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AIRCRAFT ACCIDENT EVALUATION USING QUALITY ASSESSEMENT TOOLS

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Abstract. The case study is focused on the application of principal quality tools in a fourth generation jet fighter to evaluate a maintenance activity in an accident investigation process. The paper assesses aircraft engineers' performance on checking aircraft tyre inflation pressure before the aircraft's flight. Process evaluation is organized by the application of fundamental quality tools in order to provide vital information regarding the level of control. The methodology combines the benefits of statistical quality control, root cause determination, and preventive actions, to eliminate maintenance discrepancy in the future. The methodology revealed an approach to generate useful safety metrics from incident reporting data. Furthermore, this study pointed out the significance of participation at all technician levels for the successful implementation of Total Quality Management (TQM). Also, it discusses the value of TQM in aviation and suggests that continuous improvement is still needed. The paper is based on practical work being undertaken in a military squadron and, therefore, is demonstrated to be practical in an aviation environment. This study would encourage aviation personnel to rely on TQM methods for performing quality assessment monitoring and achieving continuous improvement.

Keywords: military aviation, quality, aircraft, cause and effect analysis, measurement analysis, SPC.

Introduction

The aviation industry operates in a very high-tech and competitive market, where flight and personnel safety is of paramount importance due to higher rate of fatalities in case of any accident (Khalid, Ilyas, Ahmad, & Asim, 2014). Furthermore, numerous industrial and personnel accidents have been maintenance related. It means that as a result of an inherent fault or a failure that took place during the maintenance process, the maintained system experienced in-service failure (Knezevic, 2012). For this reason, aerospace maintenance should always entail high levels of professionalism, quality standards, and qualitative methods (Vassilakis & Besseris, 2009). In general, maintenance and its management has moved from being considered a "necessary evil" to being of strategic importance for most competitive organizations around the world (Fraser, Hvolby, & Tseng, 2015). In response to these trends, a growing number of researchers and practitioners are turning to systems-based approaches to workplace safety, with particular focus on the examination of the interactive influences of social-organisational and technical aspects of the work environment (e.g. Wilson, 2014). Carayon *et al.* (2015) define a sociotechnical system as 'the synergistic combination of humans, machines, environments, work activities, and organisational structures and processes that comprise a given enterprise'. It is obvious that aviation maintenance environment is caracterized as a complex sociotechnical system, as it consists of various contributing parts of the aviation industry: aircraft, engines, equipment, air traffic management, communications, navigation, surveillance, airports, maintenance, pilot training, and human factors. All these aspects should be collectively and legitimately kept at optimum standards regarding safety to actually keep safety as a permanent top priority as planned (Sanfourche, 2001).

A separate but integral part of the aerospace industry is military aviation. It is of great importance for every country's geostrategic role. Therefore, it is mandatory that military aviation requires higher degrees of professionalism, quality standards, and zero-tolerances, necessary for the armed forces' readiness and effectiveness. The application of TQM principles to maintenance issues for modern jet fighters is an attempt to further predict, improve and confirm their reliability enhancement (Makrygianni, Besseris, & Stergiou, 2011).

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Furthermore, contemporary aircraft design philosophy constitutes the framework for easier and more efficient maintenance applications. Most systems are equipped with instrumentation that permits the operating crew to monitor the performance both of the systems as a whole and of many of their individual components. Nevertheless, there are some vital systems/sub-systems for which the operating crew has no view of their operating capability until they are used.

TQM is considered as an important quality and performance improvement tool (Kumar, D. Garg, & T. K. Garg, 2009; Bhat & Rajashekhar, 2009). Although TQM has been studied and implemented throughout the world in different industries and sectors, such as manufacturing, production sector, the latest being the service sector (Faisal, Rahman, & Qureshi, 2011; Bhat & Rajashekhar, 2009). The literature on the military or civilian aircraft sector is rather limited. Until now, Schrage (1990) have put in perspective the impact of TQM and concurrent engineering on the aircraft design process and have reviewed some of the essential features for successful incorporation. Cheng, Lo, Liu, and Tsay (2004) utilized the analysis method of a quality functional deployment system as a tool to improve "curriculum design and teaching quality" of the Department of Aeronautical Engineering. Furthermore, Bhuiyan, Baghel, and Wilson (2006) presented a continuous improvement methodology developed in an aerospace company with the aim of achieving world-class quality in products and processes. Vassilakis and Besseris (2009) evaluated, a depot maintenance process by implementing TQM tools in a large aerospace company. Rasˇuo and Đuknic (2013) outlined an overhaul improvement plan pointing out the priority steps to be taken in order to optimize the most critical features that jeopardize the quality of the aircraft overhaul process relating to organization, technology and design.

