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Paper 2 Part A Written Paper

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PRE-RELEASED MATERIAL

The question in Section B of Paper 2 will relate to the subject matter in these extracts. You should read through this booklet before the examination.

The extracts on the following pages are taken from a variety of sources.

University of Cambridge International Examinations does not necessarily endorse the reasoning expressed by the original authors, some of whom may use unconventional Physics terminology and non-SI units.

You are also encouraged to read around the topic, and to consider the issues raised, so that you can draw on all your knowledge of Physics when answering the questions.

You will be provided with a copy of this booklet in the examination.

This document consists of **12** printed pages.



Extract 2

Ejection Seat Propulsion

Early seat designers were mainly concerned with getting the aircrew safely away from the aircraft, but even in the very early days it was clear that the same effects that prevented the crew from manually bailing out of many aircraft would affect the seated occupant. The wind-blast effect was one of the main reasons that ejection seats were developed in the first place. In the 1930s it became apparent that at the higher speeds that aircraft were reaching, some crew members were having difficulty even opening the canopy or hatch, let alone managing to climb out into the wind. This was later more apparent to most of the air forces utilizing higher performance craft. Not only was it difficult to climb out, but also the crew member had the risk of striking portions of the aircraft. Even if that did not occur, crew members might receive injuries as they tumbled out of control at a relatively high speed. Many crew were lost to these kinds of incidents, and the investigators realized that as ejection seats were developed, stability would have to be a factor.

As they worked to develop the ejection seats, most of the diverse teams working on the problem came to similar conclusions. First of all the seat had to exit the aircraft with enough speed to clear the tail assembly at the highest expected speed. Second, the crew man had to be able to withstand not only the force of the ejection charge, but also the dynamic force or 'Q' of the wind. In Germany, the Heinkel Schleudersitz designs incorporated a set of footrest bars that the crew man was intended to place his feet on prior to ejection. This would place his knees and lower legs in a position where they would clear the instrument panel and the hatch through which he would eject. (This is referred to as the ejection path). Secondly, the footrests would keep his body in a smaller frontal area and hopefully prevent the legs from flailing in the wind.

Martin-Baker Aircraft used similar footrests and took this design one step further by utilizing an overhead ejection handle, with a face curtain, to give the crew man a method of keeping his arms more controlled. The face curtain gave some protection to the face, and the overhead reach tended to help the crew man straighten his back. SAAB in Sweden used a set of straps at each shoulder, which accomplished the same thing. This was an important consideration as the force of the seat firing was capable of injuring a crew man when they ejected.

Early German designs utilized various schemes to propel the seat and man together out of the fuselage. Some of them included compressed air, elastic bands, and pyrotechnic cartridges. The elastic bands and spring systems were dangerous to rig, and were not reliable in the amount of force they would produce. Compressed gas was a viable system, and was used in some prototype and production aircraft. It was limited, however, in the maximum amount of force it could provide without causing an injury. This made it unsuitable for the higher performance aircraft, which would require a more powerful boost to clear the tail and other obstructions aft of the cockpit at the higher speeds. The Germans switched to a cartridge system which, by careful selection of the propellant used, allowed for a gentler (relatively) ejection stroke.

There are two aspects of the initial catapult stroke which are potentially injurious. One is of course the maximum force exerted, usually referred to as the g -force experienced by the average seat occupant. The second aspect is the onset rate of the g -force expressed in g/s . This is the more tricky one as the human body is capable of astounding resilience when pushed, yet the concept of a seat that provides a $14g$ ejection causing an injury while a $16g$ jolt from another seat does not is non-intuitive. The difference would likely be in the onset rate. If the peak g -force is reached in the first example at a much higher rate, for example in $0.010s$ that would translate to a $1400g/s$ onset rate. The latter seat might take twice as long to reach maximum force so that $0.020s$ at $16g$ translates to $800g/s$. It took much experimentation to develop reasonable safe rates for both maximum g -force and maximum onset rate.

Martin-Baker Aircraft developed a multi-stage, telescoping catapult that uses a primary cartridge at the top to begin seat movement. As the gas from this cartridge expands inside the inner tube it forces the inner tube upwards, driving the seat/man upward with a relatively low onset rate. As momentum builds while the seat rises, ports in the outer tube of the catapult gun are uncovered as the inner tube slides by. This allows the hot gas to enter the secondary charge and ignite it. The additional gas pressure generated accelerates the extension of the tubes and thus increases the speed of the seat/man mass. Since this acceleration has been delayed, the onset rate is kept in reasonable bounds. Fig. E2.1 shows a secondary charge cartridge to the left of a primary catapult cartridge.

