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HELICOPTER FLIGHT OPERATIONAL QUALITY ASSURANCE (HFOQA): DEVELOPMENT OF HFOQA ANALYSIS SOFTWARE

by

Sergio Teixeira

A Thesis Submitted to the
Department of Applied Aviation Sciences
in Partial Fulfillment of the Requirements for the Degree of
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Embry-Riddle Aeronautical University
Daytona Beach, Florida
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HELICOPTER FLIGHT OPERATIONAL QUALITY ASSURANCE (HFOQA): DEVELOPMENT OF HFOQA ANALYSIS SOFTWARE

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This Thesis was prepared under the direction of the candidate's Thesis Committee Chair, Dr. Thomas R. Weitzel, Associate Professor, Daytona Beach Campus, and the Thesis Committee Members, Mr. Pete Rounseville, Associate Professor, Daytona Beach Campus, and Mr. Sam Wellington, Sales and Marketing Manager, Flight Data Management, SAGEM Avionics, Inc., and has been approved by the Thesis Committee. It was submitted to the Department of Applied Aviation Sciences in partial fulfillment of the requirements for the Degree of Master of Science in Aeronautics.

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Mission Accomplished! This academic journey was successfully planned, safely executed, and closely paralleled a helicopter flight. Although to the eyes of the public the pilots made it to the destination, a lot of support was involved during the trip; the providers merit my gratitude.

Dr. Thomas Weitzel, my first professor at Embry-Riddle Aeronautical University, taught me the hard initial steps of academic research. At that time, Dr. Weitzel performed like a helicopter flight instructor, who was challenged to teach the novice, student pilot to hover the aircraft in the early flights. Two years later, as my advisor in this thesis, Dr. Weitzel provided skillful guidance for me to execute my own gentle and refined flight. Pete Rounseville and Sam Wellington, my other committee members, also deserve recognition. Their expertise and awareness helped in keeping the helicopter flying.

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Finally, my thankfulness to Flavia Teixeira. My full-time, beloved wife, who sometimes acted as first officer, and at others as captain. We were the fight crew. She flew the entire flight with me, monitoring the instruments, maintaining our situation awareness, assertiveness, and open communications skills. Our wonderful Crew Resource Management was essential to the successful completion of this enjoyable mission.

ABSTRACT

Researcher: Sergio Teixeira

Title: Helicopter Flight Operational Quality Assurance (HFOQA): Development of HFOQA Analysis Software

Institution: Embry-Riddle Aeronautical University

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Flight Operational Quality Assurance (FOQA), or Flight Data Monitoring (FDM), has benefited flight safety in both fixed-wing and helicopter operations. The relative youth of FOQA programs has resulted in their minimal application among the helicopter fleets of the world; thus, Helicopter FOQA (HFOQA) has merited consolidation and expansion. This mixed methods design developed HFOQA analysis software via a blend of the qualitative data from helicopter and FOQA experts with quantitative data represented by a sample of de-identified digital flight data from 1,014 helicopter flights. Development of the software emphasized three domains of interest: (a) helicopter flight phases; (b) helicopter operational and maintenance events; and (c) helicopter event-related and safety/efficiency flight profile measurements. This study's resultant HFOQA analysis software has direct application to multifaceted helicopter operations (Emergency Medical Services [EMS], sightseeing, military, and others), and, in fact, has been utilized by an offshore helicopter operator in its daily operations.

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LIST OF ACRONYMS

AAIB	UK Air Accidents Investigation Branch
ACARS	Aircraft Communications Addressing and Reporting System
AHS	American Helicopter Society
ARR	Arrival
ATC	Air Traffic Control
BASIS ASR	British Airways Safety Information System Air Safety Report
CAA	Civil Aviation Authority
CAADRP	Civil Aircraft Airworthiness Data Recording Programme
CAST	Commercial Aviation Safety Team
CFR	Code of Federal Regulations
CVR	Cockpit Voice Recorder
DEP	Departure
DMC	Dead Man's Curve
DEMOPROJ	Demonstration Project
EASA	European Aviation Safety Agency
ECM	Engine Condition Monitoring
ECMS	Environmental Control and Monitoring System
EGPWS	Enhanced Ground-Proximity Warning System
EMS	Emergency Medical Services
ETOPS	Extended Twin Engine Operations

FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FDA	Flight Data Analysis
FDAU	Flight Data Acquisition Unit
FDE	Flight Data Events
FDM	Flight Data Monitoring
FDR	Flight Data Recorder
FDS	Flight Data Simulations
FDT	Flight Data Traces
FDV	Flight Data Visualization
FOQA	Flight Operational Quality Assurance
FSF	Flight Safety Foundation
GAO	General Accounting Office
GAIN	Global Aviation Information Network
GDRAS	Ground Data Replay and Analysis System
GPWS	Ground-Proximity Warning System
HAI	Helicopter Association International
HARP	Helicopter Airworthiness Review Panel
HFOQA	Helicopter FOQA
HOMP	Helicopter Operations Monitoring Programme
HSAC	Helicopter Safety Advisory Conference
HUMS	Health Usage and Monitoring Systems
ICAO	International Civil Aviation Organization

IHSS	International Helicopter Safety Symposium
IHST	International Helicopter Safety Team
MFOQA	Military FOQA
MOQA	Maintenance Operational Quality Assurance
NGATS	Next Generation of Air Transport System
NTSB	National Transportation Safety Board
OGP	International Association of Oil & Gas Producers
PCMCIA	Personal Computer Memory Card International Association
QAR	Quick Access Recorder
SESMA	Special Event Search and Master Analysis
SMS	Safety Management System
SOP	Standard Operating Procedure
TAWS	Terrain Awareness and Warning System
TCAS	Traffic Alert and Collision Avoidance System
TOPS	Tour Operators Program of Safety
UK	United Kingdom
UKCS	United Kingdom Continental Shelf
UKOOA	United Kingdom Offshore Operators Association
U.S.	United States

Chapter I

INTRODUCTION

Flight Operational Quality Assurance (FOQA), a proactive aviation safety program, has continually monitored digital aircraft flight data, irrespective of any incident/accident occurrence. The routine collection and analysis of normal flight operational data has increased safety and decreased costs (Flight Safety Foundation [FSF], 2004). FOQA has provided a comprehensive, objective overview and risk assessment capability of the aircraft operation – pilot performance, aircraft condition, and the environment – in providing the aforementioned benefits (Federal Aviation Administration [FAA], 2004). The waiting for a tragedy to occur to obtain operational knowledge and prevent accidents has been obviated by FOQA.

FOQA also has existed under different names around the world, such as Flight Data Monitoring (FDM) and Flight Data Analysis (FDA). The European commercial airlines originally introduced the systematic and proactive use of flight data from routine operations in the 1960s. Since then, this safety assessment process has gained acceptance due to the advancing technology and the expertise shared throughout the industry. In the United States (U.S.), during the 1990s, the airlines began to establish a similar program and became familiar with its advantages. In recent years, the International Civil Aviation Organization (ICAO) has approved FOQA as a standard for some commercial transport aircraft beginning January 1, 2005 (FSF, 2004).

Air carriers with FOQA implemented in their fixed-wing fleet have seen several benefits of continuously monitoring flights. The direct benefits have been the improvement of safety, training, operational, and maintenance procedures. At the same time, problems with Air Traffic Control (ATC) procedures, airport characteristics, and aircraft operation and design were brought forward and addressed. Some financial considerations and cost savings have also been mentioned; for example, insurance and fuel savings (FSF, 2004).

FOQA has been consolidated, earned trust, and assisted stakeholders within the air carrier industry during the execution of business. It has become unavoidable to ask whether the program will extend its range beyond the fixed-wing industry; the helicopter market with its diverse operational characteristics has already had some affirmative answers.

Large numbers of rotorcraft have participated in a broad variety of aviation activities. According to FAA registration data, an estimated 10,844 civil rotorcraft were active in the U.S. at the end of October 2005; 2.265 million hours were flown in 2005. The total market value of used helicopters traded in U.S. in 2005, for example, was $783.9 million (Helicopter Association International [HAI], 2006). This impressive volume of activity and wealth has necessitated safety operations.

The U.S. civil helicopter (non-commercial and commercial) accident rate was 8.09 accidents per 100,000 flight hours in 2004 and 8.52 in 2005. The latter accident rate was based upon National Transportation Safety Board (NTSB) accidents posted through mid-December 2005 (HAI, 2006). The commercial helicopter accident rate was 2.25 accidents per 100,000 hours in 2004. All these numbers have been more or less static for the past decade and were “too high” and “not appropriate” (R. Flater as cited in Klein, 2006, p. 1). Iseler and De Maio (2001), using the number of departures as the exposure factor in their analysis of U.S. civil rotorcraft accidents from 1990 to 1996, stated that “the airline fatal and total accidents rates are about one tenth those of the corresponding helicopter rates” (p. 1). The HAI and the American Helicopter Society (AHS) announced on January 31, 2006 the formation of a consortium of operators, manufacturers, and government regulatory agencies; the International Helicopter Safety Team (IHST) has been tasked to reduce helicopter accidents 80% by 2016 (IHST, 2006b).

Public transportation by helicopter has presented unique characteristics that increase the risk of the operation and also deserve to be routinely mapped utilizing objective data. Emergency Medical Services (EMS) aviation operations, sightseeing helicopter flights, and offshore helicopter operations have provided significant representation.

EMS flights, for example, have occurred under the natural pressure of quickly transporting patients or donor organs to emergency care facilities. The hazards associated with EMS operations have resulted in an increasing number of accidents which has not been seen since the 1980s. Between January 2002 and January 2005, 16 EMS helicopter fatal accidents occurred in the United States, killing 39 people (NTSB, 2006d).

The air tour industry has its own uniqueness. In one instance, an accident investigation report indicated that a sightseeing helicopter crew succumbed to pressure to fly in bad weather in 1999. The NTSB reported that helicopter flights were included in more than half of 19 sightseeing flight fatal accidents, killing 43 people, since January 2000 (Klein, 2006).

Offshore helicopter operations (to be discussed further) have been distinguished by over-water flights in an oil and gas environment, including turbulence and hot gas areas. All three aforementioned types of public transportation might have regularly occurred close to terrain or water, in severe weather, or at unfamiliar landing sites, and are highly subject to environmental conditions. Therefore, they have been inherently dangerous operations and an efficient hazard assessment and risk control program is needed (NTSB, 2006d).

The worldwide offshore helicopter operations, in particular, have been impressive because of the numbers and characteristics involved. In 2004, 8.5 million passengers were carried in oil industry helicopter operations (offshore, seismic, geophysical, pipeline, and others activities), with 2.5 million flights worldwide (International Association of Oil & Gas Producers [OGP], 2006). Clark (2000) compared the travel scenarios and relative travel risk experienced by an airline business passenger in an airplane and an offshore worker in a helicopter. The fixed-wing passenger flew at a high altitude in air-conditioned comfort, preceded by a short briefing on the use of the seat belt and lifejacket, and was advised on the nearest exit. The offshore worker, flew above unforgiving freezing waters like the North Sea, must have had prior training on helicopter underwater escape, and watched a detailed video on helicopter evacuation. The offshore helicopter passenger wore a thermal liner, an immersion suit, and a life jacket with self-breathing equipment providing 15 to 20 seconds of air under water in case of ditching. The helicopter flight was in a very loud, cramped, and high-vibration environment. To escape underwater, a window beside the seat must be pushed out after releasing its seal.

In summary, the accident risk that an offshore worker has faced has been significantly higher than that of a regular airline passenger.

The Gulf of Mexico has encompassed the largest offshore helicopter fleet in the world with a total of 589 aircraft in 2005 (Williams, 2006). This fleet has been responsible for 71% of the offshore flights and 42% of worldwide flight hours, according to 2004 data from OGP (2006). These statistics emphasize the importance of keeping this flight operations area safe. However, the accident rate and other safety numbers have not been improving. The Helicopter Safety Advisory Conference (HSAC; Williams, 2006) stated that 2004, with 15 lives lost, was the worst year in terms of fatalities in the 21 years of gathering data in the Gulf of Mexico. The helicopter accident rate per 100,000 flight hours in 2005 was 2.05. That has been a particularly unsatisfactory number when compared to the 22-year annual average accident rate of 1.89. The Gulf of Mexico numbers have evolved to accident rates notably higher than those of the North Sea.

The North Sea has had the second largest offshore helicopter fleet with 100 aircraft, covering 10% of worldwide flights and 15% of the total worldwide hours flown. In contrast to the current Gulf of Mexico accident rate, a fairly constant diminishing accident rate has been observed in the North Sea. Despite the fact that the North Sea operations have been carried out over longer distances and often in more severe weather, no accidents have occurred during the last 2 years of available data – 2003 and 2004. The most recent offshore helicopter accident in the North Sea occurred in 2002; the accident rate per 100,000 flight hours for that year was 1.96 (OGP, 2006).

A closer look at the North Sea safety approach to offshore helicopter operations has been revealing. The United Kingdom (UK) Civil Aviation Authority (CAA) has been promoting safety review meetings with the industry in order to develop and guarantee helicopter airworthiness for public transportation (Howson, 2005). A partnership among the offshore helicopter stakeholders of the UK has resulted in extensive research to improve safety. The ongoing research process resulted in the creation of the Helicopter Operations Monitoring Programme (HOMP), which was the first FOQA-type program applied to helicopters (CAA, 2002).

The HOMP project began as a trial in 1999; two related, final reports were released in 2002 and 2004 by the CAA. Two offshore helicopter operators and two different types of helicopters participated in the HOMP trial. The application of FOQA to helicopter operations was considered a success. Consequently, the UK Offshore Operators Association (UKOOA) committed its members to implement the program on all Flight Data Recorder (FDR)-equipped UK public transport helicopters over the UK Continental Shelf (UKCS; CAA, 2002). Moreover, Shell Oil Company has recently required a FOQA-type program in its contract with a European helicopter operator on some helicopters that the company has used in the North Sea (Croft, 2005).

Although FOQA has already proven to be a feasible tool and a safety advantage for offshore helicopters operators, the aviation industry has been awaiting its consolidation and subsequent expansion. The course of FOQA development progress with helicopters has been forecast to follow that of fixed-wing FOQA. The HOMP trial was the first step and the basis for this study. FOQA analysis software suppliers, highly experienced in the field, have started transferring know-how and familiarizing themselves with this powerful helicopter safety tool.

Statement of the Problem

FOQA has attained the status of a powerful aviation safety tool that increases flight safety and efficiency in both fixed-wing and helicopter operations. The relative youth of FOQA programs has resulted in their minimal application as tools among the helicopter fleets of the world. Current helicopter FOQA analysis software programs have arrived at a point in time where they merit consolidation and expansion.

Delimitations

The exclusive focus of this study has been the FOQA analysis software. The development of a helicopter version of the FOQA software addressed both operational and maintenance parameters. Although the industry has usually referred to the latter as Maintenance Operational Quality Assurance (MOQA), this study has concentrated on maintenance as well as flight operations under the FOQA rubric.

The analyzed flight data were historical and used solely as a means of verification and validation. No safety or efficiency appraisal was made regarding the quality of the helicopter operations that produced the data. Moreover, the flight data and the software ownership have remained confidential. Additionally, the costs associated with the helicopter FOQA have not been assessed.

Definition of Terms

The following list of key terms and their definitions has been prepared as a quick reference to facilitate reading of the report.

Dead Man's Curve (DMC) or height velocity curve: A chart (height on the y-axis and velocity on the x-axis) depicting combinations of airspeed and altitude that do not provide sufficient stored energy to permit a safe landing of the helicopter in the event of an engine failure (Cantrell, 2006).

Event: An occurrence or condition in which predetermined limits of aircraft parameters have been exceeded (FAA, 2004).

Fixed-wing aircraft: A generic term used to refer to what are more commonly known as airplanes (Wikipedia Encyclopedia, 2006)

Flight Data Analysis (FDA): "Flight Data Analysis (FDA) is the systematic collection of flight data to improve safety and operational efficiency" (IATA, 2004, ¶1).

Flight Data Monitoring (FDM): "Flight Data Monitoring (FDM) is the systematic, pro-active, and non-punitive use of digital flight data from routine operations to improve aviation safety" (CAA, 2003, p. 1).

Flight Data Recorder (FDR): A device that records pertinent parameters and technical information about a flight. A FDR is designed to withstand the forces of a crash so that information recorded by it may be used to reconstruct the circumstances leading up to the accident (FAA, 2004).

Flight Operational Quality Assurance (FOQA): "A voluntary program for the routine collection and analysis of flight operational data to provide more information about, and greater insight into, the total flight operations environment. A FOQA program combines these data with other sources and operational experience to develop objective information to enhance safety, training effectiveness, operational procedures, maintenance and engineering procedures, and air traffic control (ATC) procedures" (FAA, 2004, p. 4).

FOQA, FDM, or FDA: Different acronyms for aviation safety programs that make use of digital, recorded aircraft flight data, even if no accident occurs (Author).

Ground resonance: Emergency situation developed when the helicopter rotor blades move out of phase with each other and cause the rotor disc to become unbalanced. This phenomenon has resulted in the entire hull being ripped apart by the aircraft's own extreme oscillations (Lewis & Darbo, 2006).

Helicopter FOQA (HFOQA): The adaptation of the FOQA process, emphasizing the development of unique analysis software to be used by the helicopter industry in any of its multifaceted operations (Author).

Helicopter Operations Monitoring Programme (HOMP): A North Sea helicopter version of fixed-wing FOQA programs (Author).

Helideck: Offshore industry terminology for the heliport(s)/helipad(s) located on the offshore drilling rigs (Author).

Parameter exceedance analysis or event detection: The examination for aircraft-parameters beyond predetermined thresholds in a specific occurrence, or a programmed event (FAA, 2004).

Parameters: "Measurable variables that supply information about the status of an aircraft system or subsystem, position, or operating environment. Parameters are collected by a data acquisition unit installed on the aircraft and then sent to analysis and reporting systems" (FAA, 2004, p. 5).

Quick Access Recorder (QAR): A recording unit onboard the aircraft that stores flight-recorded data, and are designed to provide quick and easy access to the data (FAA, 2004).

Safety Management System (SMS): The effective and comprehensive safety structure developed and maintained by an air transport organization for managing safety, through an inclusive safety culture (CAA, 2003).

Special Event Search and Master Analysis (SESMA): "The first ever FDM system" (CAA, 2002, Section 3, p. 1).

Statistical analysis or routine flight data measurement: The statistical use of data from all flights to determine risk for an airline without focusing on specific event exceedances (FAA, 2004).

Validation: "The process of determining that the requirements are the correct requirements and that they are complete" (CAA, 2003, Appendix A, p. 2).

Verification: "The evaluation of the results of a process to ensure correctness and consistency with respect to the input and standards provided to that process" (CAA, 2003, Appendix A, p. 2).

Chapter II

REVIEW OF RELEVANT LITERATURE

The helicopter industry has not entirely incorporated the same improvements in design, equipment, operating procedures, training, and maintenance practices as the airline industry. A large number of helicopters have been operated with the same criteria and procedures that the air carriers' aircraft were 30 years ago. The key steps that the airlines have taken to improve their safety could be replicated by helicopters with similar effects (Stevens & Sheffield, 2006).

