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Aircraft - Escape system dependency

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Abstract

There is a strong dependency between military aircraft configuration and the design of its escape system. It is of course dependent on time e.g. a consequence of continuous technological break-trough but also driven by the configuration itself. Aircraft design is also to some extent driven by escape and oxygen systems technology. This paper presents technical dependencies with most examples from Saab AB in Sweden.

Content

Background

Saab AB in Sweden has developed military aircraft for the Swedish Air Force during forty years but is also a pioneer in escape system design for all those aircraft. This relation between aircraft and escape system design is world unique.

Design of aircraft and of their escape systems are stories of compromises. Advantages in one area is balanced by problems elsewhere. It has been proven valuable in several areas that escape system specialists are found within the same organisation as other aircraft systems and structure design specialists. The most visible examples are cockpit man machine interface, oxygen system and canopy emergency mode. System safety analysis is done in a common manner throughout the aircraft.

Saabs own seat design work has seized but experience gained from earlier programmes has influenced vendor requirement specifications. It is a goal for Saab AB and the Swedish Defence Material Administration to keep a certain level of escape system development knowledge in Sweden to maintain the Swedish Air Force for the foreseeable future. A technical cooperation agreement is therefore established between Saab AB and Martin Baker Aircraft Co Ltd in UK when their seat was chosen for the Gripen aircraft.

Aircraft propulsion method

The Saab 21 aircraft had a large Daimler Benz twelve cylinder engine with a pusher propeller behind the cockpit. It gave the Saab design engineers a lot to think about. It could be claimed that the Swede Elis Nordquist is the inventor of the ejection seat. His Swedish patent 132312 is dated October 17 1941. An ejection seat with a trajectory over the propeller blade tips was necessary to save the pilot in case of a major aircraft failure.

The first Saab ejection seat was installed vertical in the Saab 21 aircraft. It saved 23 pilots – the first on July 29, 1946.
The same Saab 21 seat was installed later in the Saab 18 twin engine bomber aircraft. Its rear seat was installed and ejected backward. Two rearward ejections were done on August 19, 1949 and September 11, 1952.

For modern military aircraft with jet engine propulsion the high maximum flight speed and escape in adverse attitudes are the major reasons for an ejection seat.

Aircraft canopy
The aircraft canopy is a part of the aircraft fuselage with many unique requirements besides low drag, low weight and enough strength. Stretched acrylic material dominates but it creates a limit for aircraft maximum speed due to aerodynamic heating. Together with the front windshield the canopy must be transparent with good optical qualities and provide high resistance against bird strike at high speed. Separate front windshield is preferable for high bird strike resistance. Good external view is achieved by a large aircraft canopy and low aircraft railings. Opening and closing must be easy.

Safe emergency opening methods must be provided from all crew stations in case of both crash landing and seat ejection. Seat ejection through the canopy acrylic is a normal requirement. It limits canopy thickness and material choice.

Most military aircraft canopies are rear hinged which allows cockpit access from both sides. Emergency jettison is started by canopy thrusters or rockets but aerodynamic forces take over later. Some aircraft canopies are side hinged but rearward emergency jettisoned - notably Saab 32 Lansen and two seat version of 35 Draken aircraft.

Canopy thrusters create recoils on the railings. Jettison creates large hinge forces in high speed which has to be borne by the aircraft structure. This means weight increase. Canopy jettison takes valuable time in low speed emergency. The seat must be delayed to avoid collision with the canopy.

The Saab 39 Gripen aircraft is provided with a left hinged canopy of stretched acrylic. A canopy fracturing system with a linear shaped charge is provided. Advantages are low weight, simple design and almost instant emergency method. A disadvantage is that the ejection seat is not easily made safe by a partly open canopy.

Aircraft drag
Minimising aircraft drag is important for high performance. The aircraft frontal area should therefore be as small as possible. This has led for aircraft Saab 29 Tunnan ”the flying barrel” already 1948 that the ejection seat was installed in a 30 degree backward angle. It was also advantageous for vertical g-load protection as was found later. The frontal area of that aircraft was however dominated by the large diameter deHavilland Ghost jet engine with its radial compressor. The available cockpit volume was on top of the large circular air intake channel.

