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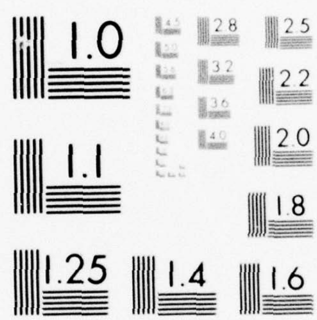

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The Principles of Underwater Escape from Aircraft

by
A.F.Davidson

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(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARDograph No.230

THE PRINCIPLES OF UNDERWATER ESCAPE FROM AIRCRAFT

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THE PRINCIPLES OF UNDERWATER ESCAPE FROM AIRCRAFT

by

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SUMMARY

Since the early days of aviation aircraft have landed in water either intentionally or by accident.

This paper attempts to review the physical, mechanical and physiological factors involved in escape from aircraft following ditching and describes some mechanical devices which can be used to assist the aircrew to reach the surface safely. It also includes comments on the conduct of trials and the training of personnel in the techniques of underwater escape from aircraft.

INTRODUCTION

Since the earliest experiments in Naval Aviation, aircraft have landed in the water either due to mechanical failure or lack of fuel or as a routine method of recovery of the aircraft by the parent ship.

Due to the lightness of the aircraft structure and the low speed at which water impact occurred, these aircraft usually floated and in many cases the pilots were recovered without getting wet.

As aircraft speeds increased the chances of survival following an accidental crash into water decreased and even planned ditching, the controlled landing of a landplane on the water's surface, became increasingly hazardous.

In the second world war 1939-45 fighter aircraft were launched by catapult from merchant ships to protect convoys. On completion of the sortie the pilot was expected to abandon the aircraft by parachute as this was considered less hazardous than ditching in the water alongside one of the ships. It was hoped that it would then be possible to pick up the pilot.

This method of operation was discontinued with the construction of small escort carriers which consisted of a merchant ship equipped with a flight deck.

With the advent of the modern jet fighter the situation changed dramatically. The introduction of ejection seats improved the chances of escape in the air while the increased density of the aircraft, increased speed of water entry and increased rate at which the aircraft sank (Anglo French Trials 1962) made airborne escape the method of choice when the aircraft had to be abandoned. In some circumstances it is however inevitable that an aircraft will enter the water before the crew can escape. It is therefore necessary to examine the factors influencing their chances of survival.

PHYSIOLOGICAL FACTORS

Many crew members who were still in the aircraft when it entered the water have failed to survive, but some have survived in situations in which the circumstances were highly unfavourable. The various causes for failure to escape must be considered. The physiological effects of immersion, rapid sink rate and subsequent ascent to the surface are listed.

1. Aircrew lose effective vision instantaneously on immersion due to the refractive effect of water, turbulence and air bubbles, lack of light and the possible lack of clarity in the water itself.

2. As the aircraft sinks the pressure increases. This can cause difficulty in clearing ears and sinuses and may produce severe pain. If the crew member has not taken a deep breath prior to immersion or if the aircraft goes much deeper than 30m compression of the chest may exceed the elastic limit of the chest wall.

3. Loss of vision associated with an unusual attitude of the aircraft may produce disorientation. Rupture of the ear drums with sudden pressure change and caloric stimulation of the middle ear is likely to result in severe vertigo. The disorientation is accentuated by the effects of buoyancy on proprioceptive sensations.

4. Underwater breathing, using the aircraft oxygen system, may be possible in favourable circumstances but is dependent upon several different factors and will be discussed fully later. Oxygen toxicity is not a problem as the time at depth is too short to be of any significance unless the aircraft comes to rest on the bottom. The regulator is unlikely to permit sufficient mass flow to meet the requirements for lung ventilation at depths much in excess of 30m.

5. Air embolism is always possible during the ascent to the surface following underwater breathing. It is unlikely to occur if the survivor breathes out during the ascent or if he has not breathed after leaving the surface.

6. As with any aquatic incident drowning or asphyxia is possible at any time from the water entry until actual rescue.

7. When operating over cold water Royal Navy and Royal Air Force aircrew normally wear an immersion coverall. This provides limited protection against cold to enable the survivor to inflate and board his life raft. It is made of a ventile material which, although waterproof, is not proof against water under pressure. Some leakage can therefore be expected if the survivor goes down with the aircraft to a depth of more than 2-3 metres.

PHYSICAL AND MECHANICAL REASONS FOR FAILURE TO REACH THE SURFACE

SINK RATE

Modern aircraft are heavy and have little unoccupied space inside them. Their density is therefore high and in general they float for a very short time. Due to their aerodynamic shape they tend to 'fly' under water and they may sink very rapidly, depending upon their attitude. The time available after impact for the crew to effect their escape is therefore limited.

CANOPY JETTISON

Distortion of the cockpit structure on impact may impede jettison of the canopy.

If the canopy is still in place when the aircraft submerges jettison becomes increasingly difficult if not impossible due to the rise in external pressure with increasing depth. The internal pressure in the cockpit may also increase due to ingress of water but the differential between the external and internal pressures is likely to reach the level at which either implosion of the canopy or collapse of the cockpit structure takes place.

EGRESS FROM THE COCKPIT

The release of safety harness and other attachments of the crew members to the aircraft must be completed prior to egress from the cockpit. Any item of clothing or equipment which snags on any aircraft structure may prevent the occupant from leaving the aircraft. In addition the rapid water-flow past the cockpit as the aircraft sinks may make exit more difficult.

BUOYANCY

Even after successful egress from the cockpit the survivor is still faced with the problem of buoyancy. Due to the increase of pressure with increasing depth, the volume of a gas inflated life jacket is reduced and it is unlikely that any aircrew who reach a depth of 30-50 metres will reach the surface. At these depths compression of the air trapped in clothing and the compression of the chest combined with the reduced volume of the life jacket results in a state of negative buoyancy and the individual will continue to sink.

SINK RATE OF AIRCRAFT

The behaviour of an aircraft following impact with the water surface depends on many different factors. The speed, attitude, and flight path of the aircraft and its weight, strength and configuration all contribute to the deceleration applied to it and the degree of damage or disintegration of structure which results.

High speed impact, particularly when associated with a steep angle of incidence, will produce complete disintegration of the aircraft, while a relatively slow controlled landing on the water surface may be carried out with negligible damage. Accidents involving water entry at high speeds are unlikely to be survivable.

Trials carried out by the US Navy (Greenberg 1958) in which an F 86 D was dropped into the water from heights of up to 50 feet at Key West, Florida, showed that the aircraft floated for a short time and then sank tail first. The trials were not truly representative, however, in that all orifices in the cockpit, including the inward relief valve of the cockpit pressurisation system, were sealed against the ingress of water.

In 1962 the Anglo-French trial at St Mandrier (Rawlins, Delorme, Seris and Riddell 1964) recorded the behaviour of a Scimitar and an Etendard VI following repeated drops from a floating crane. Again after a period floating on the surface these aircraft submerged tail first. Underwater photography, and instrumentation in the aircraft, showed that the nose then dropped and the aircraft glided through the water in a nose down attitude. The actual angle at which the aircraft descended varied but sink rates of up to 21 feet per second were achieved for short periods. (The descent angle also determines the displacement of the aircraft from the point of water-entry, which in deep water may be very considerable.)

The time that the aircraft floated on the surface depended on its density and the amount of trapped air. Engine intakes and tail pipes quickly filled but the cockpit was a major source of buoyancy while the canopy remained in place. If the canopy had been jettisoned the cockpit quickly filled with water and that buoyancy was lost.

One example of this reported by Davidson (1965) was a Buccaneer from HMS HERMES in 1961 which pitched up on take off: the crew jettisoned the canopy prior to water impact but did not have time to eject. The aircraft floated in a vertical nose down attitude with only the tail visible above the surface for fifteen seconds before sinking. In this case the aircraft sank vertically and landed on the sea bed inverted at a depth of 100 feet trapping the crew.

Helicopters on the other hand are relatively light. In addition, Naval helicopters have been equipped with flotation equipment and are therefore likely to remain on the surface giving the crew plenty of time to escape. In some cases the flotation system may suspend the helicopter just below the surface, or part of it may fail to operate satisfactorily resulting in capsize of the machine, the cabin being both immersed and inverted. The crew then has to escape from the aircraft in spite of the disorientation produced by the rotation of the craft.

Any damage to the aircraft structure will permit air to escape thus reducing buoyancy, but it is not impossible that loss of the engine or other heavy part of the structure could reduce the sink-rate of the cockpit section.

Air filled compartments which are intact are subjected to an increase in external pressure when the aircraft sinks. This can result in sudden collapse of the structure if the pressure differential is sufficient. The effects on canopy and cockpit will be considered later under the heading of canopy jettison.

From the above it will be appreciated that the time available to effect an escape is limited by the time the aircraft floats on the surface and the speed at which it subsequently sinks. In shallow water a further restraint may be the effect of impact with the sea bed and the attitude which the aircraft adopts.

High performance aircraft can be expected to float for a maximum of one minute but in many cases the time will be much shorter. The sink rate will then be rapid, increasing to between 10 and 20 feet per second. The occupants must therefore be separated from the aircraft as quickly as possible. In the Anglo-French trials it was shown that a modern jet aircraft would reach 30m in 90 seconds, and the other factors in underwater escape from such aircraft must be considered in this time scale.

CANOPY/HATCH JETTISON

Systems for jettisoning the canopy or hatch covering the cockpit of aircraft are primarily designed for satisfactory operation in the air. In this situation various factors such as aerodynamic suction over the canopy or hatch and aerodynamic lift to the canopy once it has been released into the airstream contribute to its successful removal.

If the canopy is jettisoned prior to water entry the occupants of the cockpit may be subjected to impact forces from which they could be only partially protected by the windscreen and cockpit structure. They will certainly be subjected to severe buffeting during the flooding of the cockpit and a major portion of the buoyancy of the aircraft will be lost. At the same time the oxygen mask may be displaced from the face thus eliminating any possibility of breathing underwater. The canopy is however the major barrier to escape and if it is retained until after water impact other problems arise.

Any distortion of the cockpit section of the airframe may prevent successful jettison of the canopy while the aircraft is afloat and in manual systems the occupant has to push the canopy clear of the cockpit, even after it has been released successfully.

The earlier practice of flying with the canopy open during take-off and landing on carriers was discontinued following the introduction of the ejection seat because the front arch of the open canopy obstructs the ejection pathway. As a result of the deceleration when the aircraft hits the water the canopy can slide closed and jam, making it impossible for the occupant to escape.

If the canopy or hatch is retained until after the aircraft sinks, its jettison is resisted by the external water pressure. In modern pressurised aircraft, which may enter the water without appreciable damage to cockpit or canopy, the only significant portal of water entry is the inward relief valve of the cockpit pressurisation system and the flow through this will be opposed by the build-up of pressure in the cockpit. In general, however, the rate-of-sink is such that the inflow of water is inadequate to prevent a rapid increase in differential pressure across the cockpit wall and the canopy as the external pressure increases by $\frac{1}{2}$lb/in^2 (.035kg/cm^2) for every foot of water depth (MacNaughton et al, 1959).

Rapid jettison of the canopy at a depth of even a few feet is therefore impossible unless sufficient flooding of the cockpit, to reduce the differential pressure to zero, has taken place. Trials with a Seahawk cockpit showed that this may require as much as 50 seconds after the jettison handle has been operated, which is an unacceptable delay when the aircraft is sinking.

Aircraft types will vary in the time it takes to flood the cockpit depending on the cockpit volume, the area of pressure relief valves, the efficiency of canopy seals and any leakage as a result of impact damage. If successful canopy jettison under water is an essential part of the escape system it may be necessary to fit a suitable implosion orifice to permit rapid flooding of the cockpit and consequent elimination of the hydrostatic forces impeding the removal of the canopy.

