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Evaluation of the three candidates for the Danish New Fighter Program based on their answers to the RBI 2014 questions related to Airframe Service Life

Customer

Danish Ministry of Defence New Fighter Program

NLR-CR-2014-494 - November 2014

NLR – Dedicated to innovation in aerospace

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EXECUTIVE SUMMARY

Evaluation of the three candidates for the Danish New Fighter Program based on their answers to the RBI 2014 questions related to Airframe Service Life

As part of the down selection phase of the Danish New Fighter Program (DNFP), the Danish Ministry of Defence has tasked NLR to conduct the airframe service life analysis based on the outcome of the Request For Binding Information 2014 (RBI) of the three fighter candidates: the Eurofighter Typhoon, the Lockheed Martin F-35A Joint Strike Fighter and the Boeing F/A-18F Super Hornet. The airframe service life evaluation has been based on the Evaluation Model for Airframe Service Life, defined by the DK-NFP office in February 2014 in cooperation with NLR.

The activities required by the contract consist of the following:

- An outline of and an initial assessment of the RBI answers provided by each candidate related to the airframe service life;
- Analysis of the answers related to pre-defined key elements of the airframe service life according to the acknowledged evaluation model;
- Identification of risks in relation to the intended Danish operational usage of the three fighter candidates with the aim of including the risks in the DNFP Candidate Risk evaluation process.

Taking the maturity of each candidate into account, it can be stated that all three original equipment manufacturers have made it plausible that sufficient measures have been taken to guarantee the claimed service life. The qualified service life of the

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Eurofighter Typhoon is 6000 flight hours, for the F-35A Joint Strike Fighter it is 8000 flight hours and for the F/A-18F Super Hornet it is 6000 flight hours. At the same time provisions are being provided, both onboard and off-board, to get insight into the actual usage severity related to the design assumptions, by means of a loads and usage monitoring system. Based on this, the operator can take timely measures, whether or not in cooperation with the original equipment manufacturer to guarantee the safe use of each aircraft in the fleet within the qualified service life.

Whether this will suffice for the Danish Projected Usage Pattern cannot be confirmed as none of the candidates has provided adequate substantiation that its design usage actually covers the projected Danish usage.

Approved by:

Author(s)	Reviewer	Managing department
[redacted]		
Date 27/11/14 29/11/14	Date 27/11/2014	Date 28/11/2014

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Content

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Abbreviations

Acronym	Description
AAF	Austrian Air Force
ALIS	Autonomic Logistics Information System
ASIP	Aircraft Structural Integrity Program
CSI	Country Specific Information
CSTM	Composite Set of Training Missions
CTOL	Conventional Take Off and Landing
DNFP	Danish New Fighter Program
DUL	Design Ultimate Load
FH	Flight Hour
FI	Fatigue Index
FLE	Fatigue Life Expended
FSTA	Full-Scale Test Articles
GAF	German Air force
IAT	Individual Aircraft Tracking
IMAT	Integrated Metallic Analysis Toolset (Lockheed Martin software)
IMC	Integrated Maintenance Concept
IND	INDustry
JCS	Joint Contract Specification
JDL	Joint Data Library (Lockheed Martin)
JPO	Joint Project Office
KPP	Key Performance Parameter
LEF	Leading Edge Flap
LEFM	Linear Elastic Fracture Mechanics
LRIP	Low Rate Initial Production
L/ESS	Loads and Environment Spectrum Survey
MES	Master Event Spectrum
MMH	Maintenance man Hours
MU	Memory Unit
N.A.	Not Applicable
NAVAIR	(US) Naval Air Systems Command
NDI	Non Destructive Inspection
NFP	New Fighter Program
Nz	Vertical acceleration
OEM	Original Equipment Manufacturer
PBL	Performance Based Logistics
PMAFT	Production Machine Aft Fuselage Test
PMD	Portable Maintenance Device

Acronym	Description
PSI	Product Support Integrator
PSM	Product Support Manager
PUP	Predicted Usage Pattern
RBI	Request for Binding Information
RCM	Reliability Centered Maintenance
RDAF	Royal Danish Air Force
SAFE	Structural Appraisal of Fatigue Effects (Boeing software)
SDD	System Design and Development
SHM(S)	Structural Health Monitoring (System)
SIFT	SIngle Fuselage test
SL	Service Life
SLAP	Service Life Assessment Program
SLEP	Service Life Extension Program
SMG	Structural Monitoring Group
SOU	Squadron Operating Unit
SPHM	Structural Prognostics & Health Management
SSWG	System Safety Working Group
TEF	Trailing Edge Flap
USAF	United States Air Force
USN	United States Navy
WFD	Widespread Fatigue Damage
WSDS	Weapon System Design Specifications

1 Introduction

As part of the down selection phase of the Danish New Fighter Program (DNFP), the Danish Ministry of Defence has requested NLR to conduct the airframe service life analysis based on the outcome of the Request For Binding Information (RBI) of the three fighter candidates, Ref. [1]. The airframe service life analysis was based on the Evaluation Model for Airframe Service Life, defined by the DNFP office and provided in February 2014 in cooperation with NLR. The evaluation model Ref. [2] was reviewed and acknowledged by NLR.

The activities performed under this contract consisted of three parts. They are:

- An outline of and an initial assessment of the RBI answers;
- Analysis of the answers related to key elements of the airframe service life according to the acknowledged evaluation model;
- Identification of risks in relation to the intended Danish operational usage of the fighter.

The results of these activities are described herein according to the format outlined in Ref. [3] and in the guidelines for the risk assessment in Ref. [4].

Chapter two in combination with appendix A presents the results of the initial assessment of the RBI answers, as has been provided by the DNFP office to NLR in Ref. [5]. The RBI answers were for each candidate supplied by their respective national defence organizations (the German Ministry of Defence for Eurofighter, Joint Program Office (JPO) for Lockheed Martin and US Navy for Boeing) in close cooperation with each manufacturer.
In chapter three for each fighter candidate an analysis has been performed on specific aspects of airframe service life as defined by the DNFP office in Ref. [3]. In particular the candidates answers have been viewed with the following key questions in mind: how realistic is the substantiation basis of the original design airframe service life by the manufacturer, what is the effect of the differences of the Royal Danish Air Force Projected Usage Pattern with the design usage pattern as foreseen by the manufacturer on the desired airframe service life, and in which way is the operator going be able to monitor its fleet lifetime development with sufficient reliability.

Based on the evaluation of all answers and the performed analysis a number of risks have been identified and listed in Appendix B according to the format and guidelines described in Ref. [4].

2 Outline of the received answers

Appendix A contains the review of the answers of the candidates on the RBI questions in Ref. [5]. For each question the answer has been summarized and an assessment has been given for each candidate. For each RBI question an assessment has been given of respectively the completeness, the depth and the openness of the presented answer.

In the completeness evaluation the degree in which the answer answers all (internal) questions is given in terms of full, fair, limited and low (high to low).

In the depth assessment the degree of extensiveness of the presented answer is graded in terms of full, fair and low. Examples of full depth are the inclusion of clarifying graphs, examples and substantiating data. If only a short statement, affirmative or negative, has been given without further elaboration, the qualification low was given.

In the evaluation of the openness or responsiveness of the answer attention was paid as to how open or closed the answering was done by the candidate and how much effort was spent in preparing, clarifying and supporting the answer on each question. Qualifications for this evaluation vary between open, moderate and low.

In addition to these qualifications also a short remark has been placed in the assessments in Appendix A clarifying the assessment and/or short comments on the contents of the answers are presented.

Table 1 shows a review of the results of the assessment of the RBI answers in terms of the rated qualifications. Table 2 presents a quantitative estimation of the assessment classifications.

Table 1 Review of the results of the assessment of the RBI answers

RBI question	Eurofighter Typhoon			F-35A Joint Strike Fighter			F/A-18F Super Hornet		
	completeness	depth	openness	completeness	depth	openness	completeness	depth	openness
A1-GD-09	fair	fair	open	full - fair	fair	open	full	fair - low	open
A1-GD-10	full	full	moderate	full	full	open/moderate	full	fair - low	open
A1-GD-11	full	full	open	full	full - fair	moderate	limited	low	moderate
A1-GD-12	full	full	open	full	low	moderate	full - fair	low	moderate
A1-GD-13	full	full	open	full	full - fair	moderate	full	full - fair	moderate
A1-GD-14	full	full	open	full	full	open	full	low	low
A1-GD-15	full	fair	moderate	full	fair	moderate	full	fair	low
A1-GD-16	limited	fair	moderate	full	fair	moderate	limited	fair	moderate
A1-GD-17	full	fair	moderate	limited	full	moderate	full	fair	moderate
A1-GD-18	full	fair	moderate	full	fair	moderate	full	fair - low	moderate
A1-GD-19	full	full	open	limited	fair	moderate	limited	low	low
A1-GD-20	fair	low	low	fair	low	moderate	fair	low	low
A1-GD-21	full	fair	moderate	full	fair	moderate	full	fair	moderate
A1-GD-22	full	full	open	full	full	moderate	full	full - fair	open
A1-GD-23	full	fair	open	full	full - fair	open	full	fair	moderate
A1-GD-24	full	fair	moderate	full	fair	moderate	full	fair	moderate
A1-GD-25	full	fair	open	full	fair	moderate	full - fair	low	open
A1-GD-26	full	fair - low	moderate	full	fair	open	full	low	moderate
A1-GD-27	full	fair	moderate	fair	fair	moderate	full	fair	open
A1-GD-28	fair	fair	moderate	full	full	open	full	fair	moderate
A1-GD-29	full	low	low	fair	fair	open	full	fair	open
A1-GD-30	full	full	open	full	full	open	full	full	open
A1-GD-31	full	fair	open	limited	low	moderate	full	fair	open
A1-GD-32	full	full	very open	full	fair	open	full	full	open
A1-GD-33	full	low	moderate	full	fair	open	full	low	open
A1-GD-34	full	fair - low	open	fair	full	open	low	low	low
A1-GD-35	full	full	open	full	fair	open	full	full	open
A1-GD-36	full	full	open	full	fair	open	full	full	open
A1-GD-37	full	full - fair	open	low	low	low	full	fair	open
A1-GD-38	fair	fair	open	fair	fair - low	open	full	full	open
A1-GD-39	full	fair	open	full	low	moderate	full	fair - low	open
A1-GD-40	full	full	open	full	fair	moderate	full	full	open
A1-GD-41	fair	fair	moderate	low	low	low	low	low	low
A1-GD-42	fair	low	moderate	fair	low	moderate	fair	low	moderate
A1-GD-43	full	fair - low	open	full	low	open	full	fair	open
A1-GD-44	low	fair - low	open	fair	fair - low	open	full	fair	open
A1-GD-45	low	fair	open	full	fair	open	full	fair	open
A1-GD-46	fair	low	open	fair	low	open	fair	low	open
A1-GD-47	full	fair	open	fair	fair	open	full	low	open
A1-GD-48	full	fair	open	full	fair	open	full	fair	open
A1-GD-49	full	fair	open	full	fair	open	full	fair	moderate
A1-GD-50	full	fair	open	full	fair	open	full	fair - low	open
A1-GD-51	full	fair - low	open	full	low	moderate - low	full	fair - low	moderate
A1-GD-52	low	low	low	full	fair	open	full	low	open
A1-GD-53	full	full	very open	full	full	open	full	fair	moderate
A1-GD-54	full	full	open	full	full	open	full	full	open
A1-GD-55	full	full	open	limited	low	moderate	full	full	open
	completeness	depth	openness	completeness	depth	openness	completeness	depth	openness

