COMPARISON OF HUMS BENEFITS—A READINESS APPROACH

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The Army's Aviation and Missile Command (AMCOM) is pursuing a robust Condition Based Maintenance (CBM) program across its entire aircraft fleet. The CBM program is aimed at decreasing the maintenance burden on Soldiers, increasing platform readiness and availability, reducing operations and support costs, and enhancing safety. From the program's inception, AMCOM leadership anticipated it would reduce the maintenance burden and improve maintenance practices that would increase platform readiness and availability[1]. This paper details the analysis to demonstrate the effect of CBM on Army helicopter Non-Mission Capable for Maintenance (NMCM) rates on a fleet-wide basis. This paper outlines the analysis and methodology behind the initial study to calculate NMCM reductions across the fleet as a result of the application of CBM hardware, software, and maintenance practices on the UH-60A/L. The analysis reflects the increase in readiness and availability of aircraft for commanders to generate additional combat power.

Notation

Aircraft-month – denotes statistics unique to an aircraft in a given month
AMCOM – Army Aviation and Missile Command
CAD – Command Analysis Directorate
CBM – Condition Based Maintenance
DSC – Digital Source Collector
FMC – Fully Mission Capable
HUMS – Health Usage Monitoring System
LOGSA – Logistics Support Agency
MC – Mission Capable
PMC – Partially Mission Capable
NMC – Not Mission Capable
NMCM – Not Mission Capable-Maintenance

Introduction

Two goals of AMCOM's CBM program are to reduce the maintenance burden on soldiers, as well as increase platform availability. From the beginning, AMCOM leadership has anticipated that a CBM program using Digital Source Collectors (DSC)—HUMS in industry parlance—would both improve maintenance practices and reduce the requirements of maintenance down-time. Such a reduction in maintenance down time should be measureable in readiness rates reported by Army helicopter units. While the initial study presented in this paper contains only a sample of aircraft for one platform, AMCOM's task is to demonstrate via logistical reporting data (LOGSA) the effect of NMCM rate reduction on a fleet-wide basis. In an effort to measure the benefits provided by CBM, the AMCOM has developed six metrics to assess the long-term impact of the program on the helicopter fleet. One of the metrics is an analysis of NMCM rates by aircraft type.

This paper outlines the initial study involving a sample of UH-60A/L aircraft reporting from 7/2004-8/2008 and AMCOM G3's initial methodology and results in being able to capture, filter, and analyze the available data on NMCM rates in the helicopter fleet since the time of the study.

The NMCM metric is intended to highlight the benefits provided by CBM when comparing HUMS- against non-HUMS-equipped aircraft. This methodology has been tested against current and historical data. The study produced promising results for UH-60A/L and that methodology has been refined and will be implemented into the analysis of the Army's AH-64 Apache and the CH-47 Chinook fleets.

Methodology

The primary data source for this metric is the Army's monthly readiness reporting for its aviations fleet, historically known DA Form 1352 (*Army Aircraft Inventory, Status and Flying Time*)[2,3] stored by LOGSA. This form is completed and submitted at the unit level and contains information including aircraft model, serial number, mission capable hours and rates, and not mission capable hours and rates. These include Fully Mission Capable (FMC) hours and rates, Partially Mission Capable (PMC) hours and rates, and Not Mission Capable [due to] Maintenance (NMCM) hours and rates. NMCM hours are comprised of the sum of Aviation Intermediate Maintenance, Aviation Unit Maintenance, and Not Mission Capable Depot. FMC hours describe an aircraft that can perform all of its

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combat missions without endangering the lives of crew or operators. Finally, PMC hours describe an aircraft capable of performing one or more, but not all, assigned missions, due to one or more of its mission-essential subsystems being inoperative for maintenance or supply. The secondary source is AMCOM G3's list of DSC/HUMS-equipped aircraft (by tail number and date of DSC installation).

Analysts working for AMCOM G3's CBM office and its Command Analysis Directorate (CAD) developed approximately ten rules that must be applied to the aggregated data set for each aircraft. The primary purposes of the rule set are to screen erroneous entries (from LOGSA data) and ensure results have a reasonable confidence in the eyes of analysts, program managers, Army Aviators, and AMCOM leadership. A portion, but not all, of these rules will be detailed to give the reader an appreciation of the screening necessary to conduct meaningful analysis and draw statistically valid results from the data sets.

Assumptions and Limitations

There are several assumptions that must be recognized before the analytical approach. First, hours and categories they are entered under are recorded by hand, or electronically, by the unit and are assumed to be accurate and correct. Second, flight hours reported in LOGSA are assumed to be accurate for the purposes of some rules and filters. To maintain these assumptions, several rules used in the study focus on filtering invalid entries from the data set.

