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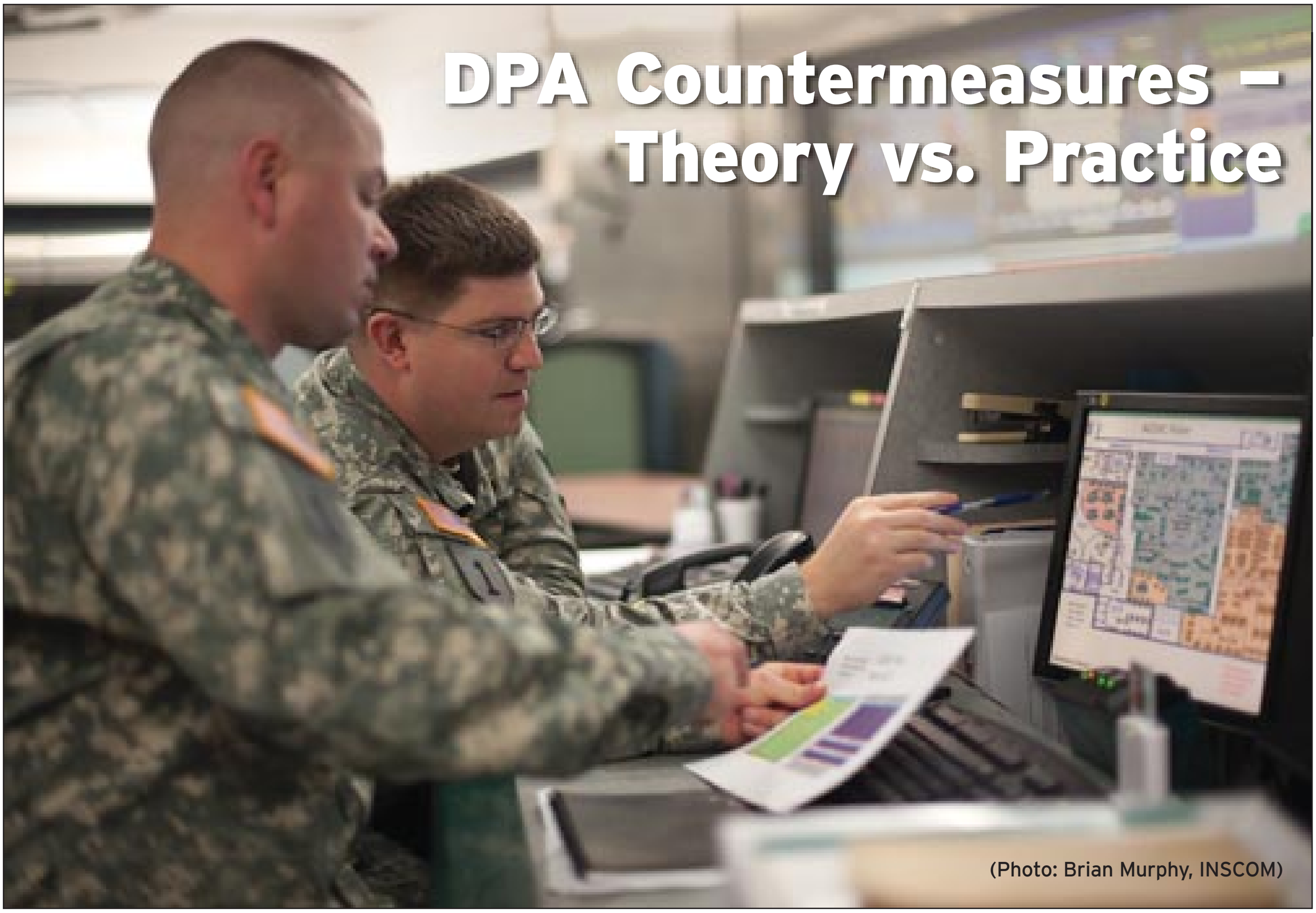
ON THE COVER

An Airbus Defence & Space A400M releases flares during a flight demonstration. Airbus DS is hoping that its expanded product portfolio will give the company a stronger global presence in military markets, complementing its success in civil markets. To learn more, read the feature article on page 20.

(Photo courtesy of Airbus DS)

DPA Countermeasures – Theory vs. Practice



(Photo: Brian Murphy, INSCOM)

The Threat

In today's interconnected world, the information that we generate, store, transmit, and receive has become a valuable commodity. We have increasingly turned to cryptography as a tool to protect the confidentiality and integrity of this information, but we read almost daily about those protections being defeated. Skilled practitioners can often successfully mount attacks using only very modest resources to break unprotected devices. Attacks on FPGA bitstream encryption, as often reported in the open literature, represent significant examples of the DPA (Differential Power Analysis) threat for the aerospace and defense community.

The magic of cryptography is the ability to protect our data – large secrets – with much smaller secrets, in the form of cryptographic keys. It has long been understood among experts in cryptographic implementation that the generation, storage, and use of keys must be performed in a way that prevents the loss of those keys, because loss of a key is tantamount to losing all of the data that has ever been protected using that key. It has been demonstrated that one does not have to physically tamper with a device to recover a cryptographic key – cryptographic keys may be recovered from an electronic device via information leakage in the form of timing variations, electromagnetic (EM) emanations, or variations in power consumption resulting from the operation of a cryptographic function. As a class, these methods are referred to as side-channel attacks; however, these attacks are often generically referred to as differential power analysis (DPA) attacks.

DPA attacks are particularly powerful techniques that can uncover the cryptographic key from large amounts of data by using statistical methods to determine the variance in a system's electrical activity when the cryptographic element is operating. The electrical activity data can be obtained through direct circuit power measurement or electromagnetically via an antenna. Electric power or EM signal traces can be very noisy due to system or measurement effects. The statistical methods used in DPA help reject the noise and make it an effective technique in real-world applications.

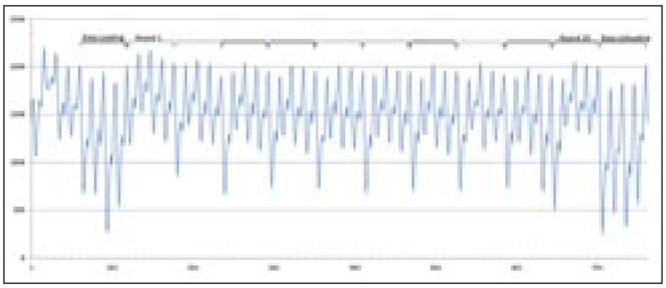


Figure 1. AES-128 operation without countermeasures power trace. Note clearly visible characteristic AES 10-round structure with different 10th round.

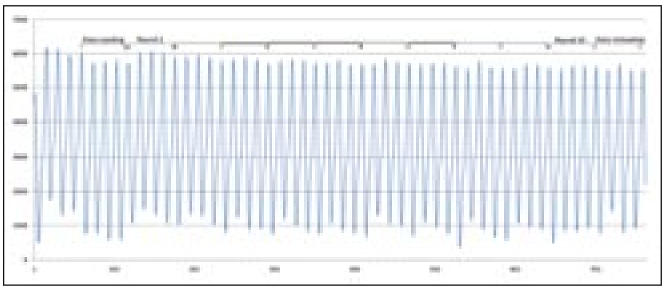


Figure 2. AES-128 operation with countermeasures power trace. Location of AES rounds provided by a separate trigger signal (not shown).

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What to Do About It

Fortunately, it is possible to create countermeasures against side-channel attacks. Different algorithm implementations leak in different ways, so each algorithm implementation will have different countermeasures requirements. Some algorithms may leak in such a way that collecting a power or EM trace from a single operation may reveal a key, while other algorithms may require collection of traces from a number of operations to recover a key. Selecting an effective countermeasure strategy requires knowing how much an algorithm implementation leaks and how many operations will be performed in the actual system. If a large number of operations will be performed in a short period of time, then an adversary may be able to collect a large amount of data quickly, which implies that stronger countermeasures may be required compared to an implementation that performs infrequent operations.

There are several general classes of countermeasures, each with advantages and disadvantages [see sidebar]. The strongest countermeasure implementations combine several techniques to create a robust solution. Two classes of countermeasures that reduce the signal-to-noise ratio (SNR) are leakage reduction and adding uncorrelated noise. Leakage can be reduced using a number of proprietary methods, and uncorrelated noise can be added by operating other circuitry using random data. Protocol countermeasures and other sources of randomness, if used, can provide a multiplicative benefit on top of SNR reduction. It is important to be aware when implementing countermeasures that there is a significant body of patents in this domain.

Figure 1 shows a very typical appearing power trace for a representative AES operation without countermeasures. Individual clock cycles are clearly identifiable in the trace, and the 10-round structure of the AES operation with a 128-bit key is readily apparent. Furthermore, the 10th round, which lacks the MixColumns operation of the prior 9 rounds, is distinct. Experienced attackers have learned to recognize structures such as the power trace shown in Figure 1 and use such structures to mount attacks.

Classes of Countermeasures

- **Protocol countermeasures.** Protocol countermeasures limit the number of traces that may be collected with a fixed key by changing the key frequently – sometimes as often as once every operation. One example of this is key rolling – changing the key after every operation using a non-linear one-way function such as a hash. This is a very strong countermeasure; however, it is not applicable in standards-based operations, such as IPsec, that do not have provisions for such countermeasures.
- **Leakage reduction and adding noise.** Leakage reduction countermeasures and additive noise are often combined to reduce the signal-to-noise ratio (SNR) of side-channel leakage. Reducing the SNR of side-channel leakage increases the number of times that a key can be used before an adversary might be able to recover it. Unlike protocol countermeasures, this class has the significant benefit of being transparent to the application enabling its use in standards-based operations such as IPsec.
- **Incorporating randomness.** Randomness may be incorporated in a number of ways in the implementation. For example, there might be multiple implementations of an algorithmic step in a software implementation, and the specific version used can be randomly selected on each usage of the step.