Table 2 Quantitative estimation of the assessment classifications[1]

score - completeness			
Classification	EF Typhoon	F-35A	F/A-18F
FULL	77%	68%	81%
FAIR	15%	19%	9%
LIMITED	2%	9%	6%
LOW	6%	4%	4%

score - depth			
Classification	EF Typhoon	F-35A	F/A-18F
FULL	33%	22%	19%
FAIR	49%	52%	45%
LOW	18%	26%	36%

score - openness			
Classification	EF Typhoon	F-35A	F/A-18F
OPEN	66%	52%	55%
MODERATE	28%	43%	32%
LOW	6%	5%	13%

[1] Intermediate classifications (e.g. 'full – fair') evenly divided between main categories (e.g. 'full' and 'fair')

Based on this assessment and on the answers the following remarks per candidate can be made.

(a) Eurofighter Typhoon

- Airbus D&S has scored very well for the openness and fair for the depth and completeness of their answers. With some exceptions all questions were answered, with much detail in the form of examples, figures and supportive information.
- As only candidate they have tried to estimate the impact of the Danish projected usage pattern in the RBI on the Eurofighter design spectrum and service life by means of an engineering estimate[i].
- As only candidate some information has been provided on the fleet fatigue usage report of two operators with some illustrations of their operational usage[ii]
- In one occasion the candidate gave a different answer than asked.[iii]

(b) Lockheed Martin F-35A Joint Strike Fighter

- Lockheed Martin has scored reasonably averaged with their answers in the area of completeness, depth and openness, but much information was only descriptive of nature. For more information frequent references were made to design documents, which are accessible via the Joint Data Library (JDL)[iv] of Lockheed Martin.
- No effort was made to evaluate the impact of the Danish six RBI missions on the service life except for a statement of compatibility of the Danish missions with the F-35 design missions and a description of the required input data needed for a more detailed assessment[v].
- No information on the actual fleet fatigue usage data was provided on the ground that US Government regulations are prohibiting sharing Country Specific Information (CSI) without official consent.[vi]
- Due to the current development phase of the F-35A answers to questions related to the validation of the service life and the usage experiences are more of an descriptive nature and less supported by substantiating information, resulting in relatively high scores for the 'fair' and 'low' classifications for depth.

(c) Boeing F/A-18F Super Hornet

- Boeing has scored reasonably well with their answers in the area of completeness, but scored only fair for depth and openness; much information was only descriptive and/or closed of nature. For more information frequent references were made to design documents, which are not directly accessible.

- No effort was made to evaluate the impact of the Danish six RBI missions on the service life except for a statement of assumption that the RBI mission scenarios are comparable to the F/A-18F design missions[vii].
- No information on the actual fleet fatigue usage data was provided on the ground that the US Navy did not authorize Boeing to share this data as this is considered Country Specific Information.[viii]
- In general less supportive information have been included in the answers and they were more closed in nature than the other candidates, resulting in relatively high scores for the 'low' ratings for depth and openness.

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i A1-GD-19-A
ii A1-GD-41-A
iii A1-GD-44-A
iv A1-GD-28/30/31/32-A
v A1-GD-19-C
vi A1-GD-41-C
vii A1-GD-19-D
viii A1-GD-41-D

3 Analysis of airframe service life

3.1 Eurofighter Typhoon

3.1.1 Designed Service Life

The Eurofighter Typhoon has been designed for a service life (SL) of 6000 flight hours [redacted]

[redacted]

[redacted]

[redacted]

Extension of the service life is only possible if the full scale fatigue tests will be conducted to extend the qualified life. [redacted]

[redacted]

[2] Safe life is the 'Safety-by-Retirement' concept: Critical parts of the structure are routinely replaced before any fatigue damage can become critical or have been designed for the entire lifetime of the aircraft.
[3] This 'Safety-by-Inspection' concept assumes that any fatigue damage can be detected before it can get critical.

[redacted]

3.1.2 Actual airframe performance by current users

The actual airframe performance as measured with the aircraft Structural Health Monitoring (SHM) system is based on the usage factor, which allows a clear comparison of the in-service usage against the design assumptions for each relevant parameter (like fatigue index value or other metrics). Again it should be noted that the usage factor is related to the qualified service life as demonstrated during the full-scale fatigue tests.

[redacted]

An international fleet wide combined analysis is currently not performed, as the detailed data are not shared between the participating nations. Only the results of the national analysis are presented and used for the assessment of the structural integrity of the fleet for the participating nations and Industry (IND) in the Structural Monitoring Group during their annual data analysis workshop.[xiii]

3.1.3 The Effects of Danish Operations on the Predicted Service Life

No detailed analysis of effect of the Danish six RBI missions on the Predicted Service Life of the Eurofighter has been performed. By means of a preliminary engineering assessment Airbus D & S has estimated the impact of the Danish operations using the six RBI missions on the most important load type, the vertical acceleration spectra, of the Eurofighter. From this it was estimated that the Eurofighter Typhoon fatigue design spectrum for 6000 FH does cover an equivalent service life of 8000 FH based on the Danish RBI spectrum defined in the six missions[xiv].

[redacted]

This estimation was only based on the comparison of the vertical acceleration design spectrum for 6000 flight hours and the expected vertical acceleration spectrum for the Danish operations for 8000 flight hours, since other important spectra are expected to be equal. However, the service life is in reality not only dependent on the flight spectrum from manoeuvers, but may also be dependent on the number of certain events like undercarriage cycles (take-off/landing cycles) or the usage of the airbrake for certain components of the airframe[6].

Although Airbus D&S was not able[7] to respond to the RBI question on the actual analysis needed to qualify the service life of the Eurofighter based on the Danish PUP[xv], it is expected that if the effect of the Danish PUP on service life must be evaluated, the following main tasks will have to be executed: fleet usage analysis, development of a Master Event Spectrum (MES), loads calculation, finite element modeling, fatigue spectra generation, selection of structural locations to be analyzed, and, finally, calculation of fatigue lives at each of the selected airframe locations. For the flight release a formal airworthiness certification by an independent and competent authority (design authority) has to be provided as well.
For an accurate study it is desirable to perform a more detailed PUP analysis to establish a more realistic impact study on the service life.

3.1.4 Predicted service life as a result of the differences between the Danish use pattern and the designed use pattern of an operator to monitor its fleet lifetime development

The design service life of the Eurofighter has been based on the expected usage and loads as derived for the four original Eurofighter Partner Nations in the definition of the Composite Set of Training Missions (CSTM). Using the information from the load and usage monitoring system in each aircraft (part of the structural health management system), the operator will be able to determine its actual usage of each aircraft in terms of the fatigue consumption expressed as the usage value at the [redacted] structural control points and in the number of specific life metrics like number of landings or airbrake events.

Due to the differences in the Danish Predicted Usage Pattern (PUP) and the Design Usage Pattern as defined in the CSTM, the RDAF operator may reach a value of 1.0 (i.e. 100% Design Life consumed) for one or more of the usage factors before the qualified service life of 6000 FH[8]. At that time either the component has to be replaced/retrofitted[xvi] or the aircraft have to be

[redacted]

[7] Concerning the answering of question A1-GD-44-A it should be noted that Airbus D&S only presented the answer how the effect of the difference between the actual usage with the design usage can be determined, not the actual question how the effect of the difference between the Projected usage and the design usage can be evaluated.

[redacted]

grounded, since there is no qualified demonstration of residual life based on the Safe Life approach. Extension of the service life by extending the full scale tests from a qualified service life from 6000 to 9000 FH as being planned by the EF partner nations and IND will be then beneficial.

3.1.5 Monitoring Fleet Service Life

The Eurofighter has a Structural Health Management System that calculates among others the fatigue consumption at [redacted] locations. It determines not the real "fatigue life" of a structural location but calculates the fatigue life consumption against the qualified life demonstrated in the full scale fatigue test, which will be 6000 FH. These fatigue consumption rates will be with other parameters off-loaded after each flight to a ground station and being added to the accumulated database for each aircraft. Data from all ground stations in the fleet will be collected in the national data warehouse and processed by IND on contractual basis for fleet wide analysis and generation of annual national reports to be presented within the international Structural Monitoring Group (SMG) if desired and permitted by the national operator[xvii]. Using this international platform and being informed on the annual national analyses from the IND will enhance the operator capabilities to act as a smart operator.

In this described process the actual load time histories will be determined and processed on-board and not be part of the data off-loaded[xviii] and therefore these raw data will not be available for later study of e.g. flight related incidents or for second opinion[9].

3.1.6 Corrosion

According to the manufacturer no components are affected by corrosion[xix] and there are no implications on the service life/maintenance program[xx]. All airframe components are either made of corrosion resistant materials or non-corrosion resistant metals are protected by organic coatings in combination with material specific pre-treatments. Assembly of components and fasteners is carried out with sealant for avoidance of contact and crevice corrosion[xxi]. The coatings are according to the manufacturer "basically chromate free, manufacturer will substitute chromate[xxii]".

