"The Control and Reduction of Wear in Military Platforms"
Technical Evaluation Report

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1.0 INTRODUCTION

Following recent events in desert scenarios, this specialist meeting was formulated to examine the implications of wear and erosion on the performance of vehicles across all military platforms. The meeting opened with a session examining '**Service experience and in field repair.**' and then was followed by technical sessions focussed on '**Reciprocating engines and the lubrication system.**', '**Modelling of wear and erosion processes.**', '**Gas turbine wear and erosion.**', and concluded with an evaluation and summary presented by the technical evaluator to this specialist meeting.

As a light-hearted, but true, opening statement to this evaluation, it is noted that "**sand gets everywhere….**". This comment was made by many at the workshop and affects all military platforms. Which includes ship's propellers and water lubricated bearings operating in littoral waters, sand ingestion into helicopter engines, for sealed bearing systems on tracked vehicles and army personnel carriers, down to the erosion of blades from air fans used to cool army military vehicles. It is evident from the papers presented at this meeting that sand ingestion, wear and erosion is a big problem converting 'acceptable wear' into an unacceptable life limiting scenario. To illustrate this, case studies from each of the technical sessions will be examined, starting with "service experience and field repair" then examining problems in reciprocating engines, bearings, shipping and gas turbine engines. Relevant mechanistic understanding, models and possible palliatives as documented in the technical presentation will be highlighted.

2.1 Service Experience and Repair

This first technical session on "Service Experience and Repair" reviewed wear related problems across five military platforms, including helicopters, ships, tracked military vehicles, aircraft and guns. The first paper investigated bearing failures in the 24000 series main gearbox of the CH124 SeaKing Helicopter (paper MP-AVT-109-01). This is an excellent paper that highlights the need for **Health Monitoring** through the use of a combination of techniques (…acoustic emission, vibration analysis, oil analysis…). Clearly, health monitoring works, it helps to identify potential failures, but only if the early warning signs are noted, not ignored(!) and the database/materials directories are up to date and applicable to components currently in use on a given military platform. This paper demonstrated that a potential fatal incident was only narrowly avoided because key indicators of the gearbox's state of health were overlooked. The second paper (MP-AVT-109-02) continued this theme. It provided a review and case studies on "Rolling Contact Fatigue" and demonstrated that the early signs of damage may be sub-surface and therefore difficult to detect in the field. Once, these sub-surface regions of damage breakthrough to the surface and are therefore detectable as wear debris in oil filters etc – wear is significantly advanced. This **wear debris can exacerbate wear** and as will discussed later may lead to local lubrication breakdown, enhancing metal-metal contact and further advancing the whole wear process. This paper on the mechanisms of rolling contact fatigue illicited considerable interest from the audience, particularly on the ability of HUMS (Health and Usage Monitoring Systems) to detect early signs of failure. There was a wish that it may be extended to detect sub-surface damage prior to the release of wear debris (see the questions and answers session following this report).

These two papers, in concert, clearly show that from a knowledge of the most likely failure mechanisms, together with a well structured health monitoring system – that is kept up to date! – it is possible to detect component failures before they occur catastrophically in the field. A salutary lesson is that this is only possible provided the early warning signs are not overlooked, or ignored, under the pressures of military conflict.

The third paper (MP-AVT-109-03) sees a change in platform from helicopters (papers 1 and 2) to ships. Paper 3 reports a rig based test programme to investigate "Wear in Naval Submerged Shaftline Bearings". Although a different scenario the overall theme is similar. Firstly, there is a need to understand the mechanisms, in this case related to the breakdown of hydrodynamic lubrication, which creates the water wedge that supports propeller shaft loads. Breakdown of lubrication is a recurrent theme in many later papers in this meeting. Once lubrication fails metal-metal contact ensues and wear rates rapidly increase. Many factors may influence this, in littoral sea water entrained sand exacerbates the problem. Other factors include the surface finish of contacting surfaces (in this case the liner), geometry, bearing pressure and surface speed. For this application the most important factor is the **compatibility of bearing and liner materials** in rubbing contact in a marine environment. Thus this paper highlights the importance of the **local environment** and possible **contacting surfaces** in the wear process. Thus close simulations of wear mechanisms within the laboratory are often only possible through the design of specialist test rigs aimed at simulating the local tribo-corrosion environment.

