Explanatory Notes on CA-EBS (Compressed Air Emergency Breathing Apparatus) for Oil & Gas UK Examining Doctors

Background:

Following a helicopter crash off Sumburgh in August of 2013 in which four passengers died (two from drowning, one from cardiac arrest, and one from an incapacitating head injury) the CAA directed the UK oil and gas industry to introduce a more easily deployed emergency breathing system, and the 'PSTASS' (Passenger Short-Term Air Supply System) compressed-air breathing apparatus was introduced to service for passengers on offshore helicopter flights in the UK sector of the North Sea in 2015. Following trials in November 2015 and December 2016, the HSE has concluded the risks of introducing PSTASS equipment into survival training courses can be sufficiently mitigated, and in-water training exercises using PSTASS are expected to commence at survival training centres no later than January 2018.

Risks of helicopter incidents:

CAP1145, the CAA report following the August 2013 crash, lists 24 helicopter incidents between 1992 and 2012, 7 (28%) of which involved fatalities. Many incidents were 'other' in nature (for example, lightning strike, landing gear problems) but three were ditchings (a controlled landing on water) and five were uncontrolled impacts with the sea (a crash). The overall rate of helicopter incidents was 1 in 588,235 flying hours (1 in 1.25 million flights) for a controlled ditching into the sea, and 1 in 357,142 flight hours (1 in 714,285 flights) for uncontrolled impact with the sea.

The PSTASS system:

The PSTASS system consists of a small compressed air cylinder integrated into the passenger lifejacket, providing sufficient air for up to one minute, connected to a conventional demand valve and mouthpiece. The system is easily and rapidly deployable and being 'always on', has no need for operation of on/off switches for successful use.

The general hazard of breathing compressed air underwater:

The general hazards of breathing compressed gasses and/or air in water are well understood from both the commercial and recreational diving experience. The principle hazard to be considered for the helicopter scenario is that of overpressure damage ('barotrauma') occurring in gas-filled spaces in the body. The principle effects which could immediately cause harm both in training and in a helicopter emergency are pneumothorax and/or arterial gas embolism, which arise as a consequence of the relationship between gas volume and pressure changes with depth.

Risk of barotrauma in commercial and recreational diving:

The 2003 British Thoracic Society guidelines on medical fitness to dive provide some figures on incident rates in Royal Navy submarine escape training, military diving, commercial diver training, and recreational diving. From these figures, the overall risk of barotrauma can be calculated to range from 1 in 76,968 (pneumomediastinum in military divers) through 1 in 200,527 (pneumothorax in military divers) to 1 in 491,000 (gas embolism in recreational divers). It is considered that for a trainee in normal health, the risk of barotrauma from in-water PSTASS training exercises (where the pressure and volume changes are substantially less – see below) should not exceed these figures.

The nature of in-water PSTASS exercises:

Survival training pool exercises will involve a series of six exercises with the PSTASS unit, beginning with facial immersion in the water, then minimal submersion of the head underwater, followed by a shallow underwater swim/pull along a bar on the side wall of the pool. Each exercise lasts at most 30 seconds, during which five or six breaths are taken from the EBS. The specific exercises are:

a) deploy EBS above water, place face in water while floating on surface, breathe from EBS
b) place face in water on surface, deploy EBS underwater and breathe from EBS
c) place face in water on surface, deploy EBS underwater (with non-dominant hand) and breathe from EBS
d) deploy EBS above water, then descend to maximum 70 cm depth, breathe from EBS
e) descend to maximum 70 cm depth, then deploy EBS underwater and breathe from EBS
f) deploy EBS, swim/pull 'hand-over-hand' along a bar at maximum depth 70cm while breathing from EBS

The purpose of exercises a), b) and c) [figures 2&3] is to gain the trainee's confidence that the system will provide air without inhalation of water; the purpose of exercises d) and e) is to gain the trainee's confidence that the system can be deployed and used with the head and mouth submerged (figure 4), and the purpose of exercise f) (figure 5) is to gain the trainee's confidence that the system can be successfully used while moving through the water (as it would be in the cabin of an inverted ditched or crashed helicopter). Trials of the EBS system with volunteer subjects have shown universal positive feedback from trainees in meeting these objectives.