[redacted]

3.2 Lockheed Martin F-35A Joint Strike Fighter

3.2.1 Designed Service Life

The F-35A airframe is designed to an 8,000 hour service life requirement or [redacted] years of operation and currently contracted to test demonstrate [redacted] Execution of a third durability test life is planned however for the airframe, and horizontal, and vertical tail components to support future F-35 fleet management decisions and activities. This will lead to a total of [redacted] of full scale durability testing to be carried out.

[redacted]

Compliance with the 8,000 hour service life durability requirement will be demonstrated by subjecting Full-Scale Test Articles (FSTA) of the airframe, horizontal tail and the vertical tail and rudder to [redacted] of spectrum fatigue service loading, representative of a 90th percentile fleet design use severity. [redacted]

[redacted]

[11] Lockheed Martin report 2YZS00017, September 30th, 2005.

[redacted]

[redacted]

Lockheed Martin claims that to date there are no known primary structure components limiting the service life of the F-35A airframe. All issues with primary structure which have been identified so far are all identified during testing, and are addressed by retrofit/modification for existing fleet built F-35A aircraft and revised production design for future builds [xxvii].

3.2.2 Actual airframe performance by current users

Besides the fact that actual operational airframe performance information is very limited due to the phase of the program, load and usage data is considered Country Specific Information (CSI) and per the U.S. Government regulation, CSI is not to be shared without specific permission from the user owning the data [xxviii].

At the present time there are no known life limitations resulting from flight test measured loads data. [redacted]

The actual fleet and individual aircraft usage will be monitored and reported in the Individual Aircraft Tracking (IAT) reports and the Loads and Environment Spectrum Survey (L/ESS) Reports. All F-35 IAT tracking to date has resulted in lower damage rates than designed usage; this is expected though due to the lesser flight envelope initially authorized for the F-35 Fleet Aircraft while the flight test opens up the flight envelope [xxx]. [redacted]

[redacted]

3.2.3 The Effects of Danish Operations on the Predicted Service Life

No evaluation of the impact of the Danish operations as defined in the 6 RBI mission scenarios has been performed by Lockheed Martin. The 6 RBI mission scenarios are, in essence, considered as a subset of the F-35 design missions which defined the Nz requirements for the aircraft. Therefore, any Nz requirements of the Denmark missions should be met with the basic F-35 design [xxxi].

The 6 RBI mission scenarios are based on weapons loads, air vehicle configurations, speed, maneuvering, take-off and landing events which have all been considered individually for airframe strength and are authorized within the F-35A flight envelope. As such, Lockheed Martin expects none of the 6 RBI mission scenario elements should limit the designed service life of any of the airframe components on the F-35 [xxxii].

If Denmark however still desires a detailed RBI mission scenario response a Structural Service Life Analysis Study by the Lockheed Martin Structures Development department could be performed. Additional details will need to be provided by Denmark in order to fully answer questions on the RBI specific scenarios. In particular a mission mix or life usage distribution for the 6 missions along with detailed mission profiles and maneuver activity are required. Once this information is a provided, funding will be required in order to perform this assessment. The Royal Danish Air Force usage pattern will then be used to create a representative Master Event Sequence (MES) using relevant manoeuvers and other load conditions. Using the particular RDAF MES, the life or crack growth rates for each existing fatigue control point can then be recalculated using a proprietary Lockheed Martin Aero-developed tool known as the Integrated Metallic Analysis Toolset (IMAT) which uses Linear Elastic Fracture Mechanics (LEFM). By using the representative MES, the differences in damage rates becomes readily apparent [xxxiii].

3.2.4 Predicted service life as a result of the differences between the Danish use pattern and the designed use pattern of an operator to monitor its fleet lifetime development

The F-35A airframe design spectrum was developed according to USAF methodology based upon on a set of twelve peace time training missions defined in the JSF Air System Contract Specification. Based upon this design spectrum the F-35A is "dimensioned" to meet the required service goal: "Ninety percent of all delivered JSF Air Vehicles, by variant, shall achieve either [redacted] 8000 flight hours" whichever comes first. Actual operational usage may differ however from the design usage.

To get insight in the severity and consequences insight in the actual operational usage is required. The Structural Prognostic Health Monitoring (SPHM) system is therefore being developed to provide Individual Aircraft Tracking (IAT) for the F-35.

Due to potential differences, though not expected by Lockheed Martin, in the Danish Predicted Usage Pattern (PUP) and the F-35 design usage the Royal Danish Air Force may be confronted with a more severe or benign usage affecting the service life of the airframe[15].

3.2.5 Monitoring Fleet Service Life

All tenets of the Aircraft Structural Integrity Program (ASIP) as defined by the US Government in MIL-STD-1530C are addressed. The roles and responsibilities of partner nation participants in the F-35 ASIP process largely align with legacy program experiences and allows for extensive partner nation flexibility and participation in fleet management support [xxxv].

[redacted]

In this described process it is unknown if the operator will actually obtain the actual load time histories and therefore these raw data may not be available for later study of e.g. flight related incidents or for second opinion[16].

3.2.6 Corrosion

Any airframe components made from a metallic material would potentially be affected by corrosion, particularly Aluminum in electrical bond and dissimilar material joints.[redacted]

Aircraft maintainers are trained to look for corrosion during the normal course of performing their activities. Their visual observations may be enhanced by Non Destructive Inspection (NDI) methods and techniques after visual indications are noted.[redacted]

[redacted]

3.3 Boeing F/A-18F Super Hornet

3.3.1 Designed Service Life

The Boeing Super Hornet F/A-18F has been designed for a service life of 6000 flight hours [redacted] For non-carrier based operations the service life of certain components would increase the service life for structure designed for catapult launches and arrested landings specified by the US Navy. The US Navy has also started a Service Life Assessment Program (SLAP[18]) to evaluate operation of their F/A-18F beyond 6000 flight hours[xliii].

All metallic components of the airframe have been designed according to safe life principles and tested for two lifetimes[19]. An additional damage tolerance requirement is imposed on critical primary structure to mitigate the risk of initial flaws or in-service damage. This requirement is one service lifetime (6,000 flight hours) of crack growth (damage tolerance) from a predetermined initial crack size and with a minimum acceptable critical crack size in addition to the fatigue crack initiation/safe life specifications.

[redacted]

No life limited fatigue critical parts are known[xliv] and the safe life of the complete structure including redesigned components has been demonstrated by analysis and full-scale fatigue tests,

[redacted]

[18] An airframe SLAP is a fatigue life assessment of selected structural locations based on a spectrum representing actual fleet usage.

[redacted]

with the exception of the structure unique to the two-seat configuration, which was not part of the full scale fatigue tests[20] [xlv].

At this time there are no concrete plans to extend the service life, but if needed a SLAP could be implemented along with a Service Life Extension Program (SLEP[21]) [xlvi]. To meet the 6000 FH fatigue life requirement, certain life improvement techniques [redacted] have been used, limiting partly the possibility to extend locally the service life[xlvii] [22].

3.3.2 Actual airframe performance by current users

Due to operator's requests (e.g. United States Navy (USN)) no detailed information is available or has been presented in the RBI answers on the actual airframe performance by current users[xlviii].

[redacted]

An international fleet wide combined analysis is currently not performed, as the detailed data are not shared between the nations.

3.3.3 The Effects of Danish Operations on the Predicted Service Life

No evaluation of the impact of the Danish operations as defined in the six RBI missions on the different manoeuvre spectra has been performed by Boeing. Instead it is assumed that the RBI mission scenarios are comparable to the missions for which the Super Hornet was designed[li].
Since no information of the design missions defined for the F/A-18F are presented this is difficult to check or evaluate.
It may be envisaged that due to the absence of carrier based operations like catapult take-offs, off-shore landings and wing fold bending, components mainly subjected to those loads will not be affected by the Danish operations, but other components may be significantly differently loaded in time.

[redacted]

[21] A SLEP defines the corrective actions for those locations not meeting new fatigue life goals.

[redacted]

If the effect of the Royal Danish Air Force projected usage on service life must be evaluated[23], the following main tasks have to be executed: fleet usage analysis, development of a Master Event Spectrum, loads calculation, finite element modeling, fatigue spectra generation, selection of structural locations to be analyzed, and, finally, calculation of fatigue lives at each of the selected airframe locations[lii].

3.3.4 Predicted service life as a result of the differences between the Danish use pattern and the designed use pattern of an operator to monitor its fleet lifetime development

The design service life of the Super Hornet has been based on the expected usage and loads as derived for the US Navy requirements. Using the information from the load and usage monitoring system in each aircraft, the operator will be able to determine his actual usage of each aircraft in terms of the fatigue consumption expressed as the Fatigue Life Expended (FLE) at the [redacted] control points[liii] and in the terms of the number of specific life metrics like number of landings or airbrake events.

Due to the differences in the Danish Predicted Usage Pattern (PUP) and the Design Usage Pattern as defined in the USN Weapon System Detailed Specification report, the Danish operator may either reach a value of 1.0 for one or more of the FLE values (i.e. >=100% Design Life consumed) before the qualified service life of 6000 FH[24]. At that time either the component has to be replaced or the aircraft have to be grounded, since there is no qualified demonstration of residual life based on the Safe Life approach. Extension of the service life by performing a SLAP as being planned by the USN will be then beneficial if this also would be combined with a SLEP program with additional testing or analysis to extend the qualified service life[25].

3.3.5 Monitoring Fleet Service Life

[redacted] A backup set of strain sensors is positioned for redundancy as close as possible to the primary set in each of these locations. Relationships have been established among the measured strains at the seven key monitored locations to [redacted] other fatigue critical areas on the airframe. These relationships, [redacted] is used to provide tracking capability at other critical locations on the F/A-18F. Of the [redacted] locations are published for fleet management

[redacted]

and [redacted] are used for engineering evaluation[liv]. After each flight the operator will process the downloaded data on the Memory Unit (MU) with the Boeing provided-and-maintained SAFE software, which builds a spectrum for each location using the recorded strains, accelerations and trajectory data. In addition an FLE value is assigned to each location, which represents the fraction of Safe Life that has been consumed. In addition to FLE calculations, the software has many features to tabulate, segregate, and categorize structural usage data. The various spectra extracted from the SAFE software can be used by the operator to assess damage tolerance using original equipment manufacturer tools or other fracture mechanics methods[lv].