The remaining four papers in this session focus on the mitigation of wear through repair, re-design or coatings. Large navy guns (paper MP-AVT-109-04), military vehicles (papers MP-AVT-109-05 and MP-AVT-109-06) and fighter aircraft (papers MP-AVT-109-06 and MP-AVT-109-07) are cited in the various cases studies. A laser based systems (LENS), for in-field repairs, is proposed in paper 5. Such a system has been shown to work in the field and permits the repair of worn components by laser melting powders into the worn surface whilst limiting the heat affect zone when compared to more traditional welding techniques.

Paper 6 (MP-AVT-109-06) is the first of many papers at this meeting that illustrates the benefit of **innovative design** once the damage mechanisms are well understood. In this paper component re-design and the incorporation of a soft solid bonded film for the bush/pin inner geometry and a monolithic ceramic bush for the outer wear parts simplified the design of track chain driven transport systems.

The final paper (MP-AVT-109-07) in this session returns to flying platforms and look specifically at "Protection Systems for Reduction of Wear on Tornado Aircraft". Three wear problems are examined 'Fretting/Adhesive Wear', 'Thermal Erosion, due to hot exhaust gases' and 'Rain Erosion of air intake ducts'. In each case wear has been mitigated through the selection of appropriate coatings. A Teflon liner was used to mitigate wear between steel and titanium components of the flap-track. Polyurethane coated silicon rubber was proposed to minimise damage from hot erosion, where as both hard-coatings (sprayed tungsten carbide) and elastomeric materials have been suggested to mitigate rain water erosion.

In technical terms this first session highlights the diversity of wear related problems, the need to identify the tribo-system and the need to limit sand induced erosion and 'three body' abrasion as a result of entrained particles. One must remember to examine wear in the context of the whole system, '**the system approach**'. It is clear that wear requires that two, or more, surface are in physical contact with three-body abrasion more severe than two-body sliding or rolling contact. **The local, microenvironment is very important** and determines whether low wear conditions can be established under practical service conditions. **Health monitoring** is also an important step in assessing a platform's/vehicle's susceptibility to serious failure through wear. When signs of damage are seen they should not be ignored! One must recognise that **issues that give rise to severe wear conditions should be first addressed at the design stage, coating systems, though often offering improved performance, cannot mitigate poor design.**

2.2 Reciprocating Engines and Lubrication Systems

The second session focuses on "Reciprocating Engines" and its associated "Lubrication Systems". Here innovation in design provides the key to future success. Four out of six papers (MP-AVT-109-08, MP-AVT-109-09, MP-AVT-109-12 and MP-AVT-109-13) in this session examine novel design solutions to wear problems. Each, as reviewed, should be considered as a case study of what is possible and feasible. The remaining two papers (MP-AVT-109-10 and MP-AVT-109-11) consider modifying the fuel system and wear particle analysis as methods of minimising wear in reciprocating engine systems and there effect on durability issues.

The first of these papers (MP-AVT-109-08) presents an innovative design to oil filtering, with the aim of eliminating hands on maintenance in the field. It uses centrifugal filtering to remove all particle sizes about 0.1µm, including oil-borne soots. Innovation comes from recognition that only a proportion of the oil stream needs to be filtered (10% is passed through the centrifugal filter to progressively clean the whole lubrication system.

Following this theme of lifetime lubricated engines, paper MP-AVT-109-09 examines alternative lubrication systems based on tribo-reactive materials. The paper presents an excellent review of lubricated tribology and demonstrates that lubricious oxides, e.g. Magneli phases of titanium oxides, and or polar based oil substitutes can extend the life and thus permit long oil-drain-time operation. To the future, one can foresee a lifelong lubricated engine, using tribo-reactive materials and strategic oil injection to minimise losses. Future oils will be both renewable and bio-degradable.

Whilst on the theme of **lifelong lubrication systems** paper MP-AVT-109-11 addresses engine oil diagnostics with the ultimate aim of developing "on-line" systems. The diagnostic system recognises the multi-variant nature of wear and uses statistic methods to trend-line changes in particle distributions present in engine oils. The critical next step is to produce characteristic spectra of particle distributions that define the state of wear in the engine. Such an approach recognises that global patterns of damage develop in reciprocating engines that reflect a balance between the particles generated by the engine and those removed by filtration, oil change etc.

