MASAAG Paper 120

Guidance on Helicopter Operational Data Recording Programmes

Prof S C Reed, Mr G K Terry, Mr B H E Perrett

27 October 2017

DISTRIBUTION

Task Sponsor

Military Aviation Authority - Certification (Structures 3 – Helicopters)

MASAAG Members

Military Aviation Authority – Certification (Structures & Aircraft Design Standards)
Military Aviation Authority – Certification (Structures 1 – Large Aircraft)
Military Aviation Authority – Certification (Structures 2 – Fast Jets & Unmanned Aerial Vehicles)
Military Aviation Authority – Certification (Structures 3 – Helicopters)
Military Aviation Authority – Certification (Structures 4 – Gen)
Military Aviation Authority – Certification (ADS – DS970)
DES DAT- Aircraft Eng Mgr
Prof S Reed, Dstl
Dr M Mishon, 1710 NAS
Mr T Cook, Airbus UK
Mr M Collins, Airbus UK
Mr M Overd, Leonardo Helicopters
Mr K Fisher, BAE Systems
Mr D Patterson, Bombardier Aerospace
Mr S Dosman, Marshall Aerospace
Mr TBN, Marshall Aerospace
Mrs A Mew, QinetiQ
Military Aviation Authority – Certification (Structures 4a - Gen)

Authorship Panel

Mr Sean Perkins, Aviation Requirements
Mr Tim Shucksmith, 1710 NAS
Mr Jeff Day, 1710 NAS
Mr Mike Overd, Leonardo Helicopters
Mr Mike Rees, Leonardo Helicopters
Lt Cdr Mark Hepplewhite, DES Lynx-Wildcat EDA WildcatMech
Mr Mick George, DES P2G PumaEngProjMgr

EXECUTIVE SUMMARY

An Operational Data Recording (ODR) programme is identified in Ministry of Defence (MOD) Regulatory Article 5720(4) – Validating Structural Integrity - as the means by which Operational Loads and Usage Validation of MOD helicopter fleets should be carried out. Currently there is little guidance material (GM) available on how to undertake such a programme.

ODR is one of a range of programmes undertaken to provide Structural Integrity (SI) assurance. The aim of ODR is to validate the in-service operational usage, in terms of frequency of occurrence of fatigue-significant events and their associated severity, using representative flight data, for comparison against the design assumptions and substantiation.

The aim of this paper is to provide guidance on the conduct of an ODR programme. MASAAG Paper 109 – Guidance for Operational Loads Measurement Programmes, the fixed-wing equivalent of ODR, contains useful information on instrumentation, data acquisition and analysis, equally applicable to helicopters and hence, to avoid unnecessary repetition, the focus of this paper is on defining the ODR requirement and identifying the helicopter-specific issues associated with usage validation programmes.

The contribution of the Authorship Panel members, who have provided input and comment during the development and review of this paper, is gratefully acknowledged.

Paper 120 was accepted by the MASAAG membership at the 83rd MASAAG meeting on 26 October 2017.

AUTHORSHIP

Principal Authors:

Prof Steve Reed, Technical Fellow Structural Integrity and Ageing Aircraft, Dstl
Mr Glenn Terry, RAE (Structures)
Mr Brian Perrett, Helisac Ltd

Authorship Panel:

Mr Sean Perkins, Aviation Requirements
Mr Tim Shucksmith, 1710 NAS
Mr Jeff Day, 1710 NAS
Mr Mike Overd, Leonardo Helicopters
Mr Mike Rees, Leonardo Helicopters
Lt Cdr Mark Hepplewhite DES Lynx-Wildcat EDA WildcatMech
DES P2G PumaEngProjMgr

TABLE OF CONTENTS

ABBREVIATIONS

ADD	Analysis Definition Document
AGARD	Advisory Group for Aerospace Research and Development
AGL	Above Ground Level
AMC	Acceptable Means of Compliance
AOB	Angle of Bank
BCAR	British Civil Airworthiness Requirements
CG	Centre of Gravity
CS	Certification Specification
.csv	Comma Separated Variables
DAU	Data Acquisition Unit
DEF STAN	Defence Standard
DO	Design Organisation
DT	Delivery Team
DUS	Design Usage Spectrum
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration
FC	Flight Condition
FCR	Flight Condition Recognition
FDR	Flight Data Recorder
FLS	Flight Load Survey
FTI	Flight Test Instrumentation
FTR	Fatigue Type Record
GAG	Ground Air Ground
GM	Guidance Material
HIGE	Hover In Ground Effect
HOGE	Hover Out of Ground Effect
HUMS	Health and Usage Monitoring System
IAS	Indicated Air Speed
ISAA	Independent Structural Airworthiness Advisor
MAA	Military Aviation Authority
MASAAG	Military Aircraft Structural Airworthiness Advisory Group
MDRE	Manual Data Recording Exercise
Mil Std	US Military Standard
MOD	Ministry of Defence (UK)
NAS	Naval Air Squadron
ODR	Operational Data Recording (Rotary Wing)
OEM	Original Equipment Manufacturer
OLM	Operational Loads Measurement
OSD	Out of Service Date
PT	Project Team
RA	Regulatory Article
RF	Radio Frequency
SI	Structural Integrity
SIWG	Structural Integrity Working Group
SOI	Statement of Operating Intent
SOIU	Statement of Operating Intent and Usage
SOO	Special Order Only
SOR	Statement of Requirement
SPC	Sortie Profile Code
TAA	Type Airworthiness Authority
UK	United Kingdom
US	United States

Intentionally Blank

1 INTRODUCTION

An Operational Data Recording (ODR) programme is identified in Ministry of Defence (MOD) Regulatory Article 5720(4) – Validating Structural Integrity - as the means by which Operational Loads and Usage Validation of MOD helicopter fleets should be carried out. Currently there is little guidance material (GM) available on how to undertake such a programme.

ODR is one of a range of programmes undertaken to provide Structural Integrity (SI) assurance. The aim of ODR is to validate the in-service operational usage, in terms of frequency of occurrence of fatigue-significant events and their associated severity, using representative flight data, for comparison against the design assumptions and substantiation.

The aim of this paper is to provide guidance on the conduct of an ODR programme. MASAAG Paper 109 – Guidance for Operational Loads Measurement Programmes [2] - the fixed-wing equivalent of ODR, contains useful information on instrumentation, data acquisition and analysis, equally applicable to helicopters and hence, to avoid unnecessary repetition, the focus of this paper is on defining the ODR requirement and the helicopter-specific issues associated with usage validation programmes.

Within each of the sections in this paper, the work needed to undertake ODR is identified as ODR Actions - with additional explanation where necessary. The ODR Actions have been collated into a generic statement of requirement (SOR) and this has been reproduced in Appendix A.

Defining the detailed requirements for ODR is one of the key aspects of the programme and may well vary significantly between platforms. The detailed requirements for each ODR programme will depend upon the design and substantiation approach for the platform, the SI history and the existing depth, understanding and validation of the usage and loads. The Design Organisation (DO) has the understanding of the aircraft design, substantiation and broad service usage history (including MOD) necessary to identify where further validation of in-service usage may be required necessary. Therefore, the ODR programme needs to be undertaken either by the DO or in close cooperation with the DO.

Language:

This paper has been written as guidance material (GM) in support of the Structural Integrity Validation sections of RA 5720. Therefore, language appropriate to RA has been used where possible; the term 'shall' has been avoided and 'should' has only been used to reflect existing acceptable means of compliance (AMC). Frequent use of the terms 'need', 'will', 'may' and 'can' has been used as these have no regulatory significance but give some indication of the relative importance of the actions identified. However, the use of such restrictive verbs does affect the flow of the paper and readers are requested to be tolerant of this.

2 ODR DEFINITION

A definition of ODR is provided in the following paragraph:

> **ODR Definition**: Operational Data Recording is an in-flight measurement programme undertaken to validate the in-service usage of a helicopter in terms that relate to structural integrity. Metrics such as the frequency of occurrence of fatigue-significant events and their associated severity are derived, using representative flight data, for comparison against the design assumptions and substantiation evidence.

Where structure is defined in the MAA02 Glossary [3] as:

> **Structure:** Aircraft structure consists of all load-carrying members including wings, fuselage (including some transparencies), empennage, engine mountings, landing gear, flight control surfaces and related points of attachment, control rods, propellers and propeller hubs if applicable and, for helicopters: rotor blades, rotor heads and associated transmission systems. The actuating portion of items such as landing gear, flight controls and doors must be subject to System Integrity Management regulation (RA 5721) as well as Structural Integrity Management regulation.

[REC 1]: *It is recommended that the MAA considers adding the ODR definition in this paper to the MAA02 Glossary [3].*

[REC 2]: *For the purposes of consistency, it is recommended that the MAA includes rotating and stationary rotor controls, power transmission drive shafts and under-slung load attachments to the list of structure for helicopters.*

A glossary of terms used in this paper is provided in Appendix B.

3 ORIGINS AND REGULATIONS

3.1 ORIGINS

ODR was initially introduced as a read across from the fixed wing Operational Load Measurement (OLM) programmes, with the intention to build confidence in the design usage spectrum (DUS), a fundamental building block in the helicopter fatigue substantiation process. Historical reports and papers from the late 1960s [4] and 1970s [5] identify that surveys were being undertaken to validate the usage spectra of a number of helicopter types. As discussed in AGARD-R-674 - Helicopter Fatigue, published in 1979 [6], the UK evolved the usage validation activity to include some limited loads measurement; however, the principle aim of these later programmes was to enhance the knowledge of service loads to improve design input into the next generation of helicopters [7].

3.2 MILITARY REGULATORY AND GUIDANCE MATERIAL

The extant regulatory material for ODR is contained in Regulatory Article 5720 [1] and Defence Standard 00-970 (Def Stan 00-970) Part 1, Section 3, Leaflet 38 [8]. This regulatory material will undoubtedly be updated in future years and hence readers are advised to refer to the most up-to-date sources.

During the drafting of this paper, RA5720 was revised to Issue 5. Issue 5 incorporated many of the amendments proposed in the peer-review draft of this paper and hence these recommendations are no longer required and have been removed from this final paper.

GM on the conduct of Operational Loads Measurement (OLM) programmes, the fixed-wing equivalent of ODR, was developed under MASAAG paper 109 [2]. MASAAG paper 109 also contains useful information on detailed technical aspects such as data acquisition and signal processing, which are equally relevant to ODR programmes and hence these sections have not been repeated in this paper. Although MASAAG paper 109 was written over 10 years ago, it is considered that the technical principles outlined in this paper remain valid today. The prime focus for this paper is providing guidance on defining the ODR requirements and identifying how best to meet those requirements with reference to helicopter-specific issues.