Even when this has been done it may be necessary to push the canopy clear of the cockpit after its release.

The implosion orifice must open without undue delay when the aircraft starts to sink to enable rapid equalisation of external and internal pressures, but in a high performance aircraft during a rapid descent from attitude it is possible for the increase in internal cabin pressure to lag behind that of the ambient pressure. If the implosion orifice is actuated by the differential pressure the mechanism must not be too sensitive or it may open inadvertently in the air. The actual pressure differential selected will vary from one type of aircraft to another depending on the efficiency of the cabin pressurisation system and any inward pressure relief valves which may be fitted.

RAWLINS J.S.P.

Trials of underwater blast from the Martin Baker Type 4
ejection seat gun.

POWER ASSISTED RELEASE (CARTRIDGES)

Canopy jettison in the air in many cases requires power assistance to ensure that the canopy will clear the aircraft structure. Power is usually applied by means of jacks, operated by the high pressure gases produced by the firing of one or more explosive cartridges. Although this is effective in the air, the system suffers from disadvantages when immersed. Activation of the system may be electrical or mechanical, and may fail either partially or completely if water enters the system. A short circuit could prevent an electrical system from operating while the velocity of the firing pin in a mechanical system could be reduced by a hydraulic lock if water has leaked into the firing mechanism.

If the cartridges do fire successfully any delay in separation of the canopy or hatch will result in cooling of the gases in the system and consequent loss of pressure. This would leave the occupant at best with an unlocked canopy which could be pushed off and at worst with a partially unlocked canopy which effectively bars his egress. Any subsequent attempts to penetrate the canopy using the ejection seat would then be jeopardised.

During trials in 1961 (Rhodes, 1961) attempts were made to improve the reliability of cartridge systems by modifying the firing mechanism of the canopy jettison system of a Sea Vixen aircraft and insulating the pipes to delay the cooling of the gases and prolong the application of sufficient gas pressure to the canopy jettison jacks. Although some improvement was achieved these modifications were not entirely successful and the efficiency of the system was unpredictable.

COMPRESSED AIR

The use of compressed air to provide canopy or hatch jettison proved much more satisfactory. Since the compressed air was already cold when released into the system no loss of pressure resulted from reduction of temperature. Provided there were no leaks in the system, after actuation, pressure was maintained in the system until the differential pressure had decayed sufficiently to permit its normal operation. It was also possible to use longer stroke jacks and consequently, although jettison was not rapid it was reliable (Rawlins, 1962).

In aircraft in which the canopy has not been jettisoned and which sink rapidly the rapid increase in differential pressure may continue until implosion or inward collapse of the canopy takes place. This has been shown to occur when the differential pressure reaches between 5 psi and 16 psi depending on the type of aircraft and the area and thickness of the canopy. Assuming no leakage into the cockpit these pressures represent depths from 10-30 feet below the surface.

When implosion of the canopy occurs the canopy starts to bend inwards and then shatters. Large pieces of the canopy transparency are then accelerated rapidly towards the floor of the cockpit, and the occupant would be subjected to injury from these rapidly moving fragments plus the effects of the sudden massive increase in pressure.

It is considered unlikely that the occupant would survive the effects of implosion (McNaughton and Rawlins, 1960).

USE OF EXPLOSIVES TO SHATTER THE CANOPY

Miniature detonating cord has been employed in many aircraft to weaken the canopy prior to penetration by the ejection seat. While this is acceptable in an air filled cockpit the situation becomes completely changed if the cockpit is flooded. Experiments have shown that the blast transmitted through the water would render the occupant incapable of further action even if he did not suffer severe injury.

MANUAL ESCAPE

The time available for escape from a ditched aircraft is limited by the length of time that the aircraft floats, the rate at which the aircraft sinks and the breath holding capacity of the individual crew member. This may be modified in some cases by the use of oxygen equipment for breathing under water or by collision of the aircraft with the sea bed.

The crew member may panic when he is suddenly subjected to immersion and this may preclude any chance of escape by inhibiting logical thought and action. A degree of familiarity with the situation as a result of practical training in methods of underwater escape is likely to improve the individual's chance of survival. The details of training devices and methods will be discussed later.

If the aircraft floats, as in the case of a helicopter fitted with flotation bags, or with a fuselage designed for water landing, escape can be accomplished during the normal unstrapping techniques, and the crew members can leave the aircraft either through the normal doors or via escape hatches or windows which have been jettisoned.

As soon as the crew member is immersed in water the position becomes more difficult. Time is limited. The crew member is subjected to disorientation first by possible changes in attitude of the aircraft, secondly as a result of buffeting as the cockpit fills with water and thirdly as a result of the changes in proprioception due to the buoyancy of his body and clothing.

It is therefore highly desirable that the individual remains securely attached to his seat by the restraint harness until movement of the aircraft has ceased and, if the cockpit floods, until after any buffeting produced by the inflow of water has subsided.

The aircraft may then remain close to the surface in an unusual attitude. Helicopters, depending on the type and efficiency in operation of flotation devices, may adopt any attitude from upright and level to inverted, nose-down, with some degree of bank. Fixed wing aircraft have even floated in a vertical nose-down attitude.

Aircrew are familiar with the cockpit layout of their own type of aircraft and can be expected to be able to place their hands on levers, switches, etc., without difficulty even with their eyes shut. They compensate automatically for the effect of gravity by the appropriate adjustment of muscle tone. However, when immersed in water, the limbs are supported by their buoyancy and by that of any clothing worn at the time. Vision is restricted or completely lost and the effect of the limb buoyancy will also deflect the hand upwards, thus making it more difficult to find and identify such items as canopy jettison levers and restraint harness quick-release fastenings.

Even after they have been located, it is more difficult to operate quick-release fastenings under water than in the air. Gloves, particularly those made of leather, become slippery and may cause problems in the operation of any piece of equipment which relies on friction. Aircrew may have to modify their usual actions in order to operate the harness quick-release fastening under water. Many devices require two separate actions before the harness is released. The crew member may have to rotate a plate to unlock the box then either hit or squeeze the box to effect the harness release. When submerged it is not possible to hit the box with sufficient force and it is necessary to place either one or both thumbs behind the box and squeeze. Complications arise if any of the harness webbing is able to lodge behind the plate thus preventing the release mechanism from operating. A snag of this type is relatively simple to correct in an air filled cockpit but under water it is difficult to diagnose the problem and the harness webbing becomes stiff making it more difficult to pull clear.

Even after the quick-release fastening has been operated successfully the stiffness of the webbing harness will impede its normal run through any rings or buckles and increase the time needed for the individual to separate from his seat.

The problem likely to be encountered with any particular harness must be assessed separately and will depend on the type of quick-release fastening, the design of the harness and any additional equipment worn, for example life jackets or life raft packs. In some cases in aircraft fitted with ejection seats the harness includes leg restraint lines and it is necessary to ensure that these are completely free before attempting to leave the cockpit.

With the exception of the oxygen hose all other attachments to the aircraft should be disconnected prior to the release of the harness because the crew member will find it much easier to locate them while he is fixed in his seat than after he is free. The oxygen hose can be left till last with advantage if the crew member is able to breathe under water from the aircraft oxygen system but, if he finds that underwater breathing is not possible, release of the O_2 hose before that of the harness would ensure that the buoyancy of his clothing did not float him upwards leaving the O_2 connection beyond his reach.

Having successfully separated himself from his seat the crew member must leave the cockpit or cabin. The problems in fixed-wing military aircraft and those in helicopters tend to differ. In high performance fixed-wing aircraft the cockpit is relatively small with a large opening after the canopy has been jettisoned. The exit path is relatively clear but there is not much room in the cockpit and the aircraft is likely to be sinking rapidly. This will produce a rapid flow of water over the exit path. American experiments have indicated that at the speeds likely to be encountered it is still possible to climb out of the cockpit (Bond, G H).

Depending on the configuration of the harness a decision must be made to determine policy with regard to life rafts. During escape they constitute an additional snag hazard but this may be considered justifiable in view of the improved survival prospects after the surface has been reached.

In helicopters, after release of the restraint harness, maintenance of correct orientation is vital to ensure that the escape route can be found. Guide rails attached to the inside of the cabin will lead the crew members to the available exits and Beta lights have been used to act as permanent markers of emergency exits to aid their location in the dark. Some escape hatches, windows, etc., are small and pose a further problem. Crew members may have to squeeze through a relatively small opening and the wearing of a life raft pack could possibly be sufficient to prevent egress.

In both classes of aircraft projections and loops of cord, material or webbing should be avoided to reduce the chances of snagging on any part of the aircraft during the escape.

The life jacket should never be inflated until after the individual is completely clear of the aircraft. A variety of operating knobs, loops and handles are in use at present. The direction of pull required for their operation also varies and it is essential that the aircrew are thoroughly familiar with the pattern which they themselves use to enable them to inflate the life jacket without difficulty after leaving the aircraft.

SPECIAL SITUATIONS

In addition to the safety of the normal crew of an aircraft one has to consider sorties which present special problems. In the Search and Rescue role the helicopter may pick up survivors with no previous flying experience, in a state of exhaustion and wearing life jackets of the inherent buoyancy type which meet the requirements of the merchant shipping safety regulations. It is not impossible for a ditching of the rescue helicopter to occur, especially in storm conditions where salt ingestion by the engines may result in loss of power.

It is necessary to consider the alternatives available to minimise the risk to both crew and passengers in such circumstances. The bulk and buoyancy of a Merchant Navy life jacket could impede escape from the helicopter, but if the survivor did escape he would be sure to reach the surface and he would then have support while awaiting subsequent rescue. If extra gas-inflated life jackets are carried it may be desirable to remove the survivors' inherent buoyancy life jackets and give them the gas-inflated jackets instead. Although this would reduce the problem of egress from the aircraft the survivors may be unfamiliar with the inflatable life jackets and fail to actuate them. They may therefore fail to reach the surface even if they do get clear of the aircraft. If no alternative life jackets are available the choice is reduced to whether or not the inherent buoyancy jacket will improve their chance of survival following ditching. In my opinion survivors should retain their life jackets unless their bulk is such as to reduce the total number of survivors who can be rescued.

It must be remembered that briefing of the survivors in a helicopter is difficult because of the ambient noise and, because of their condition and possible language problems, the amount which they are likely to understand will be minimal.

Casualties and medical patients have at times to be flown over water by helicopter. Ideally a stretcher patient should be secured in the stretcher (litter) by a harness incorporating a single point quick release fastening, and the stretcher in turn should be secured to strong points in the aircraft. The patient should if possible be provided with personal buoyancy of the gas-inflated type which is capable of supporting both him and the stretcher. In the majority of cases the patient will be unable to help himself and will rely on the aircrewman or medical attendant to get him out of the aircraft if it ditches.

With the increasing use of twin-engined helicopters and the development of improved helicopter flotation devices it is hoped that in most cases, even after a ditching, the crew and patients will be able to leave the aircraft without going underwater.

Perhaps the worst situation is the ditching of a helicopter carrying fully equipped troops ashore from their parent ship in Arctic conditions. If the aircraft fails to remain above the surface the problems of underwater escape will be greatly increased by the numbers of people attempting to leave the cabin and the amount of heavy equipment which they will be carrying. This will impede their egress and the cold water will make breath holding much more difficult. In addition the bulk and buoyancy of their Arctic clothing, particularly if covered by an impervious exposure suit, may prevent the troops using small emergency exits. Those near the back of the cabin will therefore have to wait until others nearer the cabin door have got out before they themselves can escape.

ASSISTED ESCAPE

If aircrew are to escape successfully from a sinking aircraft it is necessary to leave the aircraft before it reaches too great a depth. Due to the high sink rate of modern high performance aircraft time is short. It may not therefore be possible to jettison the canopy, release the safety harness and other attachments to the aircraft, and climb out in the time available. It was therefore inevitable that attempts would be made to devise a system which would mechanically assist the crew member in leaving the aircraft underwater. As many aircraft were already equipped with ejection seats for airborne escape the possibility of using the seat was investigated in order to determine its potential underwater.

