QUALIFICATION AND CERTIFICATION OF SPECIAL PATROL INSERTION & EXTRACTION (SPIE) EQUIPMENT FOR MILITARY HELICOPTERS

B. Timmerman, N. Münninghoff
Netherlands Aerospace Centre – NLR
P.O. Box 90502, 1006 BM Amsterdam, the Netherlands

Abstract

Special Patrol Insertion & Extraction (SPIE) is a type of military operation to rapidly insert personnel in and/or extract personnel from areas where it is not possible to land with a helicopter. The equipment used to perform SPIE operations usually must comply with specifications to ensure adequate performance. Additionally it needs to meet certain airworthiness criteria in order to be certified by the military airworthiness authority. Requirements 27.865 and 29.865 of the civil airworthiness codes provide a useful baseline regarding external loads, which can be adapted to take into account the military operation and environment. This paper discusses the development of the requirements of a qualification and certification programme for a SPIE system to be used on a helicopter. The tests to show compliance with these requirements, both at component level and at system level are discussed as well.

1. ABBREVIATIONS

BQRS – Backup quick-release subsystem
CEN – European Committee for Standardization
DAD – Dual actuation device
EASA – European Aviation Safety Agency
EMI – Electromagnetic interference
FAA – Federal Aviation Authority
HEC – Human External Cargo
NLR – Netherlands Aerospace Centre
PCDS – Personnel Carrying Device System
PQRS – Primary quick-release subsystem
PSE – Primary Structural Element
QRS – Quick-Release System
RLC – Rotorcraft Load Combination
SPIE – Special Patrol Insertion & Extraction

2. INTRODUCTION

Special Patrol Insertion & Extraction (SPIE) is a type of military operation to rapidly insert personnel in and/or extract personnel from areas where it is not possible to land with a helicopter, such as rough terrain, large bodies of water, unstable surfaces or rooftops of small buildings. The SPIE rope is lowered from a hovering helicopter. Personnel on the ground will connect their harness to a loop in the rope using a connector. Once all personnel are attached, the helicopter will climb vertically until the rope and personnel are clear of obstructions, before initiating forward flight.

The equipment used to perform such operations usually must comply with specifications to ensure adequate performance, in order to obtain an approval for its use on helicopters. The execution of SPIE operations with helicopters is also subject to approval from a military airworthiness authority, since it involves a human external load application. In addition, the parts of the system which have a direct interface with the helicopter must comply with airworthiness requirements in order to be certified by the military airworthiness authority.

NLR has acquired experience in this area, contributing to the writing of specifications, executing the corresponding qualification process, establishing the certification plans and supporting the corresponding certification process.

3. QUALIFICATION AND CERTIFICATION REQUIREMENTS

Currently no dedicated military specifications exist which can be used for the qualification and certification of SPIE equipment. Therefore separate specifications were drawn up for this application. The EASA Certification Memorandum “Helicopter External Loads Personnel Carrying Device System” is a useful reference in providing guidance on how to proceed, but tailoring to the military operation and environment is needed.

Requirements 27.865[1][2] and 29.865[3][4] of the civil FAA and EASA airworthiness codes provide a useful baseline regarding external loads, which can be adapted where needed to cover the original design baseline of the helicopter and take into account the military operation and environment.

Additionally, AC 27-1B[5] and AC 29-2C[6] provide guidance on acceptable means of compliance for requirements 27.865 and 29.865.

According to AC 29-2C, SPIE operations would classify as a class D Rotorcraft Load Combination (RLC), being a single point suspension external

Presented at 44th European Rotorcraft Forum, Delft, The Netherlands, 19-20 September, 2018

airborne personnel load. For jettisonable RLCs (such as when using a cargo hook), the external load attaching means should include a quick-release system (QRS) to enable the pilot or a dedicated crewmember to release the external load quickly in case of an emergency. The QRS should consist of a primary quick-release subsystem (PQRS) and a backup quick-release subsystem (BQRS), which are isolated from one another. To provide a higher level of safety for class D RLCs, each quick-release subsystem should have a dual actuation device (DAD). This should prevent inadvertent activation of the QRS.

