Abstract

In order to improve the operational readiness of Naval aviation, the Department of the Navy (DON) is implementing a knowledge management process known as Military Flight Operations Quality Assurance (MFOQA). MFOQA utilizes available flight data from existent onboard data collection systems to provide information that can be used to improve efficiencies in aircraft maintenance and operations, flight safety, and aircrew training. The improved efficiencies promote operational excellence which translates to increased operational readiness. A two-year demonstration of prototype MFOQA capabilities involving Fleet operational units was conducted to better understand the potential benefits and challenges associated with the development and implementation of an MFOQA program and evaluate its potential impact on operational readiness. Senior command leadership, aircrews, and maintenance personnel utilized the prototype capabilities during day-to-day operations and provided objective feedback. In some cases potential applications of MFOQA capabilities that had not been previously envisioned were also identified. It was concluded from the demonstration that MFOQA can enhance the operational readiness of Naval aviation. In addition, the impact of MFOQA was assessed to be directly related to the relevance of the capabilities to user needs, the justness of the policies and processes implemented, and the effectiveness of personnel training and motivation. This paper presents an overview of applications of MFOQA capabilities during the demonstration and follow-on activities, and related lessons learned and conclusions specifically pertaining to operational readiness. Similarities and differences between the DON MFOQA concept and civil aviation flight data analysis applications are also presented.

Introduction

Operational readiness is defined as the capability of a unit/formation, ship, weapon system, or equipment to perform the missions or functions for which it is organized or designed. It is a direct reflection of how well fielded weapon systems satisfy mission requirements, how well personnel are trained to maintain and employ the weapon systems, and how effectively organizations minimize material and personnel losses.

The modernization of weapon systems to improve the Warfighter’s ability to carry out missions more effectively and with improved survivability is essential to the strategy of maintaining acceptable levels of operational readiness. However, modernization efforts typically result in increased systems complexity that requires improvements in troubleshooting and maintenance techniques to achieve acceptable levels of reliability and availability at the lowest possible life cycle cost. In addition, increased complexity often brings the need for improved efficiencies in the training of operators to employ the weapon systems with the greatest effectiveness while minimizing the risk of losses due to mishaps and hostile actions. This paradigm of ever increasing systems complexity, with its maintenance, training, and safety related issues, holds particularly true for military aviation.

In 2005 the Department of Defense (DOD) established a policy directing all DOD components to implement a knowledge management process known as Military Flight Operations Quality Assurance (MFOQA). The MFOQA process incorporates the download, analysis, and visualization of flight data to provide operators with actionable information. The DOD Directive cited MFOQA as having the potential to enhance aircraft operations and mission readiness by reducing aircraft mishaps, improving aircrew performance through flight performance feedback, and providing maintenance personnel with quantitative aircraft systems information.

In order to better understand the potential benefits and challenges associated with the development and
implementation of an MFOQA program the Department of the Navy (DON) conducted a comprehensive two-year demonstration and evaluation of prototype MFOQA capabilities fielded in select operational squadrons. Aircrews, maintenance personnel, and senior command leadership utilized the prototype capabilities during day-to-day operations in tactical fixed wing, rotary wing, and tiltrotor squadrons. Inputs and recommendations from the Navy and Marine Corps Demonstration participants contributed significantly to the identification and prioritization of requirements for MFOQA system functionalities, procedures and processes, and implementation policies. Their efforts laid the framework for DON-wide MFOQA program development and implementation. This paper presents an overview of results from the Demonstration, as well as follow-on activities, and addresses how the MFOQA process can increase operational readiness by providing operators with objective and actionable information for use in improving efficiencies in aircraft maintenance, aircrew training, and flight operations and safety.

Background

The collection and use of flight data are not new to aviation. The Civil Aeronautics Administration first mandated the use of flight data recorders in 1958. Although only six parameters were initially required (time, airspeed, heading, altitude, vertical acceleration, and time of radio transmission), the flight data recorders provided mishap investigators with previously unavailable information that proved extremely valuable for mishap reconstruction. As the quality and accessibility of flight data improved, operators utilized the data for more proactive applications beyond the determination of mishap causal factors. In the 1960s some major commercial air carriers began monitoring data from routine flights to capture airworthiness data. With the continued maturation of data collection technology and analytical capabilities, the collection and analysis of operational data evolved into structured Flight Operational Quality Assurance (FOQA) programs. [1]

The initial focus of commercial FOQA programs was on flight safety, and both U.S. and non-U.S. airlines with FOQA programs and experience attested to the potential of FOQA to enhance safety by enabling the identification and correction of possible safety problems before they result in a mishap. However, economic benefits were also quickly identified as airlines implemented and gained more experience with flight data collection and analysis processes. A FOQA Demonstration Study, referred to as “DemoProj,” was started in 1995 and sponsored by the Federal Aviation Administration (FAA) in response to a Flight Safety Foundation recommendation. The purpose of the Study was to facilitate the voluntary establishment of trial FOQA programs, demonstrate safety and operational benefits, develop implementation guidelines, and determine critical success factors. Documented results from “DemoProj” included examples of achievable savings from FOQA programs such as reduced engine removals, detection of out-of-trim conditions, improved fuel management, reduced hard landing inspections, brake wear reduction, and reduced insurance premiums. European air carriers with FOQA experience also reported economic as well as safety benefits. For example, the Safety Regulation Group of the United Kingdom Civil Aviation Authority (CAA) reported the monitoring of fuel efficiency, engine condition, crew procedures, noise violations, and aircraft structural fatigue as FOQA benefits in addition to safety related documentation of unusual autopilot disconnects, Ground Proximity Warning System (GPWS) warnings, hard landings, and rushed approaches. [2]

