THE UK GENERAL SERVICE RESPIRATOR

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ABSTRACT

Since the introduction of the current UK NBC respirator, the S10, in the 1980s, military equipment, operations and the NBC threat have all changed. The direction and nature of the threat are now more uncertain, and there is increased emphasis on biological agents. In response to these changes, the UK is procuring a new General Service Respirator (GSR). This paper describes the concept development of the GSR at Dstl Porton Down to increase protection while increasing equipment compatibility and decreasing the user burden.

Protection was considered in terms of air management, face seals, filters, exhale valves and dead spaces. User burden issues mainly concerned physiological load (respiratory resistance, carbon dioxide build-up and heat and sweating), perceptual-motor impairment (mainly vision and speech); psychological effects (eg isolation, motivation, mood), and ergonomics (sizing, ease of use, maintenance). Equipment compatibility issues involved iterative design and testing to improve the interface between the respirator and equipment, mostly optical equipment, weapons and communications systems. Dstl successfully met the main requirements, but it is not possible to find a complete solution for every problem and everybody, as all the factors impact on one another, and different user groups have different requirements.

INTRODUCTION

The current UK NBC respirator, the S10, was designed originally in the 1980s for a Cold War scenario. Since then, military equipment, operational requirements and the NBC threat have all changed. In particular, the nature and direction of the threat are more uncertain, and there is now an increased emphasis on biological agents. In response to these changes, the UK is procuring a new GSR, working towards an in-service date of the latter half of 2005. Dstl was tasked with the concept development and proof of principle to identify, research, devise and develop technologies to meet the new requirements, and to integrate them into a prototype respirator under three main headings: improving protection, reducing user burden, and improving equipment compatibility.

This paper describes Dstl's approach and some of its work to meet these requirements. It is not possible to cover all the work, and the paper concentrates on some of the most problematic and interesting aspects. Solutions are not offered for every problem as it was recognised that a complete solution for everybody and every problem was not possible: different users have different requirements, and all the respirator components would impact on one another such that improving matters in one direction would exacerbate or introduce problems in another. However, the work described offers some insight into the problems and suggests some ways of dealing with them.

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PROTECTION

Protection is the primary requirement of any respirator, and is only as good as the worst leak path. There are three main leak paths into a respirator: the filter (and attachment); the exhale valve and the face seal, all influenced by the air management within the respirator.

1 AIR MANAGEMENT

In most passive, or negative-pressure respirators, air is drawn through the filter and ducted over the eyepieces to demist them before being inhaled, and exhaled air passes out directly through an exhale valve. The main problem here is that inhaling reduces the internal pressure, which encourages leaks.

Dstl investigated two possible solutions[1]. The first (dual cavity; Fig 1) incorporated an oro-nasal mask, with its own seal (rather than an airguide), inside the respirator. This was to confine the pressure changes due to breathing inside the oro-nasal cavity and eliminate, or at least reduce, the pressure changes across the main face seal. The results showed that the oro-nasal mask did eliminate the pressure drop across the faceseal, but the eyepieces tended to mist as there was no airflow over them.

In order to overcome this, a small pump was introduced, which required power and extra space, but had several advantages. First, it prevented eyepiece misting; second, it provided a slight overpressure which discouraged leaks; third, it helped purge the respirator; fourth, excess air could be ducted over the exhale valve to maintain a clean valve deadspace (see below). A reversionary mode was needed in case of pump or power failure, and was achieved using an air switch to re-direct the airflow back to an S10-type pattern. This offered two levels of protection, and worked well, but increased the size of the respirator "snout".

The second solution incorporated a sealed eye cavity as well as a sealed oro-nasal cavity (triple cavity; Fig 2). Here, inhaled air is ducted through the eye cavity to demist the eyepieces, and then into the oro-nasal cavity, which avoids the need for a demisting pump and a separate reversionary mode. However, the complex topography around the eyes and nose made it difficult to achieve a good seal, and it was found that the same effect could be achieved by combining the eye and oro-nasal cavities, with an airguide between them. This was further simplified by moving the eyepiece and oro-nasal seals further outwards until they became, in effect, a second face seal. A pump could still be used, but its load would be reduced as it would only be required to provide overpressure in the space between the seals and a clean exhale valve deadspace.