Fig 2 breathing at surface Fig 3 deploy EBS at surface: note much of thorax is out of the water, and demand valve is at ~15 to 20cm depth

Fig 4 breathe from EBS at ~50cms: head and thorax completely immersed

Fig 5 – hand-over-hand pull along bar:
bar at 70cm; buoyancy of body means thorax and head are shallower – back of head is 'breaking surface', and depth of thorax/demand valve is shallower than 70cm.

In diving terms, the survival training exercises are closest in nature to the early stages (pool training exercises) of recreational scuba diving training, but will not reach the same depth. In addition, survival training using PSTASS differs from scuba diving in that offshore workers will not progress to open-water diving in the cold or dark (survival training pools are warm [29 degrees C] and well-lit); there is no requirement in survival training to undertake marked physical exertion (there is no need to swim against a tidal current, wear weights or large tanks, or pull a heavy 'umbilical'), and there is no need for the worker to rescue a 'buddy' or self-rescue (at least one safety diver in the pool at all times). The exercises do not require more than minimal in-water physical effort and while it is known that immersion in water may cause an increase in cardiopulmonary system workload, for the vast majority of participants this should not result in significantly increased respiratory effort.

Risk of barotrauma in PSTASS in-water exercises:

The risk of barotrauma in the PSTASS exercises described is considered to be 'very low', and very much lower than in submarine escape training, military diving, commercial diver training, and recreational diving, for which there is some quantitative data. The potential pressure/volume relationships are much less extreme than in recreational or commercial diving, and the circumstances of the exercises are much less prone to panic-inducing incidents. Risk mitigating measures during survival training PSTASS exercises will include a) strict control of depth, b) progressive exercises to gain confidence and reduce scope for anxiety, and c) individual instructor/trainee direct supervision during exercises to ensure no breath-holding on ascent. BSAC (the British Sub-Aqua Club) reports training many thousands of recreational divers without a single known occurrence of barotrauma in pool training exercises in the past seventeen years, and experience from Canada has also been event-free to date (see below).

PSTASS training experience in Canada

In-water HUEBA (Helicopter Underwater Emergency Breathing System, the same type of system as the UK PSTASS equipment) exercises were introduced into survival training in Canada in 2009. CAPP (the Canadian Oil & Gas UK equivalent) reports that at least 10,000 Canadian offshore workers have undertaken shallow-water exercises similar to those which will be undertaken in the UK, and in addition have also undertaken SWET (Shallow Water Escape Trainer) chair training (which is NOT expected to be undertaken in the UK), without any reported adverse medical events. The Canadians have since gone further, introducing PSTASS equipment to HUET training exercises in June 2016, again so far without reported problems.

Medical assessment considerations for PTSASS/EBS:

The assessment of recreational divers in the UK provides a useful reference point. In the UK, an offshore worker who wished to take up recreational sports diving (which could ultimately include open-water diving to the depth limit of air diving at 50metres) may do so by completing a self-declaration form in which they confirm that they do not have any of a number of relevant medical conditions. Note that no specific medical examination or test is required. Those unable to make a declaration of absence of such medical conditions are required to contact a medical referee for further discussion and assessment, which may or may not involve specific medical examination or test(s). The UKDMC (UK Sports Diving Medical Committee) provides the rationale that it considers this a safe and appropriate system of medical assessment for a leisure activity.

The Health and Safety Executive (HSE) considers use of compressed air breathing equipment in survival training in principle to be 'diving at work'. This would legally require trainees to undergo a full commercial diver medical examination by an HSE Approved Medical Examiner of Divers. However, having observed the December 2016 pool trials of the specific five exercises described above, the HSE has subsequently exempted trainees from this requirement provided that they a) possess an in-date Oil & Gas UK medical and that b) they also follow a similar system of self-declaration of absence of relevant medical conditions. This is consistent with practice in Canada, where CAPP medical assessment for in-water PSTASS training (including PSTASS in HUET) is for the inclusion of a number of questions within the CAPP medical (Oil & Gas UK medical equivalent) to elicit a history of clinical pathology relevant to increased risk of barotrauma, with further assessment (involving specialist input in some cases) of those with a history of such pathology.