Although early FOQA initiatives were predominately focused on major commercial fixed wing aircraft operations, interest later extended to the rotary wing community. A two-year operational Flight Data Monitoring (FDM) trial known as “Helicopter Operations Monitoring Programme” (HOMP) was conducted under the auspices of the CAA to demonstrate the use of FDM techniques in helicopter operations and evaluate the benefits obtained. Not only were significant safety issues identified during the HOMP trial but the operator was also provided objective information on which to act to effectively address the issues. In addition, aircrews responded positively to the trial and were receptive to feedback provided. Among the conclusions from the trial is that HOMP is a practical and cost effective flight safety tool that can bring about improvements in flying practices, training, operating procedures, and coping with the operational environment. [3] Successes from FOQA related initiatives, including proven safety and direct economic benefits, have led to increased interest in FOQA applications within the rotary wing community. In August 2007 the FAA approved the first FOQA program for a commercial (Part 135) helicopter operator.

Safety professionals in DON, as well as other DOD components, began to research commercial FOQA capabilities during the 1990s to become more knowledgeable of related safety and economic benefits. They remained informed of FOQA technology and procedural advancements and associated benefits through various forums including direct liaison with FAA and industry FOQA representatives. The concerted efforts of safety professionals to educate DOD leadership on the potential benefits of FOQA
programs led to DOD’s direction in October 2005 for all U.S. military services to implement MFOQA programs in order to enhance aircraft operations and mission readiness by reducing aircraft accidents and providing quantitative aircraft systems information to maintenance personnel. Whereas the different DOD services vary in their implementation approaches and specific MFOQA requirements, the expected benefits from MFOQA DOD-wide include improved mitigation of human factors related mishap causal factors and increased operational readiness from improved maintenance and operational efficiencies.

The DON MFOQA concept, like commercial FOQA, includes aggregate data analyses, trending, and querying capabilities. DON MFOQA also includes operations, training, and aircraft maintenance functionalities in addition to serving as a proactive safety program. However, one distinct difference between DON MFOQA and commercial FOQA is the availability of flight data visualization, analysis, reporting, and animation functionalities at the squadron, or operator level, following every flight. The DON MFOQA post-flight data visualization capabilities provide aircrews and maintenance personnel with objective flight related information in a timely and user-friendly manner to enhance post-flight debriefs. The post-flight capabilities can also provide relevant decision makers with quantifiable and actionable information pertaining to aircrew and/or aircraft systems performance during individual flights.

In order to aid the development and refinement of MFOQA concepts, policies, procedures, and technology requirements, DON conducted a two-year demonstration that involved the fielding of prototype MFOQA systems for use and evaluation by Fleet operational personnel and leadership in the tactical fixed wing, rotary wing, and tiltrotor communities. Follow-on efforts have also been continued to support further MFOQA policy and procedures development. Inputs from Fleet participants have contributed significantly to the identification and prioritization of requirements for MFOQA system functionalities, procedures, processes, and implementation policies. User feedback has also laid the framework for future DON MFOQA program development and implementation, and indicates that MFOQA, if implemented properly, can enhance Naval aviation operational readiness.

**DON MFOQA Prototype Capabilities**

Prototype capabilities fielded during the early part of the DON MFOQA Demonstration supported squadron post-flight debriefs with animation, analysis, and reporting capabilities. Existing onboard data collection systems, originally intended to provide data principally for maintenance purposes, served as data sources. These data were processed, analyzed, and visualized using commercial off-the-shelf (COTS) software that had been modified for each specific aircraft type and mission. After the squadron post-flight brief capabilities were refined and modified in response to user feedback, the Demonstration expanded to include the analysis and reporting of aggregated flight data at the squadron and higher command levels.

Evaluations of the prototype post-flight brief and aggregate analysis capabilities were conducted by participating aircrews, maintenance personnel, and leadership. The assessments were accomplished using a combination of oral and written feedback from end users, formal written surveys completed in formal group settings as well as one-on-one interviews, and observations by onsite Demonstration support personnel. The lessons learned and conclusions from the Demonstration include MFOQA-related technical, policy, and procedural issues. Among the final conclusions is that MFOQA capabilities can provide actionable information for effecting improvements in the areas of aircraft maintenance, flight operations, safety, and aircrew training, with a resulting positive impact on Naval aviation operational readiness.