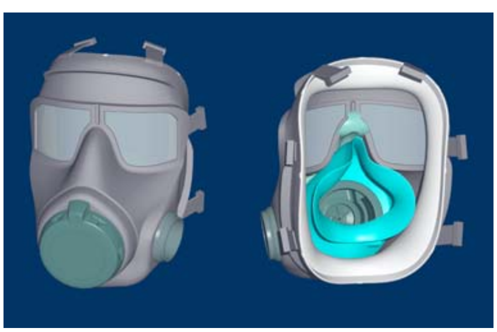

Figure 1: Dual cavity GSR design.

Figure 2: Triple cavity GSR design.

2 SEALS

The faceseal is the most vulnerable leakage path, and the most difficult to deal with: it has to accommodate a wide variety of face sizes, shapes and movements (eg speaking), and must also cope with face secretions, soiling and beard growth. A variety of face seals designs is possible, the main ones being single-skin, airbag, reflex and double-bladed. The dual-cavity design also had to consider an oro-nasal seal.

All types of seal have advantages and disadvantages[1]. Single-skin seals provide the least protection, but are simple and cheap to manufacture. Airbag seals provide very good protection and are conformable to face shapes and movements, but they are much more expensive as they need separate moulding from the facepiece. Reflex seals are cheaper than airbag seals and require only a single piece moulding, but they involve complex tooling and are less comfortable and conformable to face variations. Double-bladed seals are very compliant and tolerant of face variations within a given size, but they are difficult to manufacture and their sizing is critical. Whatever the type, faceseals must not extend beyond the hairline, otherwise trapped hair will cause leaks, and all need a cross-sectional skin contact of about 10 mm to be effective, which reduces the available space on the facemask, particularly with small sizes of respirator.

3 FILTERS

Filter assemblies commonly consist of canisters containing a particle filter (often glass fibre paper, usually pleated to increase surface area), a vapour adsorbent (usually activated carbon), and impregnants to deactivate agents that are not easily adsorbed. The amount and type of filter material are dictated by the expected nature and extent of the threat, and in turn dictate the breathing resistance and the size and shape of the canister. This makes for a bulky canister that is vulnerable to fouling and intrudes into the visual field.

Dstl work on filters[1] has concentrated on new forms of carbon, such as fibres and monoliths, for vapour filtration, and electrets, which capture particles by electrostatic attraction, for particle filtration. These materials offer the same filtration efficacy with reduced breathing resistance, and can be shaped, allowing smaller, more ergonomic canisters. However, a problem with electrets is that they can lose their electrostatic charge over time and if exposed to some substances commonly found on the battlefield, including Diesel exhaust, components of explosives and smokes, and water.

4 EXHALE VALVE ASSEMBLY

The exhale valve assembly comprises the valve itself, the valve housing, and a deadspace: a partially-enclosed space immediately outboard of the valve. The deadspace is needed because all valves leak: the deadspace holds some of the exhaled air next to the valve and ensures that any back leakage is clean. The more that clean air is maintained in the deadspace, the better the protection will be. An obvious solution is to use two valves in series, but this tends to increase exhalation resistance unacceptably.

Dstl looked at two alternatives[1]. First, it was found that the deadspace could be maintained by a flow of clean air over the surface of the valve, and this could be achieved by bleeding off excess air from the demisting and overpressure supply (above). Second, new deadspace designs were made and trialled, including “pepperpot” and spiral or volute structures that accelerate and decelerate airflows, making it easier for air to get out and difficult to get in. These designs work well, but some can also increase exhalation resistance.

USER BURDENS

Dstl divided user burdens into six: physiological (mostly breathing resistance, carbon dioxide build-up, heat and sweating), perceptual-motor (mainly visual acuity, field of view and speech); psychological (eg isolation, motivation, mood), ergonomic (eg sizing, ease of use, maintenance, decontaminability), cognitive (thinking, reasoning), and biochemical (changes in hormones, enzymes etc that can reflect or presage performance degradation). Most work was carried out on the first four.

1 BREATHING RESISTANCE

Inhalation resistance is caused by the filter, inhalation valve and inward airflow management; exhalation resistance is caused by the exhale valve and valve deadspace (the outward airflow path is usually direct and not a problem). These resistances impose extra work on the respiratory muscles, which will fatigue more quickly and reduce physical work endurance. Inhalation resistance can be reduced by using new forms of carbon and particle filters, and exhalation resistance can be reduced by new valve and valve deadspace designs (above).

