IN-SERVICE HISTORY OF THERMAL/ACOUSTICAL INSULATION

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ABSTRACT

Fuselage thermal/acoustical insulation blankets installed aboard passenger aircraft must comply with the Federal Aviation Regulation (FAR) 25.853(a), Appendix F, Part I, (a)(1)(ii) at a minimum. In addition, original equipment manufacturers may impose their own more stringent requirements.

Insulation blankets in operating planes often do not contain state-of-the-art materials and are typically contaminated from continual exposure to direct contact with foreign matter or deposits from air and moisture circulation. Physical damage is usually repaired by patching and taping. <u>They are rarely replaced.</u>

Used insulation blankets were procured from a narrow body jet at least ten years old for comparison to newly fabricated ones. In vertical burn tests, most of the former still meets the regulatory requirements. The old samples did not perform as well as the new parts in fire propagation and cone calorimeter tests.

INTRODUCTION

The aircraft fuselage thermal/acoustical insulation blankets of today have evolved to meet ever more strict functional demands regarding weight, strength and durability, water management, flammability, and cost. They must also perform the nominal tasks of enhancing passenger comfort by passive noise reduction and providing a thermal envelope around the cabin and can be used to protect cargo from extreme cold at flight altitudes.

These blankets are highly engineered packages consisting predominately of extremely lightweight fibrous glass batts bound inside very thin, protective, multi-layer laminates. The coverings are based primarily on films of low water vapor permeance and flammability such as flame retardant polyester or, less frequently, polyvinyl fluoride or polyimide. Flexible materials are generally specified for ease in installation and manipulation. Other components including foams, mats, cloths, hook-and-loop fasteners, metal snaps and eyelets, may be incorporated to perform special functions. The joining techniques of sewing, taping, and heat sealing are all used.

Insulation blankets are configured to fit precisely in assigned spots along the fuselage. Not only do the amounts and types of materials vary for first class, coach, and cockpit sections of a plane and passenger versus cargo compartments as examples, but the parts must also conform to various obstructions, pass-throughs, and structural features. For instance, openings for windows are required along the sidewalls, and thinner blankets, called cap strips or over frame blankets, are designated for the areas of narrower clearance between vertical framing members and interior panels compared to the thicker bay blankets that can fit in the deeper spaces between frames. Because of these variations in materials, features, and shapes, the design of a typical passenger jet contains hundreds to thousands of different fuselage thermal/acoustical insulation parts.

A few guidelines on blanket maintenance have been provided by aircraft manufacturers, which traditionally design and specify the insulation systems. Usually, visible tears in the coverings are patched, preferably with the specialized films and tapes developed for this application. Except in the rare cases of irreparably damaged individual blankets or known locations subject to heavy wear such as cargo doors, operators rehabilitate and reuse rather than replace insulation blankets.

Since the blankets are typically as old as the aircraft itself, they are composed of whatever products were available at the time of manufacture, which may no longer be state-of-the-art. For example, just this year, suppliers introduced new generations of several raw materials for particular lines of aircraft. Some of these were developed to meet the additional requirements of manufacturers on flammability.

After being in service awhile, the insulation blankets become soiled. A probable driver is the water movement around them due to the tendency of the moisture generated on the warm inboard side to condense on the cold outboard side, which falls below the dew point in flight. Air circulation is likely to deposit more foreign matter. In other cases, direct contamination may occur through spillage or handling during maintenance.

Aircraft fuselage insulation is assumed to remain effective as it ages, but its actual performance is not well documented. For this study, various used blankets were obtained from a narrow body passenger jet undergoing maintenance. Its date of manufacture was 1986. Printing on the facings support the later year and also indicated that some of the blankets were either replacements or add-ons produced in the early to mid 1990's. These parts would normally have been kept in service. Their part numbers were identified, and the original design information was located. With this, The Mexmil Company was able to fabricate duplicates from currently specified raw materials. The flammability properties of the old and new blankets were then tested by various methods. Supplemental data on thermal, acoustical, and other physical properties are also presented.

