Technical Evaluation Report

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SUMMARY

The meeting objective was to review the status and future opportunities for multifunctional structural systems, enhance collaboration and foster innovation on an expert level and that objective was fully met.

That meeting combined some very much "Technology Watch" subjects, and others close to practical application, all with the potential to have a significant impact (evolutionary/revolutionary) on future military systems.

One of the recommendations was that durability/repairability concerns should be addressed in the design of multifunctional structures.

Another recommendation, for the very interesting subject of integrated antennas is that multidisciplinary cooperation is to be expanded.

1.0 INTRODUCTION

1.1 Background

The current design philosophy of developing independent systems and packing them into military vehicles, in particular aircrafts, has resulted in systems that tend to increase system weight, restrict available volume for future enhancement and limit performance capabilities.

There is already a trend towards more integration of functions for electronic systems.

A further step could be to develop multifunctional structures, or structures that carry loads and perform system functions. Multifunctional system technologies such as conformal load bearing antenna structures, structurally integrated energy storage/harvesting, mechanised structural systems for morphing vehicle geometry, integrated/distributed sensing and associated technologies form the basis for major advancements in future air/ground/naval vehicle capabilities.

Morphing aircraft structures can enable an air vehicle to adapt to his mission requirements.

For example, new multipoint design capabilities for future aircraft may require certain aspects of the vehicle configuration (and therefore its structure) to reconfigure during an operational broad range of flight conditions (e.g. loiter and dash). Structurally integrated actuation and control technology is anticipated to result in flow control and structural shape control leading to breakthroughs in vehicle drag reduction.

Future vehicle will require increased situation awareness and communication capabilities including new data link concepts with additional sensors and antennas. Field of view and aperture requirements of these elements often conflicts with installation limits in term of size, locations and coupling effects of different

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sensors. Integrated /distributed sensors/antennas may bring very large operational benefits. Effective and safe functional and mechanical integration of sensors and antennas in load carrying structures, their robustness and maintainability as well as compatibility aspects with the parent structural material and qualification concepts will become an important aspect of weapon system design.

1.2 Objectives and Organisation of the Meeting

The meeting objective was to review the status and future opportunities for multifunctional structural systems, enhance collaboration and foster innovation on an expert level.

The meeting was also an occasion to develop the integration of multiple disciplines into design processes for future military applications on a system level. To this purpose, the meeting, organized by the Applied Vehicle Technology (AVT) panel of the RTO did also include an important participation of the Sensors and Electronics Technology (SET) panel.

The programme of the meeting comprised 25 papers, and was organized in 4 sessions in addition to the keynote and overview papers:

- 2 Overview papers
  - Morphing structures technology (US)
  - Antenna integration into Composites (NL)
- 2 Keynotes (US / GE):
  - Research directions and emerging materials / future applications
- Sess.1 Integrated Energy Management / 4 Papers
- Sess.2 Health Management Sensing systems / 5 Papers
- Sess.3 Shape Control – Actuation / 5 Papers
- Sess.4 Structurally Integrated Antennas / 7 Papers

At the end of the meeting, during the technical evaluation session, a preliminary version of the technical evaluation was presented by the technical evaluator for discussion and comments from the floor. A good discussion did take place and main results of this discussion are integrated into this final technical evaluation report.

2.0 EVALUATION

2.1 Preliminary Remarks on the Development of Military Vehicle Structures

The subject of this meeting was multi functional structures. This implies than these multifunctional structures will have also to fulfill the same basic requirements than the present “monofunctional” structures.

Experience of previous military vehicle systems has shown us two hard facts:

1) Time between two subsequent generations of major vehicle systems is now more than 20 years. And during the production run there are generally no major evolution in the primary structure. Example for USAF air superiority fighters: P 80- F 86- F 100- F 4- F 15- F22.
2) Service life of an individual vehicle is 30 years or more, normally without replacing major parts of the structure.
   Example: B 52!!

This is also valid for land vehicles and sea vehicles.

These facts have two series of consequences:

1) Durability and /or reparability concerns: durability and reparability have to be taken into account before application to structures.
2) Timing and technological readiness: to gain large benefits it is necessary to have large scale application. Large scale application is only possible at the occasion of the development of a brand new generation of vehicle. This in turn can happen only if the technology is in a sufficient state of readiness at the start of the programme. Otherwise the “firing window” will be missed.