**Post-Flight Animated Debrief (PFAD)**

The post-flight brief capabilities provided during the Demonstration included data animation, analysis, and reporting functionalities following each flight. The Post–Flight Animated Debrief (PFAD) capability enabled aircrews and maintenance personnel to visualize a high-fidelity 3D animated replay of a recorded flight, and/or any selected portion thereof, using a digital model of the aircraft and imagery of local topography. The display was interactive and views were selectable from any perspective internal to, or outside of, the aircraft. Users could select and display different windows with values and plots for any of the downloaded parameters, as well as movements of engine and flight controls, all time-synchronized with the aircraft animation. In addition, a capability was incorporated to automatically detect and indicate predefined events that were based on select operational and aircraft system performance thresholds, as well as Boolean expressions to identify more complex events of interest. An animated multi-ship replay capability for tactical debriefs was deemed essential by tactical fixed wing participants, who were provided the capability to animate up to eight aircraft simultaneously. Figure 1 is a screenshot of a representative SH-60B PFAD display.
At the beginning of the Demonstration aircrews were expected to be the principal users of PFAD; however, maintenance personnel quickly found the ability to replay and visualize available aircraft performance and systems data, typically not readily available via other means, to be highly beneficial for troubleshooting certain system malfunctions and evaluating system functional checks. PFAD, supplemented by flight summary reporting, provided objective information regarding overall aircraft performance when a system component malfunctioned that may not have been documented by the aircrew on a written maintenance action form or provided during aircrew maintenance debrief. Exact values of recorded system parameters at the time of a system failure could be viewed quickly without reliance on aircrew observation or memory. PFAD functionalities helped reduce the number of ‘can not duplicate on deck’ occurrences by providing detailed information on specific system performance at the actual time of failure or system malfunction. They also provided a quantifiable means to confirm or validate results from post-maintenance functional check flights with a level of accuracy normally not possible via routine aircrew in-flight documentation.

**PFAD – Benefits and Impact on Operational Readiness**

End users of the PFAD capability concluded that it can enhance aircraft maintenance, operations, safety, and aircrew training efficiencies. The demonstrated functionalities were assessed to have a positive impact on operational readiness by helping decrease aircraft turnaround times, providing improved visibility into how aircraft are being operated, reducing aircraft and aircrew losses and non-availability due to mishaps, and improving the effectiveness of aircrew training. PFAD provided the ability to replay systems and performance data recorded in-flight in a user-friendly and intuitive manner when events of interest or systems malfunctions actually occurred. The visualization methodology provided improved visibility into the data with greater accuracy than is typically available during routine aircrew and maintenance debriefs. In addition, PFAD provided for easier archiving and retrieval of data for later use, and provided a means to readily share relevant data and information with others. Examples of improved efficiencies were documented in the areas of maintenance, operations, safety, and training.
PFAD provided maintenance personnel with quicker access to available aircraft systems data and in a format more user-friendly than most current flight data handling and processing technologies. It facilitated more timely troubleshooting of system malfunctions and in some cases provided information that could be used to avoid unnecessary maintenance actions. For example, following a gas turbine temperature indication malfunction during flight, maintenance personnel were able to use PFAD to view multiple system data parameters and determine the cause as a faulty wiring harness saving several hours of sequential troubleshooting steps that would have otherwise been required to isolate the problem. Another operator estimated that using the PFAD capability to view systems and aircraft performance data saved approximately eight hours of troubleshooting time for an engine fuel control malfunction; varying time savings for troubleshooting other malfunctions were also identified. PFAD was also cited as a valuable aid in troubleshooting a recurring in-flight flight control system malfunction that could not be duplicated on the ground by providing an accurate and comprehensive review of flight data recorded before, during, and after the system malfunction. One operator also documented a case in which a functional check pilot reported that a critical flight system had failed an in-flight check; maintenance personnel, using PFAD, were able to ascertain that the system failure indications were due to incorrect flight control inputs during the check and not an actual system malfunction. The replay of this particular event was later incorporated into the squadron’s Functional Check Pilot training program. [4]

Operations personnel were able to use PFAD to conduct post-flight assessments of aircrews’ performance relative to prescribed tactics and/or weapons delivery profiles. In one instance PFAD was the only means available to accurately verify the aircrew executed an actual combat weapons delivery maneuver in accordance with prescribed tactical doctrine after a malfunction of onboard mission recording systems. PFAD also provided a unique capability for familiarizing aircrews new to a theater of operations with specific mission profiles before actually conducting the missions for the first time. In addition, it provided a means to evaluate individual aircrew compliance with existing or revised standard operating procedures, and an objective basis for determining if and what changes to normal procedures may be needed.

The safety of aircraft operations was also enhanced with the use of PFAD. Following an engine rollback during an approach to landing, PFAD was used by the squadron’s Safety Officer to objectively review the aircrew’s performance and debrief them on what procedures were executed correctly as well as incorrectly. A video segment of the PFAD replay was generated and used for subsequent aircrew training. Another aircrew that experienced an in-flight engine failure used the replay capability to self-evaluate their performance and were able to confirm the correct procedures were executed and the proper flight profile was flown. PFAD also provided an easy means for aircrews to objectively review their low altitude missions post-flight and to self-monitor their adherence to altitude and maneuvering restrictions for this type of mission profile. The PFAD capability was used by a mishap investigation team to review relevant portions of a flight following an aircraft mishap; the team credited PFAD with expediting the completion of the investigation, which allowed the mishap aircrew and aircraft to be returned to flight status more quickly than would have otherwise been possible. Instructor pilots also credited PFAD as enhancing flight safety by providing an accurate data source for post-flight debrief that reduced their administrative workload in-flight and allowed them to remain more focused on flight safety and situational awareness while airborne.