3.3 CIVIL REGULATIONS

For civil certified platforms, the continued airworthiness requirements of European Aviation Safety Agency (EASA) Part M – Continuing Airworthiness Requirements [9] require that airworthiness assurance measures, defined in the Aircraft Maintenance Schedule and Manual, are carried out correctly by competent persons. Furthermore, this requires that regular assessments are carried out into the physical condition, fault trending and configuration so that shortfalls or weaknesses in the airworthiness publications can be identified and corrected across the type. This activity assumes that no changes in usage or configuration have invalidated the assumptions made in the Civil Type Certificate. Consequently, ODR is not a confidence or validating activity that the Civil Regulator requires for Civil Type Certified fleets carrying a Civil Registration.

However, the loads validation requirements in design for civil certified aircraft are no less stringent than those in military codes. For example, EASA CS 27.571 (Small Rotorcraft) [10] and EASA CS 29.571 (Large Rotorcraft) [11] both require in-flight measurements to determine the fatigue loads or stresses.

4 ORGANISATION AND TIMING

4.1 ORGANISATION

<u>ODR Action 1:</u> *Establish ODR Programme Management and Specialists' Groups at the outset of the ODR programme.*

Experience has shown that such a group, chaired by the Delivery Team (DT) (formerly Project Team (PT)), reporting to the Structural Integrity Working Group (SIWG) and including representation from the DO, DT, Independent Advisors and the ODR Project Officer (responsible for day-to-day running of the programme) needs to be established at the outset of the programme. Additionally, an ODR Specialists' Group, reporting to the ODR Programme Management Group, will need to be formed to determine and manage the in-depth technical aspects of the ODR Programme. This group will usually include core representatives from the DO's Specialists and the Independent Structural Airworthiness Advisor (ISAA).

It is assumed in the remainder of this paper that the ODR Programme Management and ODR Specialist Group will be the organisations within which the technical and logistical aspects of the programme are decided. In the interests of brevity and to preserve the flow of the paper, this has not been repeated within each section.

As was identified in the introduction, the Design Organisation (DO) has the understanding of the aircraft design, substantiation and the service usage history (MOD and wider) required to identify where validation of in-service usage may be necessary. Therefore, the technical aspects of the ODR programme will need to be undertaken either by the DO, or in close cooperation with the DO.

4.2 TIMING

RA5720(4) Issue 5 [1] identifies that:

- ODR should be undertaken for a new Air System, commence once usage is stable in service or no later than 3 years after entry to service
- The requirement for repeat ODR should be reviewed every 6 years by the TAA (concurrent with a triennial SOIU review)
- ODR should be considered following a major change in usage, major modification of life extension

These revised timings (when compared with Issue 4 of RA5720) align with the timings recommended in the peer-reviewed draft of this paper and hence no further recommendations are made here.

5 AIMS AND REQUIREMENTS DEFINITION

The identification of clear and concise aims, which are in turn developed into requirements, is pivotal to the success of any technically complex programme and ODR is no different. Guidance on defining the aims, the detailed requirements and developing a methodology to meet these requirements is outlined within this section. It is assumed in this paper that the ODR programme being planned is the first ODR to be undertaken on the platform. For subsequent ODR programmes much of this initial work may have already been undertaken and hence the scope for subsequent programmes may well be significantly reduced.

5.1 AIMS

ODR Action 2: *Establish the primary and any secondary aims of the ODR programme and gain endorsement of the Structural Integrity Working Group (SIWG) / Type Airworthiness Authority (TAA). The primary aim of an ODR programme is:*

- *To validate the in-service operational usage, in terms of frequency of occurrence of fatigue-significant events and their associated severity, using representative flight data, for comparison against the design assumptions and substantiation*

The secondary aims, which will depend upon the existing usage and loads validation evidence available and SI history of the platform, may include but are not restricted to the following:

- *To validate fatigue spectra for critical structural features and their associated lives or inspection periodicities*
- *To measure or validate loads or strains for critical structural features*
- *To identify or measure particularly damaging events, conditions or manoeuvres*
- *To provide data to support investigations of structural issues or as part of a life extension programmes*
- *To provide non-structural usage information*

The primary aim is clear but identifying the requirements and the methodology needed to meet this aim is significantly more challenging and this is discussed in the following sections. Some secondary aims may have been identified prior to the start of ODR programme, from in-service failure investigations for example. However, further secondary aims may also be identified during the requirements definition study, which is discussed below.

5.2 REQUIREMENTS DEFINITION STUDY

ODR Action 3: *Undertake a Requirements Definition Study to identify the detailed ODR requirements, derived from primary and any secondary aims, and the proposed methodology for meeting those requirements.*

The following sections contain guidance on how the aims of the requirements definition study might be met.

5.3 PRIMARY AIM – VALIDATE IN-SERVICE USAGE AGAINST DESIGN ASSUMPTIONS AND SUBSTANTIATION

ODR Action 4: *Detail the fatigue substantiation process used for critical structural features, including development of the Design Usage Spectrum (DUS) and the use of loads validation undertaken within the Flight Loads Survey (FLS).*

The information needed to undertake ODR Action 4 will largely be already available to the DO and it is expected that much of it would be found in a Fatigue Type Record (FTR) and supporting or equivalent documents. However, it may not be available in an easy-to-digest format and therefore ODR Action 4 may largely be a task of collating existing information from a variety of DO sources and reports and will need to be either undertaken by the DO or will require engagement with DO specialists. However, this step is fundamental to identifying where and how to focus the assurance efforts of the ODR programme.

5.3.1 FATIGUE SUBSTANTIATION PROCESS

Irrespective of fatigue design methodology (safe life, fail safe or damage tolerance), or the code to which a helicopter has been certified, the DO will have made assumptions of the likely service usage, based upon a range of inputs including: customer requirements, the intended role or roles for the aircraft, design standards, aircraft performance, previous experience and modelling. These assumptions will then be used to assemble the design usage spectrum or spectra (DUS). The DUS is a fundamental building block in the fatigue design process and includes the time spent in various ground and flight conditions (FC), (e.g. transition to hover or hover in ground effect (HIGE)), anticipated occurrence of low-frequency events (e.g. rotor start-stop cycles and ground-air-ground (GAG) cycles) and physical parameters such all up weight and centre of gravity distribution. Example DUS, from several design standards are reproduced in Appendix C for reference.

The DO will then identify the low-frequency and the high-frequency loading events, as appropriate for each critical structural feature in the mechanical and dynamic / rotating components, airframe and the landing gear. These will be associated with fatigue damage rates, obtained from detailed material, component and full-scale analysis and fatigue testing evidence.

The DO will also have undertaken a comprehensive flight loads survey (FLS) programme. Here, instrumented development aircraft (far beyond any potential in-service instrumentation fit) will have been used to validate and refine the loading assumptions for these critical structural features. The FLS will have been undertaken in prescribed flight conditions, across the range of weight and centre of gravity positions and progressively through the flight envelope until the extremes of manoeuvre capability are reached.

The detailed approach in formulation and validation of the DUS and in substantiating the fatigue design approach may vary between DOs and, potentially, for different platforms within a DO, depending upon the historical design approach. However, the process will still be based upon detailed analysis, testing and measurement and will have evolved over many years; it will also contain the conservatism considered necessary by the DO to assure structural integrity at a design-specified minimum level of safety.

For a platform already in service with another user, where the MOD is not the launch customer, it is highly likely that the DO will have reviewed the MOD Statement of Operating Intent (SOI) against the DUS during the introduction to service. The DO may have also undertaken additional structural analysis, testing or loads surveys after the initial design, in response to in-service events or new customer requirements. Such information will be highly relevant to the working group defining the scope of the ODR programme.

Therefore, developing the method to facilitate comparison of the in-service usage with the DUS, in terms of occurrences and severity, is a key aspect of the ODR programme. The aim is to ensure that the basis of DUS and, the associated component fatigue damage rates, is fully understood and to determine how, and for which aspects therein, comparisons can be made with in-service usage.

5.3.2 IDENTIFICATION OF VALIDATION METHOD AND DATA CAPTURE

ODR Action 5: *Identify the data capture requirements and method necessary to validate in-service usage against the DUS.*

The following examples are used to illustrate possible approaches that might be taken to identify the extent of data capture necessary to validate in-service usage against the DUS and the methods that may need to be employed. The DUS will contain a percentage of time spent and the number of occurrences in a range of flight conditions. One of these conditions may be hover out of ground effect (HOGE). It is reasonable to assume that a method either already exists or could be developed to recognise the HOGE flight condition for in-service flying, using either existing instrumentation or additional instrumentation (instrumentation is discussed later in this paper) and appropriate flight condition recognition algorithms (again discussed later in this paper). However, it is essential that the DO assumptions used to describe HOGE and its boundaries with other FC are fully understood and replicated in any FC recognition approach. For HOGE these might include parameters such as: height above ground, groundspeed, airspeed, climb rate and yaw rate boundaries and a minimum time limit to establish a hover condition. The important point is that the approach taken in design and substantiated by the DO in defining these flight conditions is understood and that the data capture requirements to validate these conditions are clearly identified accordingly.

Autorotation can be used as an example to illustrate an approach to validation of the severity aspects of the DUS. The severity of an autorotation for different components might be identified by the peak descent rate during the autorotation, the rate of re-application of torque or the vertical deceleration in the recovery and the associated aircraft mass and configuration, for example. Loads will have been associated with the driving parameters for affected components within the design assumptions for autorotation (with suitable conservatism) and validated during the FLS programme. Therefore, with either existing or additional instrumentation it would be possible to identify, from in-service data, the percentage time in autorotation, the number of occurrences per flying hour and the magnitude of the corresponding driving parameter - as an indication of autorotation severity. If applied across the DUS, such an approach outlined above could meet the requirements of ODR Action 5.

5.3.3 IDENTIFICATION OF SHORT LIFE OR USAGE-SENSITIVE CRITICAL STRUCTURAL FEATURES

ODR Action 6: *Identify critical structural features with either short fatigue lives or ones with fatigue lives or inspection regimes likely to be highly sensitive to credible changes in usage.*

Identifying critical structural features with either short fatigue lives or ones with fatigue lives or inspection regimes likely to be highly sensitive to credible changes in usage is largely an information collation task. Data on critical structural features with short fatigue lives will be available from the FTR or equivalent fatigue substantiation documents. Identification of critical structural features likely to be highly sensitive to changes in usage may be a little more challenging and will depend upon what sensitivity analysis the DO has already undertaken and how conservative the DO's design assumption were initially. Component lives are likely to have been assessed in design against a range of spectra covering likely roles and hence sensitivities to changes in usage may have been identified accordingly. However, to use a simplified example, a significantly higher proportion of time spent in low-speed manoeuvring could increase the fatigue damage accrual for the tail-rotor system; sensitive critical structural features within that system may then be identified accordingly.

