Applied Thermal Engineering 94 (2016) 1–12

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Flight deck heat spreader

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HIGHLIGHTS

- Flight deck heat spreader developed.
- Flight deck underside temperature reduced from 395 °C to 94 °C.
- 60% of the weight of solid aluminum.
- Cools 8× faster than solid aluminum of the same size.
- Water based working fluids compatible with aluminum wick tested.

ARTICLE INFO

Article history:
Received 10 April 2015
Accepted 25 October 2015
Available online 2 November 2015

Keywords:
Flight deck heat spreader and heat shield
Aluminum sintered wick
Corrosion inhibitor

ABSTRACT

Deployment of modern aircrafts such as MV-22 Osprey or F35B Joint Strike Fighter has caused buckling of aircraft carrier ship flight decks due to excessive heat impact from aircraft engine exhaust plumes during landing. This work describes a development of Flight Deck Heat Spreader (FDHS) that is placed over a flight deck landing spot to protect it from hot exhaust plumes. The FDHS consists of aluminum panels with supporting pillars, aluminum wick sintered directly to panels and supporting pillars, water with corrosion inhibitor working fluid, and is sealed by welding together individual panels. The FDHS operates similar to a vapor chamber i.e. water vapor spreads the heat. The FDHS has 60% of the weight of solid aluminum of the same size, it is rigid with good strength and mechanical impact loading resistance, and it can be scaled to large areas of more than 50 m^2. This paper focuses on thermal modeling of the FDHS, fabrication and tests of 450 cm^2 and 3721 cm^2 FDHS prototypes, and selection of working fluid corrosion inhibitor. FDHS was demonstrated to effectively shield the flight deck during high temperature thermal exposure and that the FDHS cools 8-times faster than similar weight aluminum alloy plate.

1. Introduction

Deployment of modern aircrafts such as MV-22 Osprey or F35B Joint Strike Fighter has caused buckling of aircraft carrier ship flight decks due to excessive heat impact from aircraft engine exhaust plumes during landing. As a result, the flight deck landing area has to be replaced frequently resulting in long down times and high costs.

Flight decks are made of carbon steel which has low thermal conductivity and is poor heat spreader material. There is a need for lightweight, high thermal conductivity heat spreader and heat shield with an area of around 50 m^2 that shall be placed on the flight deck landing area to shield it from high temperature exhaust plumes.

A brief literature survey of heat spreader materials that could potentially be used for flight deck thermal management system was performed. Four different types of heat spreader materials were identified. They are cellular structures, porous metals with phase change material, heat pipes embedded into panels and flat heat pipes or vapor chambers. Cellular materials are ultralight structures with excellent mechanical properties [1–3]; however, they have poor heat spreading capability because of high porosity. Porous metals with phase change material have good performance in terms of heat storage and mechanical properties [4]; however, they are expected to be poor heat spreader material for flight deck thermal management because of low thermal conductivity of the phase change material. Heat pipes were successfully embedded into satellite load carrying structures and radiator panels and were reported to provide large savings in satellite volume and mass [5,6]. Heat pipes embedded into lightweight panes such as aluminum panels could form a good heat spreader material for a flight deck. However, it is not clear how to transfer heat between adjacent panels with heat pipes embedded into them. Also heat pipes underneath the high temperature plumes might not operate because of high heat loads that may exceed heat pipe boiling or capillary limit. An aluminum flat heat pipe or vapor chamber with nickel foam wick, water as working fluid, and an array of supporting crosses was demonstrated to provide good heat spreading and also it offers good

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http://dx.doi.org/10.1016/j.applthermaleng.2015.10.113

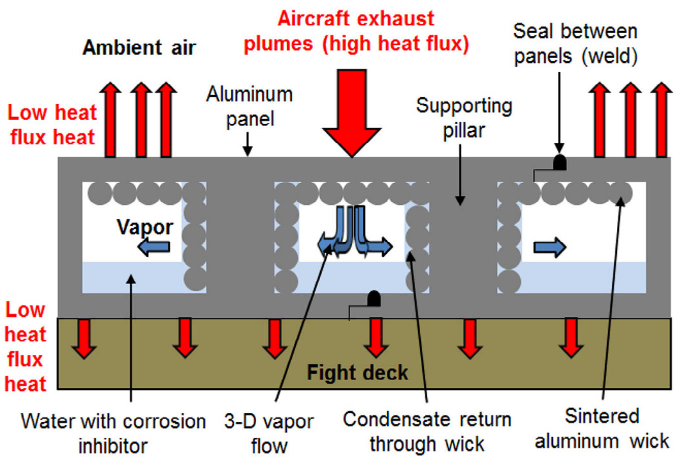

Fig. 1. Flight Deck Heat Spreader (FDHS). Aircraft exhaust plumes impinge on top panel and vaporize working fluid absorbed in sintered aluminum wick; vapor spreads the heat to panels away from the heat source, and rejects the heat to ambient and flight deck at low heat flux over a large area. Working fluid condenses and drips into a liquid pool formed on the bottom of the FDHS and the condensate is wicked back to the evaporator wick located underneath the heat source.

structural load support [7]. This could be a good technology to form flight deck heat spreader; however, durability of this heat spreader is not clear because the nickel foam wick is not bonded to the panel, but rather held by supporting crosses.