FOQA and the Airline Industry

The aviation industry represented by the airlines has strengthened its business and public credibility through a long-term investment in safety. Extraordinary advances in aircraft airworthiness, airport and navigation facilities, air traffic management, and pilot training through high-fidelity flight simulator devices, for example, reduced the accident rates significantly in the past (Matthews, 2002). These features have already been incorporated into the airline industry and their roles continue to exist within the system. However, the increasing numbers of flights over the years has caused the airline industry to not accept the current low accident rates. More flights have represented more accidents and losses if the number of accidents per flight has remained the same as the past (FAA, 2004). FOQA, incorporated into a Safety Management System (SMS), has been highlighted as one of the safety programs with the potential to minimize the low, but steady, long-term accident rate per airline departures (FSF, 2004).

SMS and FOQA

The SMS has been generally defined as the effective and comprehensive safety structure developed and maintained by an air transport organization for managing safety. A commitment to minimizing the risk of flight operations through an inclusive safety culture has been the focus of the SMS. An effective SMS has relied basically on information obtained from all sources available from the aviation industry to predict risks (CAA, 2003); an example has been the information from voluntary, non-punitive incident and hazard reporting programs (CAA, 2002). Regulatory authorities and organizations involved with air transportation safety have geared their plans and actions to achieve safety in a partnership culture with the industry. The capability of the SMS and Oversight Systems to collect, integrate, and analyze data from different sources has been the major trend initiative demonstrated in projects for the future. The FAA has planned to establish a full SMS and Oversight System by 2008. The ICAO target date for SMS and Safety Management Oversight Systems implementation has been 2011. In the U.S., the Next Generation of Air Transport System (NGATS), with full integration and linking among federally related air transport agencies, has been projected for 2025 (D. Farrow, personal communication, January 21, 2006).

FOQA has delivered objective, quantitative data from the airlines of the world to the SMSs. The program has been included in operators' overall operational risk assessment and prevention programs. FOQA data, obtained from special acquisition devices, such as Quick Access Recorders (QARs), or directly from the Flight Data Recorders (FDRs), have discovered and addressed risk, thereby enhancing air safety (FAA, 2004).

FOQA Definition

The primary characteristic that has distinguished FOQA from other safety reporting programs has been that FOQA has provided objective, quantitative data. The program, instead of relying on perceived problems or risks subjectively reported by individuals, has yielded precise information on many aspects of flight operations. Such information has been used to objectively evaluate a wide range of safety-related issues (General Accounting Office [GAO], 1997).

The FSF (2004) has defined the FOQA program as the process of obtaining and analyzing data recorded in flight operations to improve safety. The CAA (2003) has emphasized the systematic, pro-active, and non-punitive use of the program. Non-punitive has meant that information obtained from FOQA would not be used, for example, as the basis for a disciplinary action against a pilot (FSF, 2004). In the U.S., the FAA (2004) has additionally addressed the voluntary aspects of the program and the protection assurance of the submitted data, under Title 14 of the Code of Federal Regulations (14 CFR) Part 193. "Protection of data sources" has meant that "data could not be disclosed publicly or for purposes other than aviation safety" (FSF, 2004, p. 2). ICAO and its 188 contracting states, followed by the European Aviation Safety Agency (EASA), have ratified the FOQA data protection issue (Wall, 2006).

FOQA History

At least eight non-U.S. airlines have had FOQA/FDM programs in operation for more than 34 years (GAO, 1997, p. 20). A forerunner of British Airways and TAP Air Portugal have received credit as the first airlines in the world to use FDM techniques during the early 1960s (FSF, 2004). The CAA (2002) proclaimed that the FDM history has been in alignment with one of its "longest running safety research projects: the Civil Aircraft Airworthiness Data Recording Programme (CAADRP)" (Section 3, p. 1). The CAADRP's efforts to improve aviation safety through FDM in the 1960s relied on flight data recorders with ultraviolet paper as the medium to collect data from the jet transports then entering service. This diligent work "led to the development of the Special Event Search and Master Analysis (SESMA) program – the first ever FDM system" (Section 3, p. 1). SESMA has developed into the British Airways' FDM program and an essential component of the airline's SMS.

British Airways' FDM program has served as the model for similar programs in the U.S. and around the world (GAO, 2002). For example, in Asia, All Nippon Airways began a program to analyze flight data in 1974 and Japan Airline's FOQA program has been in effect for more than 24 years (GAO, 1997). In the 1980s and 1990s many non-U.S. airlines shared their FOQA expertise in seminars and workshops promoted by the FSF. In a 1993 study for the FAA, the FSF coined the term Flight Operational Quality Assurance and stated that there were "approximately 25 air carriers with FOQA-like programs" worldwide (FSF, 2004, p. 2).

In July 1995, the FAA initiated a 3-year $5.5 million FOQA Demonstration Project (DEMOPROJ) to encourage the voluntary implementation of FOQA programs by

U.S. airlines. The FAA project initially provided hardware and software to US Airways, United Airlines, and Continental Airlines, which met the DEMOPROJ requirements (GAO, 2002). Other airlines began to consider FOQA programs; by 1997, about 33 foreign airlines and four U.S. airlines had implemented FOQA or FOQA-type programs (GAO, 1997).

From 1997 to 2004, the FAA worked together with the Department of Justice and aviation industry stakeholders to develop a proposed FOQA rule that would be acceptable to all interested parties. In 2001, the 14 CFR Part 193 became effective and provided protection to U.S. air carriers from enforcement actions based on FOQA data; in 2004 the FOQA Advisory Circular (AC) was published by the FAA. According to the FSF (2004), the FOQA AC has provided "the most complete guidance yet for U.S. air carriers on acceptable methods of establishing a FOQA program with all the available regulatory protections" (p. 2). (An amplified timeline of notable events pertaining to the evolution of FOQA has been delineated within Table 1.)

Since the 1960s, the number of airlines that have implemented FOQA has risen steadily. Fernandes (2002) affirmed that approximately 70 air carriers worldwide had established fully operational FOQA/FDM programs by that year. (The FSF [2004] added that another 50 carriers were at various stages of establishing programs during that time.) These numbers evolved partially as a result of ICAO involvement. ICAO recommended implementation of FOQA on aircraft certificated with a Gross Takeoff Weight (GTW) of more than 20,000 kilograms (44,000 pounds) effective January 1, 2002. ICAO and EASA later ratified FOQA as a standard on airplanes with a maximum GTW greater than 27,000 kilograms (60,000 pounds) effective January 1, 2005 (FSF, 2004).

Table 1

FOQA Timeline (Adapted from the GAO, 2002; CAA, 2002; and FSF, 2004)

Date	Agency/Industry	Action
Early 1960s	British Airways / CAA TAP Air Portugal	Inaugurate use of FOQA programs.
1974	All Nippon Airways	Begins a program to analyze flight data.
1980s and 1990s	FSF	Non-U.S. airlines shared their FOQA expertise in seminars and workshops.
1993	FSF	Publishes study recognizing that acceptance of FOQA programs by the aviation industry hinges on adequate protection of data collected.
March 1993	FAA	Begins rulemaking effort. However, progress quickly stalled by airline concerns about FAA's intended use of FOQA data.
July 1995	FAA	Begins a FOQA demonstration project and issues statement indicating commitment to using FOQA data for safety analysis purposes only.
1997	DOJ	Cautioned FAA that a federal regulator may not be able to exempt regulated parties from enforcement actions, even information is submitted voluntarily.
1997-2004	FAA and DOJ	Work together to develop a proposed FOQA rule that would be acceptable to all stakeholders.
1998	FAA	Publishes a policy statement indicating intent to use FOQA data for enforcement purposes, but only when rule violations are egregious.
July 2000	FAA	Formally publishes a Notice of Proposed Rulemaking on voluntary implementation of FOQA programs by U.S. airlines.
August 2000	Joint service safety chiefs	Formally endorse military FOQA programs (MFOQA), and recommend full funding for their implementation.
July 2001	FAA	Rule issued protecting voluntarily submitted aviation safety and security data are protected from release under Freedom of Information Act.
October 2001	FAA and DOT	Publication of final FOQA rule.
November 2001	FAA	14 CFR Part 13 FOQA data inviolable.
September 2003	FAA	14 CFR Part 193 FOQA participant confidentiality.
2004	FAA	AC 120-82 FOQA programs.

Thus, FOQA has become a well established practice among fixed-wing operators, having demonstrated enhanced safety and other benefits. The growth in the number of airlines utilizing FOQA has been illustrated by Figure 1.

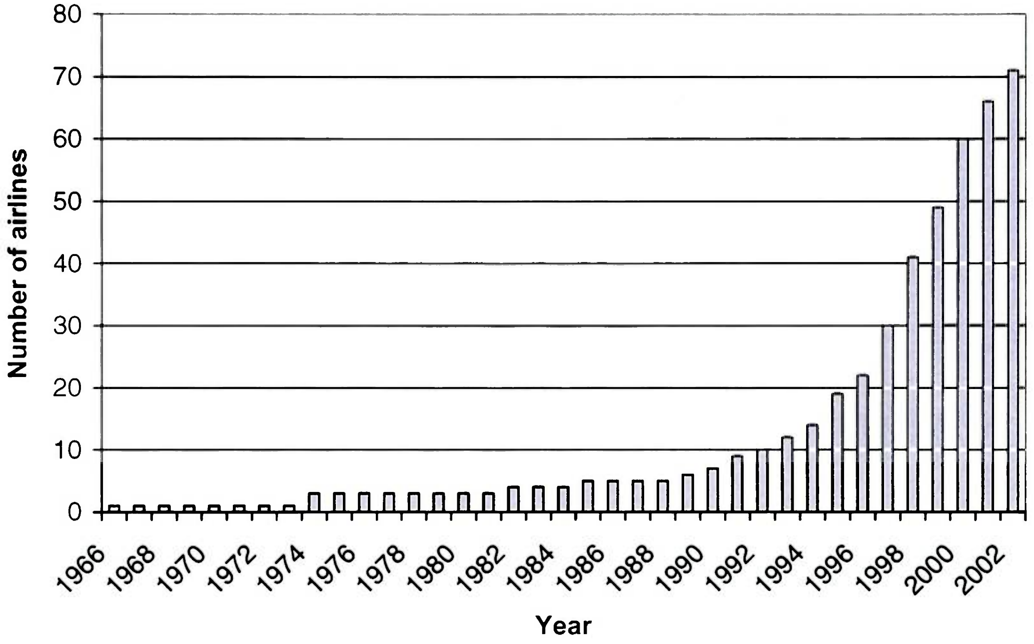


Figure 1. The Growth of the Number of Airlines that Implemented FOQA Techniques throughout the Years (Adapted from Fernandes, 2002).

FOQA Benefits

Post-crash analysis of FDR data has played a crucial role in determining accident causes. As opposed to the post-accident or -incident use, FOQA has routinely examined the digital data from uneventful airline flights to identify potential problems and correct them before they lead to accidents (GAO, 1997). The most important benefits from FOQA have certainly been safety related (CAA, 2002).

The detection of "technical flaws, unsafe practices, or conditions outside of desired operating procedures" (GAO, 1997, p. 1) has allowed improvement in "flight crewmembers' performance, air carrier training programs, operating procedures, air traffic control (ATC) procedures, airport maintenance and design, aircraft operations and design" (FSF, 2004, pp. 1-2). The Global Aviation Information Network (GAIN) stated that "a successful FOQA program encourages adherence to standard operating procedures (SOPs), deters nonstandard behavior and so enhances flight safety" (FSF, 2004, p. 2).

The CAA (2002) illustrated FOQA safety-related benefits with the results of a study by Scandia Insurance. The report compared FAA data to associated data from non-U.S. airlines as illustrated by Figure 2. The comparison underscored that airlines using FOQA data for 7-14 years had a lower accident rate than the U.S. airlines. Those airlines that used FOQA for more than 14 years had an accident rate less than half the rate experienced by the U.S. carriers.

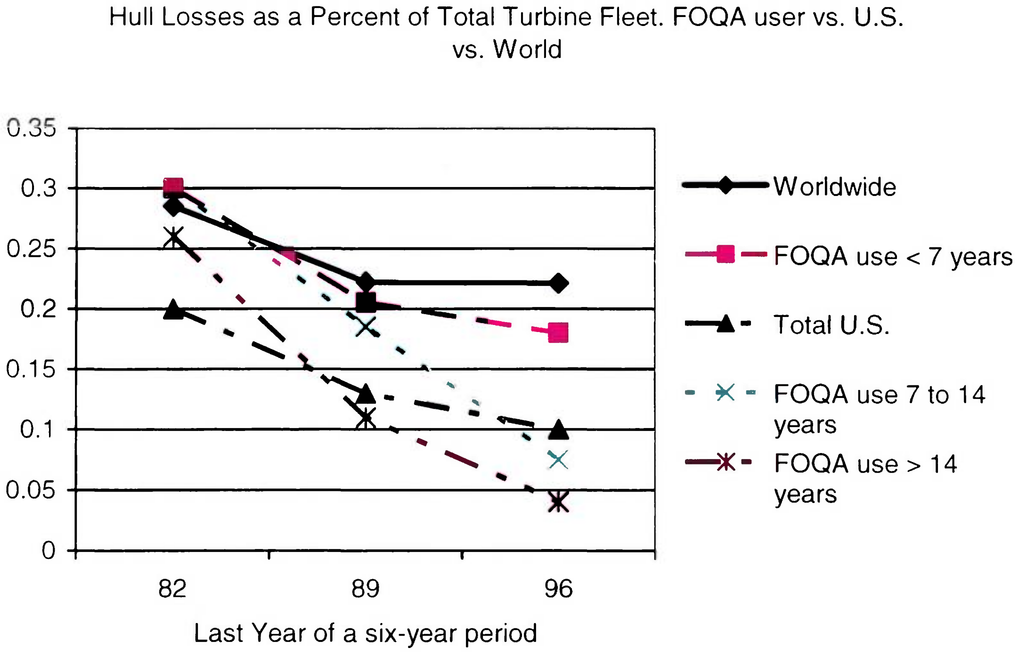


Figure 2. Safety Benefits of FOQA (Adapted from CAA, 2002).

The FSF (2004) presented flight operational issues that have been addressed by the airlines utilizing FOQA analysis:

> Air carriers with FOQA programs have used flight data to identify problems such as unstabilized approaches and rushed approaches; exceedance of flap limit speeds; excessive bank angles after takeoff; engine over-temperature events; exceedance of recommended speed thresholds; ground-proximity warning system (GPWS)/terrain awareness and warning system (TAWS) warnings; onset of stall conditions; excessive rate of rotation; glide path excursions; and vertical acceleration. (p. 2)

Another range of possibilities has been related to the scope of FOQA successes. For example:

1. The FSF (2004) described FOQA analysis as having been used to determine that "aircraft problems were induced by runway surface conditions" (p. 18).
2. Excessive tire wear resulted from ATC instructions to land and hold short of an intersection runway.
3. An instrument approach was causing unstabilized approaches and should be redesigned.
4. Minimum radar-vectoring altitudes in mountainous terrain should be increased, preventing GPWS warnings.
5. Pilot training on GPWS escape maneuvers should be improved.
6. Air carriers' warranty claims to airframe, engine, and equipment manufacturers and air carriers' insurance premiums reduction requests were reasonable ones.

Although the improvement of flight safety has been the driving force behind FOQA (FAA, 2004), the airline industry has seen cost-related benefits as well. Falcón (2003) stated that US Airways revealed that FOQA resulted in more than $100 million in maintenance savings in 5 years; ". . . its aircraft engines were frequently operating at higher than recommended temperatures. Since implementing FOQA, those overtemps have been reduced by 87 percent" (¶ 1). "Delta Airlines also experienced significant procedure improvements after putting FOQA into practice, reducing flap over-speeds [*sic*] (employing wing flaps at higher than recommended speeds) from 46 to 10 occurrences per quarter" (Falcón, 2003, ¶ 2).

The CAA (2003) summarized the following examples of where FOQA data has produced cost savings, in addition to safety improvements, for a wide range of operators:

1. Engine savings – ECM [Engine Condition Monitoring] – Postponed/reduced removals, recording of use of derate.
2. Fuel savings – trim analysis, airframe differences.
3. Fuel tankering – more accurate burn calculations.
4. Brake savings – better crew awareness and highlighting heavy use.
5. Flap maintenance savings – fewer overspeeds and use as a "drag flap."
6. Inspections savings – reduced number required due to availability of maximum values for heavy landings, engine overtemp' [*sic*], flap placard, etc.
7. Safety savings – improved safety estimated from probable hull loss rates.
8. Insurance savings – based on experience of long term FDM operators.
9. Increased aircraft availability – better/faster fault diagnosis.
10. Repair savings – reduced numbers of tailstrikes, heavy landings, etc.
11. Reduced ACARS [Aircraft Communications Addressing and Reporting System] costs – ECMS [Environmental Control and Monitoring System] and other data collection from QAR.
12. Increased simulator effectiveness – better targeted.
13. ETOPS [Extended Twin Engine Operations] monitoring – automatic rather than manual.

14. Warranty support – definitive usage evidence.
15. Autoland support – record keeping and system health/accuracy. (Appendix E, pp. 2-3)

FOQA Process and Key Elements

The CAA (2002) affirmed that the objective of FOQA systems was to enable an airline to identify, quantify, assess, and address operational risks through the "closed loop" process shown in Figure 3.

