The Development of a Moisture Vapour and Air Permeable Laminate for Use in RAF Immersion Protection Garments

Abstract:
The UK RAF has a requirement for a new generation of aircrew clothing. As part of this requirement they plan to replace the Mark 10 Immersion Protection Garment (IPG) that has been in use for many years.

The RAF issued a specification for the IPG, which provided a number of challenges to the developer of such a garment. Of high importance is the requirement, that in the event of an ejection over water, the suit should withstand the potential exposure to flame as part of the ejection and still be completely waterproof when the wearer is immersed in water.

Additionally, there is the requirement for the garment to be air permeable so that in the event of loss of canopy or rapid descent from high to low altitude, there would be no problem caused by differential pressures affecting the wearer of the garment. This needs to be achieved without the aid of a mechanical device.

At last year's SAFE Symposium in Helsinki, a presentation was made of a proposed solution to these requirements utilising a variation on the current garment construction. This paper presents a Gore-Tex® alternative.

It covers the work that has been undertaken to date at Gore to develop a suitable fabric. Firstly, the lamination trials, to select suitable fabric candidates, including extensive internal laboratory tests, followed by decompression tests at RAF Henlow and Thermo-Man® tests at Du Pont® in Geneva to prove that the fabric would meet the requirements of the RAF specification when made into a garment.

After completion of this initial work and having taken input from interested parties, a programme of tests was defined to evaluate the selected fabric's "fitness for use," to show that it will meet the typical wear and tear that it could expect to see in it's lifetime. These tests included exposing the fabric to typical contaminating substances-e.g. aviation fuel, diesel & hydraulic oils. The contaminated fabrics were tested for waterproofness and a contaminated suit was burnt on the Thermo-Man tester. The fitness-for-use testing also included human subject physiological tests that were performed at the Institute of Naval Medicine in Gosport.

The paper also highlights the benefits of a Gore-Tex immersion protection garment. These include significantly reduced weight and bulk, enhanced waterproofness, fire protection and greatly improved contamination protection.

Introduction:
The UK Ministry of Defence has a requirement for Immersion Protection Garments (IPG's) to replace the current garments, which have been in use for some years. As part of the development and procurement process, they have issued the specification no. MAP34/003, detailing the requirements for such garments. Included in this specification is the requirement that following a flash fire, the IPG should still protect the wearer in the event of an immersion in water. The flash fire performance standard is set as a 4.5 second exposure at a heat flux of 84kW/m^2 (2.0 cal/cm^2).

In addition to the flame-retardant requirements there is a comfort and mobility requirement that the garment should allow automatic equalisation of pressure between the inside and outside of the IPG during changes of aircraft altitude.

These are the areas that we focussed on in our development of a fabric that could be used in the next generation of IPG for the RAF.

The Development Process:
In response to these requirements, Gore in the UK put together three garment options for evaluation at the Du Pont Thermo-Man facility. Each garment ensemble was exposed to a 4.5 seconds test at 2 $Cal/(cm^2 sec)$. The purpose of testing each garment option was to establish the performance of the garments in two areas:

1. The thermal performance of the garment in conjunction with the under-layers currently issued by the UK RAF;
2. The ability of the Immersion Protection Garment to perform, after exposure to a flash fire, in the survival scenario in resisting the ingress of water.

To enable comparison with the current clothing system in use, MoD issue under-garments, thermals and flying coveralls were used in the tests, in conjunction with the Gore-Tex garments. No outer garments, such as the pilot's waistcoat and anti-g trousers were used.

The details of each clothing ensemble are listed below, from inside, out:

1. Long sleeve cotton vest and long johns, woollen long johns, Nomex® flying coveralls, immersion protection garment made from 3 layer Gore-Tex laminate of Nomex Z200.
2. Long sleeve cotton vest and long johns, woollen long johns, immersion protection garment made from 3 layer Gore-Tex® laminate of Nomex Comfort (Farnborough), Nomex flying coveralls.
3. Long sleeve cotton vest and long johns, one piece garment constructed from Gore-Tex Airlock® laminate, Nomex flying coveralls.

