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# GKSS - Advanced Integrated System Concept for Full Protection and Heat Stress Mitigation

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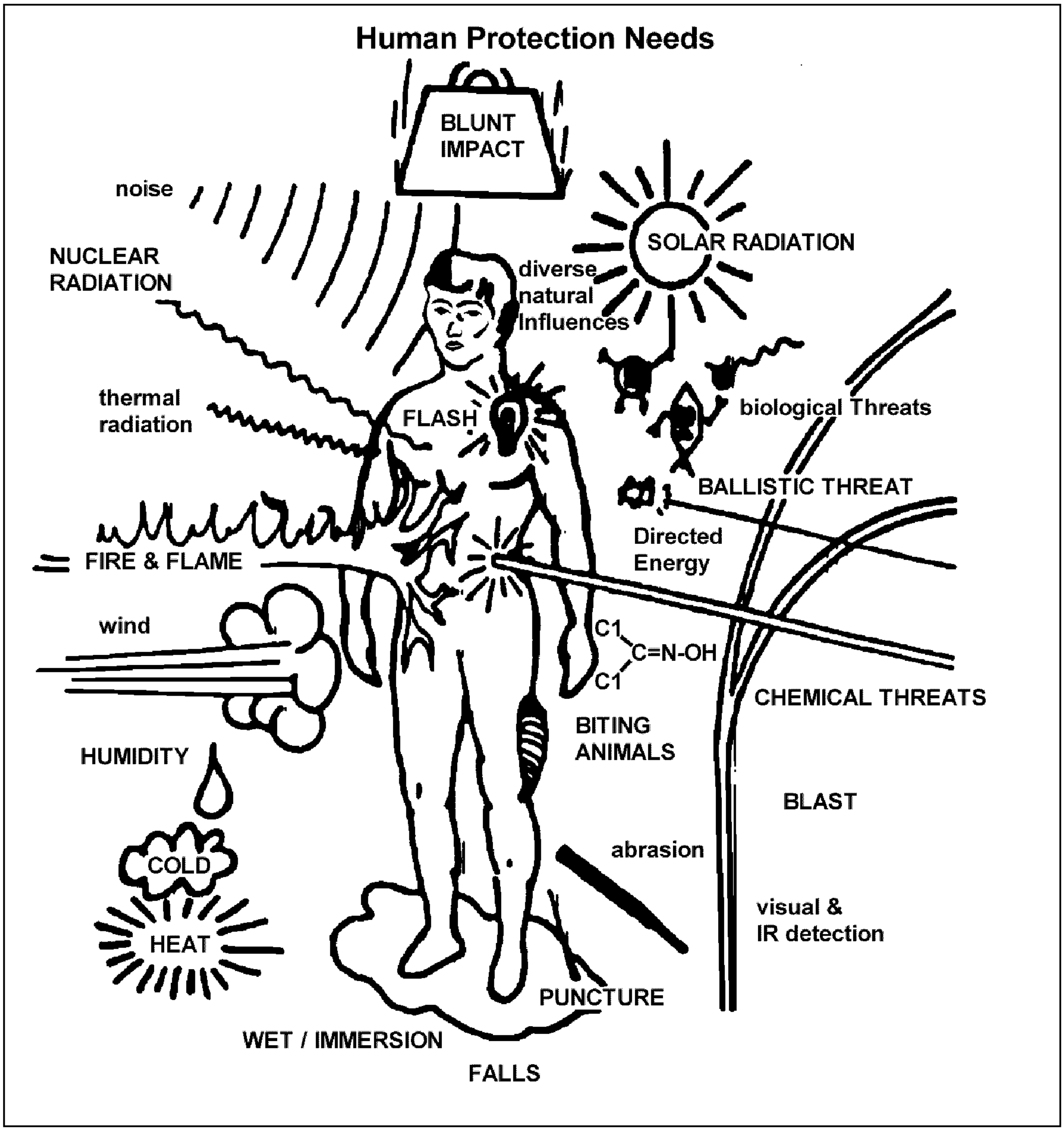
**Summary**
The increased demand for protection of the human body against external threats and environmental conditions has led to modularity of components for countering these threats and environmental conditions. However, the higher the degree of protection the more negative influence on human performance could be observed. The degradation of human performance situation is caused by multiple layered - onion like - protection garments keeping the body away from natural heat exchange mechanisms. This can be recognized in particular when looking into combat pilot equipment where the result is known as heat stress problem. This degradation is getting even worse when protective garment has to be impermeable as well as semi-permeable. As the operational workload remains it adds to the burden caused by the protective garment resulting in excessive perspiration and finally, leads to dehydration. The alternative approaches to overcome these deficiencies vary from modular components for individual protection needs with no conditioning via liquid conditioning to air cooling solutions. However, the solutions so far have been based on single component optimization with substantial deficits when trying to integrate them. Contrary to these approaches the GKSS – Full Coverage Protection System – approach considers the integrated system concept from the very beginning avoiding the deficiencies encountered with single components for single threat solutions. The GKSS, designed for the most challenging protection needs, comprises helmet, suit and the peripheral components using air ventilation for micro climatization of head and body. The GKSA suit design follows a three layer concept – the outer layer for threat / environment protection, the middle layer for distance keeping (air flow / insulation), and the inner layer for sweat transportation, insulation and limited flame protection. This concept applies in principle for the helmet as well.