PROCEDURES OF FLAMMABILITY TESTS

Uncertified tests were conducted according to FAR 25.853(a), Appendix F, Part I, (a)(1)(ii). Specimens with exposed areas of at least 50 mm (2 inches) by 300 mm (12 inches) and a maximum thickness for a single layer of fibrous glass batting of 25 mm (1 inch) are mounted in a metal holder and suspended vertically above a Bunsen or Tirrill burner. The flame is adjusted per the written procedures to a minimum temperature of 843°C (1,550°F), and then a sample is from its bottom edge for 12 seconds. Burn length and times of continued flaming of the specimen itself after removal of the burner and of any drips from it are recorded.

Flame propagation tests were performed according to Boeing Support Specification (BSS) 7358. Insulation blankets at least 0.3 m (1 foot) by 0.6 m (2 feet) by the fabricated thickness are propped vertically against a metal support with a 90º bend in its middle. The resulting creases are along the width dimensions. Cotton-tipped swabs are dipped in isopropyl alcohol, immediately ignited, touched to the surfaces of the blankets for two seconds, and then removed. This is repeated at several spots on each including the crease areas. The highest burn length in any direction from each point of ignition is recorded. A maximum value of 20 cm (8 inches) is typically allowed.

Cone calorimeter tests were run according to ASTM C 1354. Sections approximately 100 mm (4 inches) square cut from the finished blankets are wrapped in aluminum foil except on the exposed surface and mounted horizontally opposite a radiant heat source and just beneath a spark igniter. Combustion gases are exhausted through a vent system in which oxygen sensors are situated. The oxygen depletion from that in normal air along with the exhaust flow rate and temperature is used to calculate heat release rates as a function of time. The peak heat release rates (Pk HRR), average rates during the first 60 seconds of the tests (Avg. HRR, 60 sec), and times to ignition (t_{ig}) of the samples are reported. Lower heat release rates and higher times to ignitions are considered to signify reduced flammability hazards. For this testing, measurement of smoke density was also requested. The indicating parameter, specific extinction area (Avg. SEA), is calculated from measured obscuration of a laser light beam directed through the exhaust duct, the exhaust gas velocity, and the weight loss of the specimen under test. Its value is directly related to the smoke level.

RESULTS OF FLAMMABILITY TESTS

The vertical burn tests were performed on samples cut from the used insulation blankets. The materials were tested individually and in combinations. Table 1 gives representative examples of the results.

TABLE 1: 12 SECOND VERTICAL BURN TEST RESULTS

Descriptions	Burn Length, mm (in)	Flame Time, sec	Drip Flame Time, sec
FAR 25.853(a), Appendix F, Part I, (a)(1)(ii) limits	≤203 (8)	≤15	≤5
6.7 kg/cm³ (0.4 lb/ft³) Fibrous Glass – Averages of 6 Tests	33 (1.4)	0	0
9.6 kg/cm³ (0.6 lb/ft³) Fibrous Glass – Averages of 3 Tests	25 (1.0)	0	0
Polyester Covering Film - Averages of 3 Tests	126 (5.0)	0	0
9.6 kg/cm³ (0.6 lb/ft³) Fibrous Glass + Metallized Polyvinyl Fluoride Covering Film, Both Sides:			
Averages of 3 Tests On Open Edge	68 (2.7)	0	0
Averages of 3 Tests On Taped Edge	110 (4.3)	0	0
6.7 kg/cm³ (0.4 lb/ft³) Fibrous Glass + Metallized Polyester Covering Film, One Side Only (Averages of 3 Tests)	266 (10.5)	0	1.7

In the last line of Table 1 is shown the only result among some twenty or so tests that would not have met the regulatory criteria. Flaming drips were also seen in a couple of other tests involving metallized polyester covering film.

The burn lengths for the used blankets consistently exceeded those for the new ones in flame propagation tests. Holes are burned in the covering materials of the new blankets approximately the size of the flames sustained by the cotton swabs and char the surfaces of the fibrous glass batts underneath. Occasionally, flaming is sustained for a few seconds after a swab is removed but quickly extinguishes without much propagation. No burn lengths greater than 20 cm (8 inches) were measured. All of the old ones tested gave more than 20 cm (8 inches) of flame spread. After the burning swabs were removed from the old blankets, the flames steadily progressed in one or more directions from the points of ignition, continuing to involve the cover material for 30-60 seconds until an edge was reached. In a couple of trials, combustion appeared to be supported in the fibrous glass batts, and dripping or flaking of covering material with sustained burning for a few seconds was observed. These results were duplicated in two different laboratories.