A theoretical assessment of the problem indicated that the main physiological factors involved were:-

(a) Acceleration of the ejection seat;

(b) Blast, when the ejection gun separated releasing the high pressure gases into the water;

(c) Drag acting on the man as the seat was propelled through the water; and

(d) Rapid pressure change if the seat trajectory was near the vertical.

The crew member would still have to push himself clear of the ejection seat and inflate his life jacket in order to reach the surface.

Although initial opinions were pessimistic, the successful escape of Lieutenant MACFARLANE from a ditched Wyvern aircraft by firing his ejection seat through the canopy while underwater renewed interest in the feasibility of the procedure.

Experiments were carried out at the Admiralty Hydro Ballistic Research Establishment (AMBRE), Glen Fruin, Scotland, to determine the performance of various ejection seats under water and their reliability after immersion (Beckman et al, 1960).

These trials demonstrated the need for modifications to the ejection seat gun. The primary cartridge was detonated by a firing pin which was released when the firing handle of the seat was pulled. The firing pin was thenpropelled by a spring and struck the detonator of the cartridge. If the gun had been immersed it was possible for water to seep inside the firing head and cause a hydraulic lock which slowed the movement of the firing pin sufficiently to prevent detonation of the cartridge. This was overcome by drilling a number of holes into the firing head, which allowed the water to escape when the firing pin was released thus avoiding the formation of a hydraulic lock.

Water was also able to seep into the ejection gun itself. Entry of even a small quantity of water had the effect of quenching any particles of burning cordite with which it came into contact. This greatly reduced the pressure generated by the primary cartridge and since the secondary cartridges were ignited by a combination of pressure and heat produced by the primary cartridge, they frequently failed to fire.

The power of the gun was greatly reduced and occasionally failed to push the seat clear of the cockpit. This was corrected by the addition of waterproof seals to prevent water ingress past the cartridges. The gun then functioned more reliably.

On examination of the physiological factors it was shown that the acceleration produced by the seat under water was as little as 8G which is well within the tolerance of a subject sitting in the seat, restrained by the harness. It was not therefore considered to be a problem.

The blast produced by the release of the gas bubble into the water, when the ejection gun separated, was more serious, particularly with the high-powered cartridges which were required to produce a satisfactory escape envelope in the air.

The gas bubble pulsated producing waves of positive and negative pressure. The centre was behind and below, but in close proximity to, the seat pan. The pelvis and lumbar region were therefore subjected to the greatest force.

Human volunteers were exposed to the blast from a gun which was capable of accelerating the seat to 60ft/sec in air, but only anaesthetised sheep were subjected to the blast effects from the more powerful 80ft/sec gun (Rawlins, 1961).

It has been shown that the blast wave in the first case produced chest pain which in some subjects lasted for 24 hours. In the later experiments with the more powerful gun, injuries found at postmortem examination of the experimental animals included rupture of the attachments of the base of the gall bladder, some bruising of liver and bruising of lung tissue. It was considered too hazardous to risk exposing human subjects to the underwater blast produced by this gun.

Ejection downwards will of course produce an increase in pressure and a degree of compression of the chest. It is possible that in some cases rupture of the ear drums may occur. This would be likely to result in disorientation. The occupant would also be at a much greater depth when he started to separate himself from the seat and consequently would have less time in which to carry out the necessary actions.

In trials the drag produced by the movement through the water was sufficient to pull the subject's hands off the face blind of the seat and displace his head and shoulders downwards and forwards in the restraint harness. It did not however produce injury and was considered acceptable in the types of seat tested provided that the occupant was sitting upright with his head braced against the headrest prior to ejection. But it was possible, in some seats fitted with higher powered cartridges, or with rocket propulsion, that some injury to spine could result.

The degree of pressure change depended on the amount of vertical movement of the seat through water. If the seat was fired vertically it would travel about 17 feet causing a reduction of pressure of about half an atmosphere with consequent expansion of gas contained in the body cavities. Assuming a full or nearly full lung this degree of pressure change could be sufficient to cause rupture of lung tissue and air embolism, particularly if the mouth and glottis are closed.

After the seat has fired the occupant still has to carry out several actions before he is free to ascend to the surface. The combination of seat and man is negatively buoyant even with the life jacket inflated, although their sink rate is much less than that of the aircraft. The time taken to achieve separation from the ejection seat is therefore important and any delay will reduce the chances of survival.

The actions required will vary slightly depending on the type of seat and the harness used but the survivor has to:

(a) release the parachute harness and survival pack attachments and inflate his life jacket; or

(b) release the parachute harness and pull the survival pack clear of the seat, then inflate the life jacket.

Drill (b) tends to be more difficult because the survival pack is usually a close fit in the seat pan and there is in addition the possibility of snags occurring as it is pulled out of the parachute harness. A survivor who does succeed in retaining his life raft is in a better position when he reaches the surface than he would be without one, but one must remember that ditching in aircraft fitted with ejection seats is only likely to occur in close proximity to the aircraft carrier during launch or landing and the life raft is therefore less essential than it would be at a longer range from the parent vessel.

It is by no means certain that the occupant of the seat, following exposure to the blast produced when the ejection seat gun separates and the pressure effects resulting from the changes in depth, will be capable of carrying out these actions successfully. In some cases other items such as leg restraint lines may constitute an additional potential snagging hazard.

COMPRESSED AIR OPERATION OF THE EJECTION SEAT

Due to the lack of certainty of reliable function of the ejection seat cartridges and firing system under water and the unacceptable risk of injury to the occupant resulting from the blast which follows the release of the propellant gases into the water at the time of separation of the ejection seat gun, it was considered necessary to develop an alternative method of propelling the seat. This method had to be reliable and safe, but sufficiently powerful to ensure satisfactory canopy penetration in aircraft in which canopy jettison under water was considered undesirable.

As in the case of canopy jettison the use of compressed air was found to be the most satisfactory solution. Initial experiments were carried out by Royal Navy medical officers in collaboration with the Walter Kidde Company using a Martin Baker ejection seat mounted on a platform which was lowered to the bottom of the trials tank. Compressed air was released into the gun which extended relatively slowly, pushing the seat and subject smoothly upwards. The gun separated satisfactorily leaving the subject clear of the platform but still attached to the seat. The cartridge system is of course retained for airborne escape and it was essential that no modification carried out would in any way impair the performance of the ejection seat in the air.

Further efforts were directed towards the development of a satisfactory method of ensuring automatic release from the seat and automatic inflation of the life jacket. The correct sequencing of the release mechanism is vital if successful separation from the seat is to be obtained. It was found that the Barostatic time release unit functioned satisfactorily under water and released the seat harness but automatic release of the parachute was not considered desirable because of the disastrous effects of its inadvertent release during escape in the air.

Separation from the seat therefore required release of the seat harness and disconnection or cutting of the line connecting the seat stabilising drogue to the parachute, in addition to a means of ensuring that the survival pack was extracted from the seat pan and that the parachute, still in its pack, was pushed clear of its stowage on the back of the seat. Inflation of the life jacket had also to be automatic.

Since a separate means of actuation was required for underwater escape and a separate source of power was available it was possible to use the operation of the compressed air system to trigger the inflation of the life jacket. Bags placed behind the parachute pack and under the survival pack in the seat pan were inflated by a charge of carbon dioxide, ensuring that they were pushed clear of the seat. It was important that release of the seat harness should take place prior to inflation of the seat separation bags to prevent pretentsioning of the harness and consequent failure of the harness release mechanism to operate. Simultaneous actuation of both inflation bags and harness locks was satisfactory due to the time which the bags took to inflate fully. It was convenient, therefore, to use the Barostatic time release mechanism to actuate both systems. (Rawlins 1962).

Repeated trials in 1961 showed that the system could be made to operate reliably and initial experiments with automatic inflation of the life raft were also undertaken.

The method used to achieve automatic inflation of the life raft under the survivor was the direct attachment of the rigid seat of the survival pack to the inside of the floor of the single seat life raft. Following release from the seat a water actuated inflation system was armed. The time taken for it to operate was sufficiently long to permit the life jacket to bring the survivor to the surface and float him in a stable attitude on his back. Carbon dioxide was then released first into a high pressure tube round the life raft which unfolded it and ensured its satisfactory deployment prior to inflation of the main buoyancy tube. Baffles in the main buoyancy tube of the life raft then prevented the carbon dioxide reaching the head end of the life raft until full inflation of the foot had been achieved. The remainder of the buoyancy tube then inflated lifting the survivor clear of the water. Arrangements for the quick release of the survivor from the life raft were also made to enable him to escape if the life raft floated upside down. (Rawlins 1963).

The Martin Baker Company then took over development and incorporated a method of automatic actuation of the complete Underwater Escape System. A pressure sensitive device, operated by the action of water pressure on a diaphragm, released compressed air into the ejection seat gun at a depth of approximately 15 feet (5 metres) thus firing the seat, through the canopy if necessary. The power of the gun in the early stages of movement of the seat was considerably increased by the insertion of a blanking plate into the lower end of the inner tube of the gun. This reduced the effective volume of the gun prior to firing and therefore reduced the amount of compressed air which was needed.

In the Buccaneer the power of the system was sufficient to enable the seat to penetrate the canopy but the power provided reintroduced some of the problems associated with the cartridge opened seat. If the canopy had been jettisoned and the subject had not braced himself before the system fired the head was pushed forwards and downwards by the drag produced by passage through the water, until it approached the knees, with the possibility of back or neck injury as a result.

With the canopy in place it was found to be even more essential to keep the helmet firmly against the head rest. Canopy breakers on the head box of the seat punched a neat hole in the canopy but this hole was enlarged by the helmet. If the dummy's head was allowed to move it tended to slide forwards along the inside of the canopy applying considerable force to the neck of the dummy before the next section of the canopy broke free. (Rawlins 1963).

In an attempt to devise a system which could save an unconscious crew member, the risk of injury to a fully conscious but unprepared crew member was increased as he had no warning of when the seat was going to fire.

Only one live test ejection through an aircraft canopy underwater has been carried out. The subject was Surgeon Lieutenant Commander A F Davidson RN, and he was ejected through an intact Sea Hawk canopy using the Martin Baker fully automatic system designed for the Buccaneer. (Rawlins 1963). At the time of the trial the major hazard was believed to be that of incised wounds caused by broken pieces of perspex from the canopy. Subsequent experiments using dummies indicated that neck injury from forcible flexion due to impact with the canopy is a much more serious danger to the individual and a means of providing automatic head retraction and restraint would add considerably to the safety of the aircrew.

In the Sea Vixen, which had a canopy reinforced with longitudinal and transverse metal supports for the pilot's cockpit and a metal hatch covering the observer's cockpit, jettison of the canopy and hatch were necessary before the crew members could escape. With automatic actuation of the underwater escape system the movement of the seats was restricted by the canopy and hatch, and during trials it was demonstrated that even a minor leak from the system could result in loss of pressure in the ejection seat gun before the escape path was cleared. Premature firing of the seat could also result in interaction between seat and hatch causing a mechanical lock and preventing both completion of the jettison of the hatch and any further movement of the seat.

Reluctantly the automatic actuation of the system was discarded and separate levers for manual actuation of the canopy and hatch jettison systems, and the operation of the seat, were reintroduced.

Even in aircraft not fitted with ejection seats, attempts have been made to provide assistance to aircrew to escape from the cockpit underwater. A system was designed, again operated by compressed air in which the restraint harness could be released from the seat and the crew member pulled out of the cockpit by the harness which was attached to a cross beam behind his head, leaving the seat in the cockpit. Twin extending tubes fastened to the rear bulkhead of the cockpit provided the power: the outer and inner tubes separated when the individual was clear of the cockpit. Automatic inflation of the life jacket then brought the subject to the surface in the usual way. This system was tested in a Gannet cockpit in open sea at a depth of 100 feet and worked satisfactorily.