As far as the aviation service sector is concerned, Psychogios and Tsironis (2012) investigated the critical factors influencing the application of Lean Six Sigma (L6σ) in an airline company. While, Ali, Dey, and Filieri (2015) assessed foreigners and overseas Pakistanis' evaluation of the quality of the services provided by Pakistan International Airlines (PIA) and its effect on customer satisfaction. Finally, there are several studies dedicated to unyielding reliability analysis problems in aircraft components (Wong, Ng, & Xu, 2006; Leung, Carroll, Hung, Tsang, & Chung, 2007; Al-Garni, Sahin, Al-Ghamdi, & Al-Kaabi, 1999; Makrygianni et al., 2011; Pari, Kumar, & Sharma, 2008).

In the present study, a relatively straightforward approach to the TQM concept implementation is provided as part of the aircraft accident investigation process while instituting problem-solving enunciation in the daily maintenance operations of a jet fighter. This paper describes the assessment of aircraft engineers' performance when checking aircraft main wheel tyre inflation pressure before an aircraft's flight. Process evaluation is organized through the application of fundamental quality tools in order to provide vital information regarding the level of control in the selected process. The methodology combines the benefits of statistical quality control, root cause determination and preventive actions to eliminate maintenance discrepancy in the future. Due to confidentiality reasons, no mention was made to the type or name of the aircraft and military squadron. Furthermore, for the same reason, no raw data was published as the aim of this paper is to propose a new methodology that can be easily implemented in other military squadrons or civilian airlines.

1. Background

1.1. Maintenance data

A military squadron consists of the operations management department (responsible for the preparation and execution of flight missions) and the maintenance department comprising all the technicians responsible for carrying out the Organizational Level Maintenance (O-level).

O-level maintenance is divided into two main initiatives:

1. *Preventive Maintenance* that includes all scheduled maintenance actions. One type of scheduled maintenance is the preflight inspection, which is conducted before each flight to ensure there are no substantial defects or malfunctions that could endanger flight safety. One of the principal maintenance activities during the preflight aircraft inspection is the tyre inflation pressure check, based on maintenance manuals, and tyre re-inflation, if necessary. The main wheel tyre pressure should be maintained at 15.4 bars irrespective of the outside temperature. The normal operating pressure of a tyre is between the reference value indicated above (15.4 bars) and plus or minus 5% (14.63–16.17 bars).
2. *Corrective maintenance* is an unscheduled task. It consists of all actions that are deemed necessary to restore a failed subsystem (or component) to reach a fully operational condition once again.

1.2. Aircraft accident data

During a fighter jet landing, the pilot communicated with Air Traffic Control (ATC) about a malfunction in the wheel system at the time when the main wheels touched the ground, without knowing the exact problem as there was no alarm indication in the cockpit. In seconds, the aircraft veered to the right and departed the runway surface and, finally, the experienced pilot stopped the aircraft on the runway without being injured. Nevertheless, the aircraft had undergone some losses, as the lefthand (L/H) main wheel tyre had gone down.

From the malfunction:

1. The aircraft tyre was scattered onto the runway in small pieces (Figure 1). The existence of these pieces (foreign object debris-FOD) represents hazards to departing and ariving aircraft, as they may be ingested into engines, causing power loss.

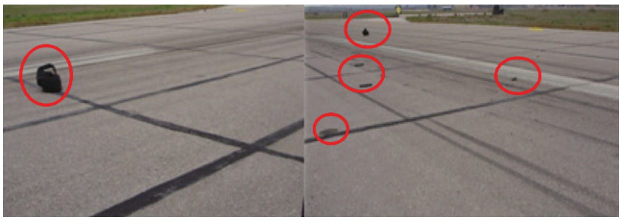

Figure 1. Tyre pieces on the runway

2. Until therunway was fully serviceable again, it was forbidden for other aircraft to use it. Thus, aircraft ready to land had to fly in a holding pattern to wait until the runway areawas cleaned up first, consuming additional fuel, while the other aircraft ready for takeoff had to postpone their mission.
3. The aircraft was out of service for about 20 days, degrading the overall military aircraft availability. Manpower, material and workdays had to be spent on unscheduled maintenance and repairs (Figure 2), delaying the execution of other scheduled maintenance activities.
4. In terms of dollars, the direct cost of the malfunction was calculated at about 25 000 $.