Several limiting factors impact the study. The study was comprised of two subsets of all UH-60A/L aircraft, one with DSC installed between 7/2005 and 8/2007, and a control group with no DSC on board for the entirety of that time period. It is assumed the analysis of the *sample* can be *generalized* to the entire fleet. As more aircraft and units are equipped with DSC/HUMS, the data sample will grow and allow stronger conclusions to the fleet as a whole.

Data is also limited by the accuracy of DSC/HUMS installation date. In some cases, organizations outside the control of AMCOM G3 CAD installed DSC systems and the actual installation date is unknown or imprecise. Aircraft with unknown or imprecise installation dates were completely removed from the data set.

The DA Form 1352 also has inherent limitations. Hours in which two possible categories are applicable may be reported in part under either. For instance, some aircraft may be down for maintenance while at the same time awaiting parts. Such an aircraft may have those shared hours reported under either NMCM or Not Mission Capable [due to] Supply (NMCS). Such entries are left to the unit's discretion; the data sets are taken "as is" from LOGSA and they have quality control authority for NMCM vs. NMCS.

Analytic Approach

The analysis for the study starts with the primary source of data, DA Form 1352 records retrieved from LOGSA's web interface. Relevant data elements include aircraft tail number, aircraft model, date of the report (reporting month), NMCM rate, Mission Capable (MC) rate (the union of FMC and PMC), FMC rate, PMC rate, and NMCS rate. Serial numbers are compared to a verified DSC/HUMS list detailing aircraft installed with HUMS. This list matches aircraft with a DSC installation date. Data is then filtered to ensure erroneous or highly questionable entries are screened out, and for data integrity. Using these fields, the study was conducted as described below.

A subset of UH-60A/L aircraft installed with HUMS was selected for analysis based upon readily available data. That data set was then compared to a control group over the same time period. The control group was filtered with all applicable filters. This comparison affirmed the HUMS aircraft were an accurate representation of average operational aircraft previous to DSC installation.

Several rules and filters were applied to the data. The data reported during the month of DSC installation for an aircraft was filtered since it is impossible to define which hours were flown before and which were flown after the date of DSC installation. Also, the readiness rates for that month are directly affected by the maintenance required to install DSC/HUMS equipment. Months in which aircraft were under-utilized were removed from the data set. These were aircraft which reported 100% FMC yet posted no flight hours for that month. Under-utilized aircraft were deemed irrelevant to any benefit provided by HUMS. Data reported during months an aircraft displaying extensive maintenance were filtered from the data sets. Extensive maintenance was qualified by aircraft reporting 100% NMCM for a reporting month and is deemed not representative of an operational aircraft. Data reported during months immediately surrounding DSC installation were also filtered. This filtered included a six-month band before and after installation due to unique conditions surrounding DSC installation including phase maintenance and the system's learning curve. For the study, months in which insufficient aircraft had data available to report were filtered and not included in the results (see Appendix A).

Results for the data sample containing DSC installations were graphed on a relative time-scale in months from installation. These graphs include NMCM% vs. time, MC% vs. time, and FMC% vs. time. Further analysis also included plotting such rates vs. calendar time.

To ensure statistical validity of the results, aircraft from the subset installed with DSC were compared with each other and to the control sample with the filters mentioned above (with the exception of any time bands) applied to each set. The DSC set was divided into two groups, Group A represented all data gathered before DSC installation and Group B represented all data gathered after DSC installation. An Anderson-Darling Normality Test showed the groups were not normally distributed. This was followed by a test for equal variances which proved to be an invalid hypothesis. Following these results, both an F-test and Levene's test was conducted to compare the distribution of Group A to that of Group B. These tests found the means were statistically different. Group A was also compared to the Control Group. Again, an Anderson-Darling Normality Test showed the control group was not normally distributed. A test for equal variances proved to be a valid hypothesis. Following these results, a two-sample T-test compared Group A and the Control Group. The difference in means was not statistically significant.

Results

The study applied this methodology to the UH-60A/L airframe types with a great degree of success. AMCOM has subsequently pursued the use of the NMCM metric for analysis fleet-wide.

