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The Defence S&T Technical Bulletin (*Buletin Teknikal S&T Pertahanan*) is the official technical bulletin of the Science & Technology Research Institute for Defence (STRIDE). It contains articles on research findings in various fields of defence science & technology. The primary purpose of this bulletin is to act as a channel for the publication of defence-based research work undertaken by researchers both within and outside the country.

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ABSTRACT

Contents of abstract.

Keywords: *Keyword 1; Keyword 2; Keyword 3.*

1. TOPIC

Paragraph 1.

Paragraph 2.

1.1 Sub Topic 1

Paragraph 1.

Paragraph 2.

2. TOPIC 2

Paragraph 1.

Paragraph 2.

Figure 1: Title

Table 1: Title

Content	**Content**	**Content**
Content	Content	Content
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Formula 1 (1)
Formula 2 (2)

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Long lists of notes of bibliographical references are generally not required. The method of citing references in the text is ‘name date’ style, e.g. ‘Hanis (1993) claimed that...’ or ‘… including the lack of interoperability (Bohara et al., 2003)’. End references should be in alphabetical order.

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Defence S&T Tech. Bull., 3(1): 1-13, 2010

DETERMINATION OF MAXIMUM USABLE FREQUENCY (MUF) FOR HIGH FREQUENCY (HF) COMMUNICATIONS

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ABSTRACT

High frequency (HF) communications is unique because it relies on the ionospheric layer of the atmosphere, which is an uncertain and variable region. This study has been conducted to predict the Maximum Usable Frequency (MUF) in Malaysian environments. In addition, the study will also assist the Malaysian Armed Forces (MAF) in determining the suitable MUF for their HF communications channels to achieve better communications link. Three locations have been chosen to implement HF transmissions; STRIDE Kajang, STRIDE Batu Arang and STRIDE Lumut. In order to obtain the MUF, theoretical analysis, MATLAB simulations, predicted HF using computer software, and actual HF transmissions have been implemented. The results of this study can be used to provide technical support and assistance to the MAF in upgrading and improving their HF communications links.

Keywords: *high frequency (HF) communications; ionosphere; Maximum Usable Frequency (MUF); HF prediction.*

1. INTRODUCTION

Decades ago, the complexity relating to high frequency (HF) communications issues coupled with the advent of more sophisticated systems, such as satellite communications, reduced the significance of HF for long-range communications. Recently, the use of HF transmission has been experiencing a renewal of interest and investment because of the realization that satellite and terrestrial communication modes are vulnerable to electronic countermeasures and physical destruction. HF communications has been an essential part of worldwide information transmission and has advanced along with information technologies, such as email, compressed multimedia voice and data services (ITS, 2006).

In addition, the popularity of HF communications is contributed by its access simplicity, free air space, cheaper communications equipment, and simpler infrastructure requirements.

In terms of operational requirements, HF communications reduces the need to deploy multi-channel line of sight (LOS) systems with relays. Therefore, HF radios continue to play a critical role in communications architecture for the requirements of the Malaysian Armed Forces (MAF), as well as other defence and security forces, in fulfilling long range communications requirements.

It is important to study the properties of HF frequencies in Malaysian environments as the frequencies always fluctuate depending on the ionospheric layer of the atmosphere. The ionosphere is not a stable medium that allows the use of one frequency over the year, or even over 24 hours. It varies with solar cycle, seasons and time of the day. Consequently, a frequency which may provide successful propagation at a particular moment may not do so an hour later (IPS, 2008). The ionosphere consists of four highly ionized regions, and the altitudes of the individual layers have average values as shown in Figure 1.

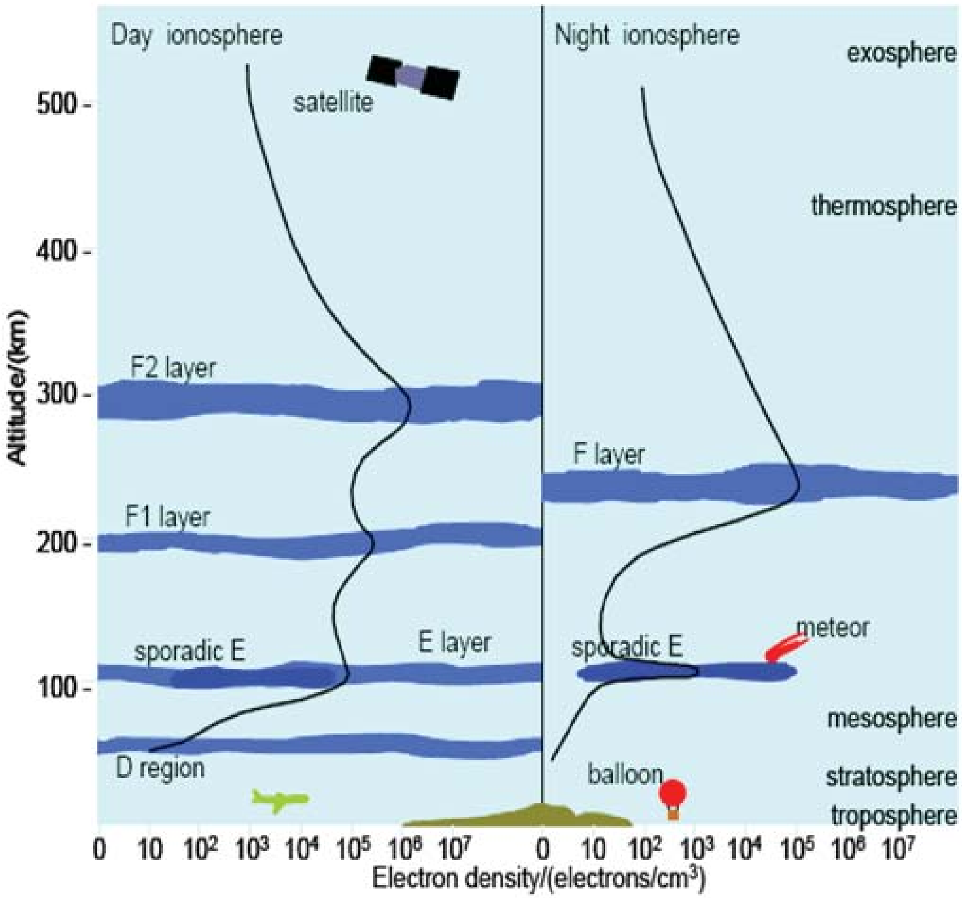


Figure 1: Day and night structure of the ionosphere.
(Source: IPS (2008))

The ionosphere in Malaysia is unique because of its location near the equator, where a lot of phenomena such as equatorial anomaly and fountain effects make it good for studies (M. Abdullah *et al.,* 2009). Parallel positions of magnetic and electric lines in equatorial regions also produce ionospheric inequality. This phenomenon causes problems to HF communications, navigation based radio signals, and surveillance systems from earth and space (Wan Salwa, 2002). Hence, HF frequencies in Malaysian have inconsistencies based solely on the ionosphere in the region.

Multiple reflections between the ionospheric layers and the earth are possible, allowing great distances to be obtained in these ranges, particularly the HF bands. The disadvantage of this type of propagation is that it depends on the characteristics of the ionosphere, which varies widely, especially during daylight hours. As a result of this varying, the HF waves are reflected differently and take different paths over a period of time as illustrated in Figure 2. This causes the signal at the receiver to vary in strength, which causes the output to fade in and out (Integrated Publishing, 2008).

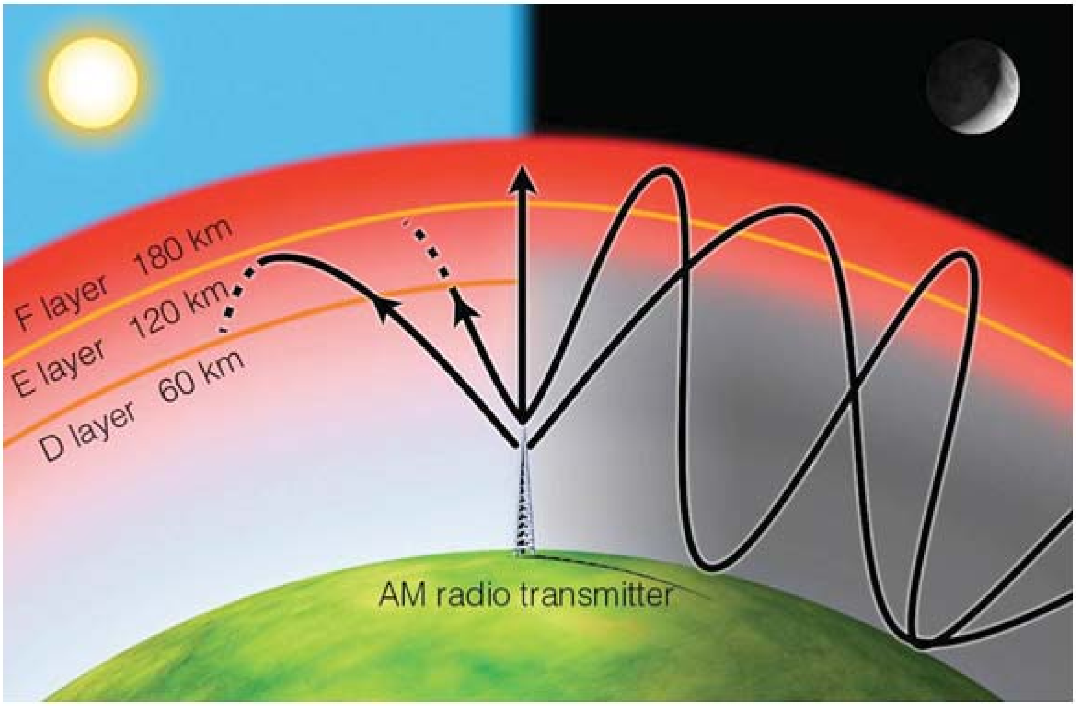


Figure 2: HF radio waves.
(Source: LSC (2008)

In this research, theoretical studies, HF prediction system, MATLAB simulations and actual HF transmissions are applied to determine the Maximum Usable Frequency (MUF) for HF communications. The overall process employed is shown in Figure 3.

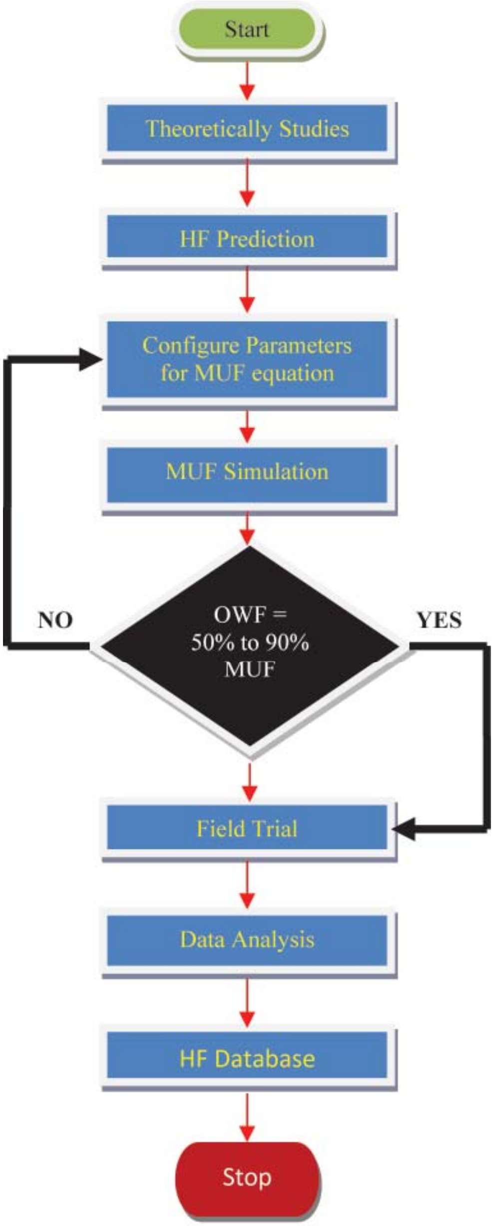


Figure 3: Configuration and simulation flow chart.

2. METHODOLOGY

2.1 Advanced Stand Alone Prediction Software (ASAPS) System

A computer prediction program known as the ASAPS system was used to predict HF frequencies. This program uses a propagation model developed by IPS Radio and Space Services in Australia. The user interface of ASAPS is quite advanced, including databases of transmitter and receiver positions, type of antenna used, time and date of prediction, transmitter power, and T-index. The ionospheric model used in ASAPS is parameterised by the so-called T-index rather than sunspot number (SSN). T-index is an "equivalent sunspot number" obtained by observing ionospheric propagation and mapping to a propagation model parameterised by SSN. MUF varies from day to day due to existing conditions in the ionosphere. Consequently, it is not possible to predict exact values. However, it is possible to predict frequencies with 10%, 50% or 90% chance of successful propagation (IPS, 2008).

2.2 MUF

MUF is important for determining the best HF frequency to use in communicating between two locations (Larson, 2008). It depends in part on the distance between two locations under specific working conditions, such as antennas, power and emission type. The MUF formulation between two locations is (ARRL, 2008):

$$MUF = \frac{f_c}{\sqrt{1-\left(\frac{R}{R+h}\right)^2}} \quad (1)$$

where: f_{cr} = Critical frequency

$$f_{cr} = \sqrt{\frac{N_e}{1.24*10^{10}}} \quad (2)$$

N_e = Degree of ionization of the ionosphere

R = Radius of the earth

h = Height of the ionosphere

The F region MUF (FMUF) in particular varies during the day, seasonally and with the solar cycle. A range of F region MUFs extends from the lower decile MUF, known as the Optimum Working Frequency (OWF), through the median MUF to the upper decile MUF as shown in Figure 4. These MUFs have 90%, 50% and 10% chance of being supported by the ionosphere, respectively. The prediction software usually covers a period of one month, so the OWF should provide successful propagation 90% of the time or 27 days of the month. The median MUF should provide communications 50% or 15 days of the month, and the upper decile MUF provides for 10% or 3 days of the month. The upper decile MUF is the highest frequency of the range of MUF and is most likely to penetrate the ionosphere (IPS, 2008).

To ensure a good communications link between two locations, the OWF is typically chosen below the predicted MUF. A commonly used formula for finding the optimal operating frequency for a given path is to calculate between 80 to 90% of the MUF. Depending on what model is used for determining MUF and OWF, this percentage of usable days may be

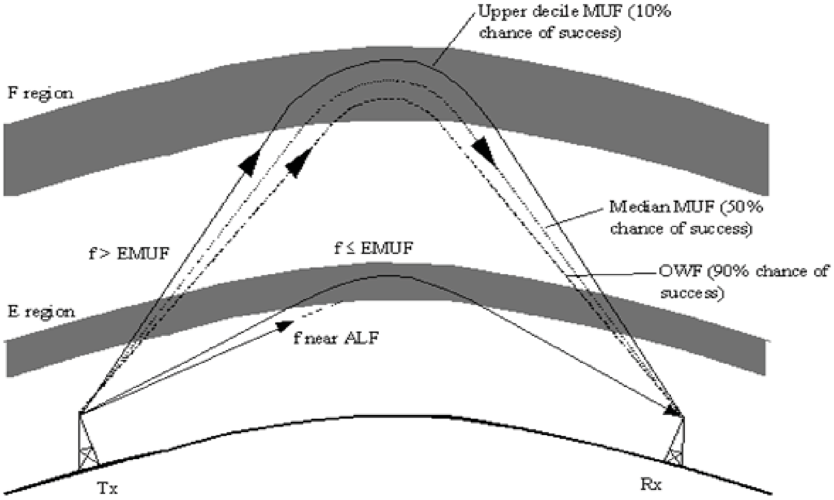


Figure 4: Range of usable frequencies.
(Source: IPS (2008))

50% or 90%. For example, VOACAP (computer prediction developed by ITS, USA) uses 50% (Amateur Radio World-Wide, 2006).

Subsequently, OWF will be found by:

$$\text{OWF} = 50 \text{ to } 90\% \text{ MUF} \tag{3}$$

2.3 HF Base Station

As a starting point, three locations have been selected to be HF base stations. These locations were used for HF transmissions and data gathering. The locations are STRIDE Kajang, STRIDE Batu Arang and STRIDE Lumut (Figure 5).

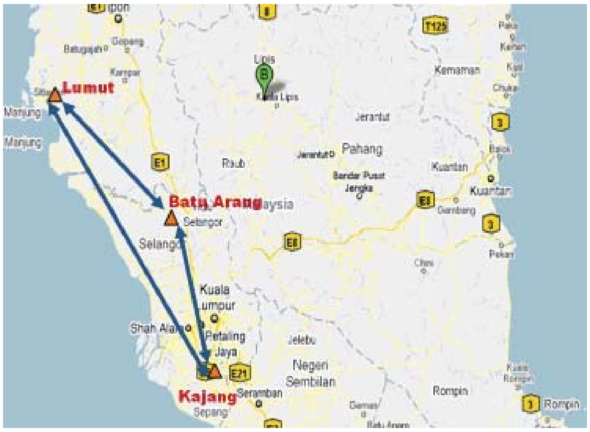
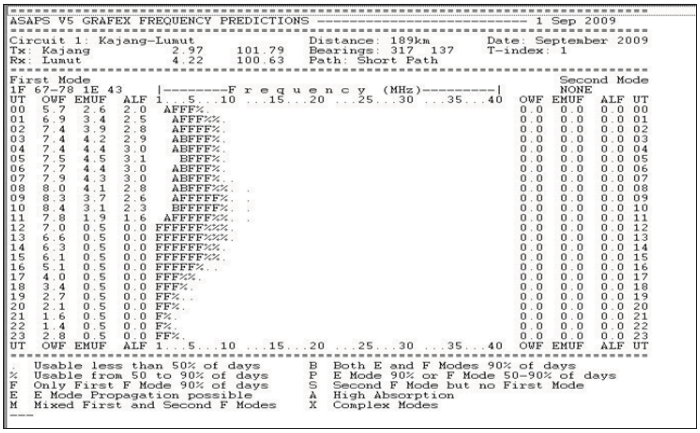


Figure 5: Transmission of HF Frequencies between three locations.

