Journal of Physics: Conference Series

Applications of thermal insulation materials by aircraft

To cite this article: A H Eze and Á Lakatos 2023 *J. Phys.: Conf. Ser.* **2628** 012018

Journal of Physics: Conference Series **2628** (2023) 012018 doi:10.1088/1742-6596/2628/1/012018

Applications of thermal insulation materials by aircraft

A H Eze[1] and Á Lakatos[1*]
[1]University of Debrecen, Faculty of Engineering, Department of Building Services and Building Engineering, Hungary

*Corresponding author e-mail: alakatos@eng.unideb.hu

Abstract. Lightweight materials such as microfiber insulation or polymer foam are typically used to insulate cars and aircraft. But here, too, the use of state-of-the-art "super-insulating" materials is a valid answer. Vacuum insulation panels also serve as reliable insulators for electric vehicles. In this study, we will analyze in depth the potential uses for aerogels, polymer foams, and microfiber insulation. In addition, their thermal properties are briefly outlined, with a special focus on thermal conductivity and compressibility. Finding the right solution for the aircraft industry is critical. To meet increasingly stringent requirements, aircraft materials must meet several criteria, including lightweight, minimal noise, and insulation from the heat.

1. Introduction

Nearly 40% of the energy used in the European Union is used by buildings, while another 20% to 40% is used by automobiles [1, 2]. The sectors indicated above must cut their energy losses in these circumstances. Regarding energy efficiency, thermal comfort, and noise reduction, the insulation of cars is crucial. Too much altitude is required for aeroplanes to operate at their most efficient fuel efficiency levels. High-altitude flights can save fuel usage, but it also means that passengers need to be protected from severe air temperature characteristics. Being in charge of the distribution of pleasant air, the air handling system is a crucial and essential component of an aeroplane. The proper operation of aviation air distribution units is a crucial problem due to the greater occupant density (passengers/m^2) and very different architecture and aircraft geometry than buildings [3]. It is critical to maintaining passenger satisfaction with sound. It is best to minimize aircraft and engine noise. To safeguard avionics and electrical systems that produce a lot of heat while in use, insulation materials are frequently utilized in aircraft avionics and electrical compartments. At temperatures of up to 600 ºC, it is also employed in aircraft radar systems to absorb microwaves, suppress surface waves, and decrease electromagnetic interference. The production technology for insulating boards has advanced as a result of technological advancement. Due to their affordability and potent insulating properties, plastic foam and micro/nano fibreglass wool insulation have emerged as the most popular insulation materials during the past two decades. However, in the last ten years, the industry has seen the introduction of innovative materials such as insulating coatings, vacuum insulation panels, and silica aerogels. These substances are frequently referred to as advanced insulating or nanotechnology substances. The goal is to use the thinnest layer thickness feasible to obtain the desired heat level. For these materials, the phrase "super insulator" is frequently used in modern times. These goods can be utilized in small amounts and automobiles since they have greater thermal insulation qualities. Particularly in the case of aeroplanes, current energy-saving rules sometimes need space-saving insulating solutions. They have emerged as an alluring substitute for reducing insulation thickness by a factor of five [4–10]. Because they must also endure sharp temperature fluctuations and repeated freezing and thawing, these materials should be utilized between -50 ºC and +70 ºC. The weight of an aeroplane is a crucial criterion that must be satisfied. Although the materials should be light, doing so makes them collapsible and reduces their heat resistance. These materials ought to be fire-resistant as well [11, 12]. Zhanga et al. made the suggestion. According to the paper, materials shouldn't absorb moisture from the atmosphere since water vapour in solid form might cause unfavourable structural alterations [13]. At an altitude of 11,000 meters, where the pressure is around one-fifth that of sea level and the humidity is roughly zero, these materials should be subjected to harsh circumstances, as is known [14,15]. A cross-section of an aeroplane cabin is shown in Figure 1 with the insulation indicated in grey [16].

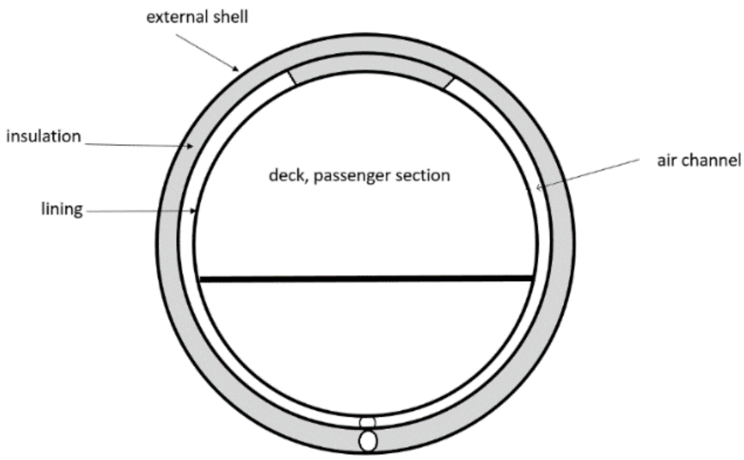

Figure 1. Cross-sectional drawing of an aeroplane

Comparing the thermal performance of insulating materials used in aeroplanes is the major goal of this study. The thermal testing of four various insulating materials is described in this article.