One parameter that should be taken into consideration during the accident investigation was the tyre inflation pressure. As there was no aircraft instrument or component to register the wheel tyre inflation pressure, the following methodology was incorporated into the investigation process.

2. Methodology

In general, aircraft airworthiness must be confirmed by numerical data and charts. The methodology presented in Figure 3 was based on the process monitoring and evaluation organized by the application of control charts with the intention of providing essential information regarding the level of control in the selected process. Quality control

Figure 2. The L/H main wheel

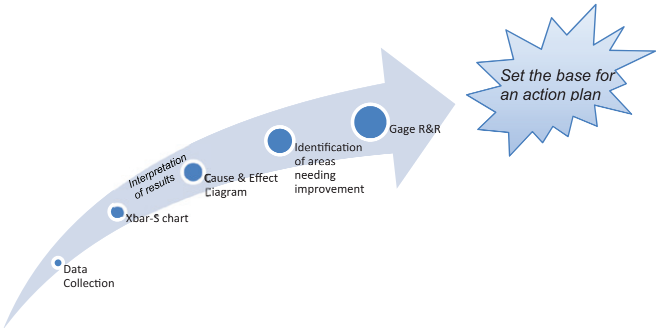

Figure 3. Quality assessment methodology

data was contrasted with the component specifications by employing control charts to provide a metric for the level of the process capability index.

The elucidation of variable control charts would be investigated through a measurement system analysis. A Cause and Effect diagram would be created as a road map for measuring and, at the same time, confronting the variability of the data. Finally, a Gage Repeatability and Reproducibility (R&R) analysis in the present study would divulge the acceptability of the measuring process. It would also facilitate the consideration of the possible sources of measurement variability. Therefore, a complete gage R&R study was carried out to assess the measuring capability of the three selected aircraft engineers on 10 aircraft wheels. All graphs and computations which have been laid down in this report have been performed on the statistical software MINITAB 17.

3. Case study

3.1. Data collection

This study was conducted in a military squadron with fourth generation jet fighters as part of the aforementioned aircraft accident investigation process. The maintenance activity chosen for the implementation of the SPC tools was the verification of tyre inflation pressure before the aircraft flight. The quality characteristic was the tyre inflation pressure.

For a valid measurement system analysis, parts must be randomly sampled and measured. Data gathered from ten aircraft of the same type spans over five random flight days. Moreover, three different aircraft engineers were used for data collection. Each aircraft engineer checked the tyre pressure of each part seperately during this time. It was a blind study, so the operators (engineers) could not subconsciously achieve the results based on what they remembered as the last reading. For this reason, each operator took the measurements alone in a random way on the wheels to avoid potential issues which could make the measurement system look better than it is performed in the real process. An analogue tyre pressure gauge of 0–40 psi was used for the measurement procedure. Of the the three engineers, one had carried out the preflight inspection on the aircraft on the day the accident took place. The Gage R&R study was planned and a worksheet for data collection was proposed by Minitab 17. For 10 parts, 3 operators and 5 replicates, the Minitab proposed a data collection plan with 150 total runs.

3.2. Descriptive statistical analysis

Computation of the respective descriptive statistics was initiated to facilitate the quantitative management of the examined data. The minimum and maximum values of the sample, the mean and the standard deviation (StDev), the coefficient of variation (CoefVar), and the skewness and kurtosis of the data for the aircraft were extracted (Table 1). The standard deviation of a random variable is defined as the square root of the variance, and is often used in place of its variance to describe the spread of its sample distribution. The coefficient of variation of a random variable is defined as the ratio of the standard deviation over the mean of the random variable; it is a dimensionless measure of the variability of the random variable. Skewness and kurtosis are statistical estimators that characterize the shape and symmetry of the sample distribution. Skewness is a measure of the degree of asymmetry of a distribution, while kurtosis is a measure that indicates the peakedness of their protrusion(s). The kurtosis and skewness estimates for data obeying a normal distribution are identically equal to zero.

From Table 1, the results are briefly summarized as follows:

1) tyre pressure values vary from 15.295 to 16.15 bar (between the specification limits);
2) the coefficients of variation are in the proximity of one, meaning that the data have low variability;
3) for the first five parts, tyre pressure values are negatively skewed, which means that mode > median > mean are in contrast with the next five tyres.