Three samples were tested in the cone calorimeter, including a new blanket with non-metallized covering, a used blanket with a metallized covering film, and a second used blanket with a non-metallized polyester covering film. A heat flux of 40 kW/m² was specified because this setting was expected to produce ignitions. Since initial screening confirmed that it caused ignition of each sample, it was used in the final testing. The averaged results from three individual tests on each sample are summarized in Table 2.

TABLE 2: CONE CALORIMETER TEST RESULTS

Descriptions	t_{ig}, sec	Pk HRR, KW/m²	Avg. HRR, 60 sec, kW/m²	Avg. SEA, m²/kg
Used Blanket With Metallized Covering	6	80	28	355
Used Blanket With Non-Metallized Covering	4	69	14	332
New Blanket With Non-Metallized Covering	6	53	10	295

In all runs, sharp spikes in heat release rates occurred within the first 20 seconds. The used blanket with metallized covering gave a substantial tail, but the two with non-metallized covering films subsided to near zero heat release rates after about 60 seconds.

SUPPLEMENTAL DATA – CHEMICAL ANALYSES

All of the used insulation blankets were visibly soiled to some degree. Since the contamination was suspected to affect their flammability properties, several different types were isolated for chemical analyses. Water was also squeezed from one blanket that was thoroughly saturated, presumably due to a small hole found in the covering laminate. After evaporation, the residue was examined.

The most prevalent contaminant, a dirty brown coating apparently broadcast across the surface of almost every blanket, gave an infrared spectrum very similar to those of commonly used aircraft aluminum corrosion inhibiting compounds. It was overlain by typical dust species, including silicates, carbonates, and cellulosics.

Pools of red drops were seen on several parts. Again, these could be most likely attributed to a corrosion-inhibiting compound, according to infrared analysis.

The infrared spectrum of some green spots was judged to be closest to that of a pigment. By non-quantitative elemental analysis, chromium was found to be the predominant species with smaller amounts of manganese, magnesium, aluminum, silicon, and sulfur present.

Dust-like matter was seen to be composed of a variety of fibers by optical microscopy. By infrared analysis, most of it was determined to be cellulose. However, other fiber types could be identified, including nylon and poly(acrylonitrile/vinyl acetate). Particles typical of household dust made up of silicates, carbonates, cellulose and polyamide were also present.

The residue of the liquid was determined to be mainly inorganic by infrared spectroscopy. Sodium bicarbonate was the primary component, and a sulfate was also identified.

SUPPLEMENTAL DATA – FLAMMABILITY TESTING

Horizontal flame propagation tests were performed on 100 mm (4 inches) × 300 mm (12 inches) sections of used and new insulation blankets. The specimens are lain flat, and a draft fan is turned on in the test cabinet to simulate airflow across their surfaces. Flaming cotton swabs are applied as in the BSS 7358 method. Johns Manville Corporation is developing this procedure.

Flame spreads on the new blankets tested were always less than 20 cm (8 inches) from the point of ignition. The used blankets invariably gave burn lengths exceeding 20 cm (8 inches). This pass/fail criterion was adopted from the regular flame propagation protocol.

Figures 1 and 2 are photographs taken during two different tests in which samples of new and used insulation blankets were ignited simultaneously. The new ones are on the left in each. Holes approximately the sizes of the flaming cotton swabs were burned in each, but no propagation occurred. On the used blankets, the flames were self-sustaining, became enlarged, and spread far from the initial spot of ignition.