The study of UH-60A/L aircraft produced statistically significant results based on available data. NMCM rates were reduced by 5.3% for the sample data set (see Appendix B). The final data set included 105 aircraft from over 10 units. The date range of the data sample was from July 2004 through August 2008 with DSC/HUMS installations between July 2005 and August 2007. The requirement for installation dates ensured sufficient data would be available for all aircraft both before and after installation of DSC. The data set yielded data from 2,708 representative aircraft-months with over 140,000 flight hours during that time. From this sample, 6 months before and after installation was filtered from the data set, as mentioned above, for all aircraft. This filter is intended to provide a true steady-state representation of the resulting difference in NMCM rate rates as seen plotted on a timeline relative to installation date.

The difference in NMCM rates of 5.3% was then verified statistically. Using a two-sample T-test, Group A (data reported before installation) was compared to Group B (data reported after installation). Using a 95% confidence interval it was hypothesized that the difference between NMCM rates was equal to zero. The results included a p-value < 0.001 from which it was determined that the rates were statistically different. The estimated difference was 5.33% with a 95% confidence interval ranging from 3.92% to 6.75%. This analysis confirmed previous results (see Appendix C). More importantly, leadership within AMCOM and other Army Aviation stakeholder organizations deem the NMCM reduction to be of serious *practical significance* to Army Aviation readiness.

Table 1. Readiness Rates Associated with NMCM

	Before	**After**	**Difference**
NMCM	16.2%	10.9%	-5.3%
FMC	75.3%	85.1%	9.8%
MC	80.2%	86.9%	6.7%

To generalize such results across the entire fleet of UH-60 aircraft, the study was particularly interested in determining if the sample of pre-HUMS aircraft were representative of the rest of the fleet. Utilizing current data—reported between 2006 and 2008—for both the control group and Group A, a statistical comparison was made. The control group consisted of 1,301 UH-60A/L aircraft (the majority of the non-DSC-equipped fleet) with data reported between January 2006 and August 2008. These aircraft provided 24,954 representative aircraft-months with over 500,000 flight hours. NMCM rates for the control group were statistically compared to that of the sample before installation of HUMS. To provide a more stringent test, no data from pre-HUMS aircraft were included in the control group. A two-sample T-test with a 95% confidence interval was conducted with the hypothesis that the difference in NMCM rates between Group A and the control group were equal to zero. The resulting p-value = 0.095 was used to determine that the control group's NMCM rates were *not* statistically different from those of pre-HUMS aircraft (see Appendix D).

Table 2. Means and Standard Deviations of Samples

	Mean	**Standard Deviation**
Control Group	$16.9\% < \mu < 17.5\%$	$0.226 < \sigma < 0.230$
Group A	$15.1\% < \mu < 17.4\%$	$0.211 < \sigma < 0.228$
Group B	$10.0\% < \mu < 11.7\%$	$0.146 < \sigma < 0.158$

Recommendations

Since the time of this initial study, AMCOM G3 CAD is currently utilizing the NMCM metric to monitor three major aircraft platforms: AH-64 Apache, CH-47

Chinook, and UH-60 Blackhawk. The current process is highly labor-intensive. However, major steps are being taken to automate the process.