Boeing and Denmark can collaborate in analyzing Danish usage, and the extent of this collaboration is at the discretion of Denmark. Denmark will own all data generated by the data acquisition system in its Super Hornets and will control the scope and extent of any data shared with Boeing or the USN.

3.3.6 Corrosion

Due to the design requirements of the F/A-18F to operate in the highly corrosive saline environment of an aircraft carrier, corrosion protection and prevention is an integral part of its design/maintenance philosophy. [redacted] Based on the more than ten year of experience with the F/A-18 on carriers it is expected that corrosion will have no impact in current corrosion protection maintenance for basing in Denmark.

[redacted]

ix A1-GD-11-A
x A1-GD-26-A
xi A1-GD-41-A
xii A1-GD-47-A

[redacted]

xiii	A1-GD-38-A
xiv	A1-GD-19-A
xv	A1-GD-44-A
xvi	A1-GD-40-A
xvii	A1-GD-38-A
xviii	A1-GD-48-A
xix	A1-GD-27-A
xx	A1-GD-29-A
xxi	A1-GD-27-A
xxii	A1-GD-54-A
xxiii	A1-GD-11-C
xxiv	A1-GD-22-C
xxv	A1-GD-12/13-C
xxvi	A1-GD-16-C
xxvii	A1-GD-14-C
xxviii	A1-GD-41/49-C
xxix	A1-GD-26-C
xxx	A1-GD-43-C
xxxi	A1-GD-19-C
xxxii	A1-GD-20-C
xxxiii	A1-GD-20/44-C
xxxiv	A1-GD-35-C
xxxv	A1-GD-34-C
xxxvi	A1-GD-39-C
xxxvii	A1-GD-27-C
xxxviii	A1-GD-28-C
xxxix	A1-GD-29-C
xl	A1-GD-30-C
xli	A1-GD-54-D
xlii	A1-GD-11-A
xliii	A1-GD-11/32-D
xliv	A1-GD-14-D
xlv	A1-GD-23-D
xlvi	A1-GD-32-D
xlvii	A1-GD-33-D
xlviii	A1-GD-41/49-D
xlix	A1-GD-25/40/43-D
l	A1-GD-47-D
li	A1-GD-19-D
lii	A1-GD-44-D
liii	A1-GD-45-D
liv	A1-GD-45-D
lv	A1-GD-45-D
lvi	A1-GD-27-D
lvii	A1-GD-54-D

4 Conclusions

Taking the maturity of each candidate into account, it can be stated that all three original equipment manufacturers have made it plausible that sufficient measures have been taken to guarantee the claimed service life. The qualified service life of the Eurofighter Typhoon is 6000 flight hours, for the F-35A Joint Strike Fighter it is 8000 flight hours and for the F/A-18F Super Hornet it is 6000 flight hours. At the same time provisions are being provided, both onboard and off-board, to get insight into the actual usage severity related to the design assumptions, by means of a loads and usage monitoring system. Based on this, the operator can take timely measures, whether or not in cooperation with the original equipment manufacturer to guarantee the safe use of each aircraft in the fleet within the qualified service life.
Whether this will suffice for the Danish Projected Usage Pattern cannot be confirmed as none of the candidates has provided adequate substantiation that its design usage actually covers the projected Danish usage.

4.1 Conclusions concerning Eurofighter Typhoon Airframe Service Life

- Completeness and depth of the answers on airframe service life of the Eurofighter Typhoon are fair, though not all questions have been answered. The questions have been answered in an open manner, giving most information directly, not by just referencing to internal documents.
- The Eurofighter Typhoon has been designed for a service life of 6000 flight hours during [redacted] years, including [redacted] landings. All metallic components of the airframe have been designed according to safe life principles, whereas all non-metallic components of the have been designed according to damage tolerance principles. An additional damage tolerance requirement regarding the residual strength capability of a damaged structure was added.
- The validation of the service life by testing is still ongoing. At this time only the single seat unique structure has been qualified for the service life of 6000 flight hours by [redacted] hours of full-scale fatigue testing, which is relatively low test duration for a safe-life approach. The full-scale fatigue test has qualified the remaining common structure with the two seat variant for [redacted] flight hours. Airbus Defence & Space will extend the service life of the single seat unique structure to [redacted] flight hours by extended full scale fatigue testing. An extension of the fatigue test on the remaining structure for a

prolonged service life up to [redacted] flight hours is under negotiation with the four original partner countries.

- The design usage spectrum has been derived from a condensed set of mission profiles, the Composite Set of Training Missions, agreed with the Eurofighter Partner Nations, and has been validated by flight and ground tests. A rudimentary engineering analysis has been provided stating that the usage spectrum following from the Danish RBI missions is covered by the EF design spectrum; however, no detailed analysis has been done.
- The loads measured onboard as part of the Structural Health Management System, are not available for ground analysis by the operator. Parts of the analysis are performed by the industry; the operator has a choice in the data selection and in the level of participation. There is a strong organizational support structure in place for sharing usage information between EF partner nations.
- According to the manufacturer no components are affected by corrosion and there are no implications on the service life/maintenance program. This assessment may underestimate the corrosion risk. The coatings are according to the manufacturer "basically chromate free, manufacturer will substitute chromate".
- The airframe is mature with more than ten years of operation; however, not all aspects have been covered yet due to the unfinished full-scale fatigue test. [redacted]

4.2 Conclusions concerning Lockheed Martin F-35A Joint Strike Fighter Airframe Service Life

- In general the directly provided information based on the RBI 2014 regarding the F-35A airframe service life was reasonably averaged considering completeness, depth and openness. Most of the information was only descriptive. Additional often referenced documents could be provided upon request or via access to the Joint Data Library (JDL) of Lockheed Martin (LM). These referenced documents could have been provided as part of the information package since Denmark has a Technical Assistance Agreement (TA 2004-12) in place to have access to this information.

- The F-35 is designed according to applicable damage tolerance lifing methodology for both primary metallic and composite structure, developed and tested to meet the 8,000 hour service life requirement or [redacted] years of operation. Compliance with the 8,000 hour service life requirement is currently being demonstrated by subjecting the full-scale test articles to [redacted] of spectrum fatigue service loading making use of a 90th percentile expected fleet design usage severity. The F-35A airframe fatigue test article has accumulated [redacted] hours of testing, of which [redacted] hours into the second life of testing. The flight test program is in progress as well and gradually opening up the flight envelope to the limits may lead to findings having to make (slight) modifications to the airframe design.

- Since testing has not been completed the airframe design cannot be considered mature. Service life extension possibilities are not foreseen at this time, but possible service life extensions will be based upon additional damage tolerance analysis and performing the appropriate tests.

- Structural fatigue testing to two simulated service lifetimes is the minimum requirement for a damage tolerant design to demonstrate the certified service life. Performing the execution of the planned third test life must therefore be considered a positive additional effort to support future structural fleet management activities i.e. get insight in the effects of a more severe usage than accounted for in the expected design usage. The expected design usage is based upon 12 expected peacetime training mission and legacy programs which is expected to fully cover the Danish Projected Usage Pattern though no effort has been made as part of the RBI 2014 to substantiate this.

- To gain insight in the actual severity of operational usage the F-35 is equipped with a Structural Prognostic Health Management system which enables loads and usage monitoring for the purpose of Individual Aircraft Tracking (IAT) and the collection of Loads and Environment Spectrum Survey (L/ESS) data to perform this task as part of the F-35 Aircraft Structural Integrity Program (ASIP). The F-35 ASIP program is fully based on the ASIP approach as defined by the US Government in MIL-STD-1530C. Not fully clarified is to which level of detail an operator will have ownership and therefore access to the actual monitored data to perform additional analysis when required. This may also be of relevance when both the original equipment manufacturer and operator start to explore their mutual Performance Based Logistics (PBL) ambitions during the sustainment phase as the airframe matures.

- [redacted]

4.3 Conclusions concerning Boeing F/A-18F Super Hornet Airframe Service Life

- In general the directly provided information based on the RBI 2014 regarding the F/A-18F airframe service life was reasonably well considering completeness but fair considering depth and openness since most of the information was only descriptive.

- The F/A-18F is designed according to applicable Safe Life principles for both primary metallic and composite structure, developed and tested to meet the 6,000 hour service life requirement or [redacted] years of operation. An additional damage tolerance requirement is imposed on critical primary structure to mitigate the risk of initial flaws or in-service damage. This requirement is one service lifetime (6,000 flight hours) of crack growth (damage tolerance) from a predetermined initial crack size and with a minimum acceptable critical crack size in addition to the fatigue crack initiation/safe life specifications. Compliance with the 6,000 hour service life requirement has been demonstrated by subjecting the full-scale test articles to [redacted] of spectrum fatigue service loading making use of a 90th percentile expected fleet design usage severity. Some components have been tested for three or four simulated lifetimes (including the damage tolerance testing). The flight test program has validated the design loads.

- The design of the airframe of the F/A-18F Super Hornet has shown to be mature and the aircraft has been successfully operated from 1999 during carrier operations in harsh environments. At this time there are no concrete plans to extend the service life, but if needed a Service Life Assessment Program (SLAP), already planned for the US Navy, could be implemented along with a Service Life Extension Program (SLEP).

- The expected design usage is based upon US Navy requirements and on legacy programs which is expected by the manufacturer to fully cover the Danish Projected Usage Pattern though no effort has been made as part of the RBI 2014 to substantiate this.

- [redacted]

- [redacted]

References

1.	NLR letter to Danish Ministry of Defence New Fight Program office, "Offer for assistance in airframe service life/evaluation based upon the outcome of the RBI of three fighter candidates and the DK NFP evaluation model", d.d. 15-08-2014, Ref. AVGS/1401/10813.
2.	Danish Ministry of Defence, "Evaluation Model for Airframe Service Life", February 2014
3.	Danish Ministry of Defence, "NLR Outline of the Report on Airframe Service Life (Final) 2014-09-05", May 2014.
4.	Danish Ministry of Defence, "Guidance to NLR on the Identification and Documentation of Risks", September 2014.
5.	Danish Ministry of Defence, CD with set of RBI answers related to airframe service life (9 through 55) and additional CFI answers for each of the three fighter candidates, September 2014.