Although a system of this type may work satisfactorily in test conditions it has to be sufficiently robust to function reliably even after it has been subjected to the severe loads imposed by a ditching. Any distortion of the tubes, which may be of small diameter compared with that of an ejection seat gun, or of the bulkhead on which they are mounted, could cause one or both to fail to function correctly and, as the system is of no use in assisting airborne escape, it is considered more satisfactory to use an ejection seat with the well-tried underwater modifications instead.

THE USE OF BREATHING EQUIPMENT IN UNDERWATER ESCAPE

If the crew of an aircraft are able to breathe after the aircraft enters the water it increases the time available in which to prepare for, and carry out, their escape. In some cases the aircraft will float and the heads of the occupants will remain above the water surface. In others, if the canopy remains in place, the occupants may be able to breathe air trapped in the cockpit for a short period but when the aircraft finally submerges and the canopy has been released the occupants must rely on their ability to hold their breath.

To be able to breathe under water one must be provided with a supply of air or oxygen at a pressure approximately equal to that of the hydrostatic pressure applied to the chest. The level of the bifurcation of the trachea is considered to be a suitable datum and thus represents the equivalent centre of pressure of the thoracic cavity.

If pressure of the gas supplied during inspiration is too low it is not possible for the subject to expand his lungs against the external water pressure. Conversely, an excess of pressure could result in over expansion of the chest and consequent rupture of lung tissue.

It is convenient to use depth of water as a measure of pressure in this context and the limits of tolerance vary in different individuals. It is considered however that a negative pressure of 30cms water at the datum level is acceptable but it is unlikely that satisfactory respiration can be achieved if the negative pressure exceeds 50cms water. Positive pressure on the other hand could possibly cause lung damage if it exceeds 45cms water but in practice the oxygen mask is usually lifted off the face by the gas pressure, allowing gas to escape and the pressure to fall to an acceptable level.

Many experiments have been carried out to determine the usefulness of aircraft oxygen systems for underwater breathing. Continuous flow economiser systems do not function satisfactorily under water. These systems incorporate an inward relief valve through which air enters the system once the economiser has emptied. If the pressure in the system drops below the ambient water pressure in the region of the valve the valve will open and water will enter the system. Even with the oxygen flow increased to as much as 27 litres/min NTP, as could be achieved by selecting the emergency setting on the British Mk II regulator, it is unlikely that the inward relief valve will remain shut throughout the breathing cycle. One must remember that 27 litre/min flow at sea level is reduced to 9 litre/min at a depth of 20 metres and this represents only two deep breaths per minute.

Similarly the small volume obtained from continuous flow emergency oxygen systems is totally inadequate for underwater breathing. Most demand oxygen systems in which 100% oxygen is used or may be selected work well under water. Delivery pressure is normally equal to the hydrostatic pressure applied to the diaphragm of the regulator: therefore the position of the regulator relative to the datum level is of vital importance.

In aircraft the oxygen regulators may be mounted on the instrument panel, the seat, the man or the oxygen mask, and aircraft are fitted with regulators of the type which is most suitable for the particular task which they have to perform. It is unlikely that any modification of existing equipment will be considered for the improvement of underwater breathing performance alone, but appreciation of the limitations of different systems is of value.

The mask-mounted regulator will maintain a relatively constant pressure in the oxygen mask which reduces the problems of possible ingress of water, but with this system the pressure at the datum level may vary by as much as + or - 30cms water depending on the aircraft attitude. It is however likely to be satisfactory provided a sufficient maximum mass flow of gas is available.

Body-mounted regulators are usually on the front of the chest close to the datum level. In this case the internal pressure in the chest will remain nearly constant with changes in attitude but the mask pressure will vary from positive to negative relative to the surrounding water as the aircraft attitude changes. A system of this type should function satisfactorily as long as water does not enter the mask.

Seat-mounted regulators are usually mounted at the level of the subject's hip and close to the long axis of the body. When the aircraft is upright the oxygen mask will be lifted off the face by positive pressure in excess of 60cms water. Breathing is possible as all mask leakage is outboard but the duration of the supply will be limited by the high rate of flow which will rapidly empty the system. This is not serious as it is the aircraft sink-rate in most cases which determines the time available for escape. The continuous escape of oxygen from the mask interferes with vision and hence the necessary actions prior to leaving the aircraft will be dependent upon proprioceptive and tactile information.

If the aircraft inverts the situation is completely altered. It is not possible to breathe in, due to hydrostatic pressure on the chest and the relatively low delivery pressure. As there is no resistance to expiration it is likely that the occupant will breathe out and be left with his lungs close to residual volume.

The panel-mounted regulator creates similar problems but as its position in the cockpit varies in different types of aircraft one cannot generalise. The same principles apply however and the distance and direction of the regulator from the chest datum level and the oxygen mask will determine the effects of changes in aircraft attitude when under water.

Experiments have been carried out using a remote pressure sensing device inan attempt to control the delivery pressure of the regulator. This device (Davidson and Wagner 1965) had limited success but would have been affected by rapid sink rate of the aircraft and was therefore discarded.

So far only the oxygen regulator has been considered. The design and construction of the oxygen mask are also of importance. The mask usually consists of a rubber moulding which has a reflected edge seal and which is supported by a rigid carapace and is secured to the wearer's helmet by a harness, chain or lever system. It has inspirationary and expiratory valves which are mounted in the lower half of the mask.

A mask of this type is designed to provide a satisfactory seal during pressure breathing, provided the mask is held firmly against the face. At altitude the regulator provides a small safety pressure. A minor degree of outer leakage is acceptable as it does not alter the inspired oxygen concentration while airborne. Its resistance to inboard leakage when subjected to negative pressure is less satisfactory.

Under water, while the wearer is sitting upright, the differential pressure across the mask seal is usually positive thus producing outboard leakage if the seal is not perfect. If for any reason some water does enter the mask it is expelled through the expiratory valve when the wearer breathes out, thus clearing the mask prior to the next inspiratory phase.

As the attitude of the subject alters the relative position of the expiratory valve changes and some of the water which leaks into the mask will not be removed during expiration, thus making the next breath more difficult to obtain.

The worst situation is obviously the inverted position. Any water which gets into the mask collects around the nose and cannot be removed via the expiratory valve which is now at the top of the mask. In addition the negative pressure in the mask encourages leakage and some water may even enter through the expiratory valve before it closes. In pressure breathing masks which have a pressure compensated expiratory valve the negative pressure applied to the compensating capsule may tend to resist the closure of the valve and to reduce this effect a split expiratory valve is used. This modification allows the compensating capsule to load the valve during pressure breathing but permits the valve to function independently if negative pressure is applied to the compensating capsule.

Even if the regulator and mask function satisfactorily some aircraft have modifications to enable the emergency oxygen system to work in the air and during airborne ejection prior to separation of the crew member from his seat. The use of a continuous flow emergency oxygen system requires the fitting of a relief valve to allow excess oxygen to escape at high altitude, but, as ejection at high altitude may result in a long delay prior to separation from the seat, an inward relief valve is necessary to permit the survivor to continue to breathe if the oxygen flow becomes insufficient to meet the inspirationary requirement before seat ejection occurs. This inward relief valve, if fitted, is mounted close to the personal equipment connector on the side of the ejection seat and may well be in a negative pressure zone, depending on the site of the regulator. Water will in that case be sucked into the oxygen hose between the regulator and the mask, resulting either in the cessation of oxygen supply or in water being sucked into the mask, making breathing impossible.

Underwater breathing is thus possible in favourable circumstances, provided that the aircraft remains upright. It is unlikely that anyone will be able to breathe underwater from an aircraft oxygen system for more than a few breaths if the fuselage is inverted.

The method of supplying oxygen to the system may have an effect on its efficiency. High pressure gaseous oxygen is the most reliable under water. Trials with liquid oxygen converters demonstrated that a considerable drop in regulator inlet pressure may be expected when the liquid oxygen converter is immersed in water. The formation of ice round the evaporating coils reduces the heat transfer necessary for vapourisation of the liquid oxygen and the situation is aggravated if the time between recharging the system and immersion of the converter is short.

It was however possible in a recompression chamber trial at the Royal Naval Physiological Laboratory in 1962 for two subjects to breathe with a degree of restriction down to a simulated depth of 150 feet for a period of two minutes from regulators supplied by a single liquid oxygen converter. Although it is not impossible for an individual to suffer from the effects of oxygen toxicity at partial pressures in excess of two atmospheres, it is unlikely to develop in the time involved in underwater escape from aircraft and it should therefore be ignored in this context.

It has been indicated that subjects breathing 100% oxygen have found subsequent breath holding easier and have been capable of holding their breath for a longer period than they could have done if they had been breathing air. This constitutes a possible benefit from underwater breathing. Underwater breathing on the aircraft oxygen equipment is not always successful and the crew member of a ditched aircraft must not rely on its satisfactory function.

In most helicopters no oxygen equipment is required but in the Search and Rescue role a diver is carried and he is ideally equipped not only for underwater escape himself but also to assist the other crew members if necessary. The possibility of providing helicopter crews with a compact emergency underwater breathing device has been considered at various times. The first problem is to decide on the expected duration of the breathing equipment. As a compressed air supply fitted with a mouthpiece demand regulator is the simplest and most compact system, it is the most attractive proposition. The duration of the set depends on the ambient pressure and the rate and depth of respiration. This results in great variation depending on the experience of the individual. Assuming that a mouthpiece is used it will be necessary to provide a nose clip and possibly, if vision is required, a face mask. As time is required to insert the mouthpiece, and put on the nose clip followed by donning and clearing water out of a face mask if used, one must weigh the advantages of being able to breathe against the increase in time before the crew member is able to leave the aircraft.

In the majority of helicopter ditchings the crew escape quickly and without difficulty, so such a breathing device would only prove useful in a very small number of cases. It is therefore debatable whether or not the increase in personal safety equipment to be worn by the aircrew, the time required for training, and the expense involved, would be worthwhile.

FACTORS IN PLANNING OF TRIALS OF UNDERWATER ESCAPE PROCEDURES AND EQUIPMENT

In trials of life saving equipment it is essential to ensure that the risk, if any, to which the trials personnel are subjected is minimal. It is also valuable to simulate as closely as possible the conditions in which the equipment is expected to function.

Factors such as water temperature may seriously affect the efficiency of a system and an item of equipment which appears to function satisfactorily on its own may fail to do so, or adversely affect the operation of another item, if insufficient care is taken in the sequencing of the system as a whole.

Let us first consider Safety Factors:-

Ideally direct visual control of operations by the officer in charge of the trial should be possible. He should have made an assessment of all the foreseeable failures or emergencies which may occur and plan how to deal with these individually. It is considered that provision should also be made to cover the possibility of any simultaneous double failure.

Emergencies may be caused by failure of the equipment under test, the breathing apparatus or of the crane or other lifting device which may be used to lower the equipment into the water and subsequently to recover it.

In all experiments involving the use of human subjects it is essential to provide safety divers who are capable of rendering assistance to the subjects if an emergency occurs. Subjects, safety divers and the surface personnel must be adequately briefed, understand both the function and limitations of the equipment being used, and the correct action to take in the event of any likely emergency.

The use of an anthropometric dummy in some circumstances is a valuable means of carrying out the initial testing of mechanical function without risk, prior to the employment of a live subject.

It should, however, be stressed that even when a dummy is used the divers must remember to keep clear of the ejection path of the seat, and that devices such as drogue guns may fire a potentially lethal projectile. The use of the underwater lighting necessary for photography involves electric cables carrying relatively high voltages and care must be taken in handling them under water.

BREATHING EQUIPMENT AND COMMUNICATION

The subject, in a trial of an underwater escape system, will inevitably be immersed for a prolonged period before the escape. Breathing apparatus provided should therefore have a suitable endurance. As it must be worn in conjunction with aircrew equipment it must be compatible with these items and with the restraint harness.