5.3.4 IDENTIFICATION OF SHORTFALLS IN LOADS VALIDATION

ODR Action 7: *Identify any shortfalls in the loads validation undertaken with the FLS or other programmes (possible source of secondary ODR aims).*

Identifying any shortfalls in the loads validation undertaken with the FLS or other programmes is included to allow potential issues either already known or identified during the ODR definition study to influence the requirements for the ODR programme. One would expect the FLS to have thoroughly covered the loads validation requirement. Nevertheless, known shortfalls, modifications, changes in operations or cumulative weight increases, for example, may require supplementary loads validation work. However, it is important to remember that any loads measurement aspect of an ODR programme will be significantly less comprehensive in terms of instrumentation than was undertaken during the substantiation FLS.

5.4 SECONDARY AIMS

As already discussed, the secondary aims of an ODR programme may well vary significantly between platforms, depending upon the existing usage and loads validation evidence and the SI history of the platform. Secondary aims can evolve during the review of primary aims and also as a result of analyses applied during the course of the ODR programme. Often these secondary aims will be interrelated and hence the list below has been produced to provoke thought as to what may be appropriate for each programme, rather than to provide a definitive list of secondary aims. It is also important to identify that the potential secondary aims detailed below may necessitate an element of directed flying within the ODR programme, to relate measurements to particular events, conditions or manoeuvres.

5.4.1 VALIDATE FATIGUE SPECTRA, LIVES OR INSPECTION PERIODICITY

Prior knowledge, or issues identified whilst developing the programme primary aims, may indicate the need to refine or validate particular fatigue spectra, fatigue lives or inspection periodicities. An ODR programme may provide the vehicle for meeting such an aim.

5.4.2 MEASURE OR VALIDATE COMPONENT LOADS OR STRAINS

Similarly, evidence, or lack of evidence, may identify the need to measure or validate loads or strains in particular components. Significant shortfalls in the FLS programme or significant modifications in service, for example, may generate loads or strain measurement requirements.

5.4.3 IDENTIFY OR MEASURE DAMAGING EVENTS, CONDITIONS OR MANOEUVRES

In-service experience, or information from SOIU reviews or other platform experience, such as analysis of display flying for example, might identify the need to gain a greater understanding of particular events, flight conditions or manoeuvre. For example, the entry condition into a particular display manoeuvre may be flown differently than was assumed in design.

5.4.4 PROVISION OF DATA TO SUPPORT INVESTIGATIONS OF LIFE EXTENSION

Life extension requirements, either for individual components or for the complete platform, may necessitate the capture of additional in-service structural usage, loads or strain data to support revisions of lives or inspection regimes (see RA5724 and RA5725 [12, 13]).

5.4.5 PROVISION OF NON-STRUCTURAL INFORMATION

An ODR programme, particularly if additional instrumentation may be required, may provide an opportunity to capture necessary non-structural data, e.g. temperature measurements for critical polymers such as fuel seals or hydraulic system pressure.

5.5 REQUIREMENTS AND APPROACH

5.5.1 GENERATE REQUIREMENTS

<u>ODR Action 8</u>: Generate ODR requirements from primary and secondary aims.

The high-level aims discussed above will need to be converted into detailed ODR requirements, most likely for each critical structural feature. In each case the method to be used to validate the usage assumptions and to meet any secondary aims will need to be specified along with the associated data requirements. To use a simplistic example, if a component life was purely driven by rotor start/stop cycles then the ODR data requirement would be the capture of rotor start/stop cycles. However, for many components there will be a number of fatigue drivers and hence the data requirements are likely to be significantly more complex in such cases.

5.5.2 EXISTING DATA SOURCES AND ADDITIONAL DATA CAPTURE REQUIREMENTS

ODR Action 9: Review existing aircraft data systems and identify additional data capture requirements.

There are a number of potential sources of existing data that could be used to support an ODR programme. These might include:

- Manual or automated flight records
- Health and Usage Monitoring Systems / Flight Data Recorder (HUMS/FDR)
- Manual Data Recording Exercises (MDRE)
- Statement of Operating Intent and Usage (SOIU)
- Flight Loads Surveys (FLS)
- Previous ODR programme results

Data from manual flight records (MOD Form 724/725 or civil flight or technical log equivalents) or automated flight records will be required for all ODR programmes. This will be to identify the basic parameters of the data captured, such as sortie duration and Sortie Profile Code (SPC), and to ensure that the data captured are representative of the total data set. However, it is also useful to identify at the outset whether changes to the recorded data could be used to support ODR validation requirements. For example, the addition of recording start-up weight and / or shutdown weight (information already available to the aircrew) would be a minor change to the recording requirement but could significantly reduce the usage validation task on a platform where it is currently not recorded.

Where a platform is fitted with a HUMS/FDR or similar data system, which is increasingly the case for helicopter fleets, it is likely that a significant proportion of the ODR data capture requirements could be met from the existing HUMS/FDR dataset. In this context a HUMS/FDR dataset would be expected to include speeds, accelerations, angular rates, altitude, heading, control positions and rotor and engine parameters. A review of the HUMS/FDR parameters against the ODR requirements would also need to identify that the data were fit for purpose by considering the source, sample rate, signal conditioning and serviceability. Useful guidance on this aspect from the Federal Aviation Administration (FAA) is provided in [14]. Additionally, EUROCAE ED112 identifies FDR system requirements [15].

MDRE have been used on a number of platforms to validate usage and any information from previous MDRE may provide valuable information and identify areas for further investigation. However, MDRE may have significant limitations, particularly when compared with capturing data from fleet wide HUMS/FDR fits. Datasets tend to be small, they often take a prolonged period to capture data and they are only practicable for a limited range of helicopter fleets, where a crewman or passenger recording data can be accommodated.

Previous ODR programme results are a valuable source of information to assist with defining the next programme. Any information regarding unexpected findings, shortfalls in data capture and the programme conclusions and recommendations will help focus on particular components or usage profiles.

Where data capture requirements cannot be met by existing fleet wide data systems or by manual recording, other options need to be considered. Where there is still a FLS capability for the platform then a FLS aircraft could provide a very efficient and cost-effective method for supporting the ODR programme. For loads validation this would be a preferred approach as the FLS instrumentation fit is likely to be far in excess of what is practicable for an in-service aircraft.

Where such options do not exist then additional data capture requirements, necessary to meet the ODR programme requirements, will need to be identified.

5.5.3 REQUIREMENTS DEFINITION STUDY REPORT

ODR Action 10: Collate requirements and proposed approach into a Requirements Definition Study Report and gain SIWG endorsement.

The outputs from ODR Actions 1-10 need to be collated into a Requirements Definition Study Report, endorsed by the SIWG, in which the aims and the programme and data capture requirements, are clearly identified.

5.6 ODR CATEGORY

The complexity of the ODR programme will be governed by both the requirements and the existing data capture systems fitted to the fleet and may change during the course of the programme. ODR programmes will fit into one of three categories:

- Category 1 – The existing flight data set is adequate to meet ODR requirements
- Category 2 - Instrumentation or monitoring systems are required in addition to the existing flight data set to meet ODR requirements
- Category 3 - No existing flight data system. Instrumentation fit required to meet ODR requirements

The generic planning considerations and specific considerations for each ODR programme category are discussed within the following sections. For many ODR programmes, a phased approach to meeting the requirements may be worthy of consideration.

It is important to highlight that the basic usage data might be captured and analysed and used to inform the extent of any further requirement for a more detailed and more costly programme. The decision as to whether a Category 1 or Category 2 approach is required may necessitate detailed analysis of the structural risks. For example, the DO might compare usage analyses from existing instrumentation systems with their loads analysis from the lifing programmes to identify any small margins in conservatism. Such an approach could be used to identify whether a limited strain or loads survey might be required to safeguard selected features, where usage margins may have been eroded.

6 DATA SOURCES

Within this section of the paper, the use of existing and additional data sources to meet ODR requirements are discussed for Category 1, 2 and 3 ODR programmes. In each case generic ODR Actions are identified.

6.1 EXISTING DATA SOURCES

All Category of ODR programmes will utilise some data from existing sources. Even for an aircraft with no on-board data systems, manual flight records will be required for the ODR programme. The likely existing data sources, along with considerations for ODR, are discussed in the following sections:

6.1.1 FLIGHT RECORDS

ODR Action 11: Review existing F724 / F725 / technical log records for content, quality and accessibility.

Manual or electronic flight records (F724 / F725 / Tech Log) will be required for all ODR programmes. The data will be required to confirm that the sample of data used for ODR is representative of overall service usage or to weight the ODR data to reflect in-service flying. In addition, ODR data will be used to validate the manual records (e.g. recording of flying hours). Previous usage validation programmes have identified shortfalls in the extent, quality and the accessibility of the data. Therefore, it is essential that a review of the flight record data is undertaken to ensure that required information is captured (the example of lack of all up weight data recording was identified earlier in this paper). Also that the quality of the data are acceptable and that the data are available in an accessible media and format (e.g. electronically). Where shortfalls are identified, remedial action will need to be initiated promptly to support the ODR programme.

6.1.2 EXISTING ELECTRONIC FLIGHT DATA SYSTEMS (HUMS/FDR)

ODR Action 12: Review existing HUMS/FDR data for suitability, quality and accessibility.

Category 1 and 2 ODR programmes will rely wholly or partially upon existing electronic flight data systems, described as HUMS/FDR for convenience in this paper. The parameters required will have been identified in the Requirements Definition Study Report. However, a more detailed review of the available data is necessary to identify the suitability, quality and accessibility of each of the parameters and outputs from the dataset. In this scenario a review of the suitability would include ensuring the bandwidth, sample rate and resolution of the data were sufficient for its intended use. This information should be available in the system interface control document, or equivalent. It should also be noted that the HUMS/FDR system may also routinely report data that when collated can be invaluable in an ODR programme, such as ground-air-ground cycles or torque exceedence occurrences and values.

A review of the quality of the HUMS/FDR data is necessary to identify expected data loss rates and the likely frequency of anomalies in the data. No data system is perfect. There will always be some anomalies in the data and hence it is essential that an initial assessment of the quality of the data is made to identify what measures are likely to be necessary to ensure erroneous data are removed or reconstituted before analysis. It is also necessary to identify any individual data sources that may not be fit for purpose. There is no substitute for experienced eyes looking at data and it is expected that this review would include identifying data limits against expectation and plotting samples of data for visual review (i.e. does the data look like it is expected to look). Experience has shown this to be good investment. It is considered unwise to rely upon an annual output check of the FDR system alone in undertaking such a review.