Appendix A Assessment of the RBI-answers

Appendix A.1 Introduction

This appendix contains the review of the answers of the candidates on the RBI questions in Ref. [5]. For each question the answer has been summarized and an assessment has been given for each candidate in the format provided by the NFP office. For each RBI question an assessment has been given of respectively the completeness, the depth and the openness of the presented answer. In the completeness evaluation the degree in which the answer answers all (internal) questions is given in terms of full, fair, limited and low (high to low). In the depth assessment the degree of extensiveness of the presented answer is graded in terms of full, fair and low. Examples of full depth are the inclusion of clarifying graphs, examples and substantiating data. If only a short statement, affirmative or negative, has been given without further elaboration, the qualification low was given. In the evaluation of the openness or responsiveness of the answer attention was paid as to how open or closed the answering was done by the candidate and how much effort was made in preparing, clarifying and supporting the answer on each question. Qualifications for this evaluation vary between open, moderate and low. In addition to these qualifications also a short remark has been placed in the assessments clarifying the assessment and/or a short comment on the contents of the answers is given.

Answers completely quoted from the RBI answers are presented between quotation marks.

RBI/RFC question ID	**A1-GD-9**
Full text from questions	Provide an overview of the type, amount and locations of the materials applied in the airframe.
Eurofighter	
Answer	[redacted]
Completeness	*fair* – [redacted]
Depth	*fair* – [redacted]
Openness	*open* – [redacted]
F-35A Joint Strike Fighter	
Answer	[redacted]
Completeness	*Full/Fair* – [redacted]
Depth	*fair* – [redacted]
Openness	*open* – [redacted]
F/A-18F Super Hornet	
Answer	[redacted]
Completeness	*full* - [redacted]
Depth	*Fair/Low* – [redacted]
Openness	*open* – [redacted]

RBI/RFC question ID	**A1-GD-10**
Full text from questions	Describe the assembly methods used in the airframe construction.
	Eurofighter
Answer	[redacted]
Completeness	*full* - [redacted]
Depth	*full* - [redacted]
Openness	Moderate [redacted]
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*full* - [redacted]
Depth	*full* – [redacted]
Openness	*open*- [redacted]
	F/A-18F Super Hornet
Answer	[redacted]
Completeness	*full* - [redacted]
Depth	*fair* - [redacted]
Openness	*open* – [redacted]

RBI/RFC question ID	**A1-GD-11**
Full text from questions	Describe the design service goal, the design usage and the configurations on which these data are based.
	Eurofighter
Answer	Service life is 6000 hours [redacted]
Completeness	*Full* - [redacted]
Depth	*Full* – [redacted]
Openness	*open* – [redacted]
	F-35A Joint Strike Fighter
Answer	The primary governing requirement states that: "Ninety percent of all delivered JSF Air Vehicles, by variant, shall achieve [redacted] of operation or 8000 flight hours [redacted]
Completeness	*Full* - [redacted]
Depth	*Full/fair* - [redacted]
Openness	*Moderate* – [redacted]
	F/A-18F Super Hornet
Answer	The Super Hornet service life requirement is 6000 flight hours [redacted]
Completeness	*limited* - [redacted]
Depth	*low* – [redacted]
Openness	*moderate* – [redacted]

RBI/RFC question ID	**A1-GD-12**
Full text from questions	Describe the different lifing methodologies that are applied in the airframe design (metallic and composite) and which methodology is applied to which part of the airframe.
	Eurofighter
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*full* – [redacted]
Openness	*open* – [redacted]
[redacted]	[redacted]
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*Fair* - [redacted]
Depth	*Low* - [redacted]
Openness	*Moderate* - [redacted]
	F/A-18F Super Hornet
Answer	[redacted]
Completeness	*Full/fair* - [redacted]
Depth	*Low* [redacted]
Openness	*moderate*
[redacted]	[redacted]

RBI/RFC question ID	**A1-GD-13**
Full text from questions	What approach has been followed to ensure the damage tolerance of fibre-reinforced plastic airframe components in areas that are prone to barely and clearly visible impact damages (e.g., due to runway debris, tool drops)? Please specify the affected airframe components/areas.
Eurofighter	
Answer	[redacted]
Completeness	*Full* - [redacted]
Depth	*Full* - [redacted]
Openness	*Open* -
F-35A Joint Strike Fighter	
Answer	[redacted]
Completeness	*Full* - [redacted]
Depth	*Full/fair* - [redacted]
Openness	*Moderate* – [redacted]
F/A-18F Super Hornet	
Answer	[redacted]
Completeness	*Full* - [redacted]
Depth	*Full/fair* - [redacted]
Openness	*Moderate* - [redacted]

RBI/RFC question ID	**A1-GD-14**
Full text from questions	Which fatigue critical component(s) is/are limiting for the service life of the airframe?
	Eurofighter
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*full* – [redacted]
Openness	*open*
[redacted]	[redacted]
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*full* – [redacted]
Openness	*open* – [redacted]
	F/A-18F Super Hornet
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*low* – [redacted]
Openness	*low* – [redacted]

RBI/RFC question ID	**A1-GD-15**
Full text from questions	How has the service life been established for the service life limiting airframe component(s)?
Eurofighter	
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*fair* – [redacted]
Openness	*moderate* – [redacted]
[redacted]	[redacted]
F-35A Joint Strike Fighter	
Answer	[redacted]
Completeness	*full* - [redacted]
Depth	*fair* – [redacted]
Openness	*moderate* – [redacted]
[redacted]	[redacted]
F/A-18F Super Hornet	
Answer	[redacted]

	[redacted]
Completeness	*full* – [redacted]
Depth	*fair* – [redacted]
Openness	*moderate* – [redacted]

RBI/RFC question ID	**A1-GD-16**
Full text from questions	What type of loading and mission configuration is dominant in the life consumption of the service life limiting airframe component(s)?
Eurofighter	
Answer	[redacted]
Completeness	*limited* – [redacted]
Depth	*fair* – [redacted]
Openness	*moderate* – [redacted]
F-35A Joint Strike Fighter	
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*fair* – [redacted]
Openness	*moderate* – [redacted]
F/A-18F Super Hornet	
Answer	[redacted]
Completeness	*limited* – [redacted]
Depth	*fair* – [redacted]
Openness	*moderate* – [redacted]

RBI/RFC question ID	**A1-GD-17**
Full text from questions	Describe the generation of the design usage, loads spectra and environmental (climatic) conditions as used for the establishment of the service life of the airframe.
	Eurofighter
Answer	[redacted]
Completeness	*Full* – [redacted]
Depth	*fair* – [redacted]
Openness	*moderate* – [redacted]
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*limited* – [redacted]
Depth	*full* – [redacted]
Openness	*moderate* -
	F/A-18F Super Hornet
Answer	[redacted]
Completeness	*full* - [redacted]
Depth	*fair* – [redacted]
Openness	*moderate* – [redacted]

RBI/RFC question ID	**A1-GD-18**
Full text from questions	Describe in which way effects from the aero- acoustical environment, thermal environment and aeroelastic or aeroservoelastic instabilities are considered in the design spectra.
	Eurofighter
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*fair* – [redacted]
Openness	*fair*
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*fair* – [redacted]

	[redacted]
Openness	*moderate* – [redacted]
F/A-18F Super Hornet	
Answer	[redacted]
Completeness	*Full*
Depth	*fair-low*: [redacted]
Openness	*Moderate*: [redacted]

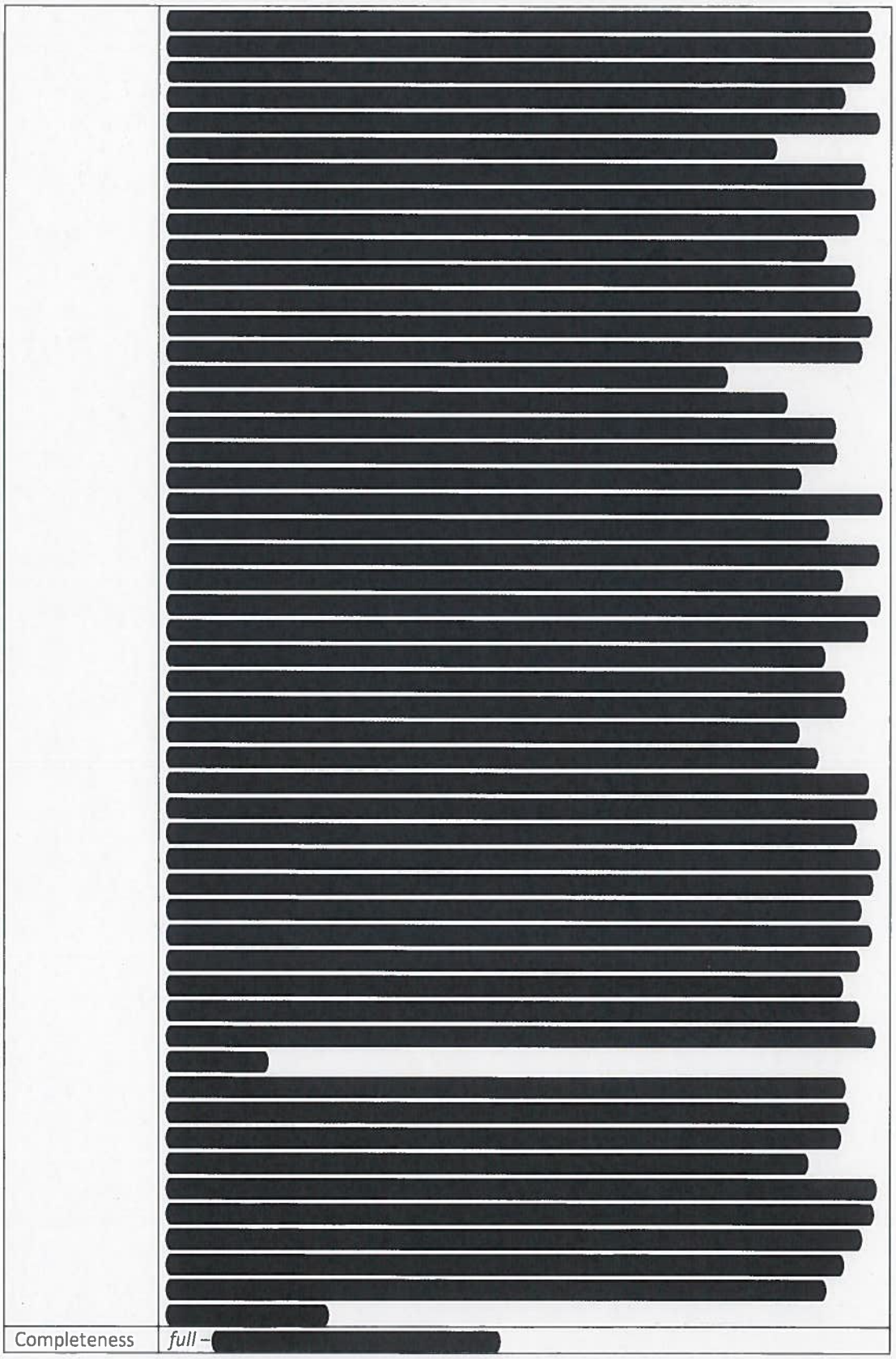
RBI/RFC question ID	**A1-GD-19**
Full text from questions	What is the expected vertical acceleration (Nz) spectrum to meet the requirements of the 6 RBI mission scenario's? And how does this compare to the design Nz spectrum? And can you provide also the answers related to the roll rate (p) and roll acceleration (pdot) spectra?
Eurofighter	
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*full* - [redacted]
Openness	*very open* – [redacted]
[redacted]	[redacted]
F-35A Joint Strike Fighter	
Answer	[redacted]
Completeness	*limited* – [redacted]
Depth	*fair* – [redacted]
Openness	*moderate* – [redacted]
[redacted]	[redacted]
F/A-18F Super Hornet	
Answer	[redacted]