Reducing breathing resistance increases exercise endurance[2], but there are arguments that it should not be reduced to zero, even if it could be. Some exhalation resistance is necessary to build up pressure to help purge the respirator, and some inhalation resistance may be important to re-assure the user that the respirator is working[1]. Also, the balance of resistances may be important: anecdotal evidence from user trials suggests that exhalation resistance may affect than inhalation resistance on physical work endurance[2].

2 RESPIRATORY DEADSPACE

Respiratory deadspace is the space between the outside air and the gas exchange surfaces in the alveoli of the lungs. This deadspace is effectively increased by the internal volume of respirators, which reduces the oxygen concentration and increases the carbon dioxide concentration. The latter is more important for physical work endurance.

The obvious answer is to reduce the internal volume of the respirator, but if it is reduced to the extent that the internal structures of the respirator begin to touch the face, then physical work endurance can be reduced, rather than increased[2]. This could be because the internal mouldings were so close to the face that they obstructed the airflow, a distracting effect, or possibly, increased feelings of claustrophobia.

3 HEAT AND SWEAT BUILD-UP

Heat and sweat build-up is caused by the impermeable nature of the respirator material reducing heat radiation and preventing sweat evaporation (sweat must evaporate to have a cooling effect). The extra heat load caused by a respirator is not significant compared with that caused by the full protective ensemble in moderate temperatures (but may be in hot temperatures)[2]. However, sweat build-up can occur even in moderate temperatures, and can be very uncomfortable, particularly as it collects around the chin and causes soreness[3]. It may also affect the faceseal around the chin.

Some respirator designs place the exhale valve at the lowest point, so that sweat can escape. However, this was not favoured for three reasons: first, valves do not work well when submerged; second, the sweat (and dried residue) can impair valve seating; third, the assembly is vulnerable to fouling when lying prone or crawling. Alternatives include channelling and super-adsorbents to remove the sweat from the face, which would require more space, or to reduce sweating, which would require drugs or anti-perspirants, which would introduce some novel problems of their own.

4 VISUAL ACUITY

Visual acuity is a function of the design and clarity of the eyepieces, which should be as optically normal and clear as possible, and also resistant to misting and scratching. Dstl carried out most work on misting. Misting is caused by the evaporation of water from the eyes and face, and by exhaled breath escaping from the oro-nasal cavity into the eyespace, particularly when the eyepieces are cold and when the wearer is breathing hard. An airflow is the best method of demisting, but anti-misting coatings can help. Hydrophilic coatings are durable but lose their anti-misting properties when they are fully loaded; hydrophobic coatings prevent misting for longer, but are less durable[1].

5 FIELD OF VIEW

Field of view is a function of the size of the eyepieces and the eye relief (distance from eye to eyepiece). Bigger eyepieces are the obvious answer, but they would compete for space on an already overcrowded facepiece, and may not actually improve matters (below). Reducing the eye relief would also help, and would improve compatibility with optical equipment (below). However, it could also exacerbate feelings of claustrophobia, and the demisting air flow would be faster, which could dry the eyes, causing irritation and possible vision impairment. Also, space must be allowed for insert spectacles to correct vision defects (the eyepieces themselves could incorporate vision correction, but this would be very expensive).

Would a one-piece eyepiece/visor help? Most users say that it would, but there are several interesting issues here[4]. Field of view is restricted more by the faceseal, filter and snout than by the visor. Vision immediately in front of the nose might be improved, but people do not normally view objects so closely. Objective field of view measurements do not agree with what wearers say they can see, which depends on what the wearers are required to do: field of view for recognising objects is less than that for detecting objects. A one-piece visor would impair compatibility with optical equipment, the larger area could reflect more light and betray a hide position, and could cause a "greenhouse effect", increasing heat load. It would also make the respirator more rigid: two eyepieces allow the facepiece to flex, which aids conformability to different face sizes, shapes and movements. However, if it makes the user feel a lot better (see below), perhaps the benefit of a one-piece visor might outweigh its disadvantages.

6 SPEECH INTELLIGIBILITY

Respirators impair speech intelligibility by attenuating and distorting sound, and by restricting lower jaw articulation. Speech modules help, but it is widely accepted that speech intelligibility in any respirator is still far from perfect.