Data accessibility can, and has been, a significant issue. There are existing platforms in service fitted with HUMS/FDR where the arrangements in place for data download and initial ground station processing are inadequate to support an ODR programme. Therefore, the importance of ensuring the HUMS/FDR data can be accessed in a format usable within the ODR programme and in a timely fashion cannot be understated. Again, where shortfalls are identified it is essential that remedial actions are implemented promptly. For many current platforms HUMS/FDR data are dispatched to 1710 Naval Air Squadron (NAS). For these platforms and others, 1710 NAS has significant experience in handling these data types and is a valuable source of advice.

It is also noteworthy that most of the HUMS/FDR systems in existence hold data in proprietary formats and hence translation software may be required, if not already available. The majority of the ground processing systems have a facility to output data from the source proprietary binary format into a machine readable comma separated variables (.csv) format. However, this may not be a practicable solution for a 25 to 50 hour FDR data block sampled at 16 samples per second and with over 1000 parameters in the FDR date set.

6.2 ADDITIONAL DATA SOURCES – CATEGORY 2 PROGRAMMES

ODR Action 13: *Identify data sources and instrumentation to meet additional Category 2 programme requirements.*

For a Category 2 programme, it will be necessary to identify the additional data sources and the instrumentation needed to meet the ODR programme requirements. The extent of this requirement will vary between programmes. The most likely scenario is that the bulk of the data, used for validation of usage will be captured from the fleet wide fit of HUMS/FDR. Thereafter, a smaller data set will then be required from the additional data source, most likely driven by any loads/stress/strain data capture requirements but may include torque meters, load cells or motion sensors for example. As already discussed, FLS will always be the better instrumentation solution for capturing or validating loads but, particularly when an aircraft has been in-service for some time, this may no longer be an option.

It is not practical to cover all the instrumentation options within this paper and hence some key generic considerations have been identified in the following sections, using strain gauge instrumentation as the example.

It is assumed that a typical intrusive Category 2 ODR instrumentation fit would be undertaken using a DO modification. Where the instrumentation requirement coincides with a previous monitoring location (e.g. from FLS), it will always be preferable to replicate the original instrumentation approach, including calibration requirements, as closely as possible to allow direct comparison with previous data. Alternatively, replication of fatigue test instrumentation for direct comparison may also be appropriate for many structural features.

Where the instrumentation requirement is new, it is likely that detailed modelling of the components in question will be required, if not already available, to identify the preferred instrumentation location. Issues such as areas of acceptably low strain gradient, multi-axial loading actions, access requirements and gauge protection will need to be considered. Moreover, the design of the instrumentation installation itself will often be complex, with the need to use slip-rings or radio frequency (RF) transfer for rotating components, establish wiring runs for twisted shielded pairs and power supplies, and identification of locations for data acquisition units, for example. For smaller helicopters in particular, space considerations can be significant and it is essential that any additional instrumentation does not impair the intended data capture requirement by limiting the operational use of the aircraft.

In addition, where the data requirement is in terms of loads, rather than stresses or strains, a loads calibration approach will need to be developed. Achieving a reasonable load range for calibration, without introducing damage into the component, may be a particularly challenging aspect of this task for some critical structural features.

As data acquisition and data transmission technologies evolve quickly, a review of appropriate equipment for additional instrumentation is worthwhile. Experience of instrumentation from other ODR/OLM programmes and the use of common equipment may also be useful. However, a more significant consideration is the use of systems that the DO has experience of and confidence in, as this can significantly reduce programme risks.

The decision as to the number of aircraft to be fitted with additional instrumentation for a Category 2 ODR programme will depend upon a range of factors. For example, where representative in-service data are required and there are capability-driven fleets within fleets, instrumentation for each sub-fleet may be necessary. Conversely, if the requirement is to supplement the loads data base with discrete data points, this may be achievable with a dedicated mini-FLS programme using a relatively small number of scripted flights, rather than from in-service representative flying. Where in-service representative data are required, it is unwise to instrument only a single aircraft in the fleet.

Irrespective of the detail, experience has shown that the time and cost for the design, fit, data capture and analysis of ODR programmes requiring additional instrumentation has often been significantly underestimated. Moreover, even short–term ODR programmes last considerably longer than was ever envisaged at the outset and longer-term support of the installation needs to be considered. Therefore, it is valuable to compare planned approaches with other ODR programmes, either underway or completed, as a sanity check.

6.3 DATA SOURCES – CATEGORY 3 PROGRAMMES

<u>ODR Action 14:</u> Identify data sources and instrumentation to meet additional Category 3 programme requirements.

For a Category 3 programme, it will be necessary to identify the data sources and the instrumentation needed to meet the requirements. For future helicopter fleets, it is increasingly likely that aircraft will enter service with a HUMS/FDR system of some kind [14, 15] due to enhanced regulation in both the civil and military environments and the level of standard fit supplied by helicopter manufacturers. However, there are a number of legacy platforms that will fall into this category for many years to come.

As with all programmes the challenge is to balance the requirement against the cost and time issues and the importance of being able to focus on the key issues. Therefore, for Category 3 ODR programmes, a phased approach may be a cost effective way of meeting the requirements. Phase 1 of the programme might be focussed upon capturing basic usage validation information for the fleet, such as occurrences and time in flight condition, with further phases being detailed as a response to the analysis of the usage information and following a similar approach as that identified for Category 2 additional requirements. For example, if a significantly greater proportion of flying was in hover, spot turns and low-speed flight than was assumed in the design spectra, then further phases of work might be concentrated on the fatigue substantiation for those components affected by such conditions (e.g. tail rotor). Such an approach is outlined in recent FCR case studies [16, 17]. In this example, a low-cost, minimal intrusion, data acquisition system, capturing a minimum data set for flight condition recognition, was used to understand the occurrences and time in flight condition for a training fleet, which had no existing data system. However, the time and cost of fitting even a minimum system, such as that described in [16, 17], should not be underestimated.

7 INSTALLATION

For Category 2 and 3 ODR programmes, some instrumentation installation will be required. As with the rest of the programme, it has been assumed in this paper that the DO is either undertaking the work under a DO modification programme or is closely involved in the process, where 3rd party organisations are undertaking the work. It is important to recognise that the DO retain a team of instrumentation engineers who support data gathering systems and preserve legacy data for the platform. The areas covered in the following sections are those where experience has shown that additional ODR-specific guidance may be useful.

7.1 MODIFICATION APPROACH

ODR Action 15: Where additional instrumentation is required for an ODR programme, make available detailed drawings, sketches and photographs (before application of protective treatments) to support in-service fault diagnosis.

A retrospective fit ODR system for Category 2 or 3 programmes can have a multitude of interfaces with existing aircraft systems, such as power supplies, data buses, instruments, wiring runs. Moreover, the system can have effects on mass and centre of gravity and hence the use of formal DO-approved modification processes is crucial. Additionally, where only a handful of aircraft will be modified the Special Order Only (SOO) modification processes may be applicable.

Service Modifications (formerly termed Special Trial Fits or Service Engineered Modifications) have been used successfully in the past to introduce short-term data capture installations or to facilitate small changes to existing DO-approved modifications, for expedience. However, this needs to be incorporated into the drawing set by a DO cover modification later to prevent a loss of configuration control.

Detailed drawings, photographs and sketches of the instrumentation locations, arrangements and wiring (with unique identifiers on the structure to ensure correct identification) can be invaluable throughout the ODR programme. Photographs taken before protective coatings have been applied have also proven extremely useful during subsequent fault diagnosis in-service.

7.2 CALIBRATION

ODR Action 16: Where ODR is reliant upon existing sensors (Category 1 and 2), undertake a review of the calibration of these sensors to ensure the calibration approach is adequate for the ODR programme.

ODR Action 17: Where additional instrumentation is installed for an ODR programme (Category 2 and 3), develop and implement a calibration plan for all additional sensors.

Calibration can be undertaken using various methods and it is imperative that the calibration tests performed during installation and post installation are appropriate for the intended use of the data. Some of the more commonly encountered calibration methods, used primarily to associate loads to fatigue tests or to stress models, are discussed in MASAAG Paper 109 [2].

The calibration requirements that may apply to the ODR installations may include the following:

- Setting of physical datum values
- On-aircraft strain gauge load calibration
- Off-aircraft loads calibration
- Strain gauge correlation to fatigue test damage
- Strain gauge airborne and on-ground calibration
- Other instrumentation calibrations

Load calibrated strain gauging applied to removable components, especially those that can be replaced by maintainers at Forward, can be used as a good example of the type of issues that may need to be addressed by the calibration approach. The calibration coefficients for the strain gauged component will need to be recorded alongside component serial number, instrumentation details and accompanied by a date of recommended recalibration, for both controlled storage and in-service use. Moreover, the mechanism for updating of calibration coefficients into any data acquisition systems, ground stations or remote analysis systems also needs to be addressed.

Other dedicated ODR instrumentation requiring calibration may include: accelerometers, motion sensors (such as linear variable differential transformers / rotary variable differential transformers) and gyros.

7.3 CONFIDENCE CHECKS

<u>ODR Action 18:</u> Where additional instrumentation is installed for an ODR programme (Category 2 and 3), undertake confidence checks during and at the end of the installation process.

Experience has shown the value in undertaking and reporting upon a series of confidence checks during the installation and calibration phases of the programme and before flight test. These checks are designed to ensure that all instrumentation is correctly identified, wired and responds in the correct sense with outputs of reasonable magnitude. Where practicable, these checks can include comparison between theoretical and measured ground loading cases.

These checks can be very simple actions such as recording strain gauge outputs for full fuel and zero fuel conditions, physical flexing of components, turning an accelerometer up-side down and checking the output provides a good confidence in the correct wiring and the calibration equations.

7.4 FLIGHT TEST REQUIREMENTS

<u>ODR Action 19:</u> Where additional instrumentation is installed for an ODR programme (Category 2 and 3), produce and implement flight test requirements.

Specific manoeuvres or flight conditions may need to be specified for inclusion in the post-installation flight test to gain confidence in the ODR data. The degree of strip and rebuild required for all but the simplest ODR installation is such that a flight test is most likely to be undertaken before release of the aircraft to the operating units. The flight test schedule is prescriptive and therefore, where necessary, additional specific flight conditions or manoeuvres can be added to establish confidence in ODR data. It may be practicable to include the validation or scripted flight schedules in with the flight test requirement. This use of validation or scripted flights is discussed further in Section 9.4.

8 PROGRAMME MANAGEMENT

This section covers a range of ODR-specific issues, grouped under programme management, where experience has shown that additional guidance may be necessary.