Paper 13 (MP-AVT-109-13) follows a similar theme of "oil analysis in the field". However, this system is ship-borne and is used in the navy for on-line diagnostics. The portable fluid analyser uses neural network methods to analyse debris shape and size (can produce particle maps as time trends) together with a viscometer and I-R oil condition analyser. The system permits identification of possible mechanical faults, fault specific diagnostics and thus provides an early warning capability of potential failures due to wear.

The last two papers to review in this session were not focussed on the oil lubrication system , but on fuel systems (MP-AVT-109-10) and bearing systems (MP-AVT-109-12) respectively, however for both applications innovation gave rise to novel solutions to enhance lubrication performance and thus reduce wear. Hence again, **innovation provides the key to success**, mitigating wear and enhancing component durability.

Paper MP-AVT-109-10 addresses US experience with the operation of ground vehicles on JP-8 fuel oil. Problems with rotary fuel pump failures was traced back to poor fuel lubricity when using JT8 fuel, particularly when the pumps are running overly hot. The solution was first to select a more durable pump and then to add a corrosion inhibitor/lubricity improver to the fuel. This joint solution led to a dramatic increase in fuel pump life. Many questions still remain: "What is the minimum level of corrosion inhibitor/lubricity improver that is required? (JP-8 specification only allows 12-24 mg/l addition); "What is the role of temperature?" (fewer pumps were required when temperatures were cooler); and "What is the best corrosion inhibitor/lubricity improver to be used for each temperature range of operation".

The last paper to be reviewed in this session (MP-AVT-109-12) again highlights and emphasises the need for innovative design. This paper presents a design for a new bearing concept – geometrically contoured bearings – which, with a suitable grease can remove sand particles and wear debris from the contacting surfaces, converting a three-body abrasion situation into two-body sliding wear. The design is outstanding and offers the potential of virtually maintenance free bearings for use in arduous conditions.

Such innovations minimise wear in the field, permit longer operations between maintenance and service and thus offer increased reliability, better performance and lower operating cost. One must conclude this session on "Reciprocating Engines and Lubrication" by stating that **Innovation in design is the key to future success** with durability under arduous service conditions directly related to the robustness of the design.

2.3 Modelling of Wear and Erosion

This session and two of the paper in session (4), on Gas Turbine Wear and Erosion, focus on our ability to model wear related processes. The papers are diverse, covering such widely different topics as "Scuffing and Micro-pitting in Gears" (paper MP-AVT-109-14), through "Wear and Erosion in Large Calibre Guns" (papers MP-AVT-109-15 and MP-AVT-109-16) to "Erosion and Foreign Object Damage to Thermal Barrier Coatings" (paper MP-AVT-109-20) and "Wear Processes in Space" (paper MP-AVT-109-18). Thus it was proved difficult to identify an underlying theme through this session and the following one on Gas Turbine Wear and Erosion, other than the recognition that **mechanistic modelling aids understanding.** Thus through modelling, it is possible to help identify potential problems and thus allows the anticipation of wear and erosion related damage.

Taking each paper in turn, paper MP-AVT-109-14 presented an excellent review of contact lubrication and its breakdown and explains how understanding the dynamics of this process permits prediction of scuffing and micro-pitting in gears. Theoretical work on micro-elasto-hydrodynamic lubrication highlights the importance of surface roughness in terms of the high pressures generated in the vicinity of asperities on gear teeth and the effect this has on the distribution of stress close to the tooth surface. Thus surface finish not only improves scuffing resistance but may also result in reduced contact friction and therefore reduce the energy losses through the gear train. It is shown that as well as improving surface finish the use of self lubricating super-hard coatings helps to reduce scuffing damage. Diamond like carbon (DLC) shows particular promise.

Transient loading effects are an artefact of gun barrel wear and erosion (see papers MP-AVT-109-15 and MP-AVT-109-16). Paper MP-AVT-109-16 presents an excellent review of the problem. Firing cycles are typically 20ms, thus a 2000 round gun barrel life has a total cyclic life of 40s!, but at extreme pressures (700 MPa) and temperatures (3000K) coupled with high contact velocities. Such severe wear/erosion conditions are tackled from a system point of view, first design solutions ensure that wear failure occurs before fatigue failure, secondly strategies are established to mitigate wear and erosion. These include: wear reducing additives to the propellant charge, e.g. talc, TiO_2, silica or a mixture of these; modification of propellant chemistry; design of the projectile, including the use of driving and oburator bands; protective coating systems for the combustion chamber and forcing cones; plus bore coatings on the most high performance guns.