In the early Royal Navy trials the standard RN oxygen rebreathing apparatus (Pattern 5562) was used but the bulk of the sodalime cannister necessary for CO_2 absorption was inconvenient and restraint was impaired by the need to route the harness straps round the sides of the counterlung of the breathing set. It did, however, have an advantage over compressed air breathing apparatus in that photography was not impeded by clouds of bubbles.

Compressed air has the advantage of simplicity of construction and use when compared with oxygen rebreathing apparatus, It does however require larger cylinders to provide the same duration. The most satisfactory solution to this problem is the use of a large storage cylinder in the test fuselage with a high pressure hose to the subject's breathing apparatus. A quick means of disconnecting the hose from the breathing set should be provided and unplugging should operate a change over valve which will permit the subject to breathe from his personal cylinder following disconnection from the main supply. In any trials involving depths of greater than 25ft it is inadvisable to breathe 100% O_2 because of the risk of O_2 toxicity and either compressed air or a nitrogen/oxygen mixture should be used.

(It is advisable to provide a separate emergency breathing system for any subject who is enclosed in an aircraft cockpit under water to cover the possibility of failure of the canopy or hatch jettison system followed by any malfunction of the subject's own breathing set.)

The safety divers may use either self contained breathing sets or one of the systems utilising a surface air supply. In the latter case they must remember that the test fuselage may be surrounded by cables from instrumentation and lighting, and it is likely to be supported by wires from a crane. The diver must therefore ensure that after any approach to the fuselage he retires by the same route to prevent his air hose from becoming tangled in the numerous cables surrounding it.

Adequate communications must be maintained between control, divers and subjects. Ideally two way voice communication should be established by use of an under water telephone system employing bone conduction transducers or by underwater loud speakers. Alternatively information may be passed by hand signals or the use of light.

A flash bulb can be used effectively as an indication to the subject to commence his escape. As the flash can be seen clearly on any cine film taken of the trial, and its operation can be linked electrically to the recording apparatus, it provides in addition a simple system of synchronising film and instrumentation records.

PHOTOGRAPHY

A photographic record of the trials should be made wherever possible. This should consist of adequate coverage by both cine and still photography in the preparation phase, during the trial and to record the results particularly when problems arise. The clarity of the water and suitability of the facility for underwater photography should therefore be considered in selection of the location for the trial.

Ideally it should be possible to record each test using fixed cameras at both normal and high speed and, in addition, the use of a hand held underwater cine camera is of value to obtain a different view of the action.

In certain circumstances it may be necessary to use specialised equipment such as the camera which was mounted on the wing of the Scimitar in the 1962 Anglo-French Sink Rate Trial. This was triggered by a differential pressure gauge fitted in the cockpit of the aircraft and succeeded in filming the actual implosion of the cockpit canopy at 1000 frames per second.

Photography is essential for satisfactory assessment of the actions of the subject and the function of the escape equipment. It enables the trials team and the subject to examine each test in detail frame by frame if necessary and so demonstrate clearly any snags which occur. Without adequate photographic coverage much valuable information would be lost.

USE OF AIRCREW CLOTHING AND EQUIPMENT

Although trials may be carried out in the early stage of development of an underwater escape system using anthropometric dummies or subjects wearing diving equipment, it is desirable, prior to the final acceptance of the system, to carry out a limited number of tests in which the subject is wearing the correct Aircrew Equipment Assembly. In aircraft which have suitable oxygen equipment he should also breathe from this system using the correct type of oxygen mask. In this phase it is particularly important for the safety of the subject to provide a reliable compressed air emergency breathing apparatus with a simple mouthpiece regulator in a convenient position inside the cockpit. This final phase of testing the system may well bring to light deficiencies in the clothing and equipment which would have an adverse effect on the survival prospects of aircrew involved in an actual escape from an aircraft which had to ditch at some later date.

MEDICAL REQUIREMENTS

Many trials of equipment for use in under water escape from aircraft require major experimental facilities which were designed and built for other purposes. The prime function of these establishments may not involve the use of human subjects and only very basic medical facilities are likely to be provided.

The risks in any particular trial vary and the degree of medical support required should be assessed accordingly. It is suggested that in most cases adequate first aid should be immediately available and suitable transport should be provided to enable the casualty to be moved to hospital if necessary. In the series of trials conducted by the Royal Navy two or more medical officers were members of the trials team and they provided the necessary medical cover. It is however considered that one doctor preferably aided by a medical assistant would normally be sufficient to deal with any medical emergencies which might arise.

In any situation involving the movement of heavy equipment or the use of explosives physical trauma of one form or another must remain a major hazard. In underwater operations the possibility of drowning must also be considered. In addition panic or thoughtlessness on the part of a diver may result in his forgetting to breathe out while ascending to the surface, particularly if he is attempting to cope with other emergencies at the same time. This could easily result in overdistension of the lungs, rupture of lung tissue and air embolism.

If explosives are used to break the canopy or to power the ejection seat there is also the possibility of blast effects causing injury to the lungs and other internal organs.

I would not presume to discuss the treatment of such injuries but I would emphasise the importance of planning in detail methods of removing potential casualties from any situation in which injury could occur.

This may involve the safety divers removing the injured man from the fuselage while it is under water and his subsequent transfer from the water, first to the working platform at the tank top and then to the first aid room for further resuscitation. Life saving measures must be carried out as soon as access to the patient is possible. Expired air resuscitation may have to be given by the safety diver on reaching the surface even prior to the patient's removal from the water.

If the injured man is in the test fuselage after it has been removed from the water an underarm lifting sling, similar to that used by SAR Helicopters, and a length of rope reeved through an overhead block may be needed to lift the patient clear of the cockpit.

As with all diving operations knowledge of the location and state of serviceability of the nearest recompression chamber is valuable and confirmation of the procedure to be adopted if it is necessary to alert the facility should also be made. The method of transport and route from the trials site to the recompression facility should be planned before the start of the trial.

Minor injuries and illnesses and treatment of such conditions as otitic or sinus barotrauma can be carried out either by the medical member of the team or by the local medical organisation. They are only of importance from the safety aspect in the measures required for their prevention. They may, however, have a major effect on the conduct of the trials programme if one or more key members of the trials team are affected.

TRAINING

Aircrew have received training in the technique of underwater escape from aircraft for many years. Initially crude devices were used. One such device was simply a canvas covered framework with an aircraft seat and restraint harness. This was lowered with the trainee into a swimming pool. Later more sophisticated equipment such as the Dilbert Dunker was developed and more recently training has become specialised with separate courses for fixed wing aircrew, and for helicopter passengers and crews. This has become necessary because the problems of escape from these two classes of aircraft differ in many respects.

An underwater escape training scheme should be designed to eliminate all risk to the trainee while simulating the expected conditions of an actual escape sufficiently closely to provide realistic training.

Fixed wing naval aircraft tend to be dense and sink relatively rapidly. They are usually fitted with oxygen breathing systems for the crew members. Ditching may well occur with the cockpit canopy still in place. Following ditching each crew member will have to jettison the canopy, release his harness and leave the cockpit, then inflate the life jacket and ascend to the surface. It is therefore desirable that they undergo theoretical instruction in the procedures and then practice underwater escapes from a specially constructed training device.

It is convenient to combine the training in breathing underwater using the aircraft oxygen system with the release of the harness and egress from the cockpit of the training device. As buoyant ascent to the surface entails a definite risk to the individual particularly after breathing underwater at an ambient pressure above that of the atmosphere, it is best to separate the instruction in buoyant ascent from that of escape from the cockpit. The cockpit of the training device should therefore never go deeper than one or two metres below the surface.

If buoyant ascent training is considered necessary it should be carried out in a similar manner to that employed for training personnel in escape from submarines. Close medical supervision is required and a recompression chamber must be immediately available, preferably at the top of the training tank, thus ensuring that the time taken to recompress a suspected casualty is reduced to an absolute minimum.

While it is desirable that the cockpit dimensions are as close as possible to those of the aircraft which is normally flown by the trainee, and that the canopy jettison handles are in the proper position relative to the seat, it is not essential and in many cases not practicable to use the actual aircraft equipment and the normal canopy release mechanism. Aircraft canopy jettison systems are designed for operation in an emergency. There is no need to reset the system rapidly. The equipment itself may not be sufficiently robust to withstand repeated operation, and as it is not intended for routine regular immersion in water corrosion is also likely to create problems. Similarly aircraft O_2 regulators and harness quick release fastenings function satisfactorily underwater in an emergency but need modification or replacement by alternative items to ensure reliable operation during a long term training programme. Trainees should use the type of harness and quick release fastening which is fitted to their own aircraft. This should be prepacked with waterproof grease as a protection against corrosion.

As aircraft oxygen regulators may suffer from severe corrosion when used underwater it is preferable to use a demand valve designed for diving. The delivery of gas from the regulator depends primarily on the relative position of the regulator to the chest of the subject, so small variations in regulator characteristics are unimportant. The regulator should be corrected to the supply hose of the oxygen mask in the usual way.

The release of the canopy should be actuated by a handle or lever similar in operation and position to that in the subject's usual aircraft. By fitting the appropriate jettison handle the same cockpit can be used to represent several different types of aircraft.

The canopy release mechanism must be capable of being reset quickly to enable a course of several students to gain practical experience in the shortest possible time. It is not necessary for the canopy to be detached from the fuselage as long as it completely clears the escape path. The mechanism can be very simple as it doesn't have to withstand aerodynamic loads, and by allowing the cockpit to flood freely there will be no differential pressure to distort the structure.

It must be possible to lower the cockpit into the water rapidly down to a predetermined depth and if a trainee gets caught underwater, it must be possible to raise the cockpit above the surface without delay.

A safety diver, who must be able to open the canopy using an external lever, and release the subject's harness, should observe the subject continuously during the time that he is under water. The diver must carry a knife with which to cut the harness if necessary if he is unable to open the quick release fastening.

After ditching helicopters frequently float for a long time and in some cases they may even remain upright. Usually they turn upside down and although they stay close to the surface both cockpit and cabin are flooded. As the crew do not normally use oxygen, they must rely on breath holding from the time of their immersion until they reach the surface.

The rear cabin is relatively large and it may not be possible to reach an exit prior to releasing the restraint harness. Disorientation is also a problem and this is increased if the harness is released before the turbulence caused by flooding of the cabin has ceased.

Training must be directed towards the prevention of panic and should encourage the trainee to remain secured in his seat until water movement in the cabin has stopped. Jettison of doors and windows should be carried out as soon as ditching is inevitable and the crew members should then place one hand firmly on the sill of the window or door which they intend to use as an escape route.

The present RN Helicopter Underwater escape trainer can be fitted with alternative sections resembling either the pilot's cockpit plus the rear fuselage fitted like that of an antisubmarine helicopter, or the rear fuselage only in the passenger configuration.

In both cases the fuselage can be lowered into the water adopting a nose down attitude and rolling either to the right or left, as selected by the instructor, until it reaches the inverted position. On cessation of movement the trainees release their harness quick release fastenings and pull themselves out through their selected escape routes. Each trainee carries out four escapes via different routes and the instructors insist that these are repeated if the trainee shows a lack of confidence.

As several trainees are underwater at one time it is necessary to provide more than one safety diver. Normally four are employed, two inside the fuselage and one on each side of it. These divers are immediately available to render assistance if necessary and as they can see what each subject does during the escape they can advise them prior to the next run.

The usual time taken for the escape is about 5 seconds from the time the fuselage stops moving. This means that the maximum period of breath holding required seldom exceeds 15 seconds. Many non-swimmers have carried out the drill successfully and in the last few years large numbers of civilian employees of the oil companies developing offshore oil fields have completed the training.