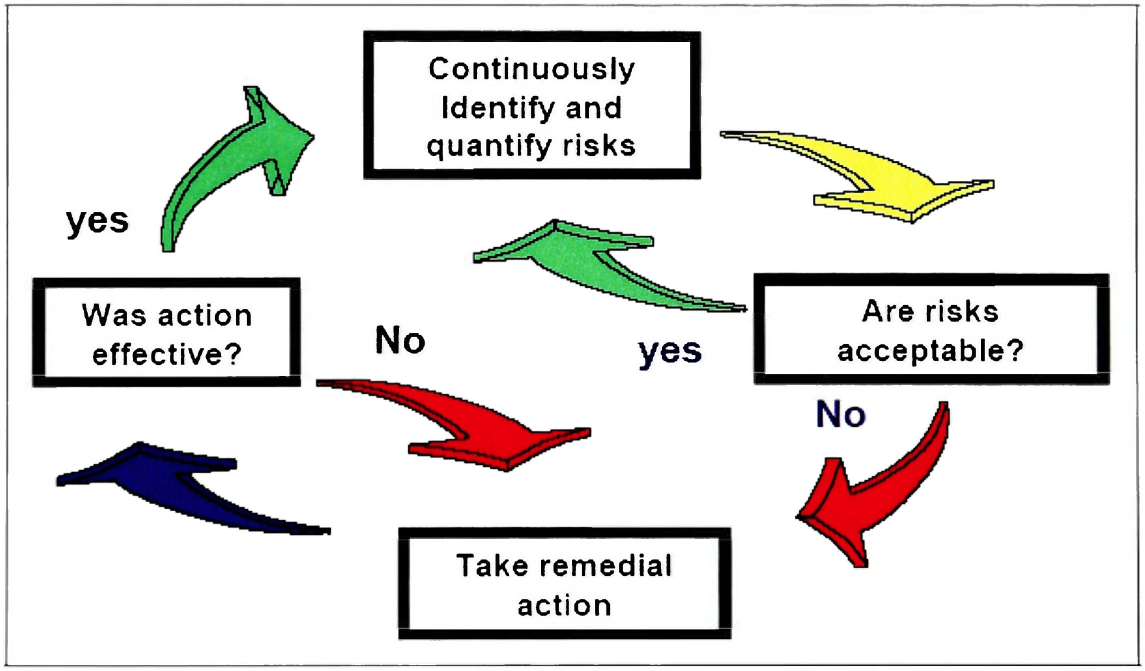
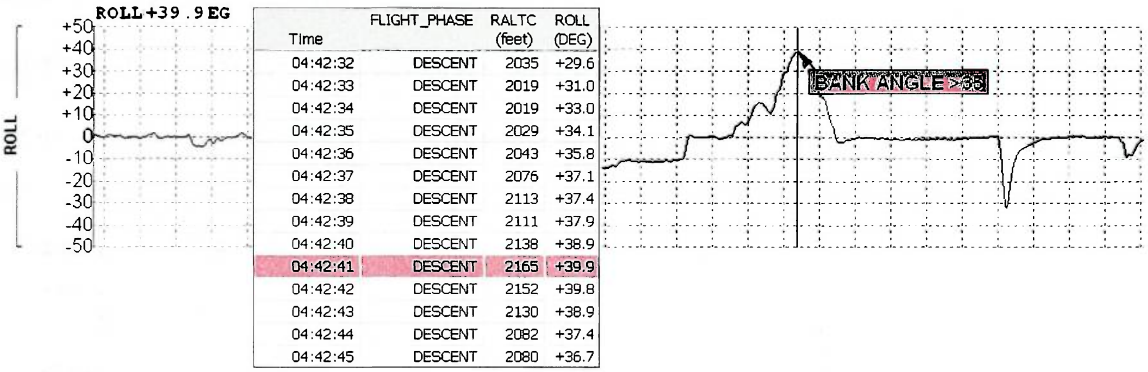


Figure 3. The "Closed Loop" FOQA Process (Adapted from CAA, 2003).

FOQA data have typically originated from various onboard systems and sensors throughout the aircraft (GAO, 1997). The Flight Data Acquisition Unit (FDAU) and the QAR, utilizing either a Personal Computer Memory Card International Association (PCMCIA) card or an optical disk cartridge as a storage device, have gathered, processed, and managed the digital data representing multiple parameters of flight. The FAA (2004) provided an overview of the total process from the data capture through the data analysis and utilization.

In the FAA-described FOQA routine, data have been periodically retrieved and sent to the air carrier's FOQA office for analysis, using one of several available transmission methods. The methods for transferring data have been ground-based transportation, electronic, or wireless transmission; all have required close coordination and the retrieval time period has needed to coincide with the recording medium's memory capacity. The FOQA office has been located within the flight safety organization of the air carrier. There, the data have then been validated and analyzed using specialized processing and analysis software, known as the Ground Data Replay and Analysis System (GDRAS). The validation process has been the data review "to see that they were not generated as a result of erroneous recording or damaged sensors" (FAA, 2004, p. 3). The two analysis techniques applied to FOQA data have been (a) the parameter exceedance analysis, or event detection, and (b) statistical analysis, or routine flight data measurement (2004). There has also been some usage of FOQA data for incident investigation.

The parameter exceedance analysis or event detection has involved examination for aircraft-parameters beyond predetermined thresholds in a specific occurrence, or a programmed event, during various phases of flight. For example, a GDRAS event could be programmed to detect each time the aircraft bank angle (the parameter analyzed) exceeded 35 degrees, as displayed in Figure 4. These data could be trended over multiple flights to determine the number of abnormal events occurring per flight segment. In addition, the data could be trended to determine phase of flight, airport, or runway, if appropriate, depending on the event type. Levels of exceedance have been programmed for particular events, based on the operator's risk assessment, to assist in focusing resources on corrective action in the highest perceived operational risk area(s) (FAA, 2004).



Time	FLIGHT_PHASE	RALTC (feet)	ROLL (DEG)
04:42:32	DESCENT	2035	+29.6
04:42:33	DESCENT	2019	+31.0
04:42:34	DESCENT	2019	+33.0
04:42:35	DESCENT	2029	+34.1
04:42:36	DESCENT	2043	+35.8
04:42:37	DESCENT	2076	+37.1
04:42:38	DESCENT	2113	+37.4
04:42:39	DESCENT	2111	+37.9
04:42:40	DESCENT	2138	+38.9
04:42:41	DESCENT	2165	+39.9
04:42:42	DESCENT	2152	+39.8
04:42:43	DESCENT	2130	+38.9
04:42:44	DESCENT	2082	+37.4
04:42:45	DESCENT	2080	+36.7

Figure 4. Parameter Exceedance Analysis, or Event Detection, of Bank Angle Greater than 35 Degrees.

Statistical analysis, or routine flight data measurement, has been used to create flight profiles. The profiles have used several measurements to build distributions of various criterion parameters. The distributions of data have shown all flights and enabled a carrier to determine risk based on the means and the standard deviations. One area of flight operations carriers have analyzed has been final approach tracks. A profile has typically been designed to measure the different criteria of an approach. Parameters involved have been airspeed, rate of descent, configuration, and power setting. For example, the GDRAS has captured the maximum airspeed of every flight on final approach. The distributions "painted a picture" of the performance of each flight. The carrier was then able to determine when an approach track resulted in an unstable approach or landing (FAA, 2004).

Similar to parameter exceedance analysis, routine flight data measurement has utilized data distributions to "drill down" and examine the phase of flight (as displayed in Figure 5), the airport, or the aircraft type. The value of using statistical analysis has been that data from all flights have been used to determine risk for an airline without focusing on specific event exceedances. The use of data distributions has developed a risk assessment process by establishing a baseline for trending data and determining critical safety concerns. Statistical analysis has been a means to determine the total performance of an airline's operation and root causes of systemic problems (FAA, 2004).

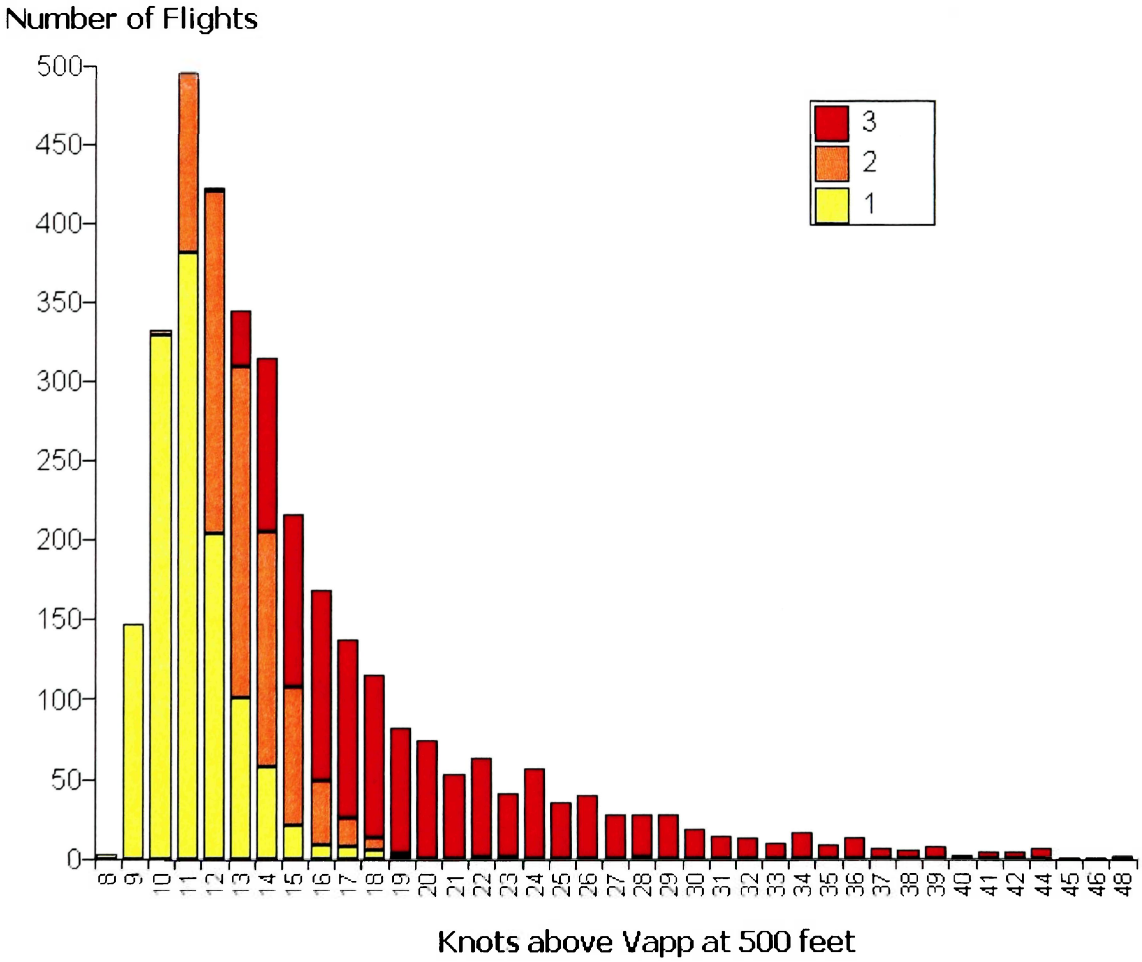


Figure 5. Routine Flight Data Measurement Utilizing a Distribution for a Phase of Flight – Final Approach at 500 Feet (Adapted from S. Wellington).

In summary, FOQA personnel utilizing GDRAS have extracted abnormal events, or exceedances, and routine operational measurements. Ultimately, these analyses were presented to those airline departments (stakeholders) that were recipients of the safety improvements and continued airworthiness benefits (CAA, 2003). Features of the GDRAS have enabled the FOQA analysts to present elaborate operational reports and flight animations. Details of the cyclical nature of the FOQA process have been illustrated in Figure 6.

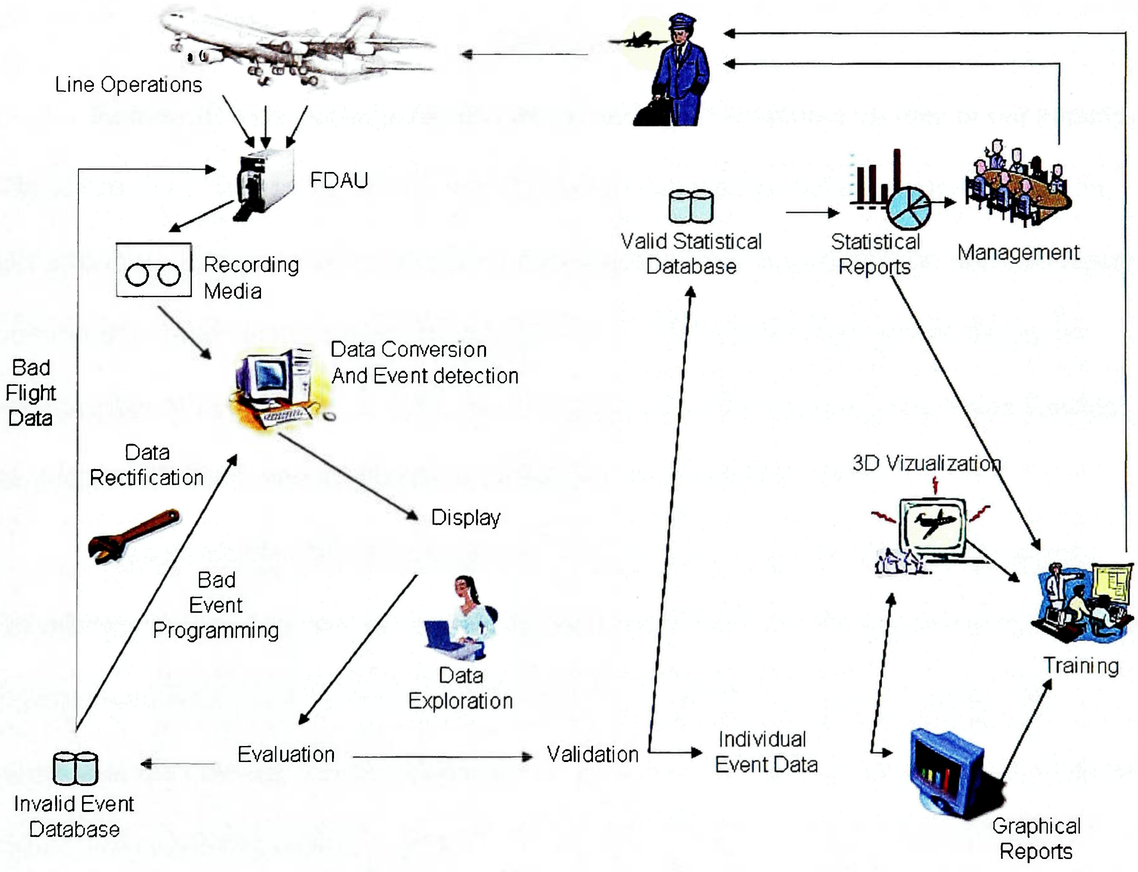


Figure 6. The FOQA Cyclical Process (Adapted from S. Wellington).

The entire FOQA process has been characterized by confidentiality. The flight crewmember identity has been removed from view (de-identified) in the electronic record as part of the initial processing of the airborne data. However, a gatekeeper, charged with the primary responsibility for the security of the identified data, has been able to link FOQA data to an individual flight or crewmember. This capability has been provided "for a limited period of time, in order to enable follow-up inquiry with the specific flight crew associated with a particular FOQA event" (FAA, 2004, p. 8). Gatekeeper identification of the flight and/or the crewmembers has been limited to situations where further insight into the circumstances surrounding an event was needed.

Helicopters

Rotorcraft have participated in a broad variety of aviation activities in our society. These activities have included not only the day-to-day routine helicopter transportation, but also those in support of relief efforts during emergency situations. The non-helicopter community could clearly perceive the importance of helicopter deployment during the catastrophes of September 11, 2001, the December 26, 2004 tsunami, Hurricane Katrina on August 29, 2005, and the Pakistan earthquake on October 8, 2005.

Approximately 265 representatives from the helicopter manufacturing industry, the military and civil operators, and the international regulatory communities attended the International Helicopter Safety Symposium (IHSS) 2005 in Montreal, Canada. The purpose of the meeting was to discuss the need for an international collaborative effort to reduce both civil and military accidents in the vertical flight industry. The two most significant achievements of IHSS 2005 were acknowledgment by all participants that the helicopter accident rate had been excessive and unsustainable, and the collaborative effort by all should be able to reduce that rate by 80% (Stevens & Sheffield, 2006).

A comparison among accident rates of different types of operations throughout the aviation industry provided a glance of the current risk involved in helicopter operations. Figure 7 has displayed accident rates used as benchmarks by the aviation industry. Although comparisons based only on accident rate calculations have not provided the most accurate picture (Wood, 2003), they have been sufficient to motivate efforts toward improved helicopter operation safety. In order to obtain a better overview of the current helicopter world, EMS, sightseeing, and offshore operations were separated, and some safety-related data were stated for each type of operation, considering their differences in equipment, mission, and/or environment.

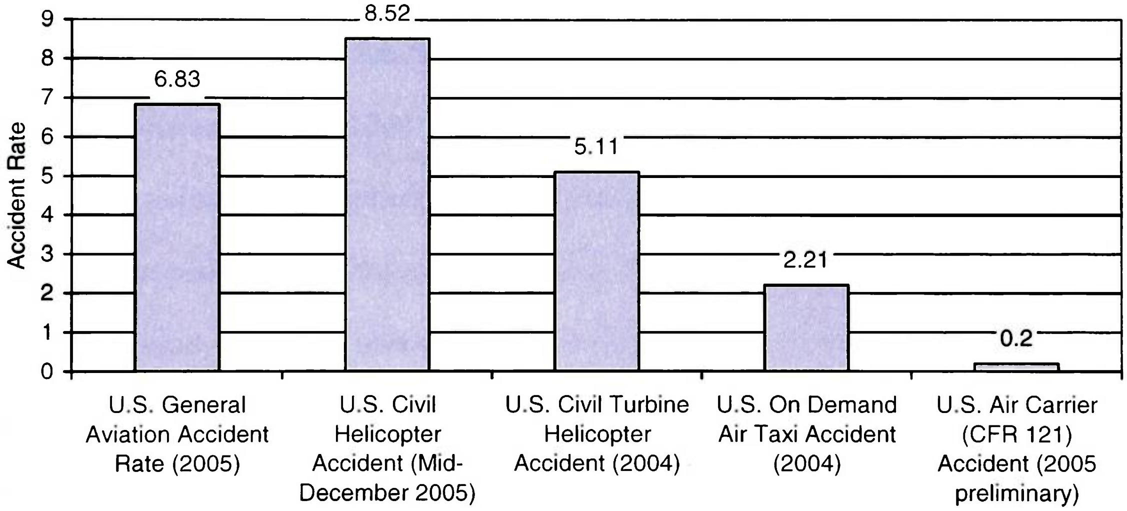


Figure 7. Representative Accident Rates per 100,000 Flight Hours (Adapted from HAI, 2006; IHST, 2006a; and NTSB, 2006a).

EMS

In January 2006, the NTSB released a Special Investigation Report on EMS Operations. It stated that between January 2002 and January 2005, 41 EMS helicopter accidents occurred in the U.S., 16 of which were fatal, resulting in a total of 39 fatalities and 13 serious injuries – numbers that had not been seen since the 1980s (NTSB, 2006d).

The number of hours flown by EMS helicopter operations has increased substantially over the years. For example, EMS helicopters flew about 162,000 flight hours in 1991 and an estimated 300,000 flight hours in 2005. Due to the increased number of hours flown, with the accident rate per flight hours over the years having remained a constant, the absolute number of accidents would be increased by approximately 85%. However, the average accident rate has also increased from 3.53 accidents per 100,000 flight hours between 1992 and 2001 to 4.56 accidents per 100,000 flight hours between 1997 and 2001. The absolute number of real accidents has become an incredible statistic. The numbers of EMS aircraft (helicopters and airplanes) accidents for the 15-year period from 1990 to 2005 has been displayed in Figure 8.

As a result, the NTSB investigated a group of EMS accidents in detail and identified recurring safety issues. These issues included "lack of aviation flight risk evaluation programs for EMS operations" and "no requirements to use technologies such as terrain awareness and warning systems (TAWS) to enhance EMS flight safety" (NTSB, 2006d, p. vii). The NTSB (2006d) also claimed that despite the FAA's positive steps to improve EMS operational safety, the FAA has not yet imposed any requirements for all EMS aircraft operators concerning risk management, or the use of current technologies. "Although the Board recognizes that the nature of EMS operations involves some risks, operators should be required to provide the best available tools to minimize those risks and help medical personnel, flight crews, and patients arrive at their destinations safely" (p. xi).