Paper MP-AVT-109-15 presents a predictive model for the pressure cycle and thermal cycle of a vented gun barrel. By considering transient heat flux due to convection, conduction and radiation predicted wear rates are some 30% lower than those measured in practice. This is an extremely good result and demonstrates how a mechanistic understanding of the wear process permits computation models to be developed that predicts high transient load, both mechanical and thermal, wear processes.

Paper MP-AVT-109-17 addresses models for the erosion and erosion-corrosion performance of cast and thermally sprayed nickel aluminium bronzes. The application is the propulsion and sea water handling systems on naval platforms. This paper presents an excellent overview of erosion-corrosion in the marine environment and demonstrates that damage results from a complex interplay of microstructure, corrosion rates and impact dynamics. The influence of this synergy was found to depend on flow characteristics and flow energy, sometimes being beneficial and other times detrimental. For nickel-aluminium bronzes (NAB) good erosion-corrosion behaviour correlates with the formation of a stable, strongly adherent oxide films on the component’s surface. The observed variable behaviour relates to the damage/de-passivation of the surface oxide film, which may occur through exposure to high velocities, due to cavitation and due to direct particle impingement. High Velocity Oxy-Fuel (HVOF) sprayed coatings were explored, but these also showed variable behaviour. Porosity introduced as part of the coating process permitted liquid penetration of the coating, giving rise to galvanic corrosion between the coating and substrate, accelerating material wastage.

Paper MP-AVT-109-18 investigated material/coating solutions to tribology related failures in a simulated space environment. Spacecraft failures are associated with increase frictional forces and the mechanical ‘binding’ of metallic parts in high vacuum environments. Solid lubricant films are shown to be a mandatory requirement for high load conditions, reducing the likelihood of metal-metal binding of metallic parts. Under vacuum conditions, the interfacial bond strength between bare metal and ceramic parts is often greater than the cohesive bond strength of the metal. Thus the metal parts fail by shear, transferring metal to the ceramic component surfaces. Solid lubricants prevent this micro-welding between contacting parts, reducing friction. But a note of caution, coating detachment may create unwanted hard wear debris exacerbating the wear process.

The last paper in this session (paper MP-AVT-109-19) investigates an integrated logistic support approach to managing wear and erosion damage. The aim is to integrate wear mitigation solutions into aircraft design. However, as such solutions can only delay wear problems, not prevent them, a necessary part of aircraft support must provide effective wear preventative measures and once detected, monitor and identify corrective measures. Three examples of preventative wear designs are cited: self -lubricating tapes, wear resistant films and the use of 'wear' parts to protect other parts. Visual indicators of wear are incorporated in the aircraft system, aiding inspection. Corrective maintenance of wear damage has to be undertaken at the earliest opportunity once a repairable level of damage is identified, but prior to an unacceptable damage condition. It has been found that by adopting such procedures corrective and preventative maintenance, related to wear, can be optimised as a result of in service experience and technical awareness of operators.

2.4 Gas Turbine Wear and Erosion

The final session of this specialist meeting on "The Control and Reduction of Wear in Military Platform" reviews Gas Turbine Wear and Erosion. Five papers were presented, three related to erosion issues, both within the compressor (2) and turbine (1) sections, and two related to fretting fatigue problems, principally within the compressor. Considering first the compressor and then the turbine, four of the papers relate to compressor problems (MP-AVT-109-21, MP-AVT-109-22, MP-AVT-109-23 and MP-AVT-109-24) with an equal division between fretting fatigue and erosion. The turbine focussed paper researches the 'Erosion and Foreign Object Damage to Thermal Barrier Coatings' on first stage turbine blades (paper MP-AVT-109-20).