*Paper presented at the RTO HFM Symposium on "Blowing Hot and Cold: Protecting Against Climatic Extremes", held in Dresden, Germany, 8-10 October 2001, and published in RTO-MP-076.*

**Introduction**

Before addressing the advanced technology applied for heat stress mitigation, the situation of human beings in relation to nature shall be looked at. When man is borne he is naked as many of the creatures. However, when growing up man remains naked while most creatures will build up protective covers like furs, feathers or fish scales.




Since man needs protection against rapidly changing environmental conditions - from hot to cold, from sun to rain or snow, or calm to windy conditions - he started covering and protecting himself accordingly by imitating nature using leaves, furs or feathers. And man was the only creature being capable to develop and manufacture protective clothing by means of his hands. But this protection was just against natural environmental conditions. As the evolution of man continued, unfortunately hostile actions with different kind of weapons came into place. Consequently, the priority changed from needs for protection against environmental conditions to protection against threats.

**State of today**

The above situation is generally relevant to all man working under protection - civil & military - but in particular for all warfighters. For the following considerations, we will refer to the combat fighter pilot as an example with most challenging requirements. During one mission he could encounter extreme environmental conditions as well as all kind of threats – only little difference with peace time flying or combat operation. In order to meet these needs and maintain a certain kind of flexibility the most popular protection concept applied is the single component / single threat / environment approach with optimized protection features for special environments or threats.

From the pilots' standpoint this situation is shown below.

**Traditional Pilot Equipment**

**Shell By Shell - Like An Onion**

However, the requirement to simultaneously wear impermeable, semi-permeable or permeable protection components generated new problems: heat stress on the one side and incompatibility of the components on the other side. When trying to perform system integration based on these single components, it usually is considered at the very end of a development. The result is very often: It is either too late for integration or worse - not even feasible at all. Example: To our knowledge, there is no integrated protection against CB and cold water immersion available for fighter pilots - at any service worldwide!

Does this indicate the limit of the single component / single threat approach - onion like - for life support equipment?

**New Technical Approach: Integrated System**

To our understanding, integrated life support systems offer a way to overcome the discrepancies of single component / single threat systems.

If we are right - one may ask: Why have they not been introduced yet?

There are several reasons for this:

- The need for a high degree of integration for protection garments was not prevailing in the past - but latest experiences in hostile engagements revealed this necessity.

- Since integrated garments include multiple protective functions simultaneously they might look bulky on the first glance and they might not be worn on all occasions – therefore they are often lacking acceptance by pilots under daily (peacetime) operation.

