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L5 Safety and Hazard Assessment
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Abstract

This document outlines a comprehensive risk assessment and ALARP (As Low As Reasonably Practicable) justification process divided into two parts. Part 1 involves a detailed written risk assessment based on a group exercise, expanding on hazard identification, risk estimation, control identification, and mitigation strategies. The assessment includes a task/system description, hazard descriptions, pre-control and post-control risk estimates, and a list of controls and mitigations, aiming to cover a wide array of hazards across the Manufacture to Target Disposal Sequence (MTDS). Emphasis is placed on detailing controls, referencing industry standards and best practices, and effectively communicating risks and mitigations to the intended audience.

Part 2 focuses on selecting one hazard from the risk assessment and producing a detailed ALARP justification report. This report explains how the hazard is mitigated to an ALARP position, discussing the selection of controls, their effectiveness, and compliance with industry standards and legislation. The justification includes evaluating the 'reasonable practicability' of controls against implementation costs and effort, as well as describing any controls discounted due to being 'Grossly Disproportionate.' The report concludes with strategies for maintaining ALARP status, considering future technological advancements and cost reductions that might make previously discounted controls viable.

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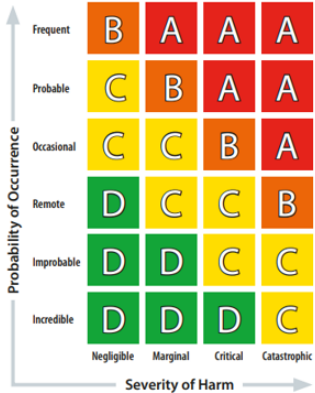
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1. Part One Risk Assessment.

Capability/System: Storm Shadow Description: This risk assessment has been created for the Storm Shadow (SS) Selectable Precision Effects At Range Operational Missile (OM) for use on the Royal Air Force (RAF) Typhoon aircraft. Storm Shadow is a long-range, air-launched, Conventionally Armed Stand-Off Missile, designed to attack high-priority targets deep inside enemy territory. The design standard of the Storm Shadow. The Storm Shadow missile is programmed before launch, meaning that once launched it cannot be commanded or controlled to self destroy. Missile target information also cannot be changed. Hazard is anything that may cause harm, e.g. working at height on a ladder. Risk is the chance that someone or something could be harmed by the hazard, measured by combining (multiplying) the likelihood of it happening with its impact (severity). For example, there may be a 'possible' likelihood that someone that is not competent could fall from a ladder (3 rating – see right) combined with a 'moderate' impact of multiple injuries (2 rating), which creates a score of 6 (minimal risk). However, the risk should be reduced to as low as reasonably practicable (ALARP) through the implementation of control measures, such as ensuring that only trained people climb the ladder. Risk Assessment compliments generic and specific risk assessment. Regardless of completing this AF 5010, it is beholden on the person creating the risk to continue to monitor the activity and the control measures. Any changes to the activity (including the environmental conditions) or the control measures, must be addressed via the mechanism of a dynamic risk assessment such that risks remain ALARP. Note however that persons undergoing training cannot be deemed competent until their capability is accurately assessed	Probability Frequent Probable Occasional Remote Improbable Incredible	Severity Catastrophic Critical Marginal Negligible	
5 Step Process → Step 1 – Identify the hazards Step 2 – Decide who might be harmed and how Step 3 – Evaluate the risks and decide on precautions (control measures) Step 4 – Record your significant findings and include in Ex / Coord instructions, as necessary. Implement control measures Step 5 – Review your risk assessment and update as necessary			

