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# COMPOSITE RUBBER TRACK (CRT) FOR ROBOTIC & AUTONOMOUS SYSTEMS (RAS)

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## ABSTRACT

*Militaries worldwide are increasing their Research and Development (R&D) into RAS. Within the next 10 – 15 years RAS will play an active part in operations as the future battlefield becomes more complex. CRT technology can significantly reduce platform weight, fuel consumption, noise and vibration levels[1][2][3]. Armies and vehicle manufacturers have initiated a series of independent trials that confirmed the benefits and reliability of CRT on a tracked military vehicle. With the increase in RAS technologies comes a desire to utilize the proven benefits identified from manned platforms. The author's objective is to highlight the findings of these trials[1][2][3] and provide substantiated data on how CRT technology can benefit RAS in terms of weight saving, whilst reducing maintenance and vibration.*

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## 1. INTRODUCTION

Maintaining capability overmatch into the future will require reliable advanced technologies. The integration of RAS will help US forces to achieve this. Robotic Combat Vehicle (RCV) operations will require leaders to consider the limitations and operational benefits of RAS.

The benefits (improved buoyancy, reduced fuel consumption, increased vehicle range, noise and vibration reductions aiding "silent watch/silent operation", weight reduction, better Mobility Index) of Soucy's CRT[1] already widely understood on manned platforms, become even more critical in meeting RAS capability objectives[4]:

- Increase situational awareness through a common operating picture (COP)
- Lighten the Soldiers' physical and cognitive workloads
- Sustain the force with increased distribution, throughput, and efficiency
- Facilitate movement and maneuver and increase force protection

Meeting these objectives will not be easy unless leaders understand RAS constraints and the benefits CRT delivers in support of the RAS capabilities.

Approved for public release

'Global Strategic Trends'[5] states that 'Automated Combat Systems' are likely to be developed along two different paths: high-end, multi-role, seeking to emulate and potentially replace high-end manned systems; and low-end systems that are highly specialised and limited to one or two missions'. In all instances these systems will be highly technical and come at a premium price tag.

CRT directly increases availability while contributing to RAS survivability through noise reduction/stealh.

## 2. MAINTENANCE

### *2.1. CRT reduced vehicle maintenance*

RAS capabilities will allow US forces to project combat power in multi-domain operations across land-maritime domains. Initially in unmanned insertion, teamed with optionally manned or fully manned systems equipped to expand the battle space.

In order to **lighten the physical workload**, warfighter's need not be burdened with the additional maintenance of accompanying RAS systems - RAS system availability is critical, and importantly manpower to support RAS maintenance is spread across multiple platforms. A reduction in combat power due to the maintenance burden associated with Steel Track (ST) (changing track pads, early road wheel assembly wear etc.) is challenging in austere conditions and can reduce availability of critical RAS enablers.

A 5000km trial on the UK's Warrior vehicle[1] also showed the significant weight saving of CRT (50%), reduced the engine workload and increased the operational range of the platform by 25% due to fuel efficiencies, further increasing platform availability.

CRTs reduced maintenance and extended reach not only ensures increased RAS availability, but it allows warfighter freedom of action, with increased ability to reach a position of advantage based on predicted maintenance requirements not burdened with Mean Time Before Failure (MTBF) rates associated with ST systems.

### *2.2. CRT supporting components optimized for lower maintenance requirements*

RAS systems will be complex, potentially with innovative power trains and hybrid electric drives, requiring skilled maintainers for even the simplest of tasks. Wheel assemblies and the hardware that accompanies CRT (sprockets, road wheels, idler, tensioners and support rollers) are designed to enhance reliability of the track system (See Fig1). The maintenance free characteristics of CRT ensures RAS systems stay 'on task' longer, reducing the need for human support and therefore aiding to **lighten the physical workload.**

**Fig 1 - A complete CRT system**

## 3. VIBRATION

### *3.1. CRT reduce vehicle vibration / shock*

RAS will carry sophisticated mission modules which will allow for persistent surveillance, the development of a COP and increase stand-off, ideally operating where manned systems cannot. These highly sensitive systems, though ruggedized, will be sensitive to shock and vibration. CRT reduces vibration by up to 75%[3] thereby contributing to **Increased situational awareness.**

Figure 2 & 3 show the overall results and mean reduction of vibration recorded during the WARRIOR AV trials in the UK. Source: NPRIME.