Any failure mode of the external load system (including QRS, hook and attachments to the rotorcraft) leading to a loss of the human external cargo (HEC) should be considered as a Catastrophic event. As such, it is necessary to prevent single failures which can lead to loss of the HEC. This means all components of the external load system should either be fail-safe or executed redundantly. When using a cargo hook this would require a backup device to catch the SPIE rope, in case of a cargo hook failure leading to unintended release of the rope.

In case there is a direct interface between the SPIE system and a structural element of the helicopter, this element will either have to be fail-safe or demonstrated to comply with the requirements for a Principal Structural Element (PSE). A structural element is classified as PSE if the failure of the element could result in a catastrophic event.

If the personnel carrying device system (PCDS) or QRS contains electrical components, tests should be performed to ensure the system is not impaired by electromagnetic interference (EMI) and lightning. Such tests are not necessary for a purely mechanical system.

Since SPIE is a military application, military certification criteria, such as MIL-HDBK-516[7], might provide additional requirements to be considered.

The certification process is based on national regulations (for instance, EMAR-21[8] or similar) and would apply to:

- Any added means of attachment and any backup and release device;
- Flight with SPIE external load and its impact on the helicopter.

4. SPIE SYSTEM DESCRIPTION

The main component of the SPIE system is the SPIE rope. This rope can be fitted to the helicopter to a cargo hook or other structural element. The rope can have one or more attachment points (e.g. rope-loops or D-rings) for personnel and/or cargo.

When using a cargo hook, the SPIE system should include a backup and release device. This device catches the SPIE rope in case of a cargo hook failure preventing unintended release of the rope, and releases it in case of an emergency.

The backup and release device is used to secure the SPIE rope against unintended release from the cargo hook, for applications where the cargo hook is used as main attachment point for the SPIE rope. The backup device would consist of a flexible strap affixed around the cargo hook construction. The sling goes through the top eye of the SPIE rope or through the shackle attached to the cargo hook. The release device would consist of a dual-redundant cutting mechanism attached to the strap. The flight crew can activate the cutting mechanism in the helicopter cabin to release the SPIE rope in case of an emergency.

The last part of the SPIE system is the body harness with connector (carabiner).

5. QUALIFICATION PROCESS

The qualification focuses mainly on the body harness, the connector and the SPIE rope. As the backup and release device would already be covered by the certification process, the military specification for the backup and release device should be drawn up to be consistent with the airworthiness requirements as dictated by the certification process.

The qualification process aims at obtaining an independent verification of the military specification requirements by means of a Notified Body, accepted as such by the relevant military authority.

5.1. Body harness

The body harness is composed of polyester webbing, stitched together and in some places connected by metal D-rings and buckles.

5.1.1. Compliance EN

The European Committee for Standardization (CEN) has already defined specifications for body harnesses designed for mountaineering (EN

Presented at 44th European Rotorcraft Forum, Delft, The Netherlands, 19-20 September, 2018

12277[9]) or working at a height (EN 358[10] and EN 361[11]). These specifications can be taken as a baseline for the specifications of the body harness for use in SPIE operations. The drop test from EN 361 should be modified to take into account the weight of a fully equipped soldier. In addition, it should be checked whether it covers the dynamic load caused by the fall into any backup device that is used to catch the SPIE rope. All possible body harness configurations should be tested to the modified specifications.

5.1.2. Webbing

The webbing of the body harness should be resistant to the environmental conditions likely to be encountered during its lifetime. A suitable reference to be used as guidance for the military specification could be TSO-C167[12], for a Human Harness type of PCDS. Requirements might have to be adapted to the military environment.

5.1.2.1. Webbing UV-resistance tests

To establish the body harness webbing's resistance to degradation by UV-exposure, strips of webbing material should be exposed to a UV test as described in for instance EN ISO 4892[13], for a representative exposure time. Afterwards the webbing should be subjected to a breaking strength test, for example as prescribed in 8.2 of SAE AS8043[14].

5.1.2.2. Webbing resistance to salt water, cleaning fluids, fuels and lubricating oils

To establish the body harness webbing's resistance to degradation due to salt water, cleaning fluids, fuels and lubricating oils, strips of webbing material should be tested in accordance with AECTP 300[15] Test 314, MIL-STD-810[16] or similar. After exposure the webbing should be dried and inspected for degradation, followed by a static strength test until breakage. It may be taken into account that the expected exposure of the webbing to fuels and lubricating oils is incidentally and locally, considering the use of the body harness in SPIE operations.