It is not considered necessary or desirable to instruct helicopter crews in buoyant ascent from depth. It is unlikely that they will be able to breathe underwater as few helicopters ever use oxygen, and most crew members escape before the helicopter has sunk more than a few metres. The definite risks involved in buoyant ascent training are therefore unjustified.

APPENDIX I

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APPENDIX II

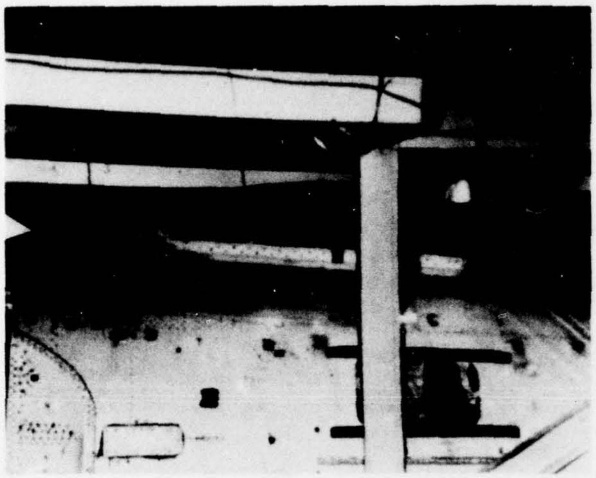


Figure 1.

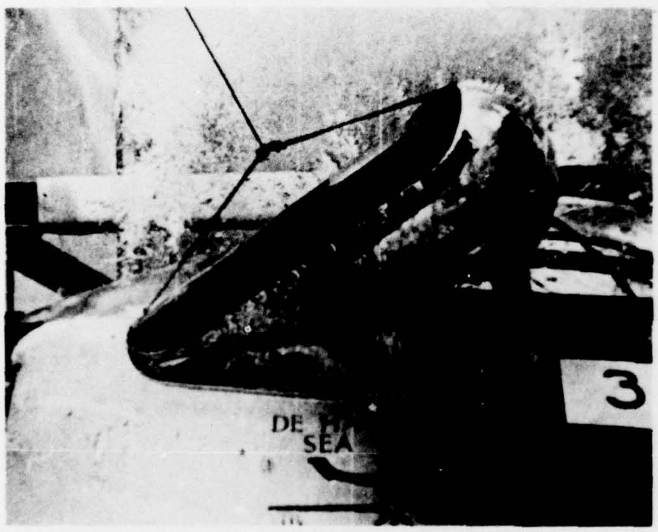


Figure 1A.

Figures 1, 1A & 1B. Observer's window opened by water pressure thus allowing equalisation of the differential pressure prior to canopy and hatch jettison.

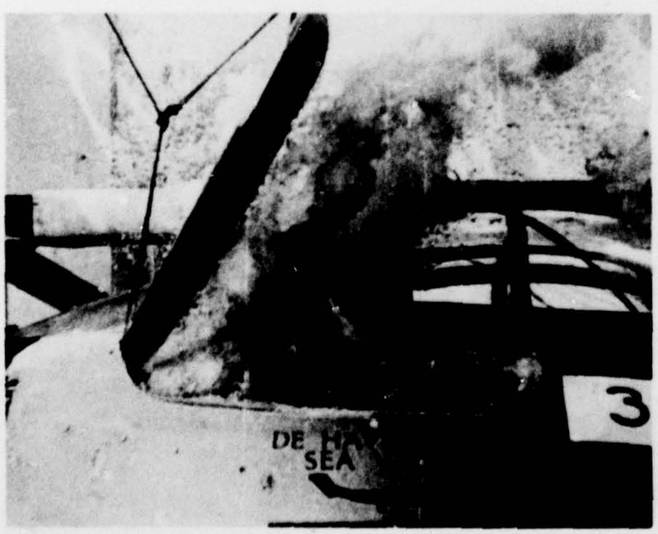


Figure 1B.

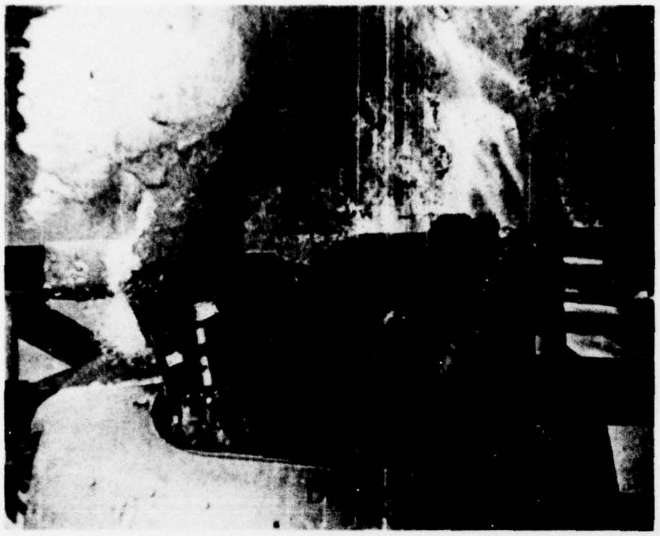


Figure 1C

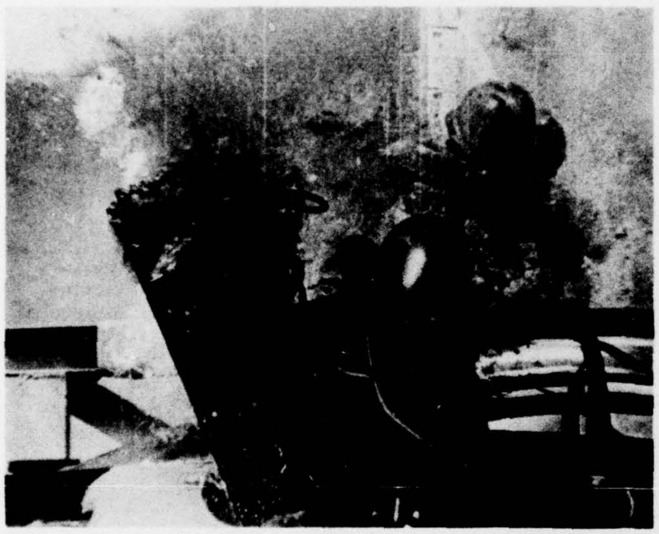


Figure 1D

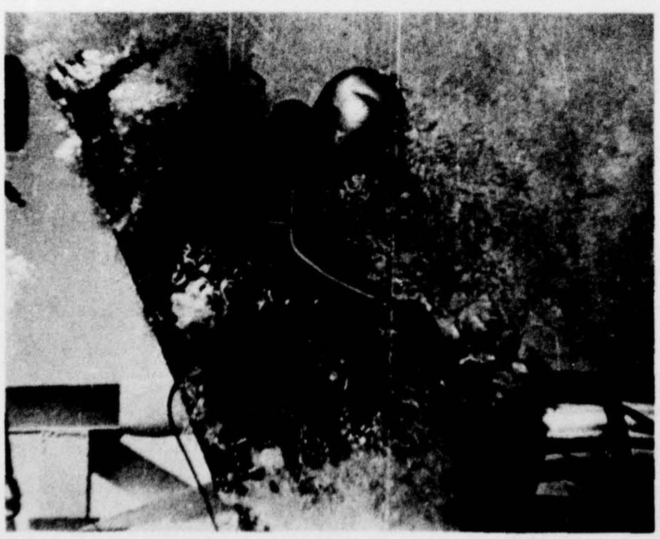


Figure 1E

Figures 1C, 1D & 1E. Jettison of observer's hatch followed by ejection using the compressed air operated underwater escape system. Note that the subject is wearing diving equipment in this trial.

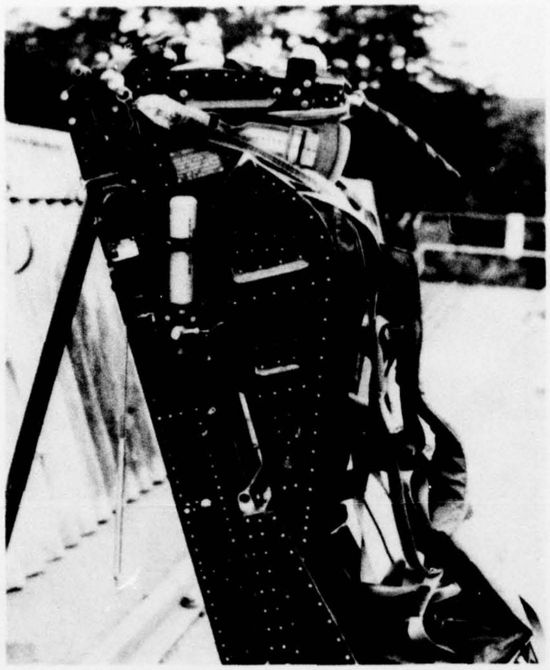


Figure 2. Right (starboard) side of Sea Vixen ejection seat showing gas cylinder which inflated the seat separation bags.

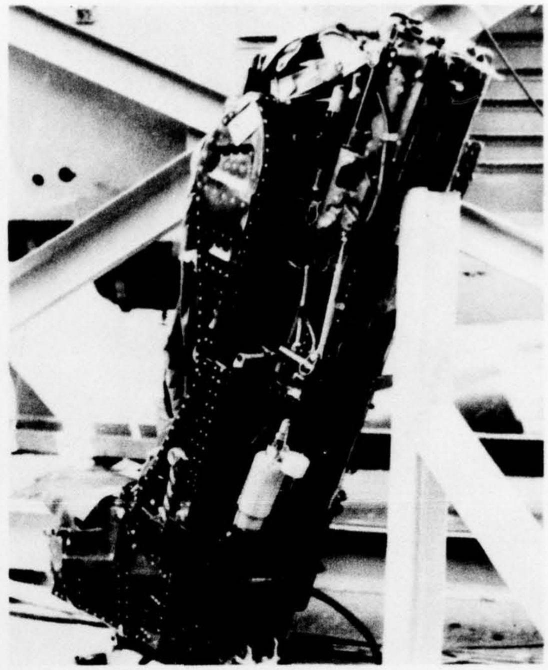


Figure 3. Left (port) side of the seat showing the cylinder containing compressed air which propelled the seat during underwater escape. The drogue link-line guillotine can also be seen.

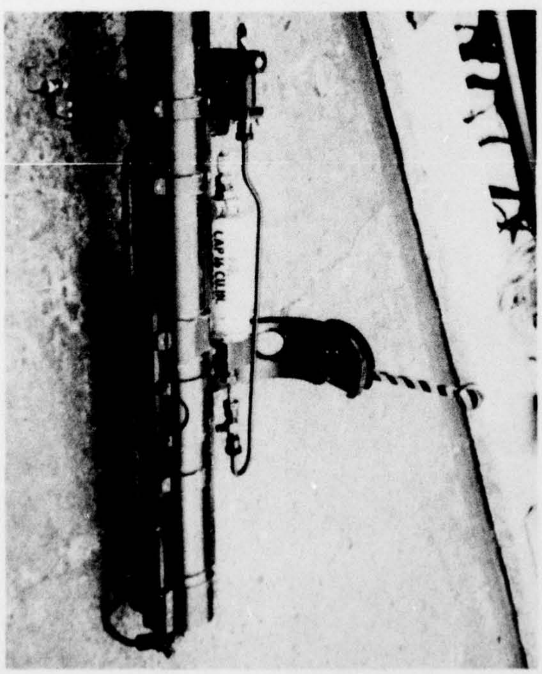


Figure 4. Sea Vixen ejection seat gun modified for underwater escape showing compressed air cylinder and operating lever.