Moreover, to discover a suitable reference law of the maintenance data from several candidate distributions, the dataset was fitted to: Weibull, exponential, loglogistic, normal and logistic distributions. The maximum likelihood estimation method was used per candidate distribution to furnish the fitting function. The suitability of the fitted parameters was assessed by applying the Anderson-Darling (AD) goodness-of-fit test. The tabulation of the computed Anderson-Darling statistics for the five theoretical fitted distributions of the total tyre pressure data is summarized in Table 2. A smaller AD statistic value hints that the corresponding distribution fits the data closer. According to the AD values, it is confirmed that the data set is well-modeled by a normal distribution.

3.3. Xbar-S chart

In statistical process control, the analysis of measurement data is described by two main statistical tools: mean () and standard deviation (s). The data are depicted on control charts. The main purpose of control charts is to indicate how the level of performance varies across the data set (Mitra Debnath & Shankar, 2014). Control charts provide the graphical means to observe a maintenance process over a selected period of time and to easily identify whether a process is in control or not as well as whether an undesirable change is caused by random or assignable causes (Duffuaa & Ben-Daya, 1995). The first and simplest approach for producing control charts is to determine control limits for each individual control chart, according to the following mathematical relations (Montgomery, 2005).

For the Xbar control chart:

Centre line: $$\bar{\bar{x}} = \frac{\sum_{i=1}^{n} \bar{x}_i}{n}; \quad (1)$$

Upper control line: $$CL = \bar{\bar{x}} + A_3 \bar{s}; \quad (2)$$

Lower control line: $$CL = \bar{\bar{x}} - A_3 \bar{s}. \quad (3)$$

Here n is the subgroup size, and s is the standard deviation computed for each subgroup separately as follows:

Table 1. Descriptive statistical analysis

Parts	Mean	StDev	CoefVar	Minimum	Maximum	Skewness	Kurtosis
No 1	15.790	0.235	1.49	15.420	16.100	–0.27	–1.31
No 2	15.721	0.235	1.50	15.360	16.075	–0.03	–1.29
No 3	15.819	0.174	1.10	15.515	16.095	–0.29	–0.66
No 4	15.720	0.193	1.23	15.295	16.100	–0.07	1.13
No 5	15.828	0.204	1.29	15.475	16.100	–0.21	–1.08
No 6	15.777	0.192	1.22	15.500	16.150	0.62	–0.50
No 7	15.719	0.193	1.23	15.475	16.100	0.78	–0.52
No 8	15.690	0.237	1.51	15.390	16.100	0.61	–1.21
No 9	15.730	0.227	1.45	15.370	16.150	0.07	–0.76
No 10	15.652	0.135	0.87	15.435	15.935	0.57	0.09

Table 2. The Anderson-Darling statistics for aircraft tyre pressure data

	Weibull	Exponential	Loglogistic	Normal	Logistic
Tyre pressure data	2.640	67.038	1.379	1.190	1.409

$$s=\sqrt{\frac{\sum_{i=1}^{n}(x_i-\overline{x})^2}{n-1}}\ ; \qquad (4)$$

and $$\overline{s}=\frac{\sum_{i=1}^{n}s}{n}. \qquad (5)$$

In this case study, 15 subgroups of 10 aircraft tyre pressure values were collected. Due to the fact that our data follows the normal distribution, the factor A_3 equals 3.

For the S control chart:

Centerline: $\overline{s}$

Upper control line: $CL=B_4\overline{s}$; (6)

Lower control line: $CL=B_3\overline{s}$. (7)

Here B_3, B_4 are functions of the sample size n and are tabulated in the Tables of statistic books.

An out-of-control point or any out-of-control pattern of the depicted data for any of these statistics is an indication that a special cause for the variation is present and that an immediate investigation should be made to identify the special cause (Pyzdek, 2003).

According to Figure 4, the S chart for the tyre pressure data can be summarized as follows.

1. The lower and upper control limits are 0.3438 and 0.0568, respectively. Therefore, the subgroup ranges are expected to fall between 0.3438 and 0.0568. The center line (estimate of process standard deviation) is 0.2003.
2. None of the examined data subgroups fall outside of the control limits. Furthermore, the points inside the limits display a random pattern. This S chart does not provide any evidence for lack of control. Thus, the process variation is in control and the Xbar chart can be examined.

As far as the Xbar chart for the tyre pressure data is concerned, it can be summarized as follows.

1. The lower and upper control limits are 15.9399 and 15.5491, respectively. Therefore, the subgroup averages are expected to fall between 15.9399 and 15.5491. The center line (estimate of process average) is 15.7445.
2. There is no data located below or above the control limits.
3. All the subgroups are marked in less than one s from the two sides of the center line.