Hazard Number	Hazard Title	Hazard Description	Accident Number	Accident(s)	Cause Number	Cause Title(s)	Cause Descriptions
H1	Structure Failure	The potential for the overall weapon system overall structure to fail. In this case, failure refers to any situation where the system is not in its standard operating configuration.	A1	Take out platform - loss of platform and personnel	Z1	Launched outside of launch envelope - too great of speed	Speed higher than its maximum rated speed due to a miscalibration of the launch system. Shortly after launch, the missile's airframe experiences structural failure, leading to its fragmentation in mid-air.
			A2	Fragmentation - debris over an area	Z2	Manufacturing Defect	A missile is produced with a batch of substandard metal alloy used in its casing, due to a supplier's failure to meet material specifications. During launch, the missile's casing cracks under the stress of ignition.
			A3	Strikes unintended target	Z3	Birdstrike	During flight, a large bird strikes the missile shortly after launch, impacting the nose cone. The collision damages the guidance system housed in the nose, leading to a loss of control.
					Z4	FOD - Foreign Object Debris (loose screws etc and anything left during supporting operations)	During maintenance, a loose screw is inadvertently left inside the missile's electronics bay. Upon launch, the screw shifts due to vibrations and causes a short circuit in the guidance system.
H2	Fails to generate thrust	The potential for the propulsion system to not generate thrust during normal operating conditions. In this case, normal operating conditions relate to the planned consent to release/fire the munition, the munition undergoing the designed arming process, and the munition receiving the correctly specified detonation stimuli.	A3	Strikes Unintended Target	Z5	No Fuel	Missile launched from aircraft, missile immediately drops and fails to gain thrust. Fuel was not properly input due to a procedural error during pre-flight preparations.
					Z6	Ignition Failure	Missile fails to ignite and falls immediately. A short circuit in the electrical wiring prevented the igniters from receiving power.
					Z7	Impedance of Turbo Fan - Fan does not spin	Fails to generate thrust and drops immediately. Loose debris had obstructed the turbo fan, preventing it from spinning.
					Z8	Ice/water in fuel - fuel flow restriction	Ice or water in fuel can cause significant issues including fuel flow restriction.
					Z9	Structural failure of propulsion system	Repeated stresses and strains on components such as turbine blades or shafts can lead to material fatigue, causing them to weaken.

Hazard Number	Hazard Title	Hazard Description	Accident Number	Accident(s)	Cause Number	Cause Title(s)	Cause Descriptions
H3	Engine Overheats	Overheating or fire causes munition to fail	A4	Detention of weapon	Z10	Over Idling --> fans going too fast while not going under own power (envelope) (Air intake cover is removed)	Operational inefficiencies and potential equipment damage. It's crucial to reinstall the intake cover and adjust operational settings as necessary to maintain safe and optimal performance within the equipment's designed operational envelope.
					Z6	Ignition Failure	Missile fails to ignite and falls immediately. A short circuit in the electrical wiring prevented the igniters from receiving power.
H4	Inadvertant Detonation of the Munition	The potential for the munition warhead to undergo detonation outside of normal operational conditions at any point during its predicted lifespan. In this case, normal operational conditions relate to the planned consent to release/fire the munition, the munition undergoing the designed arming process, and the munition receiving the correctly specified detonation stimuli.	A5	Early Detonation - Take out platform	Z11	Failures in the SAU	The safety arming unit has failed causing the potential for the missile to detonate / fail.
			A6	Platform Failure	Z12	EMI - Electromagnetic Interference (HERO)	Various forms of EMI may cause electrical & electronic malfunctions
			A7	Debris	Z4	FOD - Foreign Object Debris (loose screws etc and anything left during supporting operations)	During maintenance, a loose screw is inadvertently left inside the missile's electronics bay. Upon launch, the screw shifts due to vibrations and causes a short circuit in the guidance system.
					Z14	ESD	The heat generated from electrostatic discharge can melt Metal circuitry, cause oxide breakdown or cause a junction failure.
					Z15	Energetic Aging	Missiles that are manufactured, but are then left on the shelf will slowly degrade overtime. The lethal package undergoes energetic aging were its radioactive atoms decay overtime results in a measurable half life.
H5	Loss of Navigation	The potential for the weapon system to loose connection to the Navigation System during normal operating conditions. In this case, normal operational conditions relate to the planned consent to release/fire the munition, the munition undergoing the designed arming process, and the munition receiving the correctly specified detonation stimuli.	A3	Strikes unintended target	Z16	Software Failure	A software failure leading to the unintended denonation of the missile
					Z17	Power Failure (Thermal Battery and Thermal alternator)	Missile fails to launch and dentonates while still on aircraft
			A8	Strikes Launching Platform	Z18	GPS Error	GPS malfunctions and sends missile to an unintended target
					Z19	Human Factor - No Flight Data Inputed	Missile has no intended target information and goes astray once fired