8.1 DATA CAPTURE REQUIREMENTS

ODR Action 20: Identify the data capture requirements (e.g. flying hours, sortie distribution) for the ODR programme.

The following factors are among those that will influence the data capture requirements for the ODR programme:

- Programme aims
- Fleet size and disposition
- Annual flying task and achievement
- Range of roles undertaken / sortie types flown
- Fleet-within-fleet issues (capability and structural build standard)
- Seasonal and syllabus variations (at least one year's data)
- Cost
- Attrition

Although there is no defined method for ascertaining the data capture requirements at the outset, experience has shown that, where fleet-wide usage is to be validated, a 1000-flying-hour programme, with at least 10 flying hours in each SPC, covering at least one year's representative flying, is a good starting point, for planning purposes. The requirement can then be adjusted based upon the above factors to define the appropriate data capture for each programme. The aim is to ensure sufficient coverage across all flying and to account for reasonable variation within each sortie type. Where discrete elements of the programme are being satisfied, such as supplementing loads data points in a mini-FLS, a much reduced data capture requirement is more likely.

8.2 DATA MANAGEMENT PLAN

<u>ODR Action 21:</u> Develop and implement an ODR data management plan.

Data management is one of the key issues to address early in the development of an ODR programme. The aim is to maximise the data capture while minimising the burden to the front line. This can be achieved by ensuring that there is a clear ODR data management plan, where all functionality is identified, alongside defined and practicable responsibilities.

The maximum use of existing data transfer systems will minimise the burden on the front line. Where the introduction of additional data transfer systems is necessary, it is essential that the systems are fit for purpose and demonstrated accordingly. Training is discussed later in this section.

Limited ground station functionality has impaired a wide range of aircraft data capture programmes in the past; hence it is essential that this aspect is considered carefully within the ODR data management plan and, if necessary, remedial actions implemented to enhance ground station functionality before the ODR programme is underway.

8.3 IN-SERVICE MAINTENANCE AND THROUGH-LIFE SUPPORT

8.3.1 ODR SYSTEM MAINTENANCE

<u>ODR Action 22</u>: Identify and promulgate any ODR-specific system maintenance requirements.

ODR-specific equipment maintenance requirements, such as periodic datum checks, through-range checks or electrical shunt calibrations need to be identified. These actions may need to be promulgated either by formal aircraft and ground equipment documentation amendment or, for short-term programmes by the production of a Topic 2(N/A/R)1 leaflet, for example. Where practical, components that have been specifically instrumented for ODR need to be interchangeable with the originals; however, it is prudent to identify these with a unique part marking system.

8.3.2 EFFECT ON AIRCRAFT MAINTENANCE

<u>ODR Action 23</u>: Identify and promulgate the effects of the ODR system on aircraft maintenance.

The effects on aircraft maintenance, including modification requirements to ground equipment need to be identified and promulgated by formal aircraft and ground equipment documentation amendment.

8.3.3 ODR Support Policy, Spares, Support and Test Equipment

ODR Action 24: Develop and promulgate a support policy for ODR-specific installations.

The support policy for the ODR-specific installation needs to be defined. This will affect the requirement for spares, support and test equipment, including instrumentation recalibration and repair. Some aspects of maintenance, such as strain gauge troubleshooting and repair, are beyond the skillset of the general trade boundaries and as such specialist instrumentation engineers will need to be called upon quickly to prevent prolonged loss of data for such systems when faults occur.

8.3.4 Repeat Calibration Plan

ODR Action 25: Develop and implement a repeat calibration plan for ODR-specific installations.

A repeat calibration plan for the life of the ODR programme, for each element of the installation, needs to be produced. For most Flight Test Instrumentation (FTI) type transducers (e.g. accelerometers) the recommended equipment recalibration periodicity is generally annual. For loads calibrated installations (such as strain gauge bridges) recalibration in a loads rig may need to be undertaken if the component is changed in any way (such as repair or overhaul). This will need to be repeated periodically if the instrumentation is installed for longer than approximately 18 months in order to retain confidence in the loads data output. This can be a very significant undertaking for large or complex items, even if they are easily removable from the aircraft. For many strain data acquisition units, monitoring of the shunt calibration data can provide a useful indication of strain gauge drift.

8.3.5 Obsolescence Reviews

ODR Action 26: Develop and implement an obsolescence review plan for the ODR-specific equipment.

A schedule of obsolescence reviews of all ODR equipment including continued support statements from Original Equipment Manufacturers (OEMs) and a review of media and data storage facilities needs to be scheduled; a 3-5 yearly review is likely to be adequate and may not be necessary for a short-term programme.

8.4 OPERATING UNIT INVOLVEMENT

8.5 Unit ODR Project Officers

ODR Action 27: Establish Operating Unit ODR Project Officers and issue terms of reference.

The establishment of Operating Unit ODR Project Officers, to act as the focal point for ODR activity on the unit or station and to act as the units' representatives on the ODR Programme Management Group has proven to be a valuable approach. The Unit ODR Project Officers need to be issued with terms of reference which might include the following:

- Monitoring data capture against requirements
- Influencing the allocation of the ODR aircraft to particular flying requirements (for Category 2 and 3 programmes) within the unit
- Monitoring data transfer and associated flight records from units
- Monitoring maintenance of ODR-specific installations to ensure early visibility on issues and rectification of faults.
- Act as a focal point on the units for ODR issues

8.6 Training

ODR Action 28: Establish appropriate ODR Training for Unit personnel.

Training courses covering all tasks required to be undertaken by unit personnel in support of the ODR programme need to be developed and provided to the operating units. Specific ODR training and demonstration needs to include any additional data transfer systems introduced as part of the ODR programme. This is an area that has often been weak in previous programmes.

8.7 Unit Presentations (Pre and Post ODR)

ODR Action 29: Initiate presentations to Operating Units pre and post ODR programme.

Unit presentations to engineering staff and aircrew are a useful method of explaining the ODR programme, its aims and the importance of the units' role. Additionally, feeding back findings to unit staff, as well as incorporating their suggestions on how to improve the programme, to ensure their continued support has proven invaluable. For long-term programmes, unit briefings may need to be periodic to ensure continued focus on the programme and to account for personnel turn over.

8.8 Trials Directive

ODR Action 30: *Issue an ODR Trial Directive.*

Unless the ODR programme is invisible to the operating units, a Trials Directive (TD) (often published in the aircraft Topic 2(N/A/R)1) will need to be produced. The TD provides an overview of the ODR programme aims and the system; it is also used to promulgate data capture and reporting requirements, dispatch and fault reporting processes and to identify points of contact within the programme.

9 DATA ANALYSIS

9.1 DATA ANALYSIS PROCESS DESIGN

ODR Action 31: Develop an Analysis Definition Document covering the entire ODR data analysis process.

The design of the data analysis process needs to be detailed in a formal Analysis Definition Document (ADD). The content of the ADD will vary depending upon the ODR programme aims but it is likely to include the following:

- Analysis requirements
- Analysis process schematic
- Data download periodicity
- Data extraction and initial integrity checks
- Raw data storage and back-up
- Input and reconciliation of F724/ F725 / Tech Log records
- Data translation / re-formatting requirements
- Extraction and use of data error codes
- Identification of expected data file sizes (for completeness checks)
- Application of calibration equations
- Data anomaly detection
- Data visualisation
- Data trending
- Combined data channels
- Data confidence checks
- Data reduction and filtering

- Data repair/reconstitution
- Frequency analysis
- Fatigue analysis
- Algorithm validation (including flight condition recognition and manoeuvre severity algorithms)
- Output reporting and data visualisation
- Data archive

It should be possible to follow the full data analysis process through the ADD and the above list can be useful as an aide-memoire. Guidance on several of the key issues to consider when establishing the data analysis process is contained in the following sections and additional information is in MASAAG Paper 109 [2].

9.2 MAXIMISE USE OF EXISTING ANALYSIS TOOLS

<u>ODR Action 32:</u> Make maximum use of existing DO-approved, validated, analysis tools, while ensuring fitness for purpose for ODR.

The primary aim of the ODR is to compare in-service usage with design assumptions. Usually, the best approach to achieve this will be to maximise the use of existing DO-approved and validated analysis tools. A DO will have its own approved methods for a whole range of the functions needed for ODR including: extracting data from FLS programmes, fatigue analysis, frequency content analysis, etc. Therefore, it is both cost effective and a risk reduction exercise to maximise the use of these tools. However, it is important to ensure that the tools are appropriately configured for the expected flight data. For example, the inputs to a design fatigue analysis tool might consist of separated low frequency and high frequency fatigue cycles. Therefore, it may be necessary to separate the frequency content in the flight data accordingly to use the fatigue analysis tool in its intended function.

9.3 DATA ANOMALY DETECTION

<u>ODR Action 33:</u> Ensure robust, validated, data anomaly detection processes are included in the analysis process.

It is most likely that flight data will contain anomalies at some point. Therefore, it is essential that robust and validated anomaly detection algorithms are included within the analysis process.

As has already been discussed in this paper, there is no substitute for visualising flight data. However, it is impractical visually to review in sufficient detail over 1000 flying hours of data with for example 50 channels in the data set. Therefore, algorithms will be necessary to identify potentially erroneous data. Identification of incredible erroneous data (e.g. airspeed of 450kts) is relatively simple but identification of erroneous but credible data is more complex and may require more sophisticated approaches, including channel cross checking (possibly with an accept /reject authority) to provide sufficient confidence in the anomaly detection process.

9.4 FLIGHT CONDITION RECOGNITION ALGORITHMS

ODR Action 34: Ensure the use of robust, validated, flight condition recognition algorithms.

The extent to which an ODR programme relies upon the use of flight condition, regime or manoeuvre recognition algorithms will vary from programme to programme. However, flight conditions are an intrinsic element of the helicopter design and fatigue substantiation process and the universal tool for describing what a helicopter is doing at a particular time. Flight condition identification will be required to some extent when explaining ODR results, particularly if they are unexpected. Moreover, as more and more helicopters have HUMS/FDR systems fitted as standard, it is most likely that future ODR programmes will make greater use of FCR to efficiently compare large fleet-wide in-service data sets with design usage assumptions.

Therefore, where the DO has a validated FCR tool for the relevant platform, then use of this approved tool needs to be maximised within the ODR programme. Where a FCR tool exists, and has been developed either by the DO or with the DO, but may not have been fully validated, it is most likely that a validation exercise will be more cost effective and less time consuming than developing a new FCR tool. Where no FCR tool exists, development, either by the DO or with the DO's support, is likely to be the most efficient and lowest risk approach.