These results indicate that the process average is stable and the process is in control.

In this paper, Process Capability (Figure 5) demonstrated a maintenance activity conforming to the specification limits as it falls within them (USL = 16.17 bar and LSL = 14.63 bar). In addition, the term Sigma Quality Level is used as an indicator of process goodness. A lower sigma quality level means a greater possibility of defective products, while, a higher sigma quality level means a smaller possibility of defective products within the process (Harry & Schroeder, 2000; Breyfogle, 2001). The main goal of this approach is to reach the level of quality and reliability that will satisfy and even exceed the demands and expectations of today's demanding customer – in our case study, the demanding safety and aircraft availability levels (Pyzdek, 1999). The goal of "six sigma" (6-s) became a by-word for the management and engineering practices used to achieve it, since this defect level corresponds to 3,4 ppm defective products (Sokovic & Pavletic, 2006).

For tyre pressure data, the Pp, relating how the process is performing to how it should be performing, is 1.25, which indicates that the specification spread is 1.25 times greater than the 6-s spread in the process. Since the Pp is 1.25 and the Ppk (0.69) are not close to one another, it indicates that the process is not centered on target, but is displaced in the upper specification limit. Furthermore, the number of parts per million (PPM) that have measurements beyond the specification limits is zero, pointing out that all measurements are located inside the specification interval. 0.03 parts per million are expected to have measurements less than the LSL and 19 402, 62 parts per million are expected to have measurements greater than the USL (Figure 5).

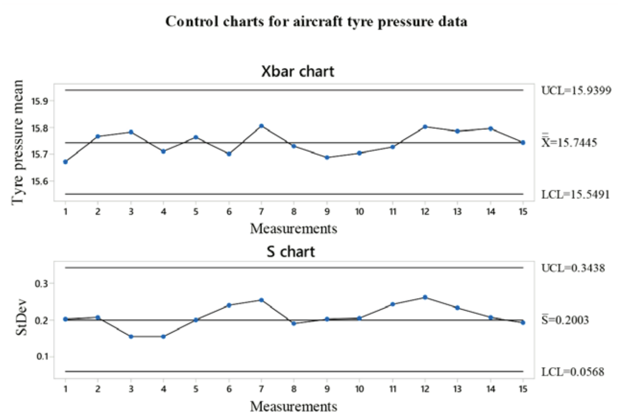

Figure 4. Control charts of main wheel tyre inflation pressure

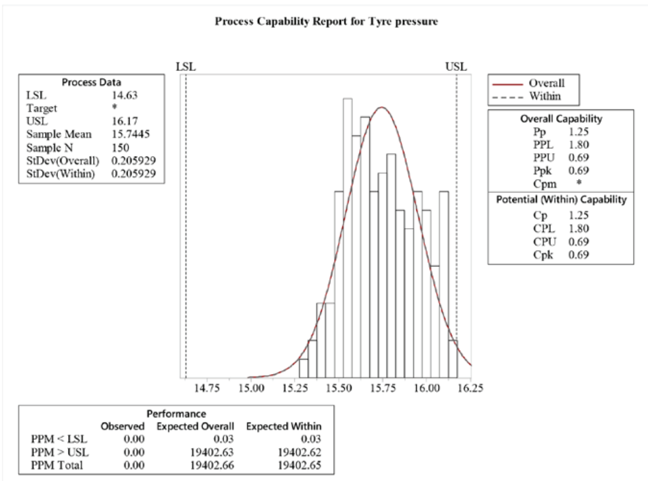

Figure 5. Process capability of the tyre inflation pressure of the main wheels

In addition, the Process Capability Indices (PCI) are an important kind of indices, as they provide single-number assessments of the inherent process capability to meet the specification limits – in our case study, the values as defined in maintenance manuals, on the quality characteristic of interest (Sun 2002). Overall and potential capability indices are illustrated in Figure 5. The fact that $P_p = C_p$, $P_{pl} = C_{pl}$, $P_{pu} = C_{pu}$ and $P_{pk} = C_{pk}$ indicates that the examined process is in control. Whereas, $C_{pm} = 0.64$ points out that the process mean is shifted from the target value, closer to the upper specification limit.