The Oil & Gas UK scheme for medical assessment of trainees prior to in-water PSTASS exercises will be as follows:

1. Potential trainee completes a specific questionnaire, focused on (mostly respiratory) conditions that would improve the chance of identifying increased risk of barotrauma.
2. The potential trainee discusses his/her questionnaire with an Oil & Gas UK doctor, to clarify that the questions and their significance are understood, and where non-negative answers are given.
3. Where the Oil & Gas UK doctor is satisfied that there is no history or clinical suspicion of a relevant medical condition, the trainee is certified 'fit to train'.
4. Where a history of relevant medical condition is apparent, the Oil & Gas UK doctor will perform relevant clinical examination and test(s) (for example, lung function tests), and use condition-specific guidance to classify examinees as either ‘fit to train’ or ‘unfit to train’. Where a medical condition is clinically suspected by the Oil & Gas UK doctor despite a negative history, the Oil & Gas UK doctor will perform relevant clinical examination and test(s) (for example, lung function tests), and refer appropriately for confirmation of

diagnosis and reports to allow completion of assessment against the condition-specific guidance.

The format of the assessment allows for documented discussion with the potential trainee of the nature of the hazard of breathing compressed air underwater, the risk of doing so applicable to the PSTASS exercises, the risk mitigation measures in training, provision of specific instruction to those 'fit to train' with medical conditions (e.g. asthma), and the trainee's understanding and acceptance of that advice.

There are some conditions (e.g. history of spontaneous pneumothorax, cystic fibrosis of lungs) which would be regarded as absolute contraindications to in-water EBS training, while others (COPD for example) will be 'relative contraindications', the outcome of assessment depending on the extent and severity of the condition.

It is understood that oil and gas industry personnel found medically 'not fit to train' will be excused in-water training, and will complete their survival training by 'dry-training for EBS'.

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Supplementary explanation - some Gas Law Physics

Remember: a) Boyle's Law: Pressure x volume = constant 'k' (assuming constant temperature)

b) Pressure changes by 1 atmosphere (='bar') for every 10 metre change in depth

c) normal atmospheric pressure at the earth's surface is 1 atmosphere, not 'zero'

Physics of pressure and volume changes in a notional recreational (sports) diving problem scenario:

Divers typically suffer barotrauma in ‘problem situations’ resulting in acute anxiety and rapid ascent to the surface while breath-holding. Consider a recreational scuba diver who dives to 30 metres below the surface: since pressure increases by 1 atmosphere for every 10 metres depth, at this depth the surrounding pressure is 4 atmospheres. Boyle’s Law of gases (Pressure x Volume = constant 'k', assuming constant temperature) means that if the diver takes a breath (tidal volume) of 700mls, 'k' will be = 700 (V) x 4 (P) = 2800. In a rapid ascent while breath-holding and with the glottis closed, as the diver ascends to 20 metres, 'k' remains at 2800, pressure reduces to 3 atmospheres, and the volume of that tidal volume breath would increase (if able to freely expand) to 2800 / 3 = 933mls. At 10 metres pressure has reduced further to 2 atmospheres, and with 'k' still at 2800, volume would increase to 2800 / 2 = 1400mls. As the diver reaches the surface, where pressure is 1 atmosphere, volume would reach 2800mls. These changes can be summarised in Table 1 below:

Table 1 – Boyle’s Law at various depths

Depth	Original inspired volume	Absolute Pressure (atmospheres)	'k'	New volume at depth
Surface	700 mls	1	2800	2800 mls
10 m	700 mls	2	2800	1400 mls
20 m	700 mls	3	2800	933 mls
30 m	700 mls	4	2800	n/a

While the actual physiological situation is clearly more complex (the discussion above ignores the volumes of air within residual volume and expiratory reserve volume, for example), diagram 1 illustrating typical lung volumes during the respiratory cycle clearly shows the nature of the hazard – in the situation described above, the diver's original tidal breath volume alone (ignoring residual and expiratory reserve volumes) of 700mls inhaled at 30m depth could increase to 2800mls at the surface. The 'extra' 2100mls increase on the original 700mls is alone a volume which is greater than the maximum further physiological expansion of his thorax, the inspiratory reserve volume (of approx. 2000mls). Provided the diver breathes normally during ascent, the 'extra' 2100mls volume is eliminated through respiration, but in breath-holding with a closed glottis and no route for the excess volume to pass to the surrounding environment via the mouth, gas expansion causes a corresponding 'overpressure' which may cause the 'extra' gas volume to rupture through the lung parenchyma to the pleural cavity (pneumothorax), mediastinum, and/or enter the vascular system and be transported round the circulation as an arterial gas embolism (AGE), with potentially fatal effect.