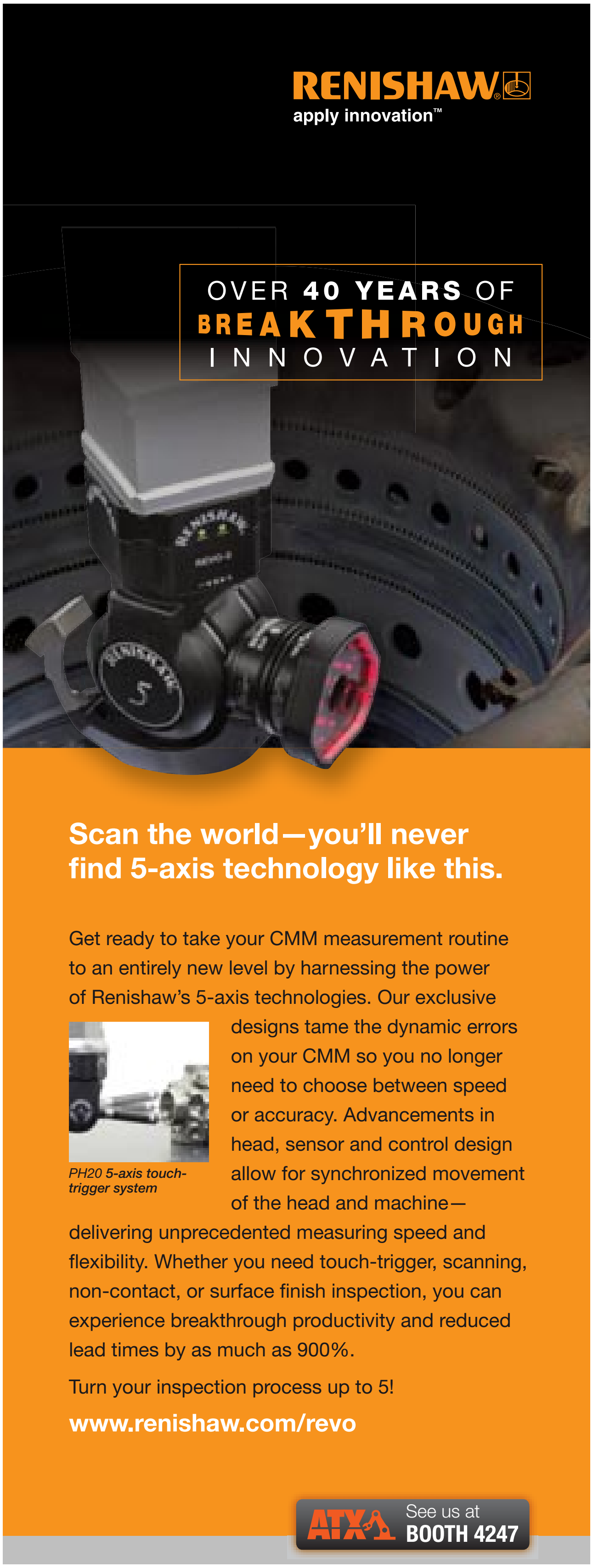
Figure 2 shows a power trace for the same AES operation, but with SNR reduction countermeasure. Note the lack of apparent structure of the AES operation, especially when compared to Figure 1. Moreover, Figure 2 data was captured in a clearbox test environment using a dedicated trigger to identify the start of the AES operation. The blackbox environment available to an adversary creates a decided disadvantage for even locating the operation, let alone beginning an attack. While this compelling visual evidence demonstrates the impact of the countermeasures, what is really needed is quantitative evidence about the robustness of an implementation against SCAs.

Does it Work? Statistical Proof

Knowing that a countermeasure is effective is a challenging problem. Much of the literature on side-channel attacks focuses on actually recovering a key from a device. If such an attack recovers a key, then it certainly leaks; however, if an attack fails, the only conclusion is that the specific attack failed. Further, the result of a specific attack provides little or no information about the robustness of an implementation against another attack – extant or future. The challenge for the designer is to verify the robustness of their implementation against any attack.

The solution is to measure the cryptographic function operation for any statistically significant variation in emanations that is correlated to the key and any related intermediate values against a specific number of traces. This method, introduced by Rambus Cryptography Research Division, is called test vector leakage assessment (TVLA). As its name implies, leakage of information is assessed by the execution of millions – even billions – of test vectors. Power and EM fluctuations are measured and processed as each vector is executed by the device under test, revealing if there is any statistically significant correlation between the measured fluctuations and the keys. The TVLA measurements are normally taken in a laboratory environment using advanced test equipment to provide the best data possible.

TVLA provides a means to assess the effectiveness of countermeasures. Significantly, TVLA shows whether there is a side-channel information leak, but does not show how to exploit it, or whether it can be successfully exploited. Therefore, TVLA is a pessimistic assessment tool; however, to have confidence in the resistance of countermeasures to future attacks, each implementation must pass TVLA



for the specific use case. In specific, if TVLA shows information leakage, there is a probability that an attack can be developed to exploit it, provided that the adversary can observe the number of operations used for TVLA. Conversely, if TVLA shows no statistically significant leakage, the probability is that no effective attack could be developed based on observing the number of operations used for TVLA. This is the ultimate goal.

There are many countermeasures described in the open literature, and many of the resulting implementations leak – a lot – against TVLA. There are a variety of specific reasons why a countermeasure that mathematically should be effective might not work in practice; however, in general there is a large abstraction between the mathematical representation of a countermeasure and its implementation in digital logic, which itself is an abstraction constructed from an analog circuit.

The takeaway is that the effectiveness of any countermeasure implementation must be verified. Verification using a key recovery attack may reveal a leak; however, a failed key recovery attack proves little. The TVLA methodology is a kitchen-sink approach that identifies any leakage, whether exploitable or not.

Countermeasures: Costs and Benefits

The development of countermeasures is a costly endeavor. Successfully developing effective countermeasures may require hundreds of iterations, potentially over a period of years, through a costly process of design, implementation, and assessment. Therefore, to produce a new design with countermeasures, it is necessary both to establish the design and test infrastructure and invest the necessary human resources. In addition, implementing countermeasures actively changes system computational and/or electrical operations in ways that can make the system more difficult to design and more expensive to build. And then there is the ongoing cost of ownership when the design is applied to new systems with varying requirements and evolving implementation technologies.

Like other cybersecurity techniques, countermeasures address a particular type of threat. The system security as a whole must be designed with an understanding of the role that countermeasures play in the system solution, balanced with the cost/benefit of their implementation. For example, many unique countermeasures techniques may be used in tandem, as individually each unique technique can incrementally contribute to overall countermeasure performance. Therein lies the tradeoff analysis – how strong do the countermeasures need to be, and what are costs in terms of performance, area, power, and schedule? Correctly implementing security is difficult, and correctly implementing DPA countermeasures is even more so. There is no simple blueprint.

This article was written by Dr. Jonathon Mellott, Chief Technology Officer, The Athena Group, Inc. (Gainesville, FL). For more information, visit ***http://info.hotims.com/61058-500.***

A Hardware-Centric Approach to Countering Side-Channel Threats

From laptops and mobile devices to cars and airplanes, we are seeing near-daily threats to the systems and devices we use. Systems being used and deployed in the aerospace and defense industry are facing the same problem. As their complexity has increased, so has their attack surface, making them increasingly vulnerable to security threats. There has also been substantial growth in malicious, state-sponsored organizations targeting defense systems that are adept at discovering vulnerabilities, and using them to compromise the integrity of systems and exfiltrate sensitive information.

Cryptography is a basic building block for ensuring system security. For example, within a single system, digital signatures can be used to verify the integrity of the code, allow for code updates, and configure data before they are executed on a system. In addition, encryption and message authentication codes are used to protect sensitive information kept on the system from leakage or modification. Lastly, communications between systems can be protected by public-key infrastructure, encryption and authentication.

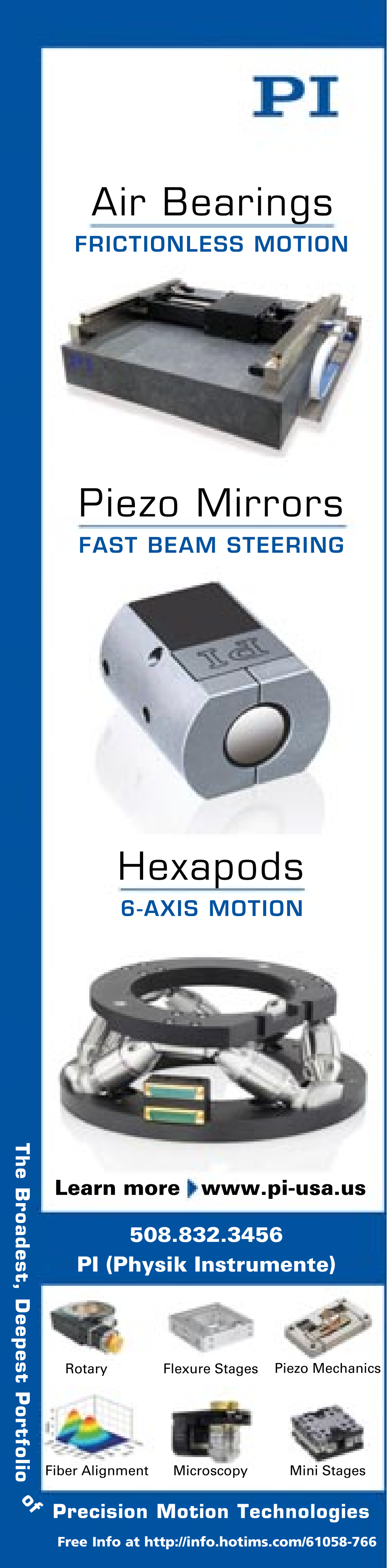
However, cryptography itself relies on operations with secret keys that must be maintained securely to ensure the secrecy and integrity of the information it is defending, and protecting these secret keys can be a significant challenge. Given the large number of vulnerabilities in complex software-based systems, most well-secured systems used in the aerospace and defense industry rely on tamper-resistant hardware to securely store and operate these secret keys. But, even in well-secured systems, there is a class of attacks applicable to all software or hardware cryptographic implementations that can easily and non-invasively steal secret keys.

Known as "side-channel attacks," these attacks measure information that comes out of a piece of hardware – biases in power consumption, EM, and heat emissions - with the intent of using that information to uncover secret cryptographic keys within a device. Once an attacker has gained access to this information – often remotely – they can analyze the collected data to recover the key. Unlike physical attacks, side-channel attacks are non-invasive, easily-automated, and can be mounted without knowing the design of the target device.

Adding to the threat is the fact that these attacks require a relatively low degree of sophistication, using tools as common as a laptop and an oscilloscope that can be easily purchased on the consumer market. Using an automated routine, an attacker can perform a side-channel attack on an unprotected device in minutes.

There are two classes of side-channel attacks. The first, known as a simple power analysis (SPA), recovers a key from a single cryptographic transaction. This requires a strong signal, close proximity to the target device, and is more commonly applied to public-key cryptography-based systems, where bits of the secret, private key control the sequences of operations performed within the device. In these settings, different operations create different observable features within the side-channel signal. By observing the sequence of features in the side-channel signal, the attacker gains information about the key-dependent sequence of operations that were performed in the device, from which the secret key can be deduced.

More concerning is Differential Power Analysis (DPA) and a related attack known as correlation power analysis, which can piece together a key from the statistical analysis of multiple side-channel measurements from operations performed using the key. By leveraging the law of large numbers to exploit small sources of power variations – all the way down to single transistor switching – an attacker can conduct an extremely devastating intrusion. This means it can be applied to symmetric key-based algorithms, where the sequence of operations is



key-independent and only the data processed by the operations varies, as well as in situations where the collected side-channel data is very noisy or of otherwise poor quality. In essence, DPA exploits the fact that every hardware component or subcomponent involved in cryptographic processing makes a data-dependent contribution to the overall power or EM measurement, and this contribution, however miniscule, compared to other unrelated activity or noise, can be detected and targeted using statistical analysis, given a sufficient number of traces.

A successful side-channel attack can give an attacker access to otherwise restricted systems within a device. For instance, keys can be used to decrypt or forge messages, issue rogue commands, clone a device, and insert Trojans. Given these significant security threats, there are requirements for power analysis countermeasures to be used in tamper-resistant products.

Early research into side-channel attacks focused on smartcard transactions, but time and study has shown that the threat goes far beyond smartcards into large, complex systems, mobile devices, point-of-sale devices, and much more. The integrity of many computer systems, and often entire networking infrastructures, can depend on a handful of critical root keys that can be discovered via side-channel attacks. Power-analysis attacks are a threat to any device or system that processes sensitive information and requires tamper resistance.

So, how can we ensure that side-channel attacks are not used to penetrate sensitive pieces of hardware? One solution is to simply make hardware that does not show biases in power consumption. However, this is nearly impossible to achieve in a way that is affordable or scalable. Instead, we must secure the hardware available to us today, and the most secure approach is to have countermeasures built-in to the cryptographic hardware.