For each test, a prediction of burn injury was calculated using the sensors contained in the manikin. The head remained uncovered in each test and this alone gave a burn injury prediction of approximately 6%. Additionally, an estimate of the burn injury versus time, and burn injury survival prospects according to age groupings were plotted.

On completion of the Therno-Man testing the garments were returned to Gore in the UK and testing was performed to establish the waterproofness of the garments.

The results were as follows:

1. Using the Z200 IPG:
The fabric used in this laminate is Nomex Z200, a recent development launched by Du Pont. It is a modified co-polymer, which, on exposure to flame, expands to form a barrier to heat.

The total predicted burn injury on this occasion is stated as 6%. This is accounted for in the head, which as was stated earlier, is completely unprotected.

The garments under the IPG were undamaged, with no apparent damage to the laminate. There is some evidence that the seam tape is curling at the edges. It should be noted that the seam tape used in this garment was a nylon tape, and not the recommended type of tape and which would normally be used to seal a garment of this type, which uses a Nomex backer.

When the garment was returned to Gore, hydrostatic head tests were performed on a variety of locations to determine the leakage of the garment. All suit parts that were tested passed a 10psi leakage test. However, the seams leaked as expected.

2. **Using the Nomex Comfort IPG:**

In this instance, the purpose of this test is to simulate a suit made with an internal layer of Nomex Gore-Tex "Farnborough" laminate and an external layer of Nomex. Lab testing has shown that while the Farnborough laminate offers a high degree of thermal protection, after direct exposure to flame the fabric may become brittle and break open, therefore reducing the protection offered in an immersion situation. Therefore, in this instance the Nomex layer is sacrificed in the flame exposure in order to protect the Gore-Tex laminate beneath.

The total predicted burn injury is stated as 7%. The difference of 1% can be explained by the design of the garment, the previous one having a higher collar which gave protection higher up the back of the head.

The flying coveralls showed signs of shrinkage and were very brittle, breaking up when removed. The IPG, while slightly discoloured on the outside, was undamaged. The seamed seals inside the garment remained intact. This garment was made up using the Nomex seam tape discussed earlier.

Again, when the garment was returned to Gore, hydrostatic head tests were performed on a variety of locations to determine the leakage of the garment. On this occasion all laminate and seam tape locations that were tested were waterproof to a high degree; the lowest failure was 6.8 psi, nearly 5m water.

3. **Using the Gore-Tex Airlock Inner Coverall:**

This product consists of a 2-layer Gore-Tex laminate with the addition of silicone hemispheres which act as a spacer, providing an air gap to provide thermal protection, but with much reduced weight. This product has been tested and shown to meet the requirements of EN469, for fire-fighter's garments.

For this test, a one piece "trial" under-garment was produced. This was unsealed and had no neck or cuff seals, as in the other IPGs. As a result of the burn injury performance of the previous two ensembles, we took the decision to leave out the thermal long johns for this test and so on this occasion the Airlock laminate was providing the thermal protection.

In this instance the Airlock suit had been made very bulky and assembling the flying coverall over the top involved compressing the undergarment. After the test, some points of the suit have obviously been in direct contact with the fabric of the coverall and show signs of scorching, but not break-open. This is particularly evident on some creased areas. The inside of the suit is largely undamaged and the membrane is completely intact, with only some discolouring corresponding to the contact points mentioned earlier.

In this instance the lowest leakage was found at 4.7 psi.

Using the results of these tests, a decision was taken to move forward in the development of a product based on the Nomex Z200 face fabric. Working with the fabric manufacturers, we produced a modification to this face material, and the subsequent laminate was given the name "Yeovil."

Laboratory tests had indicated that the air permeability of the laminate was similar to that of a double layer of cotton ventile. The laminate was made into a suit and taken to the Royal Air Force Centre of Aviation Medicine at RAF Henlow in Bedfordshire for testing in one of their decompression chambers. Tests were conducted using a Fire Services' training mannequin. The mannequin was dressed in the immersion coverall, with external anti-G trousers and survival waistcoat assembled over the top of the garment. Care was taken to ensure that the wrist and neck seals were secure. The chamber was configured to follow the following profile:

1. Ascent to a height of 8,000ft (pressure equivalent) at a rate of 10,000ft per minute;
2. Rapid decompression to a height of 25,000ft at the maximum rate, in approximately 1.6 seconds;
3. Continue ascent at a rate of 10,000ft per minute to a height of 50,000ft;
4. Maximum rate of descent from 50,000ft at approximately 150,000ft per minute, in approximately 20 seconds.