3. HF FREQUENCIES IN MALAYSIA

Table 1 is a Grafex Frequency Prediction from the ASAPS system that shows estimated OWF in September 2009. The table shows OWF values that can be used in different time of the day for that month. Table 1 indicates that the range of OWF is between EMUF and OWF. This range is also illustrated in GRAFEX graph in Figure 6. When the GRAFEX symbol is “F”, it should ensure that good communications is achieved on most days of the month, i.e. 90% of the time or 27 days of the month. Using a frequency when the symbol is “%” should be satisfactory on more than 50% of the days in the month. In this case, a secondary frequency should be considered for those periods when the selected frequency is not supported because of the day to day variability of the ionosphere.

Table 1: MUF values for in September 2009.



```
==========================================================================
ASAPS V5 GRAFEX FREQUENCY PREDICTIONS -------------------------- 1 Sep 2009
==========================================================================
Circuit 1: Kajang-Lumut                Distance: 189km        Date: September 2009
Tx: Kajang             2.97    101.79  Bearings: 317  137     T-index: 1
Rx: Lumut              4.22    100.63  Path: Short Path
==========================================================================
First Mode                                                          Second Mode
1F 67-78 1E 43     |---------F r e q u e n c y  (MHz)----------|      NONE
UT   OWF EMUF   ALF 1...5...10 ...15...20 ...25...30 ...35...40  OWF EMUF  ALF UT
00   5.7  2.6   2.0  AFFF%.                                      0.0  0.0  0.0 00
01   6.9  3.4   2.5   AFFF%%.                                    0.0  0.0  0.0 01
02   7.4  3.9   2.8   AFFFF%.                                    0.0  0.0  0.0 02
03   7.4  4.2   2.9   ABFFF%.                                    0.0  0.0  0.0 03
04   7.4  4.4   3.0   ABFFF%.                                    0.0  0.0  0.0 04
05   7.5  4.5   3.1    BFFF%.                                    0.0  0.0  0.0 05
06   7.7  4.4   3.0   ABFFF%.                                    0.0  0.0  0.0 06
07   7.9  4.3   3.0   ABFFF%..                                   0.0  0.0  0.0 07
08   8.0  4.1   2.8   ABFFF%%. .                                 0.0  0.0  0.0 08
09   8.3  3.7   2.6   AFFFFF%. .                                 0.0  0.0  0.0 09
10   8.4  3.1   2.3   BFFFFF%. .                                 0.0  0.0  0.0 10
11   7.8  1.9   1.6  AFFFFF%%. .                                 0.0  0.0  0.0 11
12   7.0  0.5   0.0 FFFFFF%%%.                                   0.0  0.0  0.0 12
13   6.6  0.5   0.0 FFFFFF%%%.                                   0.0  0.0  0.0 13
14   6.3  0.5   0.0 FFFFFF%%.                                    0.0  0.0  0.0 14
15   6.1  0.5   0.0 FFFFFF%%.                                    0.0  0.0  0.0 15
16   5.1  0.5   0.0 FFFFF%..                                     0.0  0.0  0.0 16
17   4.0  0.5   0.0 FFF%%.                                       0.0  0.0  0.0 17
18   3.4  0.5   0.0 FFF%.                                        0.0  0.0  0.0 18
19   2.7  0.5   0.0 FF%..                                        0.0  0.0  0.0 19
20   2.1  0.5   0.0 FF%.                                         0.0  0.0  0.0 20
21   1.6  0.5   0.0 F%.                                          0.0  0.0  0.0 21
22   1.4  0.5   0.0 F%.                                          0.0  0.0  0.0 22
23   2.8  0.5   0.0 FF%.                                         0.0  0.0  0.0 23
UT   OWF EMUF   ALF 1...5...10 ...15...20 ...25...30 ...35...40  OWF EMUF  ALF UT
==========================================================================
.  Usable less than 50% of days        B  Both E and F Modes 90% of days
%  Usable from 50 to 90% of days       P  E Mode 90% or F Mode 50-90% of days
F  Only First F Mode 90% of days       S  Second F Mode but no First Mode
E  E Mode Propagation possible         A  High Absorption
M  Mixed First and Second F Modes      X  Complex Modes
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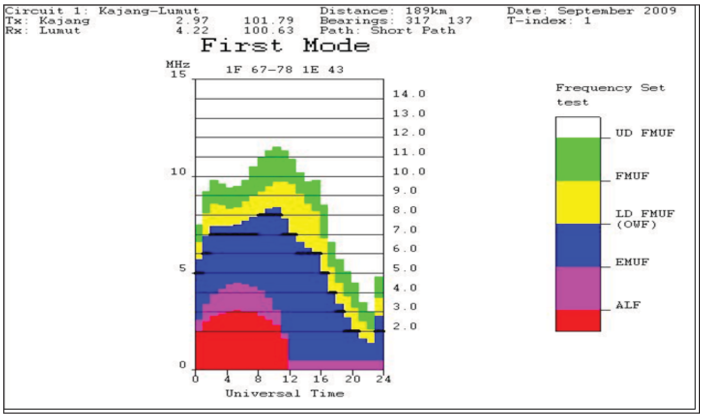
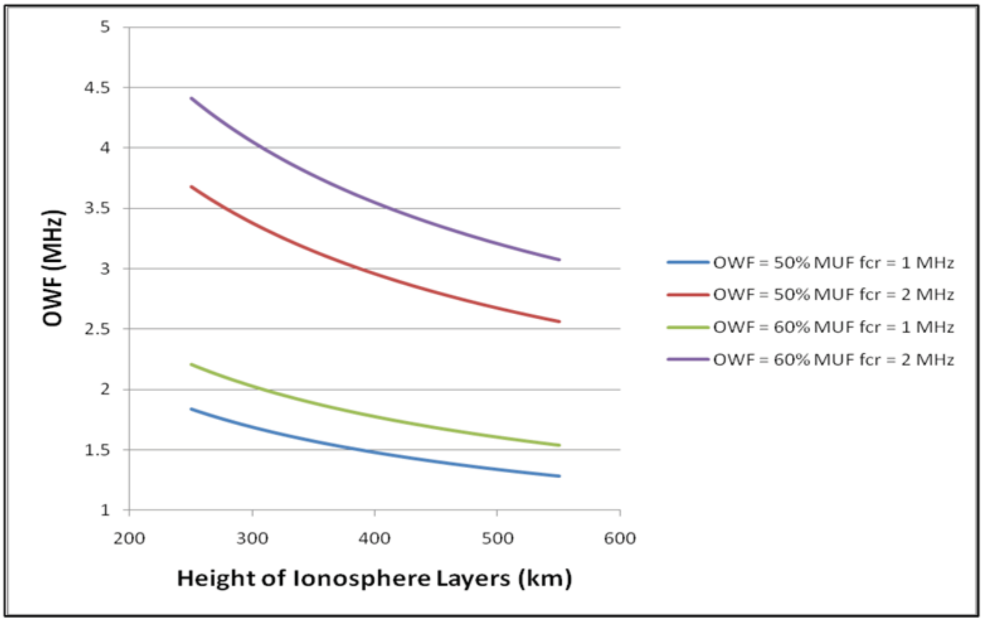
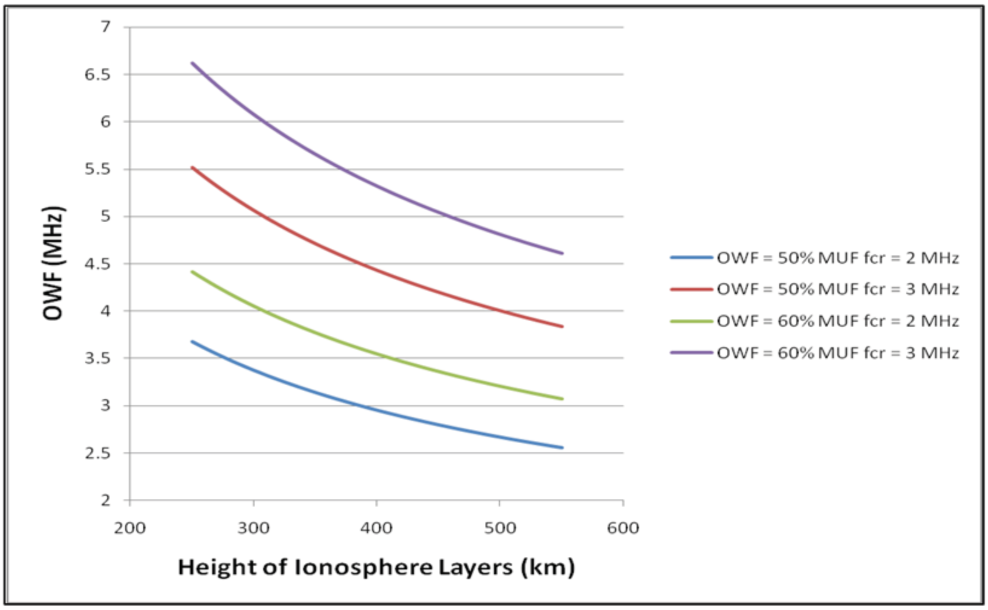


Figure 6: GRAFEX graph for MUF.

Using MATLAB modelling of Equations 1-3, simulations were done according to different times of the day; pre-dawn, morning, evening and night, giving four different sets of OWF values, as shown in Figure 7. Observations from the graphs show that there is a relationship between height of ionosphere and OWF. Whenever signals hit the ionosphere layers, the values of OWF depend on ionospheric height. The OWF values drop off when ionosphere layers are high.



(a)



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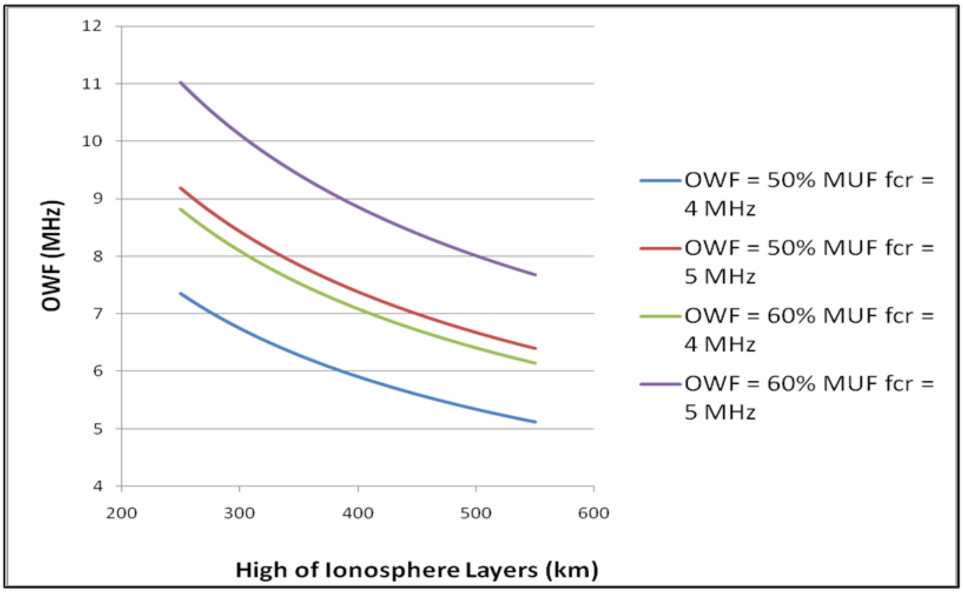
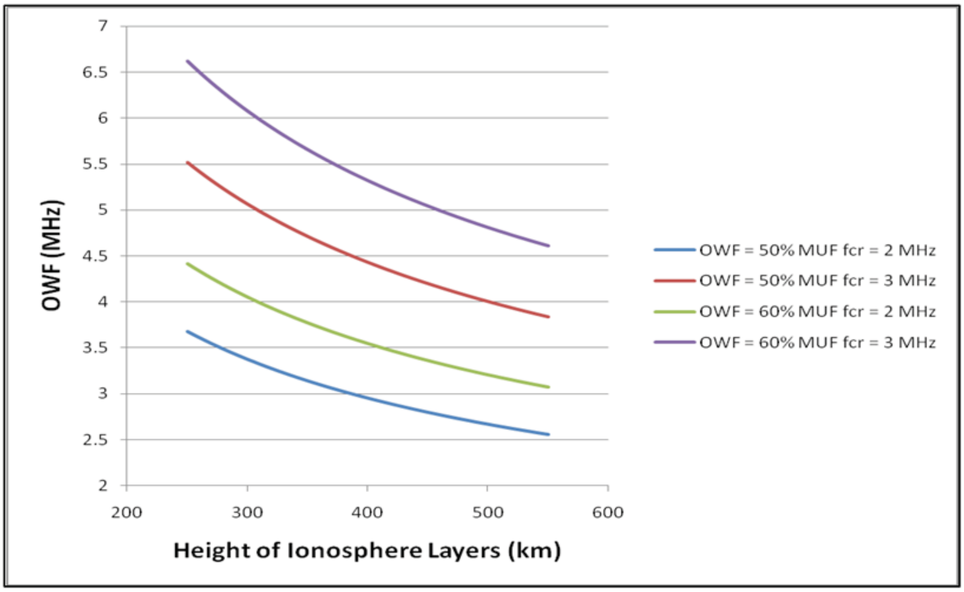


(c)



(d)

Figure 7: OWF values in: (a) pre-dawn, (b) morning, (c) evening and (d) night.

The OWF values have been utilized to make actual HF transmissions between the three locations. The HF Telefunken Radio shown in Figure 8, which complies with the world's strictest standards for radio communications equipment, including MIL-STD-810 and ALE per MIL-STD-188-141B (Telefunken, 2006), has been used as the transceiver system. Better HF communications channels or links were identified during trial transmissions between April to December 2009.

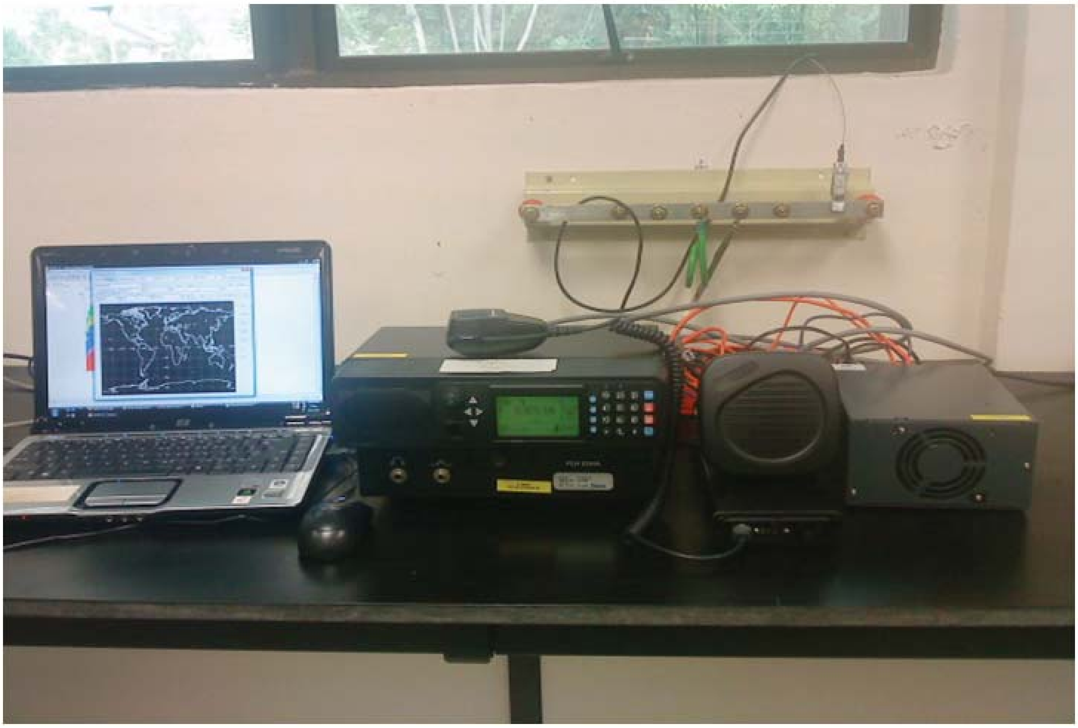


Figure 8: HF transceiver system.

The ionospheric map in Figure 9 was obtained from the IPS Ionospheric Map Website (IPS, 2008) (updated hourly). It provides a general representation of global MUF values on 16th September 2009. The data presented in this website are derived from the automated interpretation of ionograms from around the world. These data are obtained from the IPS space weather observation network known as IPSNET, the NICT Space Weather Information Centre of Japan, the Space Physics Group at Rhodes University's Hermanus Magnetic Observatory, the Istituto Nazionale di Geofisica e Vulcanolgia, Rome, Italy, the Laboratorio de Ionosfera, Universidad Nacional de Tucuman, Argentina, (South American Region), and the United States of America Space Weather Prediction Centre's (SWPC). The data available from the SWPC ftp server are contributed by the International Space Environment Service's (ISES) Regional Warning Centres (RWCs) from around the globe and various ionospheric observatories operated by the United States Air Force (USAF). The map can be used as a guide to NVIS ionospheric frequency support and to generate real time HF predictions to assist the HF radio communicator. The map illustrates that MUF in Malaysia is around 6 to 7 MHz.

Consequently through theoretical studies, the ASAPS system, MATLAB simulation and actual transmission between those locations, general HF frequencies in Malaysia for 2009 were identified (Table 2). These frequencies can not only be used in 2009, but also can be used as reference frequencies for the future.

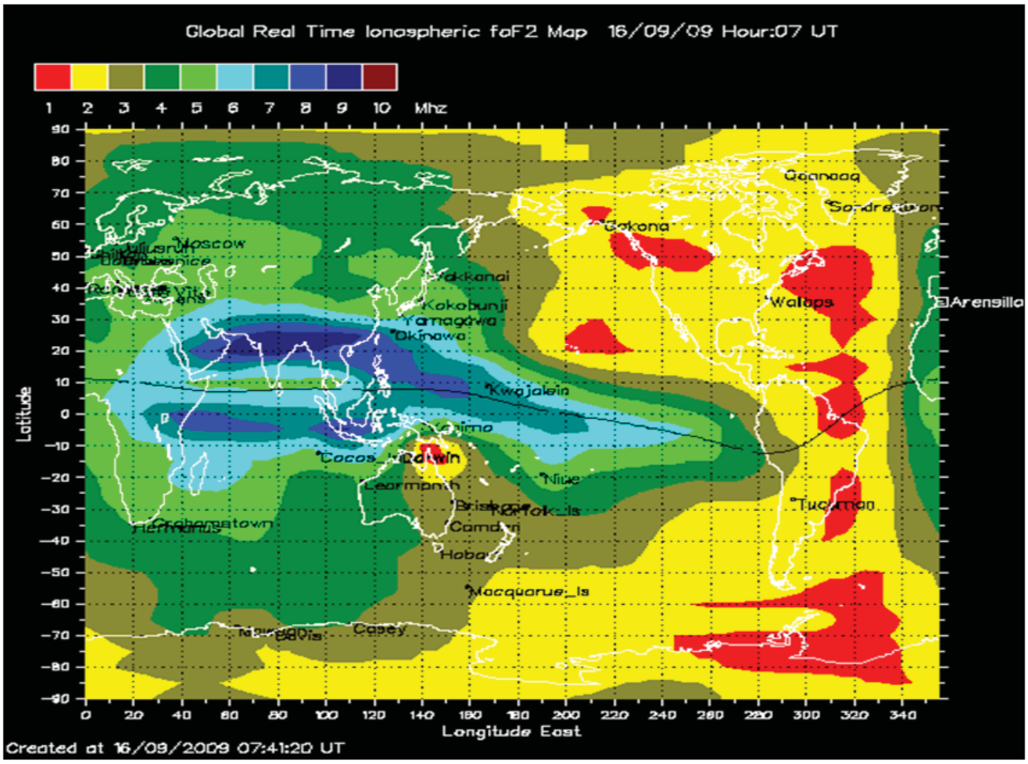


Figure 9: World ionospheric map.
(Source: IPS (2008))

Table 2: General HF frequencies for Malaysia in 2009.

Time of the day	Frequency (MHz)
Pre-dawn	1.6 to 3
Morning	3 to 7.5
Evening	3 to 8.5
Night	2 to 5

4. CONCLUSION AND RECOMMENDATION

HF communications still have critical importance that could provide solutions to many of MAF's future long-range communications requirements. Whilst studies on HF communications have been conducted in other parts of the world, in Malaysia, this area has not been fully explored. Nowadays, as higher data rates become practical, military use of HF is increasing. This is due to modern and improved systems that are highly reliable in exploring sky wave communications, as the cost per bit of information is very low, owing to the relay medium, that is the ionosphere, being free.

The HF prediction and transmission conducted in this study only covers a quarter of West Malaysia. Therefore, to get better results on HF frequency prediction for the whole of Malaysia, HF transmission should be done throughout Peninsula Malaysia, Sabah and Sarawak. The HF base stations employed should be in West Malaysia and East Malaysia. Additionally, HF transmissions will be jointly conducted with the MAF using their HF radios and facilities. Additionally, data on SSN, T-index and critical frequencies should be based on Malaysian environments to improve the computer modelling. In order to obtain higher quality signals, higher quality communications channels must be selected. In the future, this research can also be used as a reference for researchers to further study HF communications parameters in Malaysian environments.

ACKNOWLEDGEMENT

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Defence S&T Tech. Bull., 3(1): 14-28, 2010

EVALUATION OF POWER LEVELS REQUIRED BY INTERFERENCE SIGNALS AT VARIOUS DISTANCES TO JAM THE GLOBAL POSITIONING SYSTEM (GPS) L1 COARSE ACQUISITION (C/A) SIGNAL

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ABSTRACT

Previous tests conducted by the Instrumentation & Electronics Technology Division (BTIE), Science & Technology Research Institute for Defence (STRIDE), were aimed at evaluating the minimum interference signal power level required to jam the Global Positioning System (GPS) L1 coarse acquisition (C/A) signal. However, the tests were only performed using low interference power levels, for a distance of 3 m. In order to evaluate the power levels of interference signals required to jam a Garmin GPSmap 60CSx handheld receiver over various distances, a test was conducted on 21st January 2010 at the STRIDE Kajang Block B car park. It was observed that the power levels required to affect the location fixes are significantly high compared to the received GPS signal power received. This is because the noise-like C/A code structure, which spreads the L1 signal over a 2 MHz bandwidth, allows for the signal to be received at low levels of interferences. The minimum power level required to conduct GPS jamming is dependent on various error parameters, including ionospheric and tropospheric delays, satellite clock, ephemeris and multipath errors, and unintentional signal interferences and obstructions. On the whole, this test demonstrates the ease to conduct GNSS jamming. Relatively low power level interference signals, from intentional or unintentional sources, can disrupt GNSS signals over long range of distances. Given the dependence on GNSS for positioning, navigation and timing (PNT) applications, GNSS disruption could prove to be problematic, if not disastrous. Hence, GNSS vulnerability mitigations steps should be given emphasis, including PNT backups, making full use of ongoing GNSS modernisation programs, increased ability to identify and locate GNSS jammers, integrity monitoring and augmentation, and anti-jamming technologies.

Keywords: *Global Positioning System (GPS) receiver evaluation; radio frequency interference (RFI); location fix; GPS L1 coarse acquisition (C/A) signal power level*

1. INTRODUCTION

There is a steady growth in the entrenchment of Global Navigation Satellite Systems (GNSS) in current and upcoming markets, having penetrated various consumer products, such as cell phones, personal navigation devices (PND), cameras and assimilation with RFID tags, for various applications, including navigation, surveying, timing reference and location based services (LBS). While the Global Positioning System (GPS), operated by the US Air Force (USAF), is the primarily used GNSS system worldwide, including by Malaysian defence & security forces, the upcoming Galileo and Compass systems, and the imminent conversion of *Global'naya Navigatsionnaya Sputnikovaya Sistema* (GLONASS) signals from frequency division multiple access (FDMA) to code division multiple access (CDMA) look set to make multi-satellite GNSS configurations the positioning, navigation & timing (PNT) standard for the future.

However, many GNSS users are still not fully aware of the vulnerabilities of GNSS systems to various error parameters, such as ionospheric and tropospheric delays, satellite clock, ephemeris and multipath errors, satellite positioning and geometry, and unintentional signal interferences and obstructions. There error parameters can severely affect the accuracy of GNSS readings, and in a number of cases, disrupt GNSS signals (Volpe, 2001; Harding, 2001; Adams, 2001; Forssell, 2005; Kaplan & Hegarty, 2006; Gakstatter, 2008; Last, 2008, 2009; IDA, 2009; GAO, 2009; Dinesh, 2009; Schwartz, 2010; Palmer, 2010).

In his keynote speech during the Tuft University Institute for Foreign Policy Analysis (IFPA) Fletcher Conference on National Security Strategy and Policy, the USAF Chief of Staff, Gen. Norton Schwartz, pointed out that "*Another widely-known dependence that creates an exploitable vulnerability is that of GPS. It seems critical to me that the Joint Force should reduce its dependence on GPS-aided precision navigation and timing, allowing it to ultimately become less vulnerable, yet equally precise, and more resilient. The global value of GPS will endure, but our forces must be able to operate in GPS-denied environments in the future*" (Schwartz, 2010). Given these vulnerabilities, various recommendations have been provided on the application of PNT backups, including inertial navigation systems (INS), enhanced long range navigation (eLORAN), VHF omnidirectional range distance measuring equipment (VOR/DME), and internet time services and network time protocols (Volpe, 2001; Lilley *et al.*, 2006; Last, 2008, 2009; Grant *et al.*, 2009; IDA, 2009; Dinesh, 2009; Schwartz, 2010; Groves, 2010).

One particular vulnerability that has received significant attention is jamming. Since GNSS satellites, powered by photocells, are approximately 20,200 km above the Earth surface, GNSS signals that reach the Earth have very low power (10^{-16} – 10^{-13} W = -160 – -130 dBm), rendering them highly susceptible to jamming (Pinker & Smith, 2000; Adams, 2001;