To thwart hostile electronic eavesdropping, researchers have developed countermeasures that negate or significantly limit the threat of DPA and SPA attacks. One technique is to add noise in the side-channel measurements to drown out the sensitive cryptographic activity with other unrelated activity or by activating noise generators (amplitude noise). A related technique is to add clock-jitter, random-delays, instruction sequence reordering, or dummy operations to introduce uncertainty as to when a particular operation occurred. These noise countermeasures decrease the signal-to-noise ratio for attackers, forcing them to collect a much larger number of traces to detect and target the cryptographic activity.

However, in practice, noise addition can be costly and is not a strong deterrent by itself as the number of traces grows quadratically with decrease in signal-to-noise. A stronger technique is to incorporate randomness in the cryptographic calculation itself. With this approach an internal hardware-based random number generator is used to mask the data values that are processed within the cryptographic calculation, so that each data processing step, and thus the side-channel leakage from it, is statistically independent of secrets. The cryptographic calculation itself is modified so that it can operate on randomly masked data values and the random masks to still produce the correct result.

While these masking techniques do increase size of the implementation by a small factor, they increase the number of traces needed to perform an attack exponentially. Noise addition and random masking based techniques work in concert to ensure that information about the key contained within the side-channel measurements collected by any attacker are substantially reduced or dispersed, making key reconstruction from any reasonable number of traces statistically infeasible. These hardware solutions start with the core itself, ensuring that processing components powering aerospace or defense systems are immune to the threat of side-channel attacks from the moment they leave the production design.

This article was written by Pankaj Rohatgi, Fellow, Hardware Security Solutions, Rambus Cryptography Research Division (Sunnyvale, CA). For more information, visit ***http://info.hotims.com/61058-501.***

Optimizing Thermal Management to Meet SWaP-C Requirements

As defense systems continue to shrink, corresponding thermal management concerns expand exponentially. Designers have learned that overheating can be the downfall of even the most well-designed systems. Suppliers of today's box-level systems continue to make strides in reducing the size, weight and power (SWaP) of these systems to meet mil-aero deployment demands. However, smaller systems may be more difficult to cool, adding an additional design mandate to keep the system within specified heat parameters, making thermal management that much more important in meeting environmental deployment specifications. Therefore, optimized cooling techniques need to be employed to meet SWaP-C (Size, Weight, Power and Cooling) needs that are now a vital part of the development process.

Designing ruggedized systems for high mission-critical reliability requires testing and validation employing sophisticated thermal modeling tools and computational fluid dynamics (CFD) evaluation techniques to accurately predict airflow, temperature distribution, and heat transfer in components, boards and ultimately the complete system. These tools must take many thermal methodologies into consideration, such as optimal fin geometries based on the internal system layout along with the component conduction path. This article covers the main critical focus areas in box-level computing platforms that need to be solved with thermal optimization.

Thermal Design Approaches

The thermal design approach that has proven most effective over time is to implement all of the required system functionality in a chassis that has been pre-certified for ruggedized operation in contrast to trusting a chassis that is categorized as "designed to meet." Systems that have been manufactured and validated to meet the various environmental requirements of MIL-STD-810G give developers assurance of their ability to withstand specified extremes of temperature, vibration, shock, salt spray, sand and chemical exposure. This way, the system is certified to maintain a sealed and temperature-controlled environment protecting and ensuring the reliability of the electronics inside.

Another thermal management consideration is to evaluate the possible effects of radiative cooling in passively cooled convection systems that operate at low power. The size, weight and power reductions in military electronics cause radiation to have a significant impact on where components can be placed or where the completed system can be deployed. A frequent remedy for radiation-impacted systems is to look for a sealed system design that uses a natural convection approach that delivers both scalability and excellent power dissipation.

Designing for ruggedization requires testing and validation employing sophisticated thermal modeling tools and CFD evaluation techniques to accurately predict airflow, temperature distribution, and heat transfer in components, boards, and ultimately the complete system. Consider that a typical small form factor aluminum chassis, where the enclosure is 15 to 20°C over ambient, may dissipate up to one third of its power through the effects of radiation. This is a significant proportion of overall power dissipated and can become even more significant at the higher altitudes experienced by UAVs for example.

Evaluating Thermal Optimization Techniques

For the thermal optimization of rugged box-level systems, there are four primary focus areas to explore and ultimately solve:

1. Computational fluid dynamic (CFD) driven parametric optimization of the enclosure fin interface with the ambient environment.
2. A system level thermal analysis to determine the power dissipation trade-offs and impacts of one internal sub-system versus another.

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3. Exploration of primary internal thermal conduction paths to the enclosure.
4. An evaluation of installation platform thermal contributors to overall system performance.

The design of the cooling fin geometry is a good first step when perfecting the thermal performance of a natural convection cooled product. For example, a baseline design that has proven to work well is to incorporate finning formed into the enclosure housing upper surface. This design takes away as much heat as possible from the circuit board and processor, which is typically placed just underneath the housing surface. The upper surface fins can be supplemented if needed with various sized modular rear and side wall mounted heat sinks.

With multiple fin design parameters to evaluate in addition to the four finned surfaces on the enclosure, the frequently used iterative and general understanding approach typically takes too much valuable development time and may not result in meeting the application's performance goals. Today, there are new advanced software tools that allow the designer to get more detailed data than what is offered with traditional CFD software tools. For example, there is a design optimization tool that compliments the existing ANSYS Icepak CFD software that uses powerful algorithms to evaluate sensitivities against multiple variables to guide the engineer to the most advantageous fin geometries for a given design.

Through the careful application of these new tools and analyzing a large "Design of Experiments" suite of design scenarios, these sophisticated software tools streamline the task of determining the fin geometry best suited for a specific application environment in the fewest number of iterations. It is still always wise to verify these fin design parameters in the final CFD analysis. There are graphs that show the relative heat dissipated from the processor when various fin parameters are plotted (thinner vs. thicker; fin spacing) and which direction the design should take next.

Subsystem Evaluation

The other sub-systems inside the enclosure also need to be evaluated. From this evaluation, designers can best determine what design trade-offs, if any, are required. A typical trade-off evaluation can include looking at the power dissipated by an optional XMC expansion card, and the potential rise in operating temperature from the processor on a computer-on-module board in close proximity. This is where CFD tools can be used to test the thermal relationships between the various electronic modules.

As most companies have finite element analysis, using CFD tools to test likely areas that can cause heat problems becomes invaluable information. Key subsystem areas to look at include component maximum operating temperatures, low and high temperature processor thresholds, power and power density of components, and sidewall versus internal to external wall conductive path components. All these are important when selecting an optioned product profile for a specific application, as well as to maintain compliance with customer-specified MIL or RTCA test standards.

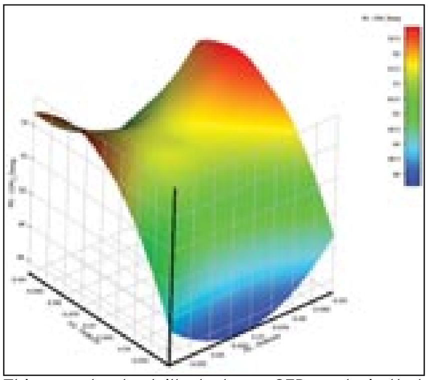
Internal Conduction Path Optimization

The solid state conduction paths from high-power components inside the enclosure must also be confirmed to make sure there are efficient thermal paths to the enclosure walls. To accomplish this, thermal simulation tools inside the CAD design software can be leveraged to find an optimal solution. As an example, the width of heat spreader may need to be changed to optimize the gradient thermal path to the top surface. The final solution should provide minimal thermal resistance while at the same time maintain a low mass to be most effective.

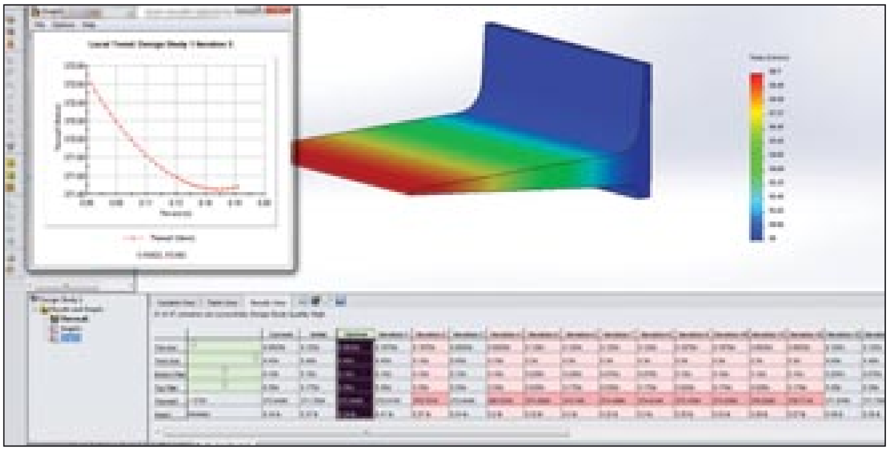
Operational Platform Thermal Factors

The last area to evaluate is operational environment where the intended box-level platform and full system will be deployed. Local environmental factors can considerably impact the "as installed" performance.

So how close to the performance envelope is the system and platform if it needs to be deployed in, for instance, thinner air conduction conditions? Thus, the mounting platform material, mounting orientation, vicinity to other electronic equipment, altitude and potential solar loading are all factors that require careful consideration. A system on a UAV may have the benefit of a colder environment but there still is the thinning atmospheric effects at higher altitudes to consider that can affect, for example, cooling fans.



This sample chart illustrates a CFD analysis that evaluates CPU temperature versus fin parameters on a response surface.



Using CAD design software, this example shows that the heat spreader geometry would need to be revised in the final solution.

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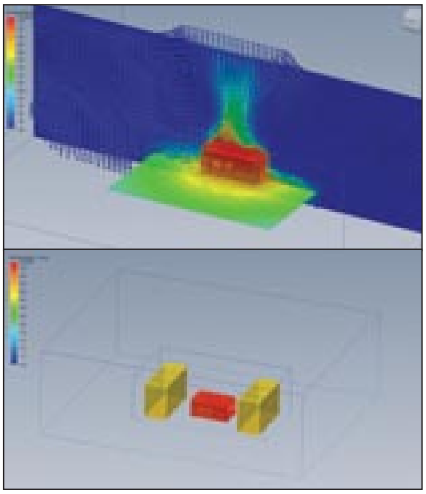

Thermal optimization must look at operational factors such as cold plate placement and neighboring electronics radiation exchange.

The two relevant examples here show typical operational factors to evaluate for thermal optimization. The first considers the impact of mounting a small box-level form factor platform on an aluminum cold plate. The second considers the radiation exchange of neighboring electronic enclosures of similar power.

These evaluations spotlight the need for a thorough understanding of contributing thermal factors to select the right solutions that address the issues and ensure reliable operation of the system in the "as installed" environment. For the most part, defense system engineers are innovative in finding creative cooling solutions to complex problems and are expert at designing for worst case scenarios.

Thermal Optimization Makes Trusted Systems

What doesn't seem to change is that expectations of current and next-generation defense systems continue to expand, calling for ever more integrated capabilities from increased computational performance and communication bandwidths that equate to greater power consumption, resulting in higher heat generated. These same systems must also meet SWaP-C and extreme ruggedization requirements. While currently available box-level computing systems have advanced to meet these requirements, it cannot be underestimated that careful consideration must be made to maintain mission-critical reliability by effectively handling many thermal issues — from the ambient environment and inherent component/subsystem power dissipation to additional "as installed" thermal factors. A comprehensive understanding of these contributing thermal factors will ensure the reliable operation of a deployed rugged system.