Acknowledgements

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References

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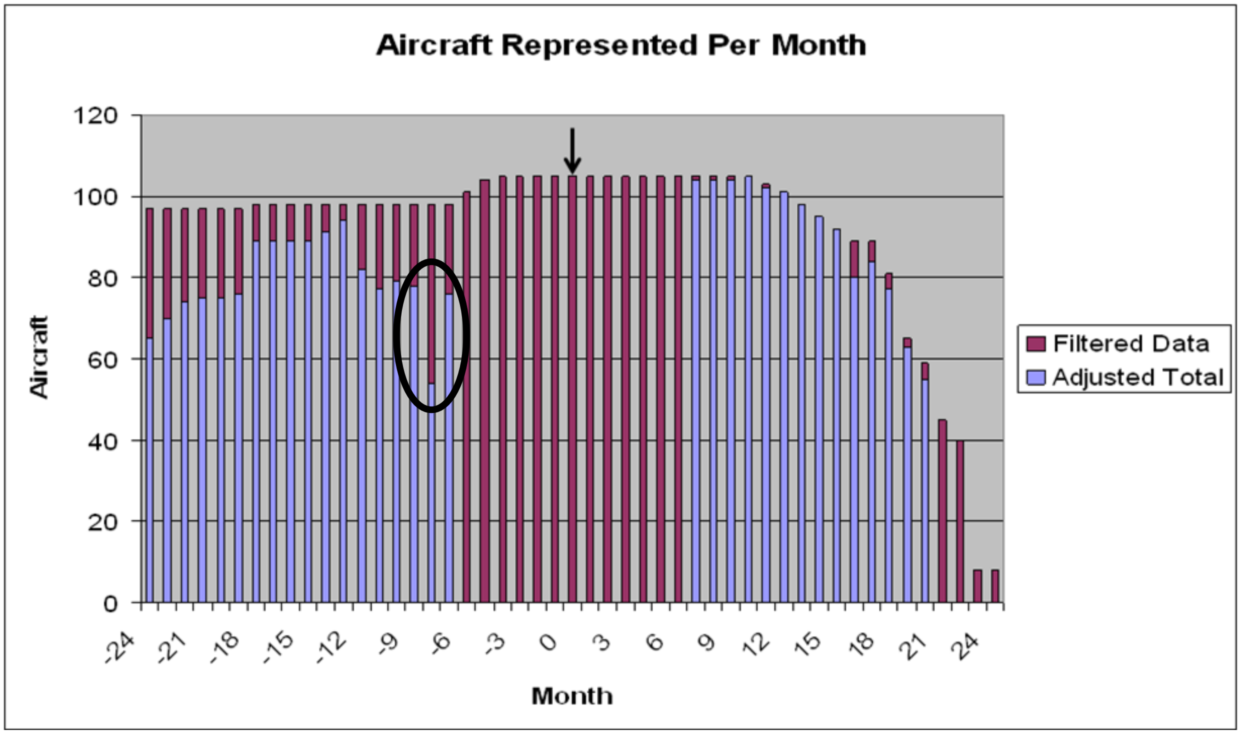
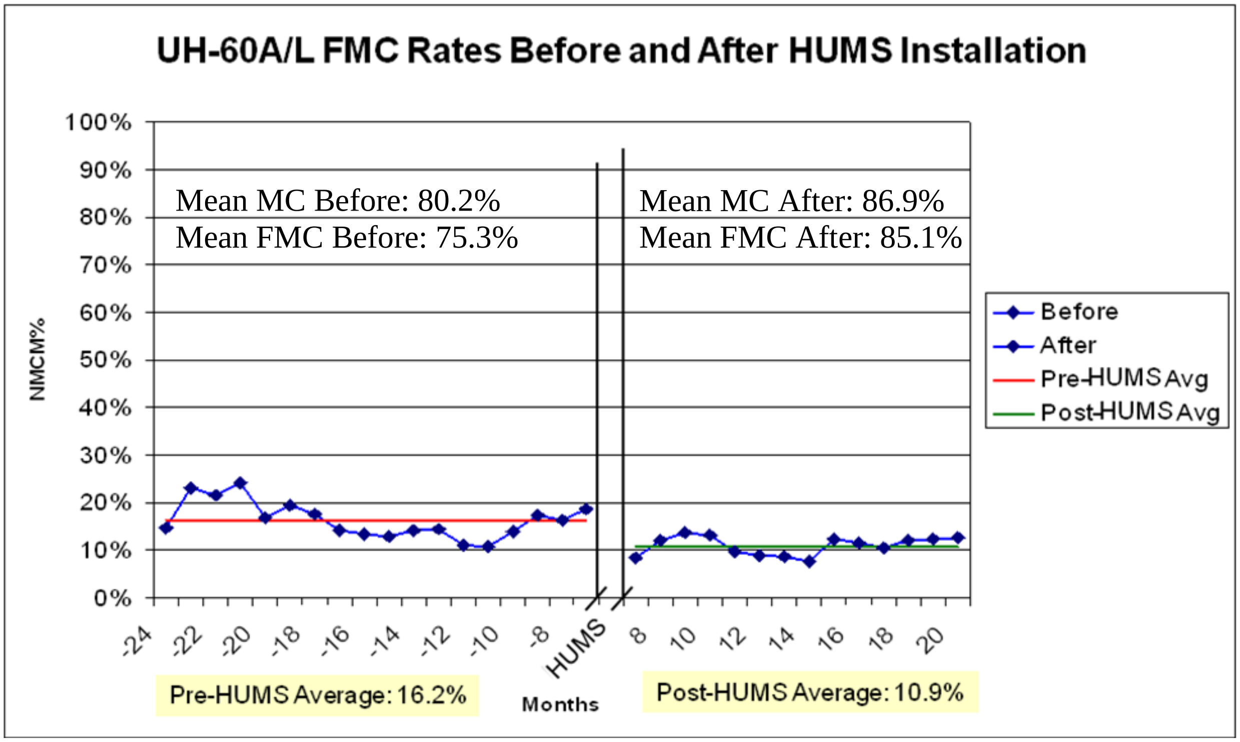
2. DA Form 1352. http://www.apd.army.mil/pub/eforms/pdf/a1352.pdf
3. DA Form 1352 Automated Entry Form https://liw.logsa.army.mil/help/general/mergedProjects/maint_mgmt/da_form_1352_automated_entry_form.htm