Dstl has mapped sound transmission through respirators, and found that the major contributors are the speech module, the exhale valve and, at certain frequencies, the eyepieces. The exhale valve needs only to be open slightly for sound transmission to increase markedly, but it tends to vibrate and distort the sound. This can be remedied by asymmetrically weighting the valve to dampen the vibration, but it may affect valve operation. The eyepiece effect is interesting, and opens the possibility of tuning the eyepieces to increase the effect, or using them as speakers. Microphones may be used to advantage, but need to withstand the very large pressure changes caused by speaking, and need to be sited carefully to capture the speech. Power would be required, but with careful management, even a small cell could last several days.

A problem here is that the standard methods of measuring speech intelligibility, the Speech Attenuation Value (SAV) and the Modified Rhyme Test (MRT) have deficiencies, and their results often disagree. The SAV measures certain physical features of sound transmission but does not measure intelligibility. The MRT measures intelligibility, but is subjective and hence suffers from wide variability. Also, the MRT is American and not entirely appropriate for Britons, and it is old and not entirely representative of current word usage. Dstl is currently working on new methods including normalised insertion loss and an adaptive MRT using up-to-date British vocabulary.

7 PSYCHOLOGICAL

Psychological burdens consist of effects on conative function, feelings, mood and subjective state, and comprise a variety of ill-defined effects including discomfort, anxiety, psychosomatic problems such as headache and gut upset, feelings of isolation and claustrophobia, impaired motivation and communication, depressed mood and subjective feelings such as hotness and breathing difficulty[2,4].

These effects might sound trivial, but are actually quite serious: they can cause distraction and degrade performance, and tempt the user to keep adjusting the respirator with the risk of breaching the faceseal. Comfort could be increased, but most materials that are comfortable are not chemically hard, and cushioning would increase the size of the respirator and affect equipment compatibility. Full-face visors might help reduce feelings of isolation and claustrophobia, but would introduce a variety of other problems (above). Perhaps respirators should be designed to look "cool".

EQUIPMENT COMPATIBILITY

Equipment compatibility could be considered as an ergonomic user burden, but is often considered in its own right. It is important not only because respirators can impede proper use of equipment, causing performance degradation, but also because trying to overcome the difficulties can affect the respirator and compromise protection. For example, pushing the face harder into optical equipment to obtain a better view can distort the respirator facepiece and faceseal, possibly causing leaks.

Dstl carried out several iterative assessments of prototype respirator facepieces with several military units including infantry, armour, artillery, special forces, marines, naval personnel and airforce groundcrew[5]. The results of each assessment were fed into the design of the next prototype. The range of equipment was wide, and included vision aids such as binoculars and night vision goggles, personal weapons, other shoulder-fired weapons, crew-served weapons, various vehicles including armour, vehicle-mounted sights, and communications equipment including command and personal radios.

The results highlighted several areas of interest. The eye relief should be low to improve access to optical equipment, but this could cause vision problems (above). The respirator brow profile should be low to fit under helmets, but this could weaken the seal in this area. Cheek profiles should be low and smooth to improve the use of shoulder-fired weapons, and the snout and filter canister profiles should be low to improve access to equipment and confined spaces, and to reduce the fouling hazard and intrusion into the visual field. The problem here is that there are limits to reducing the profiles while still accommodating components such as face seals, filter canisters, valve assemblies, drinking assemblies and speech modules. It is possible to reduce some profiles, but not all, and different user groups will have different priorities.

OTHER WORK

Other work carried out by Dstl on the GSR includes: self-powered pressurisation to avoid the need for batteries and pumps; integration of the respirator and hood to reduce the challenge to the faceseal without increasing the user burden; respirator sizing using 3D head scanning and rapid prototyping; drinking and eating; improving protection measurement in terms of sensitivity and sampling statistics; battlefield protection measurement; real-time respirator confidence checking; studies of particle properties and sizes to ensure appropriate protection; filter life indicators; harnesses and new respirator materials.

CONCLUSIONS

Dstl has identified, developed and demonstrated technologies that can improve the protection afforded by respirators, while reducing the user burden and improving equipment compatibility. A complete solution for every problem and everybody is not possible, as all the factors impact on one another and different user groups have different requirements. However, the work has provided valuable insights into the issues involved and the approaches to take to deal with them.

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