This article was written by Simon Parrett, Conceptual / Structural / Thermal Engineer, Kontron (Poway, CA). For more information, visit ***http://info.hotims.com/61058-502****.*


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Fighting for Life in Military Markets

Airbus Defence & Space is looking to revitalize and ramp up production rates of its military aircraft portfolio.

by Richard Gardner

Nose view of the Airbus Defence & Space A400M, which has a very extensive DASS system that includes radar warning receivers and other systems, some of which are customer specific. (Richard Gardner)

Visits to the Seville headquarters of Airbus Defence & Space (Airbus DS) have often reflected stormy prospects for the company's large-capacity A400M Atlas transport, which has suffered cost increases, delivery delays, technical issues, and order losses.

One media briefing in particular had been scheduled for May 2015, but by a cruel twist of fate, had to be cancelled at the last moment due to the fatal crash of a brand new Atlas aircraft on its first flight after emerging from the assembly line.

The cause of the crash, as the aircraft climbed out after lift-off, was soon tracked down (it involved the engine electronic control unit) and was quickly rectified, and the rest of the year was dedicated to recovering from the period when final assembly was halted. This was particularly problematic as the monthly production flow had been gearing up before the crash incident. Now, every effort is being made to get the program back on schedule, with Atlas deliveries steadily building up again.

A Test Program for A400M

The flight test program for the A400M Atlas was to form a major part of the update briefing at Seville. The A400M flying totals have risen to 7903 hours on 2901 flights. Particular achievements during 2015 included many important way points: the first flight refueling receiver trials from an A330 MRTT, DASS (defense aid subsystem) and RWR (radar warning receiver) self-defense tests, paratroop deployment trials, and off-runway surface tests.

Associated with low-level flights was certification of an enhanced vision system with night vision goggles (NVGs). Certification of low-level free-flight down to 150 ft was achieved in late 2014, with height down to 500 ft using NVGs. Infrared sensors and flare systems were also tested under many different conditions and included full flare jettison.

Various dynamic air drop tests have taken place with live jumps, which have unfortunately confirmed that there are issues involved in using the two rear side doors for troop air drops. Turbulence from the engines causes cross-over problems that can bring departing paratroopers into contact with each other after exit. A test aircraft is being fitted with a spoiler that it is hoped may solve the problem, but tests will continue into 2016 using full-size representative dummy troopers.

Past tests in September and October 2015 included landings and takeoffs from grass runways and soil surfaces. The third stage in these tactical op tests involved further operations from sand surfaces.

The landing gear of the A400M incorporates the first certification of technology based on micro-strain measurement to indicate to the pilots that the gear has functioned correctly and wheels are on the ground or in

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flight. The traditional system based on proximity sensors has been changed by a calibrated pin (strain measurement) design. Due to the aircraft's landing gear configuration this new system has significantly improved the landing run performances on low friction surfaces.

A400Ms are shown during mission prep on the flightline. Airbus DS was known previously as Airbus Military but it now also includes other defense businesses of the former EADS, which have combined and been re-packaged. (Richard Gardner)

Expanding Product Lines

Airbus DS Chief Salesman Antonio Rodriguez Barberan recently provided an overview of the military product line, which extends beyond the main Seville products—the A400M and C295 and CN235 transports—to Eurofighter, the A330 MRTT, UAV developments, and extensive military upgrade and sustainment support services.

He said the company's aim is to be present in most military market segments and to be number one or two in each segment. This may seem a tall order, but Airbus DS is apparently well on its way to achieving this with worldwide military products that include 1800 aircraft sold to 70 countries, with 145 operators and over 5 million flight hours accumulated. An ever-growing global footprint is making the products more supportable.

Over the past year or so, Barberan said the A00M has become operational with five air forces (France, U.K., Germany, Turkey, and Spain) and presentations have been made to nine more potential customers, with "serious negotiations underway." The medium-size military transport aircraft achieved 28 orders in 2014, and 15 more were added in 2015. Airbus expects to maintain its 75% market share in this category long term.

In addition to the primary transport role of the C295 and CN235, these types are being continuously developed to cover other tasks including search & rescue, maritime surveillance, marine pollution control, anti-submarine and surface warfare, and aerial photography. The combined C295 and CN235 market penetration is around 60%. The biggest regional market is Asia Pacific with 140 sales, while Africa and the Middle East have ordered 130 aircraft.

The new C295W features enhanced engine performance and has winglets. These improvements give an 8% increase in range (out to 2300 nmi with a 4-ton load). The winglets provide an aerodynamic gain that translates into a 5.5% fuel advantage on a typical mission. The engine mode upgrade also allows a larger payload from hot and high airfields.

Efforts to further expand applications for this platform have included modifications to allow a fire-fighting role and a version for Special Forces use as a transport or a fire-support gunship. The C295's capacious cabin allows room for extensive mission systems and displays so that the aircraft can act as a signals intelligence or ground surveillance platform, with specialist sensors and multiple target tracking radar, with communications intercept and jamming equipment.

Modifications to give the C295 more weapons capability in the Maritime Patrol (MPA) and anti-submarine (ASW) roles is underway so that air-launched homing torpedoes and air-to surface missiles can be carried. The C295 and CN235 can both be given a cost-effective MPA or SAR role as they feature high maneuverability at low levels above the sea surface, combined with an endurance of up to 11 hours. The U.S. Coast Guard uses a large fleet of CN235s for law enforcement, border patrols, and para-rescue operations. Special large size bubble windows give excellent visual coverage for crew members, while electro-optical video cameras, including IR, allow all-weather and night operations.

Palletized ISR mission systems can be provided for the C295 MPA/ASW so that the aircraft can be used for transport duties when not required for ISR or MPA duties. If required to provide electronic surveillance, onboard ELINT/COMINT analysis or electronic countermeasures can also be supplied in a very compact package.

Israel's ELTA has supplied a fourth-generation AESA radar, which has been trialed atop a C295 in an aerodynamic rotating dome for the detection of multiple small and fast targets, giving 360° coverage. For the ground surveillance task, the C295 can carry high-resolution SAR/GMTI radar arrays and an EO/IR target designation turret, ESM, ELINT, and COMINT. It would seem that Airbus is keen to exploit every possible combination of ISR and EW mission roles that can be carried aboard its C295 and CN235 aircraft.

It's been suggested that close air support would be an ideal role for the C295, which could deploy parachutists and supplies and also carry underwing weapons and stores. However, the company's future planning is already looking beyond the C295 platform.

A330 Futures

Airbus DS recently shared an image of an A330 fitted with a fuselage-mounted rotating radome, which could potentially become a replacement for the current generation of Boeing E-3D AWACs that are in widespread use around the world, but many of which are over 40 years old.

Such an A330 AEW&C platform would offer plenty of volume for electronic equipment, environmental control, electrical generation and distribution systems, crew rest areas, and additional operational ISR/EW tasking potential, with extremely long range and/or endurance on station, and

Tail end of an A400M shown during final assembly in Seville. (Richard Gardner) high transit speed. But the future vision for Airbus DS doesn't end there, as it has stated that it was looking at a military configured A320 platform (which could presumably also be sized as an A319 or A321, depending on customer need), which could have a ground surveillance, EW, or MPA role, and could become a future European rival to Boeing's P-8A Poseidon.

The A330-based Multi Role Tanker Transport (MRTT) has continued attracting new customers, including two for Qatar, and three for a joint NATO MRTT group. France is to buy twelve, and South Korea has ordered four. India has announced its selection of the type. To date there are now 26 A330 MRTTs in service.

Antonio Caramazana, head of the MRTT program, said that the A330 tanker transport had been very active on military operations. Most of these operations have involved air-to-air refueling missions, but the aircraft have also been used, particularly by the RAF, for overseas deployments carrying up to 200 troops, and for supporting combat aircraft deployments carrying equipment and ground personnel.

A refueling boom capability now allows full use of the Airbus-developed control-by-wire boom to refuel USAF combat aircraft such as the F-15 and F-

The Airbus DS MRTT Voyager has settled down to being a very capable and mature military air asset, and a leader in its field, offering more usable cabin space and fuel off-load capacity, endurance and a more modern airframe than rivals. (Richard Gardner)

In addition to the primary transport role of the C295 (Chilean aircraft shown) and CN235, these types are being continuously improved to cover other tasks including search and rescue, maritime surveillance, marine pollution control, anti-submarine and surface warfare, and aerial photography. New roles being developed include ISTAR/EW, signals intelligence, firefighting, airborne early warning, and a gunship fire-support role. (Airbus DS)

16, as well as larger types such as other MRTTs and Boeing Wedgetails (737-based AEW&Cs). The MRTT has also been cleared to refuel combat fighters using the FRU drogue and probe method including the Typhoon, Tornado, Mirage, Rafale, F-18 Hornet and Super Hornet, and AV-8B Harrier.

Night refueling can now be undertaken on all these types and clearance trials were successfully undertaken at Edwards AFB and Patuxant River for additional U.S. types including the EA-6B, A-10, and B-1B. This included the first MRTT wet boom refueling of the F-35A by RAAF MRTTs. In the UK, expansion of the FRU refueling functionality included clearance of refueling trials with two different types of C-130Js, the E-3D Sentry, and A400Ms.

A series of enhancements is now being applied to new MRTT deliveries. The initial customers will be Singapore, France, and Korea for delivery from 2018. This performance improvement package has been triggered by new increased weight capability resulting from the standard upgrade of the basic A330, which has structural and aerodynamic improvements.

Inside the aircraft, there will also be new computer displays associated with an avionics upgrade. Adjustments to the military systems fitted in the MRTT include improvements to the industrialization process with more standardization of electrical and mechanical solutions. The MRTT has now settled down to being a very capable and mature military air asset, offering ample cabin space and fuel off-load capacity, endurance, and a more modern airframe.

Eurofighter Update

Eurofighter continues to offer upgraded Typhoon combat aircraft with AESA radar and other improvements. The latest customer to select the fighter is Kuwait, which is expected to buy 28. Work continues on a proposal for a new joint European MALE UAV definition phase. Other upgrade programs include improved Tornados for Saudi Arabia and refurbished P-3s for the German Navy.

Joey Borkenstein, Senior Advisor Air Combat Operations, Eurofighter, Airbus DS, says a steady program of upgrades continues to roll forward, though keeping the momentum going has not been an easy task as some customers have been slower to respond as they have not been so actively engaged in combat operations as others, who have long recognized the need to adopt progressively better avionics, radar, and weapons systems.

However, the first four upgrade packages are being implemented over the next five years, with others following out to at least 2030, ensuring the Typhoon has a long operational future. One of the most immediate upgrades is the clearance of new missiles for the RAF. The first of these will be the Storm Shadow/Taurus, which is a long-range stand-off weapon for use against well-defended key targets.

The Storm Shadow is battle-proven aboard Tornado and combines low observability with high precision. It is to be delivered for service on Typhoon by 2017. The MBDA Meteor is intended as an air dominance long range air-to-air missile with a two way data-link and an unprecedented “No Escape Zone.” This is also due to be cleared over the next year. The next enhancements cover the carriage of the latest Paveway IV precision bombs. Available in 500- and 1000-lb versions, the weapon has laser guidance and GPS/INS guidance, and Typhoon can be configured to carry up to six while retaining its full air defense role. The third new missile, being pushed as a priority by the U.K. is the clearance for Brimstone air-to-surface attack missiles.

The improved Brimstone II has been developed from the standard Brimstone, which has a proven combat record over Afghanistan, Iraq, and Syria, and features a dual-mode high accuracy seeker with a very good performance against small moving targets. It has all-weather day or night capability and is very compact so up to 12 can be carried on four triple launch mountings, without compromising AAR missile capability.