Development and validation of FCR tools is a complex exercise. There is no universal definition for flight conditions. The most important issue is to ensure consistency with how the DO would define the flight condition boundaries to ensure alignment with FLS fatigue loads data, e.g. condition entry, exit and steady state, and the DUS flight condition hierarchy (necessary for when conditions overlap) used in the design and substantiation process. There is also a range of methods that can be used to validate a FCR tool [16-20]. These include direct comparison with flight conditions flown within a FLS, comparison with scripted flight schedules and ground station data visualisation. Where possible all three approaches can be combined to provide valuable validation evidence. An example scripted flight schedule for FCR validation is reproduced in Appendix D.

9.5 ANALYSIS TOOL VALIDATION

ODR Action 35: *Ensure validation of tools developed for ODR data analysis.*

The specific issues of maximising the use of DO-approved tools, data anomaly detection and FCR were discussed in the previous sections. However, it is most likely that additional analysis tools will need to be developed to support the ODR process. For example, tools may be required in support of flight condition severity analysis and it is essential that appropriate validation of these tools is included in the ODR programme.

10 REPORTING

In addition to the Requirements Definition Study Report and the Analysis Definition Document, a range of reporting will be required within an ODR programme. As with aspects discussed so far in this paper, these will vary between programmes but may include the following:

10.1 POST INSTALLATION AND FLIGHT TEST REPORT

ODR Action 36: Undertake post installation / flight test reporting.

It is essential that the condition of any ODR-specific instrumentation is fully understood. Therefore, following the flight test or initial flying after the installation of the ODR-specific system on each allotted aircraft, post-flight analysis needs to be undertaken promptly and reported. This analysis may include the following:

- Identify the serviceability status of data channels
- Identify any data losses or anomalies
- Comparison of channel values with expected values, including low and high frequency content
- Check of analysis process
- Recommended remedial actions

It is essential that rapid analysis of the initial flight or flights and confirmation of any recommendations for remedial action is undertaken. Having confidence in the data is essential in ultimately achieving the aims of the programme. Where confidence in the data is lost, remedial action to recover the situation can be extremely costly and time consuming.

10.2 PROGRESS REPORTING AGAINST PROGRAMME REQUIREMENTS

ODR Action 37: Undertake regular ODR progress reporting against programme requirements.

Regular reporting of data received, analysed and status against programme requirements needs to be undertaken with remedial action recommended as required. It is essential for any ODR programme for the status of the data to be monitored closely and regularly. Initial data analysis or acceptance needs to keep pace with data capture otherwise there is a risk of recording large quantities of unserviceable data when remedial action should have been initiated. Experience has shown that the most successful data capture programmes have had a dedicated team undertaking analysis of the data. If a temporary data backlog does occur, the more recent data needs to be analysed first to ensure that unserviceable channels are identified soonest.

10.3 INTERIM REPORTING AGAINST PROGRAMME REQUIREMENTS

ODR Action 38: Undertake interim reporting against ODR programme requirements.

Interim reporting needs to be initiated when a reasonable body of data have been received. Depending upon the time frame for the programme, further interim reports may need to be generated periodically thereafter. The content of an interim report will vary between programmes, depending upon the aims, but may include the following:

- Identify the serviceability status of any dedicated data channels
- Identify any data losses or anomalies
- Comparison of channel values with expected values, including low and high frequency content
- Check of analysis process
- Review channel sample rates
- Review of thresholds set for limits and anomaly detection
- Consider usage distribution versus expectations (e.g. SOI/SOIU)
- Review noteworthy parameter correlations
- Compare captured data with programme requirements
- Assess progress against programme aims and data capture criteria
- Develop provisional observations / conclusions based upon data received against programme aims.
- Update estimate of data requirements to meet programme aims, based upon data received (e.g. variance in damage in SPC X is far greater than expected hence data requirements increased)

- Recommend remedial action as required (e.g. changes to data capture programme, changes to ODR configuration or installation repairs)

10.4 FINAL REPORTING

ODR Action 39: *Undertake final reporting against ODR programme requirements.*

At a point determined by the programme requirements, a final report needs to be raised. This report will form a natural progression from the interim reports but also will be considered as the definitive historical record for the programme as a standalone document with references to lower-level detailed reports generated during the course of the programme. The final report may include the following:

- Programme aims and requirements
- Observations concerning existing data sources
- Additional ODR data source and installation
- Calibration process
- Data analysis process
- Data capture programme
- Data capture achievement
- Data quality
- Data analysis
- Conclusions by programme aims and requirements
- Recommendations for remedial airworthiness action or further work
- ODR report references
- Lessons identified (both platform specific and wider generic issues for escalation by the Delivery Team)

- Future ODR programme recommendations, including data capture, system enhancements, recommendations for progression to continuous usage monitoring, system care and maintenance requirements

10.5 FOLLOW-UP ACTIONS

ODR Action 40: *Monitor progress of implementation of endorsed ODR recommendations at SIWG.*

Progress against endorsed ODR recommendation implementation target dates needs to be monitored at SIWG.

11 Recommendations

This section contains a summary of the recommendations relating to regulatory material made within this paper, for consideration by the MAA.

[REC 1]: *It is recommended that the MAA considers adding the ODR definition in this paper to the MAA02 Glossary [3].*

[REC 2]: *For the purposes of consistency, it is recommended that the MAA includes rotating and stationary rotor controls, power transmission drive shafts and under-slung load attachments to the list of structure for helicopters.*

12 REFERENCES

1. UK Ministry of Defence, Military Aviation Authority Regulatory Article 5720 - Structural Integrity Management, Issue 5.

2. Reed, S. C. and Holford, D. M., Guidance for Aircraft Operational Loads Measurement Programmes, Military Aircraft Structural Airworthiness Advisory Group (MASAAG) Paper 109, May 2007.

3. UK Ministry of Defence, MAA02 Military Aviation Authority Master Glossary Issue 6.1.

4. Webber, D. A., and Ray, G. V., Investigation or Parameters for Helicopter Operational Recording, Royal Aircraft Establishment Technical Report 69216, October 1969.

5. North Atlantic Treaty Organisation, AGARD Conference Proceedings No. 206 Specialists Meeting on Helicopter Design Mission Load Spectra, August 1976.

6. North Atlantic Treaty Organisation, AGARD-R-674, Helicopter Fatigue, February 1979.

7. North Atlantic Treaty Organisation, AGARD-AG-292 (Agardograph 292), Helicopter Fatigue Design Guide, November 1983.

8. UK Ministry of Defence, Defence Standard 00-970 Part 7: Rotorcraft Supplement 3 Strength Requirements (Subpart C) Clause 7.1.6 and Part 1 Section 3 Leaflet 38.

9. European Aviation Safety Agency, Part M – Continuing Airworthiness Requirements, European Commission Regulation 1321/2014.

10. European Aviation Safety Agency, Certification Specifications and Acceptable Means of Compliance for Small Rotorcraft CS-27, Amendment 4, 30 November 2016.

11. European Aviation Safety Agency, Certification Specifications and Acceptable Means of Compliance for Large Rotorcraft CS-29, Amendment 4, 30 November 2016.

12. UK Ministry of Defence, Military Aviation Authority Regulatory Article 5724 – Life Extension Programmes, Issue 4, December 2014.

13. UK Ministry of Defence, Military Aviation Authority Regulatory Article 5725 – Out of Service Data Extension Programmes, Initial Issue, December 2014.

14. U.S. Department of Transportation, Federal Aviation Administration, Assessment of Helicopter Structural Usage Monitoring System Requirements DOT/FAA/AR-04/3, April 2004.

15. EUROCAE ED 112, Minimum Operational Performance Specification for Crash Protected Airborne Recorder Systems, Revision A, September 2013.

16. Perrett, B. H., Flight Condition and Severity Monitoring for Helicopters In: International Committee on Aeronautical Fatigue and Structural Integrity, Helsinki, 2015.

17. Reed, S. C., Understanding the Structural Usage of Rotary-Wing Aircraft in the Military Environment, In: International Committee on Aeronautical Fatigue and Structural Integrity, Nagoya, 2017.

18. Moon, S., and Phan, N., Rotary Wing Aircraft Maneuver Recognition Algorithm Development and Validation Approach, In: American Helicopter Society 64th Annual Forum, Montreal, Canada, 2008.

19. Teal, R. S., Evernham, J. T., et al., Regime Recognition for MH-47E Structural Usage Monitoring, American Helicopter Society 53rd Annual Forum, Virginia Beach, 2011.

20. Barndt, G., Sarkar, S., and Miller, C., Maneuver Regime Recognition Development and Verification for H-60 Structural Monitoring, In: American Helicopter Society 63rd Annual Forum, Virginia Beach, 2006.

Appendix A: Generic Statement of Requirement for ODR

Note to Readers:

This appendix contains a generic statement of requirement for an ODR programme. The ODR Actions identified in preceding sections have been collated in this Appendix and illustrated schematically in Figure 1 to allow a clear view without the background explanation.

Organisation

ODR Action 1: Establish ODR Programme Management and Specialists' Groups at the outset of the ODR programme.

Aims

ODR Action 2: Establish the primary and any secondary aims of the ODR programme and gain endorsement of the Structural Integrity Working Group (SIWG) / Type Airworthiness Authority (TAA). The primary aim of an ODR programme is:

- To validate the in-service operational usage, in terms of frequency of occurrence of fatigue-significant events and their associated severity, using representative flight data, for comparison against the design assumptions and substantiation

The secondary aims, which will depend upon the existing usage and loads validation evidence available and SI history of the platform, may include but are not restricted to the following:

- To validate fatigue spectra for critical structural features and their associated lives or inspection periodicities
- To measure or validate loads or strains for critical structural features
- To identify or measure particularly damaging events, conditions or manoeuvres
- To provide data to support investigations of structural issues or as part of a life extension programmes
- To provide non-structural usage information

Requirements

ODR Action 3: Undertake a Requirements Definition Study to identify the detailed ODR requirements, derived from primary and any secondary aims, and the proposed methodology for meeting those requirements.

ODR Action 4: Detail the fatigue substantiation process used for critical structural features, including development of the Design Usage Spectrum (DUS) and the use of loads validation undertaken within the Flight Loads Survey (FLS).

ODR Action 5: Identify the data capture requirements and method necessary to validate in-service usage against the DUS.

ODR Action 6: Identify critical structural features with either short fatigue lives or ones with fatigue lives or inspection regimes likely to be highly sensitive to credible changes in usage.

ODR Action 7: Identify any shortfalls in the loads validation undertaken with the FLS or other programmes (possible source of secondary ODR aims).

ODR Action 8: Generate ODR requirements from primary and secondary aims.

ODR Action 9: Review existing aircraft data systems and identify additional data capture requirements.

ODR Action 10: Collate requirements and proposed approach into a Requirements Definition Study Report and gain SIWG endorsement.