2. Materials and methods

To get the optimum results in terms of fuel efficiency, aircraft must fly at too high an altitude. Improved passenger safety, reduced fuel consumption, increased plane availability, improved noise reduction, and quicker and simpler operation, maintenance, and installation are all benefits of advances in aircraft thermal insulation. Different temperature rooms are separated by thermal insulation material. Other duties and demands put on them include fire protection, strong mechanical strength, and safeguarding neighbouring materials and systems from chemical and mechanical harm in addition to thermal insulation and decreased energy usage.

2.1. The tested materials

A microfiber blanket is made of a thin, elastic, thermal, and acoustic material that is intended to seal up air gaps and retain body heat. They have a waterproof, flame-resistant, thermoplastic phenolic finish that provides excellent flat balancing. To make cured ceilings waterproof for repairs in locations where high-altitude moisture condensation may develop, additives are employed. A distinct phenolic layer may be identified when moisture is not a problem. Per weight of insulation, these blankets offer exceptional acoustic and thermal performance. The blanket is simple to hit General Exothermic Standards, phenolic bonded, and fire resistant. Considering that blankets are subcellular and moisture-resistant, life cannot develop on them. They also offer a great age-related balance. The fibre’s extreme flexibility prohibits single-event arbitration and preserves both its superior thermal and acoustic attenuation properties [10]. One orange and one pink type of insulation were tested (see Figure 2).

Figure 2. The tested materials (slentex, microfiber orange, polymeric, microfiber pink)

To satisfy the stringent requirements of the aerospace and aviation sectors, polymeric aircraft foam products can be used as precise insulating material. They provide very low weight, excellent acoustic and thermal insulation, and retain planar balance and adjustability over the whole temperature range. They outperform typical fibreglass insulation by safeguarding insulating surfaces for a longer period, as demonstrated by their proven in-service durability in humid, warm environments. Polymeric foams can be handled easily, installed quickly, and with fewer fasteners, since they are impartial and non-stringy. They may be used in a variety of aerospace applications, including the International Space Station, Mars Rover, solar energy shields, and cryostat fuel tanks. The investigated fabric's density is approximately 15 kg/m^3. Another tested material is a blanket made entirely of silica aerogel that can be instantly moulded, i.e., easily fitted to places that we would no longer typically be able to access. It is non-combustible, meeting the increased furnace safety requirements. As a result, it is also appropriate for hard-to-reach places where a stronger furnace is required. Additionally, it may be used to insulate cars. Spaceloft A2 is another name for Slentex thermal insulation (see Figure 2).

2.2. Thermal conduction

Thermal conduction is a framework for heat dissipation whereby reliance on particles no longer departs from their macroscopic equilibrium. Through the dispersion of free electrons in metals and the collision of certain medium-speed molecules, heat is transferred from one molecule to another. The heat energy causes the particles' vibrational energy to rise. Different degrees of material behaviours heated. We employ thermal conductivity, a fabric constant (in W/mK), to describe the conductivity degree.

Equation (1) and a state-of-the-art paper [10] both describe how to easily determine the thermal conductivity of homogeneous solids by measuring the equilibrium heat flux (j_q in W/m^2) that flows in a pattern beneath the influence of a temperature gradient (grad T):

$$j_q=-\lambda(grad(T)) \tag{1}$$

Results

The thermal conductivities of four insulation materials—polymeric foam, two varieties of microfibre insulation, and an aerogel—were measured using Netzsch 446 HFM equipment. The mean temperatures throughout the measurement were fixed at 0, and 10 ºC, whereas the temperature differential between the plates was maintained at 20 ºC in each case. Figure 3 displays the first sample data, including density and thickness. It is visible that the density of the slentex is much greater than the density of the other materials, while the greatest thickness belongs to the orange micro-fibre sample.