The results were little, if any, reaction of the suit ensemble in either the rapid decompression or rapid descent. There was some movement around the neck seal, which is not air permeable, but the other exposed parts of the suit did not appear to change. The socks, which are made of non air-permeable material reacted briefly before returning to the normal state.

The Next Steps

To fully illustrate this product's fitness for use, it is necessary to take into account all aspects of the environment to establish, with the help of the end user community, what the garment could be expected to encounter in a typical lifetime. One important requirement of the fabric concerns contamination resistance. The specification requires that contamination of the garment should not cause deterioration of materials, which will affect the garment reliability or the water resistant, fire retardant or thermal performance properties.

In order to identify a realistic set of contaminants, we approached Beaufort Air Sea Equipment Limited, in their capacity as Design Authority for the current IPG, and obtained from them a list of the contaminants that they would typically use in their qualification processes. These were:

Avtur	Aviation fuel
Diesel	Fuel
OM15	Hydraulic oil
OM13	Lubricating oil
XG287	Aeroshell grease
XG315	Molykote 33 grease
PX24	Corrosion preventative compound

The test method used to contaminate the fabric was a US standard AATCC 130-1990.

Following contamination of samples of fabric with these items, the samples were tested for waterproofness and breathability.

Three samples were contaminated with each substance and tested for moisture vapour permeability according to BS7209:1990, Appendix B. This test compares the breathability of the test fabric to that of a standard material, which is PE18 polymer. The results are shown below:

Contaminant	**Mean MVPI**
Avtur	**89.23%**
Diesel	**88.74%**
OM13	**79.34%**
OM15	**89.25%**
XG287	**45.95%**
XG315	**48.65%**
PX24	**83.57%**

The fabric, when uncontaminated, had a mean value of MVPI of 89.66%.

As can be seen from the results above, only two of the contaminants had a serious effect on the breathability. These were the two greases: XG287 and XG315 which were observed to have heavily coated the whole of the fabric sample. The other contaminants had little effect, the biggest drop in breathability being 10%.

The samples containing the greases XG287 and XG315 were put through a 40°C domestic wash to see if washing would remove the contamination. After drying, the samples were re-tested with the following results:

Contaminant	**Mean MVPI**
XG287	**77.49%**
XG315	**49.28%**

The waterproofness test was performed according to ISO 811. The samples were clamped onto the hydrostatic head tester and the water pressure was ramped up to 10psi at a rate of 2psi per minute. At 10psi the pressure was held for 5 minutes. This pressure is equivalent to approximately 7 metres of water.

The results are as follows:

Contaminant	**Result**
Avtur	No leaks at 10psi; after 3 minutes some wicking observed
Diesel	Passed 10psi for 5 minutes
OM15	Passed 10psi for 5 minutes
OM13	Passed 10psi for 5 minutes
XG287	Passed 10psi for 5 minutes
XG315	No leaks at 10psi; after 2 minutes some wicking observed
PX24	No leaks at 10psi; after 3 minutes some wicking observed

As can be seen from the results, all of the contaminants reached 10 psi without leaking. After some minutes the fabric was found to have wicked moisture in 3 cases: Avtur, XG315 and PX24. The moisture is observed by dabbing the fabric with tissue paper.

A final Thermo-Man test was conducted at Du Pont in Geneva. In this test the suit was contaminated at various points with the contaminants used in the tests on breathability and waterproofness. The suit was contaminated the day before the test by applying a 6ml amount, in the case of the liquid contaminants and a 3.5g amount, in the case of the solid contaminants. After contamination, the suit was sealed in a plastic bag before transportation to Geneva. Apart from the IPG, the only other clothing on the mannequin was the cotton underwear.