Data Sources

ODR Action 11: Review existing F724 / F725 / technical log records for content, quality and accessibility.

ODR Action 12: Review existing HUMS/FDR data for suitability, quality and accessibility.

ODR Action 13: Identify data sources and instrumentation to meet additional Category 2 (additional instrumentation required) programme requirements.

ODR Action 14: Identify data sources and instrumentation to meet additional Category 3 (no existing flight data system) programme requirements.

Installation

ODR Action 15: Where additional instrumentation is required for an ODR programme (Category 2 and 3), make available detailed drawings, sketches and photographs (before application of protective treatments) to support in-service fault diagnosis.

ODR Action 16: Where ODR is reliant upon existing sensors (Category 1 and 2), undertake a review of the calibration of these sensors to ensure the calibration approach is adequate for the ODR programme.

ODR Action 17: Where additional instrumentation is installed for an ODR programme (Category 2 and 3), develop and implement a calibration plan for all additional sensors.

ODR Action 18: Where additional instrumentation is installed for an ODR programme (Category 2 and 3), undertake confidence checks during and at the end of the installation process.

ODR Action 19: Where additional instrumentation is installed for an ODR programme (Category 2 and 3), produce and implement flight test requirements.

Programme Management

ODR Action 20: Identify the data capture requirements (e.g. flying hours, sortie distribution) for the ODR programme.

ODR Action 21: Develop and implement an ODR data management plan.

ODR Action 22: Identify and promulgate any ODR-specific system maintenance requirements.

ODR Action 23: Identify and promulgate the effects of the ODR system on aircraft maintenance.

ODR Action 24: Develop and promulgate a support policy for ODR-specific installations.

ODR Action 25: Develop and implement a repeat calibration plan for ODR-specific installations.

ODR Action 26: Develop and implement an obsolescence review plan for the ODR-specific equipment.

ODR Action 27: Establish Operating Unit ODR Project Officers and issue terms of reference.

ODR Action 28: Establish appropriate ODR Training for Unit personnel.

ODR Action 29: Initiate presentations to Operating Units pre and post ODR programme.

ODR Action 30: Issue an ODR Trial Directive.

Data Analysis

ODR Action 31: Develop an Analysis Definition Document covering the entire ODR data analysis process.

ODR Action 32: Make maximum use of existing DO-approved, validated, analysis tools, while ensuring fitness for purpose for ODR.

ODR Action 33: Ensure robust, validated, data anomaly detection processes are included in the analysis process.

ODR Action 34: Ensure the use of robust, validated, flight condition recognition algorithms where used.

ODR Action 35: Ensure validation of tools developed for ODR data analysis.

Reporting

ODR Action 36: Undertake post installation / flight test reporting.

ODR Action 37: Undertake regular ODR progress reporting against programme requirements.

ODR Action 38: Undertake interim reporting against ODR programme requirements.

ODR Action 39: Undertake final reporting against ODR programme requirements.

ODR Action 40: Monitor progress of implementation of endorsed ODR recommendations at SIWG.

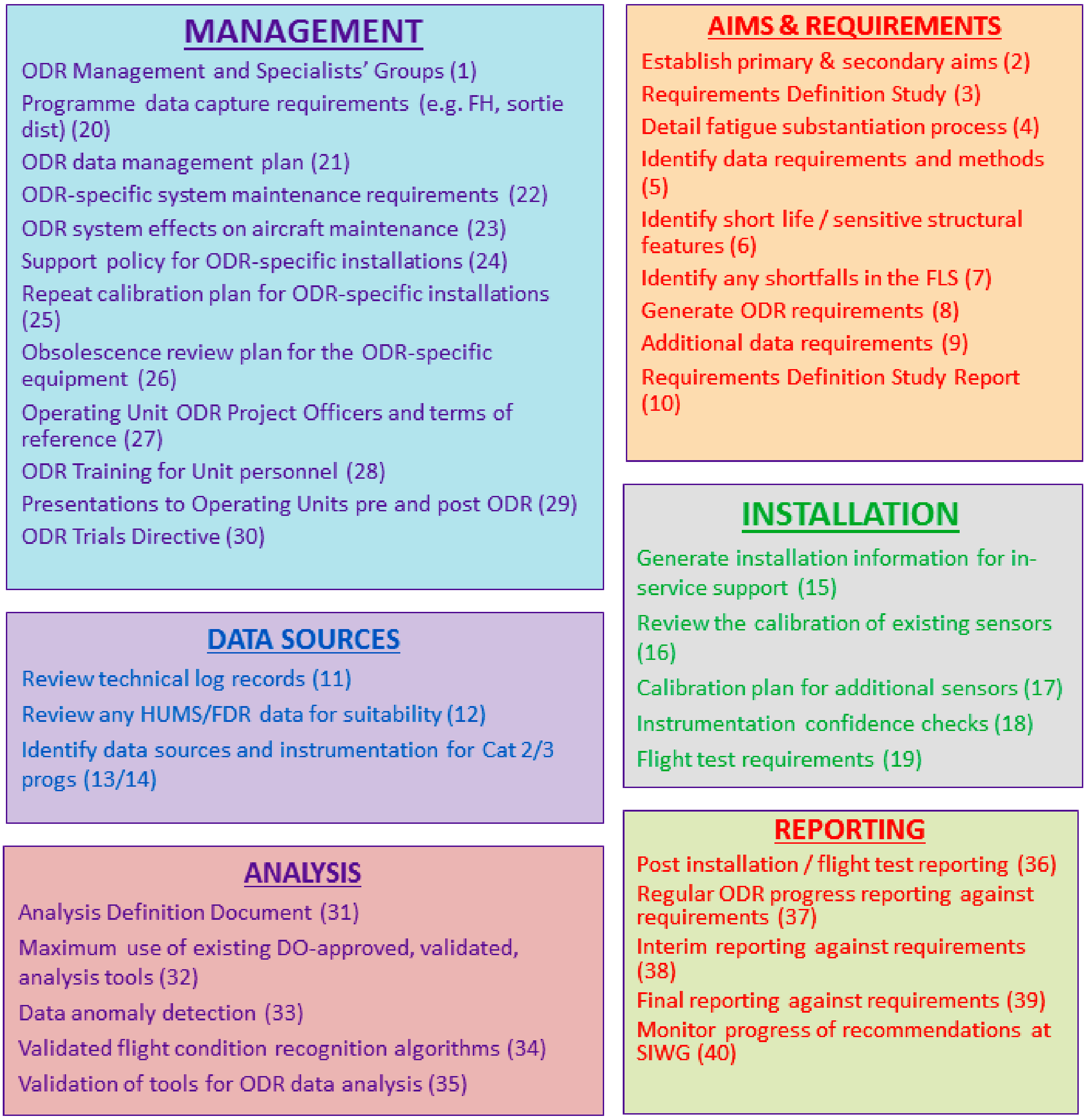

Figure 1: ODR Actions Schematic

Appendix B: Glossary of Terms

Structural Qualification: Structural qualification is a term which encompasses static strength, fatigue substantiation and mechanical/dynamic stability. In the context of this paper, the primary focus of structural qualification is fatigue substantiation.

Design Usage Spectrum: The design usage spectrum is the usage spectrum specified in the design phase of the aircraft and is based on a conservative estimate of the percentage of total flying time which will be spent in each flight regime when the aircraft is flown in its anticipated operational role. The design usage spectrum may also include the frequency of occurrence of fatigue significant events, such as: rotor starts, landings, transitions between steady-state conditions and control reversals and in some cases pertinent details of mass and centre of gravity configuration and density altitude distribution. The level of detail afforded to the design spectrum is generally related to the development era, with older designs having a much more limited range of flight conditions, events and relevant sub-distributions. More recent designs generally have highly detailed spectra (because of the availability of improved computing power for data processing and analysis). It should be noted that the design usage spectrum is usually defined to envelope the worst-case usage within a platform type’s fleet; therefore, for many individual platforms the design spectrum may be highly conservative.

In-Service Usage Spectrum: The in-service usage spectrum generally defines the way the aircraft is used in the service environment. The service spectrum has traditionally been defined with a reduced level of detail compared with the design usage spectrum. In its simplest form the in-service usage spectrum may merely provide a distribution of sortie profile codes. The in-service spectrum is usually defined in the SOIU, which is used to communicate the in-service usage to the DO, for comparison with the design usage spectrum. Where possible, in-service spectra will be confirmed or validated using quantitative data gathered during a triennial SOIU review.

Usage Severity: Usage severity in the context of ODR is the measure of how damaging the overall, or specific aspects of, usage is. Usage severity may be measured directly by inertia, load or strain sensing instrumentation, or it may be inferred through indirect means such as rate of change of aircraft motion or placement in a distribution of selected parameters. Usage severity may be indicative or absolute, depending on the complexity and type of instrumentation fitted and will be designed to satisfy specific requirements, as determined by the programme definition study.

Ground and Flight Load and/or Strain Survey: A programme of controlled ground and flight events used to measure loads and/or strains by the use of dedicated instrumentation (often involving strain gauging). The load/strain survey usually attempts to characterise and measure the worst case fatigue loads/strains for each event or condition in the design spectrum for use in the fatigue substantiation programme. Ground and flight load/strain surveys are undertaken in highly controlled conditions, usually on a prototype or pre-production aircraft operated by one or more DO test pilots. It is important to note that a flight loads survey / flight strain survey is the primary mechanism for loads validation and is a key component of the design and substantiation process.

Critical Structural Feature: Essential geometry where mechanical load and displacement are transferred and which has been the subject of analysis/testing during the strength substantiation programme. Such features may or may not have published service lives.

Appendix C: Example Design Usage Spectra

C-1: FAA Civil Aeronautics Manual Part 6 Appendix A (1962)

Description	% time
Ground Conditions	
Rapid increase of rev/min to quickly engage clutch	0.5
Taxying with full cyclic control	0.5
Jump take-off	0.5
-	-
Hovering	
Steady hovering	0.5
Lateral reversal	0.5
Longitudinal reversal	0.5
Rudder reversal	0.5
Forward Flight Power On	
Level flight 20% VNE	1.0
" " 40% VNE	3.0
" " 60% VNE	18.0
" " 80% VNE	25.0
Maximum level flight <VNE	15.0
VNE	3.0
111% VNE	0.5
Right turns 30, 60, 90% VNE	3.0
Left turns 30, 60, 90% VNE	3.0
Climb (take-off power)	2.0
Climb maximum continuous power	4.0
Change to A/R from power on flight 30, 60, 90% VNE	1.5
Partial power descent (incl. zero flow through rotor)	2.0
Cyclic and collective pull-ups from level flight	1.0
Lateral reversals at VH*	0.5
Longitudinal reversals at VH	0.5
Rudder reversals at VH	0.5
Landing approach	3.0
Sideward flight	0.5
Rearward flight	0.5
Autorotation Power Off	
Steady forward flight	2.0
Rapid power recovery from A/R flight	0.5
Right turns 30, 60, 90% VNE	1.0
Left turns 30, 60, 90% VNE	1.0
Lateral reversals	0.5
Longitudinal reversals	0.5
Rudder reversals	0.5
Cyclic and collective pull-ups	1.0
Landings (including flares)	2.0
Total	100.0
*VH maximum speed in level flight at maximum continuous power.	