The most anxiously awaited upgrade remains the adoption for Typhoon of the Captor-E AESA radar from Selex. This features the biggest "field of regard" for any AESA of its type, thanks to its mounting on a moveable, rather than a fixed, plate. This wide angle capability allows even more multiple targets to be identified, tracked, and addressed, with multiple uses, from air-to-air interception to sea search and surface strike. It has a high resistance to jamming and can operate with various active and passive detection options. Other developments include an upgraded defensive aids suite with a more powerful jamming capability and passive geolocation.

Eurofighter continues to offer upgraded Typhoon (shown with a Paveway) combat aircraft with AESA radar and other improvements out to at least 2030, ensuring the Typhoon has a long operational future ahead of it. (Eurofighter)

Airbus DS is hoping that its expanded product portfolio will give the company a stronger global presence in military markets, complementing its success in civil markets. Airbus has had its fair share of A400M challenges to date, but now that Boeing has delivered its final C-17 military transport aircraft, bringing an end to the famous Long Beach aircraft production line, customers requiring a larger military air transporter than the C-130J Hercules, will only have the Airbus A400M Atlas available from Western manufacturers. This may indeed ensure that it will have a long production future ahead of it.

Clamoring for More Entertainment

Connected consumers drive demand for bandwidth, though seatback entertainment remains popular.

by Terry Costlow

Consumer expectations for information and entertainment are creating big challenges for airlines that need to provide Internet access while providing inflight services that mirror what's available in the home and office.

Seatback screens are being eliminated on some flights, but they still remain important for lengthy flights, prompting system designers to create cost-effective displays and sound systems that mimic the performance of HDTVs and high-resolution tablets.

Whether they're on the plane one hour or 12, consumers have made connectivity the watchword in commercial cabins. For many passengers, Internet access is almost as important as a pressurized cabin. The race to provide high bandwidth links is making satellite services a critical part of the airline industry.

Constant Contact

Many of today's constantly-connected consumers balk at spending a few hours without Web access. Commercial airlines are responding by forging links with satellite providers that give flyers the same capabilities they have on the ground. Increasing bandwidth is one of the focal points for inflight entertainment and connectivity (IFEC) systems.

"High throughput satellites (HTS) are going to be launched in early 2016, which will make exponentially more capacity available," said Panasonic Avionics Corp. spokesman Brian Bardwell. "Layering these HTS spot beams over our existing wide-beam network ensures both global coverage and the greatest throughput. Our wide-beam network today covers 99.6% of all commercial flight hours, offering up to 50 Mbps. HTS capacity that will bring 200 Mbps, as well as extremely high throughput capacity, that will bring up to 3.3 Gbps in certain regions."

Panasonic's satellite partner, Intelsat, currently estimates that its global broadband aeronautical throughput is 350 Mbps. That's expanding rapidly now that newly launched Intelsat's EpicNG satellites each add 25-60 Gbps of capacity. They offer both wide and spot beams, enabling intelligent use of spectrum to provide as much as 200 Mbps to a plane flying through any given beam.

Lufthansa is giving passengers the option of using portable electronics or seatback systems.

Other airline and satellite partners are making similar moves. Jazeera Airways plans to install Rockwell Collins' PAVES Cabin Wireless and Inmarsat's Global Xpress connectivity on its Airbus A320 aircraft by late 2016. That will let more than 500 passengers stream video content simultaneously while also using an array of apps and services.

"Inmarsat's Global Xpress constellation is set to transform the passenger experience. Airlines can offer inflight connectivity that is fast, reliable and consistent, with coverage across the world," said Leo Mondale, President of Inmarsat Aviation.

Inmarsat also equipped more than 150 Lufthansa planes with its Global Xpress commercial Ka-band satellite network. Lufthansa plans to continue this rise in bandwidth.

"To keep up with the new Ka satellite technology, the Ku system used for the airlines will be upgraded to high-throughput satellites, and at a later stage to extreme high-throughput satellites," said Sabine Hierschbiel, Connectivity & IFE Systems Manager at Lufthansa. "This will improve performance, providing much more bandwidth to the individual user."

Passengers will readily ask for more bandwidth, but airlines and satellite providers have to figure out how to provide it profitably. At some point, consumers and providers alike will determine that they're no longer willing to continue the upward spiral. Airlines may be the ones to tell consumers that their usage will have some limits.

"All this has a natural end, either technology-wise or in an economical aspect," Hierschbiel said. "So it will be interesting to see how long the industry is willing to continue this growth, or if at some time the industry will set parameters to the kind of usage being offered inflight."

Security will be a key factor regardless of how much bandwidth is used. Connectivity always brings the downside of the Internet: hackers and malware. A hacker who figures out how to take control of a plane could extort huge sums.

System designers block attacks through the IFEC systems by isolating aircraft control systems from the information systems used by passengers and crew. That prevents a hacker or a problematic app from causing problems with flight controls. Airlines are also ensuring that their IFEC systems aren't compromised.

Rockwell Collins teamed with Inmarsat to provide wireless communications.

"We only use the latest IT security mechanisms to ensure the data transferred over the connectivity system cannot be manipulated," Hierschbiel said. "This includes end-to-end encryption, use of certificates, hardening of connected devices, and the enforcement of strong passwords. Security analyses and audits are performed and continuously repeated. Additionally, airlines, aircraft manufacturers, and authorities are working together on regulation and processes to avoid the possibility of interference with any operational aircraft interface."

Make Me Smile

While many passengers will link their personal devices to these broadband services, others expect to leave their portable electronics home or in their carry-on. Airlines still need to give them some form of entertainment, especially on long flights.

Seat-back IFE and connectivity and streaming to passengers' devices can be complementary technologies. When airlines install seat-back screens, they're increasingly turning to technologies like high-definition displays. Consumers used to huge in-home TVs and lifelike tablets won't give good performance rating scores to airlines that offer low-resolution screens.

Passengers' desires to match their in-home environment extends to sound quality. Headsets provide an ideal way to let users set volume levels and block out the outside world. They can also provide features like immersive sound that can't be provided in cabins.

"HD Audio, the latest advancement in our IFE solutions, complements the display's visual quality," Bardwell said. "A custom HD-headset connects via USB to provide Hybrid Active


Panasonic headphones provide high quality sound and noise cancellation.

Noise Cancelling and theater-like digital surround sound. HD-Audio also features Open-Ear, which allows passengers to converse naturally when wearing the headset."

Design teams throughout the industry are striving to reduce noise in cabins. For example, Boeing's 777X interior will provide noise levels that are comparable to those of its 787 Dreamliner. Lower cabin noise is achieved through the new engine nacelle design, new high bypass ratio engines, better insulation, and a passenger cabin that doubles the number of air nozzles with lower velocity and less noise.

Getting Personal

The link between consumer technologies and IFE extends into software, leveraging cell phone operating systems. Early last year, Thales Avant rolled out an Android-based IFE and connectivity solution, first used by SriLankan Airlines' passengers. Avant lets them stream live content from BBC News, AFP, and AccuWeather.

The use of Android opens the door for more personalization. No advanced entertainment system can evolve without app support. Providers are making it simpler for consumers, advertisers, and others to leverage apps to meet varying passenger requests.

"With our Companion App mobile technology, airlines can consolidate passenger frequent flyer profiles with IFEC preference data," Bardwell said. "Onboard the aircraft, passenger preferences can be shared from the app to the in-seat monitor allowing the airline to deliver a tailored passenger experience."

Development software is also making it easier for airlines to develop their own look and feel for passengers while they also manage content. The Rockwell Collins' graphical user interface developer kit, which can be accessed through a web portal management tool, simplifies this customization. It also features an open-software architecture for third-party applications.

Rockwell Collins' PAVES seat-centric design also includes hardware advances that eliminate single points of failure. Each in-seat system is independent, so seat monitors store viewing content. The hardware also features a quick-release mechanism so in-seat displays can be replaced quickly and easily.


Boeing is helping improve passenger comfort by making cabins quieter.

Members of an Air Force, Navy, and Lockheed Martin team test the MUOS satellite communications system in Antarctica. (Air Force photo)

Cellular Satellites:

Joint Communications with Integrated Acquisition

It's a familiar image: a soldier crouching with a radio next to a spidery antenna pointing skyward to reach a distant satellite. But that view of military communications is on the verge of change, being replaced by troops rapidly exchanging data while moving seamlessly around the battle space.

This progress is possible due to the Mobile User Objective System (MUOS), the next-generation narrowband military satellite communication system that will support worldwide, multi-service users in the Ultra-High Frequency (UHF) band. MUOS will use Earth-orbiting satellites as the equivalent of cellphone towers in space, providing smartphone-like service that keeps users connected while on the move, and in challenging urban, jungle, or mountainous terrain. As the current UHF satellite constellation reaches the end of its life, MUOS will replace it with a communications capacity that is more than 10 times greater.

Through this improved connectivity, MUOS will provide military radios with a secure version of what users would expect from commercial cellular service: mission voice, data, and video on demand. It will connect warfighters on ships; in submarines, aircraft, and vehicles; and while dismounted and on the move, providing the vital link between troops in advanced positions or remote areas and the rest of the Department of Defense (DoD) military global network. Using MUOS will allow troops to stay in communication beyond line of sight, whether they are on the other side of a mountain, or the other side of the world, thereby enabling a more agile and expeditionary force.

This exponential increase in capability also brings a significant value proposition. MUOS supports all service branches and interfaces with Defense Information Systems Network (DISN) capabilities, reducing duplication and providing improved joint communications across the tactical and strategic environments. MUOS will function on numerous new or modified radios being developed by industry, supporting a competitive radio marketplace that will drive innovation and lower costs.

More than just satellites, MUOS is a complex DoD orchestra comprised of a five-satellite constellation, four ground stations across the globe, an integrated waveform, the radios, and a complex software to manage the network. It also requires that all these individual segments of the system work together seamlessly and reliably, which requires close coordination and teamwork across the programs delivering these capabilities. The acquisition warfighters of the Army Program Executive Office (PEO) for Command, Control and Communications-Tactical, and of the Navy PEO Space Systems have come together to meet this challenge and are on track to achieve MUOS full operational capability in 2017.

Capability Progress

MUOS satellites carry two distinct payloads. The legacy UHF payload provides the capability of the UHF Follow-On satellite constellation, while a new UHF MUOS waveform payload will significantly increase availability and throughput to the user. The dual-payload design supports a gradual transition to MUOS capability, allowing backward compatibility with legacy UHF terminals while providing a next-generation waveform to support communications on the move and higher data rates for dismounted users. The new MUOS waveform leverages widely used commercial Wideband Code Division Multiple Access (WCDMA) cellphone technology.

The first satellite, MUOS-1, was launched from Cape Canaveral, FL in 2012, and transitioned into operational use for legacy terminal users in November of that year. MUOS-2 launched in July 2013, and relocated in January 2014 to its operational slot more than 22,000 miles above the Earth, where it also provides legacy UHF communications. MUOS-3 was launched in January 2015, and MUOS-4 was launched in September 2015. MUOS-4 will be relocated this spring to its on-orbit operational slot in preparation for operational acceptance. MUOS-5, an on-orbit spare, also will be launched this year.

Operationally, user information will flow to the satellites via UHF WCDMA links, and the satellites will relay that information to one of four interconnected ground sites in Hawaii, Virginia, Italy, and Australia via a Ka-band feeder link. These facilities identify the destination of the communications and route the information to the appropriate ground site for Ka-band uplink to the satellite, and UHF WCDMA downlink to the correct users — a rapid, behind-the-scenes process that is transparent to the warfighter.