Appendix A: Filtering Results



In the above chart, the total number of aircraft reporting data for each month (relative to month of installation) is plotted. These are results of quality and time filters. The area circled in black on center-left was caused due to data missing from electronic logs. Upon contacting the unit, 17 more aircraft with data were added to that point successfully. This is simply one of the benefits of a tail-to-tail comparison. Also of note is the dramatic decline in available data starting gradually at month 10 and continuing through month 24. This lack of data is attributed to the fact that only a portion of aircraft in the sample had DSC/HUMS installed for significant periods of time. Since the time of this study, the readiness data for these aircraft has significantly improved from the dramatic drop as seen above.

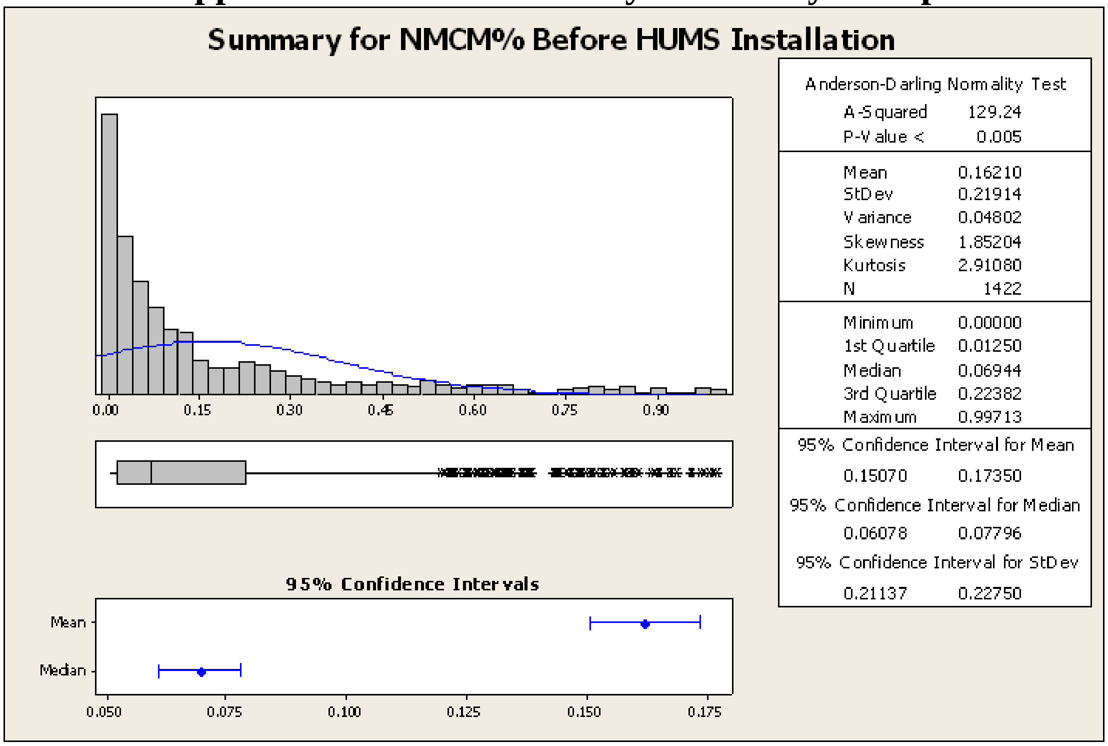
Appendix B: NMCM Before/After Installation