C-2: British Civil Airworthiness Requirements (BCAR) Section G Appendix 2 (1966)

Description	% time
Ground Conditions	
Rapid increase of rev/min to quickly engage clutch	0.5
Taxying with full cyclic control	0.5
Normal take-off	0.5
Hovering	
Steady hovering	0.5
Lateral reversal	0.5
Longitudinal reversal	1
Directional reversal	1
Forward Flight. Power On	
Level flight 20% VNE	5.0
" " 40% VNE	10.0
" " 60% VNE	18.0
" " 80% VNE	18.0
Maximum level flight <VNE	10.0
VNE	3.0
111% VNE	0.5
Right turns	3.0
Left turns	3.0
Climb (maximum one-hour power)	2.0
Climb maximum continuous power	4.0
Change to A/R from power on flight 30, 60, 90% VNE	0.5
Partial power descent (incl. zero flow through rotor)	2.0
Cyclic and collective pull-ups from level flight	0.5
Lateral reversals at VH	0.5
Longitudinal reversals at VH	0.5
Directional reversals at VH	0.5
Landing including approach	3.0
Sideward flight	0.5
Rearward flight	0.5
Autorotation Power Off	
Steady forward flight	2.5
-	-
Right turns	1.0
Left turns	1.0
Lateral reversals	0.5
Longitudinal reversals	0.5
Directional reversals	0.5
Cyclic and collective pull-ups	2.0
Landing (including flares)	2.5
Total	100.0

C-3 US Naval Air Systems Command AR-56 (Structural Design Requirements (Helicopters))

	Mission Profile in Percent Service Life					
Type	CH (Crane)	CH (Other)	SH	UH	AH	TH
Ground Conditions	1.0	1.0	1.0	1.0	1.0	2.0
Take Off	(400)	(400)	(50)	(400)	(400)	(1000)
Steady Hovering	16.0	12.0	35.0	10.0	5.0	15.0
Turns Hovering	(1000)	(1000)	(1000)	(1000)	(400)	(1500)
Control Reversals						
Hovering	(1000)	(1000)	(1000)	(1000)	(400)	(1500)
Sideward Flight	1.0	1.0	1.0	1.0	1.0	1.0
Rearward Flight	0.5	0.5	0.5	0.5	0.5	0.5
Landing Approach	(500)	(500)	(1000)	(500)	(500)	(1000)
Forward Level Flight:						
20% VH	4.0	5.0	11.0	5.0	2.5	8.0
40% VH	2.0	2.0	2.0	5.0	4.0	5.0
50% VH	2.0	2.0	2.0	2.0	4.0	5.0
60% VH	5.0	5.0	4.0	8.0	8.0	8.0
70% VH	18.0	8.0	4.0	10.0	8.0	10.0
80% VH	16.0	10.0	8.0	15.0	15.0	15.0
90% VH	16.0	33.0	12.0	18.0	15.0	5.0
VH	1.0	6.0	5.0	10.0	15.0	5.0
115% VH	1.0	1.0	1.0	1.0	1.0	1.0
Take Off Power Climb	3.0	1.0	1.0	1.0	1.0	2.0
Full Power Climb	4.0	3.0	3.0	3.0	3.0	4.0
Partial Power Descents	(500)	(500)	(500)	(500)	(500)	(1000)
Power Dives	2.5	2.5	2.5	2.5	1.0	2.5
Right Turns	2.5	2.5	2.5	2.5	3.5	3.5
Left Turns	2.5	2.5	2.5	2.5	3.5	3.5
Control Reversals	(800)	(800)	(800)	(800)	(2000)	(1500)
Pull Ups	(250)	(250)	(250)	(250)	(500)	(250)
Power to Autorotation	(40)	(40)	(40)	(40)	(100)	(100)
Autorotation to Power	(40)	(40)	(40)	(40)	(100)	(100)
Autorotation -Steady	1.0	1.0	1.0	1.0	2.0	2.0
Autorotation -Left Turn	0.2	0.2	0.2	0.2	0.5	0.5
Autorotation -Right Turn	0.2	0.2	0.2	0.2	0.5	0.5
Autorotation -Control Reversals	0.3	0.3	0.3	0.3	0.3	0.5
Autorotation - Landing	0.3	0.3	0.3	0.3	0.3	0.5
Autorotation - Pull Ups	(40)	(40)	(40)	(40)	(100)	(100)

	Mission Profile in Percent Service Life					
Type	CH (Crane)	CH (Other)	SH	UH	AH	TH
Ground-Air-Ground Cycles	(100)	(100)	(100)	(100)	(100)	(250)
Gunnery Manoeuvres:						
Hovering					0.1	
Dives					1.5	
Dive Pull-Outs					0.7	
Turns:						
Right					1.0	
Left					1.0	
S turn					0.2	
	100.0	100.0	100.0	100.0	100.0	100.0
NOTE 1: Numbers in parentheses are manoeuvres per 100 flight hours and are in addition to the steady state condition times.						

Appendix D: Example Scripted Flight Schedule for FCR Validation

FCR Validation Flight Schedule for ac Tail Number .... Type ………. Date flown ....

Note: Where possible each steady FC (e.g. HIGE, HOGE) should be carried out for at least 1 min

Flight Conditions	Measurements	Remarks
1.Windspeed and Direction Prior to Start	Kts.............. Direction..................	
2. Main Rotor Engagement	Time..............................	RADALT (ft) =
3. Take Off	Time	Press Alt (ft) =
4. Hover Inside Ground Effect (IGE) into wind	Start Time .... Finish Time......................	AGL (ft) =
5. Spot turns (IGE) (right)	Start Time .... Finish Time......................	AGL (ft) =
6. Hover Inside Ground Effect (IGE) tailwind	Start Time .... Finish Time......................	AGL (ft) =
7. Spot turns (IGE) (left)	Start Time .... Finish Time......................	AGL (ft) =
8. Landing (rotor running)	Time	Press Alt (ft) =
9. Take Off	Time	
10. Hover Outside Ground Effect (OGE) into wind	Start Time .... Finish Time......................	AGL (ft) =
11. Spot turns (OGE) (right)	Start Time .... Finish Time......................	AGL (ft) =
12. Hover Outside Ground Effect (OGE) tailwind	Start Time .... Finish Time......................	AGL (ft) =
13. Spot turns (OGE) (left)	Start Time .... Finish Time......................	AGL (ft) =
14. Sideways Flight (right) (up to 20 kts estimated	Start Time .... Finish Time......................	AGL (ft) =

airspeed) – into wind		
15. Sideways Flight (left) (up to 20 knots estimated airspeed) – into wind	Start Time .... Finish Time.......................	AGL (ft) =
16. Rearwards Flight (up to 20 knots estimated airspeed) – into wind	Start Time .... Finish Time.......................	AGL (ft) =
17. Landing (rotor running)	Time	Press Alt (ft) =
18. Take Off	Time.....................................	
19. Hover Inside Ground Effect (IGE) into wind	Start Time .... Finish Time.......................	AGL (ft) =
20. Vertical Climb (>1000 ft) ground referenced	Start Time .... Finish Time.......................	Start AGL (ft) = End AGL (ft) = TQ(%) = Climb Rate (ft/min) =
21. Partial Power Descent (> 1000 ft)	Start Time .... Finish Time.......................	Start AGL (ft) = End AGL (ft) = Descent Rate (ft/min) =
22. Full Power Climb (>1000 ft)	Start Time .... Finish Time.......................	Start AGL (ft) = End AGL (ft) = TQ(%) = Climb Rate (ft/min) =
23. Standard training circuit	Start Time .... Finish Time.......................	Circuit Description =
24. Downwind training circuit	Start Time .... Finish Time.......................	Circuit Description =

25. Wingover (left turn)	Start Time .... Finish Time......................	Start AGL (ft) = End AGL (ft) = Start IAS (kts) = Max Pitch Up (deg) = Max AOB (deg) = Max Pitch Down (deg) =
26. Wingover (right turn)	Start Time .... Finish Time......................	Start AGL (ft) = End AGL (ft) = Start IAS (kts) Max Pitch Up(deg) = Max AOB (deg) = Max Pitch Down(deg) =
27.Straight and level flight (100 kts IAS)	Start Time .... Finish Time......................	AGL (ft) =
28. Level flight – 5 deg sideslip (right) (100 kts IAS)	Start Time .... Finish Time......................	AGL (ft) =
29. Level flight – 5 deg sideslip (left) (100 kts IAS)	Start Time .... Finish Time......................	AGL (ft) =
30. Standard Turn (left) Bank Angle = 30 deg	Start Time .... Finish Time......................	AGL (ft) = Entry IAS (kts) =
31. Standard Turn (right) Bank Angle = 30 deg	Start Time .... Finish Time......................	AGL (ft) = Entry IAS (kts) =
32. Standard Turn (left) Bank Angle = 45 deg	Start Time .... Finish Time......................	AGL (ft) = Entry IAS (kts) =
33. Standard Turn (right) Bank Angle = 45 deg	Start Time .... Finish Time......................	AGL (ft) = Entry IAS (kts) =

34. Steep Autorotation to flare (end at hover)	Start Time .... Finish Time......................	Start AGL (ft) = End AGL (ft) = Max descent rate (ft/min) =
35. Shallow Autorotation (max range) to overshoot	Start Time .... Finish Time......................	Start AGL (ft) = End AGL (ft) = Max descent rate (ft/min) =
36. Autorotational Turn to hover	Start Time .... Finish Time......................	Start AGL (ft) = End AGL (ft) = Max descent rate (ft/min) = Max AOB (during turn) (deg) =
37. Quickstop (into wind)	Start Time .... Finish Time......................	Start AGL (ft) = End AGL (ft) = Start IAS (kts) =
38. Quickstop (downwind)	Start Time .... Finish Time......................	Start AGL (ft) = End AGL (ft) = Start IAS (kts) =
39. Main Rotor Shutdown	Time..............................	
40. Rotor Brake Applied	Time..............................	
41. Windspeed and Direction at Shut Down	Kts.............. Direction..................	

End of Paper