5.1.3. Metal components

In addition to the tests on the body harness webbing, all load-carrying metal components of the body harness should be removed from the webbing and tested for fatigue and ultimate load along with the connectors.

5.2. Connector

5.2.1. Compliance EN

As the baseline specification for the connectors these should comply with the EN norms for connectors for mountaineering (EN 12275[17]) and falls from a height (EN 362[18]).

5.2.2. Vibration tests

The connectors should not be damaged by the vibrational loads it will experience during SPIE operations. Therefore the carabiners should be subjected to vibration tests, see Figure 2. The most demanding vibration condition on the carabiner is when the largest static load is applied where the carabiner gate can still move. The maximum load of a fully equipped soldier will cause the carabiner gate to latch to the carabiner nose. This will close the carabiner body and increase the strength of the carabiner. The vibration spectrum should be determined using the latest MIL-STD-810 helicopter vibration test, extended with possible dominant frequencies occurring at the personnel positions as found during flight tests (section 6.2.1).

5.2.3. Fatigue tests

After being subjected to the vibration test, the connectors, along with the metal components from the body harness, are to be subjected to fatigue tests, see Figure 1. The load spectrum for the fatigue tests should take into account the foreseen usage and life expectancy of the components. The amplitude and frequency of the fatigue test should be based on flight test measurements (section 6.2.1).

5.2.4. Crack inspection

To establish the effect of the fatigue and vibration tests, the metal components should be inspected for cracks. The inspection can be performed using a non-destructive method such as according to EN 3452-1[19]. The items are exposed to a fluorescent penetrant solution and inspected under UV light. The penetrant solution would seep into surface cracks and light up under UV light.

5.2.5. Static strength test

EN 12275 requires a static strength test until breakage for connectors. EN 362 requires a similar load test, but only up to a certain strength value. Although the metal components from the body harness do not require a separate load test according to the EN for body harnesses, all connectors and metal components should be subjected to a static strength test until breakage, to determine any impact of vibration and fatigue on the ultimate load.

5.2.6. Corrosion resistance

The metal components and connectors should be subjected to a corrosion test as specified by ISO 9227[20]. This test is prescribed for body harnesses (EN 361), connectors (EN 362) and rope access systems (EN 12841[21]). The

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specimens were placed in a spraying cabinet and exposed to a salt spray under controlled pressure and humidity. After the test the specimens were visually inspected for deterioration.

5.3. SPIE rope

5.3.1. Temperature and UV tests

The rope should be able to cope with temperature extremes and the effects of outdoor light that it will experience during its intended life. One way to show this is to perform static strength tests with the full scale rope under these environmental conditions. This will require a large climate chamber with a large static test bench, which might not be feasible. Another option is to determine the effect of the environmental conditions on small sections of the rope material, see Figure 7, and establish a load factor to apply in a static strength test of the full-scale rope under normal environmental conditions.

5.3.2. Static strength test

The main SPIE rope is still a single point of failure which could lead to a catastrophic event. The SPIE rope and the personnel attachment loops should be subjected to a static strength test representative of the maximum loads which can occur during SPIE operations. This can be represented by the load cycle of Figure 4, as described in section 6.1.1. The SPIE rope and the personnel attachment loops are not allowed to break under these loads. It can however be useful to continue increasing the load until breaking after application of the load cycle, to establish the margin of the design.

5.3.3. Resistance to fluids, algae/fungus

Similar to the body harness webbing, the SPIE rope itself should be resistant to the fluids it might encounter during its service life, such as salt water or fuel. This can be demonstrated through AECTP 300 Test 314 “Contamination by fluids”. It should be evaluated how often the SPIE rope will come into contact with which fluids and to what extent. This might indicate that although the rope material is susceptible to a certain oil used in aircraft maintenance, it poses no harm. Maintenance will rarely be performed on the platform or runway, and the rope will not remain on the helicopter during maintenance.

Resistance of the rope to algae, fungus and other biological influences can be determined through AECTP 300 Test 308 “Mould growth test”. Since this effect is merely dependent on the rope material, it might be worthwhile to consider earlier tests of the material properties indicating the material’s resistance to mould.