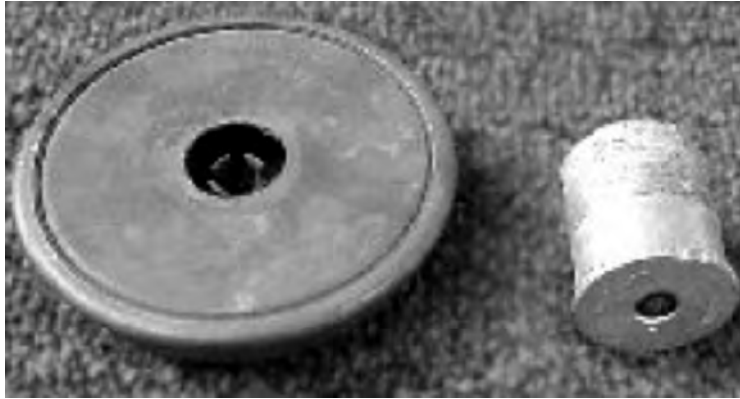
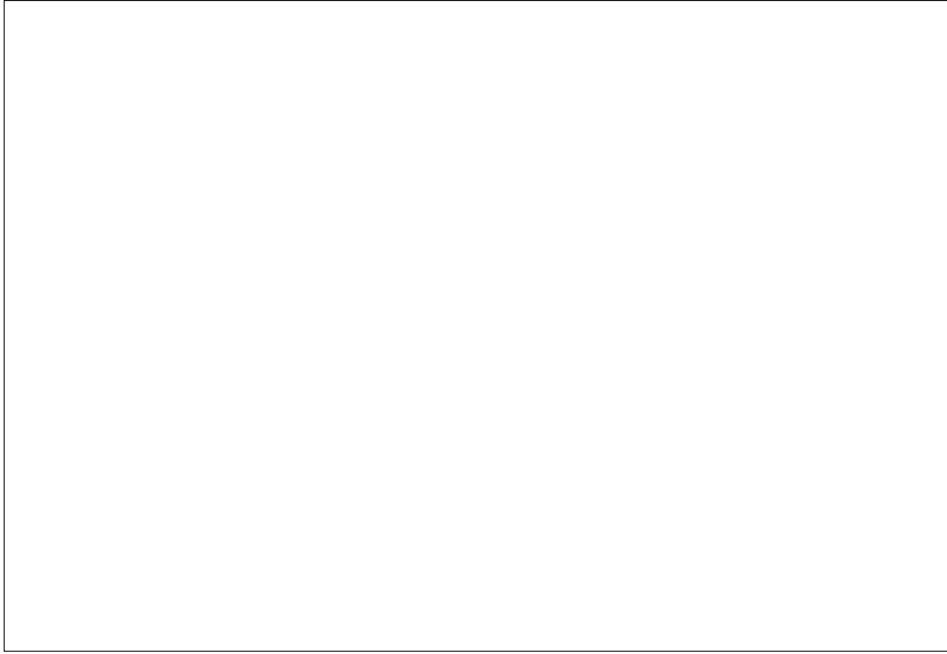


Fig. E2.1

Later, as it became apparent that the seats were saving aircrew at altitude, but the limited safe ejection envelope did not extend down to the ground where many accidents occurred, the seat engineers went back to work on improving the seat propulsion systems. This led Martin-Baker Aircraft to add a third tube to allow for further expansion and lengthen the catapult stroke. At the same time they added more secondary cartridges to increase the staggered gas pressure. These changes increased the ability of the seat to clear the tail assembly, and allowed for ejection at altitudes as low as runway level. There were several modifications to other mechanisms on the seat to allow for safe ejection on the runway. Once these were accomplished, the Martin-Baker Aircraft seats were much in demand by the Naval Aviation branches of several militaries.

Adapted from: <http://www.ejectionsite.com/>



Extract 4

Ejector Seat Development

When ejector seats are referred to, it is usually those found in aircraft that are meant. In (mostly military) aircraft, the ejector seat is a system designed to rescue the pilot or other crew in the event of the aircraft becoming unflyable. There have been exceptions, like the famous ejection seat in James Bond's Aston Martin in the film *Goldfinger*, to get rid of unwanted passengers. In most designs, the seat is propelled out of the aircraft by a rocket motor, carrying the pilot with it. The concept of an ejectable escape capsule has also been tried. Once clear of the aircraft, the ejector seat deploys a parachute which descends safely to earth.

While a bungee-assisted escape from an aircraft took place in 1910, the ejector seat as we recognise it today was invented in Germany during World War II. Prior to this, the only means of escape from an incapacitated aircraft was to jump clear, and in many cases this was difficult due to injury, the difficulty of egress from a confined space, the airflow past the aircraft and other factors.