### Shock response spectrum comparison

Shock response analysis – rubber tracks in blue, steel in red. Frequencies are shown from 5 Hz - 2000 Hz.
Notes:

- Unit used is g = 9.81 m/s$^2$
- X, Y and Z axes orientation with respect to vehicle of interest (valid for all graphs of this paper):
  - X is moving forward / back
  - Y is left/ right
  - Z is vertical axis

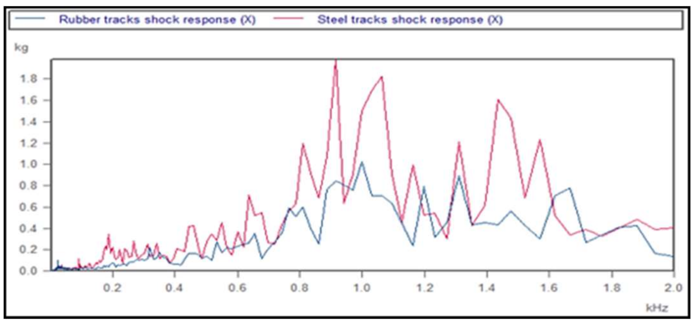



**Fig 2 - Shock response analysis X**

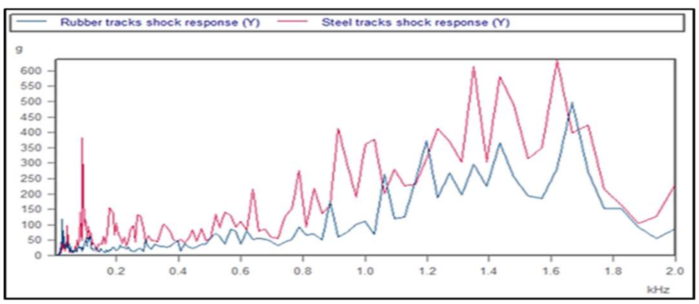



**Fig 3 - Shock response analysis Y**

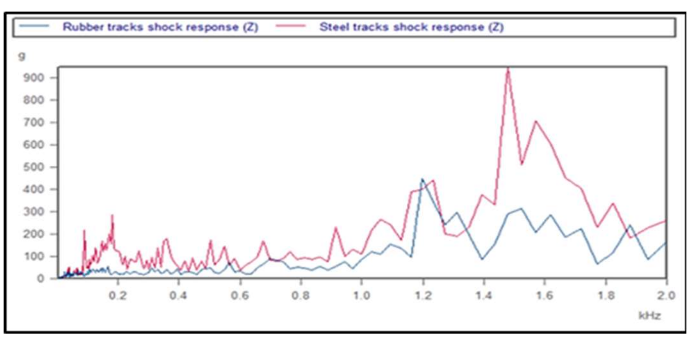



**Fig 4 - shock response analysis Z**

Figures 2 to 4 shows CRT transfers less vibration to the electrical equipment and ammunition compared to ST across a spectrum of platform configurations. Less vibration reduces early failure, increases reliability, further reducing logistical effort. For platforms with armament / decisive lethality, ammunition can be stored for longer periods on the platform before failing or becoming inaccurate. By reducing or removing the need for direct human support, you **Protect the force** by reducing the sustainment burden through reducing vibration, the RAS remains combat effective longer.

## *3.2. Enhancing on-board Electric and Electronics*

### Effect of Vibration on Electrical Component in Tracked Vehicle

The future RAS Strategy is to control multiple RAS from one or more controllers, assuming small RAS systems will function as larger complex platforms and be subjected to the same constraints, vibration is one of the most important parameters when considering survivability, life of electronics and system availability. Reducing the vibration is paramount in improving RAS availability by enhancing component life. Considering that there will be a considerable amount of Printed Circuit Boards (PCBs) in RAS, it is important to understand the benefits of reducing vibration and how this would influence the life of the component and reduce the maintenance burden.

Using the modularity concept, the NGCV CFT will develop a platform capable of integration of technology from different warfighting functions to enable non-maneuver formations.

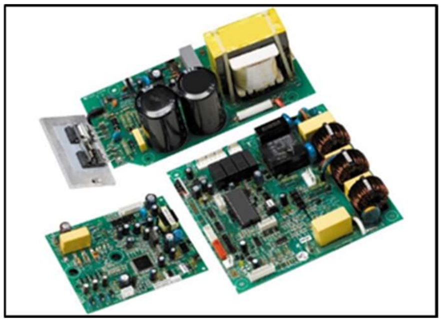


**Fig 5 - PCB illustration**

The life of a PCB and its components are determined in the same way as other materials and is a characteristic of Youngs Modules. The life of the board is also a component of the components applied to that board, these can be capacitors, chips, resistors, LEDs and transistors.