To prove these capabilities, MUOS is progressing through a series of rigorous developmental and operational tests, while simultaneously leaning forward with select capability demonstrations in a variety of challenging environments. A major step took place in March 2013 with the first end-to-end system test, and testing has continued with progressively more complex integration and scenario-based events. While each piece of the program conducted earlier laboratory evaluations to ensure they were meeting their individual requirements, the end-to-end tests bring all of the components from multiple programs together and demonstrate secure voice and data calls through MUOS-1 and the ground network. Utilizing the Army's Handheld, Manpack, and Small Form Fit Manpack Radios, testers have completed a series of different call types, lasting from 3 minutes to 24 hours, with data rates up to 64 kilobytes per second. The test results have shown increased stability of the system, while allowing engineers to reduce risk by addressing integration issues that had not arisen during individual component tests.

In 2014, Lockheed Martin opened its Test Radio Access Facility (TRAF) to assist other industry providers in testing, developing, and certifying MUOS radio terminals and government applications more quickly in order to get MUOS's advanced communications capabilities in warfighters' hands faster.

In conjunction with the ongoing end-to-end tests, the team has supported several demonstrations to gauge MUOS potential in different operational scenarios while reducing risk for future record testing. One such demonstration was performed at the Arctic Circle in October 2013, where very high latitudes pose a challenge because the satellite is in geosynchronous orbit above the equator, and therefore harder to see. The MUOS team tested the ability of the Manpack Radio to reach the MUOS satellite communications network at latitudes up to 89.5 degrees north. The demo included both fixed-site locations around Anchorage and Barrow, Alaska, and aboard an aircraft operating above the Arctic Circle. The Manpack Radio successfully completed multiple point-to-point voice and data calls, as well as group calls connecting more than five radios.

Another demonstration, the Navy Submarine Ice Exercise, was conducted in March 2014. MUOS was operational for 15 days at Ice Camp Nautilus, a temporary research facility set up on the ice for Arctic submarine exercises, where operators successfully demonstrated long-term connections across multiple enclaves in a challenging environment.

In August 2014, the Air Force Research Laboratory conducted an airborne MUOS risk-reduction event featuring the in-flight demonstration of the MUOS waveform ported onto two different radios developed by two vendors — the PRC-155 HMS Manpack and the ARC-210 — on a C-17 aircraft. Both radios performed well, transmitting and receiving over the air while the aircraft was on the ground and while airborne, and recording progress in voice quality, data exchange, and airborne call completion rates.

The MUOS team further stressed the system during North American Aerospace Defense Command/Northern Command Arctic Shield and ICE CUBE in August 2014, and Pacific Command Operation Deep Freeze in November 2014, where they demonstrated MUOS network performance through multiple nodes in extreme latitudes. Other demonstrations continue, including assessments of communications performance with different applications and antenna configurations including the Joint Strike Fighter and a scenario-based integration event with Naval Special Forces.

Joint Acquisition Approach

The acquisition of this complex system across several program offices has not been without its challenges. The Navy's Communications Satellite Program Office has overall responsibility to deliver MUOS end-to-end capability. It is supported by the Army's Project Manager for Tactical Radios, which supplies the Manpack Radio, and Project Manager Joint Tactical Networks (JTN), which provides the MUOS waveform along with the network management system that provisions the radios and displays network information such as phone numbers and call groups. The Joint Tactical Networking Center maintains an information repository of secure networking waveforms and applications for the DoD, which allows for interoperability across the Joint Services and continuous upgrades to waveform capability.

The MUOS waveform is part of that repository and available to industry, enabling a competitive environment where different vendors can develop terminals and radios that support MUOS. Six vendors have already evaluated their hardware's connectivity with MUOS by using three laboratories that opened in 2014: a Lockheed Martin facility in Sunnyvale, CA; a General Dynamics facility in Scottsdale, AZ; and a JTNC facility in San Diego, CA. By realistically simulating the MUOS satellite network and various challenging environmental conditions, the laboratories support the integration of new and existing terminals with MUOS capability.

For the Manpack Radio, which will be the primary MUOS terminal for ground users, the Army is moving forward with a competitive procurement of approximately 70,000 radios through the program's Full Rate Production (FRP) phase. The Manpack, delivered in vehicle-mounted and dismounted configurations, is the Army's first two-channel, software-defined radio capable of supporting advanced and current force waveforms. Under a full and open competition, the Army plans to award contracts to multiple vendors, creating a "radio marketplace" where vendors will compete for delivery orders as needed, after they achieve technical and operational requirements.

To enable compatibility with MUOS, the Army developed the MUOS High Power Amplifier (MHPA) accessory to replace one of the Manpack's standard High Power Amplifiers. The MHPA includes special circuit boards and a full duplex modem that allow the MUOS waveform to run on the standard Manpack Radio. This technology, which eventually will become part of the radio itself, also is planned for use by the Navy, Marine Corps, and Air Force.

Conclusion

Shoot, move and communicate — of these fundamental soldier skills, the ability to do the latter is changing rapidly. With adversaries taking full advantage of progress in the commercial communications market, continued modernization is essential for the U.S. military to maintain information dominance in the future.

MUOS is a critical piece of this plan, replacing the aging UHF satellite constellation with a significant increase in narrowband communication capability. Users will notice the difference — more bandwidth that is accessible on demand as opposed to preplanned channels, better voice quality, and reliable service, even in remote regions, urban environments, or inclement weather. By combining satellites with cellular technology, MUOS will provide troops on the move with high-speed voice, data, and network connectivity. To deliver these improvements, the MUOS team must manage significant technical and programmatic complexity, as well as interface with multiple vendors in a competitive environment.

*This article was written by Maj. Gen. Daniel P. Hughes, Army Program Executive Officer for Command, Control, Communications-Tactical; and Rear Adm. Christian Becker, Navy Program Executive Officer both for Space Systems and for Command, Control, Communications, Computers and Intelligence for the Defense Acquisition University, Fort Belvoir, VA. For more information, **visit www.dau.mil.***

Virtual Flight Testing of Radar System Performance

Flight testing is the ultimate way to evaluate the performance of a radar system. During the actual aircraft flight, data such as Probability of Detection, Signal Strength, and clutter might be gathered. While effective, this approach does pose a number of challenges. The operational cost of flight testing a radar system using real aircraft can be over $100,000 per hour. Additionally, the results from one flight to the next are not repeatable. Each flight is slightly different, and getting enough flights in to be statistically significant is simply too cost-prohibitive.

While final operational verification may still be necessary for contractual or legal reasons, “virtual flight testing” is a faster, more cost-effective alternative for earlier stages of R&D, such as algorithm and countermeasures development. In simulation, complex radar systems can be evaluated hundreds of times an hour, using the same or different scenarios for each run (flight), and at significantly less cost than a single hour on a flight range. By evaluating realistic flight testing scenarios before or in place of physical flight testing, engineers can validate electronic warfare algorithms earlier, saving both time and money.

A virtual flight test solution was created by marrying the capabilities of Keysight Technologies’ (Santa Rosa, CA) SystemVue software with those of the AGI STK tool from Analytical Graphics (Exton, PA). The W1461BP SystemVue Comms Architect is an electronic-system-level design software that integrates modeling, simulation, reference IP, hardware generation, and measurement links into a single, versatile platform. It enables system architects and algorithm developers to innovate the physical layer (PHY) of wireless and aerospace/defense radar and communications systems, and provides unique value to RF, DSP, and FPGA/ASIC implementers. The W1905 Radar model library provides baseband signal processing reference models for a variety of radar architectures.

STK is a physics-based software geometry engine that accurately displays and analyzes land, sea, air, and space assets in real or simulated time. It can include the aircraft flight dynamics, terrain effects, and the aircraft’s 3D radar cross section (RCS). The basic STK process is to define a system link scenario with moving transmitter (Tx), receiver (Rx), and interferer objects. The scenario is then analyzed to obtain system metrics as a function of time (e.g., range, propagation loss, RCS, noise bandwidth, and Rx signal strength). Almost everything in STK can be controlled by third-party tools. However, the software has no inherent ability to process signals from radar/communications applications through the dynamic environment link. Linking STK with SystemVue allows arbitrary Tx/Rx radar/communications systems to be modeled with the STK dynamic environment link characteristics. During virtual flight testing, SystemVue models the radar system including waveform generation, Tx, and Rx non-ideal behavior; DSP and RF processing; and radar post-processing. STK models the flight scenario and signal path characteristics (e.g., path loss, Doppler, aircraft aspect RCS, and atmospheric losses).

To gain a clearer understanding of the interface between SystemVue and STK and its application to virtual flight testing, consider the 3D STK simulation scenario of a fighter sortie (Figure 1). In this example, assume the sortie starts at 10,000 feet and is detected by radar. To try to get below the radar, it dives down to do low-level terrain-following — sometimes successfully, and sometimes not. The same run can be repeated hundreds of times, with different radar or electronic countermeasure assets in place as modeled by SystemVue, along with the terrain, aircraft (including 3D RCS), and the radar site characteristics as modeled in STK.

As shown in Figure 2, a custom user interface can be easily implemented within SystemVue to make repetitive tasks and complex measurements much easier to manage. Here, SystemVue creates a radar waveform and passes it through a transmit chain to multiple target models (including jamming and added clutter). The resultant RF waveform can then be input into an arbitrary waveform generator and introduced into a receiver for performance validation. SystemVue also has a tight integration with MATLAB, C++, and HDL simulators so existing radar algorithms can also be integrated into the scenario. Measurement-based data, such as a

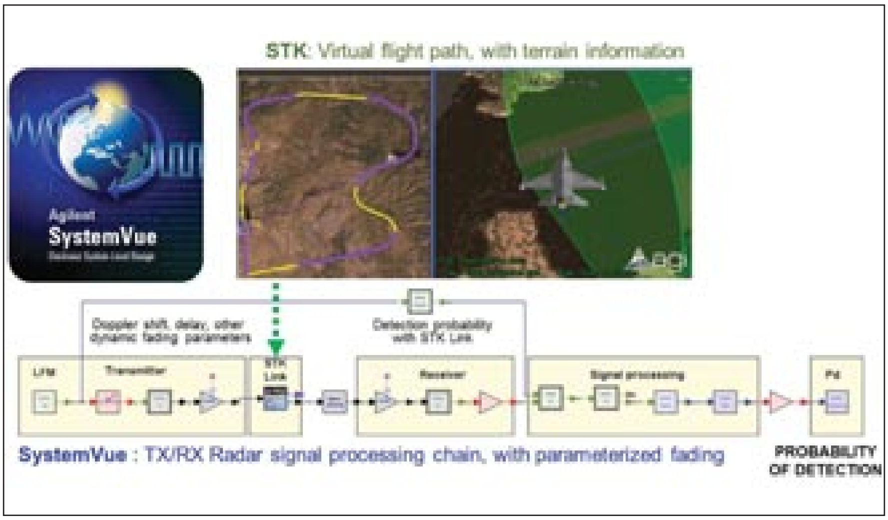


Figure 1. One application of the interface between SystemVue and STK is the ability to do virtual flight testing of radar systems, including DSP, RF impairments, jamming, and interference as an aircraft encounters targets and clutter along a virtual flight plan.