Hazard Number	Hazard Title	Accident Number	Accident Title	Cause Number	CauseTitle(s)	Severity	Probability	Pre-mitigated Risk Class	Risk Reduction / Controls	Post-Mitigated Severity	Post-Mitigated Probability	Post-Mitigated Risk Class	Overall Hazard Risk Class
H1	Structure Failure	A1	Take out platform - loss of platform and personel	Z1	Launched outside of launch envelope - too great of speed	Catastrophic	Remote	B	Procedural and training. Platform mitigation to prevent pressing launch button	Catastrophic	Improbable	C	C
		A2	Fragmentation - debris over an area	Z2	Manufacturing Defect	Catastrophic	Remote	B	QA during manufacturing, Validation and verification. Through life management - (Procedural) - establish inspection scheme	Catastrophic	Improbable	C	C
		A3	Strikes unintended target	Z3	Birdstrike	Catastrophic	Improbable	C	Flight at altitude about birds. Design Change (cost-benefit analysis) further mitigate risk	Catastrophic	Incredible	C	C
				Z4	FOD - Foreign Object Debris (loose screws etc and anything left during supporting operations)	Catastrophic	Remote	B	Procedural - preflight inspection - red tags before launching	Catastrophic	Improbable	C	C
H2	Fails to generate thrust	A3	Strikes Unintended Target	Z5	No Fuel	Catastrophic	Occasional	A	QA, engineered capability to detect fuel level (preflight check - procedural) - Human Factor (training/procedural)	Catastrophic	Improbable	C	C
				Z6	Ignition Failure	Catastrophic	Remote	B	redundancy (engineered) Servalliance and life extension program - through life inspection (Procedural) Pyro qualification industry Standard	Catastrophic	Incredible	C	C
				Z7	Impedance of Turbo Fan - Fan does not spin	Catastrophic	Improbable	C	Maintenance procedures, Inspections	Catastrophic	Incredible	C	C
				Z8	Ice/water in fuel - fuel flow restriction	Catastrophic	Occasional	A	Climatic controls in storage (temp and humidity)	Catastrophic	Incredible	C	C
				Z9	Structural failure of propulsion system	Critical	Remote	C	QA during manufacturing, Validation and verification. Through life management - (Procedural) - establish inspection scheme	Critical	Incredible	D	C
H3	Engine Overheats	A4	Detention of weapon	Z10	Over Idling --> fans going too fast while not going under own power (envelope) (Air intake cover is removed)	Critical	Remote	C		Critical	Incredible	D	C
				Z6	Ignition Failure	Catastrophic	Remote	B	redundancy (engineered) Servalliance and life extension program - through life inspection (Procedural) Pyro qualification industry Standard	Catastrophic	Incredible	C	C

Hazard Number	Hazard Title	Accident Number	Accident Title	Cause Number	Cause Title(s)	Severity	Probability	Pre-mitigated Risk Class	Risk Reduction / Controls	Post-Mitigated Severity	Post-Mitigated Probability	Post-Mitigated Risk Class	Overall Hazard Risk Class
H4	Inadvertant Detonation of the Munition	A5	Early Detonation - Take out platform	Z11	Failures in the SAU	Catastrophic	Improbable	C	Safety integrity levels, (redundancy), engineered status indicators	Catastrophic	Incredible	C	C
		A6	Platform Failure	Z12	EMI - Electromagnetic Interference (HERO)	Catastrophic	Improbable	C	Safety integrity levels, (redundancy), engineered status indicators	Catastrophic	Improbable	C	C
		A7	Debris	Z4	FOD - Foreign Object Debris (loose screws etc and anything left during supporting operations)	Catastrophic	Remote	B	Procedural - preflight inspection - red tags before launching	Catastrophic	Improbable	C	C
				Z14	ESD	Catastrophic	Improbable	C	Safety integrity levels, (redundancy), engineered status indicators	Catastrophic	Improbable	C	C
				Z15	Energetic Aging	Catastrophic	Occasional	A	Inspections, inservice servaliance (Shelf live), IM, Procedure record keeping	Catastrophic	Incredible	C	C
H5	Loss of Navigation	A3	Strikes unintended target	Z16	Software Failure	Catastrophic	Remote	B	Redundancy, preflight checks	Catastrophic	Incredible	C	C
		A8	Strikes Launching Platform	Z17	Power Failure (Thermal Battery and Thermal alternator)	Catastrophic	Occasional	A	Redundancy (use of battery), preflight checks	Catastrophic	Incredible	C	C
				Z18	GPS Error	Catastrophic	Probable	A	Intetial navigation (redudancy) Preprogram flight path, talking to more than one satelite (reducancy) Seeker head. GPS Qualificaion program	Catastrophic	Improbable	C	C
				Z19	Human Factor - No Flight Data Inputed	Catastrophic	Occasional	A	Training Procedural	Catastrophic	Improbable	C	C