Johnston & Warner, 2004; Papadimitratos & Jovanovic, 2008; Last, 2008, 2009; IDA, 2009; Dinesh, 2009; Schwartz, 2010; Palmer, 2010). Jamming is defined as the broadcasting of a strong signal that overrides or obscures the signal being jammed (DOA, 2009; JCS, 2007; Poisel, 2002). Given the various incidents of intentional and unintentional jamming of GNSS signals, including military GNSS signals (Adams, 2001; Williams, 2006; Jewell, 2007), the development of various GNSS anti-jamming technologies has received significant attention (Casabona & Rosen, 1999; Gustafon *et al.*, 2000; Deshpande, 2004; Loegering, 2006; Meng *et al.*, 2008; Zhuang *et al.*, 2009; Wilde & Willems, 2010). In addition, many current GNSS receiver evaluations are concentrated on radio frequency interference (RFI) operability. For example, GNSS evaluations conducted by SIRIM Bhd. only involve RFI testing (Ooi & Mustafa, 2009).

Given the increasing importance of GNSS based equipment in the Malaysian Armed Forces (MAF) and other national defence & security agencies, the Instrumentation & Electronics Technology Division (BTIE), Science & Technology Research Institute for Defence (STRIDE), is at present working on studying the effect of RFI on GNSS signals. Two test were conducted on 10th (STRIDE, 2009a) and 17th (STRIDE, 2009b) November 2009 in order to aimed at evaluating the minimum interference signal power level required to jam the GPS L1 coarse acquisition (C/A) signal (Dinesh *et al.*, 2009). However, the tests were performed using only low interference power levels, for a distance of 3 m.

In order to evaluate the power levels of interference signals required to jam a Garmin GPSmap 60CSx handheld receiver (Garmin, 2007) (Figure 1), employing the GPS L1 C/A signal, over various distances, a test was conducted on 21st January 2010 at the STRIDE Kajang Block B car park (Figure 2) (STRIDE, 2010). This paper is aimed at discussing the procedure employed during the test, and the overall conclusions observed from its results.

Figure 1: A Garmin GPSmap 60CSx handheld receiver.

Figure 2. Test area located at N 2º 58' 4.9" E 101º 48' 35.5".
(Source: Screen capture from Google Earth)

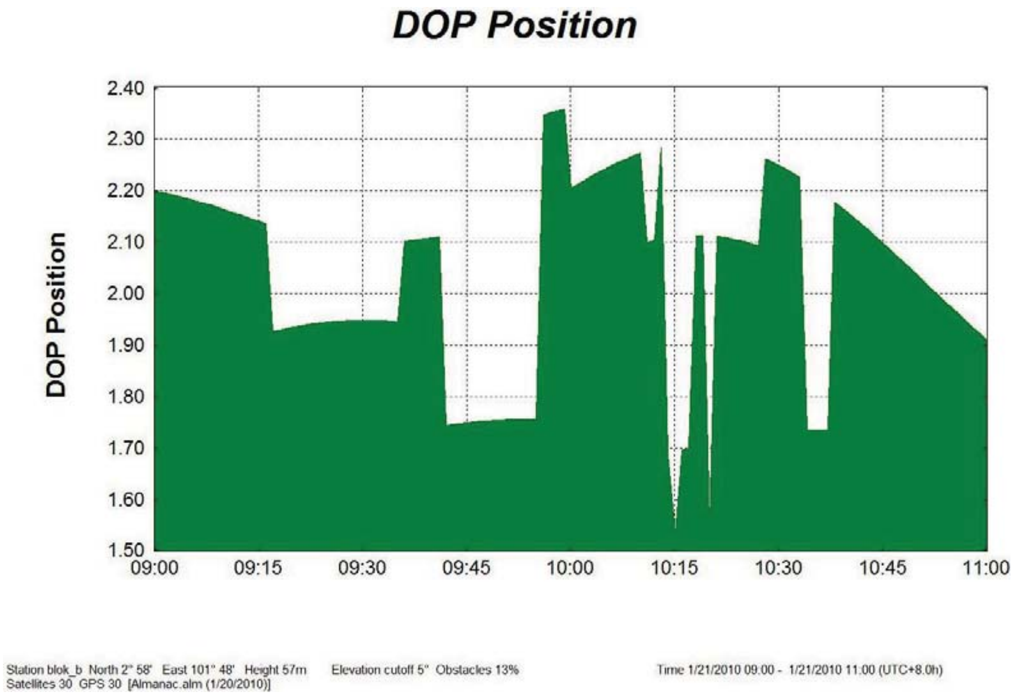
2. METHODOLOGY

2.1 Site Survey

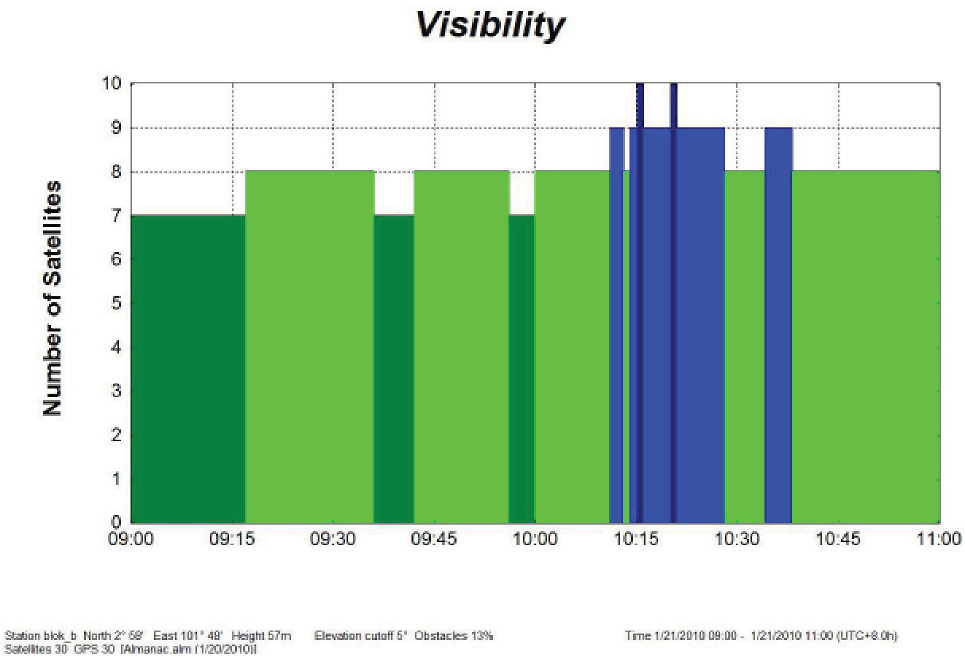
The chosen test site has a clear line of sight (LOS) of approximately 96 m, making it suitable for the purposes of the test. There is partial LOS after this point, for up to 59 m, making this area suitable to place a reference GPS receiver.

2.2 Preliminary Preparation

The Trimble Planning software (Trimble, 2009) was employed to estimate the GPS satellite coverage in the test area on 21st January 2010. It was observed that the period of the test, 0900 – 1100, coincided with a period of good GPS coverage (Figure 3), with low position dilution of precision (PDOP) values (1.53-2.35) and high satellite visibility (7-10 satellites). Nevertheless, the Trimble Planning software only takes into account estimated satellite positions and geometry, and does not consider other sources of GNSS errors, including ionospheric and tropospheric delays, satellite clock, ephemeris and multipath errors, and unintentional signal interferences and obstructions. Furthermore, the parameters of elevation cutoff and obstacles were estimated from 30 m resolution terrain models, which do not take into consideration man-made structures, and thereby, are subject to errors.


DOP Position
DOP Position
2.40
2.30
2.20
2.10
2.00
1.90
1.80
1.70
1.60
1.50
09:00
09:15
09:30
09:45
10:00
10:15
10:30
10:45
11:00
Station blok_b North 2° 58' East 101° 48' Height 57m
Elevation cutoff 5° Obstacles 13%
Time 1/21/2010 09:00 - 1/21/2010 11:00 (UTC+8.0h)
Satellites 30 GPS 30 [Almanac.alm (1/20/2010)]

(a)


Visibility
Number of Satellites
10
9
8
7
6
5
4
3
2
1
0
09:00
09:15
09:30
09:45
10:00
10:15
10:30
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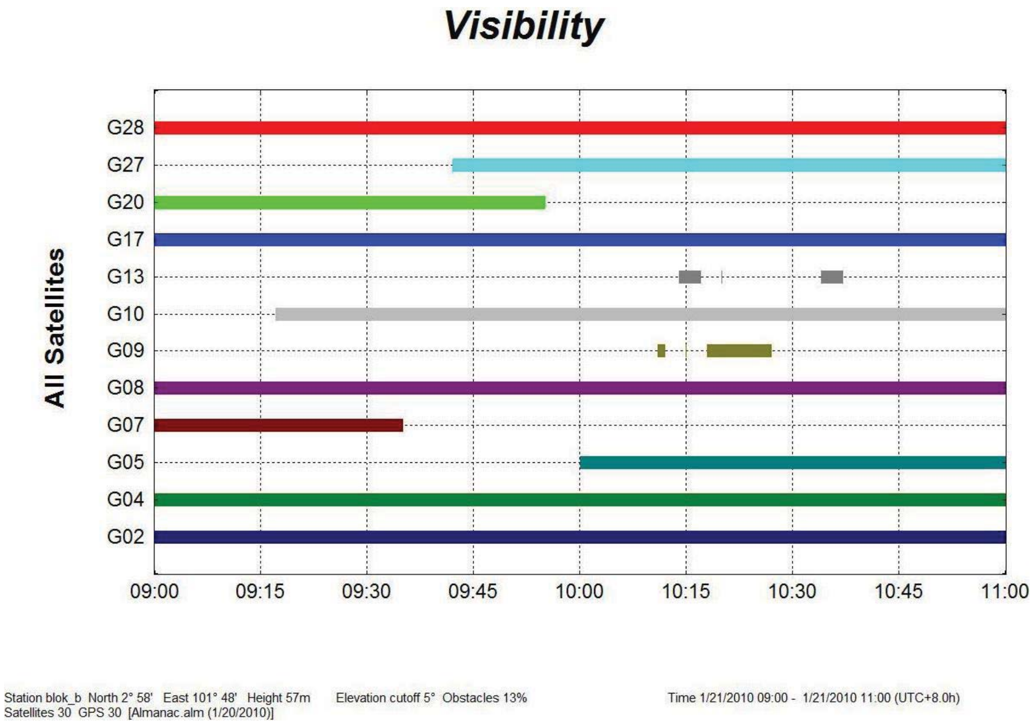
11:00
Station blok_b North 2° 58' East 101° 48' Height 57m
Elevation cutoff 5° Obstacles 13%
Time 1/21/2010 09:00 - 1/21/2010 11:00 (UTC+8.0h)
Satellites 30 GPS 30 [Almanac.alm (1/20/2010)]

(b)



(c)

Figure 3: GPS coverage in the test area during the test period (21st January 2010, 0900 – 1100): (a) PDOP; (b) and (c) satellite visibility. (Source: Screen captures from the Trimble Planning software)

2.3 Test Procedure

The apparatus used in the test were an Advantest U3751 spectrum analyser (Advantest, 2009), an IFR 2023B signal generator (IFR, 1999), a Hyperlog 60180 directional antenna (Aaronia, 2009), and a Garmin GPSmap 60CS handheld receiver (Garmin, 2004) (used as a benchmark reference). The test procedure employed is as follows (Figures 4 and 5):

a) The signals in the frequency range of 1,560 - 1,590 MHz are measured.
b) The evaluated GPS and reference GPS 1 are placed at the same height and as close as possible to each other.
c) Reference GPS 2 is placed in an area unaffected by the jamming (approximately 150 m away).
d) A location fix is obtained using each of the three GPS receivers.
e) The directional antenna is used to transmit an FM signal with the following properties:
    i. Carrier wave frequency: 1,575.42 MHz (frequency of the L1 signal)
    ii. Peak deviation: 1 MHz
    iii. Information frequency: 5 kHz
f) At transmitted power level of 13 dBm, the received power level at 3 m is measured. The

transmission is then switched off.

g) The evaluated GPS receiver and reference GPS 1 receiver is placed 3 m away from the transmitting antenna.

h) The transmission is started at power level of -60 dBm.

i) The power level is increased by increments of 1 dBm.

j) For each GPS receiver, the power levels when following occurs is noted:
   i. The first degradation of accuracy is noticed
   ii. The location fix is lost.

k) Steps g-j are repeated, using distances of 10 - 90 m (increments of 10 m).

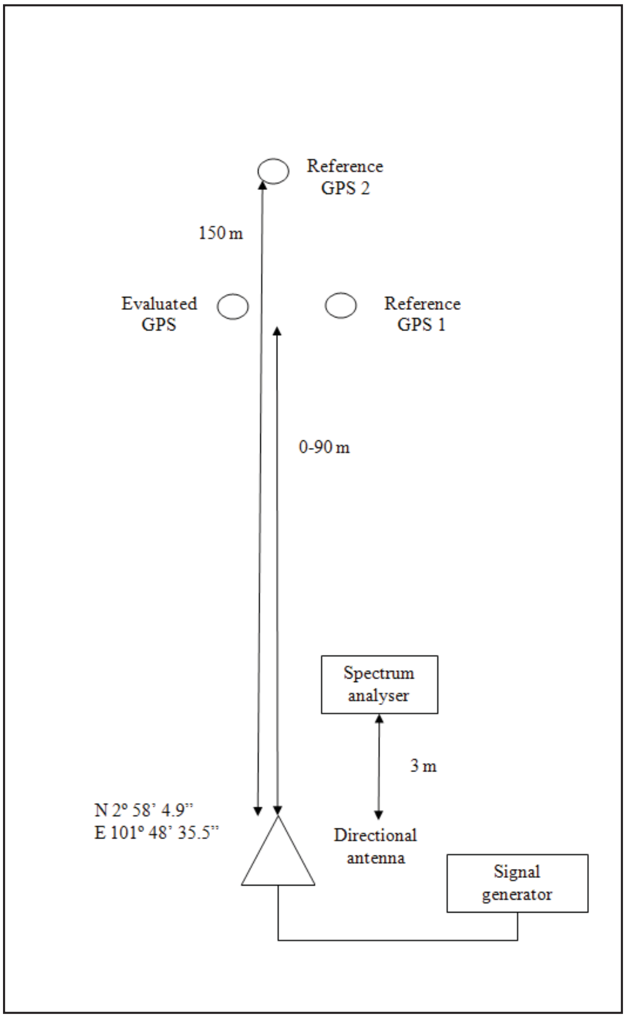


Figure 4: The test setup employed.

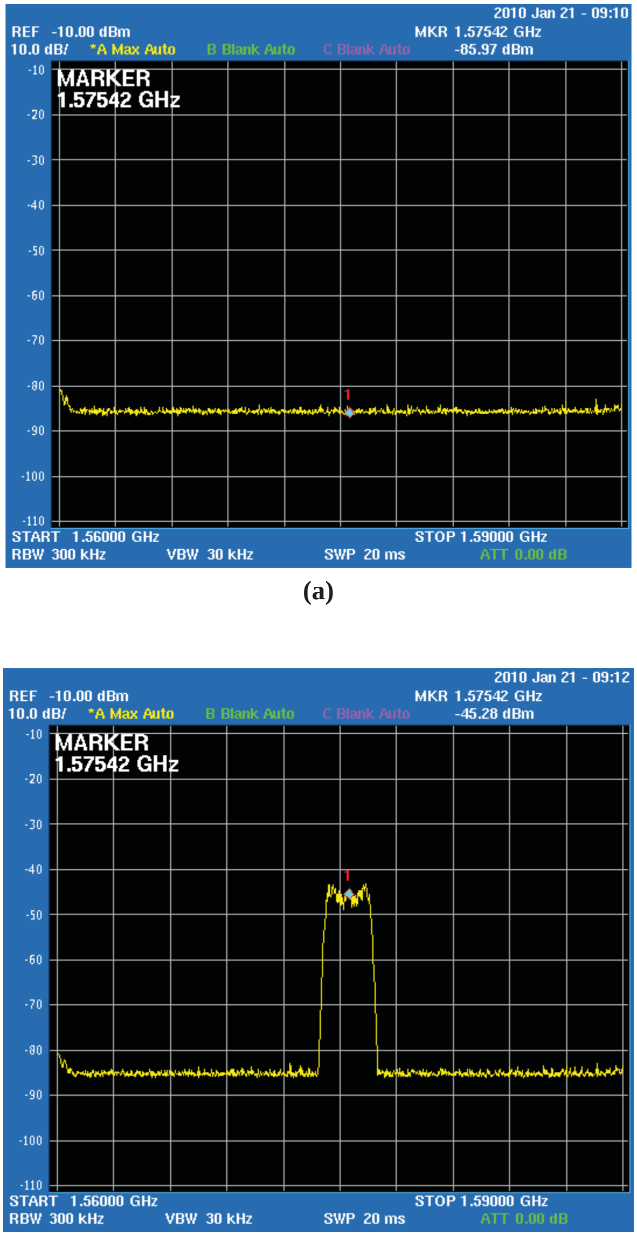
Figure 5: BTIE officers and staff conducting the GPS jamming test.

3. RESULTS

No discernible signals were observed in the range of 1,560 – 1,590 MHz (Figure 6(a)). However, it should be noted that the spectrum analyser was only able to measure received signals above -80 dBm, well over the minimum power levels required to jam GNSS signals. It is unknown if there are any unwanted interference signals below this threshold.

For the transmitted signal, at power level of 13 dBm, the received signal at distance of 3 m is shown in Figure 6(b). The measured signal is used to estimate received power levels which were too low to be measured with the spectrum analyser (appendix). It is noted that all three GPS receivers were unable to obtain location fixes during the duration of this step.

For the distances evaluated in the test, the power levels at which the first degradation of accuracy is noticed and the location fix is lost is shown in Table 1.



2010 Jan 21 - 09:10
REF -10.00 dBm
10.0 dB/ *A Max Auto B Blank Auto C Blank Auto
MKR 1.57542 GHz
-85.97 dBm
MARKER
1.57542 GHz
START 1.56000 GHz
STOP 1.59000 GHz
RBW 300 kHz VBW 30 kHz SWP 20 ms ATT 0.00 dB

(a)

2010 Jan 21 - 09:12
REF -10.00 dBm
10.0 dB/ *A Max Auto B Blank Auto C Blank Auto
MKR 1.57542 GHz
-45.28 dBm
MARKER
1.57542 GHz
START 1.56000 GHz
STOP 1.59000 GHz
RBW 300 kHz VBW 30 kHz SWP 20 ms ATT 0.00 dB

(b)

Figure 6: Advantest U3751 spectrum analyser readouts: (a) Frequency range of 1,560 – 1,590 MHz (no signals transmitted). (b) Received signal, at a distance of 3 m, for interference signals transmitted at power level of 13 dBm.

Table 1: Power levels of interference signals at which the first degradation of accuracy is noticed and the location fix is lost.

Distance (m)	Power Level (dBm)							
	Evaluated GPS				Reference GPS 1			
	The first degradation of accuracy is noticed		The location fix is lost		The first degradation of accuracy is noticed		The location fix is lost	
	Effective Transmitted	Estimated Received	Effective Transmitted	Estimated Received	Effective Transmitted	Estimated Received	Effective Transmitted	Estimated Received
3	-40.00	-103.28	-32.00	-95.28	-44.00	-109.28	-40.00	-105.28
10	-29.00	-102.74	-27.00	-100.74	-36.00	-111.74	-35.00	-110.74
20	-28.00	-107.76	-22.00	-101.76	-35.00	-116.76	-32.00	-113.76
30	-24.00	-107.28	-20.00	-103.28	-30.00	-115.28	-27.00	-112.28
40	-18.00	-103.78	-12.00	-97.78	-24.00	-111.78	-22.00	-109.78
50	-15.00	-102.72	-10.00	-97.72	-22.00	-111.72	-15.00	-104.72
60	-14.00	-103.30	-9.00	-98.30	-21.00	-112.30	-14.00	-105.30
70	-12.00	-102.64	-7.00	-97.64	-19.00	-111.64	-14.00	-106.64
80	-11.00	-102.80	-6.00	-97.80	-16.00	-109.80	-13.00	-106.80
90	-9.00	-101.82	-4.00	-96.82	-14.00	-108.82	-12.00	-106.82

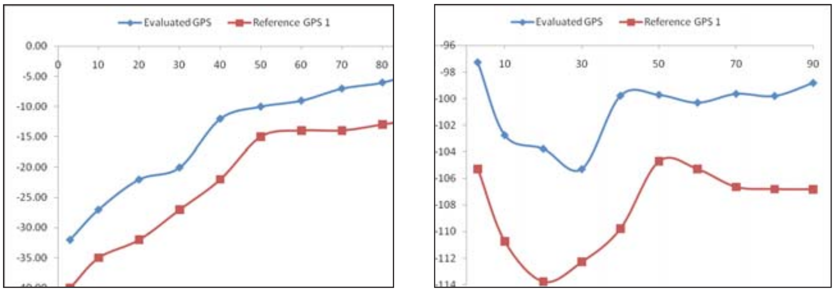
4. DISCUSSION

It was observed that the received power levels required to affect the location fixes of the GPS receivers are significantly high compared to the received GPS signal power. The noise-like C/A code structure, which spreads the L1 signal over a 2 MHz bandwidth, allows for the signal to be received at low levels of interferences. The P(Y) code (restricted to the US military) has a more robust structure, modulating the L1 and L2 signals over 20 MHz bandwidths, and hence, has better resistance to interference.

It was also observed that higher transmitted (Figure 7(a)) and received (Figure 7(b)) power levels were required to jam the evaluated GPS receiver, as compared to reference GPS 1. This is because the evaluated GPS receiver has higher receiver sensitivity compared to reference GPS 1, and hence, better RFI operability. The varying values of received power levels required to jam the GPS receivers over the evaluated distances were due to the effect of various error parameters, such as ionospheric and tropospheric delays, satellite clock, ephemeris and multipath errors, and unintentional signal interferences and obstructions, all of which are immeasurable and user-uncontrollable. The ideal testing methodology, to get more accurate results, would be using a GNSS simulator which can be used to generate multi-satellite GNSS configurations, transmit GNSS signals which simulate real world scenarios, and adjust the various error parameters. This would allow for the evaluation of GNSS receiver performance under various repeatable conditions, as defined by the user. The advantages of GNSS simulators, as compared to field evaluations, such as conducted in this test, are discussed in Dinesh *et al.* (2009b).

It should be reiterated that this test was conducted during a period of good GPS satellite coverage, with low ranges of PDOP values. During periods of poor satellite coverage, the power levels required to jam the L1 C/A signal will be smaller.

Reference GPS 2 was unaffected during the jamming test as it only involved interference power levels affecting up to 90 m. However, during the signal power referencing, when the power level of the transmitted signal was set at 13 dBm, reference GPS 2 was jammed. An interesting follow up test would be to evaluate the power levels required to conduct GPS jamming over a larger range of distances. This would require a more suitable test site, with a longer range with clear LOS.



(b) **(a)**

Figure 7: Power levels required to jam the evaluated GPS receiver and reference GPS 1: (a) Effective transmitted. (b) Estimated received.

5. CONCLUSION

This test has demonstrated the ease to conduct GNSS jamming. Relatively low power level interference signals, from intentional or unintentional sources, can disrupt GNSS signals over long range of distances. Given the dependence on GNSS for PNT applications, GNSS disruption could prove to be problematic, if not disastrous. Hence, GNSS vulnerability mitigations steps should be given emphasis, including PNT backups, making full use of ongoing GNSS modernisation programs, increased ability to identify and locate GNSS jammers, integrity monitoring and augmentation, and anti-jamming technologies.

ACKNOWLEDGEMENT

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APPENDIX

Estimation of distance:

P_T : Transmitter power
P_R : Receiver power
G_T : Transmitter gain
G_R : Receiver gain
L : Free-space path loss
L_E : External losses
R : Distance (km)
f : Frequency (MHz)

$$P_R = P_T + G_T + G_R - L - L_E \tag{A1}$$

$$L = 32.44 + 20\log R + 20\log f \tag{A2}$$

Effective transmitted power P_{Teff}:

$$P_{T_{eff}} = P_T + G_T \tag{A3}$$

Effective received power P_{Reff}:

$$P_{R_{eff}} = P_R - G_R \tag{A4}$$

With L_E and f being constant:

$$P_{R_{eff}} = P_{T_{eff}} - 20\log R - L_O - G_R \tag{A5}$$

where:

$$L_O = 32.44 + 20\log f + L_E \tag{A6}$$

For the directional antenna, G_T = 5 dBi.
For the receiving antenna, G_R = 1 dBi.
For FM signal with bandwidth of 2 MHz, P_{Teff} = 18 dBm, P_R = -45.28 dBm and R = 3 m:

$$L_O = 18 - (-45.28) - (-50.46) - 1 = 112.74\ dBm \tag{A7}$$

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DETERMINATION OF WHOLE BODY VIBRATION (WBV) OF MAIN BATTLE TANK (MBT) PT-91M

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ABSTRACT

Vehicles expose humans to mechanical vibrations which can interfere with comfort, working efficiency and, in some circumstances, health and safety. Safer vehicles for the military applications are very important to ensure that military personnel are always in good health and at the level best of performance. This will allow them to perform their tasks with optimum capabilities. One of the factors that need to be examined in order to maximise human comfort inside the military vehicles is the ergonomic aspect. For this purpose, monitoring ergonomic factors such as Whole Body Vibration (WBV) is important and necessary. This study is aimed at assessing the WBV level of the Main Battle Tank (MBT) PT-91M Pendekar. The methods employed are based on current standard practices, which refer to Directive 2002/44/EC, 2002 and ISO 2631-1, 1997. For measurement of WBV, the equipment used are WBV set type B&K model 2238.From this study, it is concluded the WBV inside the PT-91M has to be improved because from the results show that the WBV values are relatively high, causing discomfort for the drivers and passengers.

Keywords: Whole Body Vibration (WBV); Main Battle Tank (MBT) PT-91M Pendekar; human comfort.