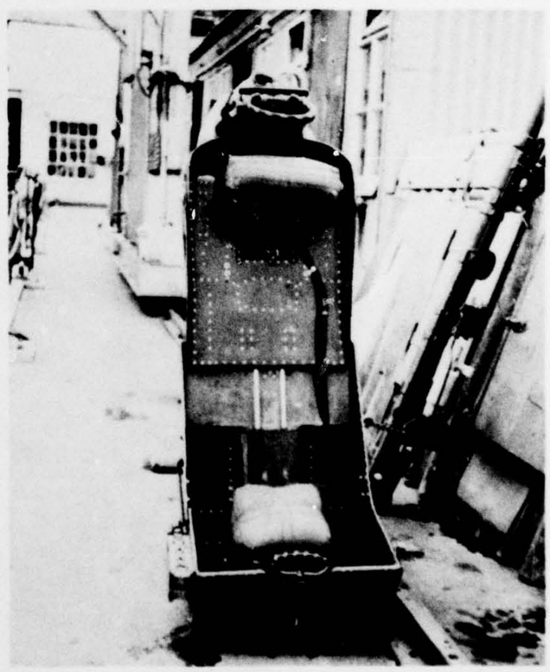


Figure 5. Sea Vixen ejection seat with seat separation bags inflated.

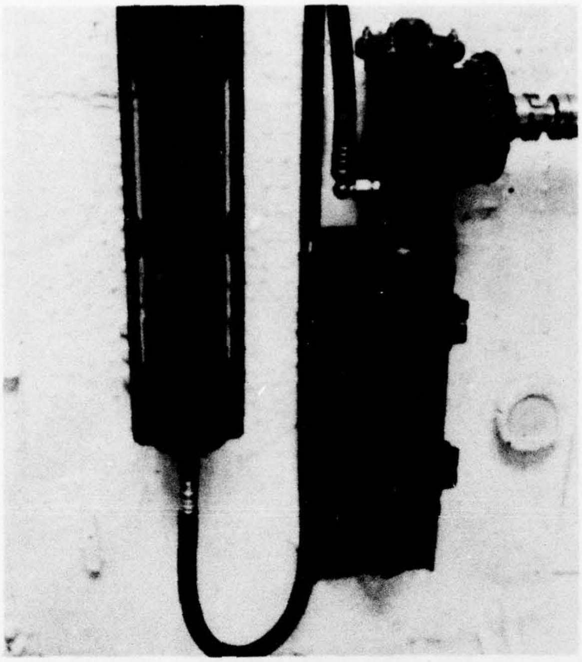


Figure 6. Automatic operating head and connection to lower end of ejection gun.

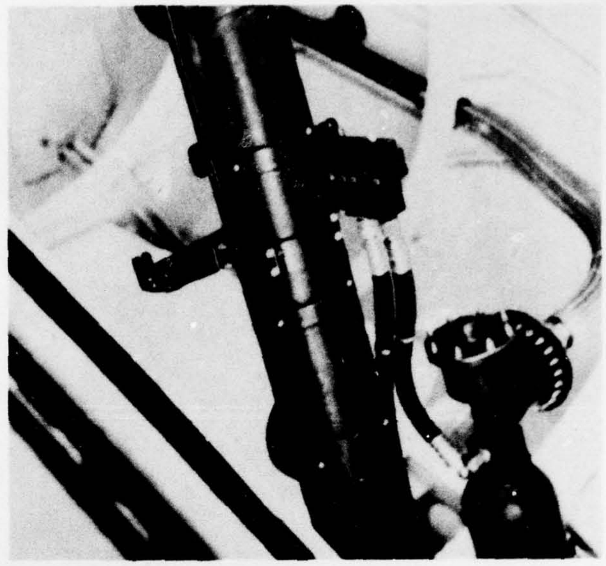


Figure 7. Gun fitted in Buccaneer pilot's cockpit showing the tube which transmits external pressure to the operating head.

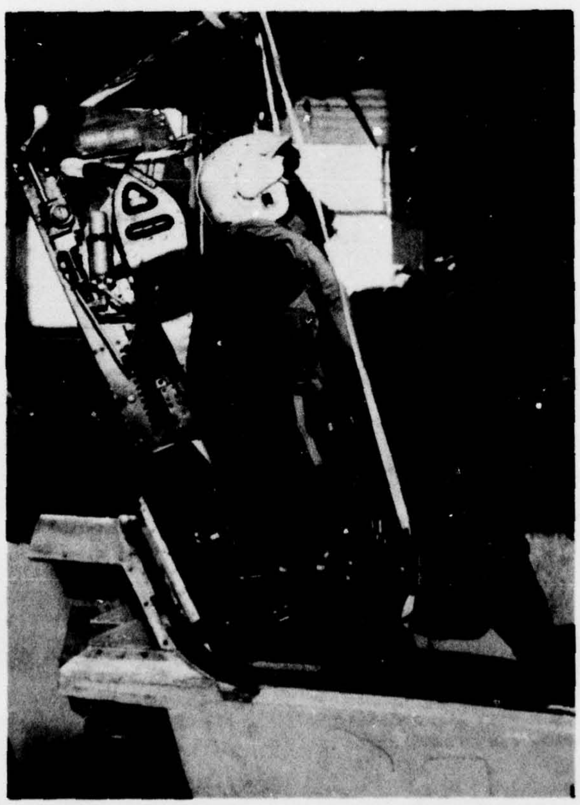


Figure 8. Buccaneer observer's ejection seat being lowered into fuselage.

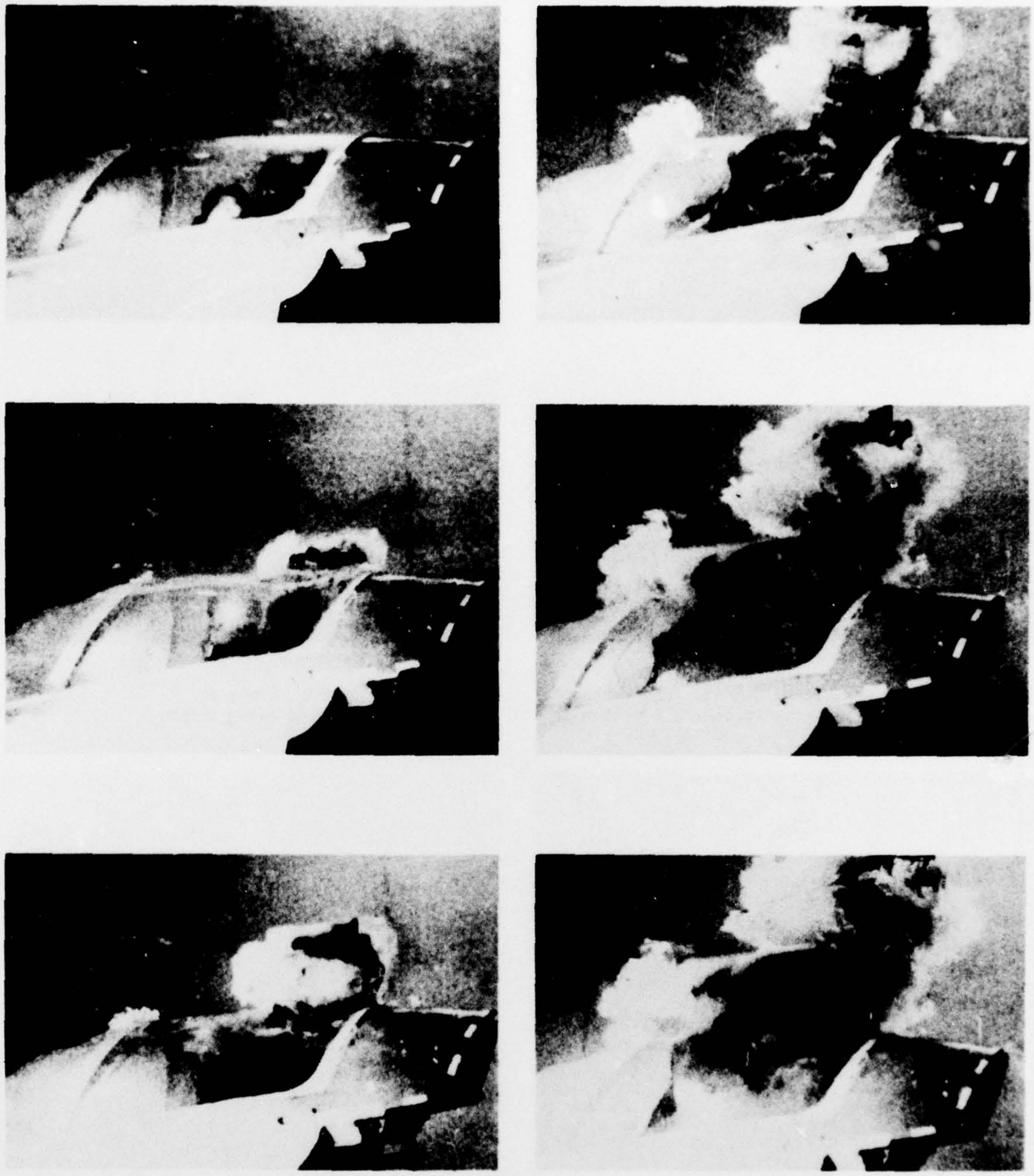
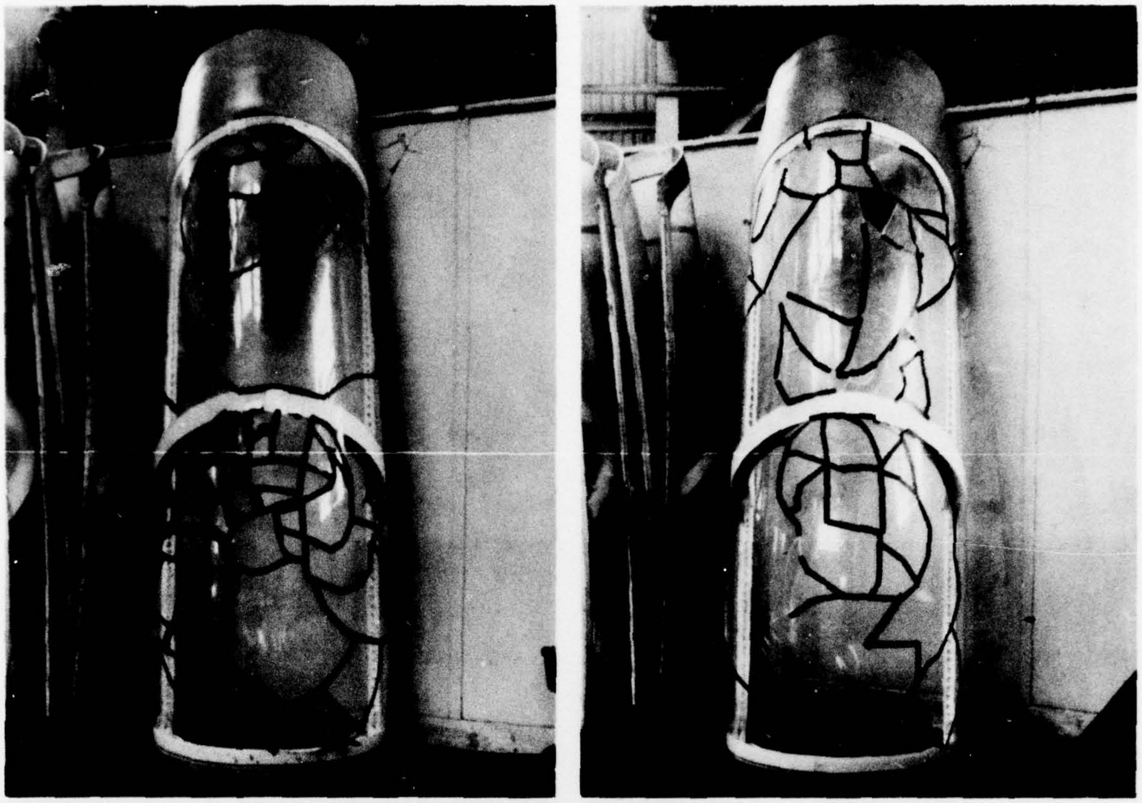


Figure 9. Ejection through canopy from flooded observer's cockpit (dummy).