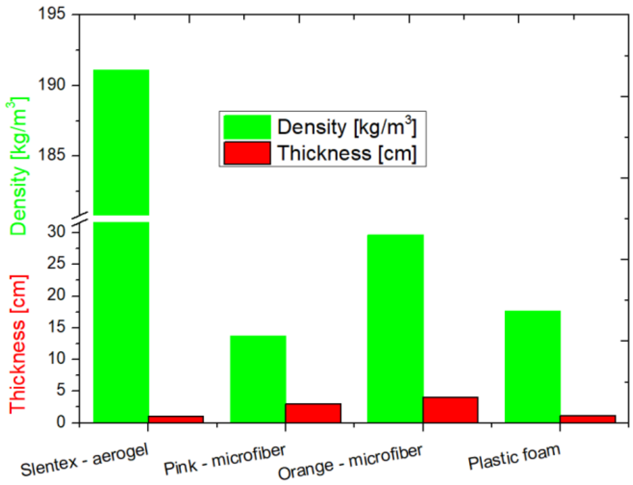

Figure 3. The tested materials with declared densities and original thicknesses

Table 1 represents the samples' observed thermal conductivities. Thermal conductivities increase along with mean temperature increases. Further examination indicates that the slentex aerogel is substantially denser than its rivals, which restricts its use. Due to weight restrictions, this material cannot be used in many components of the aircraft.

Table 1. The measured thermal conductivities

	Thermal conductivity at 0 ºC [W/mK]	Thermal conductivity at 10 ºC [W/mK]
slentex	0.0184	0.0186
pink	0.0288	0.0304
orange	0.0271	0.0285
plastic foam	0.0360	0.0379

Calculations

Based on the measurement results we have executed calculations to see the possible heat losses through the passenger section of an aircraft by using the (Eq. 2). For the passenger section, we supposed a cylindrical shape and for this q, heat loss can be calculated by "r" radius, where table 2 presents the heat loss geometry.

$$q=(T_i-T_e)/(((1/2\pi\, \lambda_1) *In\ r_2/r_1) + ((1/2\pi\lambda_2)*In\ r_3/r_2) + (1/2\pi\, \lambda_3 *(In\ r_4/r_3))) \quad (2)$$

Internal temperature: T_i=20 ºC
The external temperature at 1: heights (2000m): T_e=10 ºC
The external temperature at 2: heights (4000m): T_e =0 ºC

Table 2. Aircraft geometry

cabin	r_1 [cm]	1.8	
plastic	r_2 [cm]	1.81	Thermal conductivity=5 W/mK
insulation	r_3 [cm]		
external shell	r_4 [cm]		Thermal conductivity =200 W/mK

Table 3. The calculations are based on the measured data at 0°C.

	Slentex	Pink	Orange	Plastic
r_3 [cm]	1.821	1.840	1.850	1.822
r_4 [cm]	1.831	1.850	1.860	1.832
Thermal resistance, R_1 [m²K/W]	1.764E-04	1.764E-04	1.764E-04	1.764E-04
Thermal resistance, R_2 [m²K/W]	5.019E-02	9.139E-02	1.257E-01	2.923E-02
Thermal resistance, R_3 [m²K/W]	4.361E-06	4.315E-06	4.292E-06	4.358E-06
Thermal resistance, R_{total} [m²K/W]	5.037E-02	9.157E-02	1.259E-01	2.941E-02
q (delta 20)	3.971E+02	2.184E+02	1.589E+02	6.800E+02

Tables 3 and 4 present the calculation results for both cases. One can see that due to increasing temperature differences, heat loss also increases.

Table 4. The calculations are based on the measured data at 0°C.

	Slentex	Pink	Orange	Plastic
Thermal resistance, R_2 [m²K/W]	4.941E-02	8.659E-02	1.198E-01	2.775E-02
Thermal resistance, R_3 [m²K/W]	4.361E-06	4.315E-06	4.292E-06	4.358E-06
Thermal resistance, R_{total} [m²K/W]	4.959E-02	8.677E-02	1.200E-01	2.793E-02
q(delta (10)	2.016E+02	1.152E+02	8.334E+01	3.580E+02

In Figure 4 we have plotted the calculated heat losses belonging to the different materials applied as insulation for the same aircraft construction. One can see that the greatest value for the heat loss belongs to the plastic foam, while the less value belongs to the orange microfiber.