The objectivity that the PFAD capability added to post-flight debriefs during the Demonstration validated its significant training benefit to aircrews. PFAD enabled data-based reviews of aircrews’ performance that were not subject to inaccuracies, omissions, and misinterpretations that can occur during debriefs that rely on memory or notes hastily written in-flight. A training squadron that utilized the PFAD capability noted that although it did not reduce the number of flights required to complete a pilot training syllabus it did frequently reduce the in-flight training time required for a pilot to achieve acceptable performance for required maneuvers. PFAD was cited as providing a more accurate understanding of what actually occurred in-flight than what may have been perceived by the aircrew. One squadron estimated an approximate 1/3 reduction in the time required to debrief multi-aircraft events because of the more accurate visualization of multi-aircraft orientation and geo-spatial relationships. PFAD enabled aircrews to compare their performance for a specific maneuver with the replay of a “Gold Standard” maneuver that represented a properly flown profile; the same “Gold Standard” replay could also be used by aircrews for familiarization prior to executing the maneuver in the aircraft for the first time. PFAD supported Crew Resource Management training by providing the ability to review crew coordination and procedures post-flight. One operator stated that it could also increase the utilization rate of flight simulators by supporting student pilot simulator debriefs in lieu of debriefs in the simulator as is currently required.

PFAD also demonstrated notable utility for refresher, currency, and advanced training of aircrews beyond
their initial qualifications. Naval pilots must remain proficient in conducting many diverse missions, yet they typically have significantly less flight experience than most pilots with major commercial operators. In addition, their assignment rotations usually include one or more non-flying tours between assignments involving flight duty. Therefore, there is a dominant training focus during Naval pilots’ flying careers to better sustain required mission readiness that is enhanced by the increased objectivity of PFAD flight performance evaluations and reviews. The value of PFAD to pilot training was summed up by one squadron Commanding Officer who described PFAD as a “Force Multiplier that makes good pilots even better.”

Post-Flight Debrief Analysis and Reporting

Post-flight analysis and flight summary reporting functionalities developed during the Demonstration provided added objectivity to aircrew and maintenance post-flight debriefs with timely, user-friendly presentations of select flight data and analytical results. In addition to providing aircrews with quantifiable information to support self-evaluation of their performance, actionable information was also available to maintenance, operations, safety, and training personnel to aid in monitoring adherence to established standard operating and/or emergency procedures, as well as identify anomalies that warranted further analysis and/or possible intervention. The “snapshot” view of systems parameter values and automated detection of predefined events eliminated the need for aircrews and other personnel to manually screen and analyze recorded systems data to obtain similar results. Figure 2 is an example Flight Summary Report for a tiltrotor aircraft; the green dots on the two charts are data points from an actual flight overlaid on graphs from the pilot’s operating manual/handbook.

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**Flight Control**

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**Protection**

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<td>Total Time</td>
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**Figure 2 – Flight Summary Report**
Flight summary reports that evolved during the Demonstration provided an overview of aircrew and aircraft system performance for a single flight that could be quickly and easily assimilated by aircrew and other appropriate personnel. Greater insight into aircrew and aircraft systems performance for each flight was made possible with the quantifiable information provided that may have otherwise gone unnoticed, been inaccurately represented, or otherwise deemed irrelevant. Flight summary reports provided an automated means to identify any predefined events that occurred during the flight, such as aircrew or systems performance threshold exceedances, and complemented the capability of PFAD to provide an objective review of each flight.

Post-Flight Debrief Analysis and Reporting – Benefits and Impact on Operational Readiness

The post-flight analysis and reporting capabilities developed during the Demonstration were assessed to have the potential to enhance mission readiness with the timely availability, user-friendly presentation format, and objectivity of the information provided. End users identified various examples of benefits from their use.

The post-flight analysis and reporting capabilities were assessed to provide aircrews with more in-depth and objective insight into the details of each flight, including individual performance and flying techniques, in a format that allowed for the rapid assimilation of the information as exemplified by the example Flight Summary Report in Figure 2. This functionality was deemed especially beneficial for pilots undergoing initial training for the applicable aircraft type. Aircrews could more readily self-assess their performance, identify any skill areas requiring improvement, and monitor their progress during subsequent flights using the information provided. For example, operators of a tiltrotor aircraft reported that gearbox cavitation will occur whenever a change in proprotor rpm, as required following nacelle rotation, is initiated below a specific torque value. An event was developed to detect whenever the required rpm change had been initiated below the minimum specified torque. The addition of the event to the flight summary report can provide pilots with increased awareness as to when the procedure is improperly executed and a means to monitor self-corrective actions, as well as an objective source of information to quantify the frequency of such occurrences in order to better assess the overall impact on gearbox maintenance requirements.

Post-flight analysis and reporting provided timely and automated monitoring of adherence to prescribed procedures for which relevant data existed as well as the detection of significant safety hazards that may have occurred. The capabilities were cited as a means to help identify pilots with negative habit patterns and provide a basis for refocusing their training to “train out” negative habit patterns and correct performance deficiencies prior to them becoming flight safety issues. They were also assessed as a potential filter for identifying portions of a flight for which PFAD could enhance the evaluation and/or discussion of events detected. If used in conjunction with PFAD, end users stated that post-flight analysis and reporting can be used to identify root causes of aircrew variances from prescribed techniques. Particular interest was expressed in the graphical presentation of relevant flight data related to specific flight regimes such as approach to landing.