FIGURE 1: HORIZONTAL FLAME PROPAGATION TEST #1

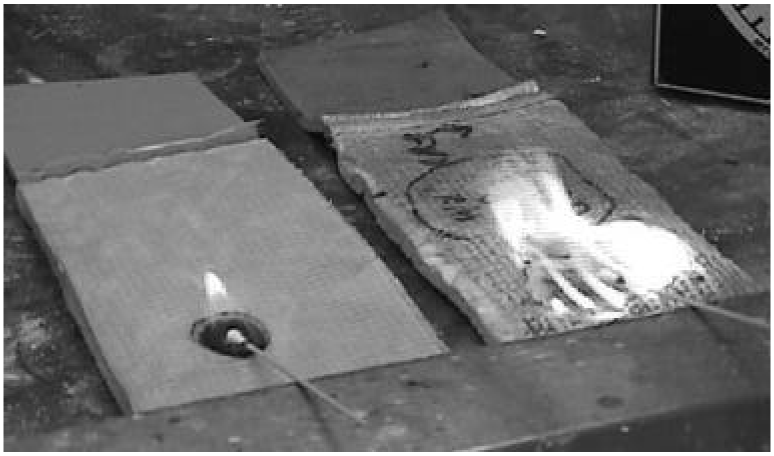


FIGURE 2: HORIZONTAL FLAME PROPAGATION TEST #2

Differences in the flammability properties of used and new blankets could be due to either aging and contamination or to the improved raw materials available today. An accelerated aging program was designed for subsequent comparison of aged and unaged blankets that were prepared at the same time from the same raw materials. Two simple parts consisting of one 25 mm (1 inch) layer of a 9.6 kg/m³ (0.6 lb/ft³) fibrous glass batt heat sealed in a polyester film based covering laminate were prepared. One was kept in a conditioned atmosphere at about 22°C (72°F) at 50% relative humidity while the other was artificially aged for one week. The regimen included temperature cycling hourly between -34°C (-30°F) and 49°C (120°F), daily spraying of one side with a widely used corrosion inhibiting compound and loading with 100 ml of tap water on weekdays, and manually running a 5 kg (11 lb) roller over it each hour on weekdays. Holes were then created in the aged blanket, and it was dried in an oven, since it was saturated with water after the aging period. Flame propagation tests were conducted on the aged and unaged blankets according to BSS 7358.

The unaged blanket behaved as normal, giving burn lengths of less than 20 cm (8 inches). The aged blanket did show flame propagation exceeding 20 cm (8 inches). The unexpected result was that this phenomenon occurred upon both sides of the blanket, even the face that had not been sprayed with the corrosion inhibiting compound.

SUPPLEMENTAL DATA – THERMAL, ACOUSTICAL AND PHYSICAL PROPERTIES

The thermal conductivity (k) of the fibrous glass batts from used and new insulation blankets were determined according to ASTM C 518 at a mean temperature of 24ºC (75ºF). The results are summarized in Table 3. The measurements were done at both the actual thickness of the specimens and their nominal thicknesses of 25 mm (1 inch) each including air gaps equivalent to their permanent compactions.

TABLE 3: THERMAL CONDUCTIVITY DATA

Description	Test Thickness, mm (in)	k, W/[m·K] ([Btu·in]/[hr·ft²·°F])	R, [m²·K]/W ([hr·ft²·°F]/Btu)
Used Batt Dated 1990 – Actual Thickness	19 (0.75)	0.0342(0.237)	0.557(3.16)
Used Batt Dated 1990 – Nominal Thickness	25 (1.00)	0.0391(0.271)	0.649(3.69)
Used Batt Dated 1997 – Actual Thickness	19 (0.75)	0.0345(0.240)	0.551(3.13)
Used Batt Dated 1997 – Nominal Thickness	25 (1.00)	0.0391(0.271)	0.649(3.68)
New Batt – Actual Thickness	24 (0.95)	0.0361(0.250)	0.668(3.80)
New Batt – Nominal Thickness	25 (1.00)	0.0377(0.262)	0.673(3.82)

Since the old batts are compacted relative to the new ones, their thermal conductivity's are lower than that of the latter. However, even at their nominal thicknesses, the new insulation shows higher thermal resistance (R) than the used materials.