1. INTRODUCTION

Vehicles and machineries expose humans to mechanical vibrations which can interfere with comfort, working efficiency and, in some circumstances, health and safety. Safer vehicles for the military applications are very important to ensure that military personnel are always in good health and at the best level of performance. This will allow them to perform their tasks with optimum capabilities. One of the factors that need to be examined in order to maximise human comfort inside military vehicles is the ergonomic aspect. For this purpose, monitoring ergonomic factors such as Whole Body Vibration (WBV) is important and necessary.

Whole Body Vibration (WBV) is a mechanical vibration (or shock) transmitted to the body as a whole. It is often due to the vibration of a surface supporting the body (Griffin, 1994). Directive 2002/44/EC,(2002) defined WBV as the mechanical vibration that, when transmitted to the whole body, entails risks to the health and safety of workers, in particular lower-back morbidity and trauma of spine. WBV is transmitted to the body through the body's supporting surfaces, such as the legs when standing, and the back and buttocks when sitting. There are three principal possibilities of how vibration is transmitted to the human; sitting on a vibrating seat, standing on a vibrating floor, and lying on a vibrating bed. For the purpose of this study, sitting on a vibrating seat is the sole target.

In a vehicle, exposure to vibration can be experienced in two ways; through an instantaneous shock with a high peak level enough to jar a seated person out of the seat, or through repeated exposure to low levels of vibration created by regular motion of the vehicle over rough terrain. Seated persons exposed to WBV are often simultaneously exposed to local vibrations of the head, hands and feet. Vibrations may also enter the body as a result of contact with the backrest of a seat. Vibrations between 2.5 and 5 Hz generate strong resonance in the vertebra of the neck and lumbar region. If the body experiences vibrations between 20 to 30 Hz, it can cause resonance between the head and shoulders, which may lead to chronic musculoskeletal stress, or even, permanent damage to the effected regions. The most common effect is lower back pain (ISO 2631-1, 1997). The mentioned ailments will not happen in a short period of time, but rather, will happen a few years later.

Table 1 shows the potential WBV exposures faced by U.S. Navy personnel. From the table, it is observed that combat vehicle drivers are exposed to high levels of WBV, which could potentially impair their performances. In addition, prolonged vibration exposure in transit can increase fatigue and tension for both passengers and crew.

Table 1: Potential WBV exposures relevant to the U.S. Navy.
(Source: Naval Safety Center (2009))

Equipment Type	Exposed Personnel	Remarks
Rotary wing aircraft	Aircrews	Exceptional circumstances such as icing of rotors can create vibration that can jeopardize aircraft operation. Can affect visual acuity.
Fixed wing aircraft	Aircrews	Smaller aircraft tend to be more susceptible to turbulence because of their size. Small aircraft reciprocating (piston) engine and propellers also create some vibration.
Combat vehicles	Operators	Potentially impaired driver's performance is associated with high vibration exposures.
	Passengers	Prolonged vibration (and noise) exposure in transit can increase fatigue and tension to both passengers and crew.
Heavy construction equipment (bulldozers, earthmovers and similar equipment)	Operators	No Remarks
Materials handling vehicles (forklifts and similar equipment)	Operators	Dependent upon work surface, load and equipment maintenance
Large road transport vehicles	Operators	No remarks
Hovercraft	Navy SEALs	No remarks
* Note: WBV (resonance) in the range of 4 Hz vertical and 1-2 Hz side to side will create loss of control for vehicle operators		

ISO 2361-1 (1997) does not provide specific limits of vibration values as related to comfort due to the various factors which vary with each type of environment and application. However, it does make allowances for health guidance caution zones, which allows for the application of rough assessments of likely health effects, taking into account the vibration values and exposure periods. As show in Figure 1, vibration values which are more than 6.3 m/s^2 are potential health risks, and needs to be limited to only 10 minutes of exposure continuously. However, the standard does not offer a definite means for predicting such effects. For exposures below the comfort zone, the ISO 2631-1 standard warn that the health effects have not been clearly documented and/or objectively observed. Caution with respect to potential health effects is indicated, along with likely above the comfort zone health risks (Joubert, 2002).

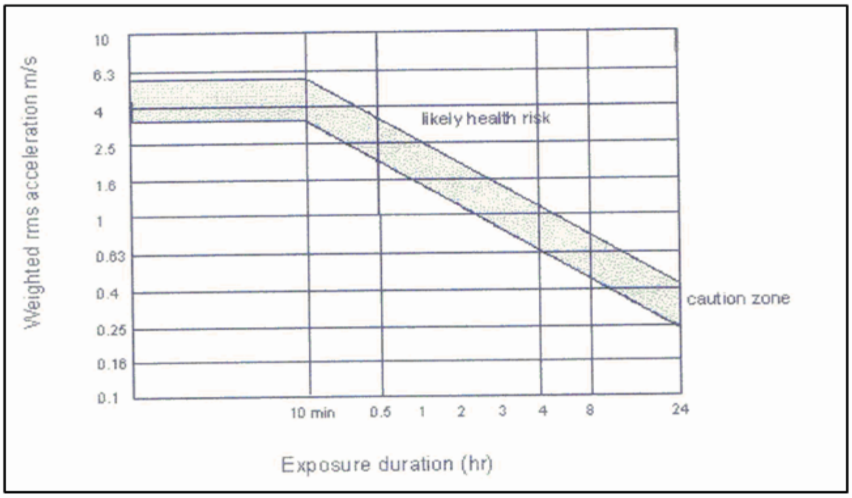

Figure 1: Health guidance zone.
(Source: ISO 2631-1 (1997))

Table 2 shows vibration values which have been categorised based on comfort reaction. Values less than 0.315m/s^2 are classified as in the comfort zone, while the range between 0.63 m/s^2 to 1.0m/s^2 is considered as less comfortable. If the vibration value is more than 2.5 m/s^2, it is considered as uncomfortable. This high level of vibration, if not controlled can cause a lot of problems to the health and safety of Malaysian Armed Forces (MAF) personnel.

Table 2: Comfort reactions to vibration environments.
(Source: ISO 2631-1 (1997))

Vibration Value (m/s^2)	Comfort reactions
< 0.315	not uncomfortable
0.315 - 0.63	a little uncomfortable
0.5 – 1.0	fairly uncomfortable
0.8 – 1.6	Uncomfortable
1.25– 2.5	very uncomfortable
> 2.5	extremely uncomfortable

Sophisticated tanks, such as the Main Battle Tank (MBT) PT-91M Pendekar, play a crucial role in the defence of the country. Realizing this, in March 2002, the then Malaysian Prime Minister, Tun Dr Mahathir Mohamad announced that Malaysia will procure modernised PT-91 Twardy tanks. Following this, on 14th October 2002, the then Defence Minister (and current Malaysian Prime Minister) Datuk Seri Najib Tun Razak announced that Malaysia would sign an agreement on the tank procurement with Poland at the end of the year. The announcement made by the Defence Minister was given full support by the armed forces. In April 2003 Malaysia signed a USD 375 million contract with Poland, covering the supply of 48 PT-91Ms, 6 of the latest WZT-4 armoured recovery vehicles (ARV), 5 PMC armoured vehicles launched bridges (AVLB) and 3 MID-M obstacle breaching vehicles, complete with ammunition and training (Global Security, 2009).

The PT-91M, which is also referred to as the Twardy (Hard), was developed from the Zaklady Mechaniczne Bumar-Labedy SA version of the Russian-designed T-72M1, which was produced under a licence in Poland for many years (Military Factory, 2010). The first prototype of the PT-91 was completed in late 1992 and underwent trials with the Polish Army. PT-91, and its variant, T-72M1Z, were derived from T-72 through modernisation, replacement and upgrading of its systems. They were designed to be highly reliable systems having superior firepower, improved crew protection and impressive mobility. The PT-91 has a number of improvements over the earlier T-72M1 in key areas of armour, mobility and firepower. To meet the PT-91 standard, most of these modifications can be backfitted to existing T-72M1s, while others, for example the armour package, can be backfitted to other vehicles (Janes, 2008).

The PT91-M will be tested in this study due to its usage in rough and robust conditions, contributing to high vibration levels. As mentioned earlier higher vibration levels will entail to health risks to the crew members. A vehicle's movements cause mechanical energy in the form of vibration that propagates throughout the vehicle's structure. This vibration can affect the health and readiness of the military personnel and can cause lumbar spine and may affect the connected nervous system.

The vibration is normally generated by the vehicle itself, or results from travelling over specific road surfaces. However, it is important to take into account that PT-91Ms may have different vibrations under different operating conditions compared with other vehicles.

2. METHODOLOGY

The complete set of equipment to perform the vibration test consisted of triaxial transducers (Figures 2 and 3), an amplifying device and an amplitude recorder. The basic operation and characteristics of the equipment used was recorded and reported along with the results obtained. It was important to report such characteristics, including frequency sensitivity, and dynamic properties, dynamic range, and resolution of the equipment.

Figure 2: Triaxial seat accelerometer 4515-B.

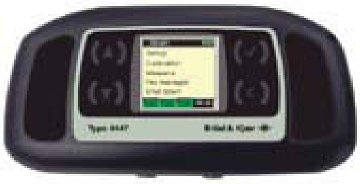

Figure 3: Bruel & Kjaer 4447 WBV meter.

For this vibration measurement, a seated driver and co-driver were examined. ISO 2631-1 requires that the measurement of frequency-weighted acceleration be conducted at the point of entry into the body. Acceleration measurements were performed along 3 mutually perpendicular directions. The sensitivity of the body to vibration at different frequencies was accounted for by frequency weightings inserted into the measurement chain.

A triaxial accelerometer, embedded in a nit rile rubber seat pad (Figure 2), was placed in the centre of the driver's seat with the axes aligned, and the driver sitting on the cushion. The measurements were made as close as possible to, or through, the point which the vibration was transmitted (ISO 2631-1, 1997). The triaxial tranducer (Figure 3) was fastened to the rigid structure to ensure the right measurements were achieved.

The measurement was carried out in four conditions; idle, and at speeds of 20 km/h, 30 km/h and 40 km/h (Shamsul *et al*., 2008). The vehicle's speed was in stable condition for a few minutes at every condition. The pavement road condition is straight for at least 3 km to ensure the standard speed can be achieved. For WBV measurement, three positions were selected, at the driver, co-driver and passenger positions. The data obtained were analyzed, and comparisons were made with Figure 1 in order to get the exposure limit. The conclusions were made based on the parameters given in Table 2.

3. RESULTS AND DISCUSSION

Table 3 shows the results of WBV measurements for the various tested conditions. The comfort levels of the driver, co-driver and passenger were assessed by comparing the measured WBV values with Table 2.

At the idle condition, all the tanks recorded WBV values that were much lower compared to the comfort level threshold (0.315 m/s^2). At the speeds of 20 and 30 km/h, the WBV values for the drivers were marginally within the comfort zone, and the "a little uncomfortable" zone (0.315-0.630 m/s^2) for the co-drivers and passengers. However, at the speed of 30 km/h, tank ZC393 recorded significantly higher passenger WBV values, in the "fairly uncomfortable" zone (0.500-1.000 m/s^2). This could be due to undulations on the surface during the test. At the speed of 40 km/h, the WBV values for all the crewmembers were in the "a little uncomfortable" zone. The comfort levels of the crew members at the various speeds are summarised in Table 4.

Table 3: Recorded WBV values.

Tank PT91	Vehicle Speed (km/h)	Driver Seat (m/s^2)	Exposure Limits (hour)	Co-Driver Seat (m/s^2)	Exposure Limits (hour)	Passenger Seat (m/s^2)	Exposure Limits (hour)
ZC393	Idle	0.003	>8	0.015	>8	0.016	>8
	20	0.30	4	0.324	3	0.373	2.5
	30	0.29	4	0.407	2	0.689	1.25
	40	0.33	3	0.474	1.5	0.581	1.5
ZC399	Idle	0.003	>8	0.008	>8	0.009	>8
	20	0.310	4	0.333	3	0.341	3
	30	0.310	4	0.378	2.5	0.424	1.5
	40	0.429	2	0.404	2	0.427	1.5
ZC402	Idle	0.0029	>8	0.017	>8	0.008	>8
	20	0.301	4	0.400	2.25	0.332	3
	30	0.313	4	0.390	3	0.394	2.5
	40	0.428	2	0.436	2	0.456	2

Table 4: Comfort levels of the crew members at various speeds.

	Comfort Level		
	Driver	**Co-driver**	**Passenger**
Idle	Not uncomfortable	Not uncomfortable	Not uncomfortable
20	Not uncomfortable	A little uncomfortable	A little uncomfortable
30	Not uncomfortable	A little uncomfortable	A little uncomfortable
40	A little uncomfortable	A little uncomfortable	A little uncomfortable

It is observed that for all three tanks, the drivers experienced much lower WBV exposure compared to the co-drivers and passengers. This is because the vibration exposure spring for the driver seat is more effective compared to the co-driver and passenger seats. This was designed in such a way as the driver has to be seated at all times during operations, hence requiring a better seat. It is also observed that the WBV values increase with speed. Based on Figure 1, the recommended maximum continuous operation time for crew members, in order to avoid overexposure to WBV, is 4 hours.

4. CONCLUSION

This evaluation, conducted based on relevant standards and test protocols, have provided significant insight into the comfort and safety levels of PT-91Ms for military operations.

Vibration exposure depends on the type of terrain and the vehicle speed, which are factors that are unlikely to be controllable in practice. This study also provided information about the WBV spectra of PT-91Ms, which was not previously available. This data is useful for the design of future studies on the effects of vibration on performance. Minimizing the vibration exposure of MAF personnel is important to reduce the injury risks associated with vibrating equipment and hand tools, as well as maximizing productivity. From this study, it is concluded that the WBV inside the PT-91M has to be improved because results obtained show that the WBV values are relatively high, causing discomfort for the drivers and passengers.

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VIBRATION ANALYSIS FOR MAINTENANCE OF AGUSTAWESTLAND A109 LIGHT OBSERVATION HELICOPTERS (LOH)

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ABSTRACT