The availability of aircraft systems performance data immediately post-flight and the automatic detection of predefined parameter threshold exceedances were assessed to provide maintenance personnel with information that, in conjunction with PFAD, can reduce the time required to troubleshoot certain aircraft systems faults as well as more easily detect imminent systems malfunctions. In addition, exceedances of prescribed thresholds, such as engine over-torques, G-loads, and temperatures that exceed allowable limits that aircrews may not be aware of during flight or choose not to report, can be automatically detected. In other instances, the information can possibly preclude the need for maintenance action by providing data that confirm whether or not an exceedance suspected by the aircrew actually occurred. This enhanced functionality can reduce aircraft down time due to unscheduled or unnecessary maintenance and result in a corresponding increase in aircraft availability and mission readiness.

The increased objectivity that the MFOQA post-flight analysis and reporting capabilities provided to aircrew and maintenance debriefs, and actionable information to other relevant end users, was assessed to have a positive impact on operational readiness. The enhanced quality of aircrew debriefs enabled better detection of unsafe or unsatisfactory performance requiring mitigation to reduce the risk of loss from a mishap. Timely availability of systems data and automated detection of anomalous conditions or occurrences provided time savings for systems troubleshooting and repair. The maintenance, operations, training, and safety benefits considered attainable will have a notable positive impact on overall readiness by supporting more timely troubleshooting, the reduction of unnecessary maintenance actions, reduced losses attributable to preventable causal factors, and improved pilot training efficiency.
Aggregate Analysis and Reporting

DON MFOQA aggregate reports developed during the Demonstration presented analytical results for recorded flight data from multiple flights of similar type aircraft. The aggregate reports provided varying levels of visibility into derived information in a user-friendly format at the squadron level as well as the senior command level for squadrons Fleet-wide. Recurring rollup reports for varying time periods, such as weekly, monthly, and quarterly, were prepared with pertinent summaries and overviews to provide actionable information relevant to aircraft maintenance, operations, safety, and training. Some one-time aggregate reports were also developed in response to end user requests.

The aggregate reports provided objective information regarding aircrew and aircraft systems performance to squadron and senior command leadership that increased their awareness of how aircraft were being operated and maintained, including systems performance trends not readily available via other means. In some instances, areas requiring increased focus and possible intervention were identified. The reports also provided a means to quantify the need for implementing policy or procedural changes as well as monitor the results from, and effectiveness of, such changes.

Aggregate Analysis and Reporting – Benefits and Impact on Operational Readiness

Aggregate analysis and reporting capabilities were assessed to provide specific benefits to aircraft operators and maintainers that enhanced aircraft operational efficiencies and availability. Multiple examples were identified during the Demonstration and follow-on activities.

The aggregate analysis and reporting capabilities provided information to increase aircrew and leadership’s awareness of actual or potentially adverse performance trends, and, when appropriate, used as justification for corrective intervention. For example, recurring aircrew deviations below the minimum prescribed separation distances during multi-aircraft maneuvering were revealed by aggregate flight data analyses. The closest point of approach (CPA) analyses not only automatically detected whenever two aircraft passed within close proximity, but also filtered out maneuvers such as formation flight for which minimal separation distance is normal. In addition to the graphical plot of the involved aircraft flight paths as shown in Figure 3, details including separation distance, heading differential, and the altitude and airspeed for each aircraft at the time of CPA were reported. The results were provided to the squadron’s senior leadership who then shared them with pilots to increase their awareness of the frequency of such deviations. Subsequent analyses showed a significant decrease in the identified deviations.

Figure 3 – Closest Point of Approach Analysis

Increased awareness of leadership also served as a catalyst for policy change. In one case aggregate data analysis showed a higher than expected number of airspeed exceedances with landing gear extended. Squadron leadership provided guidance to all pilots to extend landing gear ten knots lower than the previously prescribed limitation and subsequent reports indicated a substantial decrease in the number of such airspeed exceedances. The improved aircrew situational awareness and policy change by senior leadership were based on objective information obtained from the analysis of flight data and not from subjective perspectives of aircrews or leadership. The impact from the increased awareness and policy change could be quantified using the same aggregate analysis capability utilized to identify the performance discrepancies.

Aggregate analyses also detected some abnormally aggressive maneuvering during approaches to landing at one of the Demonstration squadrons. By analyzing pitch, roll, and drift values prior to landing, maneuvers were easily identified that were outside the norm for the typical approach to landing. When presented with the results squadron personnel determined that the anomalous approaches were to a landing pad that required nonstandard maneuvering just prior to landing due to its location and surrounding obstacles. Although all the anomalous approaches were determined to be within the normal flight envelope of the aircraft some were considered to possibly be more aggressive than required. The aggressive maneuvering quantified by the aggregate analysis and reporting raised the squadron’s awareness of flight operations to that specific landing pad and was the basis for a review of the squadron’s standard operating procedures for landing at that site.
Aggregate Built-In Test (BIT) trending was also provided for one type aircraft with onboard digital systems. The aggregate reporting capability provided maintenance personnel a means to monitor and trend problematic systems and associated malfunctions that was more timely and user-friendly than the methods in use. In addition to recurring BIT trending reports, one-time aggregate analyses and reports were provided in response to end user requests. Following an engine failure, an analysis of its vibration data prior to failure was conducted for comparison with other same type engines to determine if the vibration signature included any indication of the pending failure. Although the vibration levels were found to be higher than the norm (but within specification), post-failure engineering analysis determined the failure mode in this case would have most likely not been detectable in advance due to the high propagation rate of the fatigue crack that resulted in component failure. Another one-time aggregate analysis was conducted to determine the potential of detecting pending failures of an aircraft’s flight control surface actuation system. Results in this case indicated that the statistical analysis of available data could potentially provide an indication of a pending actuation system failure; in addition, it was assessed that the use of statistical measures or advanced anomaly detection algorithms could likely provide an indication of the health of the system.