Each contaminant was applied to a numbered spot. The positions of the contaminants were as follows:

Contaminant	Number	Position
Avtur	1	Left hand panel, above lower access zip.
Diesel	2	Left thigh pocket.
OM15	3	Right thigh pocket.
XG287	4	Right breast.
XG315	5	Upper middle back.
OM13	6	Left buttock.
PX24	7	Right buttock.

The test was again conducted according to the UK MoD specification number MAP34/003.

After-flaming occurred in locations 4, 6 and 7, the last flames extinguishing themselves in approximately 10 seconds after the test was stopped. These contaminants were Aeroshell Grease, lubricating oil and Corrosion Preventative Compound.

The total burn injury prediction for this test is recorded as 0% 2nd degree and 7% 3rd degree. Once again, the 7% 3rd degree burns are accounted for in the unprotected head. The continuing afterflame appeared to cause no further damage or injury. There was no burn injury shown on the body of the mannekin.

Once again, these suits were tested for waterproofness. On this occasion, the locations of the contaminants were used as the points to be tested. The results are shown below:

Contaminant	Performance
Avtur	Delamination at 4 psi and leaks noted on laminate at 8 psi
Diesel	Passed 10 psi for 5 minutes
OM15	Passed 10 psi for 5 minutes
XG287	Badly delaminated in this area; leaked at 3 psi
XG315	Passed 10 psi for 5 minutes
OM13	Some signs of delamination in this area; leaked at 10 psi
PX24	Leaked at 9 psi

To further investigate the fitness for use aspects of this fabric, Gore commissioned the Institute of Naval Medicine (INM) in Gosport to run trials using three suits made from the Yeovil laminate[1]. The purpose of the trial was to investigate the effectiveness of a suit made from Gore-Tex fabric in reducing sweat accumulation, and to determine if this affects the thermal protection given by the suits on immersion in cold water.

A total of six subjects were tested. The clothing ensemble consisted of long sleeved cotton vest, cotton long johns, woollen aircrew socks, “aircrew” shirt, ribbed woollen inner coverall, the Gore-Tex immersion suit, DMS boots and a mk 30 lifejacket.

The suits were worn by the subjects for 6 hours in the INM’s Medium Environmental Chamber at a temperature of 20°C and humidity of approximately 50%. During this period each subject undertook some light exercise which consisted of stepping up onto a 15cm block 12 times per minute for 30 minute periods. In between the periods of activity the subjects sat and rested. Drinking water was allowed and that input and urinary output were measured by weighing.

Mean skin and rectal temperatures were monitored and the subjects were weighed at various times to allow calculation of sweat production and retention.

Following the exercise period, the subjects were lowered, seated, into circulated water at 4°C. Once immersed, they attempted to hold their breath for 20 seconds. After 3 minutes seated the subjects moved off the chair, inflated their lifejacket and floated free for the remainder of the 30 minute period. The subjects gave subjective assessments of thermal and non-thermal comfort every 5 minutes while their electrocardiogram (ECG), skin and rectal temperatures were logged.

On average, the suit was found to allow the evaporation of 61% of sweat produced. Immersed performance was stated as being wholly acceptable. All of the subjects were able to achieve the 20 seconds breath-hold when immersed.

All subjects were able to remain immersed for 30 minutes with little or no discomfort. The lowest mean skin temperature calculated was 20.3°C for one subject, while the remainder fell to between 24°C and 26°C. None of the subjects became hypothermic and the lowest core temperature recorded was 36.65°C (sd 1.1°C)

Conclusions

An Immersion Protection garment manufactured using the Gore-Tex Yeovil laminate meets the needs of the UK RAF in terms of flammability protection, immersion after a fire and pressure equalisation at altitude. In addition to this there are a number of advantages associated with the Gore-Tex garment.

These include:

- ♦Significantly lighter weight.
- ♦Contamination resistance.
- ♦Ease of maintenance; the Gore-Tex garment can be washed and easily repaired.
- ♦Proven track record in the area of Immersion Protection garments and other military specialist clothing.

Reference:

1. An Assessment of a Gore-Tex® "Air Permeable" Flying Immersion Suit, by Lt P Chilcott, RN, Aug 2001.

Annemarie Nicholson
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