5.3.4. Abrasion test

If the SPIE rope is to be used in sandy environments, it is worthwhile to test its resistance to the abrasive effect of sand and dirt getting inside the rope. This can be established by treating the rope with an emulsion of sand and water and thoroughly working the sand into the rope. EN ISO 14688-1[22] could be used to define the appropriate size and type of sand.

Once the sand has been worked into the rope, the rope should be subjected to several load cycles from 0 to F_2 (see Figure 4) to simulate operational use and introduce wear and tear. Finally the rope should be subjected to the entire load cycle from Figure 4 without breaking.

5.3.5. Operational requirements

In addition to the aforementioned tests, the rope might have to comply with some operational requirements, depending on its intended use. There might be requirements on rope flexibility and braid density with regards to storage. Another requirement might be buoyancy of the rope if it is intended to be used over water.

6. CERTIFICATION PROCESS

Certification (only) covers the flight safety aspects of the SPIE system, not the operational requirements. This would mean the interfaces between the SPIE system and the helicopter (such as the QRS) and the use of the SPIE system with the helicopter.

The impact of the backup device functionality on the helicopter depends on the type of components used. When mechanical systems are used as attachment means or as backup, a certain level of reliability will have to be demonstrated.

The original certification basis of each helicopter to be certificated for operations with the SPIE system needs to be considered when determining the certification requirements. It is sensible to base the certification requirements on the most recent amendment of the certification basis. These will take into account the most recent views on human external transport beneath helicopters. If certain requirements cannot be met, this will need to be discussed with the military aviation authority. This might be because the helicopter might not be designed to a new requirement and that requirement does not significantly contribute to flight safety, or in case of operational necessity.

To achieve certification an analysis and testing programme needs to be carried out.

6.1. Backup and release device tests

System and component rig or laboratory tests are

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needed to verify several aspects that cannot be (easily) verified on the helicopter or that need to be demonstrated before proceeding with the helicopter tests.

6.1.1. Drop test

As there will always be some slack in the sling, the moment the cargo hook releases, the SPIE load will free fall into the sling and cause a dynamic shock load. After the fall the backup system should be able to hold the SPIE rope for a limited contingency period to allow the helicopter to fly to a (relatively) safe location to set down the HEC.

Without knowledge of the maximum loads occurring during a drop of the SPIE system, and possible other effects, it is dangerous to test this situation on the helicopter.

The most representative way of establishing that the SPIE system can handle the drop is to perform a drop test with a drop tower, with additional weights to simulate the appropriate manoeuvring load condition associated with the drop. The drop test should be followed by a static strength test at 1g for the contingency duration, followed by application of the limit flight load for an agreed duration. Such a load cycle is shown in Figure 4. However, a drop tower which can handle the expected loads might not be available or prohibitively expensive.

Another way is to perform a static strength test, involving both the drop load and the limit flight load. The loads to be applied in the static strength tests could be determined by an analytical simulation tool. This tool should however be validated with actual drop tests, albeit at a lower weight. This approach is only allowed if there are no relevant dynamic effects that could affect the strength of the material.

6.1.1.1. Full-scale drop test

To perform the full-scale drop tests, a drop tower is to be constructed, see Figure 3. The drop tower includes the helicopter cargo hook beam, secured to the tower on the attachment points as it would be in the helicopter. A mechanism is attached underneath the cargo hook beam simulating the cargo hook, to support and quickly release the SPIE rope. The flexible strap and cutting mechanism are installed in a representative configuration.

A SPIE rope is suspended from the simulated cargo hook in several configurations, ranging from the lightest configuration (only one dummy soldier at the top personnel loop) to the heaviest configuration (weights at all personnel loops and the bottom eye, if applicable).

To determine the loads occurring in the rope, load cells are installed at the simulated cargo hook, at each of the personnel attachments and at the bottom eye of the rope.

Drop tests are executed to represent inadvertent opening of the cargo hook. No additional load factors are applied if the results of the drop tests are used to validate the analytical simulation tool.

6.1.1.2. Analytical load model

Instead of performing a drop test including the maximum load factor, static strength tests could be performed. The maximum loads for these static tests could be estimated using an analytical model. After an inadvertent cargo hook release, the flexible strap will catch the SPIE rope after a short freefall. The elasticity and damping of the flexible strap will cause load oscillations with a peak load, until the motion damps out.