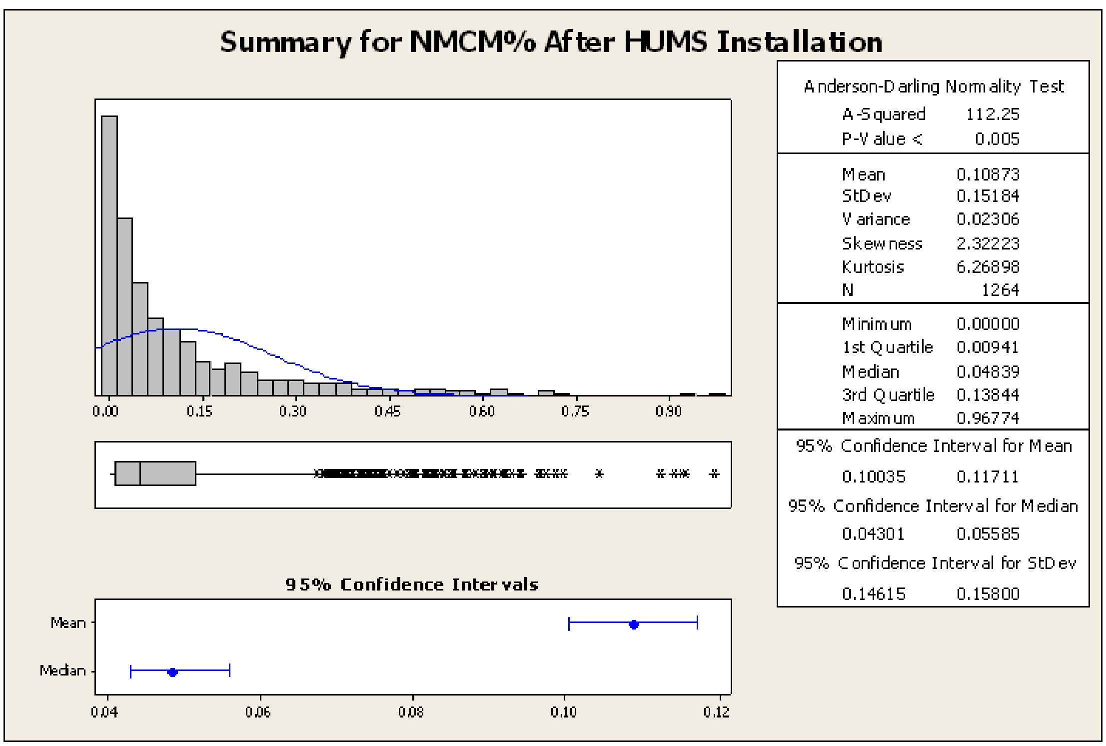
The above plot relates NMCM rates for the study group on a timescale relative to the month of installation. The resulting difference in NMCM rates before and after installation is 5.3%. The transitional 6 months before and after installation can be seen blocked out to remove unique maintenance aspects concurrent with the installation of HUMS. Also, while the preliminary study wished to compare 24 months of data before and after installation, there were insufficient aircraft with HUMS installed for a total of 24 months. As few as 16 of the 105 aircraft in the study reported data for such higher months. As a result, the graph is truncated by 2 months on the right-hand side. At the time of the study, the above plot was available. As more aircraft are equipped with HUMS and reporting readiness data for longer period post-HUMS installation, future versions of this graph will extend the after-HUMS timescale.

Corresponding values for associated readiness rates are also posted on the above graph. MC rates increased by 6.7% and FMC rates increased by 9.8%.

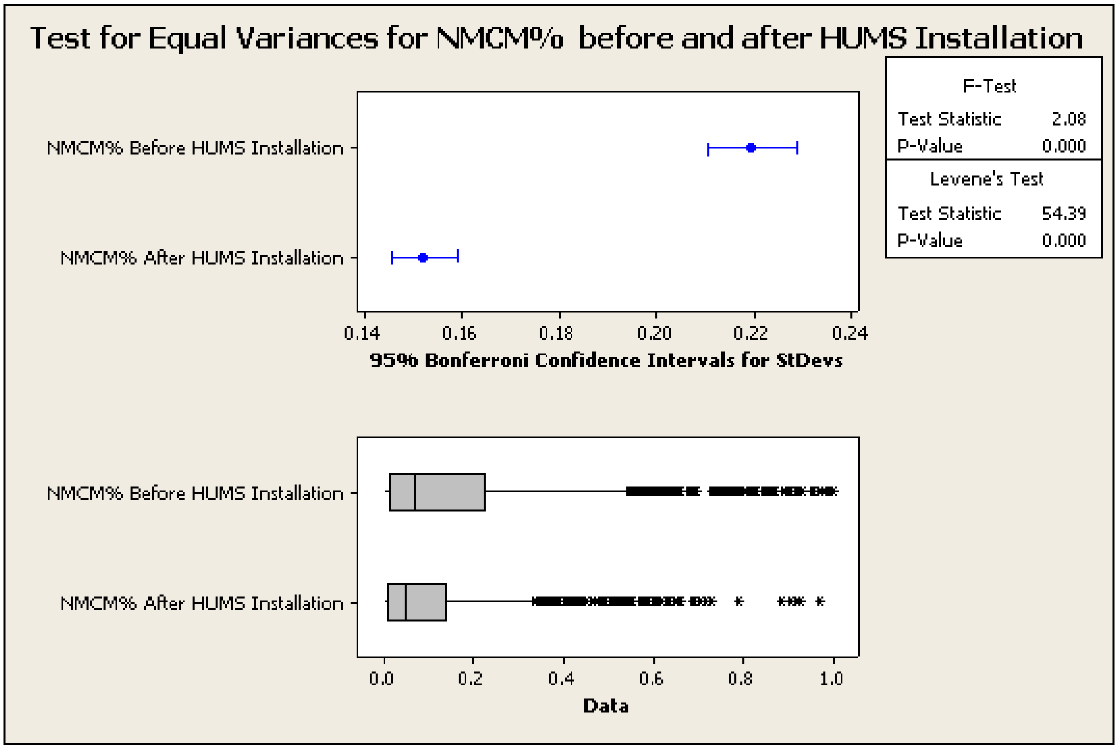
Appendix C: Statistical Analysis of Study Group