All these considerations may look discouraging, but in fact the only significance is that for structures we must think long term. Looking at the high performance composites, today an essential asset of advanced air vehicle, we must remember that about 30 years separated first structural application from widespread usage. And without that effort, none of the present large benefit could have been attained.

This means that for the introduction of multifunctional structure a progressive approach will be followed, including possibly application to demonstrators, application to less important systems (example UAVs), application to secondary or easily replaceable structural elements.

2.2 Session 1: Integrated Energy Management

The four papers in this session dealt with 3 axes:

- Integrating energy storage and structure/ armour;
- Integrating energy autonomous wireless sensors in structures; and
- Thermal energy management and harvesting for structurally integrated systems.

Integrating Energy Storage and Structure/Armour

Paper 1 addressed the difficult problem of energy storage for micro UAV and presented two innovative examples: using batteries as wing spars in a micro UAV, and using an inflatable wing spar as gas storage for an UAV engine.

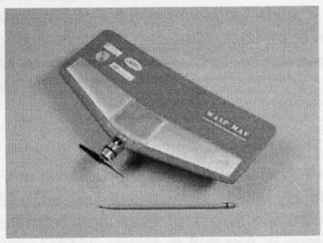


Figure 5: First generation DARPA Wasp micro-air vehicle showing custom batteries (silver quadrilaterals, top and bottom) integrated as wing-skin at the leading-outboard-edges.

Figure from Paper 1

Paper 2, considering the need for the future soldier to carry sensing and communication equipments in addition to armament, body protection and other paraphernalia, had a look at possibilities to keep the weight down. The idea was to combine armour with energy storage.

Three type of coupons were tested for mechanical performance: structural fuel cell, structural batteries and structural capacitors (the latter being potentially used for directed energy weapons, for example using the body of a future AFV).

Integrating Energy Autonomous Wireless Sensors in Structures

Paper 3 dealt with embedding energy autonomous sensors into wireless sensors networks. Today sensors/ communication nodes powered by solar or vibrational energy are available, as well as robust batteryless wireless switch modules. But before embedding such a system in a military vehicle structure it will be necessary to look at the durability issue.

Thermal Energy Management and Harvesting for Structurally Integrated Systems

In paper 1, possibilities of integrated solar cells were considered.

Paper 4 presented result of tests aimed at increasing efficiency of thermal electrical devices by using “thermal potentiometers” between the thermal source and the heat sink. This is still very preliminary as we don’t have practical thermal potentiometers.

Discussion on Session 1:

During the technical evaluation session two recommendations were made:

1) For integrated energy storage/armour application static strength tests were performed. Ballistic effectiveness should also be verified.
2) For all integrated energy storage systems durability has to be further considered.(example durability of a commercial battery).

2.3 Session 2: Health Management Sensing Systems

General objective of integrated heath management sensing systems is to get failure /damage detection better and/or faster (real time!) and/or cheaper than conventional methods.

For example it would be extremely useful to have such a system on the Space Shuttle leading edges, if it was feasible!

Paper 5 presented a very generic survey of structural sensing for aerospace applications.

Papers 7 and 9 dealt with application of fiber optic sensors (with Bragg gratings), paper 7 in an existing metallic structure, paper 9 in different examples of composite structures.

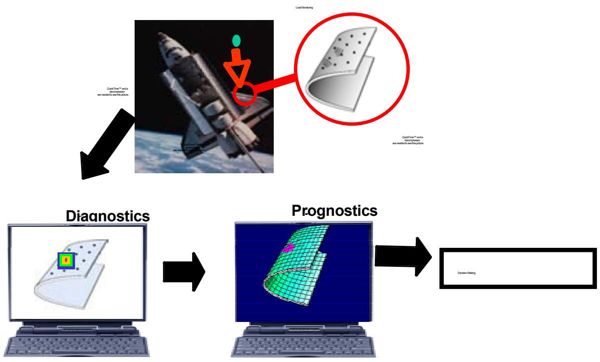


Figure from Paper 5

Paper 8 had a closer look at feasibility and advantages/ disadvantages of an array of small, integrated ultrasonic sensors in a Smart, Wide area Imaging Sensor System. (SWISS).