When considering component life and the consequences of vibration, one needs to consider the mass elastic system and the consequences of vibration on this system. A capacitor can be a large component sitting on the board and can react to vibration badly.

Once it fails this will render the system inoperable – one system failure can be critical to the entire RAS.

In order to understand certain parameters affecting the fatigue life of the electronic components sensitivity (parametric) analysis should be performed. The Figure 6 below represents the general overview of the parameters which have direct effect on the fatigue lives of the electronic components mounted on the PCBs.

Fig 6 shows the factors influencing the component life capability. “n” stands for the applied number of stress cycles and “N” is the number of cycles to failure at the stress level “S” in the S-N curve.

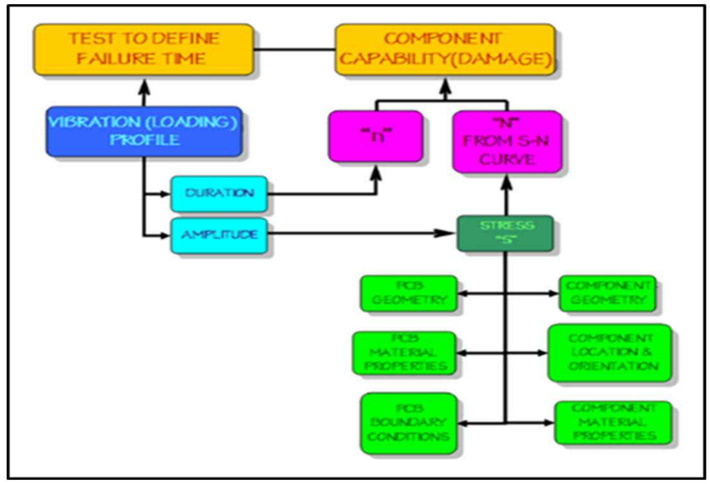
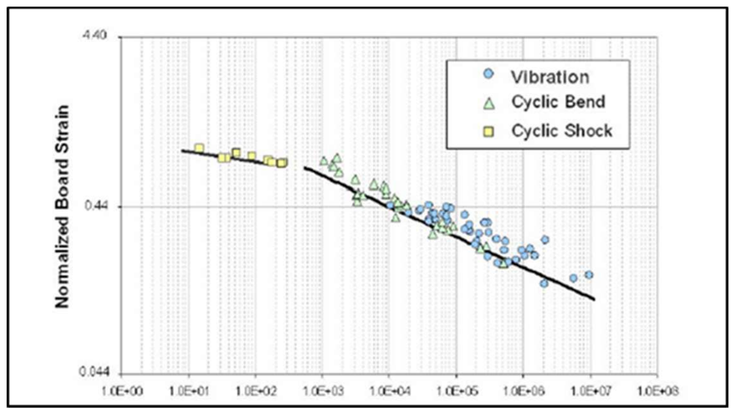



**Fig 6 - Diagram of factors influencing component life [6]**

A strain versus number of cycles, better known as SN curve, for a solder system is shown in Fig 7 below:




Normalized # cycles to failure

**Fig 7 - Mechanical fatigue curves of SnAgCu Solder system [7]**

When a PCB is exposed to vibration it deflects, this deflection is relative to the magnitude of the vibration and can be evaluated by double integrating the vibration. This will generate a subsequent stress in the board. The board itself rarely fails due to this deflection as they are designed to be resistant to it but what does occur is that the components mounted on the board and the solder joins fail. The most common is for the solder join to fail due to cyclic fatigue.

## Correlation between the vibratory components for traditional metal tracks and CRT

Over a period of 3 months testing was carried out on a vehicle with ST and with CRT[1]. The testing was conducted over the exact same profile with the vehicles in the same conditions, the same designated drivers and crew, the same weather conditions and the same equipment. Therefore, the only variable was the tracks.

The following graphs show vibration level measured by an accelerometer in X, Y and Z with both types of tracks. These graphs which are all presented on the same axis, and have been measured on the same vehicle, on the same ground. So, they are directly comparable, understanding that blue is low level of vibration and red is higher.