Total Injuries					
Year	Number of accidents	Number of fatal accidents	Fatal	Serious	Minor
1990	1	0	0	0	0
1991	1	1	4	0	0
1992	3	2	3	4	0
1993	3	2	5	3	3
1994	4	2	6	0	3
1995	5	1	3	0	2
1996	5	3	9	1	0
1997	3	1	4	0	0
1998	11	2	8	5	5
1999	6	0	0	6	0
2000	6	2	7	0	4
2001	13	1	1	2	2
2002	13	6	14	8	4
2003	19	3	3	2	16
2004	19	9	29	7	3
2005	13	6	13	5	5

Figure 8. EMS Aircraft (Helicopters and Airplanes) Accidents for the 15-Year Period from 1990 to 2005 (Adapted from NTSB, 2006d).

Sightseeing Helicopter Flight

The occurrence of accidents in the sightseeing-flight community has been of similar concern:

> The N.T.S.B. has recorded more than 140 sightseeing-flight accidents nationally since January 2000, 19 of them fatal. The accidents were split almost evenly among helicopters, balloons and small planes, but helicopter flights made up more than half of the fatal crashes, killing 43 people, 24 in Hawaii. (Klein, 2006, p. 1)

This high rate of accidents prompted the FAA to begin formulating regulations called the National Air Tour Safety Standards in October 2003. The proposed rules have required operators to equip their aircraft with floats and passengers to wear uninflated life vests before flights over water. The regulations have been expected to be finalized in the summer of 2006. However, organizations such as Tour Operators Program of Safety (TOPS) and Alaska's 5-year-old Medallion Foundation have recognized that operating beyond the proposed regulations has been determined as prudent, as well as more attention to the human factor in accidents.

Klein (2006) aggregated expert information on sightseeing industry safety and some industry initiatives implemented in order to improve safety. The FAA and insurance companies claimed that "the aircraft were only a small part of the problem, and that poor decisions by tour companies and their pilots – often involving weather – caused most helicopter accidents" (p. 2). In Alaska, officials have credited Capstone, an FAA program designed to improve safety through better terrain mapping and weather technology, with reducing aviation accident rates; the last air tour fatality in the state was in May 2003. Las Vegas-based Sundance Helicopters, on the other hand, after a 7-passenger fatality in the Grand Canyon in 2003 began placing unannounced check pilots on flights. These audits were designed to monitor the flights and report on discrepancies (e.g., the pilot flew below 500 feet or exceeded the prescribed bank angle [Klein, 2006]).

Offshore Helicopter Operations

The helicopter safety performance data for the offshore oil industry segment has been the most complete and believed to be the most accurate statistically. The OGP

(2006) has computed these data based on submissions from helicopter operators worldwide. The resulting statistics have provided a reference for the oil industry to remain on the OGP helicopter safety goal track. The OGP target has been that "the individual risk per period of flying exposure for an individual flying on OGP-contracted business should be no greater than on the average global airline" (Stevens & Sheffield, 2006, p. 28).

The 2004 number of offshore helicopter flights associated with all types of activity (offshore, seismic, geophysical, pipeline, and others) was 2.5 million, and the number of passengers transported was 8.5 million. A total of 20 helicopter accidents were reported, with 26 fatalities. These numbers resulted in 2.05 accidents per 100,000 flight hours or 0.80 per 100,000 flight stages (OGP, 2006). Stevens & Sheffield (2006) noted that achieving the OGP safety goal could save more than 200 offshore oil and gas workers' lives during the next 10 years.

The two biggest offshore regions for helicopter operation have been the North Sea and the Gulf of Mexico. The North Sea helicopter transportation has been required to serve large offshore platforms located at great distances from shore.

> Gulf of Mexico helicopter operations have historically been rather different. The majority of the offshore installations are located quite close to shore, and many services are performed using small single engine helicopters, some of which are not required to be fitted with emergency flotation equipment. (Rowe & Howson, 2005, p. 1)

Another contrast has been that the FAA has permitted exemptions or exceptions to the flight recorder regulations that allow transport-category rotorcraft, like some helicopters in operation in the Gulf of Mexico, to operate without flight recorders (NTSB, 2006b).

Although the Gulf of Mexico's weather climate has been relatively benign, the requirement to evacuate the platforms in advance of a hurricane, for example, would result in operations similar to those in the North Sea. Moreover, "with the development of the Gulf of Mexico's ultra-deep-water fields, the helicopter operations to these new platforms are becoming more akin to North Sea operations" (Rowe & Howson, 2005, p. 1).

The largest part of North Sea helicopter operations has been represented by the UKCS with an average of 90,000 flight hours of the total 130,033 hours flown in the entire North Sea region during 2004. Rowe & Howson (2005) summarized the safety performance of UKCS and North Sea operations over the years as follows. Since 1976, 12 fatal helicopter accidents associated with UKCS offshore operations have occurred; 118 lives have been lost since then. The North Sea offshore helicopter fleet experienced no accidents in the last 2 years for which statistics were available (2003 and 2004). The last fatal accident occurred in 2002 resulting in 11 fatalities. Previously, there had not been a fatal offshore accident since 1992. In 2004 the 5-year moving average total accident rate was 0.77 per 100,000 flying hours, and the fatal accident rate was 0.13 per 100,000 flying hours (OGP, 2006; Rowe & Howson, 2005).

Williams (2006) of the HSAC, in line with the Conference philosophy of sharing information with all operators to provoke safety initiatives, presented a relevant overview of Gulf of Mexico helicopter operations that was a representative sample of worldwide operations.

> The 2005 Gulf of Mexico oil industry helicopter accident rate per 100,000 flight hours was 2.05 with a total of 8 accidents (6 single engine, 1 each light and medium twin) compared to a 22-year annual average accident rate of 1.89. The fatal accident rate per 100,000 flight hours during 2005 was 0.51 with a total of 2

> fatal accidents (5 fatalities) compared to a 22-year average of 0.74. During 2005, improper pilot procedures and technical fault each accounted for 3 (32%) or 6 of the 8 accidents. The additional accidents causes were 1 unknown and 1 related to fuel quality control. In the last 5 years, there have been 47 accidents of which 15 were fatal (32%), resulting in 34 fatalities and 42 injuries. 23 (49%) of these accidents were due to pilot procedure related causes, 13 (28%) were due to technical fault, and the remaining accidents due other mixed factors. For technical accidents, there were 9 engine related events, 2 tail rotor events, and 2 for other technical causes. 13 of the 47 accidents (28%) were related to events around the helideck (5 obstacle strikes, 4 loss of control, 2 passenger control, and 1 each approach procedure / tie-down removal). The specific leading causes of accidents in the last 5 years have been: (a) 9 (19%) engine related and 9 loss of control with 3 fatalities in each category (6 total); (b) 4 (9%) controlled flight into terrain or water - with 7 fatalities, 4 helideck obstacle strikes with 4 fatalities, and 4 fuel quality control; (c) 3 (6%) loose cargo striking tail rotor; and (d) 3 (6%) unknown causes with 14 fatalities (1 night with 10 fatalities). Note - Although night flight accounts for less than 3% of the GoM [Gulf of Mexico] flight hours, in the last five years, the 3 night accidents accounted for 7% of the total accidents and 32% of total fatalities (11 of 34 total). 2 of the 3 events were fatal. (¶ 2-5)

Table 2 has summarized the operational data from the North Sea, the Gulf of Mexico, and other worldwide-regions offshore helicopter operations. The salient number of Gulf of Mexico single engine helicopters has been highlighted. Figure 9 has displayed 5-year accident rates for the same 2004 descriptives. It can be noticed that "the Gulf of

Table 2

2004 Worldwide Offshore Helicopter Operational Data Summary, with Number of Helicopters by Type (Adapted from OGP, 2006)

	Single engine	Light twin	Medium twin	Heavy twin	Total fleet	Passengers carried	Hours flown	Number of flights
North Sea	0	0	31	69	100	1,826,522	130,033	232,104
Gulf Mex	387	60	100	14	561	2,329,064	361,514	1,620,621
Other	46	20	300	63	428	4,031,790	361,942	440,152
Total	433	80	431	146	1,089	8,187,376	853,489	2,292,876

Mexico accident rate has become significantly higher than that in the North Sea, and this trend is somewhat surprising in view of the generally benign weather environment in the region" (Rowe & Howson, 2005, p. 1).

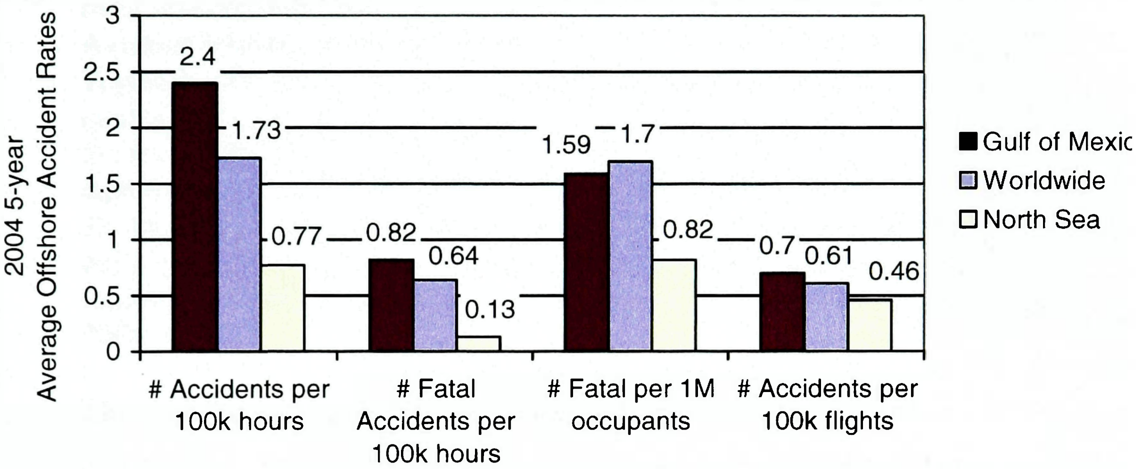


Figure 9. 2004 5-year Average Offshore Accident Rates (Adapted from OGP, 2006).

Attitudes toward Helicopter Safety

The HAI and the AHS, with a consortium of operators, manufacturers, and government regulatory agencies, announced the creation of the IHST in 2006. The commitment of all industry representatives was to work together in the voluntary Commercial Aviation Safety Team (CAST)-like environment crafted specifically for the rotorcraft community to achieve a reduction in the accident rate by 80% in 2016. The committee considered this goal to be challenging, but achievable (IHST, 2006b).

Shell's helicopter risk-reduction program has also had the goal of reducing the accident rate of their contracted-helicopter operations by 80% or more. The program has been named "7 / 7 = 1"; translated to "reduce the current fatal-accident rate for offshore helicopter operations from just under seven per million flight hours to around one per million flight hours" (Stevens & Sheffield, 2006, p. 28). (Additionally, seven key measures have been advocated for the program.) Globally, the reduction goal has been consistent with both the OGP and IHST goals; Shell's analysis showed that:

> To achieve a fatal-accident rate of one per million flight hours or less, industry must re-equip with helicopters designed to the latest requirements in Federal Aviation Regulations (FAR) 27 (for small aircraft) and 29 (for large ones). . . . Together with the established risk-reduction potential of simulator training, quality and safety management systems, HUMS [Health Usage and Monitoring Systems], HOMP, disciplined takeoff and landing profiles and defensive equipment like EGPWS [Enhanced Ground-Proximity Warning System] and TCAS [Traffic Alert Collision Avoidance System], our assessment showed that helicopters designed to the latest standards can indeed achieve the goal of reducing the fatal-accident rate by 80 percent or more. (Stevens & Sheffield, 2006, p. 30)

The NTSB has recently recommended to the FAA that:

1. All U.S.-registered turbine-powered helicopters certificated to carry at least 6 passengers to be equipped with a Terrain Awareness and Warning System (TAWS; NTSB, 2006c).
2. All rotorcraft operating under 14 CFR Parts 91 and 135 with a transport-category certification to be equipped with a cockpit voice recorder (CVR) and (FDR). Furthermore, "do not permit exemptions or exceptions to the flight recorder regulations that allow transport-category rotorcraft to operate without flight recorders, and withdraw the current exemptions and exceptions that allow transport-category rotorcraft to operate without flight recorders" (NTSB, 2006b, p. 9).

Before the current, aforementioned initiatives, offshore helicopter stakeholders had always been challenged to improve safety. The improvement of North Sea offshore helicopter operational safety has been revealing. The CAA, with the collaboration of other North Sea industry participants, experienced disappointing safety records for helicopters in the 1970s and early 1980s. This led to the formation of the Helicopter Airworthiness Review Panel (HARP). Among this group's 1984 findings were recommendations for research into helicopter health and usage monitoring, crashworthiness, and ditching. The HARP Report also called for an investigation of human factors-related accidents which led to the formation of the Helicopter Human Factors Working Group. This group reported its findings in 1987, which included recommendations for research into an additional seven, mainly operational, areas of concern (Howson, 2005).

In addition to HARP and the human factors group, a major review of offshore safety and survival was commissioned in 1993 in response to a UK Air Accidents Investigation Branch (AAIB) recommendation following the fatal accident at the Cormorant A oil rig in 1992. This study was conducted by the Review of Helicopter Offshore Safety and Survival working group, which reported its findings in 1995. The three joint initiatives by the CAA, the AAIB, and the industry formed the basis for the majority of the offshore helicopter safety research programs (Howson, 2005). The coherently developed research programs have contributed to remarkably improved safety in the helicopter operations in the North Sea region.

A review of accidents and their causes from 1976 through 2002 provided solid evidence of post-1994 improvement. The study analyzed the UKCS accident statistics by splitting the period 1976 to 2002 into three 9-year periods. A good measure of the level of improvement during the period 1994 to 2002 was the (highlighted in Table 3) reduction in the non-fatal accidents rates (both in terms of flying hours and sectors) from the previous two periods. This appeared to be largely due to the reduction in the number of technical failures since 1993. Part of this improvement could "be attributed to the introduction of Health Usage and Monitoring Systems (HUMS) on UK offshore helicopters from 1992" (John Burt Associates Limited/Bomel Limited, 2004, p. 24).

Table 3

Fatal and Non-Fatal Reportable Accident Rates in UKCS 1976-2002

	Per 100,000 Flying Hours		Per 100,000 Sectors (Flight Stages)	
Period	Occupant Fatal Accident Rate	Non-Fatal Reportable Accident Rate	Occupant Fatal Accident Rate	Non-Fatal Reportable Accident Rate
1976 – 1984	1.68	2.24	0.81	1.08
1985 – 1993	6.18	2.19	2.52	0.89
1994 – 2002	1.34	0.98	0.61	0.44
1976 – 2002	3.24	1.84	1.44	0.82

Strategies to deal with both technical failures and pilot-related accidents have emerged. One way in which helicopter technical issues have been addressed has been by the introduction of HUMS equipment (Hart, 2005). HUMS has comprised a combination of sensors, data acquisition technology, and software algorithms, both on board and ground-based. This system has been used to monitor helicopter vibration to help detect mechanical failures, which can reduce maintenance costs and improve safety (NTSB, 2006b). Alternatively, HOMP, or FOQA for helicopters, was originally tried by the CAA in 1999 to impact pilot-related accident causes.

Shell's studies provided an estimated effectiveness of FOQA for helicopters as a mitigation measure to reduce accident rates. Based on the common causes of helicopter accidents, the study concluded that FOQA had the potential to prevent about 15-17% of helicopter accidents (Stevens & Sheffield, 2006). FOQA for helicopters has been "one of the more exciting recent developments in improving the management of helicopter risk" (Hart, 2005, p. 5).

The HOMP Trial and Its Two Reports

In 1999, the CAA initiated trials of FOQA for North Sea helicopters, known as HOMP – the Helicopter Operations Monitoring Programme. The final reports on HOMP trial were published in 2002 and 2004. The trials involved two different offshore helicopter operators and two types of helicopters: AS322L Super Puma and Sikorsky S76. The results were considered successful: "In March 2004, the ICAO Helicopter Tiltrotor Study Group (HTSG) unanimously agreed to propose to add HOMP to ICAO Annex 6 Part III as a Recommended Practice for flight data recorder-equipped helicopters" (CAA, 2004, p. vi).

