JOURNAL OF PROPULSION AND POWER
Vol. 25, No. 6, November–December 2009

Air–Hydrogen Heat Exchangers for Advanced Space Launchers

Patrick Hendrick,* Nicolas Heintz,† and Didier Bizzarri†
Free University of Brussels, 1050 Brussels, Belgium
Francisco Romera‡
IberEspacio, 28010 Madrid, Spain
James Murray§
Techspace Aero, 4041 Milmort, Belgium
and
Philippe Ngendakumana¶
University of Liège, 4000 Liège, Belgium

DOI: 10.2514/1.41780

This paper deals with air–hydrogen heat exchangers intended to provide in-flight oxygen collection capability to a reusable or semireusable two-stages-to-orbit launcher with an oxygen collection phase in supersonic cruise at Mach 2.5. It aims to present a theoretical but mainly technological and experimental feasibility study of heat exchangers sufficiently efficient and reliable to suit the extreme requirements of this application. Two precoolers of two different types (shell and tubes, and plate and fins) have been selected and designed with the objective of fulfilling all constraints of the concept in terms of performance, leak tightness, reliability, compactness, etc. This design process has been validated with four subscaled breadboards (two of each type) tested on two test benches (for performance and leak tightness), developed by Belgium and Spain, in on-design and off-design conditions. All these results highlight the suitability of the new technologies given the extreme requirements of the concept. An optimum design for each technology is recommended considering its proper advantages and disadvantages. An innovative precooler technology is presented and tested.

Nomenclature

A = surface, m^2
A_{sf} = fin cross section, m^2
AU = global heat transfer coefficient, W/K
C = fluid velocity, m/s
$\dot{C}$ = capacitive flow rate, $Q.c_p$, W/K
Cr = capacitive flow rate, $(Q.c_p)_{\mathrm{min}}/(Q.c_p)_{\mathrm{max}}$
Cv = flow coefficient of a valve
c_p = specific heat at constant pressure, J/kg · K
D_{curv} = diameter of curvature, m
D_{hyd} = hydraulic diameter, m
Di = inside diameter, m
D_p = depth, m
d = outside diameter, m
e = thickness, m
f = friction factor
h = convective heat transfer coefficient, W/m^{2}K
h_f = fin height, m
K = charge loss coefficient
Kc = contraction coefficient
Ke = expansion coefficient
k = conductivity, W/mK
L_p = passage length, m
l = length of tube, m
Nu = Nusselt number
n = number of passes
P = pressure, Pa
P_f = perimeter of a fin, m
Pr = Prandtl number
Q = mass flow rate, kg/s
Re = Reynolds number
R_{th} = thermal resistance, K/W
T = temperature, K
U = global heat transfer coefficient, W/Km^2
xd = diagonal pitch coefficient
xl = longitudinal pitch coefficient
xt = transversal pitch coefficient
ΔP = pressure drop, Pa
ε = effectiveness, %
ρ = density, kg/m^3
σ = ratio of the finned surface and the total transfer surface
ϕ = contraction ratio

Subscripts

acc = acceleration part
atm = atmospheric
c = cold side
D = diameter
f = fin
$f, 0$ = finned surface
h = hot side
i = inlet
max = maximum
min = minimum
o = outlet
p = pass

I. Introduction

IN MOST of the past and current space launchers, a large and unused quantity of energy is generally stored in the liquid hydrogen present onboard as a fuel. In the 1950s, a first application was proposed to recover a part of this energy with the liquefied air cycle

---

Received 24 October 2008; revision received 5 June 2009; accepted for publication 13 July 2009. Copyright © 2009 by the authors. Published by the American Institute of Aeronautics and Astronautics, Inc., with permission. Copies of this paper may be made for personal or internal use, on condition that the copier pay the $10.00 per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923; include the code 0748-4658/09 and $10.00 in correspondence with the CCC.

*Professor, Aerothermomechanics Department. Senior Member AIAA.

†Research Engineer, Aerothermomechanics Department.

‡Research Engineer.

§Head of Advanced Space Projects, Safran Group. Member AIAA.

¶Professor, Department of Aerospace and Mechanical Engineering.