The SPIE rope can be modelled as a second order system, see Figure 5, whose behaviour can be described by:

$$(1)\quad \boldsymbol{m} * \boldsymbol{a}(\boldsymbol{t}) + \boldsymbol{c} * \boldsymbol{v}(\boldsymbol{t}) + \boldsymbol{k} * \boldsymbol{s}(\boldsymbol{t}) = \boldsymbol{m} * \boldsymbol{g}$$

with mass m, damping coefficient c, spring stiffness k, acceleration a, velocity v, displacement s and gravitational acceleration g.

The flexible strap of the backup device, the main SPIE rope, each of the personnel loops and the bottom eye can be modelled as a collection of mass-spring-damper systems. The properties of the ropes can be determined from the material specifications.

The validity of this model can be established by comparing the predicted loads to the results of the full-scale drop test.

6.1.1.3. Dynamic versus static load application

A sudden drop might induce shock loads into the system, which might have an effect on the material strength that is not captured by a static strength test. In that case, tests should be performed to establish that a potential shock load would not have a significant effect on the material strength. Otherwise, an additional load factor should be applied in the static strength tests.

The load cycle from Figure 4 can be executed with three test configurations:

- A drop test covering load section (A), immediately followed by a static strength test covering load section (B);
- A drop test covering load section (A), followed by a static strength test covering load section (B) one day later;

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- A static strength test covering both load sections (A) and (B).

As a minimum the first and the third configuration should be tested. The second configuration is an option meant to check the possibility of performing an actual drop test and continue with the static part of the load cycle one day later at another test facility.

After application of the load cycles, the load is increased until breaking. These tests can be performed with (relatively) short sections of rope and (relatively) small weights, for all rope materials present in the SPIE rope and the flexible strap.

6.1.2. Backup device tests

Correct functioning of the flexible strap should be demonstrated under the environmental conditions to which it could be exposed during SPIE operations. During its life, the flexible strap could be exposed to both high and low temperatures. The rope material might become stronger at lower temperatures and weaker at higher temperatures or the other way around. As such, it suffices to perform a static strength test at the most extreme temperature the system is expected to operate in.

The flexible strap is to be subjected to static strength tests in a climate chamber, using the load cycle from Figure 4. The strap is to be positioned in a representative configuration, connected to the cargo hook beam, see Figure 6. The temperature conditions are set according to AECTP 300 Test 302.

Apart from functional temperature tests, additional environmental condition testing might be necessary, depending on the composition of the flexible strap. If it had metal-to-metal contact, vibration tests should also be performed. Resistance to UV radiation, moisture, salt water, fungus, cleaning fluids, fuel and lubricating oils, and sand and dust would also need to be shown through testing or analysis.

6.1.3. Release device tests

Tests are to be performed to determine possible release device operating loads and confirm release under all foreseeable operating conditions, and to demonstrate sufficient static strength of the release device components.

6.1.3.1. Operating loads test

It should be demonstrated that the release device can cut the flexible strap, both in the loaded and unloaded condition. Since intentional release of the SPIE rope only occurs in an emergency, cutting of the strap should be a quick, single action. The force required to activate the release device under maximum weight loading should be small enough for a person to apply manually. The setup of the release device during the test should be representative of the configuration it will have in the helicopter.

6.1.3.2. Static strength test

In addition to the aforementioned maximum application force, the cutting mechanism will be subjected to g-loads due to manoeuvring of the helicopter during flight and landing. These g-loads have the largest effect on the control unit and its attachment points in the helicopter cabin. The g-loads can occur simultaneously with the control loads. The maximum loads caused by the release device on the attachment points in the helicopter can be derived via analysis and evaluated against the ultimate loads of the helicopter structure. The release device control unit should not detach from the helicopter interface under these loads.

The release device itself should not be deformed or damaged due to the combined control loads and g-loads either. This can again be demonstrated through a static strength test, see Figure 9. In case of an application with a mechanical lever, the lever should be placed under the angle which will introduce the highest loads and the applied load should be both limit and ultimate load.