The seat backward installation angle must be carefully chosen. Upright sitting angle is advantageous for pilot internal view and access, external view and high speed ejection but a drawback regarding aircraft frontal area, vertical g-load protection and knee clearance at ejection. Large backward sitting angle is advantageous for vertical g-load protection but makes the aircraft slightly longer. Good ejection seat stability and high fin clearance are more difficult to achieve if the seat is ejected at a large backward angle.

30 degree seat backward angle was also used for the later Saab 32 Lansen and 35 Draken aircraft.The ejection seat in 37 Viggen aircraft was raised to 17 degrees for good visibility but 28 degrees was chosen for the 39 Gripen aircraft.

Seat pan adjustment for pilot size variation is better than moving the entire seat for low aircraft frontal area. The top of the seat will maintain the same position relative to the aircraft canopy. This principle has been adapted by Saab seat designers since 1955 for the 35 Draken aircraft.

Seat crash damping will reduce the retardation forces on the pilot spine in case of a crash landing. It is more needed for large delta wing aircraft which might have the cockpit area high above the ground when the tail cone strikes the ground. The seat must be allowed to move a short distance downwards with controlled and acceptable retardation within the aircraft structure. This distance increases the aircraft frontal area and thus aircraft drag. Seat crash damping devices were installed later in all Saab 35 Draken aircraft. They are also basic features in all 37 Viggen aircraft. The Saab seat crash damping devices allow emergency seat ejection after damping should that be necessary. No seat crash damping device is installed in the small Saab 39 Gripen aircraft.

Aircraft weight

Minimising aircraft weight is important for high performance. This is driving weight reduction of all aircraft systems including canopy and ejection seat.

The escape system can be considered an unnecessary penalty in normal flight because it has no tactical value until it is necessary to save life. The same argument can also be used for the landing gear which is used only during take off and landing.

Flight and escape envelope

The aircraft flight envelope in max speed and max altitude is dependent of aircraft mission type. Earlier trend towards higher maximum speed and altitude is broken by material technology, limited tactical need and limited financial resources.

The escape envelope should ideally cover the entire flight envelope and for some aircraft types it does.

The high fin of modern aircraft creates a fin clearance problem which necessitates a powerful seat ejection gun.

The incidence of aircraft loss is high during aircraft take-off and landing. The consequences of engine failure and bad weather are more severe close to ground. Emergency escape is therefore required in adverse attitudes. This drives ejection seat design towards short recovery time, short recovery distance and zero/zero performance. Acceptable deceleration forces on the pilot must be ensured. Safe escape from extreme adverse attitudes is still impossible.

Technical difficulties and limited verification still makes supersonic escape hazardous.

Lessons learned from thorough post crash investigations in Sweden has influenced Saab seat upgrade work. Saab ejection seats are provided with an underwater acoustic beacon which is activated if submersed and aids seat location.

Seat upgrade has led to advanced high speed performance for the Saab 35 Draken and 37 Viggen escape systems. A passive arm restraint system with nets located partly on the seat and partly under the railings are installed in all Saab 37 Viggen aircraft. It is qualified for 650 knots (1200 km/h) maximum speed.

Pilot size and weight spans

The size variations of pilots is a challenge for cockpit design. Adequate view, access and manoeuvrability of important controls must be ensured for all pilot sizes.

The first firm Swedish pilot specification was written in 1970 for the Saab 37 Viggen aircraft. It is a basis for recruiting young boys and girls to the flying school of the Swedish Air Force. About 90% of the population is allowed but the smallest and largest individuals are outside. Odd combinations of measurements are limited. Recent gradual increase of back length has led to change in the pilot specification for the Saab 39 Gripen aircraft.

The size and weight variations of pilots are also challenges for seat design. The ejection seat pan is normally adjustable to cater for pilot size variations. The ejection seat in the French Dassault Rafale aircraft has a unique seat pan adjustment mechanism which combines good internal access and good g-load protection.

The variations of centre of gravity of the occupied seat should be kept small to ensure adequate seat stability and trajectory control at low speed for all pilot sizes. A heavy seat is then advantageous. The accelerations on a lightweight pilot must be low enough at high pyrotechnic temperature. The seat fin clearance at high-speed ejection with a heavy pilot must be acceptable at low pyrotechnic temperature.