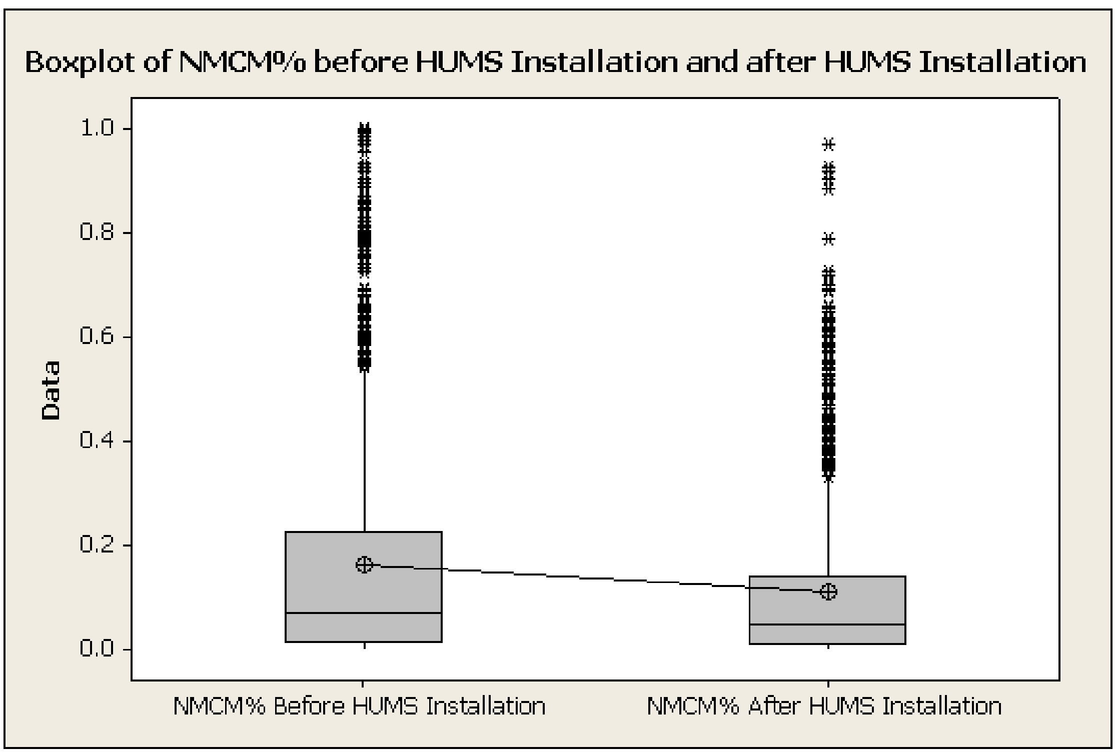
The above plot describes the distribution of NMCM rates among Group A (data reported before HUMS installation).



The above plot describes the distribution of NMCM rates among Group B (data reported after HUMS installation).