Trends related to component operational usage, and flight maneuvers that could potentially accelerate airframe fatigue and component failures, were developed from the analysis of data for different aircraft types and varying periods of time. Quantifying the time aircraft were subjected to certain G-loads during flight not only improved the squadron’s awareness of how its aircraft were being flown but also provided a means to correlate which type flights subjected the aircraft to the greatest structurally related fatigue. Such information could then be used to schedule aircraft for specific missions in order to better manage the structural fatigue life of the aircraft fleet. The identification of specific flight regimes or maneuvers during which high G-loads occurred provided squadron leadership with objective insight into whether or not pilots were subjecting the aircraft to unnecessary stress; for example, G-loads acceptable for Air Combat Maneuver training are not normally expected nor required during phases of flight such as transit or in the landing pattern overhead break. Other usage trends categorized the severity of particular flight maneuvers detected by quantifying parameters related to the dynamic loads placed on certain aircraft system components. Aggregate reporting provided added insight into how aircraft were being operated relative to the aircraft’s design spectrum based on relative time spent in different flight conditions, as shown in Figure 4. Other aggregate operational related information, such as comparisons of fuel burned on the ground versus in-flight, provided a means to more objectively assess the efficiency of existing procedures and aircrew practices.

![Flight Conditions Summary](image)

**Figure 4 – Flight Conditions Summary Report**
The aggregate reporting was also assessed to be a user-friendly means to aid in the identification of potential precursors to mishap causal factors that can be acted upon to reduce the number of aircraft and aircrew losses due to mishaps. The example Safety Summary Report shown in Figure 5 (illustrated with notional data) represents the type of analytical results that can help decision makers identify areas requiring attention.

<table>
<thead>
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<th>Safety Summary Report</th>
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<tr>
<td>&lt;Start date/time&gt; to &lt;End date/time&gt;</td>
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<tr>
<td>Report created: &lt;date/time&gt;</td>
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| Total Flights Flown: | 43 |
|-----------------------|
| Total Hours Flown: | 81.5 |
| Flight time with engine high torque: | 4.8% |
| High Rate Landings: | 12 |
| Occurrences of ROD > 1000 FPM < 500 FT AGL: | 37 |
| Occurrences Pitch +/- 25 deg: | 19 |
| Occurrences AOB > 45 deg: | 23 |
| Occurrences TGT > 925 deg: | 21 |
| Occurrences G Load > 2g: | 2 |
| Number of Autorotations: | 0 |
| Number of Landings: | 112 |
| Occurrences of excessive control inputs: | 13 |

Figure 5 – Flight Safety Summary Report
(notional data)

Through routine review of such reports, decision makers can identity trends based on objective data and better determine if further research and scrutiny, as well as appropriate intervention, may be required regarding issues within their purview. For example, if the large number of high rates of descent (ROD) below 500 feet above ground level (AGL) depicted in Figure 5 were actual data, further investigation by squadron safety, training, and operations representatives could be warranted. By continually monitoring such trends, the impact of any guidance or direction given to pilots could be assessed. In addition, the information could be used to determine if the need exists to introduce added focus to specific parts of initial and recurrent training programs, or to make changes in policies or standard operating procedures.

The aggregate analysis capabilities developed and evaluated during the DON MFOQA Demonstration and follow-on initiatives proved to be highly useful tools in monitoring and addressing aircrew training, flight safety, and overall operational issues. The objective information provided from the analyses of flight data could be used for promulgating procedures and policies for aircrews and maintenance personnel in lieu of more subjective information sources, as well as quantifying the impact of any changes made, in order to better ensure improved operational readiness.

Baseline Comparative Analysis – Evolving MFOQA Functionality

A Baseline Comparative Analysis methodology was developed during the DON MFOQA Demonstration and continues to evolve with ongoing initiatives. The functionality was initially developed to automatically compare individual helicopter approaches to landing with a baseline statistically determined from aggregated data from more than 2,600 landings by squadron pilots. Eleven criteria from the aircraft’s standardized operating procedures were used to establish a baseline landing data set, as represented in Figure 6, to which approaches to landing could be automatically compared post-flight.

Figure 6 – Example Baseline Data Set

The methodology included the plotting of data points for each of the eleven criteria to show the amount each value deviated from the statistically derived norm during an approach to landing. Presentation of results was made using the Intelligent Leading Indicators Display System (ILIDS), which incorporates multi-color codes. Green indicates values less than one standard deviation from the mean, yellow indicates values from one to two standard deviations from the mean, and red indicates values greater than two standard deviations from the mean. Data points from a specific individual approach to landing are depicted as white vertical rectangles and can be readily compared with the baseline data set using the ILIDS presentation format. Figure 7 shows the results from an approach to landing for which all values are within one standard deviation of the mean. Figure 8 shows the results from an approach to landing for which two parameters (airspeed) were
approximately two standard deviations from the mean. Although the two deviations in Figure 8 appear statistically significant, a qualified pilot or other subject matter expert would have to determine if an unsafe event or procedural error actually occurred. Whereas the Baseline Comparative Analysis methodology was initially demonstrated using helicopter approaches to landing, it is currently being developed for fixed wing approaches and can be used to automatically evaluate any flight maneuver or system performance for which sufficient data are available to derive a baseline norm. Reference 5 provides a more in-depth description of Baseline Comparative Analysis and its use in identifying leading indicators.