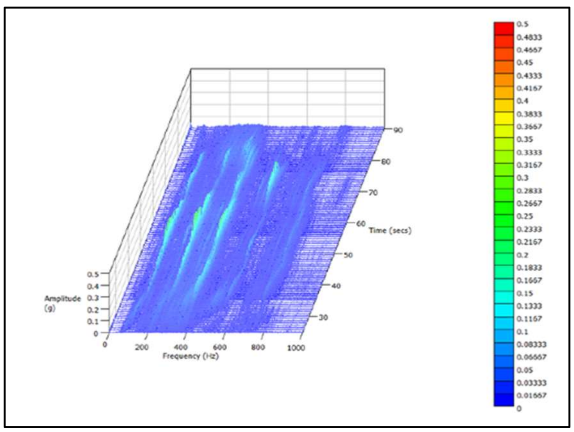



**Fig 8 - CRT Accelerometer X**

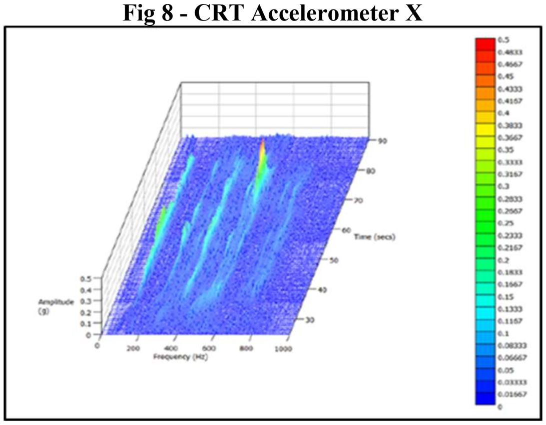



**Fig 9 - CRT Accelerometer Y**

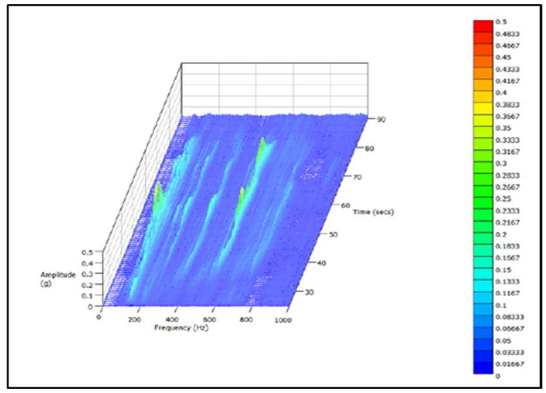



**Fig 10 - CRT Accelerometer Z**

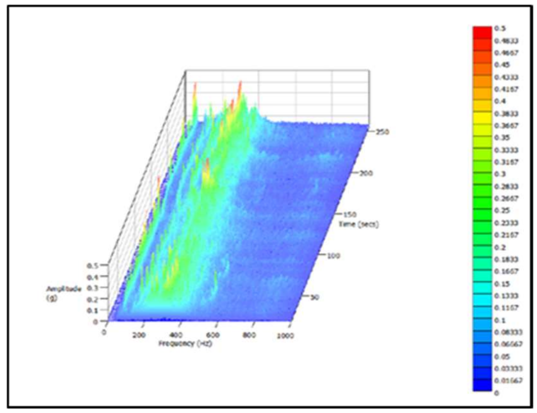



**Fig 11 - ST Accelerometer X**

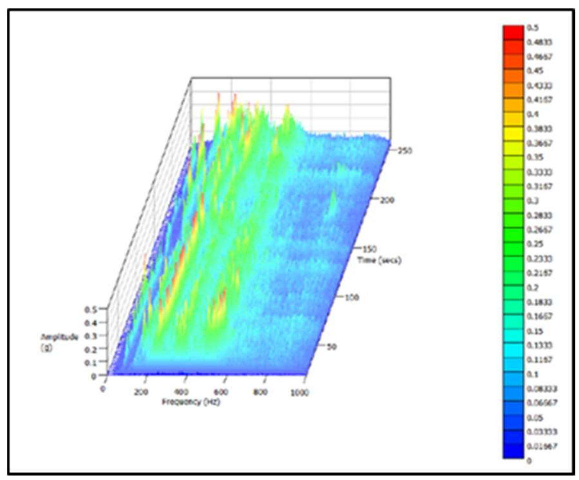



**Fig 12 - ST Accelerometer Y**

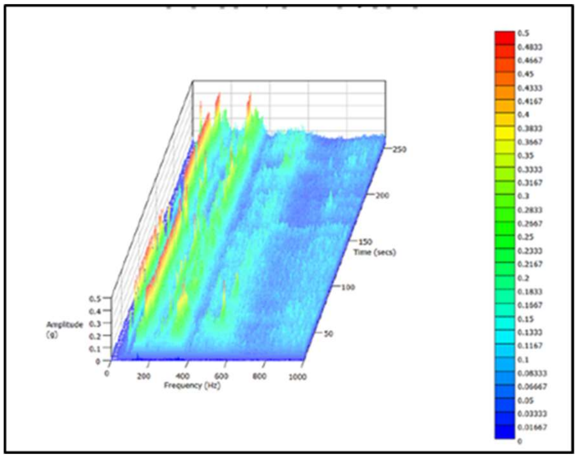


**Fig 13 - ST Accelerometer Z**
**Source: Nprime Ltd**

When we look at the waterfall plots, one must consider the frequency and amplitude of the vibratory component. To evaluate displacement from acceleration we double integrate acceleration in $m/s^2$ and this results in meters displacement. In synopsis, **low frequency high amplitude vibration is more damaging** than high frequency low amplitude even though they could have the same RMS. High displacement will lead to high strain on the electronic components. It is evident from the waterfall plots presented of the three orthogonal planes of an accelerometer on an electronic component, that there is a lot more vibration on ST against that of CRT. From the evidence provided it can be concluded that there is less vibration, less displacement and therefore less strain on the electronics within a CRT vehicle compared with a ST vehicle.

### *3.3. Detection*

The UK Warrior trial of 2017[1] reported a reduction in noise of 9dB from CRT to ST equating to 8 times sound level reduction (3dB double/divide sound level). This reduction in noise emissions would significantly benefit RAS platforms utilized in reconnaissance, surveillance and target acquisition missions. Noise reduction also has significant impact to the Optionally Manned Fighting Vehicle (OMFV) as ST noise can have a negative effect on both human health and performance.

### *3.4. Less ammunition powder compaction*

OME (Ordnance, Munitions and Explosives) testing is carried to find the harshness of vibrations experienced on locations of the vehicle where munitions are stored and evaluated against the environmental standard. The defense standard used is DEF STAN 00-035 which states “The distinguishing characteristics of tracked vehicle vibrations are a broadband random vibration spectrum onto which is superimposed a series of harmonically related narrow bands. These narrow bands are primarily generated by interaction of the vehicle’s track pads with the traversed surface”.