Probability	Definition
Frequent	Is expected to occur in most circumstances
Probable	Will occur at some time, or in most circumstances
Occasional	Fairly likely to occur at some time, or some circumstances
Remote	Is unlikely to occur, but could occur at sometime
Improbable	May only occur in exceptional circumstances
Incredible	May only occur once during life of equipment

Severity	Definition (Health Safety and Environment)
Catastrophic	- Multiple fatalities or permanent, life changing injuries. - Permanent loss or damage beyond remediation of an important and publicly high-profile natural resource, area, or species. - Multiple incidents causing a major environmental impact.
Critical	- A single death or multiple life-threatening injuries. - Severe damage over a wide area and/or on a prolonged basis to a natural resource, including controlled waters, or geography requiring multi-year remediation. - Single incident causing a major environmental effect or multiple incidents causing significant effect.
Marginial	- Multiple injuries requiring first aid. - Moderate damage to an area, and that can be remedied internally. - Multiple incidents causing minor environmental effect.
Negligible	- An Injury requiring first aid - Limited short-term damage to an area of low environmental significance/ sensitivity - Incidents causing minor environmental impacts

Step 5 - Review the generic risk assessment and update if necessary - All generic risk assessments should be regularly reviewed at a frequency proportional to the risk prior to any controls being proposed. In practice generic risk assessments should be reviewed at least annually, or more frequently:

- where required by local instructions/procedures;
- if the safe execution of the activity relies on stringent supervision and/or adherence to a safe system of work;
- if there is reason to doubt the effectiveness of the assessment.
- following an accident or near miss.
- following significant changes to the task, process, procedure, equipment, personnel, or management.
- following the introduction of more vulnerable personnel (e.g. persons under 18 or pregnant persons).

Risk Management	
Risk Rating	How Risk should be managed
D	<u>Review periodically</u> to ensure conditions have not changed and working within ALARP and risk appetite.
C	<u>Good risk mitigations</u> to ensure that the impact remains ALARP and tolerable. Re-assess frequently to ensure conditions remain the same.
B	<u>Requires active management</u> – review of desired outcome with additional resources or change to output requirements.
A	<u>Operational capability</u> where the required outcome impacts on defined military capability.

2 Part Two ALARP Justification

2.1 Introduction

HAZ01: Structure Failure of the Airframe on Missile Storm shadow



Figure 1 Storm Shadow Missile System

2.1.1 Purpose

This document evaluates whether the Risks/Accidents present within the In-Service Storm Shadow Risk Assessment are reduced to ALARP in accordance with the ALARP Methodology and Procedures [1].

2.1.2 Requirements

The Secretary of State for Defence requires by Policy, reduction of safety risk in accordance with UK legislation 'so far as is reasonably practicable'. JSP 815 interprets this requirement to 'As Low As Reasonably Practicable (ALARP)' [2]. The DS&EP Memo 08/08 requires all Hazards/Risks identified in military systems/projects to be reduced to 'as low as reasonably practicable (ALARP)' [3].

2.1.3 Definitions

A risk is defined as ALARP in Reference [4] as 'when it has been demonstrated that the cost of any further Risk Reduction, where the cost includes the loss of defence capability as well as financial or other resource costs, is grossly disproportionate to the benefit obtained from that Risk Reduction'.