**Figure 7 – ILIDS Graph – Approach to Landing #1**

**Figure 8 – ILIDS Graph – Approach to Landing #2**
Baseline Comparative Analysis – Benefits and Impact on Operational Readiness

The Baseline Comparative Analysis is a powerful methodology that can enhance MFOQA capabilities by providing an analytical tool for assessing aircrew and systems performance without the need for a predetermined set of evaluation criteria. It can also provide an objective basis for validating existing performance criteria as well as determining if and what changes to baseline criteria may be needed for greater accuracy in performance comparisons. During the Demonstration the analysis methodology combined with the ILIDS presentation format was assessed to have significant potential to better standardize grading criteria for approaches to landing, especially for shipboard operations.

With a statistically significant baseline data set, Baseline Comparative Analysis can be used to establish norms with respect to routine operations that can be used to identify anomalous outliers in the data indicative of a pending system failure or deficient aircrew performance that would likely otherwise go undetected. The methodology can impact operational readiness with improved aircraft availability and flight safety by providing decision makers with actionable information to effect systems repairs in advance of in-service failures and address deficient aircrew performance before it becomes a causal factor in a mishap.

Aviation Safety Awareness Program (ASAP) – A Complement to MFOQA

Concurrent with the DON MFOQA Demonstration, an Aviation Safety Awareness Program (ASAP) was instituted at select squadrons by the senior Naval aviation command to provide an anonymous online means for aircrew and maintenance personnel to input feedback regarding squadron flight operations. It provides a means for capturing self-reported data for the development of mishap leading indicators, operational efficiency improvements, and human factors trend analyses. Although ASAP inputs may be subject to some degree of inaccuracy due to individuals’ biases and perspectives, ASAP has proven to be a valuable source of information to complement MFOQA capabilities when data from both can be correlated.

When ASAP inputs can be correlated to MFOQA data, objective analyses can be used to obtain complementary information otherwise unavailable. The ability to correlate different information sources provides squadron leadership a means to validate relevant reports, quantify appropriate corrective action when required, and evaluate the effectiveness of any action taken. As both MFOQA and ASAP capabilities evolve, the potential exists to integrate both in order to base ASAP questions presented to respondents on results from MFOQA data analyses, and to identify areas warranting further MFOQA analyses from ASAP inputs.

The types of information obtainable from ASAP are determined in large measure by the questions posed to respondents. Most questions have a safety focus, and are tailored to some degree to the squadron’s flight operations and operating environment. The input format varies from general questions, such as pertain to the organization’s safety climate, to narrative boxes where detailed comments can be provided. Figure 9 shows a representative sample of responses regarding human factors related issues for one squadron.

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information occurred during the DON MFOQA Demonstration and follow-on initiatives.

Soon after one squadron implemented ASAP, senior leadership learned from anonymous reports that some aircrews were not following a standard operating procedure that directly impacted flight safety. The command took corrective action by placing greater emphasis on the procedure during training, and heightening awareness of the safety hazard posed by failing to comply, without the need to identify the individual aircrews whose non-compliance had resulted in the ASAP reports. ASAP reporting also included maintenance actions that had not been performed correctly or when required, as well as airfield hazards for which the information was forwarded to the appropriate authorities for corrective action.

Benefits from the correlation and analysis of MFOQA and ASAP data were also demonstrated. In one instance, both the instructor pilot and pilot under instruction submitted ASAP reports following a practice “maximum braking landing” during which both main mount tires failed during landing rollout. After touchdown the aircraft failed to decelerate as expected; the instructor pilot directed the pilot under instruction to apply more brake pressure and both tires subsequently failed. Neither pilot had recognized anything out of the ordinary during the landing that could have contributed to the less than expected deceleration rate. Since the flight in this particular example was identifiable, the corresponding flight data were obtained and analyzed using the MFOQA process to determine if there was any evidence of aircrew or aircraft system performance that could have contributed to the incident. Results from the flight data analysis indicated that the engine throttles had not been fully retarded to the idle position after touchdown, which resulted in sufficient positive thrust remaining to prevent normal deceleration. The results provided objective information that could be used to raise the awareness of all pilots to avoid recurrence of this error.

Though still relatively new initiatives within DON, MFOQA and ASAP have demonstrated benefits individually that can improve safety and operational efficiencies. However, when data from both sources can be correlated, their combined functionalities can provide even greater benefits to operators with a corresponding increase in overall operational readiness.