The analysis focuses on extracting the track patter vibration from the overall vibration signal. The frequency of the track patter can be calculated as it is function of the vehicle speed. With the frequencies of track patter and related harmonics being known, these vibration signals can be extracted from the background signal and further analysis can be done in accordance with DEF STAN 00-035 part 5 issue 5. This extraction is done from analyzing vibration signals at discrete vehicle speeds with a given tolerance of 0.5 KPH.

**ST vibration recording**

Waterfall plot of vibration on ammunition rack. The plot represents the Z-axis of the accelerometer. The diagonal lines illustrate the track patter frequencies and related harmonics.

From the evidence provided for a ST installation the frequency and amplitude content are way more significant than it was measured on a CRT installation. The waterfall plot for the ST the first, second and third orders of track patter amplitudes are very visible, but on the plot for the CRT only the first order is visible, and the amplitudes are way

lesser. OME analysis focuses on evaluating the track patter vibrations at discrete vehicle speed but Waterfall plots are useful in illustrating the change in vibration across all vehicle speeds.
Note the different scales on the graphs, the vibration is significantly reduced on the rubber track.

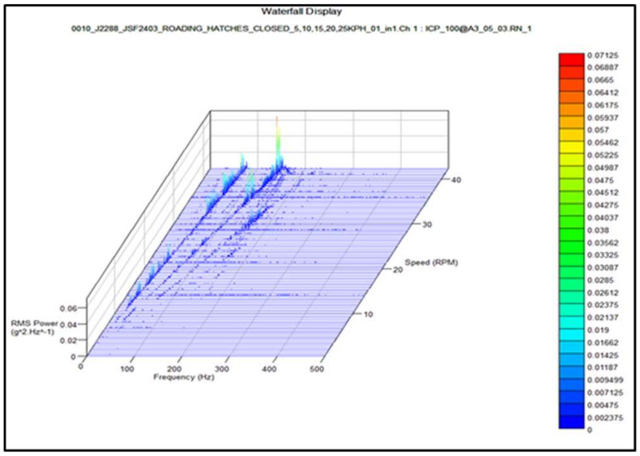



**Fig 14 - CRT Waterfall display**
**Source: Nprime Ltd**

## CRT vibration recording

CRT - Waterfall plot of vibration on ammunition rack. It appears to be a 1st order system, harmonics are barely visible. Gradient of line is also different; this is due the difference in the track plate pitch of the two track types.
Notice ranges on z-axis are different for both diagrams, vibration on CRT less harsh.