Figures 10 & 11. Reconstructed canopies showing typical break up patterns following ejection through the Buccaneer canopy under water.

Figure 12. Large piece of perspex from the canopy compared with a 2 ft rule.

Figure 13. Helmet damage following ejection through canopy.

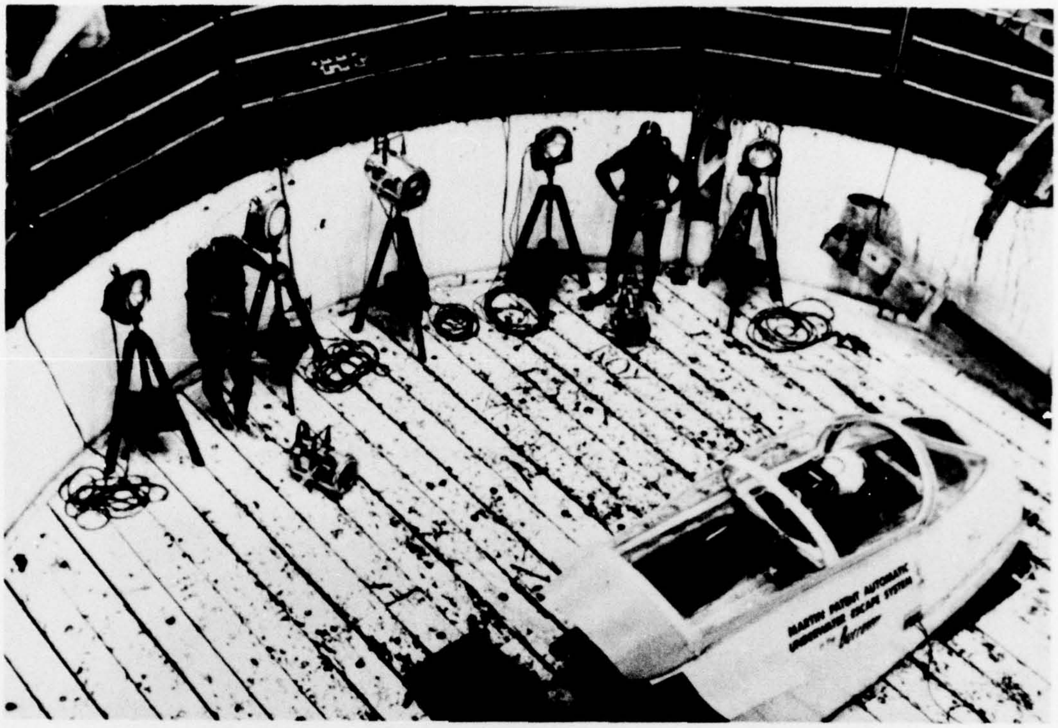


Figure 14. Buccaneer cockpit prepared for underwater ejection trial showing underwater lighting and cameras.

Figure 15. Gannet pilot's underwater escape system. In this system the compressed air rams pull the pilot out of the cockpit in his parachute harness leaving the seat in the aircraft.

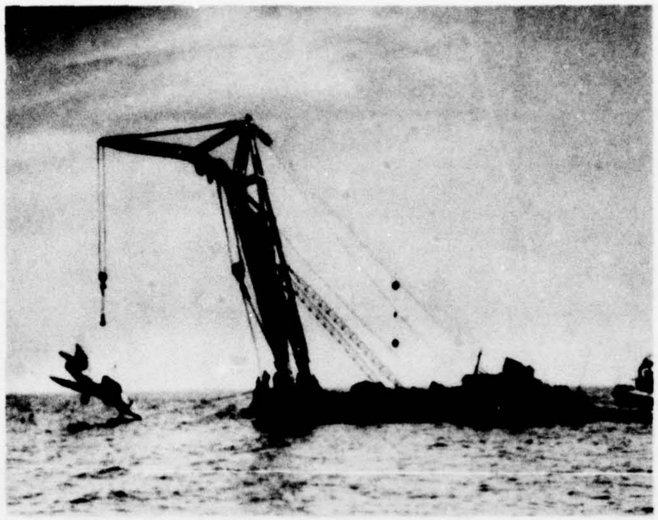


Figure 16. Etendard V1 being dropped into the sea.

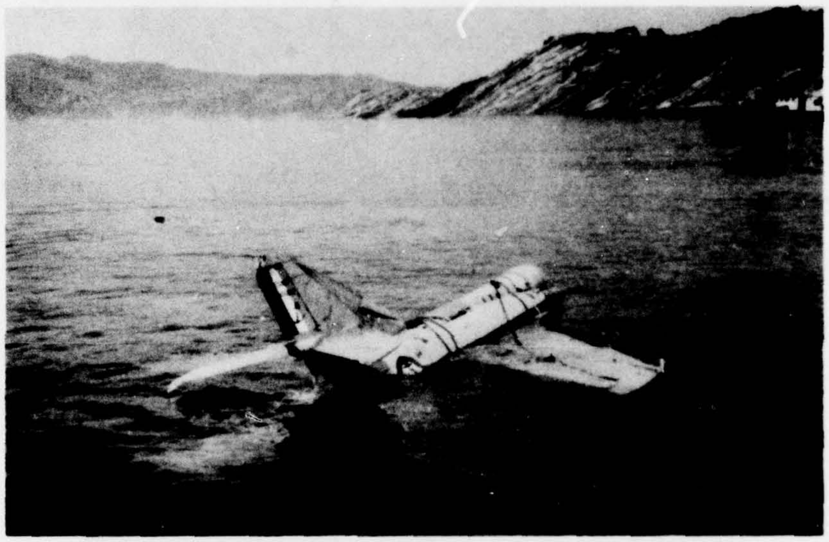


Figure 17. Flotation attitude of Etendard V1 before it sank.

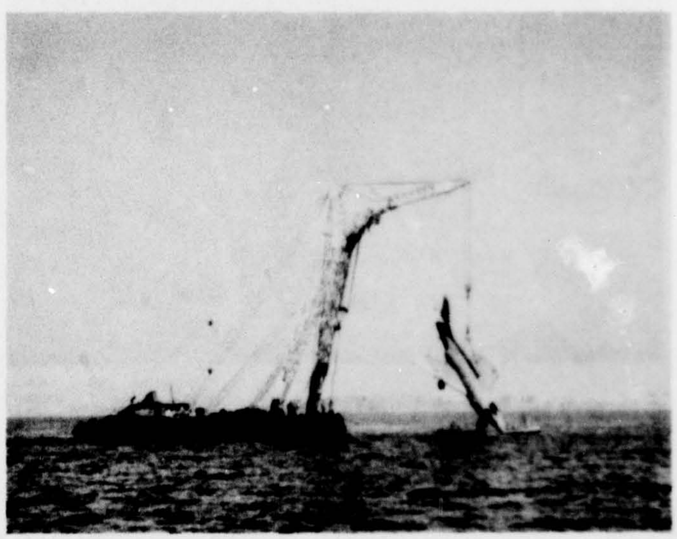


Figure 18. Scimitar ready for drop in nose down attitude.

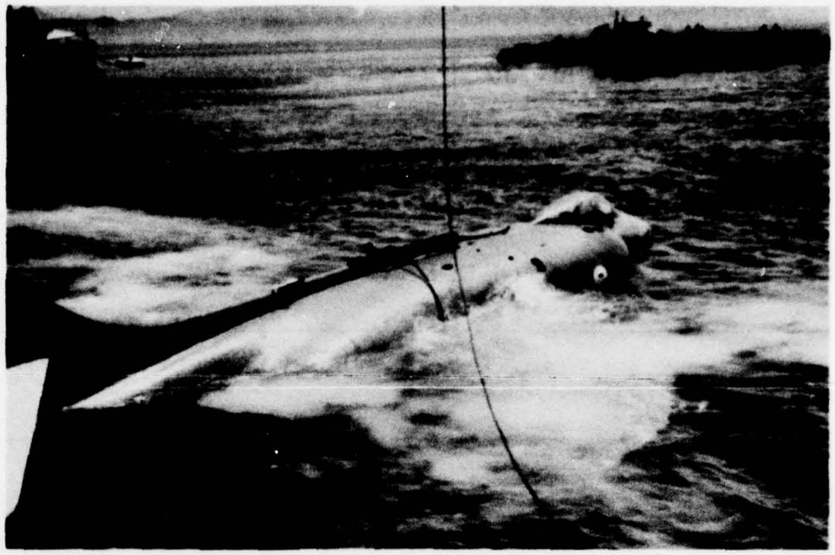


Figure 19. Flotation attitude of Scimitar after the drop before it sank.

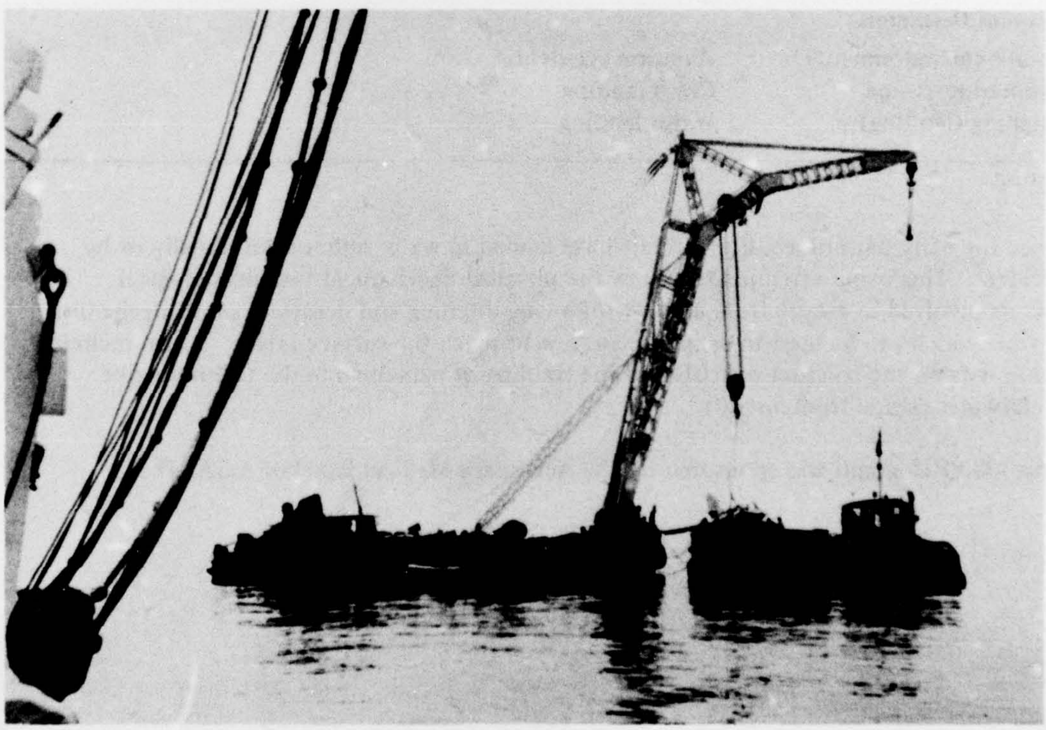


Figure 20. Floating crane barge and tug following recovery of trials aircraft from the sea bed.

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Ditching (landing)	Water landing

14. Abstract

Since the early days of aviation aircraft have landed in water either intentionally or by accident. This paper attempts to review the physical, mechanical and physiological factors involved in escape from aircraft following ditching and describes some mechanical devices which can be used to assist the aircrew to reach the surface safely. It also includes comments on the conduct of trials and the training of personnel in the techniques of underwater escape from aircraft.

This AGARDograph was sponsored by the Aerospace Medical Panel of AGARD.

AGARDograph No.230
Advisory Group for Aerospace Research and Development, NATO
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A.F.Davidson
Published November 1977
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