One of the advantages against conventional “external” NDT system is the increase in “aperture” of the phased array, giving a better sensibility to small and often unexpected defects. The prototype demonstration was encouraging, but the integration of such electronics in an actual structure is still a challenging technological issue.

Paper 10 dealt with “mesoscale multilayer surface engineering” and described the recent development of a conformal, low temperature direct write machine for both patterning and 2 ½ D engineering of multilayer circuit architectures. The audience was **strongly interested** by this paper as such a tool could be the solution for many manufacturing problems, also for integrated antennas and other applications.

As a general conclusion to this session reliability and durability of such Health Management systems is still very much an issue.

Cost is also an issue, and we should also keep into mind that "external" NDT systems did improve considerably in the past, and may continue to do so, providing a competition to integrated systems (with none of the durability problems of the later).

During final discussion the following comments where made by the audience:

- Effectiveness/durability/cost…..all need to be considered to ensure that the entire cost picture is understood.
- The sensor reliability is key.
- Very low cost sensor integration could enable many levels of redundancy on integrated sensor networks.
- The sensor itself is 1-D, the entire system needs to be considered.

2.4 Session 3: Shape Control – Actuation

Status of Smart Materials Development

Keynote paper 2 and paper 14 provided a very comprehensive survey of the numerous smart materials, existing or future.

There are many new developments but at present only two types seem close to practical application as actuators in structures:

1) PZT piezoceramics, already used for vibration control. Their advantage is high frequency response, their drawback are very limited stroke as actuator, and low elongation to failure.
2) Nitinol shape memory alloys capable of longer stroke but at very low frequency.

Even those two types have limitations and unknowns (repeatability, durability…). There is a need for standard testing.

For future smart material, carbon nanotubes seems to be good candidates as actuators, but at the time being only very preliminary results are available.

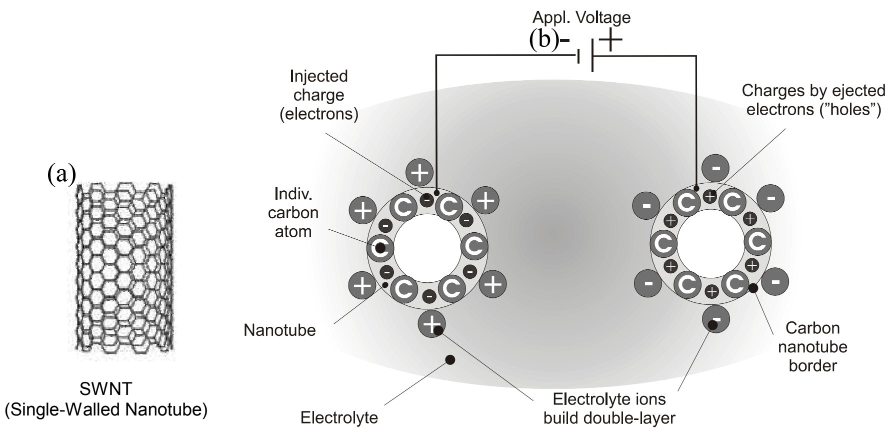
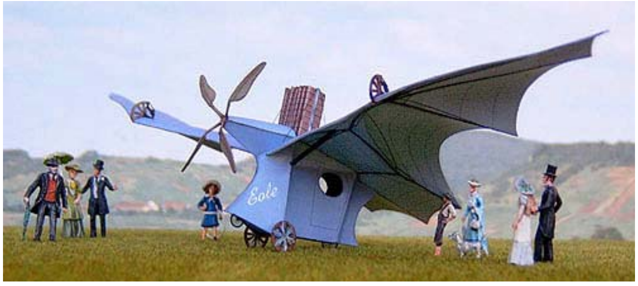


Figure from Paper K2

Morphing Aeroplane Concepts

Paper SC presented a comprehensive survey of "Morphing" or "Shape Changer" airplanes.

The first known example of shape changer was Ader's Eole in 1890. Today, some form of shape changing is quite common, such as flaps and slats, and in some cases variable geometry.