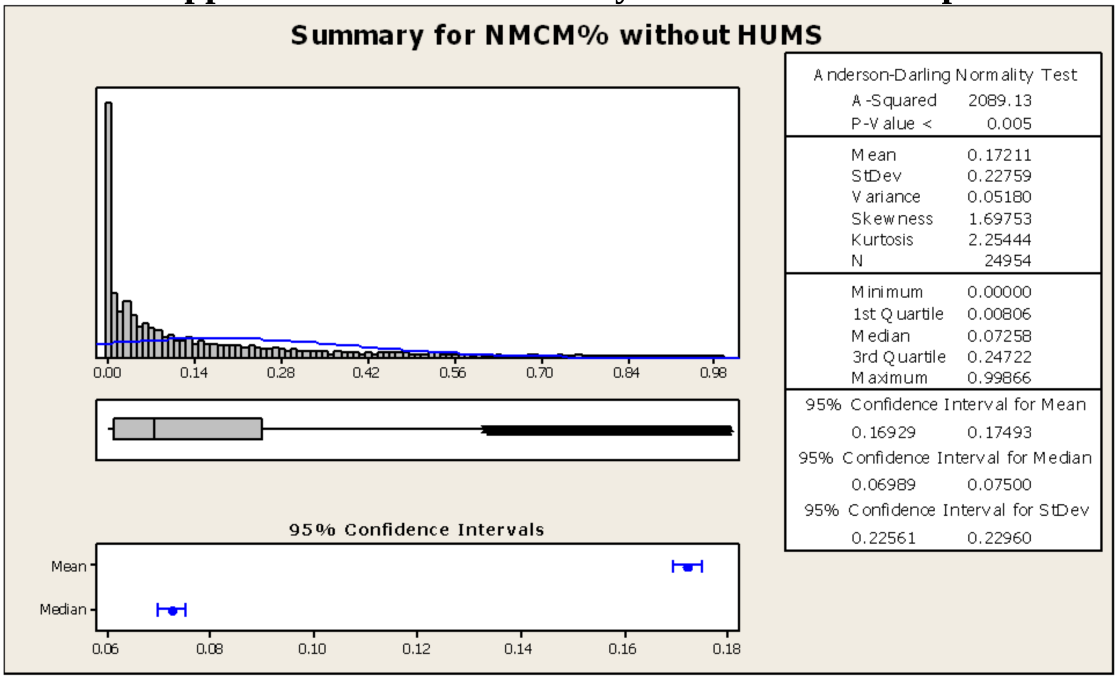


The above plot reveals the test for Equal Variances for Group A (before DSC/HUMS installation) and Group B (after DSC/HUMS installation).

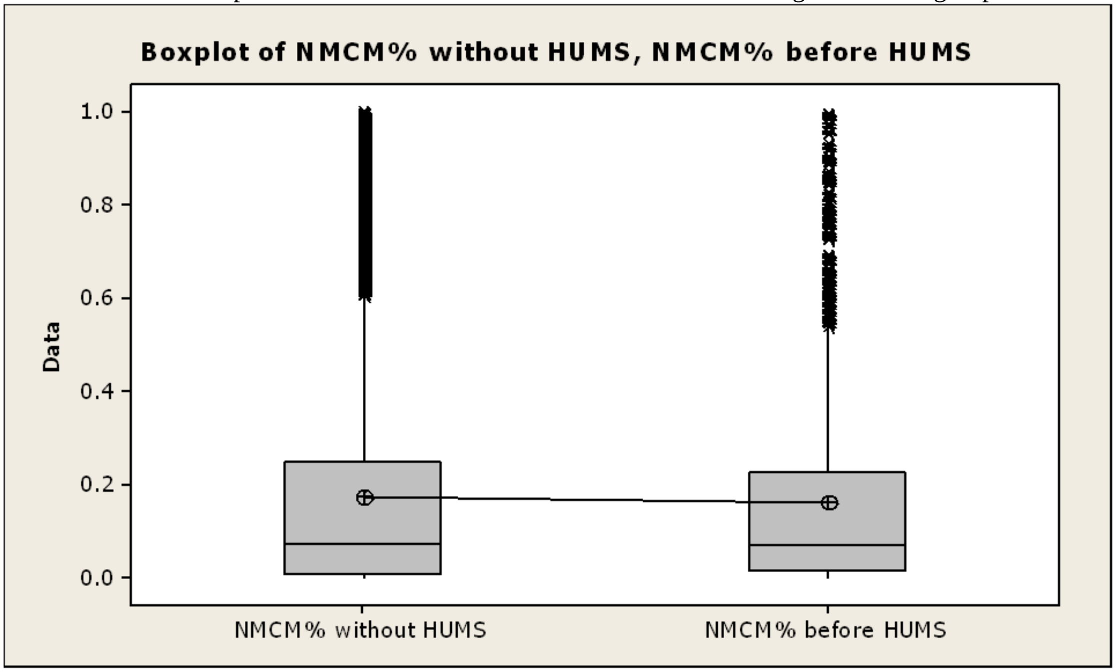


In the above plot, the 5.3% reduction in NMCM rates from before to after installation can be readily seen.

Appendix D: Statistical Analysis of Control Group



The above plot describes the distribution of NMCM rates among the control group.



In the above plot, the slight chance of a 1.00% difference in NMCM rates between the control group and HUMS aircraft before DSC/HUMS installation may be made out.