The HOMP's data had been acquired and transferred; the data were then analyzed in a manner that paralleled that of a GDRAS processing fixed-wing FOQA data. The data analysis performed by the HOMP software included event detection and routine flight data measurements. The CAA (2004) described the HOMP software (depicted in Figure 10, preceding the hypothesis), consisting of three integrated modules, as follows:

> 1. The Flight Data Traces (FDT) module reads in flight data from the CQAR, detects pre-[*sic*]defined events and extracts a set of flight data measurements. The events are stored together with their associated flight data and can be analysed by viewing event traces and flight data simulations (FDS) from

> within the module. Validated events and flight data measurements are exported to the other two modules. FDT has been designed to be user-configurable to allow events and measurements to be modified or added without the involvement of the software provider. This is important for filtering out any regular nuisance events.
>
> 2. The Flight Data Events (FDE) module stores the validated events generated by FDT which can be collectively analysed to determine trends in their frequency of occurrence or severity by location, operating base, pilot code, flight phase etc. Event severity values are allocated in FDT or FDE and, by performing a trend analysis of cumulative event severities, FDE provides an effective risk management tool. FDE has an optional link to the BASIS ASR [British Airways Safety Information System Air Safety Report] module which allows any air safety report information associated with a flight data event to be viewed. This enhances the tracking and management of overall safety performance. Also, individual events stored within FDE can be further analysed using a facility known as FDV (Flight Data Visualisation). This enables event traces to be analysed and flight data simulations to be run from within the FDE module itself.
>
> 3. The Flight Data Measurements (FDM) module also stores information generated by FDT but is not event based. This information is the collection of many flight data measurements for every single flight; e.g. maximum roll angle, height at gear retraction, estimated wind speed and direction at landing. Once in FDM this data can be usefully analysed in many different ways (by location, time period, aircraft registration etc.) to make comparisons and help to better understand normal operation in relation to problems identified in FDE. The module is also useful for determining realistic and effective event limits for FDT. (Section 1, pp. 2-3)

A set of HOMP flight phases (CAA, 2002) had been established, as follows: (a) on the ground (prior to takeoff), (b) takeoff, (c) cruise, (d) landing, and (e) on the ground (after landing). The set of HOMP events and a set of measurements have been described in Appendixes A and B. Two identical recommendations from the two reports were to:

> 1. Continue to develop and refine the HOMP events to maximise the safety benefits of the programme, and optimise the balance between detecting the widest possible range of operational risks and minimising the nuisance event rate.
>
> 2. Continue to develop and refine the HOMP measurements to maximise their accuracy in characterising different aspects of the operation and to provide

further analysis capabilities. (CAA, 2002, Section 11, p. 1; CAA, 2004, Section 8, p. 1)

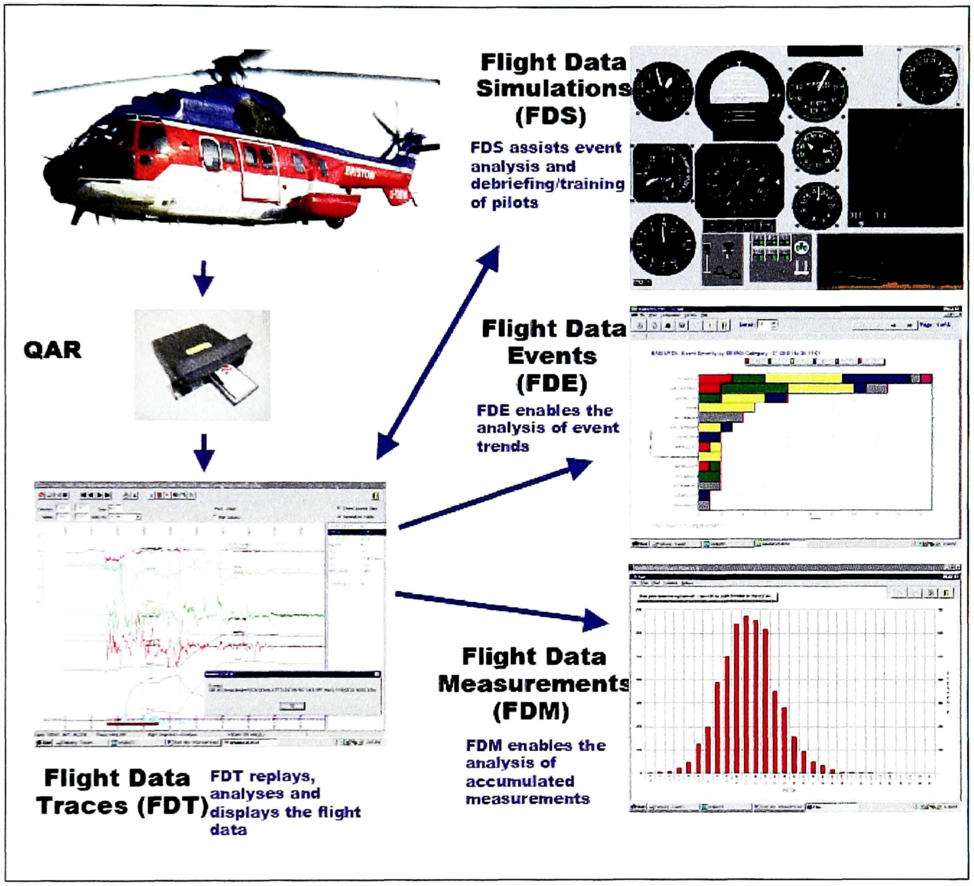


Figure 10. The HOMP System (Adapted from CAA, 2004).

The Research Hypothesis

The review of literature and the empirical HOMP studies has led to the hypothesis that flight phases, events, and measurements of the helicopter FOQA analysis software can be refined and/or developed to (a) characterize different aspects of helicopter operations, (b) detect a wider possible range of operational risks, and (c) provide further analysis capabilities. This working hypothesis has not led to deductive reasoning invoking null hypothesis testing.

Chapter III

METHODOLOGY

This study was developed during an internship with a FOQA supplier during the fall of 2005. The highly experienced FOQA vendor had been transferring FOQA know-how from the field of fixed-wing aircraft to the helicopter environment. The author, a helicopter pilot with expertise in air naval operations, and possessing limited linear programming skills, had been involved with FOQA concepts in academe. The partnering was planned as integral to the internship and provided the foundation for a research plan with three objectives. The plan was to develop a helicopter FOQA (HFOQA) version, while defining, programming, and refining the following three elements (project objectives) of the HFOQA analysis software:

1. Flight phases: The flight phases had to (a) represent the different characteristics of a helicopter flight, (b) be able to correspond to the actual flight state of the helicopter, and (c) cover a wider range of flight profiles, independently of helicopter model capabilities, or its mission.
2. Events: The events had to (a) detect a wider possible range of operational risks, (b) trigger a minimal number of false exceedances, and (c) allow, if possible, association between the event detected and the origin or destination of the flight.

3. Measurements: The measurements had to provide (a) accurate operational profiles without the preexamination of events in individual flights and (b) the maximum number of analysis capabilities.

Research Design

The three aforementioned objectives demanded actions and real world, practice-oriented solutions. Thus, the project became a problem-centered study; "instead of methods being important, the problem is most important" (Creswell, 2003, p. 5). There was a concern with application – "what works" (Creswell, p. 5). The use of "pluralistic approaches to derive knowledge about the problem" (Creswell, p. 6) was the philosophical underpinning. The three project objectives brought general philosophical ideas or "knowledge claims" (Creswell, p. 5) of pragmatism, which oriented the research to the use of a mixed methods framework.

Mixed Methods

Mixed methods could be defined as the research approach that has focused "on collecting and analyzing both quantitative and qualitative data in a single study . . . to converge or confirm findings from different data sources" (Creswell, 2003, p. 210). Because mixed methods research has been relatively new as an individual research strategy in the social sciences, Creswell encouraged that a basic description be presented. This author offered a concise report of the method and its evolvement:

> Less well known than either the quantitative or qualitative strategies are those that involve collecting and analyzing both forms of data in a single study. The concept of mixing different methods probably originated in 1959, when Campbell and Fiske used multiple methods to study validity of psychological traits. They

> encouraged others to employ their "multimethod matrix" to examine multiple approaches to data collection in a study. This prompted others to mix methods, and soon approaches associated with field methods such as observations and interviews (qualitative data) were combined with traditional surveys (quantitative data) (S. D. Sieber, 1973). Recognizing that all methods have limitations, researchers felt that biases inherent in any single method could neutralize or cancel the biases of other methods. Triangulating data sources – a means for seeking convergence across qualitative and quantitative methods – were born (Jick, 1979). From the original concept of triangulation emerged additional reasons for mixing different types of data. For example, the results from one method can help develop or inform the other method (Greene, Caracelli, & Graham, 1989). Alternatively, one method can be nested within another method to provide insight into different levels or units of analysis (Tashakkori & Teddlie, 1998). . . . These reasons for mixing methods have led writers from around the world to develop procedures for mixed methods strategies of inquiry and to take the numerous terms found in the literature, such as multimethod, convergence, integrated, and combined (Creswell, 1994) and shape procedures for research (Tashakkori & Teddlie, 2003). (pp. 15-16)

Data Collection

The data collection strategy utilized in this mixed methods approach was known as Concurrent Procedures. The collection of both the qualitative data and the quantitative data occurred at the same time (concurrently) in the research process. No greater priority or weight was given to a specific type of data; the qualitative and quantitative information were equally treated. The two types of data were integrated during the analysis and interpretation stages of the study; no overall theoretical perspective guided this strategy (Creswell, 2003).

The data originated from different sources. The qualitative data sources were represented by a helicopter pilot (the author), FOQA specialists and programmers, and an offshore helicopter operator chief pilot. The quantitative data sources were helicopter FDAUs. The selected sources were chosen to concurrently gather subjective data from a high level of expertise with accurate, objective data to incorporate and cross-validate all aspects of HFOQA programming. All data collection was oriented to achieve the real world solution for the HFOQA development.

The author was the main source of helicopter expertise as well as the computer programmer. Subjective helicopter expertise was applied throughout the programming process (e.g., knowledge of how the in-flight helicopter behavior was translated into parameter indications). Company FOQA specialists and programmers were consulted for data concepts pertaining to FOQA know-how or programming expertise (i.e., when, during the programming process, the author was unable to code information into the HFOQA software programming language). Information from the offshore helicopter operator's chief pilot encompassed the limit values of parameters, or sensitive issues regarding established SOPs.

The quantitative data retrieved from helicopter FDAUs were de-identified digital flight data. This objective information confirmed (corroborating or contradicting) the linear programming. Extensive reliance upon the digital flight data was employed during the analysis and interpretation process of the study. A total of 1,014 flights with different origins and destinations comprised the quantitative data set. Table 4 has displayed an overview of the research design utilized.

Data Analysis, Interpretation, and Validity

The author was primary trained to work with the HFOQA GDRAS and its programming language for 2 weeks. This GDRAS has been used by fixed-wing community with FOQA, included several major U.S. and worldwide airlines; it has been considered as one of the most capable in terms of functionality and processing (Wu, 2005). The combination of the GDRAS intuitive interface, together with its practical environment, allowed the author to gain knowledge of HFOQA programming techniques in a short amount of time.

Table 4

Research Design (Adapted from Creswell, 2003)

Mixed Methods Framework Elements	
1. Knowledge Claims	Pragmatic Assumptions
2. Strategies of Inquiry	Concurrent Procedures
3. Qualitative Data Sources	Helicopter and FOQA Experts
4. Quantitative Data Sources	Flight Data Acquisition Units (FDAUs)
5. Data Priority	Equal
6. Data Integration	At Data Analysis
7. Theoretical Perspective	Implicit

Accordingly, the programming stage of the study was divided into the established project objectives. The first 4 weeks of the stage were dedicated to work on the definition of the HFOQA flight phases. Upon completing and validating the definitions of the flight phases, the next 4 weeks were committed to the creation and refinement of the HFOQA events. Finally, the last 4 weeks of the study were devoted to the development of HFOQA measurements and statistical reports. (Table 5 has illustrated the study's overall timeline.)

Definition of HFOQA Flight Phases

The HFOQA GDRAS contained several modules, including one for event detection and another for statistical reports. However, before finding events or assessing

Table 5

HFOQA Study's Overall Timeline

Task	1st Step	2nd Step	3rd Step	Duration
1. HFOQA Programming Language Training	–	–	–	2 Weeks
2. Definition of Flight Phases	Selection of relevant helicopter flight segments	Selection of parameters for usage in composing the program	Programming	4 Weeks
3. Definition of Events	Selection of operational events	Selection of maintenance events	Programming and establishment of severity levels	4 Weeks
4. Definition of Measurements and Statistical Reports	Program HFOQA to store parameters of all flights in its maximum, or minimum conditions	Creation of safety/ efficiency operational procedures; program HFOQA to store related parameter values	Programming of standard statistical reports	4 Weeks

operational statistics, the HFOQA GDRAS had to recognize and correctly represent helicopter flights. The helicopter flight phases programming stage was vital; flight phases were to provide the logic for the helicopter's flight behavior with respect to its regime and location for all other HFOQA features and modules. For example, the importance of well-defined flight phases became decisive during the analysis process of a detected event in a given location of the helicopter flight path. The occurrence of a specified bank angle exceedance, whether identified in a cruise flight phase above 500 ft, or during the takeoff close to the terrain, resulted in totally different concerns and mitigation actions.

The first step of the flight phase definition and programming was to segregate a typical helicopter flight path into singular and unique pieces/segments; for example, (a) on the ground, (b) taxiing, (c) hovering, (d) climbing, (e) cruising, and (f) landing. These segments had to accurately correspond to significant helicopter flight characteristics during the period beginning with the preflight (commencing when the aircraft has initially been electrically powered) through the helicopter "engine shutdown." These selected pieces of flight became the flight phases to be programmed.

Having chosen the relevant segments of a helicopter flight path (flight phases) to be programmed, the second step was to comprehend and decide upon the recorded and/or software-calculated helicopter parameters for usage in composing the program. These parameters needed to have values that varied remarkably and according to the flight phase changes. The parameters were to trigger a flight phase start and end in the programming stage.

The programming stage of the selected helicopter flight phases was the third step. The HFOQA flight phase programming encompassed assembling the conspicuous parameters with the flight phase concepts in the HFOQA GDRAS language. Throughout the process, the digital flight data were used to verify the effectiveness and accuracy of the computer-generated flight phases. Following the programming stage, validation of the HFOQA flight phases definition was conducted through peer examination by FOQA specialists and programmers.

Definition of HFOQA Events

As the 7th week of the study commenced, the definition and programming of HFOQA events became necessary. The project dictated that both operational and maintenance risks must be detected by HFOQA. All parameters in a specific flight profile that could affect flight safety, efficiency, or SOPs needed to be monitored for exceedances. Consequently, it was decided that three levels of severity would be established for each of the monitored parameters.

The first step of the events programming was to define the events to be programmed. For the operational events, the HOMP trial events (Appendix A) were used as the basis. Events from HOMP were selected that, having been programmed, could have their effectiveness verified by the available flight data. New operational events, based on safety, efficiency, and the operator's SOPs, were also established. Definition of the maintenance events was directed by the helicopter maintenance manual.

The programming process occurred as the second step and concurrently with the establishment of severity levels for each event. The events were programmed in a manner to probe deeper than the event detection, thereby allowing for any future correlations between the detected event and the flight origin or destination, where applicable. Three severity levels and their respective limits were assigned for each event: level 1 for low severity, level 2 for medium severity, and level 3 for high severity. The quantitative flight data were used to verify if events that occurred were actually detected, and if the established limits for the severity levels were appropriate. Descriptive plots (e.g., normality of distribution) of the flight data were also generated as a reasonable check of the event detections and their assigned limit levels.

The validity check of the events definition was, once again, conducted via peer examination by FOQA specialists and programmers. The determined event limits for each severity level were also peer-validated by the aforementioned offshore helicopter operator's chief pilot. Furthermore, the overall event detection capability was validated through generated flight data from a specific real world test flight designed for that purpose.

Definition of HFOQA Measurements

The GDRAS used in this study allowed both measurements and/or a choice of statistical analysis procedures. The analysis capabilities permitted the GDRAS to offer overviews of distinct characteristics of flight operations. Correlations between the behaviors of different parameters during any desired flight profile, or specific destination (e.g., absent the preexamination of individual flight events), were possible. Specifically, a FOQA analyst could view the distribution of maximum speed values as a measure (e.g., during the approach flight phase to a given airport) in a plot with outliers and/or other relevant descriptive statistics (the mean, the standard deviation, etc.). Thus, the core strategy of this portion of the study was to actualize those statistical analysis capabilities for helicopter parameters and the created flight phases, while developing standard statistical reports for the HFOQA GDRAS.

The first step was to program the HFOQA GDRAS to store each operational or maintenance parameter (pertinent to prior programmed events) for all flights in its maximum, or minimum, condition. In addition to those event-related measurements, the second necessary step was to create and program the measurement of specific safety/ efficiency operational procedures as additional, distinct features. For example, a FOQA analyst would be able to evaluate how much time a helicopter typically endured between arriving at the offshore rig and completing the landing.

In completing the HFOQA statistical module, a set of standard statistical reports was made available to the HFOQA analyst. The programmed set included reports of the two types of measurements – those related to events and those that were specific safety/ efficiency operational procedures.

The real world flight data were used throughout the programming process to verify the utility, the functionality, and the concinnity of the statistical reports created. The validity check of the HFOQA statistical reports was addressed with peer examination by FOQA specialists and programmers. Some of the created measurements for the safety/ efficiency procedures were validated by real world flight data from the aforementioned test flight. The results of the methods employed in developing the HFOQA software have been presented in Chapter IV.

Chapter IV

RESULTS

The working hypothesis that HFOQA analysis software could be refined and/or developed to (a) characterize different aspects of helicopter operations, (b) detect a wider possible range of operational risks, and (c) provide further analysis capabilities guided the methodology. Mixed methods were utilized to combine digital helicopter flight data with (a) the helicopter expertise of the author, (b) shared FOQA knowledge, (c) one offshore helicopter operator's SOPs, and (d) aircraft maintenance manual data. The development of HFOQA analysis software resulted in the emphasis of HFOQA flight phases, HFOQA events, and HFOQA measurements that promised direct application in the helicopter industry.

HFOQA Flight Phases

The concept behind the flight phase development was to program HFOQA with the most extensive spectrum of helicopter flight situations. Consequently, the HFOQA software was programmed with recognition and representation capabilities that feasibly encompassed the broadest range of helicopter flight profiles. HFOQA thus precisely identified and demonstrated what the helicopter was doing at any given moment from the preflight (commencing when the aircraft has initially been electrically powered) through the helicopter engine shutdown. A total of 17 flight phases were established and programmed to accurately cover different helicopter model capabilities and missions.

Figure 11 has depicted the HFOQA flight phases during a typical helicopter flight profile. (Differences in flight phases in comparison to the fixed-wing phases of flight have been illustrated.)

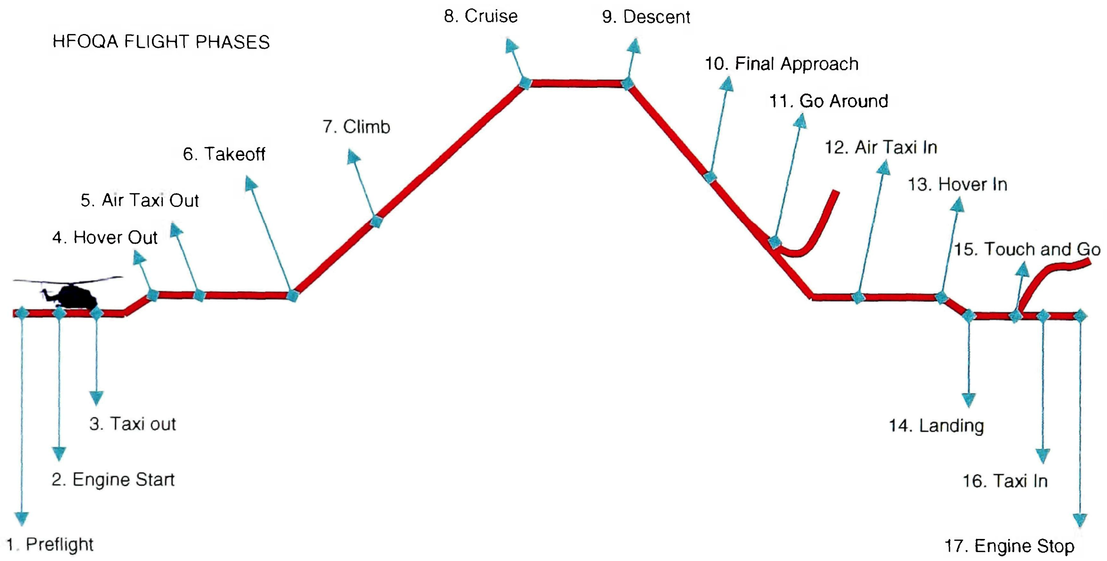


Figure 11. HFOQA Flight Phases.

The HFOQA flight phases of Figure 11 have been defined and/or briefly explained as follows:

1. Preflight – A standby flight phase utilized by the software as a reference that flight initiation has occurred.
2. Engine Start – At least one engine has experienced rotation.
3. Taxi Out – Helicopter has moved on the ground (on its wheels, if equipped) before flight.
4. Hover Out – Helicopter has become airborne, with no speed, before flight.
5. Air Taxi Out – Helicopter has become airborne (close to the ground), moving at a slow speed before flight. This flight phase has been useful to identify the

taxi of a helicopter with skid/float landing gear and no capability to move on the surface on its own wheels. The taxi of this aircraft has occurred after the hover flight phase.