One of the methods to achieve mission availability is through proper maintenance of platforms. Vibration monitoring is commonly understood to be a form of condition monitoring used extensively in the aerospace industry to monitor engines, transmissions and gearboxes to detect faults before they develop into catastrophic failures. Some applications simply warn of excessive vibration levels, whilst others are able to match vibration signatures to known failure modes. Given the safety and cost implications of catastrophic failures in these helicopter components, investment payback can occur even if very low numbers of failures are avoided. This project focuses on AugustaWestland AH109 light observation helicopters (LOH) used by Pasukan Udara Tentera Darat (PUTD), where regular vibration measurements are taken at the main engine and the vibration trending are monitored. The analysis of the vibration spectra can be used by engineers to predict when a component is going to fail, and hence, necessary remedies and actions can be taken.

Keywords: *Vibration Analysis; AugustaWestland Helicopter; PUTD; Rotating Unbalance.*

1. INTRODUCTION

The Malaysian Government procured 11 A109 light observation helicopters (LOH) (Figure 1) from AgustaWestland, Italy, for *Pasukan Udara Tentera Darat* (PUTD). This aircraft is a light-weight, twin engine, eight seat multi-purpose helicopter. It has established itself as a military light-twin helicopter, and is able to satisfy a wide range of Malaysia Armed Forces (MAF) requirements. The ability of the A109 LOH to fulfil a wide range of missions makes the aircraft a true force multiplier, providing military commanders with excellent operational flexibility (AgustaWestland, 2009).

Concept of operations of the MAF is always for strategic purposes. One of them is to protect the sovereignty of the country by preparing efficient and sufficient equipments. The A109 helicopters are one of the prominent assets owned by the MAF for military missions, including security missions and rescue operations. Hence, it is very important to maintain the effectiveness of the A109 helicopters, as well as their capabilities. Subsequently, vibration analysis for maintenance is carried out to fulfil the purposes as stated.

In addition, by using vibration analysis, sufficient warning will be provided. Therefore, maintenance can take place at the optimum time for overall mission performance, and also, when the required engineering and logistic resources are immediately available. Furthermore, by avoiding in-service failures and possible secondary damage, repair costs may be reduced.

Figure 1: *Pasukan Udara Tentera Darat*'s (PUTD) AgustaWestland A109 Light Observation Helicopter (LOH).

2. VIBRATION ANALYSIS ASSESSMENT

Vibration monitoring is commonly understood to be a form of condition monitoring used extensively in the aerospace industry to monitor engines, transmissions and gearboxes to detect faults before they develop into catastrophic failures.

Some applications simply warn of excessive vibration levels, whilst others are able to match vibration signatures to known failure modes. Given the safety and cost implications of catastrophic failures in these aerospace components, investment payback can occur by avoiding such failures. The proposed overall system describes how to replace fixed-interval maintenance with fixed-interval vibration measurements of the machines or components (Hamid *et al.,* 2009).

The status of the running condition of each individual machine or component can be monitored closely. Mechanical vibration is a good indicator of a machine's running condition. By using vibration analysis, faulty conditions can be detected. Measurements can be extrapolated in order to analyse and predict unacceptable vibration levels, and when the machine needs to be serviced. This will allow the engineer to plan repairs in advance and maintain mission availability.

3. RESPONSE OF A DAMPED SYSTEM UNDER ROTATING UNBALANCE

In rotating machines such as a turbine, unbalance is a common source of vibration excitation. Unbalance exists if the mass centre of the rotor does not coincide with the axis of rotation. Rotating unbalance is also important in rotary-wing aircrafts such as helicopters. Referring to the rotating machine as shown in Figure 2 and free body diagram in Figure 3; both depict the response of a damped system under rotating unbalance. This model and free body diagram can represent the rotating unbalance condition for A109 helicopter body itself.

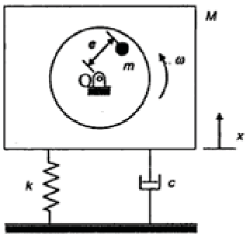


Figure 2: Rotating machine.
(Source: Dukkipati *et al*. (2005))

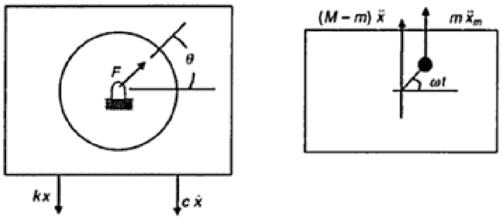


Figure 3: Free body iagram.
(Source: Dukkipati *et al*. (2005))

All acting forces at rotating unbalance can be explained using Equation 1. The unbalance mass *m* with an eccentricity *e* that is rotating with angular velocity ω. The rotating machine is constrained to move in the vertical direction *x*. Let *M* be the total mass of the rotating machine, the equation of motion of the system is:

$$M\ddot{x} + c\dot{x} + kx = mex^2 \sin wt \quad (1)$$

The vibration value is amplitude *X*, radius *r;* damping ratio *ζ* which is determined from rotating unbalance using Equation 2.

$$\frac{MX}{me} = \frac{r^2}{[(1-r^2)^2 + (2\zeta r)^2]^{1/2}} \quad (2)$$

Figure 4 shows the variation of the non-dimensional ratio *MX/me* versus the frequency ratio. It follows from the above equation.

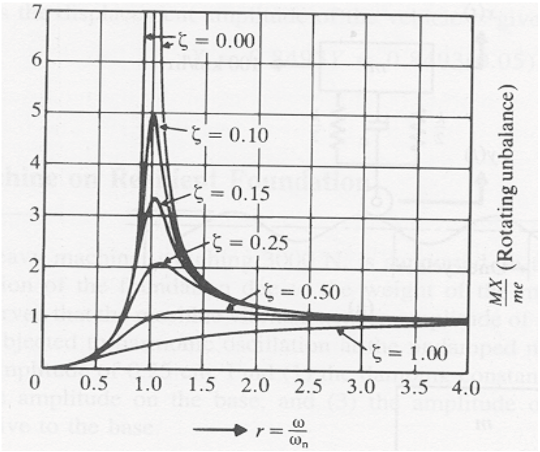
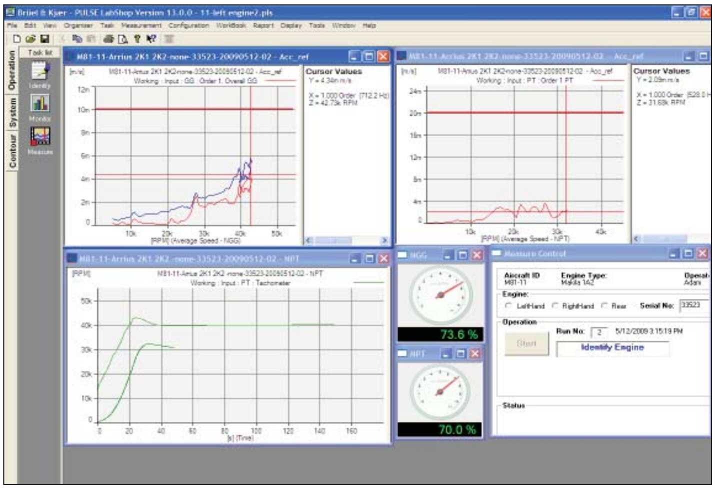


Figure 4: Plot of the non-dimensional ratio (*MX/me*) versus the frequency ratio.
(Source: Rao *et al*. (2003))

4. RESULT & ANALYSIS

In an operation, the propulsion shafting of a helicopter is deformed axially and torsionally. Both deformations cause axial vibrations, which at critical rpms may become unacceptable. The vibrations are damped by an integral axial vibration damper. The rpm is calculated based on the shafting, and measurements are performed to verify the calculated natural frequencies and the effect of the damper. The acceptable vibration limit for the Gas Generator (GG) is 10 mm/s (the red line in Figure 5, upper left) and 20 mm/s for the Power Turbine (PT) (the red line in Figure 5, upper right). Both values are already specified for the A109 helicopters' Arrius 2K2 engines by Turbomeca.



Cursor Values
Y = 4.34m m/s
X = 1.000 Order (712.2 Hz)
Z = 42.73k RPM

Cursor Values
Y = 2.09m m/s
X = 1.000 Order (528.0 H
Z = 31.68k RPM

Aircraft ID
M81-11
Engine Type:
Makila 1A2
Operat
Adani
Engine:
○ LeftHand ○ RightHand ○ Rear
Serial No: 33523
Operation
Run No: 2 5/12/2009 3:15:19 PM
Status

Figure 5: Result of a 70 second run-up of A109 helicopters' Arrius 2K2.
(Source: Screen capture from the PULSE software)

Order Analysis is used to analyse the data acquired during a change in the rotational speed of a helicopter shaft. Order Analysis can be used to measure frequency or order spectra, frequency band profiles, and order profiles as functions of rpm. The spectra can be displayed as waterfalls or colour contours (Brüel & Kjær, 2007). The frequency bands and order profiles can be cut out from the colour contour spectra and therefore, are referred to as slices. As they are defined upon inspection of the spectra as a function of rpm, these slices are called post-slices. If the frequency bands or orders of interest are known prior to the measurement, the vibration analyser can extract these slices during the measurement (pre-slices).

4.1 GG Analysis

In a colour contour, individual or harmonic orders can be extracted and viewed in a 2D graph. These slices show the amplitude or phase of the orders as a function, for example rpm or time. Slices can be extracted from tracked data using the cursors. Slices made as analyzer calculations are specified before the measurement starts and extracted during the measurement. They can be used as functions in the Function Organiser (slices extracted from a contour or waterfall plot are sub-functions) and collected in groups, simplifying data import and export, and comparison of results (Brüel & Kjær, 2007).

The contour plot in Figure 6 shows the results of a run-up test using tracking. It can be seen that order and non-order components are present. The frequency value for the 1st order is 710 Hz. During this time, the rpm of the helicopter is 73.6 % from overall GG rpm and equivalent to 42.5k rpm.

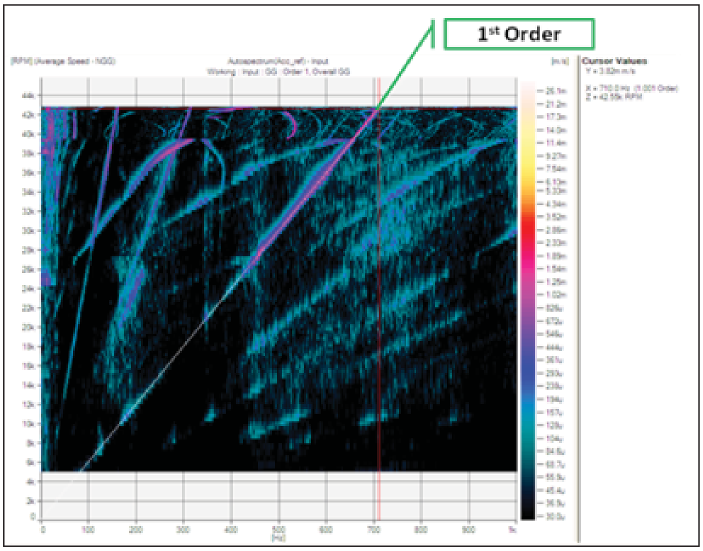

1st Order

Figure 6: Order plots from the GG.
(Source: Screen capture from the PULSE software)

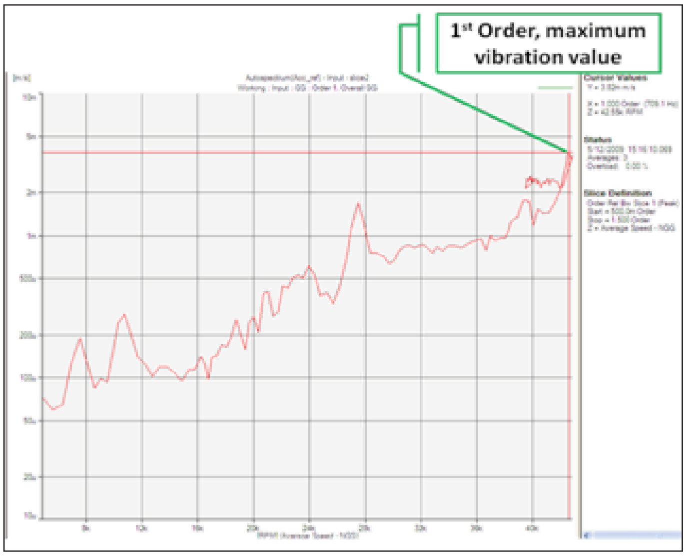

1st Order, maximum vibration value

Figure 7: 1st order vibration signal of the GG.
(Source: Screen capture from the PULSE software)

The maximum value / amplitude of the 1st order vibration is obtained by extracting slices parallel to the rpm axis (Figure 7) from contour plots showing order spectra. The cursor readings indicate that the maximum measured value at 1st order vibration is 3.82 mm/s. In comparison, the permitted vibration level as stated by Turbomeca is 10 mm/s.

4.2 PT Analysis

As shown in Figure 8, the frequency value for the 1st order vibration is 532.5 Hz. At this time, the rpm of the helicopter is 70 % from overall PT rpm and equivalent to 31.94 k rpm. The maximum value / amplitude of the 1st order vibration is obtained by extracting slices parallel to the rpm axis (Figure 9) from contour plots showing order spectra. The cursor readings indicate that the maximum measured value of the 1st order vibration is 2.48 mm/s. The permitted value as stated by Turbomeca is 20 mm/s.

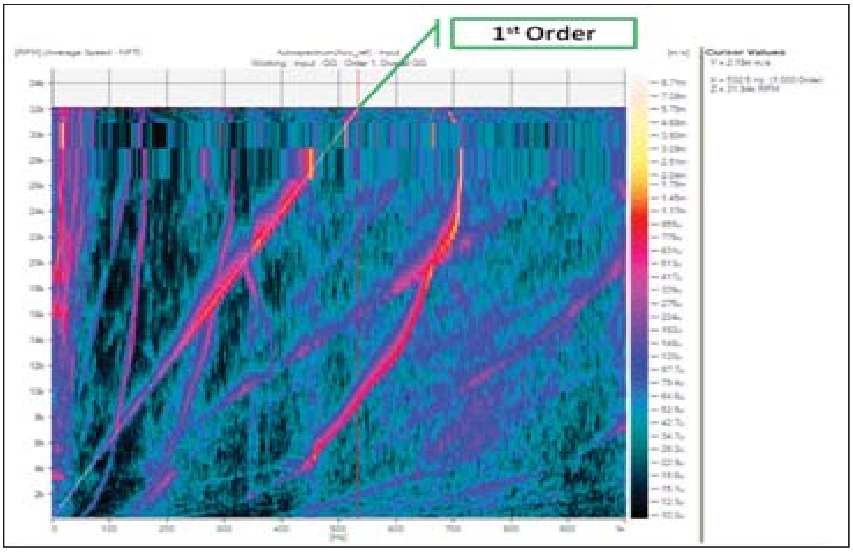


Figure 8: Order plots from the PT.
(Source: Screen capture from the PULSE software)

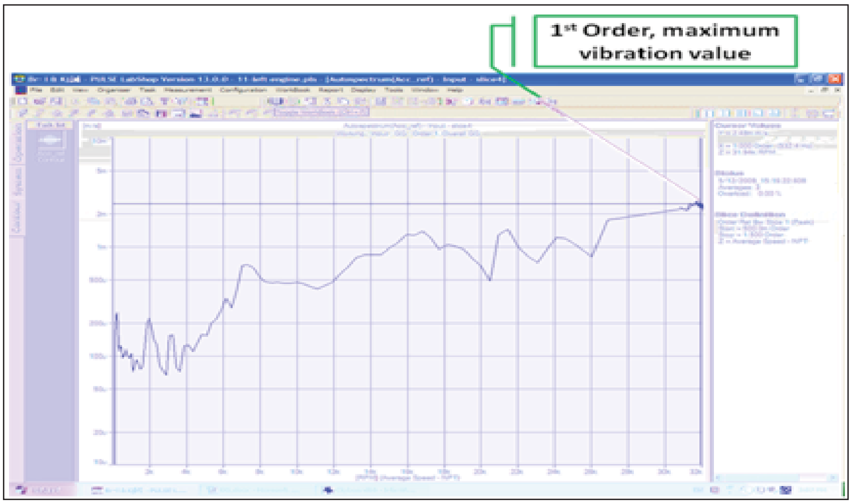


Figure 9: 1st order vibration signal of the PT.
(Source: Screen capture from the PULSE software)

5. CONCLUSION

It can be concluded that vibration analysis of AgustaWestland A109 helicopters is one of maintenance tools that is reliable and recommended. By using this equipment and system, PUTD can predict whether an A109 engine is going to fail, and detect any defects related to the situation. By using the proposed system, a test can be done successfully and it can prevent any miscalculations.

This project involved high standard military facilities and it has its own impact towards the Malaysian defence industry. The government has spent billions for the procurement of the A109 helicopters. Hence, it is important to safeguard user safety as well as the security of the helicopters. This project must be carried out vigilantly because any lackadaisical acts can lead to large losses to our country.

ACKNOWLEDGEMENT

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KEY DEFENCE R&D FIELDS TO DEVELOP THE NATIONAL DEFENCE INDUSTRY: FOCUS ON C4ISR IN SUPPORT OF NETWORK CENTRIC OPERATIONS AND UNMANNED VEHICLES

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ABSTRACT

This paper is aimed at conducting a critical assessment of two key defence R&D fields that are important in supporting the development of the national defence industry, in particular in supporting the achievement of the objectives of the Fourth Dimension Malaysian Armed Forces (4D MAF) capability plan in terms of operational awareness and mission capability. The fields that will be discussed, determined based on the author's literature review and opinions of the MAF's capabilities and requirements, and current and expected future trends of global defence technology development, are Command, Control, Communications, Computers, Intelligence, Surveillance & Reconnaissance (C4ISR) in support of network centric operations (NCO) and unmanned vehicles (UVs).On the whole, the overall capabilities of the national defence industry to produce indigenous equipment and assets that meet the requirements of the 4D MAF plan in these two fields of defence R&D are still relatively limited. Nevertheless, significant progress has been, and is being, made through collaborations with relevant agencies, institutes and industries, both local and foreign. Active participation in defence R&D, in these two fields, in addition to other fields of defence technology, including vehicle & aerospace engineering challenges, emergent naval technology, smart weapons, personnel protection & performance, and biological, nuclear & chemical terrorism countermeasures, is required to further catalyze the development of the national defence industry.

Keywords: *Defence R&D; Fourth Dimension Malaysian Armed Forces (4D MAF); national defence industry; network centric warfare (NCO); unmanned vehicles.*

1. INTRODUCTION

The Malaysian Armed Forces (MAF) is in the process of embarking to implement the Fourth Dimension MAF (4D MAF) capability plan in order to be able to meet modern security challenges. The 4D plan is aimed at transforming the MAF into a fully integrated and balanced force, giving emphasis on jointness and interoperability among the triservices; the Malaysian Army, the Royal Malaysian Navy (RMN) and the Royal Malaysian Air Force (RMAF). This will ensure that the MAF has the necessary assets, resources and capabilities to defend the nation and its strategic interests against external aggressions, and to support civil authorities in maintaining internal security (Abdul Aziz, 2008; Nasibah, 2008a; Ismail, 2009; Perajurit, 2009a,b; ADJ, 2009; Mahadzir, 2009).

The 4D plan is an extension of the significant development undergone by the MAF since 1933, when the First Dimension plan was started in the era of counter-insurgency warfare (Ismail, 2009; Perajurit, 2009a). The 4D plan covers the period until 2020 and beyond, and focuses on three main features: joint force integration and operations; information superiority, emphasising on network centric operations (NCO); and multi-dimensional operations in the sub-surface, surface, air and information warfare media (Nasibah, 2008a; Perajurit, 2009a; ADJ, 2009; Mahadzir, 2009).