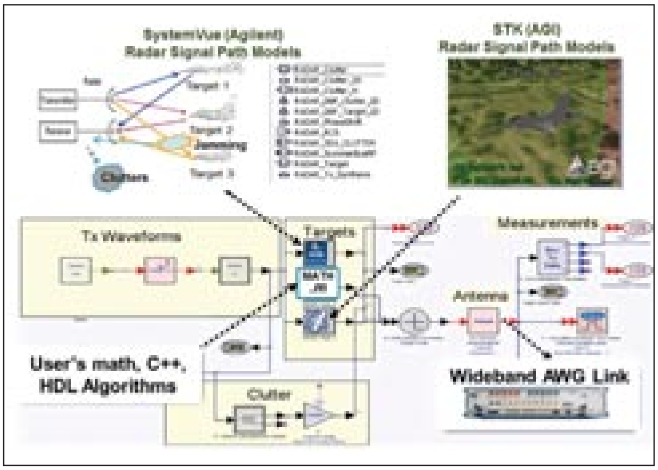


Figure 2. In this multiple-target signal emulation example, test entry comes from a custom user interface with hardware text flavor. The user does not have to open a simulation schematic. This approach integrates both signal generation and signal analysis.

jammer profile or measured interference, could also be added into the simulation directly through Keysight test equipment links.

Linking the SystemVue and STK solutions allows for quick and repeatable validation of multiple realistic radar system scenarios. These scenarios can be evaluated in lieu of physical flight testing or, in cases where operational flight testing is unavoidable, they can be evaluated beforehand to ensure they make the most effective use of resources.

Some applications of virtual testing include:

- Evaluating new jamming techniques or threats
- Injecting multiple dynamic emitters and targets into scenarios
- Allowing various types of jamming based on a defined set of criteria for dynamic operation
- Modeling and evaluating cross-domain effects, such as automatic gain control
- Use of unintended interference from commercial wireless networks

When it comes to testing radar system performance, extensive flight testing using physical aircraft is a prohibitively expensive and time-consuming proposition. Virtual flight testing, made possible by the flexible interfaces between the SystemVue and STK software tools, now offers an economical alternative for R&D validation. This allows measurement-hardened algorithms to be deployed quickly, and a minimum of true operational testing to be done with greater confidence to save costs. By closing the loop between lab-based virtual testing (simulation and test equipment) and operational testing, virtual testing can be made even more effective.

This article was written by David Leiss of Keysight Technologies. For more information, visit ***http://info.hotims.com/61058-542.***

SIRE: A MIMO Radar for Landmine and IED Detection

This radar provides an efficient, cost-effective method of detecting landmines and IEDs.

Army Research Laboratory, Adelphi, Maryland

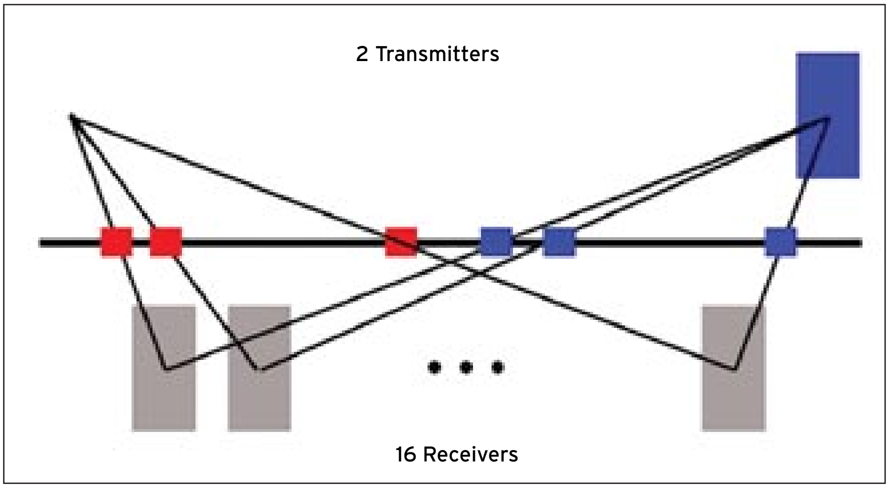
Low-frequency ultra-wideband (UWB) radar has garnered attention for the detection of landmines and improvised explosive devices (IEDs) in recent years. The low frequencies used by these radars provide the necessary ground penetration capabilities for detection, and the wide bandwidth signals used are necessary for range resolution. Cross-range resolution that depends on the size of the antenna aperture can be improved by generating a synthetic aperture. Typical airborne synthetic aperture radars (SAR) that can provide high resolution in cross range are not practical for this problem due to cost limitations.

Multiple-input multiple-output (MIMO) radars can also be used to create a virtual array aperture larger than their single-input single-output (SIMO) counterparts, allowing for improved cross-range resolution. MIMO radars operate by using multiple antennas to transmit waveforms that could be linearly independent, and also use multiple antennas (receivers) to receive the reflected signals from targets in a given scene.

A MIMO radar with collocated antennas can provide advantages over its SIMO counterpart by exploiting waveform diversity. Some of the advantages afforded by this radar include improved parameter identifiability (i.e., maximum number of targets that can be uniquely identified), and improved cross-range resolution. This improved resolution can help resolve desired targets such as landmines from clutter.

The Synchronous Impulse Reconstruction (SIRE) ultra-wideband (UWB) radar was designed as a 2×16 (2 transmitters and 16 receivers) MIMO radar with collocated antennas. This radar operates in forward-looking mode and is built for landmine and IED detection. By transmitting orthogonal waveforms, improved cross-range resolution compared to using a single transmitter can be observed, showing this radar to be a working example of a MIMO radar. This radar employs cost-effective analog-to-digital (A/D) converters to sample its large signal bandwidth using an equivalent sampling scheme, making it practical for actual ground missions.

The use of low frequencies in UWB radar is necessary for foliage/ground penetration, whereas the use of UWB pulses is necessary for good resolution. Downrange resolution of this radar is determined by the bandwidth of the transmitted pulse that occupies a frequency range of 0.3 to 3 GHz. The cross-range resolution will be determined by the physical aperture of this radar. The conventional method for imaging is performed using the standard back-projection/delay-and-sum (DAS) algorithm in forward-looking mode.



SIRE radar is a practical example of a MIMO radar that exploits waveform diversity by transmitting orthogonal waveforms from the two transmit antennas located at the edges of the receive array. These orthogonal waveforms are achieved by alternatively transmitting echo pulses (in "ping-pong" mode) from each transmitter. The virtual array created by this MIMO radar is shown.

The SIRE radar system has a physical aperture (2 m) consisting of 16 receive antennas; 14 timing and control cards are also present to provide the necessary clock references for the radar. Each antenna consists of a digitizer that integrates the radar returns from a number of pulses that it passes to the system's personal computer (PC), which acts as the operator control and display. The radar consists of two transmitters at the ends of the receive array. The returned radar signals collected from the 2D aperture can be used for imaging the scene. The images are formed 8 m (standoff range) ahead of the truck on which the radar is mounted.

Due to the large bandwidth of the returned radar signals, conventional sampling will require high-rate analog-to-digital (A/D) converters to digitize the returned radar signals. These high-speed A/D converters are expensive to build and make practical implementation improbable. The goal was to develop a radar capable of landmine detection that is affordable and in a lightweight package for practical applications. Therefore, each of the receivers consists of a low-rate (40 MHz), commercially available A/D converter. The digitizers are used to sample the large bandwidth (≈ 3GHz) of the returned signals using an equivalent sampling scheme termed the SIRE sampling scheme.

This work was done by Lam Nguyen of the Army Research Laboratory; and Ode Ojowu Jr., Yue Wu, and Jian Li of the University of Florida, Gainesville. ***For more information, download the Technical Support Package (free white paper) at www.aerodefensetech.com/tsp under the Instrumentation category.*** *ARL-0187*

Multi-Temporal Analysis of Underbody IED Theater Events on Ground Vehicles

Modeling and simulation were used to analyze the effects of underbody blasts on moving vehicles.

Army TARDEC, Warren, Michigan

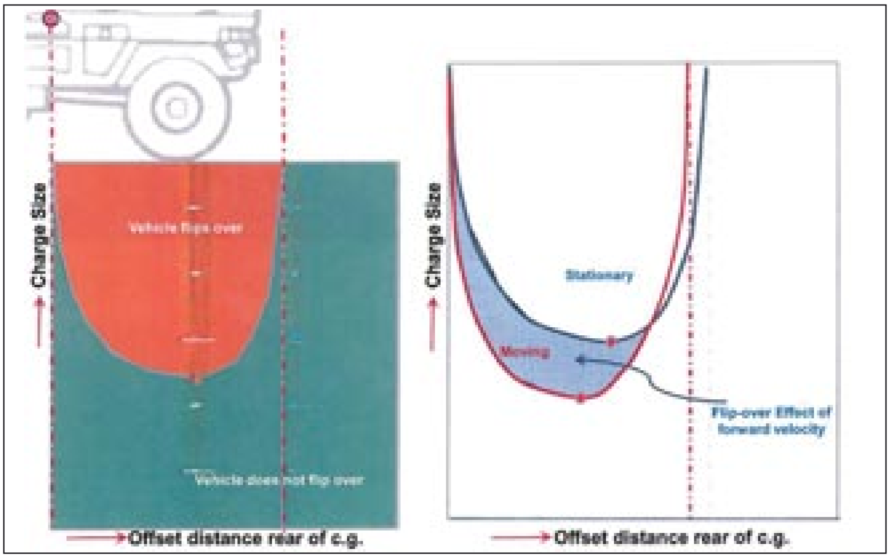
Recently, modeling and simulation (M&S) engineers have made impressive strides in improving ground vehicle reliability and soldier safety. This work involved live-fire testing and evaluation (LFT&E) of the effects of underbody improvised explosive device (IED) blasts on moving ground vehicles. A multi-fidelity, multi-temporal M&S methodology was developed and successfully applied towards reconstruction of theater IED events.

An IED blast event from blast-off to return-to-ground (RTG) lasts for about 500 to 2500 milliseconds (ms) depending on the vehicle, threat, and threat location. Since occupant injuries can happen in both stages of the event, it is imperative to analyze both of them in a multi-temporal fashion. For a successful analysis of such an event, innovative computational modeling is essential in understanding underbody blast effects on a moving vehicle structure and its occupants because it provides in-depth information on the overall physics of the event, with access to tremendous amounts of data and visualization.

Theater IED events involving vehicles moving in a convoy have always sparked considerable concern because the effects of IEDs are seemingly accentuated by the vehicle's forward velocity, especially as it pertains to vehicle flip-overs and rollovers. All LFT&E has been done to date on stationary vehicles, while the majority of the blast events in theater operations occur on moving vehicles. The computational methodology developed in this work will be able to analyze vehicle performance not only during the blastoff phase, but through the entire event (blastoff through RTG).

A two-phased, multi-temporal strategy was developed in which a high-fidelity M&S model was used to simulate the blast-off phase, and a Reduced Order Model (ROM) was utilized to capture the vehicle free flight phase including vehicle flip-overs. In the first phase of the analysis, high-fidelity models including detailed vehicle structures, along with occupants, were used, and the effects of the vehicle's forward velocity during blast-off were analyzed. This model captured the complex phenomena that occur during this very brief time; namely, the interaction between the charge's detonation, soil, air, and the vehicle's underbody. The vehicle structural performance including hull and floor deformations and occupant injury responses were analyzed.

Using the same high-fidelity approach from the first blast-off phase for the longer second phase is a prohibitively expensive and a time-consuming proposition from a computational viewpoint. Therefore, for the second phase of the analysis, a ROM was used to simulate the vehicle free flight until RTG. The innovative manner in which the geometry and the blast loading were modeled to a reduced order to obtain accurate predictions of vehicle global behavior in a timely manner is critical to the success of this methodology.



(Left) The red region represents the combinations of charge size and offset that will result in a vehicle flipping over when moving at a certain speed. (Right) The region shaded between the two curves shows the effects of forward velocity. This region represents scenarios where the same charge size and center-of-gravity offset will result in a moving vehicle being flipped over, but not the same vehicle when stationary.