While the C_{PL} and C_{PU} relate the process spread to a single-sided specification spread (m-LSL or USL-m). In our case study, $C_{PL} = 1.80$ and $C_{PU} = 0.69$ witness that the data are closer to the upper specification limit. In addition, C_P designates the spread of the process and C_{PK} witnesses both the spread and the setting of the process. For aviation industry, both the C_P and C_{PK} must be greater than 2.00 in order to minimise the production of defectives (Juran 1998). This study found the values of 1.25 and 0.69, respectively. The Process Capability Indices qualified that:

1. At the time, the process was operating within the upper and lower specification limits.
2. The process is prone to producing points out of the upper control limit, creating safety problems to pilots and maintenance personnel.

Consequently, temporarily, almost all the examined fighter aircraft were dismissed for flight with the appropriate tyre inflation pressure. Nonetheless, there should be more research on the fact that the data were not centered on the target value, as there is a great possibility for an accident to happen in the future. For this reason, a cause and effect analysis was executed.

3.4. Cause and effect diagram (ABC analysis)

The identification of a particular effect from the ABC analysis leads to the construction of a cause and effect diagram which is a graphical way to display the causes behind a problem (Vassilakis & Besseris, 2010). The cause and effect diagram is easy to develop and invites interactive participation from different departments while making constructive use of the information from many specialties (P. Garg & A. Garg, 2013). A group of experts representing the inspection and quality assurance departments from the air force base contributed to this report. Employee participation at all levels is the key to a successful implementation of TQM, as it will help to increase the flow of information and knowledge and will contribute towards resolving problems (Vouzas & Psychogios, 2007). Decoding a root cause relies on technician solidarity, as it imposes the cooperation between maintenance technicians and middle level managers (Al-Garni et al., 1999).

In this study, the team was supported by experienced maintenance technicians who comprehend the day-to-day task details. The team probed deeply into the problem, which led to categorizing the causes and displayed the relationships between the causes and the effect in a fishbone diagram (Figure 6). In addition to narrowing down the focus, brainstorming (Vulanovic et al., 2003) and brainwriting were deployed to locate the most prevailing factors that might potentially create data variability (Rasuo & Đuknic, 2013). Therefore, among the causes depicted in the fishbone diagram, the project team convened to track down and examine four focal factors through the method of measurement analysis:

1) measurement inconsistency;
2) technical inability to fine-tune the pressure indicator;
3) lack of skills;
4) aged and overused material (wheel tyre).

3.5. Gage R&R

The former causes were investigated through a measurement systems analysis. The Repeatability and Reproducibility of the data gathered should be examined to summarize system performance (Vassilakis & Besseris, 2009). The Gage R&R is used to determine if a measurement system is capable for its intended purpose. If the measurement system variation is small, compared to the process variation, then the measurement system is considered capable.

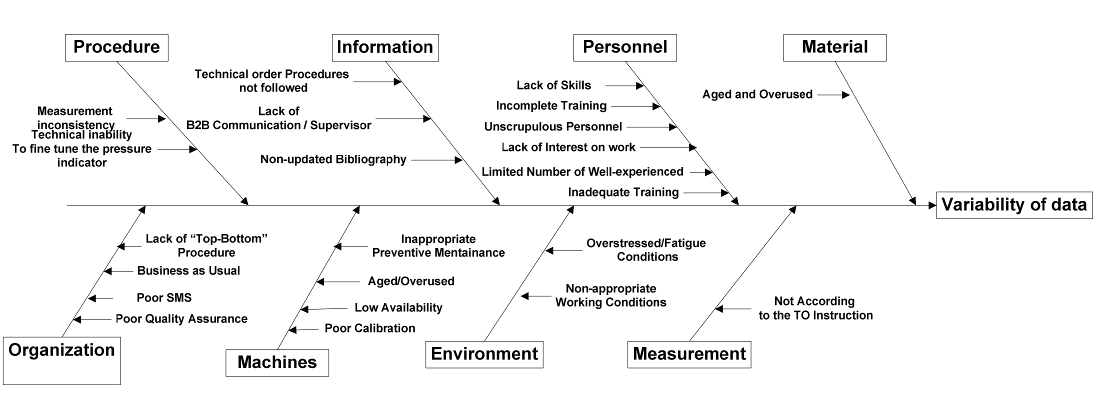

Figure 6. Cause and Effect diagram for data variability

In general, the purpose of a gage R & R study are to (Borror, 2008):

- determine the amount of variability in the collected data that can be attributed to the measurement system in place;
- isolate the sources of variability in the measurement system.

In this case study, the "parts" (tyre wheels) and the "operators" (aircraft engineers) were selected at random (except for one engineer, who carried out the preflight inspection on the aircraft of the accident), so they represent the entire operating range of the process.

