., and Kunkin, D.L.