The transformation would be based on the MAF's readiness to strengthen its capabilities through the purchase and development of high-tech equipment and assets (Norshazlina, 2009; ADD, 2009a). The rate of transformation depends heavily on the available budget. The ongoing global economic downturn has significantly affected a number defence procurement projects, with several key procurements being cancelled or deferred, including the replacements of the Sibmas and Condor vehicles (Bernama, 2008a), the procurement of two frigates from BAE Systems (Marhalim, 2009), and the replacements of the NURI helicopters (Bernama, 2008b; Shah, 2008; Muhammad Fuad, 2008a). Furthermore, the MAF's budget for 2010 has been reduced by 20% (Bernama, 2009a, Nasibah, 2010a; Tempur, 2010a). It should be noted the reduction of defence budget in Malaysia bucks the trend of increasing defence budgets among a number of other Asian countries (ADJ, 2008; ADD, 2009a,b; Defence Talk, 2009; Perajurit, 2009c, 2010; Saw, 2010). The MAF is hoping to get most of the 4D MAF plan programmes funded under the 10th Malaysia Plan (RMK10) (2011-2015) (Mahadzir, 2009; Tempur 2009a).

In making full use of limited available resources, the implementation of the 4D plan strongly depends on the requirement to develop defence self-reliance capabilities. The level of self-reliance of a country is measured by its ability to defend its territorial integrity and national sovereignty, using its own resources, without being dependent on foreign assistance. These resources include sufficient infrastructure and highly trained human resources supported by a capable national defence industry with the capacity to provide whole life logistical support to the armed forces (KL Security Review, 2008; Norazman, 2009; Nasibah, 2009a). An obvious key importance of defence self-reliance is that it can reduce the cost of procurement of foreign equipment and assets.

The Malaysian Defence Industry Council (MDIC), formed in August 1999, has played an important coordinating role in developing the national defence industry, which has shown significant progress over the years, moving from carrying out mere maintenance, repair & overhaul (MRO) type of work, to more sophisticated jobs involving design, manufacturing, sub-assemblies and through life support in various sectors, including aerospace, maritime, automotive and information & communications technology (ICT). The industry is beginning to move into high end manufacturing, design and research & development (R&D) activities in defence technology. It contributes to a growing supply of military assault rifles, small calibre ammunitions, aerial reconnaissance vehicles (ARV), patrol vessels, ICT based solutions, and military gear and apparel (Defence Industry Division, 2005; KL Security Review, 2008; Nasibah, 2009a; Bernama, 2010). The recently concluded Langkawi International Maritime and Aerospace Exhibition (LIMA) 2009 saw a significant increase in involvement of local defence companies, taking up 37 per cent of the exhibition space at the Mahsuri International

Exhibition Centre (MIEC) (Bernama, 2009b). In order to further facilitate the development of the national defence industry, it has been proposed that a defence high tech park be built in Sungkai, Perak. The park would emphasise on manufacturing equipment for sensors, imaging and surveillance, defence mobility and tactics, communications, navigation, electronics, survival, and armaments (David, 2009; Nasibah, 2010b).

Nevertheless, the national defence industry has yet to reach the desired capability to enhance indigenous defence capability. A number of challenges stand in the way of accelerating the pace of growth of the defence industry, including lack of critical mass, lack of high capital investment, lack of R&D, rigid specifications, lack of competencies, absence of uniformity, and lack of promotional and marketing activities (Defence Industry Division, 2005; KL Security Review, 2008; Nasibah, 2009a; Muhammad Fuad, 2009a).

Activities in defence science & technology R&D is vital in supporting the development of defence self-reliance capabilities, in particular in the production of equipment and assets that are tailor-made to the requirements of the armed forces (Perajurit, 2009a; Nasibah, 2009a,b; Muhammad Fuad, 2009a; Bennett, 2009; Chuter, 2010). Hence, the Science & Technology Research Institute for Defence (STRIDE), the R&D arm of the Malaysian Defence Ministry, is in the process of planning and prioritizing the key areas of defence R&D that need to be focused on under RMK10. To this effort, two RMK10 R&D Prioritization Workshops have been held, on 20th-21st July and 1st October 2009, where various research proposals were presented, discussed and assessed (Nor Hafizah *et al.*, 2009).

This paper is aimed at conducting a critical assessment of defence R&D fields that are important in supporting the development of the national defence industry. Given the very wide scope of defence R&D, this paper will not provide a concise description of all possible fields. Instead, it will discuss on two important fields of defence R&D where there is much room for development in order to ensure the achievement of the objectives of the 4D plan in terms of operational awareness and mission capability. The fields that will be discussed, determined based on the author's literature review and opinions of the MAF's capabilities and requirements, and current and expected future trends of global defence technology development, are Command, Control, Communications, Computers, Intelligence, Surveillance & Reconnaissance (C4ISR) in support of network centric operations (NCO) and unmanned vehicles (UVs).

2. COMMAND, CONTROL, COMMUNICATIONS, COMPUTERS, INTELLIGENCE, SURVEILLANCE & RECONNAISSANCE (C4ISR) IN SUPPORT OF NETWORK CENTRIC OPERATIONS (NCO)

A significant part of the implementation of 4D MAF plan involves the development of the MAF's C4ISR capabilities. At present, existing C4ISR capabilities are adequate for the MAF to conduct its operations. However, the MAF is in the process of embracing the concept of network centric operations (NCO) (also commonly known as network centric warfare (NCW)) to improve its C4ISR capabilities into a more effective warfighting capability (Nasibah, 2008b; ADJ, 2008, 2009; Perajurit, 2009a,c,d; Mahadzir, 2009).

NCO allows for a robustly networked force to share information by means of secure infrastructure that enables self-synchronization and, ultimately, more effective military operations (Alberts *et al.*, 2000; Alberts, 2002; Moffat, 2003; Alberts & Hayes, 2006; M. Zaki, 2007; CCRP, 2009). The implementation of NCO is based on four tenets: a robustly networked force improves information sharing; information sharing enhances the quality of information and shared situational awareness; shared situational awareness enables collaboration and self-synchronization, and enhances sustainability and speed of command; and these, in turn, dramatically increase mission effectiveness (DOD, 2005; CCRP, 2009).

NCO represents an evolution shift from predecessor levels of command & control (C2), including C3I, C4I, and C4ISR. It is characterized by the ability of geographically dispersed forces to create a high level of shared operational awareness that can be exploited via self-synchronization and other NCO operations to achieve the commanders' mission objectives. It supports speed of command through the conversion of superior information position into action, and has the potential to contribute to the coalescence of the tactical, operational and strategic levels of military operations (Alberts *et al.*, 2000; M. Zaki, 2007). The effective implementation of NCO does not just involve the application of new technologies to the current platforms and organizations. It requires the assimilation of concepts of operation, information infrastructure (infostructure), C2 approaches, organizational forms, doctrines, force structure, and support services into what is known as Mission Capability Package (MCP) (Alberts *et al.*, 2000; M. Zaki, 2007; Muhammad Fuad, 2009b).

While the operational concept of NCO was initially developed for military operations, it has been, directly and indirectly, employed in various commercial areas with great success, such as banking, public transportation coordination and commercial flight ticket booking (Albert & Hayes, 2006; Muhammad Fuad, 2009b). The military implementation of NCO can allow for integrated communications and information sharing between various military assets, for air, sea and land, which employ varying communications platforms and protocols (Figure 1). This will enable effective command and control of all assets, ranging from individual troops and units to the division, battlefield and theatre levels.

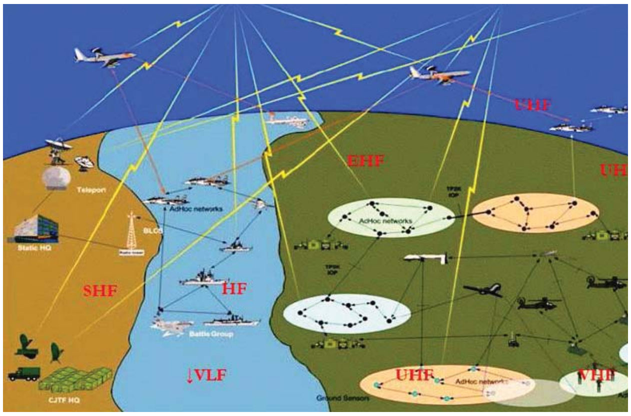

Figure 1: The implementation of NCO can allow for integrated communications and information sharing between various military assets, for air, sea and land, which employ varying communications platforms and protocols. (Source: Isode (2009))

The limitations of the MAF's NCO capabilities were highlighted during the search & rescue (SAR) operation for the downed Bell 206 Long Ranger helicopter, with seven people on board, in the dense jungle regions of Raang Ulu and Pak Pirit, Sarawak (Pravda, 2004). One of the main hurdles faced during the SAR operation, in addition to deep ravines and hostile topography, was the complete lack of communicability between the operation base and the SAR assets. This caused the operation to be conducted in a relatively uncoordinated manner, with the commanding officer unable to have a common operational picture (COP) of operational background, resulting in a period of three weeks for the wreckage to be found. Noticeably, a Sabah Air GAF Nomad N22B low altitude fixed wing aircraft equipped with an AISA airborne hyperspectral imaging system was used during the operation (Kamarulzaman, 2008). However, there was no means for the captured images to be transferred to the other platforms, including the operations base. Instead, the information had to be conveyed orally via conventional voice channels, effectively minimizing the advantages of using the hyperspectral imaging system. At one point during the operation, one of the SAR assets accidently transmitted a false emergency signal, which was misinterpreted as coming from the downed helicopter. All available SAR assets were deployed to the region of the source of the signal. It was only later that this error was discovered, after precious time and resources had been wasted (Muhammad Fuad, 2009b).

Since this incident, the MAF has taken significant steps to improve its NCO capabilities. The Joint Forces Headquarters (JFHQ) in the Subang TUDM Airbase, which is expected to be fully operational in mid-2010, will have high-tech C4ISR technology which will provide effective networking of data and information with other bases in the country. This will allow JFHQ to perform its functions of planning and coordinating all joint and combined operations. This also represents the MAF's first step in the implementation of NCO (Abdul Aziz, 2008; ADJ, 2008, 2009; Perajurit, 2009a,c,d). The MAF is looking to extend it NCO capabilities to effectively provide real-time operational information and picture of the battlefield to assist commanders to make timely and correct decisions, in addition to increasing its ability to project forces over long distances given the national boundaries (ADJ, 2008, 2009; Perajurit, 2009a,c,d; Mahadzir, 2009).

The primary problem in achieving these objectives is the fact the MAF's assets are procured from a number of countries, with significantly varying communications platforms and protocols. The available infostructure and networking capabilities is unable to cope with these varying platforms and protocols, resulting in numerous incidents of incoherent information sharing between MAF assets, such as during the July 2004 SAR operation in Sarawak. Solving this problem would require a high level of system integration of the various platforms and protocols (Nasibah, 2008b; Muhammad Fuad, 2009b).

The implementation of NCO in the MAF is not something that can be done overnight, but rather it will be conducted in phases over a number of years. The first phase is completing the full operability of JFHQ with its C4ISR capabilities. The remaining phases involve development of a database containing the various platforms and protocols of MAF assets, improvement of necessary infostructure and networking capabilities, and development of C4ISR capabilities in MAF bases throughout the country (M. Zaki, 2007; Muhammad Fuad, 2009b; Perajurit, 2009d). However, a stumbling block here is that there remains limited indigenous NCO capabilities, and hence, the MAF is heavily dependent on foreign technology for implementation and maintenance of its NCO systems (Nasibah, 2008a; Tempur, 2008).

The Sapura Group Bhd. has taken significant initiative towards supporting the implementation of NCO in the MAF. Sapura, in collaboration with Nokia Siemens Networks, is involved in developing a solution for integrated secured radio communications, which is being used in Malaysia's Government Integrated Radio Network (GIRN). The system makes use of Siemen's terrestrial trunked radio (TETRA) computer aided dispatcher (TCAD) to bridge the gap between new digital trunked radio systems and analog radio systems which are still employed by Malaysian defence & security forces (Siemens, 2007; The Star, 2009). GIRN is at present being used by 13 government agencies, allowing for a secured unified nationwide voice and data communications network (The Star, 2009).

In addition, at LIMA 2009, Sapura launched a suite of integrated secured communication solutions branded 1Network. The indigenous network can integrate communications, information, resources and assets of various organisations into a unified platform to enable faster and better communications links and operations. This technology solution resulted from the group spending more than RM70 million on R&D for the past 10 years (Bernama, 2009c,d; Sapura, 2009a). Sapura also showcased its integrated command & control and simulation capabilities. Central to this is a flight simulator which can be tailored to the needs of the users. The system provides a "train as you fight" environment through the interoperability of combat aircraft simulators at different locations. It also offers multiple engagement scenarios, enhances mission planning, and can be configured to handle joint missions with other elements of the armed forces (Bernama, 2009d; NST, 2009; Sapura, 2009a).