6. Takeoff – The helicopter has departed its origin to accomplish its mission.
7. Climb – Helicopter has ascended from point A enroute to point B.
8. Cruise – Helicopter has achieved level flight during transition from point A enroute to point B.
9. Descent – Helicopter has left level flight for arrival at point B.
10. Final Approach – Helicopter has commenced preparation for landing.
11. Go Around – Helicopter commenced the final approach; however, for any unexpected reason, it was obligated to abort the landing, probably in compliance with emergency procedures.
12. Air Taxi In – Helicopter has completed the arrival, but is in the air (close to the ground) moving at a slow speed. This flight phase has been necessitated by the taxi of a helicopter with skid/float landing gear and no capability to move on the surface on its own wheels.
13. Hover In – Helicopter has remained airborne after arrival, with no speed.
14. Landing – Helicopter touch down following arrival.
15. Touch and Go – After landing, helicopter due to any unexpected reason has been obligated to takeoff, probably in compliance with emergency procedures.
16. Taxi In – Helicopter has moved on the ground (on its wheels), after flight.
17. Engine Stop – Engines have been shutdown.

HFOQA Events

The event programming stage utilized the HFOQA automatic event detection capabilities of the software. A project objective was to detect a wider possible range of operational risks, while minimizing false exceedances. Furthermore, both operational and maintenance hazards were to be addressed by the developed HFOQA events.

The study developed 88 HFOQA operational events and 18 maintenance events. A real world test flight, designed explicitly for the purpose of detection of some of these operational and maintenance events, was flown. (Appendix C has listed the developed operational events.) Table 6 has depicted the maintenance event list.

Table 6

HFOQA Maintenance Event List

	Maintenance Event Name
1	Single Engine Flight
2	Exhaust Gas Temperature (EGT) Monitoring during Engine Start
3	EGT Monitoring during Takeoff
4	EGT Monitoring during Flight
5	Torque Split
6	Torque Sum of Two Engine Flight
7	Torque Sum of Two Engine Flight above 104%
8	Torque of Single Engine Flight above 127%
9	Torque of Single Engine Flight above 135%
10	N1 of Two Engine Flight above 100%
11	N1 of Single Engine Flight above 101.2%
12	N1 of Single Engine Flight above 104.6%
13	N1 Maximum Continuous
14	N1 Monitoring during Takeoff
15	N1 above of the 2 Minutes Limit
16	N1 above of the 30 Seconds Limit
17	N2 Maximum Exceedance
18	N2 Minimum Exceedance

Digital flight data were one of the means for verification and validation of the programming utilized throughout the study. Figure 12, for example, has displayed the use of objective flight data to verify the accuracy of the event detection and the rationality of the established severity level limits. The available flight data represented typical flights (i.e., normal flights with no reported incidents). As such, if the established severity level limits were sound, the number of levels 2 and 3 events encountered would be smaller than the number of level 1 events. This rationale was utilized to refine the preliminary limits (assigned for those monitored parameters in conditions with no required SOP controls) and prior to the final, decisive word of the offshore helicopter operator's chief pilot. Figure 12 has depicted a sample of the aforementioned technique applied during a preliminary stage of the study.

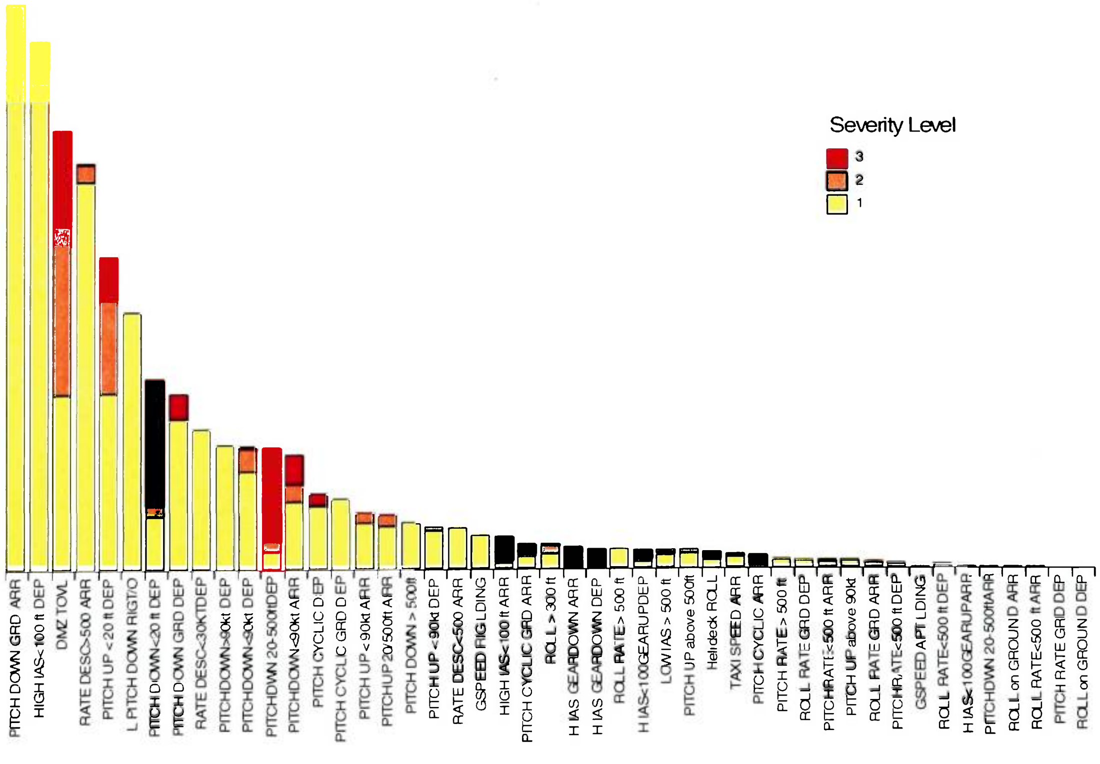


Figure 12. Event Detection and Severity Level Verification.

An example of the use of the quantitative flight data as a validation tool has been depicted in Figure 13. A real world test flight was designed to explicitly provide maneuvers that would generate exceedances. Each maneuver duplicated a possible real flight situation. For example, maneuvers such as (a) go around, (b) split engine torques, (c) bird strike avoidance maneuver, (d) orbital patterns, and (e) high speed taxi were included in the test flight. The safety boundaries of the test flight were reviewed and approved by the operator's flight safety officer. Figure 13 has displayed the test flight path in a latitude/longitude (de-identified) plot and included the events detected by HFOQA due to the intentionally induced exceedances.

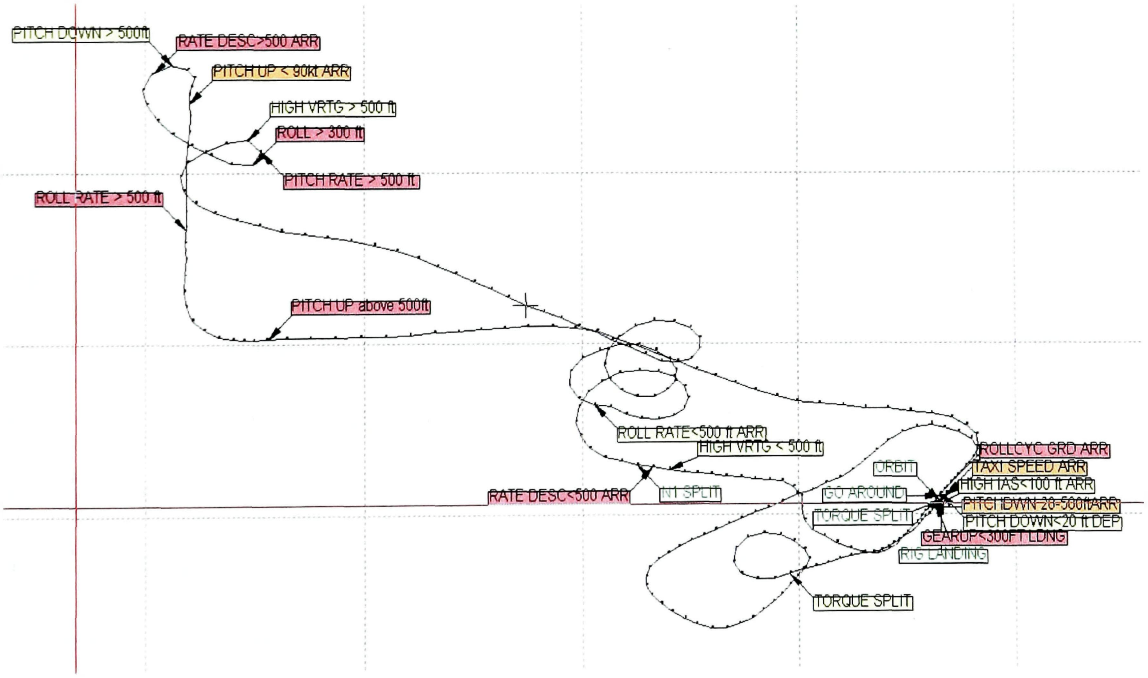


Figure 13. Event Detection Test Flight.

HFOQA Measurements

The principal goal of the measurements programming process was to enhance the previous HFOQA status of exceedance detection software to an operational analysis tool. The result was that the software's enhanced statistical capabilities allowed broader analysis studies and overviews of the ongoing helicopter operations without any preexamination of events in individual flights.

There were two types of measurement in this HFOQA study. The first type of measurement was related to the operational or maintenance parameters that were already included in the programmed HFOQA events (see Appendix C and Table 6). Each of those parameters was programmed to be measured and stored not only when an exceedance occurred, but also during all flights when any of the following occurred: (a) the parameter's maximum value, (b) the minimum value, or (c) a specific relevant condition. Additionally, helicopter altitude and velocity data at the moment of the registered maximum and minimum values were also recorded.

The second type of measurement created was that associated with other specific procedures of safety/efficiency interest. Procedures were developed and programmed to measure and store relevant information (aside from those predetermined maximum or minimum parameter values of programmed events) of particular safety/efficiency flight profiles for future operational comparisons or analyses. These measurements were expatiated to address the operational necessities of the offshore helicopter industry. Table 7 has presented these additional HFOQA measurements.

Following the measurements, the final, standard statistical reports, either with parameter correlations in the appropriate flight profiles or with the safety/efficiency procedures of interest, were developed for the HFOQA statistical report module. Some examples of these reports have been presented in Figures 14-16.

Table 7

HFOQA Safety/Efficiency Flight Profile Measurements

	Name	Definition
1	Dead Man's Curve (DMC)	Measure and store flight profile data in each takeoff or landing and compare with the helicopter model's DMC
2	Rig Landing	Measure and store flight profile data during rig landing
3	Orbit Snapshot	Measure and store flight profile data and time if the helicopter executed more than two orbits before landing
4	Helideck Movement	Measure and store helicopter parameters when landed on offshore platform to capture platform movement information.
5	Hot Plume	Measure and store outside air temperature to detect hot gas flow when landed on the offshore platform

Figure 14 has displayed a report concerned with the comparison between helicopter flight profiles and the helicopter's Dead Man's Curve (DMC) during takeoff from offshore platforms and airport runways. The DMC, or height velocity curve, is a chart (height on the y-axis and velocity on the x-axis) depicting combinations of airspeed and altitude that do not provide sufficient stored energy to permit a safe landing of the helicopter in the event of an engine failure (Cantrell, 2006). The risk exposure (for engine failure) of helicopters that made takeoffs from airport runways was minimal when compared to helicopter departures from offshore platforms. (Blue dots represent the actual helicopter flight profiles and their heights and velocities during takeoff; black dots represent the DMC.) In theory, helicopters experiencing engine failure inside the curve composed by black dots would not be able to recover and fly, or safely recover and land.

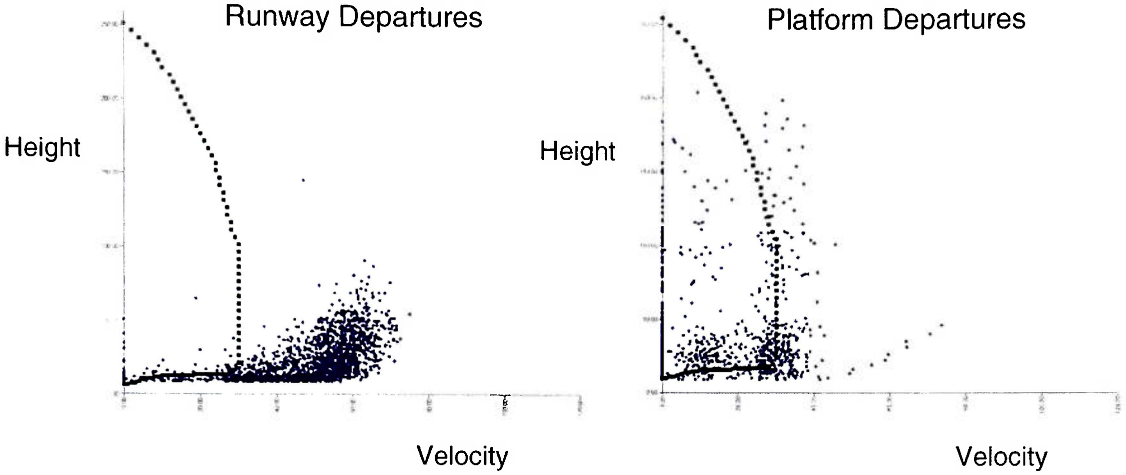


Figure 14. Helicopter Departures and the Dead Man's Curve Report.

Another HFOQA standard report has been presented in Figure 15. The helicopter flight attitude (when flying below 20 ft of altitude) was monitored. The possibility of tail strike during operations close to terrain (such as takeoff and landing) was of concern. The study demonstrated the maximum pitch-up values in blue and the average heights in red.

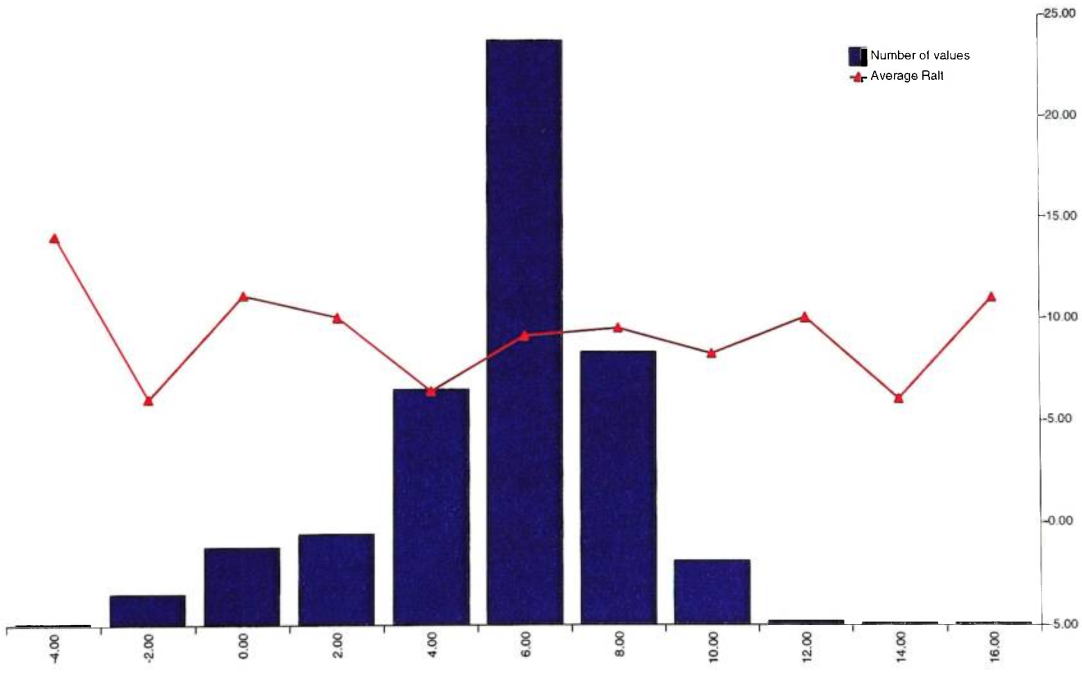


Figure 15. Maximum Pitch-up below 20 ft versus Height Report.

Figure 16 has represented a standard report created to allow assessment of route risk in terms of number of events. The number of events per year for each route flown (de-identified) has been displayed in a bar graph.

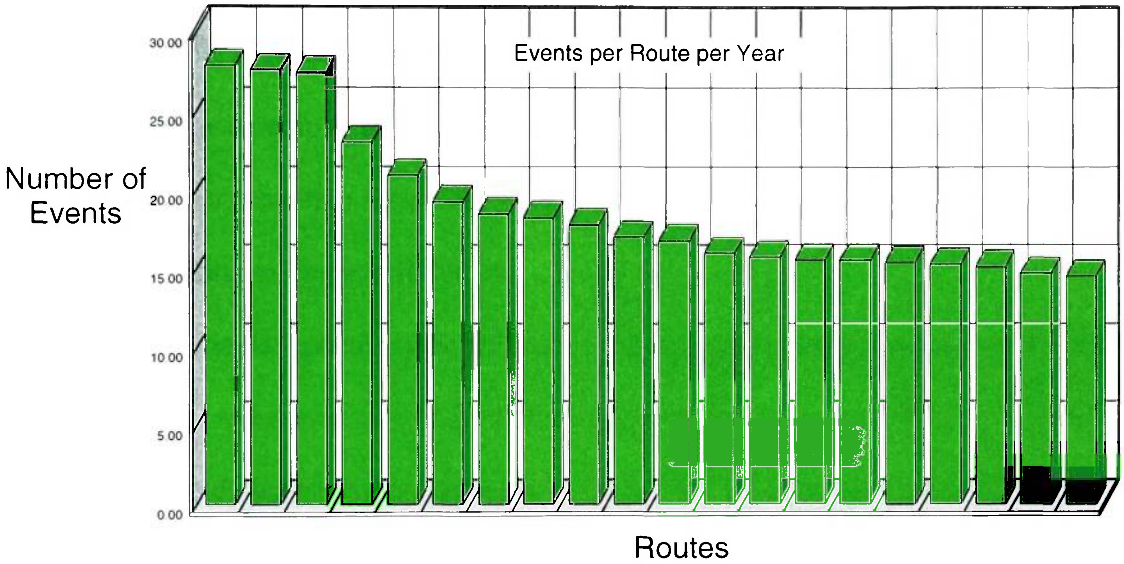


Figure 16. Number of Events per Route per Year Report.

The result has enabled risk comparison in terms of parameter exceedances for the routes considered. Interpretation of the results presented throughout Chapter IV has been discussed in Chapter V.

Chapter V

DISCUSSION

The practical results of this study can be concisely interpreted as the generation of HFOQA. The partnership comprising the helicopter operator, a FOQA analysis software vendor, and a representative of academia assembled the necessary requirements, tools, and research efforts to develop HFOQA.