Completeness	*limited* – [redacted]
Depth	*low* – [redacted]
Openness	*low* – [redacted]
[redacted]	[redacted]

RBI/RFC question ID	**A1-GD-20**
Full text from questions	What particular RBI mission scenario elements are foreseen that may limit the service life of one or more airframe components?
Eurofighter	
Answer	[redacted]
Completeness	*fair* – [redacted]
Depth	*low* – [redacted]
Openness	*low* - [redacted]
F-35A Joint Strike Fighter	
Answer	[redacted]
Completeness	*fair* – [redacted]
Depth	*low* – [redacted]
Openness	*moderate* - [redacted]
F/A-18F Super Hornet	
Answer	[redacted]
Completeness	*fair* – [redacted]
Depth	*low* – [redacted]
Openness	*low* - [redacted]

RBI/RFC question ID	**A1-GD-21**
Full text from questions	Describe the test methodology (pyramid or building block approach) that has been used in the establishment of the service life of the airframe.
	Eurofighter
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*fair* – [redacted]
Openness	*moderate* – [redacted]
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*fair* – [redacted]
Openness	*moderate* – [redacted]
	F/A-18F Super Hornet
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*fair* – [redacted]
Openness	*moderate* – [redacted]

RBI/RFC question ID	**A1-GD-22**
Full text from questions	Describe the full-scale fatigue test(s) performed on the airframe
Eurofighter	
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*full* – [redacted]
Openness	*open* - [redacted]
[redacted]	[redacted]
F-35A Joint Strike Fighter	
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*full* – [redacted]
Openness	*moderate* – [redacted]
[redacted]	[redacted]
F/A-18F Super Hornet	
Answer	[redacted]



Completeness	*full –*

Depth	*full* – [redacted]
Openness	*open* – [redacted]

RBI/RFC question ID	**A1-GD-23**
Full text from questions	To what extent did the Full-Scale Fatigue Test Article differ from the production airframe?
	Eurofighter
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*fair* – [redacted]
Openness	*open* – [redacted]
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*fair/full* – [redacted]
Openness	*open* – [redacted]
	F/A-18F Super Hornet
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*fair* – [redacted]
Openness	*moderate* -
[redacted]	[redacted]

RBI/RFC question ID	**A1-GD-24**
Full text from questions	To what extent did the Full-Scale Fatigue Test load spectrum differ from the design load spectrum?
	Eurofighter
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*fair* – [redacted]
Openness	*moderate* – [redacted]
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*fair* – [redacted]
Openness	*moderate* – [redacted]
	F/A-18F Super Hornet
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*fair* – [redacted]
Openness	*moderate* – [redacted]

RBI/RFC question ID	**A1-GD-25**
Full text from questions	Describe the process how the design loads and design load spectra have been validated in flight.
	Eurofighter
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*fair* – [redacted]
Openness	*open* – [redacted]
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*fair* – [redacted]
Openness	*moderate* – [redacted]
[redacted]	[redacted]
	F/A-18F Super Hornet
Answer	[redacted]

	[redacted]
Completeness	*Full-Fair*
Depth	*Low* - [redacted]
Openness	Open

RBI/RFC question ID	**A1-GD-26**
Full text from questions	What flight envelope issues related to airframe service life are already known?
	Eurofighter
Answer	[redacted] Airbrake Out Buffet Damage Zones [redacted]
Completeness	*Full -*
Depth	*Fair-low -* [redacted]
Openness	*Moderate -* [redacted]
[redacted]	[redacted]
	F-35A Joint Strike Fighter
Answer	[redacted]

Completeness	*full* – [redacted]
Depth	*fair* – [redacted]
Openness	*open* – [redacted]
[redacted]	[redacted]
F/A-18F Super Hornet	
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*low* – [redacted]
Openness	*moderate* – [redacted]

RBI/RFC question ID	**A1-GD-27**
Full text from questions	Which airframe components are potentially affected by corrosion?
	Eurofighter
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*fair* – [redacted]
Openness	*moderate* – [redacted]
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*fair* – [redacted]
Depth	*fair* – no[redacted]
Openness	*moderate* – [redacted]
	F/A-18F Super Hornet
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*fair* – [redacted]
Openness	*open* - [redacted]

RBI/RFC question ID	**A1-GD-28**
Full text from questions	What anti-corrosion measures are included in the design and the maintenance program of the airframe?
	Eurofighter
Answer	[redacted]
Completeness	*fair* – [redacted]
Depth	*fair* - [redacted]
Openness	*moderate* – [redacted]
	F-35A Joint Strike Fighter
Answer	[redacted]

	[redacted]
Completeness	Full – [redacted]
Depth	full – [redacted]
Openness	open – [redacted]
F/A-18F Super Hornet	
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*fair* – [redacted]
Openness	*moderate* - [redacted]

RBI/RFC question ID	**A1-GD-29**
Full text from questions	What are the implications of operating in (1) a saline environment and (2) hot/humid environment for the maintenance program and the service life of the airframe? If any, what system is in place for rating such operating environment and the impact it has on the maintenance program and/or service life?
	Eurofighter
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*low* – [redacted]
Openness	*low* – [redacted]
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*fair* – [redacted]
Depth	*fair* – [redacted]
Openness	*open* – [redacted]
[redacted]	[redacted]
	F/A-18F Super Hornet
Answer	[redacted]
Completeness	*full* – [redacted]

Depth	*fair* – [redacted]
Openness	*open* – [redacted]

RBI/RFC question ID	**A1-GD-30**
Full text from questions	Describe which corrosion inspection methods or anti- corrosion programs are present or foreseen for difficult to inspect areas in the airframe. To what extent are sensors used?
Eurofighter	
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*full* – [redacted]
Openness	*open* - [redacted]
F-35A Joint Strike Fighter	
Answer	[redacted]

	[redacted]
Completeness	*full* – [redacted]
Depth	*full* – [redacted]
Openness	*open* - [redacted]
[redacted]A-18F Super Hornet	
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*full* – [redacted]
Openness	*open*

RBI/RFC question ID	**A1-GD-31**
Full text from questions	Describe the structural margin for weight growth in terms of static strength and as service life.
	Eurofighter
Answer	[redacted]
Completeness	*Full*
Depth	*Fair* : [redacted]
Openness	*Open*
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*Limited* [redacted]
Depth	*Low*
Openness	*Moderate*
[redacted]	[redacted]
	F/A-18F Super Hornet
Answer	[redacted]
Completeness	*Full*
Depth	*Fair*
Openness	*Open*

RBI/RFC question ID	**A1-GD-32**
Full text from questions	What options are available to extend the lives of the service life limiting airframe components? If not, is it foreseen that these will be developed in a structural integrity program and how will this be funded?
	Eurofighter
Answer	[redacted]
Completeness	*Full*
Depth	*Full* : including answer A1-GD-14
Openness	*Very open*
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*Full*
Depth	*Fair* [redacted]
Openness	*Open*
	F/A-18F Super Hornet
Answer	[redacted]
Completeness	*Full*
Depth	*Full*
Openness	*Open*
[redacted]	[redacted]

RBI/RFC question ID	**A1-GD-33**
Full text from questions	Does the airframe contain components that have been subjected to a special life enhancement process to reach the design life?
Eurofighter	
Answer	[redacted]
Completeness	*full* , [redacted]
Depth	*low* , [redacted]
Openness	*moderate* [redacted]
F-35A Joint Strike Fighter	
Answer	[redacted]
Completeness	*full* , [redacted]
Depth	*fair* [redacted]
Openness	*Open* , [redacted]
[redacted]	[redacted]
F/A-18F Super Hornet	
Answer	[redacted]
Completeness	*full* , [redacted]
Depth	*low* , [redacted]
Openness	*Open* , [redacted]
[redacted]	[redacted]

RBI/RFC question ID	**A1-GD-34**
Full text from questions	Describe the (airframe) structural integrity organization from the design to the sustainment phase and the specific roles of the manufacturer, Ministry of Defences and operators.
	Eurofighter
Answer	[redacted]
Completeness	*Fair ,* [redacted]
Depth	*Fair*
Openness	*Open*
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*Fair ,* [redacted]
Depth	*Full*
Openness	*Open*
	F/A-18F Super Hornet
Answer	[redacted]

	[redacted]
Completeness	*Low*, [redacted]
Depth	*Low*, [redacted]
Openness	*Low*, [redacted]