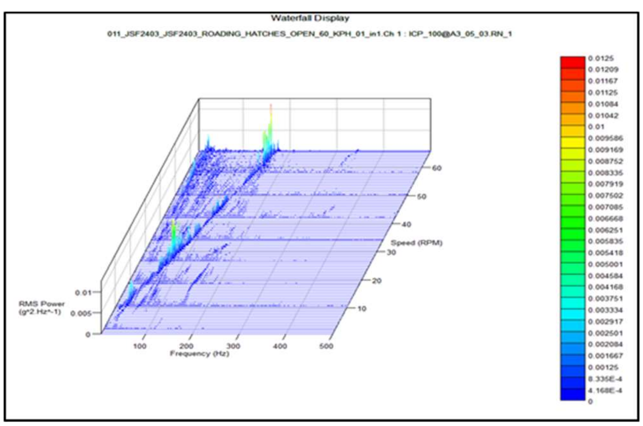



**Fig 15 - CRT Waterfall display**
**Source: Nprime Ltd**

## Analysis at different vehicle speeds

PSD (Power Spectral Density) plots have been created and compared to the reference lines given in DEF STAN 00-035 Part 5 Issue 5 Chapter 2-01 Fig A24 and A25.
These reference lines are an indication towards the performance of a vehicle in terms of OME testing. OME testing is done to find the harshness of vibrations experienced on locations of the vehicle where munitions are stored.

On the following plots the thicker red line is the reference line, this reference is used as a recommended upper limit. The analysis uses the accelerometer placed on the ammunition rack. On the plots below at all the various speeds the vibrations for the ST are consistently higher than the vibration for CRT.
Note that both axis are on a logarithmic scale.