R, not k, is directly related to heat flow in the conductive heat transfer equation (1).

$$Q = A \times (T_i - T_o)/R \quad (1)$$

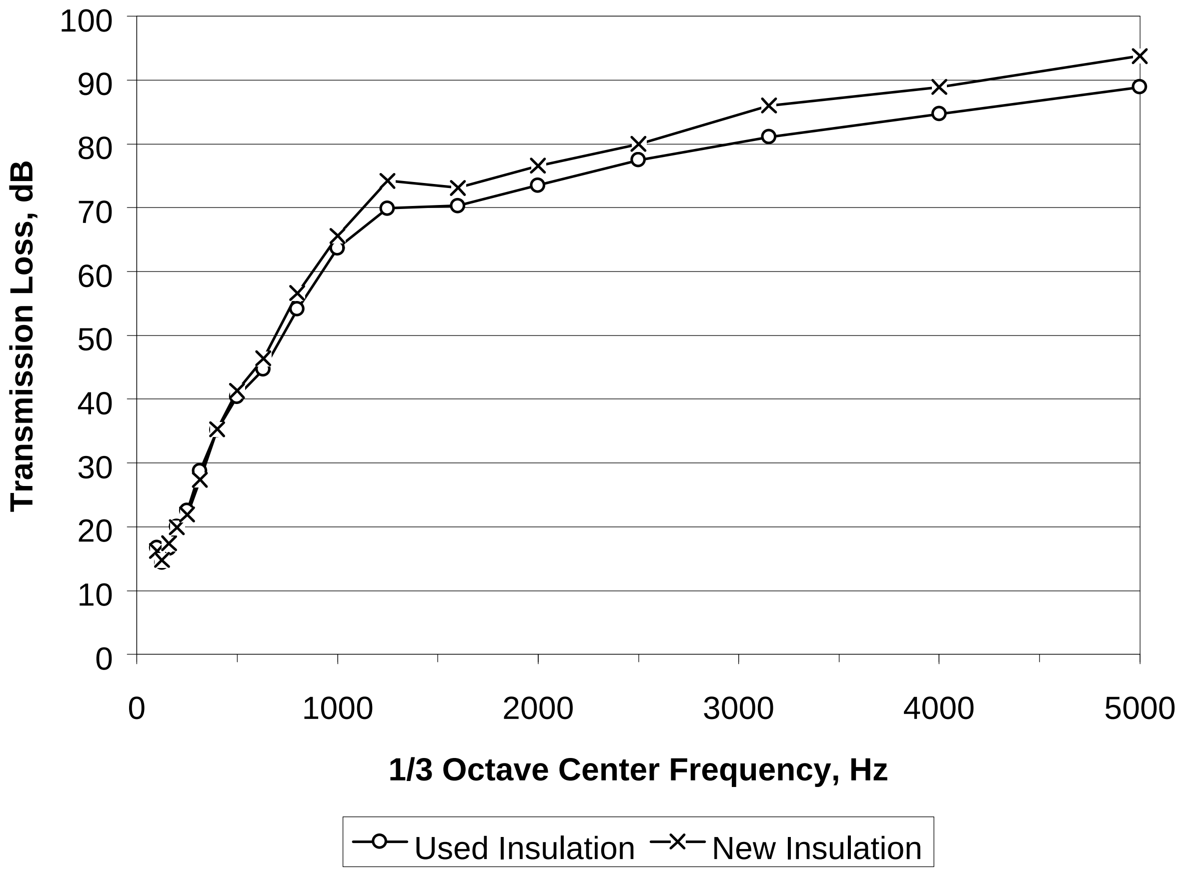
$$R = t/k \quad (2)$$

If the case of replacing used insulation blankets with new ones is considered, the area of coverage, A, is constant. Since R increases upon replacement, either the energy input, Q, required to maintain a set temperature difference, $T_i - T_o$, across the blankets decreases, or the inboard temperature and passenger comfort level in flight will rise for a constant heat input.

The best case scenario for used blankets supposes that a conductive air gap makes up the lost height in service. Then their R-values are much closer to those of new blankets. Still, the difference indicated in our measurement would predict a change in inboard surface temperature of approximately 1.5ºC (2.7ºF), assuming constant Q and A and a normal outboard surface temperature of -34ºC (-30ºF) and inboard temperature for an old blanket of 18ºC (65ºF).