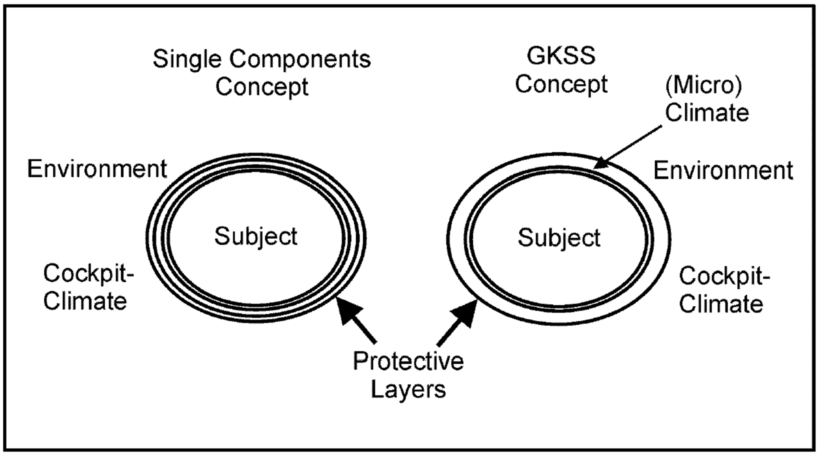
- Missing technologies and suitable materials.

- Logistics: Improvements of single components / systems are at lower cost - replacing only one component at a time (but the improvement as well is limited to even this component). On the other hand introducing an integrated system offers a major step - but would replace a number of components and is more costly therefore.

- But the major reason of all seems us to be experience - the experience with the limits of the single component approach for single threat / environmental conditions.
  These limits are well understood amongst the services, the engineers and scientists now
  - otherwise we all would not have met here at this dedicated symposium!

Our involvement in different fields of application – spacecraft and combat aircraft – and our experience with limitations of the single components approach for single environments / threats led us to initiate the advanced integrated systems approach for full protection and heat stress mitigation (GKSS). This system concept approach means - instead of looking for improvements of individual components - to consider the overall requirements and to tailor the system, all its subsystems and components to these needs. The result achieved is presented today as the GKSS – the Full Coverage Protection System. For the purpose of introducing the GKSS, it is focused on the most challenging application case - jet fighter pilots and their burdens during combat operation.

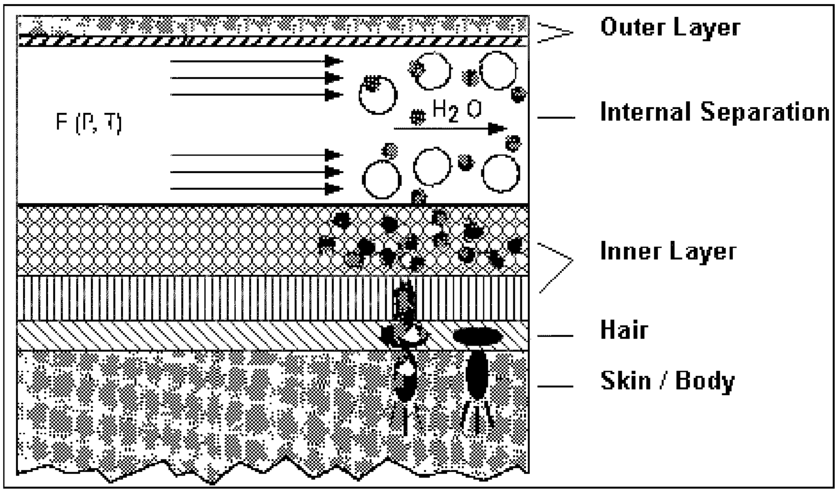
How did we proceed? Right from the beginning it was quite clear that the idea of integrating all protective components / measures between the pilot and the (hostile) environment simultaneously, would automatically insulate the pilot to a peak accumulation of heat stress. Since this was strictly to be avoided by the integrated system, our first step was to turn this design procedure upside down:




Looking at the single components concept, the protective layers are next to the pilot, thus separating / insulating him from the (cockpit) climate and causing heat stress, while the GKSS allocates a micro climate next to the body surface, thus preventing heat stress and keeps the protective layers outside / apart from the pilot.

Now, after the first step was done by "rearranging" the layers, thus incorporating the (micro) climate zone, the second step was how to implement this technically: This was achieved by what is the principle of the GKSA: comprising three special layers tailored to customer needs and with dedicated functions:

1) an inner layer,
2) a middle layer, and
3) an outer layer.