**ST (Blue) vs CRT (Red) X axis**
**Analysis at 20 km/h**

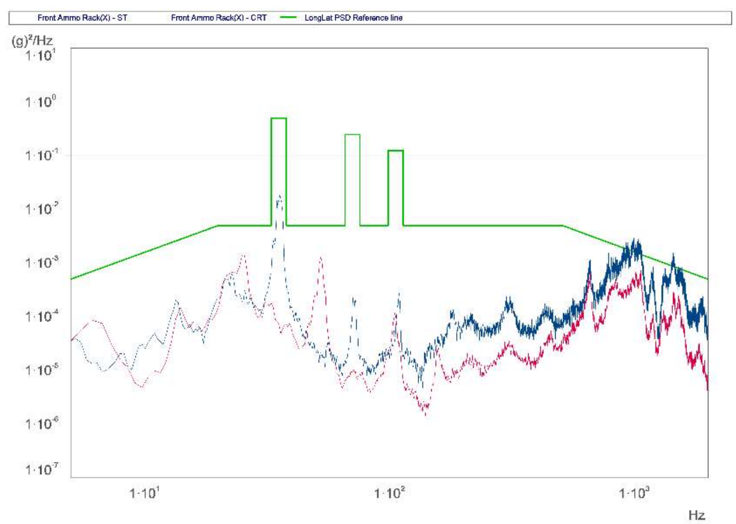



**Fig 16 - 20 km/h ST vs CRT X axis comparison**
**Source Nprime Ltd**

## ST (Blue) vs CRT (Red) Y axis Analysis at 20 km/h

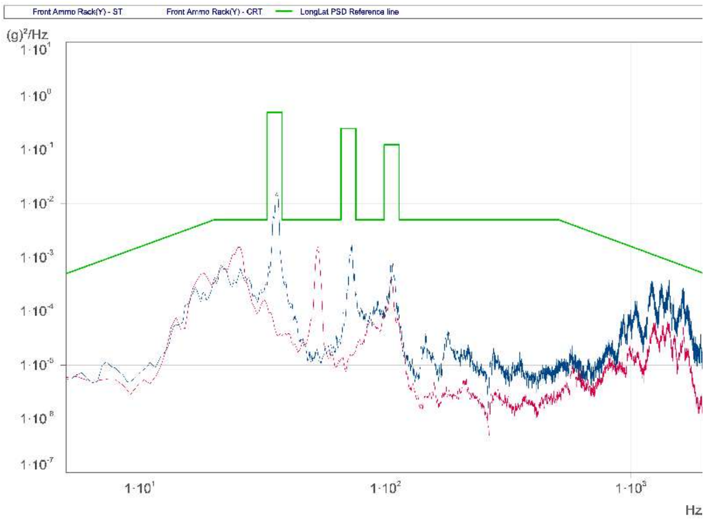



**Fig 17 - 20 km/h ST vs CRT Y axis comparison**
**Source Nprime Ltd**

## ST (Blue) vs CRT (Red) Z axis Analysis at 20 km/h

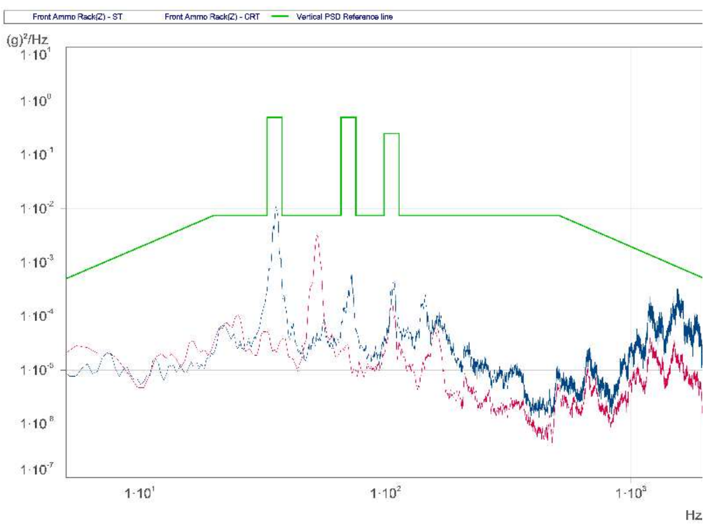



**Fig 18 - 20 km/h ST vs CRT Z axis comparison**
**Source Nprime Ltd**

## ST (Blue) vs CRT (Red) X axis Analysis at 40km/h

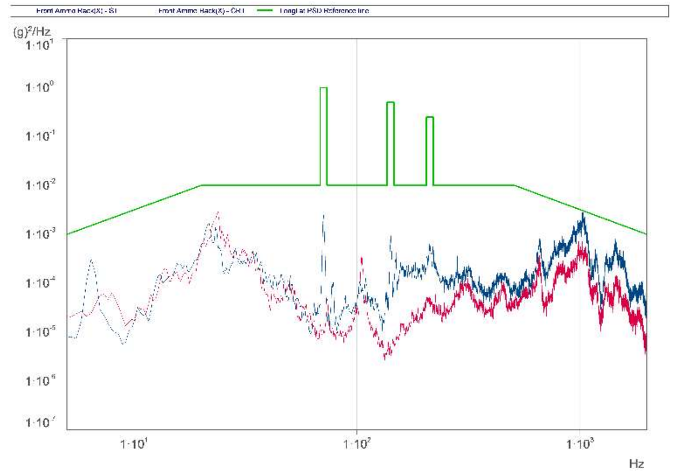



**Fig 19 - 40km/h ST vs CRT X axis comparison**
**Source Nprime Ltd**

## ST (Blue) vs CRT (Red) Y axis Analysis at 40 km/h

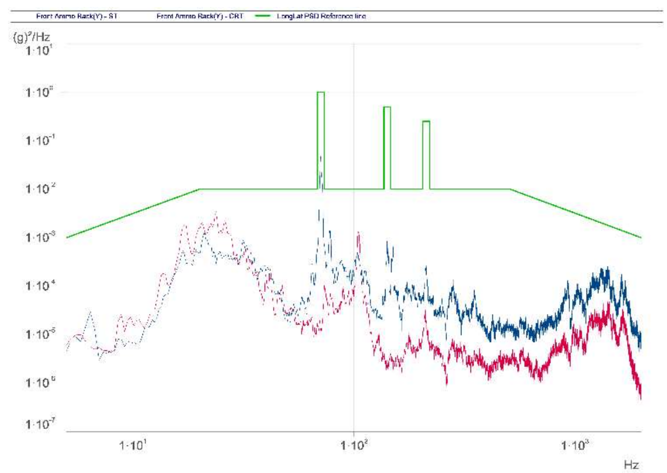



**Fig 20 - 40km/h ST vs CRT Y axis comparison**
**Source Nprime Ltd**

**ST (Blue) vs CRT (Red) Z axis**
**Analysis at 40 km/h**

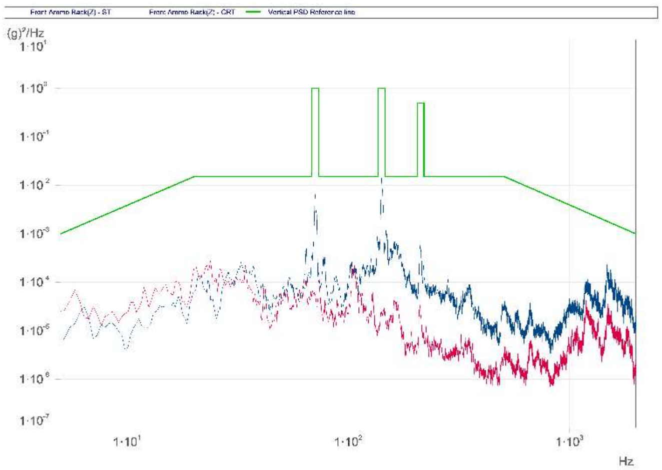



**Fig 21 - 40km/h ST vs CRT Z axis comparison**
**Source Nprime Ltd**

## 4. USAGE PROFILE

Part of the analysis process in DEF STAN 00-035 involves creating a usage profile.
This usage profile can be used to derive laboratory test severities that would induce equivalent damage to materiel that would be achieved in typical operational conditions in service.
The analysis focuses on the Root Mean Square (RMS) values of the track patter components at discrete speeds, this leads to calculating test severities and equivalent test durations. This derivation is outlined section 7 of DEF STAN 00-035 Part 5 Chapter 12-04.

| Terrain | Speed label (km/h) | Avg Speed (km/h) | Normalised Time (h) | Normalised Distance (km) | Percentage of time |
|---|---|---|---|---|---|
| Smooth Road | 5 | 3.70 | 0.050 | 0.2500 | 0.48 |
| | 10 | 8.00 | 0.300 | 3.0000 | 2.87 |
| | 15 | 12.80 | 0.720 | 10.8000 | 6.90 |
| | 20 | 17.70 | 0.850 | 17.0000 | 8.14 |
| | 25 | 22.60 | 0.880 | 22.0000 | 8.43 |
| | 30 | 27.60 | 0.950 | 28.5000 | 9.10 |
| | 40 | 37.50 | 1.200 | 48.0000 | 11.49 |
| | 50 | 42.50 | 0.975 | 48.7500 | 9.34 |
| Degraded Road | 5 | 3.70 | 0.170 | 0.8500 | 1.63 |
| | 10 | 8.00 | 0.206 | 2.0600 | 1.97 |
| | 15 | 12.80 | 0.546 | 8.1900 | 5.23 |
| | 20 | 17.70 | 0.896 | 17.9200 | 8.58 |
| | 25 | 22.60 | 0.950 | 23.7500 | 9.10 |