The present work describes a development of Flight Deck Heat Spreader (FDHS) that consists of aluminum panels with supporting pillars, aluminum wick sintered directly to panels and supporting pillars, water with corrosion inhibitor working fluid, and is sealed by welding individual panels together. The FDHS operates similar to a vapor chamber (i.e. water vapor spreads the heat), it is lighter than solid aluminum of the same size, it is rigid with good strength and mechanical impact loading resistance, and it can be scaled up to an area of 50 m^2. This paper focuses on thermal modeling of the FDHS, fabrication and tests of 300 mm × 150 mm and 610 mm × 610 mm FDHS samples, and selection of working fluid corrosion inhibitor.

2. Flight Deck Heat Spreader (FDHS) concept

FDHS is mounted to a flight deck landing spot using aircraft tie-downs. The FDHS is formed from multiple panels that are sealed at joints. The panels have supporting pillars and aluminum wick sintered directly to panels and supporting pillars. The heat spreader is charged with water that contains corrosion inhibitor. Corrosion inhibitor is required to suppress reaction between high surface area aluminum wick and water (more discussion in section 4). Individual panels are joined by welding to form leak tight seal that prevents air from enter the heat spreader and that contains the working fluid inside the heat spreader. After the assembly, the FDHS total thickness is 25 mm which is maximum thickness still acceptable without interfering with flight deck structures.

A concept of the FDHS is illustrated in Fig. 1. During aircraft landing, hot exhaust plumes impinge on the FDHS, the heat is conducted through the panels and supporting pillars to the liquid saturated wick and vaporizes the liquid. Vapor rapidly flows away from the heat impingement zone and spreads the heat to the entire FDHS. The vapor condenses and rejects the heat at low heat flux to the ambient air or flight deck while the condensate drips into the continuous liquid pool formed on the bottom of the FDHS. The evaporated liquid is continuously replenished through the pillar wick (the wick formed on the supporting pillars) by capillary pumping of the fluid from the continuous liquid pool.

A structural modeling of FDHS was performed. The model determined that top panel thickness 6 mm, bottom panel thickness 3 mm, pillar diameter 13 mm, pillar spacing 32 mm are required to meet the structural requirements resulting in acceptable heat spreader deformation during aircraft landing. Details of the structural model are beyond the scope of this paper.

Different candidate materials for FDHS panels and pillars were compared. It was determined that Al alloys 5-thousand series AA5454 and AA5052 have the best properties in terms of good corrosion resistance, high thermal conductivity, and high material liquidus temperature (required for sintering of the wick to achieve good wick adhesion).

FDHS offers several benefits: (1) it is modular and it can be assembled into FDHS of any size; (2) it is lightweight since it has hollow core that is used for vapor transport (16 mm out of 25 mm is hollow); (3) it has high lateral thermal conductivity (few tens of thousands of watts-per-meter-Kelvin) as a result of using vapor to transfer the heat; and (4) it is designed to sustain aircraft landing without plastic deformation of the supporting pillars or panels.

3. Thermal model

A jet impingement model of hot gas on the FDHS placed over a flight deck was developed. A flight deck without the FDHS was also modeled for comparison. Boundary conditions for the thermal model were provided by a customer. The customer performed a careful scaling analysis to determine boundary conditions of a subscale system with a 25 mm diameter nozzle. Flight deck size was determined to be 762 mm × 914 mm and nozzle to flight deck (or FDHS) distance 229 mm. Nozzle exit velocity was determined to be 792 m/s, nozzle exit temperature 967 °C, and duration of thermal exposure 5 seconds. Total number of thermal exposures was determined to be six and every thermal exposure was followed by 300 seconds of cooling in ambient air. The customer verified that the peak flight deck temperature under the subscale nozzle closely match the peak temperature under the actual aircraft exhaust nozzle. Geometry of the thermal model along with boundary conditions is shown in Fig. 2.

Three different cases were modeled. In the first case, we modeled hot gas impingement on 13 mm thick carbon steel plate (representing the flight deck), in the second case, we modeled hot gas impingement on 25 mm × 610 mm × 610 mm Al alloy 5454 (AA5454) plate placed over the flight deck and in the third case we modeled hot gas impingement on 25 mm × 610 mm × 610 mm FDHS placed over the flight deck. The model also included silicon rubber with thickness 1.6 mm and thermal conductivity 0.2 W/m·K between the

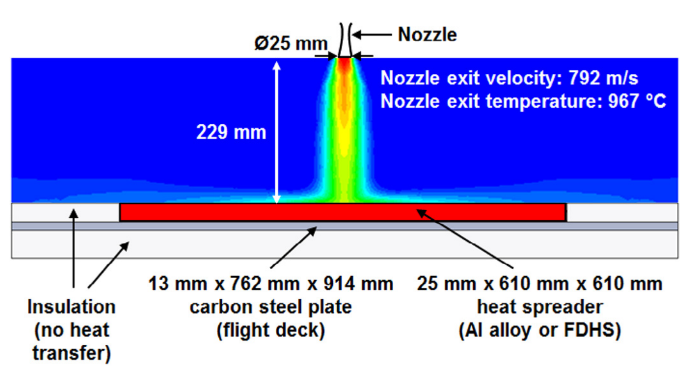

Fig. 2. Geometry and boundary conditions of subscale flight deck thermal model. Nozzle exit velocity is 792 m/s and nozzle exit temperature is 977 °C. Nozzle diameter is 25 mm and nozzle height is 229 mm. Carbon steel plate size is 13 mm × 762 mm × 914 mm and heat spreader size is 25 mm × 610 mm × 610 mm.