**MFOQA versus FOQA**

DON MFOQA, like commercial FOQA, includes the precept of using objective and actionable information from flight data analyses, reporting, and visualization to identify adverse trends, unnecessary risks, and operational inefficiencies. Both include functionalities that can help determine appropriate corrective measures when applicable, and conduct follow-up assessments of actions taken in order to take further actions as appropriate. DON MFOQA also involves the sharing of flight data, without aircrew identifying data, throughout the Naval Aviation Enterprise, and places restrictions on the use of information derived from MFOQA data for enforcement or disciplinary purposes. Similar to the FAA policy regarding enforcement actions, the DOD MFOQA implementation policy directs that data generated from MFOQA processes shall not be used for monitoring aircrew performance for the purpose of initiating punitive or adverse action, and that MFOQA data may only be used for punitive type action in cases of suspected willful disregard of regulations and procedures.

Unlike commercial FOQA, however, DON MFOQA includes post-flight animation and flight data analysis and reporting after every flight. In addition, personnel and operational issues unique to Naval aviation pose significant challenges not typical for civil aviation FOQA programs. DON squadrons have a high personnel turnover rate not normally experienced by commercial operators that requires an MFOQA program structure that readily facilitates continuity in operations with frequent changes in personnel assignments. The continual training and qualifying of aircrew and maintenance personnel in DON, as well as the re-qualification of personnel that regularly rotate between non-flying and flying tours of duty, require a training focus that differs from the typical training regimen in commercial aviation. The complex missions conducted by Naval aviation, such as air combat maneuvering, close air support, formation flights, and shipboard operations, also present unique data analysis, visualization, and reporting requirements not relevant to commercial air carriers.

Significant technological differences also exist. Most commercial operators have FOQA requirements for similar aircraft types and similar missions (varying models of either fixed wing or rotary wing aircraft). DON MFOQA, however, requires a common system architecture that will support a wide variety of operational communities and aircraft types, including fixed wing, rotary wing, and tiltrotor aircraft. The system must also sustain capabilities whether aircraft are operating at their home bases, embarked on aircraft carriers or other air capable ships, or deployed in austere airfield environments including combat operations. An effective DON MFOQA program requires specific functionalities to remain available to the operator regardless of the operating location or duration of deployment. The infrastructure must facilitate data accessibility for multiple individuals with differing
levels of access at varied commands, and allow for software maintenance and updates enterprise-wide on a timely basis. In addition, whereas commercial operators are expected to have technological and/or procedural measures to safeguard FOQA information considered to be company sensitive, proprietary, privacy related, or otherwise restrictive in nature, DON needs to consider if protective measures to properly safeguard any classified information that could be obtained through MFOQA products are required.

Conclusions

MFOQA can positively impact the operational readiness of Naval aviation with functionalities that provide improved insight into flight operations, including aircrew and aircraft systems performance, when needed by the end user. MFOQA technologies can be automated to provide actionable information while minimizing any associated increase in end user workload. The information can be presented in a user-friendly format that is relevant to, and readily assimilated by, aircrews, maintenance personnel, and individuals in leadership positions.

Specific benefits that are available to the end user are determined by the availability, quality, and accessibility of requisite data; the robustness of software algorithms to process and visualize parameters and analytical results; the infrastructure to support data handling and processing; and the procedures and policies instituted to implement, sustain, and mature fielded MFOQA capabilities. A comprehensive data source with high collection rates of all relevant flight related and systems parameters is ideal for MFOQA; however, useful information can be obtained from less robust datasets obtained from data collection systems designed for more limited purposes.

The MFOQA knowledge management process provides benefits across the full spectrum of flight operations – maintenance, operations, safety, and training. MFOQA can improve aircraft availability and reliability by reducing aircraft system troubleshooting times, aiding in the detection of pending system faults prior to failures, and decreasing the likelihood of unnecessary maintenance. It can enhance flight operations by providing a means to monitor aircrew adherence to prescribed procedures and flight profiles, and determine appropriate changes to standard operating procedures and objectively assess the impact of such changes. It can be used by safety personnel in a non-intrusive manner to monitor how well aircrews adhere to certain safety guidelines, evaluate individual aircrew performance during emergency situations, and complete mishap investigations more quickly and with greater accuracy and thoroughness. The objectivity of MFOQA data visualization and reporting greatly enhances aircrew training by improving the quality of post-flight debriefs and providing the ability for aircrews to more effectively self-evaluate and monitor individual performance. Replays of prerecorded flight maneuvers performed correctly (“Gold Standard”) are also made available for aircrews to review prior to flying the maneuver for the first time as well as conduct a comparison with their own performance post-flight.

In addition to providing improved insight into flight operations at the squadron level, MFOQA aggregate analysis capabilities significantly enhance the ability of senior Naval aviation commands to monitor Fleet-wide operations and identify aircrew and systems trends that may have a positive or adverse impact on overall operational readiness. The need for changes in policies and procedures to improve operational readiness can be assessed with greater objectivity, and the same process can be used to evaluate the impact of implemented changes and determine if further change is required.

The DON MFOQA Demonstration and follow-on activities have proven that, if implemented correctly, MFOQA will improve aircrew training, maintenance, and operational efficiencies, and reduce aircraft and aircrew losses due to mishaps. Because of MFOQA’s potentially significant impact on operational readiness, its development and implementation have been supported by senior Naval aviation leadership. A DON MFOQA Acquisition Program formally began in 2006, and general DON policies regarding flight operations and aircraft maintenance have been revised to provide guidance and direction for future Fleet-wide MFOQA implementation. The successful integration of MFOQA technologies, procedures, and policies, combined with the appropriate training and motivation of personnel, will ensure MFOQA is a contributing factor in increased operational readiness of Naval aviation.

References