Gage variability is a function of variance components. Let $\sigma^2_{Repeatability}$ represent the inherent variability in the gage and $\sigma^2_{Reproducibility}$ represent the variability due to different operators using the same gage. The measurement error variability is:

$$\sigma^2_{Measurement\ Error} = \sigma^2_{Repeatability} + \sigma^2_{Reproducibility}. \quad (8)$$

According to Table 3, the part-to-part variation (σ^2_{Part}) relating to 10 wheels had been included well at a contribution of 0. 92%. However, it was the measuring device that caused the largest percentage in variation. This variation ($\sigma^2_{Repeatability}$) was estimated at 99.08% whilst all three operators ($\sigma^2_{Reproducibility}$) did not affect the measurement variation.

The six graphs of the Gage R&R analysis (Figure 7) reveal the following main points.

1. In the Components of Variation graph (located in the upper left corner), the percent contribution from the Total Gage R&R is larger than that of Part-to-Part, pointing out that most of the variation is due to the measurement system – primarily repeatability; little is due to the differences between parts. In the By Part graph (located in upper right corner), there are large differences between parts, as shown by the non-level line.
2. In the R Chart by Operator (located in middle of the left corner), Operator 1 measures parts more inconsistently than the other two.
3. In the By Operator graph (located in the middle of the right column), the differences between operators are small compared to the differences between parts, and insignificant (p-value = 0.812).
4. In the Xbar Chart by Operator (located in lower left corner), all the points in the X and R chart are inside the control limits, indicating that the observed variation is mainly due to the measurement system.

Table 3. Gage R&R results

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.0425411	99.08
Repeatability	0.0425411	99.08
Reproducibility	0.0000000	0.00
Operators	0.0000000	0.00
Part-To-Part	0.0003959	0.92
Total Variation	0.0429370	100.00

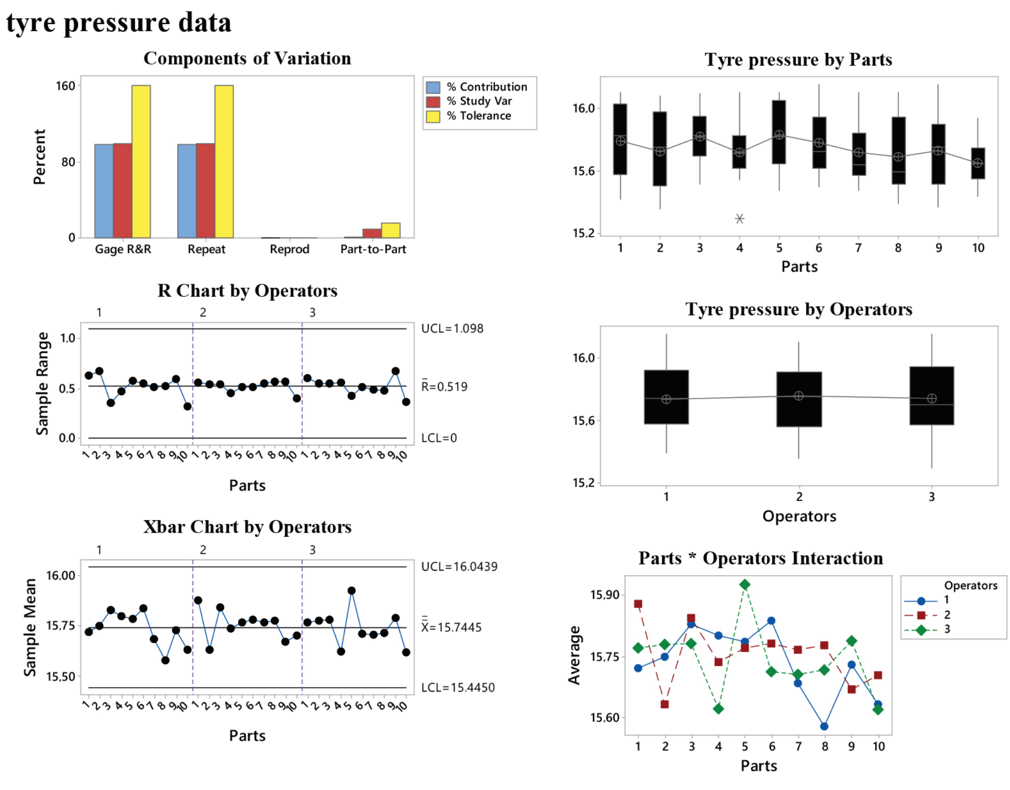

Figure 7. Gage R&R study for the main wheel tyre inflation pressure check

5. The Operator*Part Interaction graph is a visualization of the p-value for Oper*Part (0.881 in this case), indicating no significant interaction between each Part and Operator.