Fretting fatigue is a common problem that besets many turbine components that require a tight contact between mating surfaces; blade dovetail joints are a common problem area. Two papers in this meeting address this issue (papers MP-AVT-109-21 and MP-AVT-109-22), presenting a UK and European perspective. During service, fan blade and compressor blade dovetail roots are subject to a complex load cyclic, with micro-scale movements between contacting surfaces. This complex stress plus micro-scale movements ensures that any wear debris produced is unlikely to be removed and thus fretting and fretting fatigue can lead to component failure. The problem is how to experimentally simulate this behaviour and then to develop suitable predictive models. Paper MP-AVT-109-21 focuses on the development of a representative test procedure to simulate dovetail root failures in service. A new test procedure was proposed that establishes biaxial loading of the fir tree root, with super-imposed high cycle and low cycle fatigue components. Finite element (FE) modelling of the fan blade, disc configuration and the biaxial rig configuration was necessary to define the correct loading conditions to ensure that both stress levels and relative sliding displacements are representative of service and accurately predicted. Four basic control parameters are: 'the mean load' applied to the blade root, 'the vibrational load' applied to the blade route, 'the relative movement between blade and disc' and 'the number of vibration cycles to one major cycle', i.e the ratio between high frequency and low frequency cyclic conditions. Validation tests on Ti6Al4V using this biaxial ring, and support FE analysis, produced excellent correlations with development engine experience. In addition, the condition of the coatings and level of flank fretting damage closely match those seen on real components. Thus, having validated rig performance the authors were able to assess suitable fretting fatigue palliatives. Coatings tested included MoS_2 – a dry film lubricant, CuInNi – a plasma sprayed metal coating, a nano-composite coating designed for low wear rates with low friction, plus surface treatments including Laser Shock Peening, Deep Cold Rolling and Increased Intensity Shot Peening. The most promising treatments included MoS_2 on blade and disc surfaces, recoated every 500 cycles; CuInNi coated blade fir-trees, plus MoS_2 on both blade and root; and the nano-composite coating (Wearcoat) applied only to the fir-tree against an uncoated disc. Laser shock peen further improved life by preventing "edge of contact" fatigue cracking. The second paper, MP-AVT-109-22, focuses on modelling fretting fatigue life of turbine components by identifying the principal driving factors for fretting fatigue damage. Again, 2D FE models were used to solve contact conditions and thus identify major factors influencing the loading/straining conditions. Component failure was predicted on the basis of the multi-axial fatigue criteria of Dang Van and co-workers [$\{\tau(t) + a.p(t)\} \leq b$]. In addition to the parameters identified above, friction coefficient and slip distance are considered additional important control factors as these influence the magnitude of shear stress generated for a given level of biaxial load.

Three papers address gas turbine erosion problems. Two for compressor applications (papers MP-AVT-109-23 and MP-AVT-109-24) and one on the erosion of thermal barrier coatings for first stage turbine blades (paper MP-AVT-109-20).

Considering compressor requirements first, papers 23 and 24 research the erosion of compressor blade materials by solid particle impact and the design of nano-layered coatings to resist such impact damage. Paper MP-AVT-109-23 firstly examines the particle impact process, modelling the single particle impact response of erosion resistant coatings using finite element methods. Damage caused by hard particle erosion, lowers engine power, decreases fuel efficiency and shortens engine life. Under the most extreme conditions it may result in engine failure. Thus the aim of this work is to produce impact tolerant multi-layered coating structures. The ethos is well acknowledged, that of increasing surface hardness by using ceramic layers, with metal inter-layers interspersed to provide improved toughness. Thus paper 23 has developed a FE model of a single particle, high velocity impact, with the aim of optimising energy dissipation in an erosion resistant coating. Harder and thicker coatings were found to be more effective in lowering the stress levels at the coating/substrate interface. Additionally, the presence of a soft bonding interface layer further lowers the stress in the coating by effectively increasing the coatings interfacial toughness. The second paper (MP-AVT-109-24) examines the design of multi-layered coating architectures to resist erosion and impact damage. A concept proposed over 10 years ago, this paper researches the latest unbalanced magnetron sputtering process to make such coatings. Nano-structured TiN/CrN and TiN/CrN coatings multi-layered with titanium have been produced with hardnesses exceeding 40 GPa. In addition to high hardness these super-lattice coatings have lower coefficients of friction than their monolayer counterparts. In concert, this increased hardness and lower friction results in excellent wear performance.

The last paper to be reviewed in this technical evaluation, paper MP-AVT-109-20, considers the erosion and foreign object damage to thermal barrier coatings (TBCs) applied to first stage turbine blades of gas turbine engines. This paper addresses the failure mechanisms of TBCs under impact conditions relative to the unique columnar microstructure that is developed. The work shows that the column boundaries act to arrest cracks and that material is removed when 4-6 adjacent columns are damaged. For small particle impact the depth of damage is restricted to the near surface region of the coating. As the impacting particle size increases, gross near surface plastic damage is observed but without ceramic loss, thus under this condition erosion rates fall. However, further increases in particle size, or particle velocity can lead to gross plastic damage, shear crack generation and crack propagation to the substrate interface, whereupon only a few impacts may lead to total localised ceramic loss. This gross damage mechanism is known as 'Foreign Object Damage'.