Risk and ALARP Evaluation is defined as 'The systematic determination, on the basis of tolerability criteria, of whether a risk is broadly acceptable or tolerable and ALARP, and whether further Risk Reduction is necessary'. Other related definitions can be found in References [2] and [5].

2.2 Hazard Description

The selected hazard for this ALARP (As Low As Reasonably Practicable) justification report is the structure failure of the airframe. This hazard involves the potential for the overall weapon system's structure to fail, leading to catastrophic outcomes such as fragmentation and debris, which could result in fatalities and loss of critical systems and/or personnel.

The airframe is the general overall round of the munition, encompassing its entire structure. A structure failure refers to any situation where the system is not in its standard operating configuration.

This could be due to various causes such as launching outside the launch envelope, manufacturing defects, bird strikes, or foreign object debris (FOD).

2.3 Hazard ALARP Justification Statement

All structural components are deemed to be of sound design and construction and are assumed to be subject to either periodic inspection or classified as lifed components. As such, any failure of a structural component will be of systematic and not random. Maintenance is undertaken in accordance with technical publication and Standard Operating Procedures (SOPs), and the equipment is only operated and maintained by Suitably Qualified Experienced Personnel (SQEP). Industry standard control measures are also in place. Warnings and physical characteristics are stated within the technical publications. All safety design is compliant with RA1230 [6].

2.4 Pre-Mitigated Hazard Risk Assessment

Hazard Number	Hazard Title	Severity	Probability	Pre-mitigated Risk Class
H1	Structure Failure	Catastrophic	Remote	B

Table 1 Pre-Mitigated Hazard Risk Assessment

2.5 Mitigation Measures and Controls

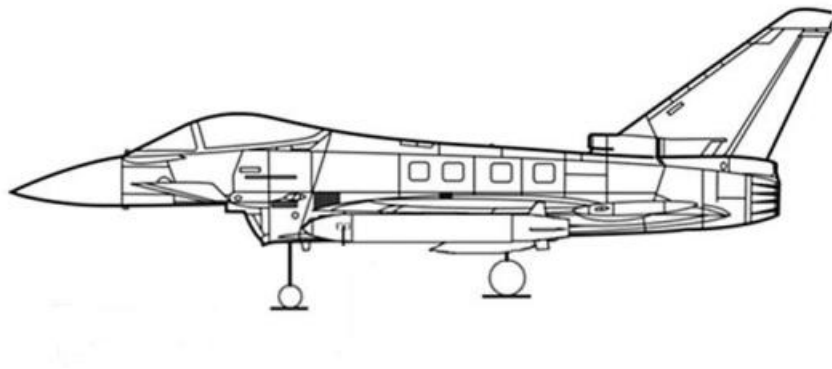


Figure 2 Storm Shadow Launch Platform Typhoon

2.5.1 Procedural and Training Improvements

Implementing rigorous procedural and training measures ensures that all personnel involved in the launch process are well-trained and adhere to strict protocols. Adhering to established military and aerospace standards for training and operational procedures represents industry good practice. Leveraging advanced simulation and training tools enhances the preparedness of personnel. The cost and effort involved in training are justified by the significant reduction in risk, making these measures reasonably practicable.

2.5.2 Platform Mitigation

Implementing platform-specific mitigations, seen in figure 1, such as interlocks and safety checks, helps prevent accidental launches. Following best practices in system safety engineering, these fail-safes and interlocks are designed to ensure reliability. Incorporating advanced sensor technologies allows for the detection and prevention of unsafe launch conditions. The cost of implementing these measures is reasonable compared to the potential consequences of a structural failure, making them a practical and necessary investment.

2.5.3 Quality Assurance During Manufacturing

Establishing stringent Quality Assurance (QA) processes during the manufacturing of the airframe ensures that material specifications are met consistently. Adhering to JSP 940, and 392 policy for quality management systems exemplifies industry good practice. Utilising non-destructive testing (NDT) methods allows for the detection of material defects without damaging the components. The cost of implementing QA processes is justified by the prevention of manufacturing defects that could lead to catastrophic failures, making these measures both reasonable and essential [7] [8].