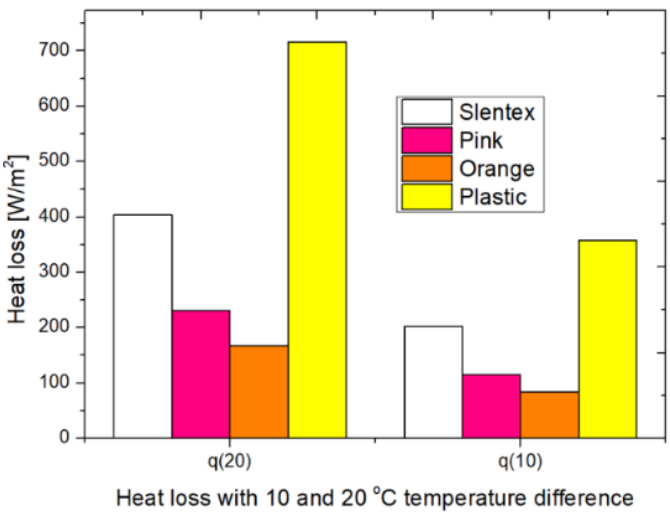

Figure 4. Heat loss with 10 and 20°C temperature difference

3. Conclusions

In this study, we described the findings from tests of thermal conductivity on the most significant aviation insulations. We compared the samples' thermal conductivities and thermal resistances. We showed that the slentex aerogel, which has the lowest thermal conductivity. The orange and pink microfibers had the highest resistance rating, according to our analysis of the samples' thermal resistance. Given the sensitivity of the thermal conductivities to temperature, we have claimed that traditional colourized microfibers can be employed in areas where load bearing is not required, whereas in areas where the weight should be reduced.

Acknowledgements

This paper was supported by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences, grant number: Ákos Lakatos/BO/269/20.

References

[1] Berardi U. 2017 A cross-country comparison of the building Energy consumptions and their trends *Resources, Conservation and Recycling* **123** 230–241 doi: 10.1016/j.resconrec.2016.03.014
[2] Directorate-General for Mobility and Transport, New transport proposals target greater efficiency and more sustainable travel, European Commission Mobility and Transport, NEWS ARTICLE (14 December 2021).
[3] Viscardi M., Arena M,, Porpora V., Di Paola G. and Aubry E. 2018 Feasibility investigation of a smart thermoacoustic configuration for general aviation aircrafts *MATEC Web of Conferences* **233**, 00012 doi: 10.1051/matecconf/201823300012
[4] Baek S.W, Lee S.W. and Kim C.S. 2019 Experimental Verification of Use of Vacuum Insulating Material in Electric Vehicle Headliner to Reduce Thermal Load *Applied Sciences* 94207 doi: 10.3390/app920420
[5] Capozzoli A., Fantucci S., Favoino F. and Perino M. 2017 Vacuum Insulation Panels: Analysis of the Thermal Performance of Both Single Panel and Multilayer Boards *Energies* **8**, 2528-2547 doi: 10.3390/en8042528
[6] Berardi U. and Nosrati R. H. 2018 Long-term thermal conductivity of aerogel-enhanced insulating materials under different laboratory aging conditions *Energy* **147**, 1188-1202. (2018) doi: 10.1016/j.energy.2018.01.053
[7] Semeniuk B. P., Göransson P. and Dazel O. 2019 Dynamic equations of a transversely isotropic, highly porous, fibrous material including oscillatory heat transfer effects The *Journal of the Acoustical Society of America* **146** (4), 2540–2551 doi: 10.1121/1.5129368
[8] Semeniuk B.P. and Göransson P. 2017 Microstructure based estimation of the dynamic drag impedance of lightweight fibrous materials *The Journal of the Acoustical Society of America* **141** (3)1360–1370 (2017). doi: 10.1121/1.4976814
[9] Lakatos Á. 2019 Stability investigations of the thermal insulating performance of aerogel blanket *Energy and Buildings* **139**, 506-516 (2019). doi: 10.1016/j.enbuild.2017.01.054,
[10] Lakatos Á., Csarnovics I. and Csík A. 2021 Systematic Analysis of Micro-Fiber Thermal Insulations from a Thermal Properties Point of View *Applied Sciences* **11**, 4943 doi: 10.3390/app11114943
[11] Johnston A., Cole R., Jodoin A., MacLaurin J. and Hadjisophocleous G. 1999 *Evaluation of Fire Performance of Composite Materials For Aircraft Structural Applications* in: ICCM-12. July 609 pp 1-10
[12] Aircraft Thermal/Acoustic Insulation Materials Functions and Requirements, https://www.fire.tc.faa.gov/pdf/insulate.pdf, downloaded, 16-03-2022.
[13] Zhanga T. T., Lia G., Linc C. H., Weid Z. and Wang S. 2017 Experimental identification of key parameters contributing to moisture accumulation in an aircraft section, *Building and Environment* **126,** 339–347 doi: doi.org/10.1016/j.buildenv.2017.10.012

[14] Bianco V., Manca O., Nardini S. and Roma M. 2009 Numerical investigation of transient thermal and fluidynamic fields in an executive aircraft cabin, *Applied Thermal Engineering* **29,** 3418–3425 doi: 10.1016/j.applthermaleng.2009.05.020

[15] Blosser M.L. 2012 *Mass efficiency considerations for thermally insulated structural skin of an aerospace vehicle* in: 43rd AIAA Thermophysics conference 25-28 June 2012, New Orleans, Louisiana, AIAA2012-3006. doi: doi.org/10.2514/1.T4008

[16] https://www.alltherm.ca/_uploads/_tech_pdf/tech_pdf_id134.pdf, downloaded: 16-03-2022.