1) The inner layer, which is similar to underwear, is designed for three functions:

- Primarily it supports the human thermoregulatory system to transport heat and to evaporate humidity from the body towards the middle layer. These processes are paramount prerequisites for heat stress mitigation.

- As a second task the inner layer functions as an insulation which applies in particular in cold or when immersed in cold water. Therefore different materials may be used for extreme insulation purposes, however, the functionality for support of the human thermoregulatory system is not compromised.

- Fire protection by flame retardant material, adding to the fire protection of the outer layer.

2) The middle layer is an internal separation consisting of a flexible, air permeable material, keeping a defined distance between the inner and outer layer. This way, an internal separation is generated, which extends around the body surface and is designed for multiple functions:

- Flow duct for circulating air around the body surface!
This is the key issue of the GKSS concept and the highlight of our presentation on heat stress mitigation.
What happens? An air flow ventilating through the system, when passing through the separation, picks up heat and – most essential – humidity / perspiration of the body, which was transported by the inner layer material to this air flow.
Only this effect, which we call “Micro Climate Zone”, allows the body to maintain it’s natural thermophysiological mechanisms for dry and evaporative cooling – even under workload, and as if it was not encapsulated by all the protective layers outside!
This is our way of heat stress mitigation under protection and workload, in principle. It is obvious, that this way offers further potential: Depending on operational requirements and working conditions, the air flow in the separation can be matched by means of lower or higher flow rate (chill effect), it may be just ambient air or conditioned air by cooling or heating it. For this purpose, the third following presentation "Air Ventilated Heating and Cooling based on Zeolite Technology" will provide you information about a new and promising technology, which is used to improve our artificial Micro Climate Zone inside the GKSS.

- The air layer contained in the separation provides for insulation against external heat, including flames, radiation and external cold, including cold water. This is true even under emergency conditions, when no air flow is available and the internal air layer is in rest.

- The air volume, contained in the internal separation provides lift in case of water immersion under emergency conditions.
  Further to this, the particular distribution of this air volume in the separation layer around the body provides a particular lift distribution while immersed, with other words: flotation attitude and flotation stability.

  All these functions are interrelated by the fact that they all are depending on the thickness and distribution of mentioned spacer material around the body. Therefore the design of the middle layer requires a sensitive and careful trade-off between ventilation, insulation, and flotation needs as well as bulkiness / mobility considerations. For instance the separation is designed with thicker distance material in those areas where compression could occur, e.g. under external forces or body weight such as in the buttocks, the back area and the areas where harnesses could hinder a free air flow. Where these requirements are less stringent the distance material will be thinner for better mobility.

3) The design of the outer layer is tailored to meet the various operational protective functions. However, the minimal requirement for the outer layer is to be air tight with respect to the internal air flow and it should fit to the individual body in order to avoid excessive space between the layers which will cause the air not to circulate properly through the internal separation. Also, the airflow may not be too high as it will cause a storm inside and balloon the system like the Michelin man, further it might harm the individual in the mid and long term.

   The material of the suit's outer layer presented today meets the general requirements for pilot equipment. Particularly it is designed to be resistant against

   - war agents like Mustard, Sarin, Soman, in all phases liquid, vapor, gas,
   - fire and flames,
   - POL,
   - wear and tear,
   - immersion;
   - blast,
   - e.t.c.

In addition to these three functional layers the system comprises an air distribution system inside the suit. This receives the air flow from an external module supplying (filtered) ambient or conditioned air and leads it to the primary human heat exchange surfaces. These surfaces - which are legs, arms, and head - have been carefully investigated and verified in close cooperation with the expertise of the GAF IAM. We can assume, that IAM harmonized with our mothers, because they already applied this knowledge when we had fever, she used to cool our wrists, calves and forehead - but never the chest (body core). So, we survived without pneumonia and got the opportunity to design the GKSS accordingly, leading the cool air flow to enter the internal separation at the ankles (and / or wrists, depending on the design) and head. From the extremities, the air flow distributes to the body center, following the lowest back pressure through the separation, picking up heat and perspiration generated according to the individual's workload and external loads and finally exits at the outlet valves.