Addressing the specifics, the HFOQA analysis software was prepared to be used by the helicopter industry in any of its different types of operations. In fact, the HFOQA process has already been used in a successful manner by the aforementioned offshore helicopter operator in its daily operations.

The HFOQA GDRAS was developed from a capable, well recognized, and highly accepted fixed-wing FOQA GDRAS. Extensive prior fixed-wing experience of the FOQA vendor was critical to the efficiency and accuracy of the project. The single helicopter operator presented its needs and a sample of de-identified digital flight data, thereby providing both the required motivation and the check-and-balance necessary to achieve the utilitarian, real world solutions.

Ultimately, integration of the industry apparatus and requirements with the research knowledge and capabilities of the academic representative were vital in achieving the results of the study. In line with the flow of the software development process, the chronological interpretations that follow address the three objectives of the project: HFOQA flight phases, HFOQA events, and HFOQA measurements.

Interpretation of HFOQA Flight Phases

The diverse helicopter flight attitudes, encountered from the preflight (commencing when the aircraft has initially been electrically powered) through the helicopter's engine(s) shutdown, were characterized by relevancy and parsed into flight phases. Each of the created flight phases (see Figure 11):

1. Had a significant operational meaning.
2. Was considered essential to the understanding of helicopter flight.
3. Provided statistical tracking of events and measurements.

Total reprogramming of the fixed-wing GDRAS used as the basis for the HFOQA GDRAS was necessary to address the characteristics of helicopter flight. Several specifics differentiated a helicopter flight profile from a fixed-wing flight profile; for example, the helicopter's hover capability. Moreover, different models of helicopters required different manners to achieve distinct flight characteristics. For example, one helicopter might be able to perform a running takeoff from a runway on its own wheels, whereas another model of helicopter has needed to assume a hover attitude prior to takeoff. Thus, Chapter IV's programmed HFOQA flight phases included all types of helicopters and their capabilities, primarily during the close-to-the-ground flight maneuvers (e.g., the programmed HFOQA flight phases: [a] Air Taxi Out/In, [b] Go Around, and [c] Touch and Go need further amplification).

Air Taxi Out/In flight phases were programmed to specifically address the operation of a helicopter with skids or float landing gear. Taxiing of this type of helicopter has occurred after the rotorcraft has become airborne, due to the absence of wheels. Skids have proliferated as landing gear on helicopters. Landing gear consisting of the less common floats for helicopters have been employed by those operators that needed to land on lakes and/or rivers.

The Go Around HFOQA flight phase represented an aborted landing of a helicopter that had commenced the final approach. The Touch and Go HFOQA flight phase has occurred when, after landing, the helicopter has been obligated to takeoff again. These two HFOQA flight phases were programmed to monitor critical, assumed helicopter flight states during the significant phase of approach for landing.

Usually, the need for a Go Around could be determined by either ATC or the pilot in command; for example, when an obstructed landing area has presented itself or an unstabilized approach has occurred. However, in many helicopter operations, landings have occurred in unfamiliar areas with no ATC services available. Therefore, the decision to Go Around has become solely the captain's initiative, thereby increasing the risk of the operation.

The Touch and Go occurrences envisioned during the programming process were, for example, those related to the pilot's maneuvering to avoid a helicopter ground resonance phenomenon. The ground resonance phenomenon has developed when the helicopter rotor blades move out of phase with each other and cause the rotor disc to become unbalanced. This emergency situation has resulted in the entire hull being ripped apart by the aircraft's own extreme oscillations, especially when the skids or wheels have touched the ground lightly. If the pilot has maintained the rotor rpm within the normal operating range after touchdown, immediate takeoff can restore rotor balance. In other words, breaking contact with the ground has been the best technique to break free of a ground resonance incident (Lewis & Darbo, 2006).

Interpretation of HFOQA Events

The programmed HFOQA events, as introduced in Chapter IV, consisted of operational and maintenance events. Each HFOQA event was designed with three levels of severity. A real world test flight was flown to evaluate the software capability to precisely detect the programmed HFOQA events.

The resultant HFOQA operational events (see Appendix C), when applicable, were designated with the words DEP (Departure) and ARR (Arrival). The events with the DEP designation were related to those programmed to detect parameter exceedances prior to the Cruise phase of flight. Alternatively, the ARR designated events were those planned to identify parameter exceedances that happened during and after the Cruise flight phase. Thus, this defined approach to the HFOQA event programming process allowed the recognition, through trend analysis, of whether a detected event was likely to be related to some operational characteristic of the flight's origin (detected DEP events) or the flight's destination (detected ARR events).

The resultant HFOQA maintenance events basically covered the recorded maintenance parameters available, and their established limits, at the time of the project development. Beyond the principal function of maintenance anomalies detection, HFOQA maintenance events were demonstrated as being a powerful tool complementing the flight operational data during specific incident investigations.

An essential element of the event composition was its severity level. The method applied (presented in Chapter IV, Figure 12) in verifying the preliminary established limits was effective. Validation of those limits, provided by the offshore helicopter operator's chief pilot, resulted in minor refinement.

The ultimate verification and validation of the HFOQA events detection capabilities were successfully effected through the real world test flight (see Figure 13). All assigned exceedances (both operational and maintenance event-related) included in the test flight were detected, and their levels of severity were correctly identified. In addition, no falsely detected exceedances were observed.

Interpretation of HFOQA Measurements

The HFOQA GDRAS has automatically stored in its data base several parameter measurements from all input flight data replayed. The two types of HFOQA measurements (event-related and safety/efficiency flight profile) introduced in Chapter IV enhanced the HFOQA software storage of desired data, thereby enabling a vast array of statistical analysis capabilities. Some statistical analysis procedures, considered to be of most frequent use, became HFOQA standard statistical reports.

Two results substantiated the establishment of measurements associated with HFOQA events as a valuable strategy. First, this approach assured that relevant information was being stored, provided the data comprised parameters generated by prior recognized risks (events). Second, the adopted measurement strategy was able to anticipate the actual events. After the event-related measurements programming, the spectrum of stored parameter data available increased significantly, as did the HFOQA statistical analysis capability.

Despite the fact that event-related measurements added a significant amount of data to the HFOQA statistical module, the second type (safety/efficiency flight profile) of measurements added little data, but the data were operationally-specific. The safety/

efficiency flight profile measurements, depicted in Table 7, were created to address requests from the offshore helicopter operator. The five measurements listed successfully addressed critical points of interest for the offshore operation. The measurements were elaborated to assist in the analysis of issues that have affected offshore helicopter flight performance on, or around, the offshore platform. For example:

1. The behavior of the helicopter during takeoff and landing, from and onto the oil rig, were assessed through the DMC and rig landing measurements.
2. The characteristics of the offshore platform in terms of movement (roll, pitch, and heave), and air temperature were covered by the helideck movement and hot plume measurements.
3. The in-flight helicopter that has arrived at the oil rig, but has waited for landing for a certain (unacceptable) amount of time, was addressed through the programmed orbit snapshot measurement. This measurement has been salient, because it has allowed observance of any unnecessary helicopter risk exposure. (In the event of a critical component failure, the helicopter's only other option for landing would be the sea.)

Chapter IV provided a comprehensive treatment of the HFOQA standard statistical reports. The chapters that follow (VI and VII) have respectively been devoted to the conclusions and recommendations of this HFOQA study.

Chapter VI

CONCLUSIONS

The HFOQA study commenced with a comprehensive literature review from which stemmed the research hypothesis. The foci of the literature reviewed were the safety aspects of the two subjects of concern, FOQA and the helicopter industry – plus the combination of them as empirically studied in the HOMP trials. The resultant guiding research hypothesis was that the refinement and/or development of flight phases, events, and measurements of the HFOQA analysis software were feasible (refer to Chapter II for the complete hypothesis statement). Thus, the study concludes with a synthesis of the interrelated findings for FOQA, helicopters, and the developed HFOQA, having utilized the relevant literature and the derived research hypothesis as the framework.

The incorporation of the FOQA concept, which can be viewed as an independent variable for this study, into the helicopter industry (as a dependent variable) has been demonstrated as both feasible and valuable for the improvement of aviation safety. The literature revealed that FOQA has become an indispensable element within the SMS of many airlines. Major airlines of the world have used FOQA data since the 1960s. The cyclic nature of the FOQA process has included flight data acquisition, followed by analysis and utilization thereof. The quantitative information provided by FOQA has the stamp of objectivity. FOQA data have disclosed to the aviation industry what has actually occurred during flight operations. Consequently, flight safety benefits and operational cost savings have been realized.

The helicopter industry has not experienced the safety improvements/records of the airline industry. Although helicopters participate in many highly-relevant aviation activities in our society, the helicopter accident rate has been acknowledged as excessive. Consequently, the stakeholders have decided to drive attitudes and implement safety innovations that aim to reduce the helicopter accident rate by 80% by 2016. The North Sea offshore helicopter industry, for example, has considerably reduced its accident rate during the years through investment in applied research projects. One of these initiatives has been the implementation of FOQA for helicopters, which has estimates of a 15-17% reduction in helicopter accidents.

The HOMP trials were the first applications of FOQA concepts to helicopter operations. The real world trials were located in the North Sea and were sponsored by the UK CAA and other stakeholders. The successful outcomes of HOMP translated to the UKOOA members' commitment of HOMP implementation on all FDR-equipped UK public transport helicopters over the UK Continental Shelf.

This study's methodology (and the resultant product) comprised development of a helicopter version of FOQA analysis software – labeled HFOQA, with direct application to the helicopter industry. Mixed methods were designed to combine qualitative data from helicopter and FOQA experts with quantitative data represented by a sample of de-identified digital flight data. In compliance with the working hypothesis, flight phases, events, and measurements were the three domains of interest during the development of the HFOQA software.

The developed HFOQA analysis software can identify 17 different flight phases of a typical helicopter flight profile. These flight phases characterize diverse helicopter flight attitudes, and meet different helicopter model capabilities and missions. This programmed flexibility enables the use of the HFOQA software as an effective safety tool by operators of all types of operations within the helicopter community with no programming changes of the flight phases.

The developed HFOQA events detect a broad range of maintenance and operational risks, as well as assign severity levels. Probing deeper than event detection, the combination of maintenance and operational data strengthens HFOQA analysis capabilities in the investigation of specific incidents. Additionally, applicable correlations can be obtained between the detected event and the flight origin or destination.

Recorded measurements, from all input flight data replayed, enhance the HFOQA GDRAS storage of data and provide broad statistical analysis capabilities. There are two types of HFOQA measurements: event-related measurements and safety/efficiency flight profile measurements. Overviews of helicopter operations, absent the preexamination of events, are possible. HFOQA standard statistical reports are available for the frequently utilized analyses.

This HFOQA software development, resulting from an industry-academia partnership, has resulted in acceptance of the working research hypothesis. This study also concludes that HFOQA's contribution to the consolidation and expansion of FOQA concepts throughout the helicopter environment (in demand by the aviation industry) has been successfully achieved.

Chapter VII

RECOMMENDATIONS

The worldwide helicopter industry is currently experiencing a favorable economic period. However, helicopter operations suffer from a considerably higher accident rate than that reported by (mostly non-profitable) major airlines. A hidden lining is that the helicopter manufacturers, the operators, the customer organizations, and the regulators have acknowledged, and commenced work, on the necessity for safer operations.

The North Sea's offshore oil exploration stakeholders have set a realistic example for the entire industry. Since the 1990s, significant safety improvements have been achieved in that geo-region. Industry partnerships involving investment in applied research have generated effective tools to reduce the number of accidents. The outcome of FOQA for helicopters is one of these tools; it has the potential to enhance the safety and the quality of flight operations.

This HFOQA study addressed the development and refinement of flight phases, events, and measurements for the HFOQA analysis software. A FOQA vendor, an offshore helicopter operator, and a representative of academe comprised the partnership that was essential to the success of the HFOQA software development. Group dynamics and understanding provided the motivation and structure for the study. The partnership's composition naturally resulted in accentuated advances in HFOQA features specific to the offshore industry (e.g., the developed safety/efficiency flight profile measurements addressed offshore platform issues). Notwithstanding the involvement of only an offshore operator, the HFOQA software was designed to be utilized by the helicopter community in its entirety.

Therefore, the following suggestions are recommended for future studies:

1. Assemble partnerships among helicopter operators, FOQA analysis software vendors, and academe to aggregate the industry experience and knowledge, the apparatus, and the scientific research familiarity in effecting new HFOQA analysis capabilities.
2. Assemble partnerships with helicopter operators involved with different missions (e.g., EMS, sightseeing, military, and others) to assess the necessities of the diverse helicopter community for the development of new HFOQA analysis tools.
3. Develop new safety/efficiency flight profile measurements to meet other offshore helicopter operation demands (e.g., pilot workload).
4. Develop new measurements, both event-related and safety/efficiency flight profile, for other facets of the helicopter community.
5. Develop additional standard statistical reports that are readily available to the HFOQA analyst.

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APPENDIXES

APPENDIX A

HOMP Trial Event List

Event Number	Title	Applicable Condition	Trigger Parameters	Rationale
01A	High Pitch-Up Attitude Below 20 ft AGL	Air	Pitch Attitude, Radio Altitude	To detect the risk of a tail rotor strike.
01B	High Pitch-Up Attitude Above 20 ft and Below 500 ft AGL	Air	Pitch Attitude, Radio Altitude	To detect excessive flare angle i.e. rushed final approach, likely to alarm passengers or cause crew to lose visual reference.
01C	High Pitch-Up Attitude Above 500 ft AGL	Air	Pitch Attitude, Radio Altitude	To detect excessive pitch up attitude in flight.
01D	High Pitch-Up Attitude Below 90 knots IAS	Air	Pitch Attitude, Indicated Airspeed	To detect excessive pitch up attitude at lower speeds.
01E	High Pitch-Up Attitude Above 90 knots IAS	Air	Pitch Attitude, Indicated Airspeed	To detect excessive pitch up attitude at higher speeds.
02A	High Pitch-Down Attitude Below 20 ft AGL	Air	Pitch Attitude, Radio Altitude	To detect excessive nose down pitch attitude during take-off transition which might result in striking the ground if an engine failed.
02B	High Pitch-Down Attitude Above 20 ft and Below 500 ft AGL	Air	Pitch Attitude, Radio Altitude	To detect excessive nose down pitch attitude during take-off transition and at other lower level flight conditions.
02C	High Pitch-Down Attitude Above 500 ft AGL	Air	Pitch Attitude, Radio Altitude	To detect excessive pitch down attitude in flight.
02D	High Pitch-Down Attitude Below 90 knots IAS	Air	Pitch Attitude, Indicated Airspeed	To detect excessive pitch down attitude at lower speeds.
02E	High Pitch-Down Attitude Above 90 knots IAS	Air	Pitch Attitude, Indicated Airspeed	To detect excessive pitch down attitude at higher speeds.
03A	High Pitch Rate Below 500 ft AGL	Air	Pitch Rate, Radio Altitude	To detect excessive rate of change of pitch attitude at lower level flight conditions.
03B	High Pitch Rate Above 500 ft AGL	Air	Pitch Rate, Radio Altitude	To detect excessive rate of change of pitch attitude in flight.
04A	Low Maximum Pitch Rate on Rig Take-Off	Rig Take-Off	Pitch Rate	To detect a low helicopter rotation rate during rotation on a take-off from a helideck which could result in a deck strike if an engine failed.
04B	High Maximum Pitch Rate on Rig Take-Off	Rig Take-Off	Pitch Rate	To detect a high helicopter rotation rate during rotation on a take-off from a helideck, which might cause crew disorientation and passenger alarm.
05A	Low Maximum Pitch-Down Attitude on Rig Take-Off	Rig Take-Off	Pitch Attitude	To detect a low nose down pitch attitude during rotation on a take-off from a helideck, which could result in a deck strike if an engine failed.
05B	High Maximum Pitch-Down Attitude on Rig Take-Off	Rig Take-Off	Pitch Attitude	To detect a high nose down pitch attitude during rotation on a take-off from a helideck, which might cause crew disorientation and passenger alarm.
06A	Roll Attitude Above 30 deg Below 300 ft AGL	Air	Roll Attitude, Radio Altitude	To detect exceedance of the Flight Manual roll attitude limit for weights above 18,410 lb at lower level flight conditions.
06B	Roll Attitude Above 40 deg Below 300 ft AGL	Air	Roll Attitude, Radio Altitude	To detect exceedance of the Flight Manual roll attitude limit for weights above 17,200 lb at lower level flight conditions.
06C	Roll Attitude Above 30 deg Above 300 ft AGL	Air	Roll Attitude, Radio Altitude	To detect exceedance of the Flight Manual roll attitude limit for weights above 18,410 lb.
06D	Roll Attitude Above 40 deg Above 300 ft AGL	Air	Roll Attitude, Radio Altitude	To detect exceedance of the Flight Manual roll attitude limit for weights above 17,200 lb.
07A	High Roll Rate Below 500 ft AGL	Air	Roll Rate, Radio Altitude	To detect excessive roll rate at lower level flight conditions.

Event Number	Title	Applicable Condition	Trigger Parameters	Rationale
07B	High Roll Rate Above 500 ft AGL	Air	Roll Rate, Radio Altitude	To detect excessive roll rate in flight.
08A	High Rate of Descent Below 500 ft AGL	Air	Rate of Descent, Radio Altitude	To detect an excessive rate of descent at low height.
08B	High Rate of Descent Above 500 ft AGL	Air	Rate of Descent, Radio Altitude	To detect an excessive rate of descent.
08C	High Rate of Descent Below 30 knots IAS	Air	Rate of Descent, Indicated Airspeed	To detect an excessive rate of descent at low airspeed (where there is danger of entering the vortex ring state).
09A	Low Airspeed Above 500 ft AGL	Take-Off, Cruise	Indicated Airspeed	To detect flight at an unusually low airspeed.
10A	Normal Acceleration Above 500 ft AGL	Air	Normal Acceleration, Radio Altitude	To detect a high normal acceleration in flight due to turbulence or a manoeuvre.
10B	Normal Acceleration Below 500 ft AGL	Air	Normal Acceleration, Radio Altitude	To detect a high normal acceleration at lower level flight conditions due to turbulence or a manoeuvre.
10C	Lateral Acceleration Above 500 ft AGL	Air	Lateral Acceleration, Radio Altitude	To detect a high lateral acceleration in flight due to turbulence or a manoeuvre.
10D	Lateral Acceleration Below 500 ft AGL	Air	Lateral Acceleration, Radio Altitude	To detect a high lateral acceleration at lower level flight conditions due to turbulence or a manoeuvre.
10E	Longitudinal Acceleration Above 500 ft AGL	Air	Longitudinal Acceleration, Radio Altitude	To detect a high longitudinal acceleration in flight due to turbulence or a manoeuvre.
10F	Longitudinal Acceleration Below 500 ft AGL	Air	Longitudinal Acceleration, Radio Altitude	To detect a high longitudinal acceleration at lower level flight conditions due to turbulence or a manoeuvre.
11A	Excessive Lateral Cyclic Control	Air	Lateral Cyclic Pitch	To detect movement of the lateral cyclic control to extreme left or right positions.