In conclusion, it seems that only the measurement system and, in particular, the measuring device could have provoked such an accident. For this reason, the project team proposed two radical measures in order to minimize the possibility of a future accident.

1. The replacement of the analogue adjustment gauge with a digital one would increase the inherent precision of the instrument itself, making initial settings and readings easier.
2. The replacement of the pressure indicator adapter with another one capable of screwing on the tyre valve could create a more accurate pressure reading.

In addition, comparing the performance of the three engineers, it seems that the technicians' capability to check tyre pressure is at a high level, as they are not thoroughly responsible for data variability. However, the first one could enhance technical skills through specialized training and more practicing sessions.

Conclusions

This paper presented a methodology as part of an aircraft accident investigation process, while instituting problem-solving enunciation in daily maintenance operations of a jet fighter. The proposed methodology combines the benefits of statistical quality control, maintenance process improvement, root cause determination, and preventive actions, to eliminate accidents in the future. More specifically, aircraft engineers' performance of a tyre inflation pressure check of two aircraft main wheels was assessed before the jet fighter was dismissed for flight. The data was gathered from ten aircraft of the same type over a span of five random flight days. Moreover, three different aircraft engineers were used for data collection. Each aircraft engineer checked each part during this time in a blind procedure. Among the engineers, one who carried out the preflight inspection on the aircraft before the accident was present. After data gathering, variable control charts (Xbar and S) were created. The control charts depicted a stable and in control process. Nevertheless, the Process Capability Indices qualified that, although the process at the time was operating within the upper and lower specification limits, it tends to produce points out of the upper control limit, creating potential safety problems to pilots and maintenance personnel in the future.

Furthermore, the possible causes responsible for the above trend were categorized and displayed in a fishbone diagram by experienced maintenance technicians. Among the causes depicted in the fishbone diagram, the project team convened to track down and examine four focal factors with the method of measurement analysis: measurement inconsistency, technical inability to fine-tune the pressure indicator, lack of skills, and aged and overused material (wheel tyre).

Based on the Measurement Analysis (Gage R&R) results, the part-to-part variation relating to aircraft wheels had been included well at a contribution of 0.92%. However, the measuring device caused the largest percentage in variation. This variation was estimated at 99.08%, whilst not all of the three operators affected measurement variation. Thus, only the measurement system and, in particular, the measuring device could have provoked such an accident. For this reason, the project team proposed two radical steps in order to minimize the possibility of a future accident.

1. The replacement of the analog adjustment gauge with a digital one would increase the inherent precision of the instrument itself, making initial settings and readings easier.
2. The replacement of the pressure indicator adapter with another one capable of screwing on the tyre valve could create a more accurate pressure reading.

In conclusion, this study proposed a scientific framework enabling to achieve justified and well-structured results of an accident investigation process. At the same time, it nurtured the significance of total involvement of the organization in the problem solving and accident investigation processes. The paper is based on practical work being undertaken in a military squadron and, therefore, demonstrates its practical application in an aviation environment. The outcome of this research is expected to contribute in the shape of a TQM measuring tool for maintenance decision makers allowing to evaluate the performance of any aviation maintenance activity not only in the military but also civilian airlines. Furthermore, the investigation of factors responsible for maintenance errors and the unit's performance has contributed to achieving a higher organizational performance (Park, Kang, & Son, 2012). Therefore, this study would indisputably encourage personnel to rely on modern TQM methods for performing their quality assessment monitoring and continuous improvement, since the absence of accidents is no guarantee that they will remain absent. Finally, this study develops enabling factors needed to introduce effective TQM such as leadership, teamwork, knowledge transfer through employees' participation, policies and procedures (Khalid et al., 2014).

Further work

This work is focused on a single maintenance activity. Further research on the area covered in this paper that would result in publications would be of great interest to both practitioners and the scientific community as it could uncover specific maintenance working environment weaknesses and lead to suitable remedies (Karanikas, 2013). Furthermore, when the complexity of the work, technology and social environment increase, the significance of the most implicit features of organizational culture as a means of coordinating the work and achieving safety and effectiveness of the activities also increases (Reiman, 2007). Further research on TQM implementation in sociotechnical environments could discuss issues involved in the development and use of TQM theories for envisioning and studying workplace safety-related issues in sociotechnical systems.

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