Summarizing, the GKSS concept is characterized by

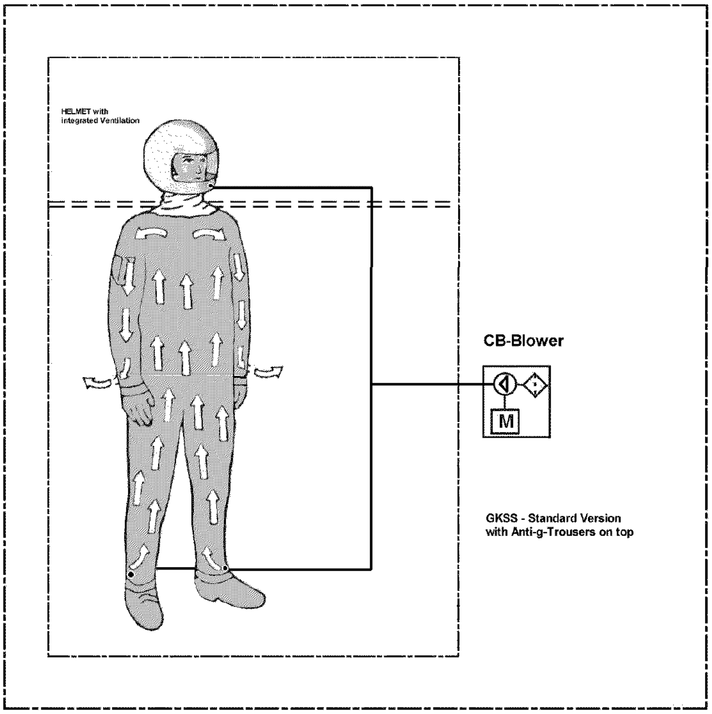
- integrating various protective functions in a total of three layers (including underwear), and leaving it open to add more protective measures on the outside, e.g. parachute, ballistic vest, survival vest, etc.

- incorporating a Micro Climate Zone close to the body for heat stress mitigation.

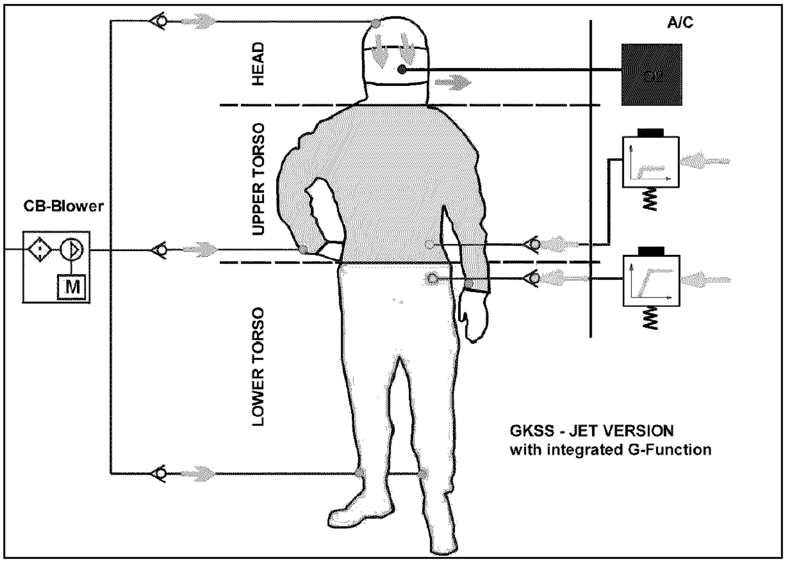
But - since we selected the combat fighter pilot Life Support System as the most challenging application to describe the GKSS principles and potential, you might be asking how to inhibit g-protection?

This has been resolved in two ways:

a) The standard GKSA configuration as just described in combination with the conventional in-service anti-g-trousers on top of the suit can provide g-protection for fighter bomber aircraft such as TORNADO without change of aircraft interfaces.




b) For g-levels of high agility fighter combat aircraft a particular GKSA - Jet configuration was designed: The micro-climate zone around the body was divided by an impermeable membrane into an upper and a lower torso regime allowing for different pressure levels of the air flow. This configuration, however, would require modification of the aircraft interface or is available for integration into new aircraft.