6.1.3.3. Electromagnetic interference tests

In case the cutting mechanism contains electronic components, it should be established that this system is not impaired by EMI and does not create hazardous EMI conditions for the helicopter. A good baseline for EMI testing is MIL-STD-461[23]. This describes requirements and tests regarding both emissions and susceptibility, for both radiation and conduction.

6.1.3.4. Environmental tests

Similar to the other SPIE components, the cutting mechanism should be resistant to the environmental conditions that it will be exposed to during its service life. As such, it should undergo environmental testing in a similar fashion, for instance in accordance with MIL-STD-810 and/or specific helicopter military specifications. The ability to release the backup device with an acceptable operating load should be part of the tests.

6.2. Helicopter ground tests

After subjecting the components of the backup and release device to individual tests at component level, the complete system should undergo a functional test. The backup and release device should be installed in the helicopter in its specific configuration. It should then be evaluated

Presented at 44th European Rotorcraft Forum, Delft, The Netherlands, 19-20 September, 2018

that the release mechanism will cut the flexible strap in an unloaded condition, with an acceptable operating force, in a safe and effective manner for the operator. It should also be evaluated that the materials and positioning of the control unit and any cables of the release mechanism are appropriate with regards to cabin safety (emergency egress, fire hazards).

6.3. Helicopter flight tests

Helicopter flight tests should be performed to establish the loads and vibrations in the SPIE system. These values are required to define the test conditions of the SPIE component tests. Additionally, the safe use of the SPIE system should be demonstrated in flight.

6.3.1. Load measurements

Dedicated flight tests should be performed to measure the static, dynamic and vibrational loads occurring during SPIE operations. During these tests a complete SPIE system is to be attached to the helicopter (cargo hook or other structural element) and fitted with dummies with the maximum foreseen weight to each of the personnel loops, as well as a cargo net at maximum capacity if applicable. Load cells are to be fitted to the cargo hook or other structural element, one of the topmost dummies and, if possible, to one other dummy further down the rope. These three locations are also to be fitted with a tri-axial accelerometer. The flight conditions during the test are to be recorded by flight test instrumentation or the helicopter flight data recorder.

The manoeuvres executed during these flight tests should exceed the airspeeds and bank angles expected to be required during SPIE operations. As such, a suitable maximum load factor for SPIE operations can be determined. The measured loads and vibrations are to be used to determine the spectrum used in the fatigue and vibration tests of the body harness metal parts and connectors (sections 5.2.2 and 5.2.3).

6.3.2. SPIE rope impact on flight behaviour

The presence of the SPIE system should not lead to dangerous flight conditions for the helicopter. Flight tests should be performed in flight conditions and manoeuvres representative of SPIE operations. During these tests the added drag and behaviour of the SPIE rope, flight stability and controllability should be evaluated. There should be no interference with other systems and the workload of the pilot and loadmaster should be acceptable.

6.3.3. Functional test quick release systems

The functionality of the cargo hook QRS in combination with the backup and release device should be demonstrated during flight. Multiple activation sequences are possible: first the cargo hook QRS activates, followed by activation of the backup and release device QRS, or vice versa. Additionally, the order in which the PQRS and BQRS of both systems are activated can vary. All sequences should be considered during the functional flight test.

6.3.4. Secure placement of backup device during flight

It should be demonstrated that the backup device will not shift during flight when it is unloaded. The cutting mechanism should remain free from the helicopter, so that neither the mechanism nor the helicopter becomes impaired or damaged. Vibrations in the cutting mechanism should not induce damaging loads in the activation cable or the cutting mechanism itself, nor be able to inadvertently activate the cutting mechanism, and should not damage the flexible strap.

6.3.5. Lowering/retrieving SPIE rope

Lowering and retrieval of the SPIE rope should not interfere with other systems on the helicopter. Additionally, it should be possible to secure the retriever line at a location which does not obstruct the flight crew.

7. CONCLUSION

The equipment used to perform SPIE operations usually must comply with specifications to ensure adequate performance. Additionally it needs to meet certain airworthiness criteria in order to be certified by the military airworthiness authority.

Requirements 27.865 and 29.865 of the civil airworthiness codes provide a useful baseline regarding external loads, which can be adapted take into account the military operation and environment.