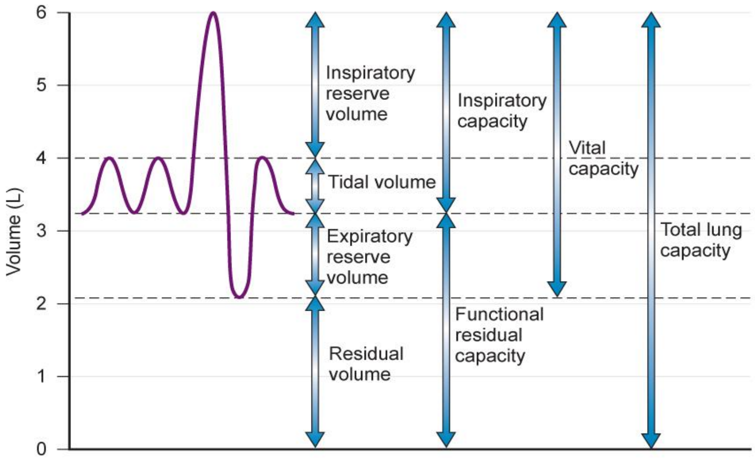

Figure 1 – typical lung volumes in respiratory cycle

<u>Physics of pressure and volume changes in PSTASS exercises:</u>

The same pressure/volume calculations as were considered earlier for open-water scuba diving may be performed for the PSTASS exercises. PSTASS training will take place at a maximum depth of 70 cm, at which the ambient pressure is 1.07 atmospheres (10m = 2 atm, 5m = 1.50 atm, 1m [100cm] = 1.10 atm, and 70 cm = 1.07 atm). Note that for most of the exercises the depth will be substantially shallower, as discussed later.

A tidal volume breath of 700mls taken at a depth of 70cm (=pressure 1.07 atmospheres) gives 'k' = 700 x 1.07 = 749, and in the worst-case scenario of a breath-hold and surface with closed glottis, this volume of air would tend to expand to 749 / 1 = 749mls at the surface. For a typical individual the 'extra' 49mls created by expansion due to ascent with closed glottis is a volume which appears to suggest low risk of barotrauma.

Table 2

Depth	Original inspired volume	Pressure (atmospheres)	'k'	New volume at depth
Surface	700 mls	1	749	749 mls
70 cm	700 mls	1.07	749	n/a

If the additional volumes of the physiological residual volume (from fig 1, around 2000mls) and expiratory reserve volume (from fig 1, around 1300mls) are also included in the calculation, the results at Table 3 are obtained:

Table 3

Depth	Original volume (VT plus RV plus ERV)	Pressure (atmospheres)	'k'	New volume at depth
Surface	4000 mls	1	4280	4280 mls
70 cm	700+2000+1300 = 4000 mls	1.07	4280	n/a

Again, the ‘extra’ 280mls potentially created by expansion due to reduced pressure is a volume which appears to suggest low risk of barotrauma.

In practice, the actual depth of the regulator, and hence inspired air pressure and potential for volume expansion, will be less. Expected values for depth and inspired air pressure for exercises a) to e) are:

a) depth 15-20 cm, pressure 1.015 to 1.02 atmospheres
b) depth 15-20 cm, pressure 1.015 to 1.02 atmospheres
c) depth 30-40 cm, pressure 1.03 to 1.04 atm
d) depth 30-40 cm, pressure 1.03 to 1.04 atm
e) depth 15-40 cm, pressure 1.015 to 1.04 atm.

For additional context, the deliberate respiratory tract 'overpressure' applied therapeutically by CPAP devices in treatment of sleep apnoea is typically 4-16 cm of water, but can be 25-30 cm of water.