Both configurations incorporating g-protection in different ways are including all other protective functions described before as well as the particular heat stress mitigation provided simultaneously. Detailed test results on both configurations will be given during the following three presentations.

The application tracks chosen for the GKSS are:

- General military multi purpose / multi function system, e.g. tactical aircraft, helicopter, transport aircraft, tanks, vehicles, infantry, etc.
- Special military multi purpose / multi function system for tactical aircraft with high agility
- Tailored commercial function system, e.g. for fire fighters, chemical fighters, nuclear power plants, racing cars, etc.

**Historical Development**

The concept to realize a close to the body micro climatization goes back to the year 1985, when it was presented to the German MoD. 1986 followed the development and manufacturing of a ventilated prototype helmet without mask, while in 1987 initial testing and ergonomic investigations have been conducted in close collaboration with the German Air Force Institute for Aeronautical Medicine IAM. Based on these results, the design and manufacturing of the first Full Coverage Protection Suit including g-function followed in 1987.

After simulation of the thermal conditions with the suit, first evaluations were conducted by French Pilots of the European Space Program as well as by the RAF - SAM (1989/1990). Also in 1990 pre-tests for air conditioning (GAF IAM) and g-function testing (USAFB Brooks, 1991) were carried out. Still in 1991 a test series for air conditioning was performed, followed by the verification of thermal conditions. Multiple presentations in 1992 and 1993 included GAF Armament Directorate, General Flight Safety, Zvezda, and SAFE Europe. Late in 1993 centrifuge testing was initiated at GAF IAM, which was continued with improved GKSA – Jet versions up to 2000.

In 2000 GAF continued g-testing and concentrated investigations on compatibility and integration possibilities between the new FAS helmet (flight helmet with NBC protection) and the GKSA helicopter version for TORNADO. Additionally, compatibility investigations have been conducted for the C160 TRANSALL transport aircraft and the new TIGER helicopter. Since one of the major requirements was flying over sea, combined FAS / GKSA immersion testing in the pool and open sea and cold water tests in the climatic chamber have been carried out in 2001. G-protection by using the standard GKSA suit and conventional in service anti-g trousers was tested in 2001 by GAF IAM.

In parallel to the efforts of GAF, extensive work based on the GKSS concept has been conducted in the USA. In 1995 the GKSA System was presented to USAF, at AFB Brooks and to USN at NAWC Warminster. In1997 USNAWC initiated the Helicopter Aircrew Integrated Life Support System (HAILSS) Program comprising a full helicopter pilot ensemble for operation under CB conditions over water. Industry conducted system performance tests and material qualification tests including fire tests on the Pyroman and CB tests. In parallel USN conducted thermal, Clo, buoyancy, CB and material testing and aircraft integration, cumulating in USN plans to perform flight verification testing on helicopters in the second half of 2001.

**GKSS Status and Test Results**

Having described the technical GKSS concept and our long way learning from mother nature how to implement it, it's now time to talk about test results in detail.

It is a particular pleasure to us, that two competent institutions, conducting test efforts in parallel over years, will report their respective results, conclusions and - hopefully - perspectives. This will be given from the side of USN by Dr. Förster and from side of GAF by Col Dr. Knöfel / Col Dr. Welsch / their representatives as well as from the BWB, Mr Fusz, in the following two presentations.

In addition to that, the mentioned innovative Zeolite technology, which is applied when cooling is becoming more stringent, will be presented thereafter by a Dr. Schmidt of Zeo-Tech GmbH.

**Results and Conclusions:**

Testing at GAF, USN and ourselves established the evidence - from our point of view - for the GKSS concept being a promising and feasible solution to integrate paramount functions for heat stress mitigation and for protection into one system - which can be tailored to particular operational needs. GKSS is clearly an innovative concept, and - as new things always do - it may create concern. But, our concern should better concentrate on the conventional equipment and it's limitations. To overcome these, a new system has to be different and thus novel. As you will see from the following test results the GKSS concept has a big potential for any man under workload requiring simultaneous protection - military as well as commercial.