| Cross Country | 5 | 3.90 | 0.110 | 0.5500 | 1.05 |
| | 10 | 8.10 | 0.221 | 2.2060 | 2.11 |
| | 15 | 12.80 | 0.602 | 9.0300 | 5.77 |
| | 20 | 17.60 | 0.814 | 16.2800 | 7.80 |
| | | | 10.44 | 259 | |

**Fig 22 - Usage profile chart**
**Source: Nprime Ltd**

**Translation into ammunition life increase**

The process in DEF STAN 00-035 leads to the derivation of test factored durations which are consistently higher for rubber tracks.
For example, in z-axis the damage done by rubber track in 11 hours will be equivalent to the damage done by steel track in 8 hours

| | Steel track | Rubber track |
|---|---|---|
| X-axis | One hour of tests equates to 6.54 hours of use or 162.28 Km of use | One hour of tests equates to 28.46 hours of use or 706.46 Km of use |
| Y-axis | One hour of tests equates to 7.74 hours of use or 192.14 Km of use | One hour of tests equates to 25.46 hours of use or 631.95 Km of use |
| Z-axis | One hour of tests equates to 8.4 hours of use or 208.56 Km of use | One hour of tests equates to 11.14 hours of use or 276.4 Km of use |

**Fig 23 - Factored duration comparisons chart**
**Source Nprime Ltd**

## 5. CONCLUSION

In order to maintain the tactical advantage over near peer competitors, the US Army has instituted an RCV Campaign plan, with increasing R&D and prototyping to facilitate the integration of RAS into multidomain operations. It's therefore critical to demand the most compatible products for RAS designs.

This paper provides substantiated data on how CRT technology can benefit RAS in terms of weight saving, whilst reducing vibration, noise and maintenance. CRT meets the operational demands of RAS with a proven record on manned and unmanned systems.

Integration of RAS technologies faces many challenges, but platform availability will underpin the ability to **protect the force** and improve situational awareness (COP). In order to meet RAS requirements OEMs and US forces must seize the advantages CRT offers.

The RCV campaign plan foresees common control over multiple RAS systems, reducing manning further while amplifying reduced CRT maintenance and human factors implications.

If the answer to improving RAS integration is to adopt a CRT solution, then this paper supports that theory.

## 6. REFERENCES

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