2.5.4 Preflight Inspections

Conducting thorough preflight inspections to identify and mitigate potential hazards, such as foreign object debris (FOD), is crucial for safety. Implementing comprehensive preflight checklists and inspection protocols represents industry good practice. Utilising advanced inspection tools, such as borescopes and automated inspection systems, enhances the effectiveness of these inspections. The time and effort involved in preflight inspections are justified by the significant reduction in risk, making these measures both reasonable and essential.

2.5.5 Post-Mitigated Hazard Risk Assessment

After controls have been inputted, the system assessment is as follows:

Hazard Number	Hazard Title	Severity	Probability	Pre-mitigated Risk Class
H1	Structure Failure	Catastrophic	Remote	B

Table 2 Post-Mitigated Hazard Risk Assessment

2.5.6 Additional Controls

In addition to existing measures, several controls can be implemented to enhance safety. Procedural preflight inspections should be conducted thoroughly and consistently to ensure all potential hazards are identified and mitigated. Design changes should be considered to further mitigate risks, such as enhancing the structural integrity of the airframe. Continuous monitoring and assessment of the airframe's structural integrity throughout its lifecycle should also be implemented to detect and address any emerging issues promptly.

2.6 Discounted Controls

2.6.1 Grossly Disproportionate Controls

Some controls were considered but ultimately discounted due to being grossly disproportionate in terms of cost, time, and effort compared to the risk reduction they would achieve.

Examples include:

1. Complete redesign of the Airframe: While a complete redesign could potentially eliminate the risk, the cost and time required would be grossly disproportionate to the risk reduction

achieved. The extensive resources needed for such an overhaul are not justifiable given the existing mitigation measures.

2. Advanced Material Substitution: Using advanced materials, such as titanium alloys, could enhance structural integrity significantly. However, the cost and manufacturing complexity involved in using these materials would be excessively high, making this control impractical compared to the benefits obtained.

2.7. ALARP Status Review and Future Considerations

2.7.1 Maintaining ALARP Status

To maintain the ALARP (As Low As Reasonably Practicable) status, regular reviews are conducted to ensure that the risk remains minimised. This involves systematically evaluating current risk levels and mitigation measures to confirm their effectiveness and identify areas for improvement. Additionally, advancements in technology are continuously monitored to identify new opportunities for risk reduction. By staying informed about emerging technologies, innovative solutions that enhance safety and efficiency can be integrated. Furthermore, ongoing cost-benefit analyses are performed to assess the feasibility and effectiveness of potential new controls. As technology advances and costs decrease, this ensures that the most effective and economically viable risk mitigation strategies are implemented. This comprehensive approach ensures that risk management practices remain robust and responsive to evolving challenges and opportunities.

2.7.2 Future Controls

By staying informed about emerging technologies for more effective and cost-efficient risk mitigation solutions, and by staying updated with relevant legislation and industry best practices to ensure ongoing compliance and safety improvements, we have effectively managed the risk associated with airframe structure failure in our weapon system. These measures not only enhance safety and reliability but also keep us abreast of technological advancements and regulatory requirements, thereby reinforcing our commitment to maintaining a robust and secure operational environment.

3 Results & Conclusion

Due to the nature of the equipment and the controls already in place, all reasonably practicable mitigation measures have been applied to reduce the risk to a tolerable level. During the hazard review meeting, no further practicable risk reduction options were identified, and the cost of any modification was considered grossly disproportionate to the benefit gained. With all current mitigations and controls in place, and no further cost-effective risk reductions identified at present, this risk is considered to be ALARP. It is advised that stakeholders review the risk annually or when appropriate to ensure that the ALARP status is maintained and improved over time. Regular reviews allow for the incorporation of any new technologies or practices that might emerge, ensuring continuous improvement. Additionally, changes in operational conditions, regulatory requirements, or industry standards should prompt a reassessment. Stakeholders should stay informed about advancements in risk mitigation techniques and remain vigilant for any new potential hazards that could affect the current risk assessment. By maintaining a proactive approach, the ALARP status can be sustained, and the safety and reliability of the equipment can be ensured.

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