RBI/RFC question ID	**A1-GD-35**
Full text from questions	Is there a load and/or usage monitoring system foreseen (Individual Aircraft Tracking, or fleet wide tracking, Structural health monitoring system, other), If so, describe and specify.
Eurofighter	
Answer	[redacted]

	[redacted]
Completeness	*Full*
Depth	*Full ,* [redacted]
Openness	*Open*
F-35A Joint Strike Fighter	
Answer	[redacted]
Completeness	*Full*
Depth	*Fair ,* [redacted]
Openness	*Open*
[redacted]	[redacted]
F/A-18F Super Hornet	
Answer	[redacted]

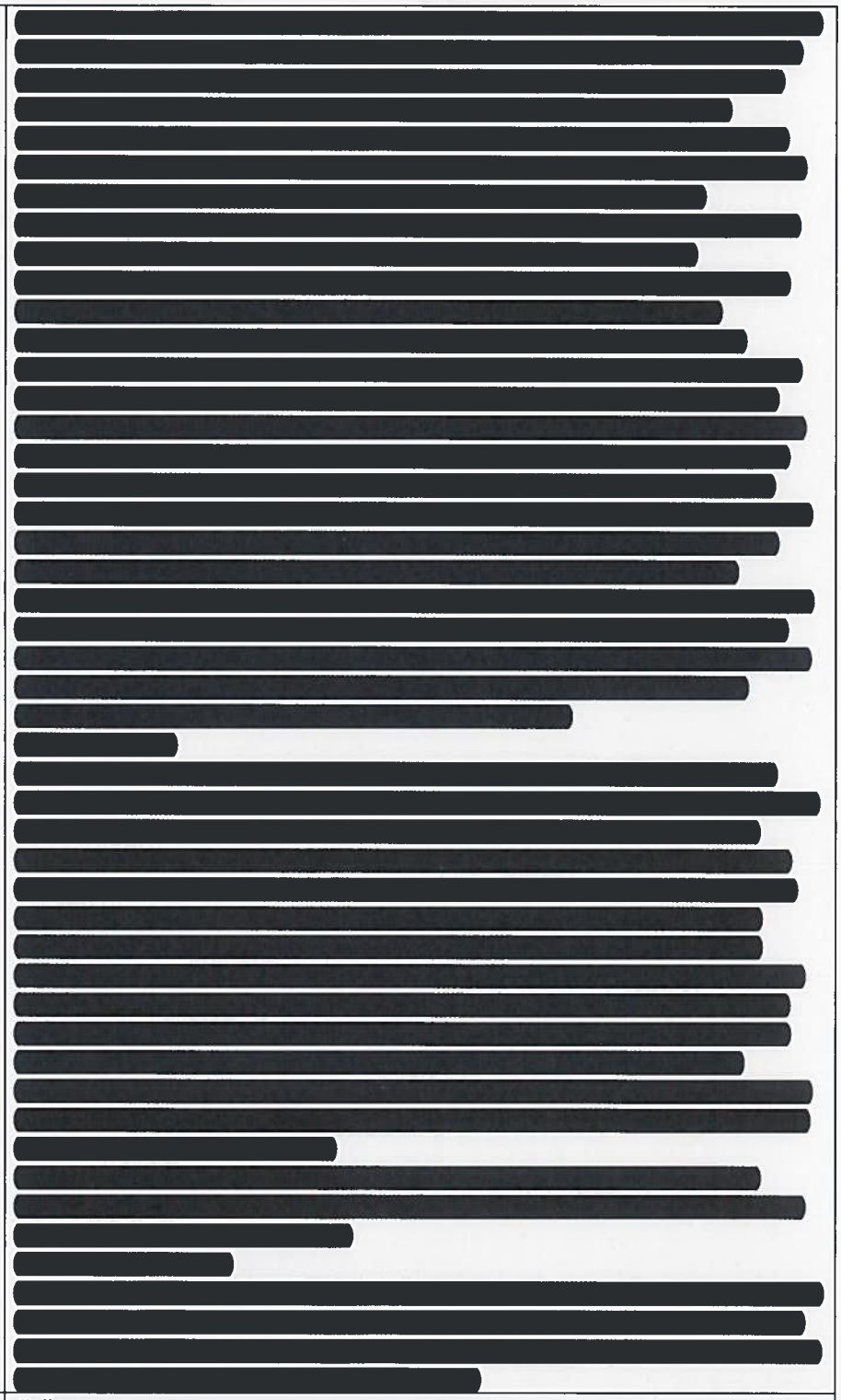
	[redacted]
Completeness	*Full*
Depth	*Full ,* [redacted]
Openness	*Open*

RBI/RFC question ID	**A1-GD-36**
Full text from questions	Describe the structural health monitoring approach applied to the airframe
	Eurofighter
Answer	[redacted]
Completeness	*Full*
Depth	*Full*
Openness	*Open*
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*Full*
Depth	*Fair*
Openness	*Open*
	F/A-18F Super Hornet
Answer	[redacted]
Completeness	*Full*
Depth	*Full*
Openness	*Open*

RBI/RFC question ID	**A1-GD-37**
Full text from questions	Describe how the monitored load and usage data is analytically processed.
	Eurofighter
Answer	[redacted]
Completeness	*Full ,* [redacted]
Depth	*Full-Fair*
Openness	*Open*
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*low,* [redacted]
Depth	*low ,* [redacted]
Openness	*low ,* [redacted]
	F/A-18F Super Hornet
Answer	[redacted]

	[redacted]
Completeness	*Full,* [redacted]
Depth	*Fair*
Openness	*Open*

RBI/RFC question ID	**A1-GD-38**
Full text from questions	Describe how the load and usage data is recorded, stored and how the data is processed to the managing entity.
	Eurofighter
Answer	[redacted]
Completeness	*Fair ,* [redacted]
Depth	*Fair ,* [redacted]
Openness	*Open*
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*Fair ,* [redacted]
Depth	*Fair-Low,* [redacted]
Openness	*Open*
	F/A-18F Super Hornet
Answer	[redacted]

	
Completeness	*Full*
Depth	*Full*
Openness	*Open*

RBI/RFC question ID	**A1-GD-39**
Full text from questions	Describe the organization managing the aircraft service life taking the actual load and usage conditions into account, and how Denmark will be integrated in to this organization.
	Eurofighter
Answer	[redacted]
Completeness	*Full*
Depth	*Fair*
Openness	*Open*
	F-35A Joint Strike Fighter
Answer	[redacted]

	[redacted]
Completeness	*Full*
Depth	*Low*
Openness	*Moderate*
F/A-18F Super Hornet	
Answer	[redacted]
Completeness	*Full*
Depth	*Fair-Low*
Openness	*Open*

RBI/RFC question ID	**A1-GD-40**
Full text from questions	Present the procedure and recent examples of how recorded airframe load and usage data has generated a change in maintenance or the implementation of a modification.
Eurofighter	
Answer	[redacted]
Completeness	*Full*
Depth	*Full,* [redacted]
Openness	*Open*
F-35A Joint Strike Fighter	
Answer	[redacted]

	[redacted]
Completeness	*Full*
Depth	*Fair ,* [redacted]
Openness	*Moderate*
F/A-18F Super Hornet	
Answer	[redacted]
Completeness	*Full*
Depth	*Full ,* [redacted]
Openness	*Open*

RBI/RFC question ID	**A1-GD-41**
Full text from questions	Present the current status of the fighter aircraft fleet fatigue usage overall and divided into nations, dedicated squadrons and specific airframe with specific tasks like training or specific mission objective.
Eurofighter	
Answer	[redacted]
Completeness	*Fair ,* [redacted]
Depth	*Fair,* [redacted]
Openness	*Moderate,* [redacted]
F-35A Joint Strike Fighter	
Answer	[redacted]
Completeness	*Low ,* [redacted]
Depth	*Low*
Openness	*Low ,* [redacted]
F/A-18F Super Hornet	
Answer	[redacted]
Completeness	*Low ,* [redacted]
Depth	*Low*
Openness	*Low*

RBI/RFC question ID	**A1-GD-42**
Full text from questions	For the fight fleet mentioned in A1-GD-41, list the overall fighter aircraft weapons and stores configurations, in relation to fleet fatigue consumption.
Eurofighter	
Answer	[redacted]
Completeness	*Fair* , [redacted]
Depth	*Low*
Openness	*Moderate*
F-35A Joint Strike Fighter	
Answer	[redacted]
Completeness	*Fair* , [redacted]
Depth	*Low*
Openness	*Moderate*
F/A-18F Super Hornet	
Answer	[redacted]

	[redacted]
Completeness	*Fair ,* [redacted]
Depth	*Low*
Openness	*Moderate*

RBI/RFC question ID	**A1-GD-43**
Full text from questions	How does the predicted airframe fatigue usage correlate with the actual usage?
	Eurofighter
Answer	[redacted]
Completeness	*Full*
Depth	*Fair-Low* [redacted]
Openness	*Open*
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*Full*
Depth	*Low*
Openness	*Open*
[redacted]	[redacted]
	F/A-18F Super Hornet
Answer	[redacted]

	[redacted]
Completeness	*Full*
Depth	*Fair,* [redacted]
Openness	*Open*

RBI/RFC question ID	**A1-GD-44**
Full text from questions	Describe which methods and/or tools are used by the manufacturer to evaluate the effect of the differences of the Royal Danish Air Force Projected Usage Pattern with the design loads and usage spectrum on the service life of the Royal Danish Air Force aircraft. And how are these methods validated?
Eurofighter	
Answer	[redacted]
Completeness	*Low* [redacted]
Depth	*Fair - Low*
Openness	*Open*
F-35A Joint Strike Fighter	
Answer	[redacted]
Completeness	*Fair*
Depth	*Fair-Low*
Openness	*Open*
F/A-18F Super Hornet	
Answer	[redacted]

	[redacted]
Completeness	*Full*
Depth	*Fair*
Openness	*Open*

RBI/RFC question ID	**A1-GD-45**
Full text from questions	Describe the technical methods and actual usage data the Royal Danish Air Force as operator will receive to assess the effect of the changes in usage on air vehicle damage tolerance and durability.
Eurofighter	
Answer	[redacted]
Completeness	*Full,* refer to A1-GD-41-A
Depth	*Fair*
Openness	*Open*
[redacted]	[redacted]
F-35A Joint Strike Fighter	
Answer	[redacted]
Completeness	*Full*
Depth	*Fair*
Openness	*Open*
[redacted]	[redacted]
F/A-18F Super Hornet	
Answer	[redacted]