Clement Ader's Eole (1890)

Figure from Paper SC

The objective of DARPAs morphing airplanes programme is to go to extensive shape changing wings, and so allow vehicle adaptability to widely changing flight regimes.

Two programs are in development, on different formulas (variable sweep versus in flight folding wing). Two large scale models will be tested in wind tunnel.

Such morphing approach will certainly have benefits for aerodynamic drag. The big question is to ascertain the corresponding structural complexity and structural weight drawbacks.

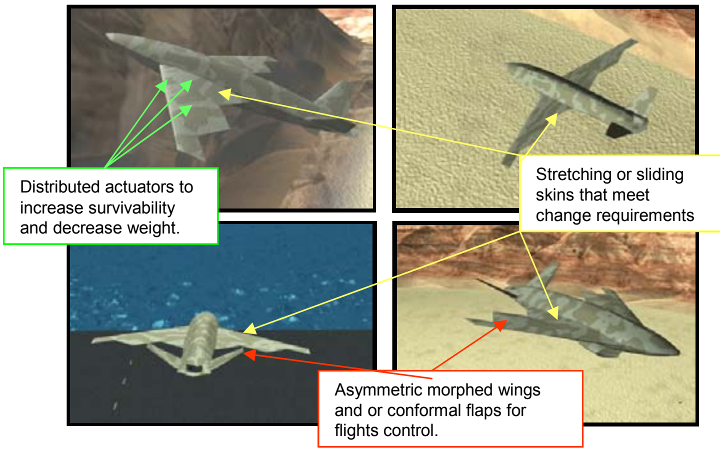


Figure from Paper SC

Application of Smart Materials to Actuation

Three papers presented interesting applications of smart materials for actuation: PZT ceramics for paper11, shape memory alloy for paper 13 and 16.

Paper 11 presented tests of multilayer PZT actuators for replacing mechanical actuators for the collective and cyclic pitch control of the blades of an UAV helicopter.

Paper 13 gave the results of the design and tests of a demonstrator structure for trailing edge shape control, using push/pull shape memory alloys wires to replace conventional mechanical alloys. These tests, including durability demonstration, showed that the design is adequate for application.

Paper 16 investigated use of shape memory alloy to vary cowl deflection, lower lip deflection and an adaptive ramp, all this on the basis of a F 15 air intake. A full scale inlet comprising cowl deflection and lower lip deflection was successfully tested under realistic loads in a transonic wind tunnel.

All these three papers are showing realistic solutions, close to application.

Adaptive Stiffness for Air Vehicle Drag Reduction

At first look, paper 15 went in opposition to all aerospace technologies trends since the advent of cantilever monoplanes: it proposes to reduce wing stiffness.

But at a second look the possibilities of active control may allow us to do that, and a further exploration of this concept may be performed in order to have a better base for judgement.

General Discussion on Session 3

During the discussion the following comments were made:

- Weight of joints and their effect on the system needs to be considered.
- There is a need for higher power density distributed actuation systems.
- We have to be careful about "over selling" morphing, we should look for smaller transition opportunities.
- We need a balance of short term / long term approaches to the tech development and transition.

2.5 Session 4: Structurally Integrated Antennas

Present day military airplanes, for example fighter airplanes, are sprouting with antennas. Future vehicle will require increased situation awareness and communication capabilities including new data link concepts with additional sensors and antennas.

Structurally integrated antennas are a way to serve the "classical" objectives (reduced weight, lower drag, lower signature) but increased antenna performance is a **very strong incentive** for structurally integrated (or conformal) antennas.

Several papers dealt with the development and testing of new conformal antenna systems for different uses, cavity backed or not.

Other papers dealt with the compensation of mechanical distortion of antennas (electronic compensation versus deformation measurement).

Survey paper A presented the design and manufacturing of two prototype antennas. The first one is a multilayer dual frequency band antenna (S-band and X-band), which is integrated in a fuselage panel with a hatch type structure. The second demonstrator antenna contains an array of cavity backed antenna elements that is integrated in a composite door. Both demonstrators have been tested for electromagnetic performance.