In flight collision risk

The risk of in flight collision is large during tactical training. It may result in serious aircraft damage e.g. loss of a fin which in turn degrade the lateral stability. The cockpit area might be damaged.

The Swedish Air Force has lost four Saab 37 Viggen aircraft in two mid air collisions and three more due to wing spar structure failure in flight. All seven pilots were saved by the escape systems.

One lesson learned is that the escape system should be tolerant and be designed to handle large coriolis forces on the canopy hinges and seat guide rails. Three radians per second of aircraft roll rate is required.

The canopy fracturing system of the new Saab 39 Gripen aircraft is qualified for large yaw angles at moderate speed which may be a future emergency scenario.

Electrical and avionic integration

The escape system function should ideally be independent of aircraft electrical supply and avionic integration. Secondary electrical functions such as seat pan movement and functional monitoring are generally used.

The high degree of avionic integration in modern military aircraft can be used to feed information of aircraft speed, attitude and altitude to the ejection seat when emergency ejection is needed. Most modern ejection seats have however independent speed and altitude sensors. Attitude sensors have been studied.

The canopy jettison and command ejection systems in Saab 35 Draken and 37 Viggen aircraft are activated electrically through redundant circuits which are hardened against lightning attack. One circuit is supplied from a separate emergency battery in the cockpit. Aircraft speed information from the fin pitot tube is transferred pneumatically and mechanically to the ejection seat during its gun stroke.

Multi-crew aircraft

If the aircraft has two or more pilots and if the escape system has rocket assisted ejection seats for runway-level performance then the ejection sequence should be controlled by a command ejection system.

For tandem positions the rear seat is normally ejected first to avoid injury risk from the front seat rocket. The hazards for the rear pilot is dependent of the design of the aircraft canopy and of the ejection seat rockets.

Both ejection seats of the two seat version of Saab 35 Draken aircraft are located under the same long canopy. The ejection sequence is activated from the front seat and conducted by pyrotechnic cartridges. The arms of the rear pilot are kept against the seat by air bags under each railing. The front seat has a manual override handle for ejection in case of command system failure. The Saab seat rocket would be very harmful for a remaining pilot in the rear seat.
The two seat version of the Saab 37 Viggen aircraft has two separate cockpits in tandem. The front emergency sequence is delayed electrically. Ejection of each seat follows mechanically after each canopy jettison.

Both ejection seats of the two seat version of the Saab 39 Gripen aircraft are located under the same canopy. The seat command sequence is controlled by hot gas pressure from both seats. Each part of the canopy fracturing system is activated by hot gas pressure from the seat under it. In case of rear system failure a remaining rear pilot might be protected from the front seat rocket by a nonfractured part of the canopy.

Two ballistic Saab seats are located side by side in the Saab 105 trainer aircraft. They are installed 19 degrees backward and 2 degrees outward. No command system is provided.

Others

The ejection seat gun creates a large recoil load which has to be taken by the aircraft structure.

Active arm and leg restraint systems which are powered by seat movement create also loads which must be taken in the aircraft cockpit floor. Passive arm and leg restraint systems require careful cockpit integration work.

Good sitting comfort reduces pilot fatigue during high g manoeuvres and long duration flight. An adequate seat harness keeps the pilot firmly in the seat during multi-axial accelerations.

Vertical g-load is normally counteracted by an advanced anti-g suit covering the lower body. It is pressurised with air or oxygen through a quick-reaction anti-g valve.

The oxygen concentrator and the anti-g suit for the Saab 39 Gripen aircraft are supplied by air from the aircraft engine through the environmental control system. The flight time is then, regarding oxygen supply, virtually unlimited. A clear disadvantage is that pressurization of anti-g suit and normal breathing oxygen supply are dependent of aircraft engine function.

Biography

Mr Georg Ohlsson is Principal Systems Engineer and Technical Manager for Escape and Oxygen Systems at Gripen business unit of Saab AB in Linköping Sweden. He has over 30 years of experience in escape system development work and update programmes for all Swedish frontline military aircraft. He holds a Master of Science degree in Aeronautical Engineering from the Royal Technical Institute in Stockholm. He is a SAFE member since 1977.