Systems Consultancy Services Sdn. Bhd. (SCS) has also made promising progress in the development of indigenous NCO technology, through the production of its Mahsuri Integrated Communications System (ICS) and Battlemap Suport System (BSS). The Mahsuri ICS is a communications network that is able to assimilate various platforms and protocols, both analog and digital, on various radio frequency bands, such as HF, UHF and VHF, in addition to GSM and internet protocol telephone systems. It is designed in modular form to suite the requirements of various users, including small, local area networks, and large, wide area networks. BSS is a geospatial intelligence (GEOINT) tool that is able to provide a commander with critical information on battlefield topography, location of troops, assets and equipment, and best route computation. This will enable the commander to make the necessary tactical decisions using real-time tactical layout maps (Tempur, 2008, 2009b).

In addition, SCS has also developed the Maritime Enforcement Management System (MEMS), which is a C4I system developed for the Malaysian Maritime Enforcement Agency (MMEA). It allows for MMEA to have a centralised information network, which is able to integrate all levels of its operations, from its headquarters in Putrajaya to its various state and district offices, and bases and harbours around the country. This has enabled MMEA to have the ability to effectively coordinate its resources, assets and manpower (Tempur, 2008, 2009b).

3. UNMANNNED VEHICLES (UVs)

UVs are vehicles that do not carry any crew, but rather, are operated remotely by human operators, or autonomously via preprogrammed software of robots. UVs are becoming increasingly prevalent; their use has increased exponentially over the last decade for a broad range of tasks including security, hazardous waste cleanup, monitoring of agricultural crops, law enforcement, as well as military operations (Oracle, 2007; Telefunken, 2008; AUVSI, 2010; Tempur, 2010b). UVs can be categorised based on area of operation; air, sea (underwater and surface) and land.

From a military perspective, UVs, which can be recoverable or expendable, are generally used to operate in dangerous or hostile territories, without endangering the operators. It is employed for surveillance & reconnaissance, information collection, detection of mines, and for combat purposes. UVs hold many attractions for the military. They are generally smaller, lighter and cheaper compared to manned vehicles as they do not need equipment to support a crew. UVs can also be used for many hours in a stretch, while switching operators (O' Rourke, 2006; Oracle, 2007; Telefunken, 2008; Writers, 2009; Tempur, 2010b). The importance of UVs is highlighted by their active use in the ongoing wars in Iraq and Afghanistan. The U.S. military had no UGVs, and only a handful of UAVs when it invaded Iraq in 2003. At present, the U.S. military has approximately 7,000 UAVs in operation (more than double the number of manned aircrafts in its arsenal), and more than 12,000 UGVs on the ground in Iraq alone (Stoner, 2009).

3.1 Air: Unmanned Aerial Vehicles (UAVs)

UAVs are evolving rapidly to emerge as indispensible military assets. The increasing demand and reliance on UAVs in warfighting and peacekeeping has increased the pace of UAV-related R&D in recent years (Wong & Victor, 2009; M. Hanif, 2009; Tempur, 2010c,d,e). Equipped with more capabilities, UAVs are able to play greater roles in critical missions. The development of UAVs do not just involve construction of the aircrafts themselves, but also the systems that are required to operate the UAVs, including ground stations and communications links (Figure 2). Therefore, the U.S. military has begun to usec term Unmanned

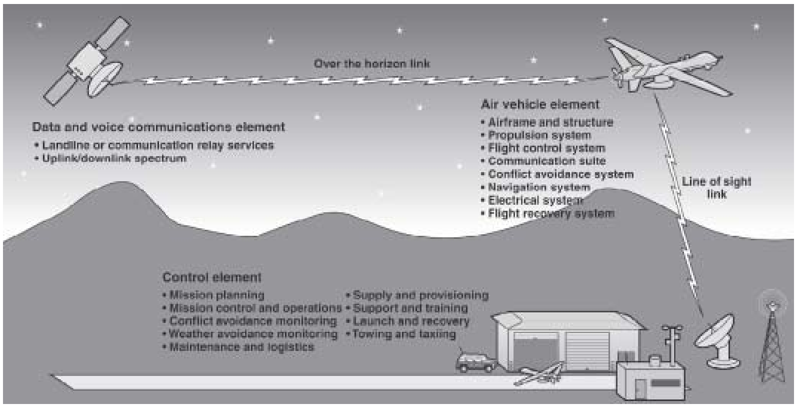

Figure 2: Elements of a UAV system.
(Source: GAO (2008))

Aircraft Systems (UAS) (DOD, 2007; GAO, 2009; The UAV, 2009). UAVs typically fall into one of six functional categories; target & decoy, reconnaissance, combat, logistics, R&D, and civil & commercial (although multi-role airframe platforms are becoming more prevalent). They can also be classified in terms of altitude and range (Defence Update, 2006; Global Security, 2008; The UAV, 2009).

UAVs are important for the MAF as they provide a cost effective platform to conduct surveillance operations (Bernama, 2009e). Malaysian development of UAVs (Figure 3) over the past decade has been dominated by two companies, Unmanned Systems Technology Sdn. Bhd. (UST), a subsidiary of Composites Technology Research Malaysia Sdn. Bhd. (CTRM), and Sapura (Defence Review Asia, 2009).

UST's Aludra Mk2 is currently being tested by the MAF as part of the *Ops Pasir* surveillance operation off the resort islands of Pandanan and Sipadan, Sabah (Bernama, 2009f,g; Suleiman, 2009; Tempur, 2010a,c). As it is still being tested, the government has no intention to procure it yet (Bernama, 2009e). An alternative version of the Aludra Mk2 is currently being developed for deployment from ship decks. UST has also developed a handheld UAV, known as the Aludra SR-08, for in-field deployment (Tempur, 2010c).

In addition, UST has produced a Medium Altitude Long Endurance (MALE) UAV, known as Yabhon Aludra, which was developed jointly with Adcom System from Abu Dhabi, United Arab Emirates (UAE). It took UST and Adcom eight years to develop the Yabhon Aludra from the initial design stage to flight testing and production. It is capable of carrying up to 50 kg of payload, including special-use sensors, thermal imagers, infrared sensors, laser designators, range finders and electro-optical sensors (Bernama, 2009h; Tempur, 2010c).

In mid-2009, UST signed a memorandum of understanding with Selex Galileo for support in the development of UAV sensor and control systems. This collaboration will allow UST to receive technologies and expertise developed by Selex through the production of the Falco UAV, a proven UAV system employed in Afghanistan (Tempur, 2010c).

Sapura, with its Perth-based subsidiary, Cyber Technology, developed the Cyber Eye II (fixed wing) Cyber Shark (helicopter) and Cyber Quad (micro vertical take off and landing (VTOL)) UAVs (The Star, 2007; Tempur, 2010c), which it is trying to market to foreign customers (Bernama, 2008, 2009i; The Star, 2009; Defence Studies, 2009). Sapura is also collaborating with Universiti Sains Malaysia (USM) on R&D in UAV systems, in addition to other defence technology fields, including radio frequency design, artificial intelligence, and communications and electronic warfare (Bernama, 2009j).

SCS, in collaboration with USM and Dian Kreatif Sdn. Bhd., developed the Nyamok UAV, one of the first Malaysan UAVs. SCS has also a produced a handheld UAV, known as Agas (Tempur, 2008, 2009b). Despite its relatively short endurance time (30 minutes), it was reported that the Agas UAV was being considered for as a surveillance & reconnaissance tool for the *Ops Fajar* operation in the Gulf of Aden, in addition to the Fennec and Super Lynx helicopters. This was due to the fact that the Agas UAV is easy and quick to launch, by hand or using a bungee (KL Security Review, 2009)

Name: Aludra Mk2
Altitude: 3,700 m
Endurance: 6 hours
Range: 150 km

Name: Yabhon Aludra
Altitude: 4,500 m
Endurance: 30 hours
Range: 500 km

Name: Aludra SR-08
Altitude: 4,000m
Endurance: 100 minutes
Range: 15 km

Name: Cyber Eye II
Altitude: 4,000 m
Endurance: 10 hours
Range: 150 km

Name: Cyber Quad
Altitude: 1,000 m
Endurance: 40 minutes
Range: 1 km

Name: Agas
Altitude: 900 m
Endurance: 30 minutes
Range: 5 km

Figure 3: Malaysian made UAVs.
(Adapted from Military Photos (2009))

3.2 Sea (Underwater): Unmanned Underwater Vehicles (UUVs)

UUVs can be divided into two categories; autonomous unmanned vehicles (AUVs), and non-autonomous remotely operated vehicles (ROVs), which are controlled via a tether that carries electrical power, video and data signals back and forth between the operator and the vehicle (Wernli, 2001; DON, 2004). Both AUVs and ROVs can be classified into various categories, as discussed in DON (2004) and ROVeXchange (2004).

Primary military applications of UUVs are mine detection, search & salvage and repair operations, and anti-submarine warfare, to detect manned submarines (Wernli, 2001; Fletcher & Wernli, 2003; DON, 2004; Mohammad Fuad, 2008b; Mohd. Zahari, 2009). UUVs can be equipped with various sensors, including sonar, magnetometer, infrared, radar and laser detectors, and weapons, including guns, depth chargers, anti-submarine mortars and rockets, torpedoes an missiles, and smart mines (DON, 2004; Mohd. Zahari, 2009). The RMN's unmanned underwater capabilities are limited to foreign UUVs, including the Bluefin-12 AUV, the Atlas Maridan Sea Otter AUV and the BVT Stealth Talisman ROV (Mohd. Zahari, 2009).

SapuraCrest Petroleum Berhad, a subsdiary of Sapura, in collaboration with Total Marine Technology Pty Ltd. (Australia), has developed a number of ROVs for deep sea drilling, including NOMAD, NAVIGATOR, SEAEYE and TYPHOON (Sapura, 2009b). TYPHOON, the latest ROV developed through this collaboration, has a modular design, and can be adapted for military applications (Sapura, 2009c).

In addition, to facilitate progress in this area, the National Underwater Research Network (NURN) was formed. Consisting of members from local agencies, institutes and industries, and the RMN, NURN provides a platform for collaboration in R&D on UUVs and related underwater technologies (NURN, 2009).

3.3 Sea (Surface): Unmanned Surface Vehicles (USVs)

With the advent of maritime and port security technologies, the use of USVs is gradually replacing small patrol boats. The primary advantage of USVs is that they eliminate risks to personnel and assets, in addition to having the ability to perform comprehensive maritime intelligence gathering and surveillance & reconnaissance tasks. When equipped with weapons, USVs could also be used to intercept and engage threats effectively. Primary areas of applications of USVs, which can be human operated or autonomous, are mine countermeasures (MCM), anti-submarine warfare (ASW), surface warfare (SUW), special operation forces (SOF) support, and maritime interdiction operations (MIO) support (DON, 2007; Perajurit, 2009e; Yusni, 2009). USVs can be categorised based on craft type, and on size and type (DON, 2007).

At present, neither the RMN nor MMEA operate any USVs. Nevertheless, with increasing awareness of vulnerability of ports and harbours to terrorist attacks, USVs are a necessary asset for effective maritime surveillance and defence. This is an area where the national defence industry is unprepared, and much collaborative R&D is required before locally made USVs can be produced.

3.4 Land: Unmanned Ground Vehicles (UGVs)

UGVs are generally capable of operating outdoors and over a wide variety of terrains, functioning in place of military personnel. Among their key applications include surveillance & reconnaissance, transportation of equipment and resources through hostile terrain, and to detect and diffuse explosives and bombs. There are also armed UGVs designed for combat, known as unmanned combat ground vehicles (UCGVs) (CAUGVT, 2002; RSJPO, 2009; Grabianowski, 2009; Tempur, 2010f). UGVs can be categorised based on their size (Global Security, 2005), or on their capability classes (CAUGVT, 2002). As shown in Figure 4, there are a number of areas of technology which are involved in the development of UGVs, along with autonomous behaviour.

In Iraq and Afghanistan, there are at least 22 different UGVs in operation. While their initial application was to counter improvised explosive devices (IEDs), the first UGCV, the Special Weapons Observation Remote Direct-Action System (SWORDS), was deployed in May 2007 (Stoner, 2009). It is expected that more UGVs and UGCVs will be deployed in order to reduce the death toll among security forces (Stoner, 2009; Writers, 2009).

The Malaysian Army has yet to employ UGVs in it operations. However, future operational requirements will require the procurement of UGVs for applications such as search & rescue and surveillance & reconnaissance in difficult topography. This area represents another field where active R&D is needed for the development of indigenous UGVs.

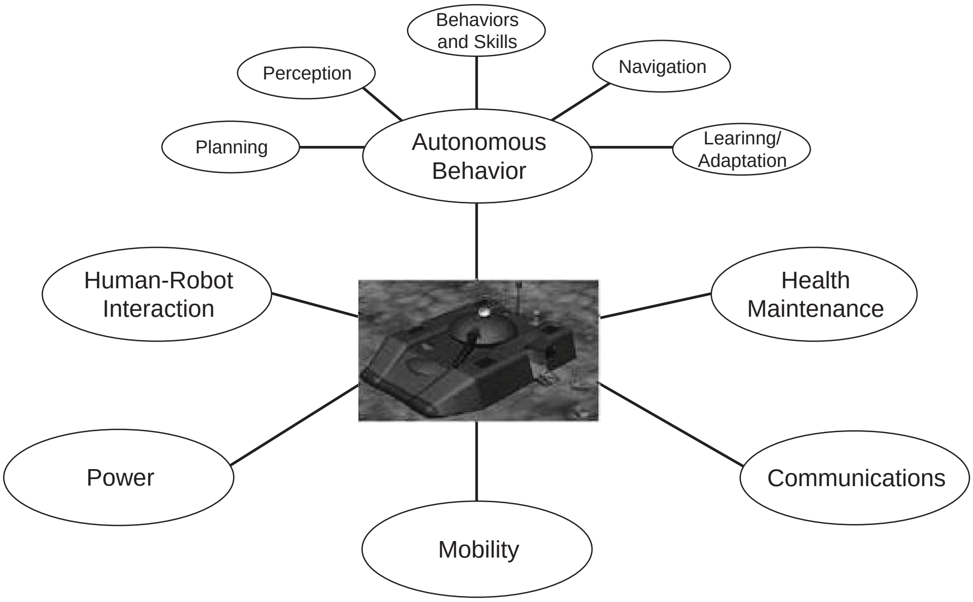

Figure 4: Areas of technology required for the development of UGVs and autonomous behaviour. (adapted from CAUGVT (2002))

5. CONCLUSION

On the whole, the overall capabilities of the national defence industry to produce indigenous equipment and assets that meet the operational awareness and mission capability requirements of the 4D MAF plan in the two fields of defence R&D discussed in this paper, C4ISR in support of network centric operations (NCO) and unmanned vehicles (UVs), are still relatively limited. Nevertheless, significant progress has been, and is being, made through collaborations with relevant agencies, institutes and industries, both local and foreign. Active participation in defence R&D, in these two fields, in addition to other fields of defence technology, including vehicle & aerospace engineering challenges, emergent naval technology, smart weapons, personnel protection & performance, and biological, nuclear & chemical terrorism countermeasures, is required to further catalyze the development of the national defence industry.

To this end, STRIDE should play a leading role in determining how the nation's limited defence R&D resources should be best utilised to cater for the present and future requirements of the MAF and the other defence & security agencies, in particular through smart technical cooperations and collaborations with the relevant local agencies, institutes and industries. The prioritization of defence R&D projects to be pursued under RMK10 should be geared towards increasing the nation's level of defence self-reliance in order to support the objectives of the 4D plan.