In summary, this last session on Gas Turbine Wear and Erosion highlights how innovative surface treatments and coatings may be used singly, or in combination, to combat wear. It is clear further optimisation is possible and finite element methods are aiding our understanding of contact dynamics and thus coating design. Future coating systems/surface treatments will inevitably be better optimised and therefore offer better wear/erosion resistance, through a better understanding of the mechanisms by which damage accumulation occurs in multi-layered, nano-structured or functionally gradient coating systems.

3.0 CONCLUDING REMARKS

Overall, the meeting was of a very high standard. Many excellent papers at the technical leading edge were presented both in the understanding of damage mechanisms and in innovation to overcome the specific wear related problems being addressed. Particularly of note were the papers addressing the understanding of wear at the 'contacting surface' interface. These showed that embryonic damage was often hidden, occurring as subsurface cracks – clearly noted in rolling contact fatigue and erosion of thermal barrier coatings. Only when the damage broke through to the surface was the wear evident at a macro-scale and at this time it was often too late to effect a suitable repair strategy. Health monitoring, under such conditions, provides early warning – enhanced wear debris in filters for example – provided such warnings are not ignored. It is clear that lubrication failure leads to wear, and that wear debris exacerbates wear. However, studies of contact dynamics further showed that wear damage often leads to the breakdown of local lubrication thus accelerating the whole failure process. Under such severe wear scenarios it may be prudent to use solid film dry lubrication in addition to liquid systems to minimise damage during start up, operation transients or if local liquid film lubrication fails. One final point, while discussing wear mechanisms, it should be noted that hard materials are not always better, it is the resistance to local impact, indentation and shear that is important. Thus, remember tough, low modulus, materials can adsorb local damage elastically and may better resist indentation and impact damage in a resilient manner.

As a final statement, I would say **'know your tribo-system well'**, **consider the total system**; **the contacting materials** – wear cannot occur without two or more materials being in contact-, **the environment** – even in a vacuum adsorbed films can provide lubrication-, **the loading conditions** and **local contact geometries**. Much has been discussed on material design and the use of coatings to combat wear, but it is worth reiterating that ' **Coatings cannot mitigate poor design…. It is necessary to design out the wear problem where and whenever possible.**' Exciting design innovations included:- 'The ceramic tracked chains incorporation dry lubrication'; 'The centrifugal oil filter, where 1% particle removal in a closed system was able to clean up diesel vehicle oil to the extent that oil changes in the field became unnecessary', and 'The design of a new bearing concept – geometrically contoured bearings – which, with a suitable grease, can remove sand particles and wear debris from the contacting surfaces, converting a three-body abrasion situation into two-body sliding wear'. Such innovations minimise wear in the field permitting longer operation between maintenance and service. It is clear that **understanding of the underlying mechanisms,** coupled with **new material solutions** and **design innovation** is the key to future success in combating severe wear problems on all military platforms.

Final Meeting Discussion

As an introduction to the final meeting discussion Prof. John Nicholls, the technical evaluator of this workshop, presented an overview of his observation and conclusion for the meeting. This led to a lively period of discussion. Probably the most discerning of these was raised by Victor Arrieta, from MTU Aero Engines in Germany, who asked; "What would be the future of preventative solutions, instead of 'post mortem' palliative solutions?"

Prof. John Nicholls replied. "In my view preventative solutions and 'post-mortem' palliatives are implicitly linked. Clearly, we would all like to find solutions that do not wear, lasting the lifetime of the component, process or plant, beit a ship, aircraft or military vehicle. However, we have learnt from experience that this will rarely be the case, because wear problems not only depend on our design, but on the local service environments under which we expect them to work and this is forever changing. Thus 'post mortem', palliatives first highlight problem areas and some quick-fix solutions. Subsequent analysis helps the design of preventative measures, whether new material combinations, coatings or innovation in design. As to the use of coating systems, to the future I see the possibility for 'designed in' coatings, rather than their use as palliatives to solve unforeseen problems. Within various laboratories work is underway on coating systems to provide novel solutions to wear (papers MP-AVT-109-23 and 24 are examples), to provide self diagnostic capability and to provide 'smart behaviour', i.e. a capability to change their characteristics as the local tribological environment changes. Thus my future, sees such systems being designed into plant and thus providing, self diagnostic, wear mitigation/wear preventative solutions.