The development of the requirements of a qualification and certification programme for a SPIE system, consisting of a backup and release device, a main SPIE rope and a body harness, to be used on a helicopter was discussed.

The qualification and certification consists of testing at component level of e.g. strength and durability, up to functional flight tests at system level.

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Presented at 44th European Rotorcraft Forum, Delft, The Netherlands, 19-20 September, 2018

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Figure 1: Fatigue and static strength test metal components

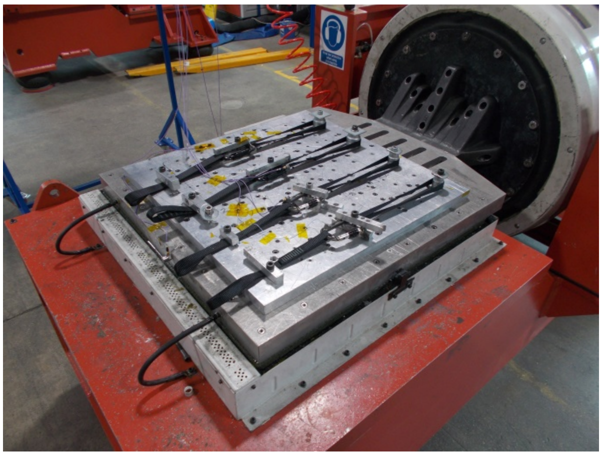

Figure 2: Vibration test connectors

Figure 3: SPIE system drop test

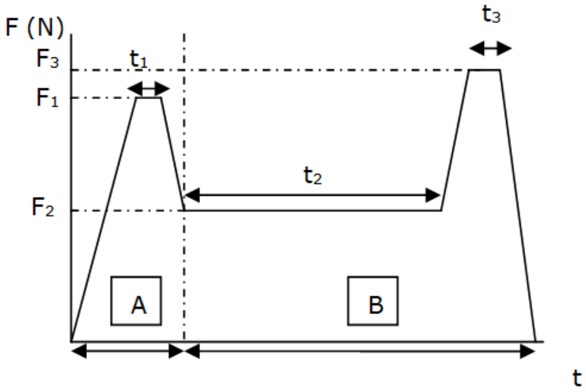

Figure 4: Load cycle static strength test

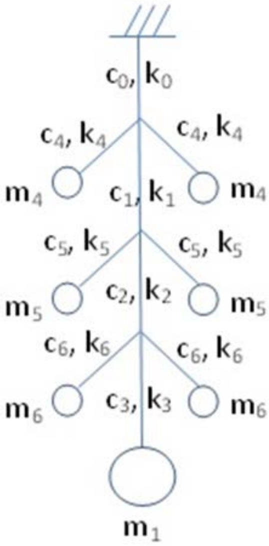

Figure 5: Mass-spring-damper model of SPIE rope

Figure 6: Static strength test flexible strap in climate chamber

Presented at 44th European Rotorcraft Forum, Delft, The Netherlands, 19-20 September, 2018

Figure 7: SPIE rope yarn strength test

Figure 8: SPIE rope strength test

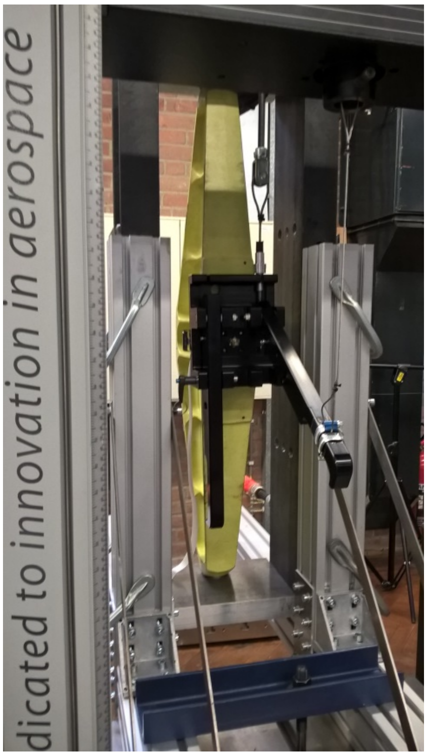

Figure 9: Backup release activation lever static strength test

Presented at 44th European Rotorcraft Forum, Delft, The Netherlands, 19-20 September, 2018