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PRELIMINARY GROUND RAIN TEST ON ALUDRA UAV

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ABSTRACT

The operation of unmanned aerial vehicles (UAVs) in raining conditions has raised serious concerns due to the level of safety and impact on UAV structure. In normal weather, a UAV can be used with minimum risk since wind and temperature effects are already taken into account. However, to fly in raining condition, on-ground analysis has to be done to investigate if the UAV will experience any physical deterioration caused by the water splash effect representing raining conditions. This project started with the design of a cubical shaped frame that will occupy the whole subject's structure, i.e. ALUDRA UAV. A few locations on the frame have been pre-determined as the water splash points which include top and bottom positions. The rate of water splash has been set up to resemble the real effect of rain. Clear view on what type of problems that may occur when a UAV is being exposed to high speed water flow are expected from this test.

Keywords: *Rain test; ALUDRA Unmanned Aerial Vehicle (UAV); Erosion; Water Leakage.*

1. INTRODUCTION

Since year 2007, a number of UAV flight tests have been done through collaboration project between STRIDE and a local research company named Composites Technology Research Malaysia (CTRM) Sdn. Bhd. Normally, these flight test activities are only done during sunny or very light rain conditions. Apart from avoiding the risk of flying in heavy rain, concerns on the physical effect and performance of unmanned aerial vehicles (UAVs) are the main factors in the decision making of test activities. Several evidence of water existence trapped inside the fuselage have been found during the testing, hence leads Aeronautical Branch to develop a ground rain test system investigating scenario of rain impact on UAV systems. From another point of study, rain erosion caused by high-velocity flights in raining conditions could also caused complication to the UAV structures (Hogg, 2001).

Not many evidence were found on rain impact on UAVs around the world. However, the nearest incident was from a Glasair single-engine plane that crashed near Irvinestown, Northern Ireland in July 2009 due to engine failure. According to the pilot, significant amounts of water was found in the tested fuel sample obtained from the header tank of the plane. The aircraft was believed to be parked outside at Glasgow Prestwick Airport for several days in moderate rain and eventually water had entered both its fuel tanks (The Impartial Reporter, 2010).

Previous researchers have built a number of rain test facilities ranging from small scale to as large as the ones that are capable to simulate rain on fighter planes. In Korea for example, Korea Aerospace Industries Ltd (KAI) has its own in-door rain test facility which was successfully employed for the ground test of a T-50 Jet Trainer, as shown in Figure 1. The objective was to verify that the T-50 aircraft is capable of operating after exposure to a maximum rain condition (KAI Structural Test Lab, 2010).

Figure 1: Rain test done on a T-50 aircraft
(Source: KAI Structural Test Lab, 2010)

The United Kingdom Defence Evaluation and Research Agency (DERA) has designed a special rain rig testing facility which is capable of doing some pre-tests on materials used for components before being installed into service, hence avoiding unexpected faults that may occur later on. They had created a whirling arm-type rig where a water jet will impinge onto a spinning disc to produce droplets. The droplets, combined with high-velocity effect, resembles rain conditions in high flight speed could cause significant destructive impact on surfaces (Hogg, 2001).

The development of rain test facility has been proposed to investigate the effect of rain on an ALUDRA UAV. All the standard and procedure used in this project is based on DOD (2000). This study is aimed at evaluating:-

a) Materials that are likely to be exposed to rain/water spray/dripping water during operation;

b) Effectiveness of protector;

c) Capability of materials to satisfy performance during/after exposure;

d) Physical deterioration caused by rain.

2. RAIN-RELATED TEST PROCEDURES

According to DOD (2000), there are various types of rain tests, such as dripping, raining (blowing rain), jetting (water tightness) and immersion. While the first three procedures represent actual application of water spread to the subject under inspection, an immersion test is conducted by placing the material tested underneath significant amount of water.

Of the three water spread test types mentioned above, the raining test is more applicable for material which will be deployed out-doors, unprotected from rain. This testing procedure will be accompanied with wind velocity. Consideration will be given for the jetting test when large subject materials are involved for which blowing-rain facilities are not practical. This test is not intended to simulate natural rainfall, but will provide a high degree of confidence in the water tightness of material. The dripping test is usually done on materials that are protected from rain but may be exposed to falling water from condensation or leakage from upper surfaces.

The jetting test was chosen due to the suitable setting. However, extra caution needs to be made to ensure the overlapping pattern of the water spread and droplet is as close as possible to the test item, to avoid air stream break up. Before initiating the test procedure, rainfall rate and nozzle spray pattern have to be verified first (DOD, 2000).

3. WATER FLOW RATE & RAIN CATEGORY

In order to produce water spread that is similar to real situations, one needs a basic knowledge of standard rainfall rate representing various types of rain condition. Table 1 shows rain categories classified according to the rate of precipitation.

In the preliminary stage, this project will focus on simulating light and moderate rain conditions. The objective is to investigate if there is any leakage on the UAV structure. If there is any, the necessary modifications will be made immediately. These processes will be repeated until acceptable operational conditions are achieved.

Table 1: Classified rain categories
(Source: Pall Corporation, 2010)

No.	Rain Type	Precipitation Rate (mm/hr)
1.	Very light rain	< 0.25
2.	Light rain	0.25 – 1.0
3.	Moderate rain	1.0 – 4.0
4.	Heavy rain	4.0 – 16.0
5.	Very heavy rain	16.0 – 50.0
6.	Extreme rain	> 50.0

4. METHODOLOGY

The technical drawing of the test frame is as shown in Figure 2. The dimensions of the frame were configured so that it could occupy the whole UAV structure. The locations of the nozzles were determined in such a way that the spray produced will have an overlapping pattern onto the top and bottom area of the structure's surface. Each nozzle should cover at least 0.56 m^2 (6 ft^2) of surface area (DOD, 2000). The setting up of water flow is done such that it resembles several types of rain.

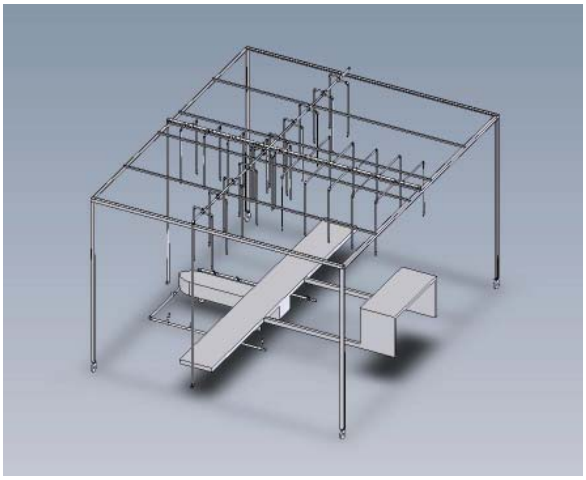

Figure 2: Technical drawing of the test frame

As shown in Figure 3, the UAV was tested without its outer wing and tail boom sections. This is because in the initial stage, the focus is solely on the expected spots of gaps and holes in the fuselage and wing parts that are suspected to cause leakage. In the future, the complete set of the UAV needs to be examined carefully since there are actuators installed within the outer wing parts.

Figure 3: Rain test being conducted on the UAV

5. FINDINGS

Under static movement with the addition of raining effect, the UAV experienced an impact from the water splash equivalent to light and moderate raining conditions. After several test sessions, it was found that some leaking did occur mainly in the fuselage body, as shown in Figure 4. This raises concerns due to the fact that the leakage might affect the safety of electronic devices installed inside the compartment area, as well as status of aerodynamic characteristics since water leakage represents air leakage criteria (Unmanned System Technology, 2009).

Thorough inspection on the UAV concluded that screw holes are the main cause of the leakage. Even after a few modifications were made by sealing the affected parts, water still managed to flow through. The gaps between covers and the fuselage body due to the manufacturing process also contribute to water leakage inside the chamber. Wet sheets have been placed in between the gap to act as a stopper for the water flow, hence minimizing amount of leakage.

Figure 4: Water leakage found inside the fuselage

Even though the described rain test facility was built to suit the ALUDRA UAV, any sizes of requested subjects under investigation can also be tested with some modifications on the test frame. Ground rain test not only helps in making pre-investigation of any concerned subjects before being allowed to operate in raining situations, it also allows any modification or improvisation to be made on the system.

Another main concern of rain effect on the structure is erosion. The impact of water splashes with high speed flow could create damage to the surface especially at the forward-facing sections of an aircraft. DERA has worked on evaluating rain erosion effect since 1950's and it comes to a conclusion that pressure generated from high-velocity water droplet impact could cause stresses, hence creating cracking in brittle materials and deformation in more ductile materials (Hogg, 2001). Therefore, it becomes a must to do material inspection of the surface after completing rain test sessions to ensure remedial action is taken before the materials fail.

6. FUTURE WORK

In this preliminary ground test, investigation was done on ALUDRA UAV to observe the severity of leakage under light and moderate raining situations. After several test sessions, screw holes and structural gaps between connecting body parts have been determined as the main contributors to the leakage problem. Hence proper modification and improvisation on the structure are required to ensure that the percentage of water seeping through body structures is minimized. It is also recommended that further examinations be done on the exposed surface to see if there is any significant impact of water splashes that may cause erosion.

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CATCH OF THE NET

Unmanned vehicles (UVs) are vehicles that do not carry any crew, but rather, are operated remotely by human operators, or autonomously via preprogrammed softwares or robots. UVs are becoming increasingly prevalent; their use has increased exponentially over the last decade for a broad range of tasks including security, hazardous waste cleanup, monitoring of agricultural crops, law enforcement, as well as military operations. UVs can be categorised based on area of operation; air, sea (underwater and surface) and land. From a military perspective, UVs, which can be recoverable or expendable, are generally used to operate in dangerous or hostile territories, without endangering the operators. It is employed for surveillance & reconnaissance, information collection, detection of mines, and for combat purposes. UVs hold many attractions for the military. They are generally smaller, lighter and cheaper compared to manned vehicles as they do not need equipment to support a crew. UVs can also be used for many hours in a stretch, while switching operators. Unmanned ground vehicles (UGVs) are generally capable of operating outdoors and over a wide variety of terrains, functioning in place of military personnel. Among their key applications include surveillance & reconnaissance, transportation of equipment and resources through hostile terrain, and to detect and diffuse explosives and bombs. There are also armed UGVs designed for combat, known as unmanned combat ground vehicles (UCGVs). The following are relatively interesting and useful websites on UGVs:

1) **Association for Unmanned Vehicle Systems International: Online Guide to Unmanned Systems**
   http://guide.auvsi.org/

   A comprehensive database of air, ground and maritime systems with detailed information on hundreds of existing technologies from around the world.

2) **UVOnline.com**
   http://www.shephard.co.uk/news/category/1/uvonline-com/

   An online news portal aimed at providing in-depth and up-to-date coverage of technology developments, news, procurement data and civil/commercial market opportunities.

3) **GlobalSecurity.org: Military Robots / Unmanned Ground Vehicles (UGVs)**
   http://www.globalsecurity.org/military/systems/ground/ugv.htm

   Provides of categorisation of UGVs.

4) **Technology Development for Army Unmanned Ground Vehicles**
   http://cart.nap.edu/cart/deliver.cgi?&record_id=10592

   Discusses UGV operational requirements, current development efforts, and technology integration and roadmaps to the future.

5) **How Stuff Works: How Military Robots Works?**
   http://science.howstuffworks.com/military-robot.htm

   Provided a tutorial on the operation of unmanned military robotic systems.

6) **Robotic Systems Joint Project Office (RSJPO)**
   http://www.rsjpo.army.mil

   RSJPO manages the development, acquisition, testing, systems integration, product improvement, and fielding of robotic systems for the U.S. Army and Marine Corps.

7) **Carnegie Mellon Robotics Institute: Unmanned Vehicle Design**

   http://www.rec.ri.cmu.edu/projects/unmanned/index.htm

8) **Sandia: Intelligent Systems and Robotics Center (ISRC)**
   http://www.sandia.gov/isrc/Roboticvehicles.html

9) **Southwest Research Institute (SwRI): Unmanned Ground Vehicles**
   http://www.swri.edu/4org/d09/avionics/ugv/default.htm

10) **Royal Military Academy: Unmanned Ground Vehicle Center (UGVC)**
    http://mecatron.rma.ac.be/index.htm

    Research institutes working on the development of macro-sized, teleoperated to autonomous, vehicles for military applications, with the focus being on extreme mobility and dexterous mobile manipulation.