The first ejector seats were developed during the war by Heinkel. Early models were powered by compressed air and the first aircraft to be fitted with such a system was the Heinkel He 280 prototype jet fighter in 1941. One of the He 280 test pilots, Helmut Schenk, became the first person to escape from a stricken aircraft with an ejector seat on January 13, 1942 after his control surfaces iced up and became inoperable. This aircraft never reached production status, and the first operational type to provide ejector seats for the crew was the Heinkel He 219 night fighter in 1942.

In late 1944, the Heinkel He 162 featured a new type of ejector seat, this time fired by an explosive cartridge. In this system the seat rode on wheels set between two pipes – ejection rails – running up the back of the cockpit. When lowered into position, caps at the top of the seat fitted over the pipes to close them. Cartridges, basically identical to shotgun shells, were placed in the bottom of the pipes, facing upward. When fired, the gases would fill the pipes, popping the caps off the end and thereby forcing the seat to ride up the pipes on its wheels, and out of the aircraft.

After World War II, the need for such systems became pressing, as aircraft speeds were getting ever higher, and it was not long before the sound barrier was broken. Manual escape at such speeds would be impossible. The United States Army Air Corps experimented with downward-ejecting systems operated by a spring, but it was the work of the British company Martin-Baker that was to prove crucial.

The first live flight test of the Martin-Baker system took place on July 24th, 1946, when Bernard Lynch ejected from a Gloster Meteor Mk III. Shortly afterwards, on August 17th, 1946, 1st Sgt. Larry Lambert was the first live US ejectee. Martin-Baker ejector seats were fitted to prototype and production aircraft from the late 1940s, and the first emergency use of a Martin-Baker seat occurred in 1949 while testing the Armstrong-Whitworth AW.52 Flying Wing.

Early seats used a solid propellant charge to drive the seat out, by exploding the charge inside a telescoping tube attached to the seat. Effectively the seat was fired from the aircraft like a bullet from a gun. As jet speeds increased still further, this method proved inadequate to get the pilot sufficiently clear of the airframe, so experiments with rocket propulsion began. The F-102 Delta Dagger was the first aircraft to be fitted with a rocket propelled seat, in 1958. Martin-Baker developed a similar design, using multiple rocket units feeding a single nozzle. This had the advantage of being able to eject the pilot to a safe height even if the aircraft itself was on or very near the ground. Today's ejector seats can still operate if the plane is safely stopped on the ground.

Since the 1950s the mechanism would automatically open up the parachute for the crewman. Despite what some movies show, the seat separates from the pilot, who is attached to the parachute. The seat detaches in a number of ways, either due to the parachute yanking the pilot from the seat, or a strap pulling them apart, or a rocket called an "ear-burner" activating and blasting the seat away from the pilot (guess why it's called an ear-burner.)

In the early 1960s, rocket-powered ejection seats designed for bailout at supersonic speeds were deployed in planes such as the F-106 Delta Dart. Six pilots have ejected at speeds exceeding 700 knots (360 m/s) and the highest altitude a Martin-Baker seat was deployed at was 17 500 m. It has been rumoured – but not confirmed – that a SR-71 pilot ejected at Mach 3 at an altitude of 24 500 m. Despite these records, most ejections occur at fairly low speeds and at fairly low altitudes.

The F-104 Starfighter was equipped with a downward-firing ejection seat as the T-shaped tail was judged likely to cut the pilot in half. In order to make this work, the pilot was equipped with “spurs” which were attached to cables that would pull the legs inwards so the pilot could be ejected. Note that such a system is of no use on or near the ground, and it was unusable during takeoff and landing. Later on, a more powerful upward-firing ejector seat became available. Aircraft designed for low-level use sometimes will have ejector seats which fire through the plastic of the canopy, as waiting for the canopy to be ejected is too slow. Many aircraft types (e.g. BAe Hawk) have an explosive cord embedded within the perspex of the canopy, which shatters it simultaneously with the firing of the seat. Some helicopters had ejector seats designed for use, such as the Russian Kaman Ka-50 Black Shark and the American AH-1 Cobra, where activating the ejector system also triggers explosive bolts in the helicopter blades, making them fly off, followed by jettisoning the canopy, and using a tractor rocket system to eject the seat and person, with parachutes automatically deploying seconds later.

Boeing, Lockheed, Northrup, and Stanley Aviation all manufactured ejector seats at one point. By December 2003, Martin-Baker ejector seats had saved 7028 lives. The total figure for all types of seat is unknown but must be considerably higher.

The purpose of an ejection seat is survival, not pilot comfort. Many pilots have suffered career-ending injuries while using ejector seats, including crushed vertebra. The pilot typically experiences a force of about 12g to 14g as he is hurled out of the airplane. Supposedly Air Force scientists had to cut holes in helmets because without them the wind shear can take off an ejecting person's head.