Event Number	Title	Applicable Condition	Trigger Parameters	Rationale
11B/C	Excessive Longitudinal Cyclic Control	Air	Longitudinal Cyclic Pitch	To detect movement of the longitudinal cyclic control to extreme forward or aft positions.
12A	Excessive Collective Pitch Control in Level Flight	Air	Collective Pitch, Rate of Descent	To detect approaches to, or exceedances of, Flight Manual collective pitch limits for cruising flight.
12B	Excessive Collective Pitch Control	Air	Collective Pitch	To detect exceedances of the absolute maximum Flight Manual collective pitch limit.
13A	Pilot Event Marker Pressed	Air		To detect when the FDR pilot event marker has been pressed.
14A	IAS Mode Engaged Below 60 knots IAS	Air	Autopilot IAS Mode, Indicated Airspeed	To detect inappropriate engagement of autopilot airspeed hold at low airspeeds.
14B	ALT Mode Engaged Below 60 knots IAS	Air	Autopilot ALT Mode, Indicated Airspeed	To detect inappropriate engagement of autopilot altitude hold at low airspeeds.
14C	HDG Mode Engaged Below 60 knots IAS	Air	Autopilot HDG Mode, Indicated Airspeed	To detect inappropriate engagement of autopilot heading hold at low airspeeds.
15A	Gear Selected Up Below 100 ft AGL on Take-off	Take-Off	Gear Select, Radio Altitude	To detect early retraction of the landing gear during take-off.
15B	Gear Not Selected Down Below 300 ft AGL on Landing	Landing	Gear Select, Radio Altitude	To detect late lowering of the landing gear during landing.
16A	Excessive Time in Avoid Area			Not yet implemented (awaiting low airspeed algorithm).
17A/C	VNO Exceedance	Air	VNO, Weight	To detect exceedance of the Flight Manual VNO limit (this is weight dependent).
17B/D	VNE Exceedance	Air	VNE, Weight	To detect exceedance of the Flight Manual VNE limit (this is weight dependent).

Event Number	Title	Applicable Condition	Trigger Parameters	Rationale
18A	No. 1 (LH) Fuel Contents Low	Air	LH Fuel Contents	To detect if the total remaining fuel contents fall below the Operations Manual limit
18B	No. 2 (RH) Fuel Contents Low	Air	RH Fuel Contents	To detect if the total remaining fuel contents fall below the Operations Manual limit.
19A	Heater On During Take-Off	Take-Off	Heater	To detect non-conformance with the Flight Manual requirement that the cabin heater should be off during take-off.
19B	Heater On During Landing	Landing	Heater	To detect non-conformance with the Flight Manual requirement that the cabin heater should be off during landing.
20A	Early Turn on Offshore Take-Off at Night	Rig Take-Off	Heading, Ground Speed	To detect an early turn after an offshore take-off at night.
21A	High Ground Speed Within 20 seconds of Rig Landing	Rig Landing	Ground Speed	To detect a high ground speed on the final approach to a helideck landing.
21B	High Ground Speed Within 10 seconds of Airport Landing	Airport Landing	Ground Speed	To detect a high ground speed on the final approach to an airport landing.
22A	High Airspeed Below 100 ft AGL	Air	Indicated Airspeed, Radio Altitude	To detect high speed flight at low level.
22B	High Airspeed Below 100 ft AGL and Gear Up	Air	Indicated Airspeed, Radio Altitude, Gear Select	To detect high speed flight at low level with the landing gear retracted.
23A	Downwind Flight Within 60 seconds of Take-Off	Take-Off	Indicated Airspeed, Ground Speed	To detect downwind flight shortly after take-off.
23B	Downwind Flight Within 60 seconds of Landing	Landing	Indicated Airspeed, Ground Speed	To detect downwind flight shortly before landing.
24A	Low Rotor Speed – Power On	Air	Rotor Speed, Total Torque	To detect excessively low rotor speed during power-on flight.
24B	High Rotor Speed – Power On	Air	Rotor Speed, Total Torque	To detect excessively high rotor speed during power-on flight.
24C	Low Rotor Speed - Power Off	Air	Rotor Speed, Total Torque	To detect exceedance of the Flight Manual minimum rotor speed limit for power-off flight.
24D	High Rotor Speed – Power Off	Air	Rotor Speed, Total Torque	To detect exceedance of the Flight Manual maximum rotor speed limit for power-off flight.
25A	Maximum Continuous Torque (2 Engines)	Air	Total Torque	To detect more than 5 minutes use of the Flight Manual take-off rating torque limit
25B	Maximum Take-Off Torque (2 Engines)	Air	Total Torque	To detect exceedance of the Flight Manual absolute maximum torque limit.
26A	Pilot Workload/Turbulence	Landing	Changes in Collective Pitch	To detect turbulence encountered during the final approach to a helideck landing.
27A	Pilot Workload	Landing	Collective, Lateral & Longitudinal Cyclic	Not yet implemented (awaiting outcome of CAA research project).
28A	Flight Though Hot Gas	Take-Off, Landing	Outside Air Temperature	To detect if the aircraft flies through the turbine efflux or flare plume during a helideck take-off or landing.
29A	High Pitch-Up Attitude on Ground	Ground	Pitch Attitude	To detect high aircraft pitch angles when on a vessel's helideck, or on sloping ground.
29B	High Pitch-Down Attitude on Ground	Ground	Pitch Attitude	To detect high aircraft pitch angles when on a vessel's helideck, or on sloping ground.
30A	High Roll Attitude on Ground	Ground	Roll Attitude	To detect high aircraft roll angles during taxiing, when on a vessel's helideck, or on sloping ground.
31A	High Normal Acceleration at Landing	Landing, Ground	Normal Acceleration	To detect a heavy landing.

Event Number	Title	Applicable Condition	Trigger Parameters	Rationale
32A	High Rotor Speed on Ground	Ground	Rotor Speed	To detect possible governor problems on the ground.
33A	Rotor Brake Applied at Greater Than 122 Rotor RPM	Ground	Rotor Brake, Rotor Speed	To detect application of the rotor brake above the Flight Manual limit for rotor speed.
34A	Excessive Long Cyclic Control with Insufficient Collective Pitch on Ground	Ground	Collective Pitch, Longitudinal Cyclic Pitch	To detect incorrect taxi technique likely to cause rotor head damage
34B	Excessive Rate of Movement of Longitudinal Cyclic on Ground	Ground	Longitudinal Cyclic Pitch Rate, Rotor Speed	To detect an excessive rate of movement of the longitudinal cyclic control when on the ground with rotors running.
34C	Excessive Rate of Movement of Lateral Cyclic on Ground	Ground	Lateral Cyclic Pitch Rate, Rotor Speed	To detect an excessive rate of movement of the lateral cyclic control when on the ground with rotors running.
35A/B	Excessive Movement of Deck	Helideck	Motion Severity Index	To detect excessive movement of a vessel's helideck when the helicopter is on the deck.
36A	High Lateral Acceleration (rapid cornering)	Ground	Lateral Acceleration	To detect excessive cornering accelerations/speeds when taxiing.
36B	High Longitudinal Acceleration (rapid braking)	Ground	Longitudinal Acceleration	To detect excessive deceleration due to braking when taxiing.
37A	High Ground Speed	Ground	Ground Speed	To detect excessive taxiing speeds.
38A	Taxi Limit (left gear lifts)	Ground	Lateral Cyclic Pitch, Tail Rotor Pedal	To detect the risk of an aircraft roll over due to incorrect tail rotor pedal and lateral cyclic control positions when taxiing.
38B	Taxi Limit (right gear lifts)	Ground	Lateral Cyclic Pitch, Tail Rotor Pedal	To detect the risk of an aircraft roll over due to incorrect tail rotor pedal and lateral cyclic control positions when taxiing.

Event Number	Title	Applicable Condition	Trigger Parameters	Rationale
39A	Single Engined flight	Air	No 1 Eng Torque, No 2 Eng Torque	To detect single engined flight.
40A	Torque Split in the Cruise	Cruise	No 1 Eng Torque, No 2 Eng Torque	To detect a possible engine problem, subsequently found to have been caused by module 2 stator vane rotation.
41A	Go Around	Cruise, Landing	Gear Select	To detect a go-around.
41B	Below Minimum Height on Go Around	Cruise, Landing	Gear Select, Radio Altitude	To detect a descent below the minimum height limit during a go around.
41C	Below Minimum Height on Go Around at Night	Cruise, Landing	Gear Select, Radio Altitude	To detect a descent below the minimum height limit during a go around at night.
42A	Autopilot Engaged On Ground Before Take-Off	Ground	Autopilot Status	To detect premature engagement of the autopilot prior to take-off which could result in unexpected control movements.
42B	Autopilot Engaged On Ground After Landing	Ground	Autopilot Status	To detect failure to disengage the autopilot after landing which could result in unexpected control movements.

APPENDIX B

HOMP Trial Measurement List

Measurement	Applicable Condition	Values
Pitch below 20ft AGL	Air	Max +ve, Min −ve
Pitch between 20ft and 500ft AGL	Air	Max +ve, Min −ve
Pitch above 500ft AGL	Air	Max +ve Min −ve
Pitch below 90kts IAS	Air	Max +ve, Min −ve
Pitch above 90kts IAS	Air	Max +ve, Min −ve
Pitch rate below 500ft AGL	Air	Max absolute
Pitch rate above 500ft AGL	Air	Max absolute
Roll below 300ft AGL	Air	Max absolute
Roll above 300ft AGL	Air	Max absolute
Roll rate below 500ft AGL	Air	Max absolute
Roll rate above 500ft AGL	Air	Max absolute
Yaw rate	Air	Max +ve, Min −ve
Rate of Descent below 500ft AGL	Air (Individual phases)	Max
Rate of Descent above 500ft AGL	Air (Individual phases)	Max
Rate of Descent below 30kts IAS	Air (Individual phases)	Max
IAS above 500ft AGL	Air	Min
Lateral acceleration above 500ft AGL	Air	Max absolute
Lateral acceleration below 500ft AGL	Air	Max absolute
Longitudinal acceleration above 500ft AGL	Air	Max absolute

Measurement	Applicable Condition	Values
Longitudinal acceleration below 500ft AGL	Air	Max absolute
Normal acceleration above 500ft AGL	Air	Max absolute
Normal acceleration below 500ft AGL	Air	Max absolute
Lateral cyclic control	Air	Max , Min
Longitudinal cyclic control	Air	Max, Min
Collective pitch control	Air (Individual phases)	Max
IAS at which IAS mode engaged IAS at which ALT mode engaged IAS at which HDG mode engaged	Air	Min Min Min
IAS	Air	Max
IAS below 100ft AGL	Air	Max
Main rotor speed above 10% total torque	Air	Max Min
Main rotor speed below 10% total torque	Air	Max, Min
Total torque	Air (Individual phases)	Max
Increase in OAT	Air	Max
Ng engine 1	Air (Individual phases)	Max
Ng engine 2	Air (Individual phases)	Max
Engine gas temperature engine 1	Air (Individual phases)	Max
Engine gas temperature engine 2	Air (Individual phases)	Max
Ice detector	Air	Max
IGB oil temperature	Air	Max

Measurement	Applicable Condition	Values
MGB oil pressure	Air	Max, Min
MGB oil temperature	Air	Max
TGB oil temperature	Air	Max
Pressure altitude	Air	Max
Pilot workload/turbulence (collective only)	Air	Max
Pitch	Ground	Max Min
Roll	Ground	Max absolute
Main rotor speed	Ground	Max
Longitudinal cyclic control	Ground	Max
Longitudinal cyclic control rate	Ground	Max absolute
Lateral cyclic control rate	Ground	Max absolute
Motion Severity Index (excluding airports)	Ground	Max
Lateral acceleration	Ground	Max absolute
Longitudinal acceleration	Ground	Max absolute
Ground speed	Ground	Max
NMLA datum value	When calculated	value
Fuel contents tank 1	At take-off	Value
Fuel contents tank 2	At take-off	value
Fuel remaining tank 1	At landing	value
Fuel remaining tank 2	At landing	value

Measurement	Applicable Condition	Values
Aircraft weight	At take-off	Value
Aircraft weight	At landing	Value
Rad alt at gear selected up	At gear up	Value
Rad alt at gear selected down	At gear down	Value
Normal acceleration at landing	At landing	Max
MR speed at application of rotor brake	MR brake applied	Value
Engine gas temperature engine 1	At engine start	Max
Engine gas temperature, engine 2	At engine start	Max
Pitch rate, rig take-off	At rotation point	Max
Pitch rig take-off	At rotation point	Max
Rad alt, rig take-off	At max pitch rate	Value
Ground speed, rig landing	Point before landing	Value
Ground speed, airport landing	Point before landing	Value
Pressure altitude	At take-off	Value
Pressure altitude	At landing	Value
OAT	At take-off	Value
OAT	At landing	Value
Average wind speed	Point after TO & before LDG	Value
Average wind direction	Point after TO & before LDG	Value

Measurement Point	**Comments**	**Measurements**
	RIG TAKE-OFF PROFILE	
1 Lift-off	Take-off reference point	Time, Pressure Altitude, Latitude, Longitude
2 Rotation – Maximum Pitch Rate	Usually coincides with start of rotation	Time from Take-Off, Radio Altitude Pressure Altitude (AAL), Pitch, Roll, Heading, Airspeed Groundspeed, Latitude (N/S distance from take-off) Longitude (W/E distance from take-off)
3 Rotation – Maximum Pitch Down Angle	Usually coincides with end of rotation	
4 35 knots Airspeed	Lift-off point if airspeed greater than 35 kts at lift-off	
5 Vy (Climb Speed)	Obtained from Flight Manual	
6 Gear Selected Up	End of take-off phase if gear not retracted by then	
7 200 Feet AAL	Definition of climb out path	
8 500 Feet AAL	Definition of climb out path	
9 1 000 Feet AAL	Definition of climb out path	
	RIG LANDING PROFILE	
1 Touch-down	Landing reference point	Time, Pressure Altitude Latitude Longitude
2 35 knots Airspeed	Start of low airspeed phase	Time to Landing, Radio Altitude, Pressure Altitude (AAL), Pitch, Roll Heading Airspeed Groundspeed, Latitude (N/S distance from landing), Longitude (W/E distance from landing)
3 Gear Selected Down	Start of landing phase if gear already down by then	
4 1 000 Feet AAL	Definition of approach path	
5 500 Feet AAL	Definition of approach path	
6 200 Feet AAL	Definition of approach path	
7 Maximum Pilot Workload	Workload based on collective only	

APPENDIX C

HFOQA Operational Event List

	Operational Event Name
1	PITCH UP below 20ft – Departure (DEP)
2	PITCH UP between 20ft and 500ft – DEP
3	PITCH UP above 500ft
4	PITCH UP below 90kt Indicated Air Speed (IAS) – DEP
5	PITCH UP above 90kt IAS
6	PITCH UP on the Ground – DEP
7	PITCH UP below 20ft – Arrival (ARR)
8	PITCH UP between 20ft and 500ft – ARR
9	PITCH UP below 90kt – ARR
10	PITCH DOWN below 20ft – DEP
11	PITCH DOWN between 20ft and 500ft – DEP
12	PITCH DOWN above 500ft
13	PITCH DOWN below 90kt IAS – DEP
14	PITCH DOWN above 90kt IAS – DEP
15	PITCH DOWN on the Ground – DEP
16	PITCH DOWN below 20ft – Arrival (ARR)
17	PITCH DOWN between 20ft and 500ft – ARR
18	PITCH DOWN below 90kt – ARR
19	High Maximum PITCH DOWN on Rig Take off
20	Low Maximum PITCH DOWN on Rig Take off
21	PITCH DOWN below 20ft – ARR
22	PITCH DOWN between 20ft and 500ft – ARR
23	PITCH DOWN below 90kt IAS – ARR
24	PITCH DOWN above 90kt IAS – ARR
25	PITCH DOWN on the Ground – ARR
26	PITCH RATE on the Ground – DEP
27	High Maximum PITCH RATE on Rig Take off
28	Low Maximum PITCH RATE on Rig Take off

	Operational Event Name
29	PITCH RATE above 500ft
30	PITCH RATE below 500ft – DEP
31	PITCH RATE on the Ground – ARR
32	PITCH RATE below 500ft – ARR
33	ROLL below 300ft – DEP
34	ROLL above 300ft
35	ROLL on the Ground – DEP
36	ROLL below 300ft – ARR
37	ROLL on the Ground – ARR
38	ROLL RATE below 500ft – DEP
39	ROLL RATE above 500ft
40	ROLL RATE on the Ground – DEP
41	ROLL RATE below 500ft – ARR
42	ROLL RATE on the Ground – ARR
43	ROLL CYCLIC CONTROL – DEP
44	ROLL CYCLIC CONTROL – ARR
45	ROLL CYCLIC CONTROL on the Ground – DEP
46	ROLL CYCLIC CONTROL on the Ground – ARR
47	PITCH CYCLIC CONTROL – DEP
48	PITCH CYCLIC CONTROL – ARR
49	PITCH CYCLIC CONTROL on the Ground – DEP
50	PITCH CYCLIC CONTROL on the Ground – ARR
51	RATE OF DESCENT above 500ft
52	RATE OF DESCENT below 500ft
53	RATE OF DESCENT below 30kt – DEP
54	RATE OF DESCENT below 30kt – ARR
55	Low IAS above 500ft
56	High IAS below 100ft – DEP

	Operational Event Name
57	High IAS below 100ft and GEAR UP – DEP
58	High IAS below 100ft – ARR
59	High IAS below 100ft and GEAR UP – ARR
60	High IAS and GEAR DOWN – DEP
61	High IAS and GEAR DOWN – ARR
62	VERTICAL ACCELERATION above 500ft
63	VERTICAL ACCELERATION below 500ft
64	VERTICAL ACCELERATION on Landing
65	LATERAL ACCELERATION above 500ft
66	LATERAL ACCELERATION below 500ft
67	LATERAL ACCELERATION on the Ground – DEP
68	LATERAL ACCELERATION on the Ground – ARR
69	LONGITUDINAL ACCELERATION above 500ft
70	LONGITUDINAL ACCELERATION below 500ft
71	LONGITUDINAL ACCELERATION on the Ground – DEP
72	LONGITUDINAL ACCELERATION on the Ground – ARR
73	High GROUND SPEED within 10 seconds of Airport Landing
74	High GROUND SPEED within 20 seconds of Rig Landing
75	Downwind flight within 60 seconds of Take off
76	Downwind flight within 60 seconds of Landing
77	Velocity-Normal Operation (VNO)
78	Orbit Detection
79	Rig Landing Detection
80	Helideck Movement – ROLL
81	Helideck Movement – PITCH
82	GEAR UP below 300ft on Landing
83	GEAR UP below 75ft on Take off
84	Go Around Detection

	Operational Event Name
85	Go Around below 75ft
86	Go Around below 100ft at night
87	Taxi Speed – DEP
88	Taxi Speed – ARR