Acoustical performance of used versus new insulation blankets was measured by the sound intensity technique of the ISO 140-5 draft standard. A mock passenger jet aluminum sidewall about 0.17 m (70 inches) square was mounted in the opening between a reverberation room and a hemi-anechoic chamber. Two window blankets were installed in the middle of one side of this partition. Areas not covered by the test specimens were filled with insulation materials common to the tests. The inboard side was enclosed with a mock cabin liner panel. A diffuse sound field was generated in the reverberation room on the skin side of the partition, and the noise received on the inboard side in the hemi-anechoic chamber was picked up by a scanning microphone and averaged across the surface. Transmission loss values for 1/3 octave bands of frequencies between 100 Hz and 5 kHz were calculated from the differences in sound intensities on each side. Figure 3 illustrates the results.

FIGURE 3: SOUND TRANSMISSION LOSS DATA



Transmission loss is an indicator of the noise blocking capabilities of the product tested. The used blankets show consistently lower performance than the new ones throughout the critical speech interference level or SIL from about 800 Hz to 2 kHz. The magnitudes of the differences are in the range of 2-5 dB, which is significant, especially considering that part of the partition was blanked in this comparison.

Airflow resistivities of fibrous glass batts are considered to be directly related to transmission loss. Therefore, the used batts should have lower air flow resistivities than new ones according to the results of the acoustical tests. As Table 4 shows, the data confirm this relationship. Fibrous glass batts only from new and used blankets were tested according to ASTM C 522.

TABLE 4: AIR FLOW RESISTIVITY DATA

Description	Air Flow Resistivity, Rayls/m
Used Batt Dated 1990	20,693
Used Batt Dated 1997	15,767
New Batt	33,247

The other physical test performed on the used fibrous glass batts was water repellency as described in ASTM C 800. The acceptance criterion is no more than 20 grams of water weight gain. All of the old samples passed this test.

CONCLUSIONS

Aged aircraft fuselage thermal/acoustical insulation blankets exhibit reduced performance compared to new ones in a variety of aspects.

The former shows a consistent and marked tendency toward greater flame spread in flame propagation tests. The results of cone calorimeter testing provide further evidence of their inferior flammability properties based on their higher heat release rates and smoke evolution. A possible contributor to these differences is the surface contamination on the used blankets. By chemical analysis, the most prevalent contaminants are likely corrosion inhibiting compounds, which are wax-like substances and therefore very flammable.

An accelerated aging experiment on a blanket made from currently available materials demonstrates that the aging process is the contributory factor to the losses in performance rather than evolution in materials of construction. Increased flame propagation was achieved even along a surface that had not been artificially contaminated with a corrosion inhibiting compound. Determining if the deterioration is a steady, step-wise, or asymptotic process was beyond the scope of this study.

The old blankets and their components still almost invariably meet the regulatory requirements of FAR 25.853(a), Appendix F, Part I, (a)(1)(ii). The only failure was probably due to use of an outdated material, the metallized polyester based covering laminate. Its flammability performance has recently been under scrutiny.

The fundamental functions of used insulation blankets are compromised. Their thermal efficiencies are reduced largely as a result of compaction. Both sound transmission loss and airflow resistivity data show that their acoustical insulating values are inferior to those of new blankets.

Examples were found of used blankets that were either thoroughly saturated with water due to small holes in the coverings or patched with tape. These add weight to the insulation system, causing extra fuel to be expended in moving it from place to place with the airplane.

SUMMARY

Used aircraft fuselage thermal/acoustical insulation blankets were procured from a jet in passenger service for at least 10 years. Their flammability and physical properties were tested for comparison to those of identical, newly fabricated blankets.

The findings of this study were:

- aged blankets showed a greater propensity to propagate flames and produce more smoke;
- surface contamination with corrosion inhibiting compounds likely contributes to their increased flammability;
- their thermal and acoustical insulating values are significantly less than those of new blankets;
- old blankets are typically compacted and may carry added weight from patching tape or moisture ingress;
- used blankets largely continue to meet the regulatory requirements of FAR 25.853(a), Appendix F, Part I, (a)(1)(ii), with perhaps the sole exception of those having metallized polyester film based protective coverings
- environmental exposure and contamination lead to the losses in properties.

Through a schedule of maintenance and replacement when necessary, aircraft operators can realize optimum performance from the insulation systems in their planes. Potential benefits include greater comfort and safety for their customers, the passengers, and lower operating costs because of reduced fuel consumption based on removal of excess weight and more efficient operation of the environmental control system due to better thermal insulating performance.

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