	[redacted]
Completeness	*Full*
Depth	*Fair*
Openness	*Open*

RBI/RFC question ID	**A1-GD-46**
Full text from questions	From the overall collected fleet load and usage data please highlight areas of interest like new future fleet capacities, i.e., integration of new sub- systems or weapons that will affect the predicted fatigue life.
	Eurofighter
Answer	[redacted]
Completeness	*Fair*
Depth	*Low,* [redacted]
Openness	*Open*
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*Fair*
Depth	*Low*
Openness	*Open*
	F/A-18F Super Hornet
Answer	[redacted]
Completeness	*Fair*
Depth	*Low*
Openness	*Open*

RBI/RFC question ID	**A1-GD-47**
Full text from questions	Based on the collected fleet load and usage what changes has been implemented on the airframe on the production line.
	Eurofighter
Answer	[redacted]
Completeness	*Full*
Depth	*fair*
Openness	*Moderate*
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*Full*
Depth	*fair* – [redacted]
Openness	*Open*
	F/A-18F Super Hornet
Answer	[redacted]
Completeness	*Full*
Depth	*Low,* [redacted]
Openness	*Open*

RBi/RFC question ID	**A1-GD-48**
Full text from questions	What specific data and how do the operators provide the fleet load and usage to the organization managing the aircraft fleet fatigue life.
	Eurofighter
Answer	[redacted]
Completeness	*Full,* [redacted]
Depth	*Fair*
Openness	*Open*
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*Full*
Depth	*Fair*
Openness	*Open*
	F/A-18F Super Hornet
Answer	[redacted]
Completeness	*Full*
Depth	*Fair*
Openness	*Open*

RBI/RFC question ID	**A1-GD-49**
Full text from questions	Does each operator have access to the global fleet load and usage?
	Eurofighter
Answer	[redacted]
Completeness	*Full*
Depth	*Fair*
Openness	*Open*
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*Full*
Depth	*fair*
Openness	*Moderate*
	F/A-18F Super Hornet
Answer	[redacted]
Completeness	*Full*
Depth	*fair*
Openness	*Moderate*

RBI/RFC question ID	**A1-GD-50**
Full text from questions	Will the Royal Danish Air Force be able to independently extract, review and act on the results of the individual loads/usage data measurements as collected by the aircraft data collection system.
	Eurofighter
Answer	[redacted]
Completeness	*Full*
Depth	*Fair*
Openness	*Open*
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*Full*
Depth	*Fair*
Openness	*Open*
	F/A-18F Super Hornet
Answer	[redacted]
Completeness	*Full*

Depth	*Fair-Low,* [redacted]
Openness	*Open*

RBI/RFC question ID	**A1-GD-51**
Full text from questions	Provide information regarding current and future airframe risk assessments.
	Eurofighter
Answer	[redacted]
Completeness	*Full*
Depth	*Fair-Low*
Openness	*Open*
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*Full*
Depth	*Low,* [redacted]
Openness	*Moderate-Low*
	F/A-18F Super Hornet
Answer	[redacted]
Completeness	*Full*
Depth	*Fair-Low*
Openness	*Moderate*

RBI/RFC question ID	**A1-GD-52**
Full text from questions	Describe in global terms the content of the Loads and Environment Spectra Survey (L/ESS) development.
	Eurofighter
Answer	[redacted]
Completeness	*Low,* [redacted]
Depth	*Low*
Openness	*Low ,* [redacted]
	F-35A Joint Strike Fighter
Answer	[redacted]

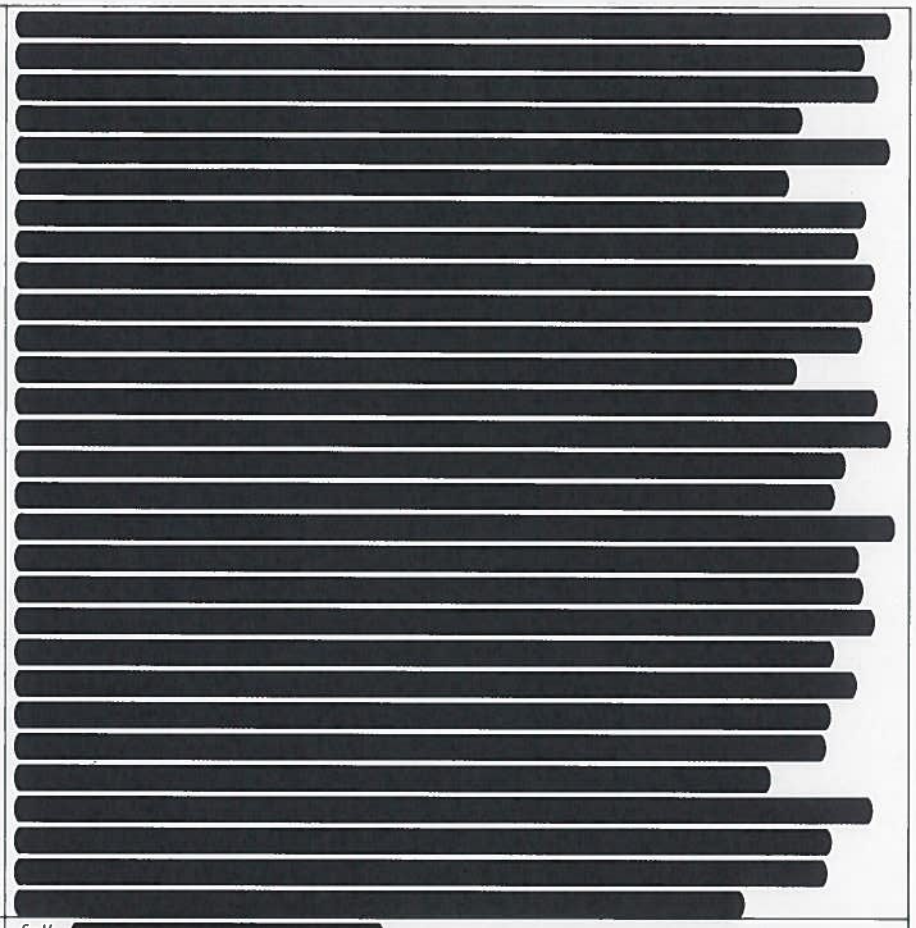
	[redacted]
Completeness	*Full*
Depth	*Fair*
Openness	*Open*
F/A-18F Super Hornet	
Answer	[redacted]
Completeness	*Full,* [redacted]
Depth	*Low*
Openness	*Open*

RBI/RFC question ID	**A1-GD-53**
Full text from questions	Are there any fatigue critical components that have shorter service lives than design service goal and have to be replaced or refurbished during the service life? If so, describe these components.
Eurofighter	
Answer	[redacted]
Completeness	*Full* – [redacted]
Depth	*Full* – [redacted]
Openness	*Very open* – [redacted]
F-35A Joint Strike Fighter	
Answer	[redacted]
Completeness	*Full* - [redacted]
Depth	*Full* - [redacted]
Openness	*open*- [redacted]
F/A-18F Super Hornet	
Answer	[redacted]
Completeness	*Full*
Depth	*Fair* - [redacted]
Openness	*Moderate*

RBI/RFC question ID	**A1-GD-54**
Full text from questions	What techniques will be used for coating removal and re- application? Are the recommended techniques environment-friendly or are special precautions necessary?
	Eurofighter
Answer	[redacted]
Completeness	*full* - [redacted]
Depth	*full* – [redacted]
Openness	*open* – [redacted]
Risk	[redacted]
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*full* - [redacted]

Depth	*full* – [redacted]
Openness	*open* – [redacted]
[redacted]	[redacted]
F/A-18F Super Hornet	
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*full* – [redacted]
Openness	*open* – [redacted]
[redacted]	[redacted]

RBI/RFC question ID	**A1-GD-55**
Full text from questions	Describe the repair strategies for composite structural parts.
	Eurofighter
Answer	[redacted]
Completeness	*full* – [redacted]
Depth	*full* - [redacted]
Openness	*open* -
	F-35A Joint Strike Fighter
Answer	[redacted]
Completeness	*Limited* -
Depth	*Low* - [redacted]
Openness	*Moderate* -
	F/A-18F Super Hornet
Answer	[redacted]

	
Completeness	*full* –
Depth	*full* -
Openness	*open* -

[lviii] Page 39, section 2.1.1 RBI-EF answers
[lix] Page 9, Figure A1-GD-09-C.1, RBI-F-35A answers
[lx] Page 31, Figure A1-GD-09-D.1, RBI-F/A-18F answers
[lxi] Page 79, section 2.3, table 1, RBI-EF answers
[lxii] F-35 Structural Analysis Methods and Design Criteria (SAMDC) document [Reference 2ZSB00001 Rev. E])
[lxiii] F-35 Structures Design Criteria (SDC) document
[lxiv] Table 1, page 82, RBI-F-35A answers
[lxv] Table A1-GD-14-C.1, page 25, RBI-F-35A answers
[lxvi] Page 100, figure 2, RBI-EF answers
[lxvii] Statement on the assumption that the performed missions are representative for the Danish in-service is discussable!
[lxviii] Page 39, Figure A1-GD-23-C.1, RBI-F-35A answers
[lxix] See page 41, RBI-F-35A answers
[lxx] See page 54, RBI-F/A-18F answers
[lxxi] See page 124, figure 1, RBI-EF answers
[lxxii] See page 125, table 1, RBI-EF answers
[lxxiii] See page 146, figure 1, RBI-EF answers
[lxxiv] See page 49, RBI-F-35A answers
[lxxv] See page 52, RBI-F-35A answers.
[lxxvi] See page 150, RBI-EF answers.
[lxxvii] See page 70, RBI-F/A-18F answers.
[lxxviii] See pages 54-161, RBI-EF answers
[lxxix] See page 55, RBI-F-35A answers
[lxxx] See figure on page 56, RBI-F-35A answers
[lxxxi] Table 1, page 82, RBI-EF answers
[lxxxii] See page Annex 1-75 of RBI-F/A-18F answers

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