Adapted from: <http://everything2.com/title/ejection%2520seat>

Extract 5

Rocket Propulsion in Ejector Seats

Seat designers were presented with the challenge of expanding the ejection envelope still further to include even slower ejections on the ground, as well as to encompass higher sink rates at lower altitudes. To do this would require more propulsive force, as well as a method of preventing the loss of some of the altitude gained by tumbling. Martin-Baker Aircraft designed and tested the underseat rocket. This rocket package is made of a manifold to which is joined a set of tubes containing rocket propellant, an ignition tube, and a set of rocket nozzles as shown in Fig. E5.1.



Fig. E5.1

The propellant is packed into the ignition tube and is highly explosive. Once ignited, it reaches an extremely high temperature very quickly. This results in the hot gas being expelled downwards at a very high speed and out through the nozzles. The reaction force is an upwards, propulsive force acting on the seat which is large enough to expand the ejection envelope.

Another positive feature enabled by the addition of the under seat rocket was the ability to lower the catapult speed from 24m/s to 18m/s. This helped reduce the potential for injury to the person being ejected.

Adapted from: <http://www.ejectionsite.com/>

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Extract 6

Ejection Seats in Military Aircraft

Ejection seats are complex and very expensive devices. Some cost as much as £100 000 each. When used in military aircraft, ejection seats have proven highly successful at saving the lives of aircrew. Complex devices require much maintenance and even though modern ejection seats are designed for fully automatic function after initiation, the occupant requires training to use the seat effectively and safely. Ejection seats are designed to cause an occupant to separate from the aircraft at a high enough speed to clear any part of the aircraft structure. This requirement necessitates a very large force being exerted to launch the seat and its occupant. Military seats are fired with a vertical force of between 12g and 22g depending on the seat design. This force varies with the type of seat propulsion. The rocket/catapult seat exerts lower values, and the pure gun type exerts the higher values. This force, however, is also influenced by the mass of the occupant, and the values quoted above are based on a seat occupant in the 70 kg–90 kg range. With the continued influx of female pilots and crew, the average mass of pilots is dropping. This is leading to much research to provide a propulsion system for an ejection seat that is usable over a much wider range of occupant weight.

Other considerations include the occupant's connection to the seat. Parachutes require more than just a simple lap belt. At a minimum, the harness requirements include a pair of leg straps, a pair of shoulder straps and a chest strap. These straps must be adjusted for each individual to be a snug (and inevitably uncomfortable) fit for each passenger. In most commercial airlines many passengers release the belt the minute the cockpit crew turn off the lap-belt indicator (this is confirmed by the occurrence of passenger injuries due to turbulence). In a military aeroplane, the pilot must not do this and so there is no delay prior to depressurizing the cabin, blowing the hatches and initiating ejection.

When the cabin is depressurized and the hatches are jettisoned, the pilot is exposed to the lower oxygen pressure in the upper atmosphere. Pilots have regular health checks and must be extremely fit and so they stand a good chance of surviving. The sudden wind blast would cause flail injuries if loose items were left in the cockpit and so pilots need to be tidy and military aeroplanes are designed to include secure locations for all necessary items. There are, however, no overhead baggage compartments, or underseat storage as there has to be adequate clearance above and, because of the seat depth, below.

The structure of a military aircraft is very strong as the ejection seat can be up to four times heavier than the pilot and furthermore it requires strong fittings which are also heavy. The floor of the cockpit must support the additional weight and resist the recoil as the seat ejects. The roof has to be configured so that it is strong even with a removable hatch. The fuselage needs many supports to allow it to hold its shape when the hatches are jettisoned. Leg room has to be sufficient so that adequate clearance is maintained and ejection leg injuries prevented.

Mechanical ejection systems (spring/bungee) do not provide enough thrust to ensure that the occupants clear the tail assembly. Compressed gas systems that do supply enough thrust, produce an initial acceleration that is too great for safety. This means that only pyrotechnic rocket/catapult systems can be used. These systems necessitate an intensive training programme for both maintenance personnel and crews. The pyrotechnics would require checks and testing on a regular basis.

In military aircraft, the delay between taking the decision to eject and initiating the process is often in the vicinity of 0.4 s to 0.5 s. This is usually a sufficiently short period for the occupants to escape a doomed aeroplane even when faced with the sort of sudden catastrophe which can occur in military conflicts. As with commercial airliners, however, the majority of disasters occur at low altitude, usually during take-off or landing and even in these cases, a delay of less than a second can be enough to save the crew. The crew are trained to remain calm in dangerous situations and need to make life-saving decisions in very short periods of time.

Adapted from: <http://www.ejectionsite.com/>