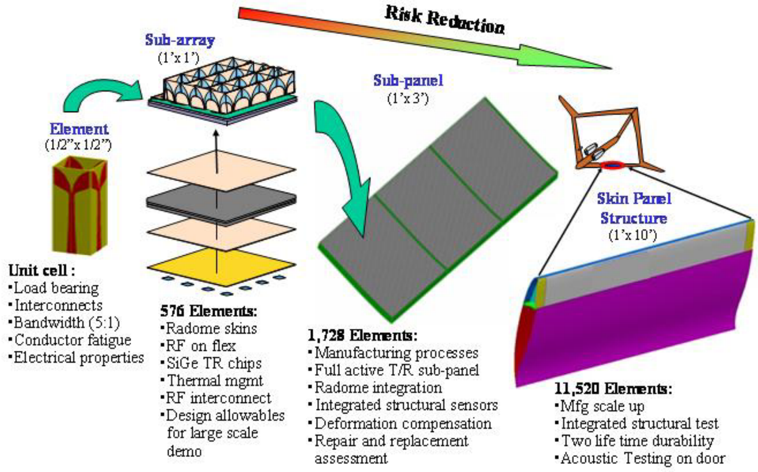
Paper 17 dealt with the development of a large structurally integrated X band array to be used on the leading edge of sensors aircraft.

This very ambitious programme is under way. The 3 by 1 foot panel is to be tested in 2007 in an anechoic chamber to check compensation of mechanical deformations.

Also durability, and repairability were a concern in the design and testing.

A quotation from the author of this paper: "conceptually very simple, But practically very complex".

Paper 18 presented the design and electromagnetic tests of an integrated array using Planar Circularly Symmetric (PCS) Electromagnetic Band Gap (EBG) structures. The tests demonstrated the expected benefits.



Paper 19 presented a theoretical study on the compensation of vibration and static deformation of non planar arrays antennas; results of a method of passive compensation of deformation based on an estimation of the element position are shown. This model works well for static or low frequency deformation, but is not very good for high frequency deformations.

Paper 20 investigated the effects of vibrations of an array of antennas on a structure. Tests were done for an array antenna on a vibrating plate; the method used for compensation was electronic measurement of phase change, and this provided significant improvements if enough "snapshots" are available.

Paper 23 shows results of the application of a commercial code for the radiation pattern of several types of antennas.

Paper 24 investigated the effects of platform deformation on a large interferometer to be implemented on a motor glider. Tests were done in anechoic chamber with a representative mock up. A compensation method using opportunity sources present in the antenna environment worked well for limited static deformations (less than half the wavelength). Other methods (hybrid methods?) will have to be considered beyond that.

Paper 25 presented the design and test results of two conformal antennas for broad band line of sight communications. In addition to electrical tests, structural tests in bending were performed satisfactorily.

Conclusions and Discussion on Structurally Integrated Antennas

For this technology, which has a strong future, many studies and developments are under way. The results are really encouraging, and practical application can be very close. Some more tests concerning durability and ageing are still necessary, but it must be noted that in all the case studied the elements are removable and replaceable, and that limits the risks in case of durability problems.

During the final discussion the following recommendations were made:

- Need to work processing with regard to time phase coherence. Consider breaking arrays into subarrays and do not worry about side lobes.
- Much effort must be devoted to the challenge of the integration of disciplines and people of three specialties:structures /RF/space time adaptive processing (STAP) (that meeting was a good example of such integration!).

3.0 GENERAL CONCLUSIONS

This meeting was successful meeting combining some very much "Technology Watch" subjects, and others close to practical application, all with the potential to have a significant impact (evolutionary/ revolutionary) on future military systems.

It provided also a very good forum for cooperation/integration between very different disciplines like structures and RF, and there was a consensus in the audience that such cooperation should be promoted.

4.0 RECOMMENDATIONS

- Long term exploratory subjects are to be pursued (in particular for structures that are by essence long term developments).
- We need a balance of short term/long term approaches to the tech development and transition (we should also look for smaller transition opportunities).
- In all cases durability/repairability of integrated structures are to be taken into account.
- For integrated amour/energy storage ballistic effectiveness should also be verified.
- For integrated health monitoring systems effectiveness/durability/cost all need to be considered to ensure that the entire cost picture is understood.
- For integrated antennas much effort must be devoted to the challenge of the integration of disciplines and people of three specialties: structures /RF/space time adaptive processing. Further cooperative actions like this meeting are to be recommended.