During this second phase, the vehicle's flip-over tendencies and the effect of forward velocity on these flip-overs were analyzed in detail. The concept of "flip-over characteristic curves" was introduced — vehicle-specific descriptors of the combinations of the three variables (speed, charge size, and charge offset) that will flip the vehicle over in an underbody blast. For example, on the left side of the figure, the red region conceptually represents the combinations of charge size and offset that will result in a vehicle flipping over when moving at a certain speed. On the right side, the region shaded between the two curves shows the effects of forward velocity. This region represents scenarios where the same charge size and center-of-gravity offset will result in a moving vehicle being flipped over, but not the same vehicle when stationary.

This work was done by Ravi Thyagarajan, Jaisankar Ramalingam, Sanjay Kankanalapalli, and Madanmohan Vunnam of Army TARDEC. ***For more information, download the Technical Support Package (free white paper) at www.aerodefensetech.com/tsp under the Information Technology & Software category.*** *ARL-0188*

Blast Mitigation Seat Testing

Drop testing evaluates performance of blast energy-attenuation seats for varying occupant weights.

Army TARDEC, Warren, Michigan

Blast energy-attenuation (EA) seats, although not new to the market, have not been fully tested with respect to energy attenuation capability and the resulting effects on occupant protection. The Ground Systems Survivability (GSS) Interiors Seat Team tested and evaluated EA seats over a one-year period using a drop tower test method.

To understand the current blast EA seats on the market and in development, 12 seat models were evaluated on the drop tower located at the TARDEC Occupant Protection Laboratory (OP Lab). Testing blast mitigation seats on a drop tower has been established as a preliminary evaluation of seat assets without introducing the variability or cost associated with a full-scale blast test. A matrix was developed to assess the seats with a simulated blast input with test variables including two severities (200 g or 350 g peak acceleration pulse), three anthropomorphic test devices (ATDs, or crash test dummies), and with or without personal protective equipment (PPE). The seats were tested in their recommended use range. Several of the seats were designed specifically for the lower input velocities. Efforts were made in the matrix development to maximize information gained with a limited number of seat assets.

Each test included an instrumented and ballasted ATD to measure forces, moments, and accelerations imparted to the occupant. The fleet of ATDs all contained the same instrumentation, which included accelerometers in the head, thorax, and pelvis (see figure). Load cells to measure forces and moments were located in the upper neck, lumbar spine, femur, upper tibia, and lower tibia. The data recorded off each transducer was compared to the ARL/SLAD crew injury criteria for accelerative events for the 50th percentile male.

The primary focus of the testing was to evaluate the test methodology developed for EA seat analysis via drop tower; namely, the ability of commercially available or prototype seats to produce occupant injury values below the internal Occupant Centric Platform (OCP) thresholds for all body segments for all size occupants. Each ATD channel was reviewed to determine if the maximum or minimum value exceeded the associated injury assessment reference value (IARV) limit.

Location	Channels
Head	Ax, Ay, Az
Upper Neck	Fx, Fy, Fz, Mx, My, Mz
Thorax	Ax, Ay, Az, Dx (displacement)
Lumbar Spine	Fx, Fy, Fz, Mx, My, Mz
Pelvis	Ax, Ay, Az
Femur	Fx, Fy, Fz, Mx, My, Mz, (per leg)
Upper and Lower Tibia	Fx, Fy, Fz, Mx, My, Mz (per leg)

The fleet of ATDs all contained the same instrumentation, which included accelerometers in the head, thorax, and pelvis.

A review of the data showed compliance with the OCP IARV limits for some of the seats in the tested configurations, leading to the conclusion that the target loads and accelerations set by OCP were attainable and appropriate. Some of the recorded data from the platform was questionable due to various issues with the accelerometers over the full series, including accelerometer mounting problems due to rough or imprecise mounting surfaces, and cable tiedown issues resulting in damaged or severed cables or cable "whip."

Throughout the test series and accompanying data analysis, several lessons were learned. Although all ATD data channels were reviewed for exceeding IARVs, an analysis of the ATD trends allowed for the formation of general observations of "go/no-go" channels to review if time is limited. Lumbar compression seems to be the go/no-go injury criteria when evaluating the seat as a survival system.

A review of lower extremity injury values led to the conclusion that some type of flooring system should be included to mitigate lower leg injuries during a blast event, as confirmed by comparing tibia IARVs between seats that featured footrests or blast mats, relative to those without.

Seat manufacturers currently design their systems for optimization during a blast event with an occupant representative of a 50th percentile male, and many seats were tuned for approximately a 200-g peak acceleration event. Consequently, the majority of the seats passed the lumbar compression load for the 50th percentile male at this test condition. A review of the lumbar compression data for the 95th percentile male demonstrates that the additional weight of the occupant and higher IARV thresholds leads to passing numbers for almost all seat models. As expected, the seats were not designed for the lightest occupant, leading to lumbar compression limits over the threshold of the 5th percentile female for 83% of the seats tested.

The purpose of testing with and without PPE was to determine if the additional weight, in the case of the 95th percentile male, would cause a seat to "bottom out," or if the lack of weight, as in the unencumbered 5th percentile female, was too light to cause the seat to stroke as designed. However, due to the limited data sets, it was difficult to complete comparative analyses between ATDs with and without PPE.

The drop tower testing and evaluation performed on commercial and developmental seats provided an objective assessment of the seats' performance with respect to the injury criteria. The test methodology and OCP IARV assessment criteria were evaluated and deemed acceptable for future use. Data analysis was performed for a quality check of the data and was used to determine general trends in ATD performance.

This work was done by Katrina Harris, David Clark, and Risa Scherer of the Army TARDEC; Kelly Bosch of Booz Allen Hamilton; and Joseph Melotik of the Naval Air Systems Command. ***For more information, download the Technical Support Package (free white paper) at www.aerodefensetech.com/tsp under the Instrumentation category.*** *ARL-0178*

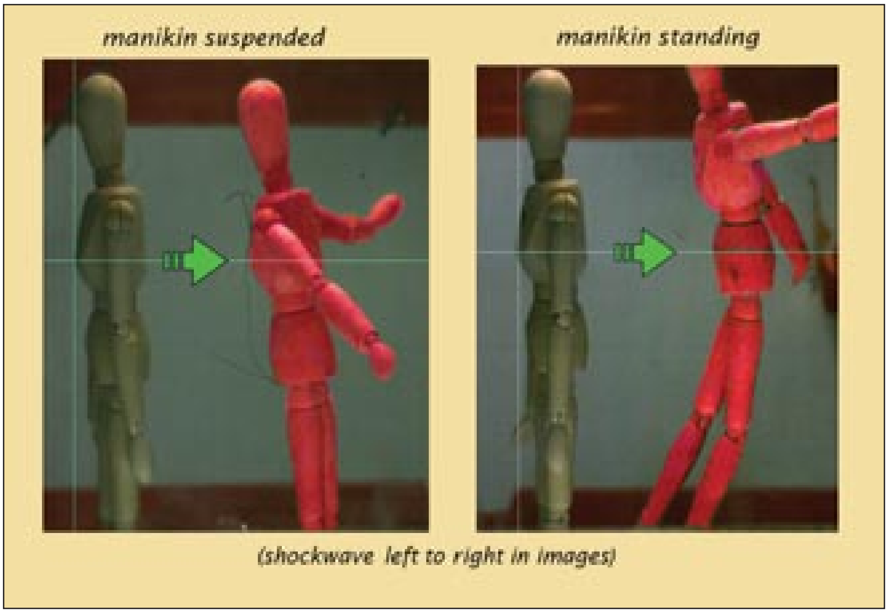
Blast-Induced Acceleration in a Shock Tube

High-fidelity simulation of blast flow conditions can aid in developing strategies to mitigate blast-induced brain injury.

Army Medical Research and Materiel Command, Fort Detrick, Maryland

The prevalence of blast-induced traumatic brain injury (bTBI) has prompted an urgent need to develop improved mitigation strategies and advance medical care targeting casualties with bTBI. Despite considerable effort, the basic mechanisms of blast-induced brain injury are still undefined. Based largely upon computational modeling, several candidate mechanisms of non-impact bTBI have been identified and include head acceleration. This work hypothesizes that explosion flow conditions can cause head acceleration sufficient to injure the brain, and that these inertial forces combine with other injury mechanisms to yield bTBI.

The primary innovation of this project is the development and utilization of a high-fidelity simulation of possible blast flow conditions. The goal was to replicate all key features of blast flow wave conditions, including the negative



Articulation differences with blast overpressure exposure of suspended and standing manikins.

phase and secondary shock. Tight control of these components (notably acceleration and displacement), in combination with functional outcome measures, will greatly enhance understanding of the relation of the former to the latter. As the use of shock tubes has greatly expanded in recent years for biomedical research and TBI research in particular, it is critical that these experimental devices be used in a manner that most effectively simulates explosive blast conditions, recognizing that creating an injury does not constitute validation of an injury model.

An explosive shockwave is unlike any other conventional mode of loading, and will impart both an abrupt transient crushing action (i.e. static pressure) that envelops the head, as well as some aerodynamic drag (i.e. dynamic pressure creating blast wind). Controversies and confusion concerning the contributions of blast-induced head acceleration to bTBI have in great part resulted from laboratory studies in which blast was inappropriately simulated, and head acceleration was likely, in many cases, an experimental artefact uniquely associated with those particular exposure conditions. In particular, positioning experimental subjects at or near the mouth of the shock tube exposes them to endjet conditions; practically all flow energy is converted to a collimated jet at the shock tube exit, yielding extreme dynamic pressure and negligible static pressure as end wave rarefaction abruptly reduces static pressure and greatly accelerates flow. In addition, cylindrical shock tubes characteristically produce shock waves with flat tops and greater-duration positive phases, which will yield unscaled drag forces greatly exceeding those occurring with an explosion in the free field. Discerning the loading conditions and role of acceleration in blast-induced TBI requires careful monitoring and validation of the fidelity of the experimental model; as noted, creation of an injury does not constitute validation of an injury model.

As a first step toward understanding the head motion of soldiers exposed to a typical IED blast (<10 msec positive phase duration), high-speed video recording was utilized to record the motion imparted by the passage of an air shockwave in an advanced blast simulator (ABS) to various inanimate spherical objects of different areal densities, and to an articulated body represented by a 1-foot-tall wooden artist manikin of a human form. Test objects were carefully suspended in the test section of the ABS by a thread that immediately detached upon arrival of the shock front. Spheres ranged in size from 0.75" diameter steel ball bearings to a 10" Synbone head form ballasted by water to approximate the global shape and mass of a human head. Blast exposures were standardized to a 13 psi by 5 msec waveform.

Velocity of spheres as a function of acceleration coefficient areal density (i.e. total mass/surface area) presented to the oncoming shockwave is considered as the dominant factor affecting blast-drag studies, and its inverse is known as the acceleration coefficient. The blast-induced velocities of spheres with a wide range of mass and size were tracked as a function of these coefficients. In all cases, blast-induced motion was imparted almost immediately (<1 msec), and terminal velocities were reached long before the end of the positive phase of the shock wave, confirming that displacement was dominated by the diffraction phase and had no relation to the quasi-steady drag forces (i.e. dynamic pressure impulse and blast wind) as has been popularly accepted.

This work was done by Dr. Joseph B. Long of The Geneva Foundation for the Army Medical Research and Materiel Command. ***For more information, download the Technical Support Package (free white paper) at www.aerodefensetech.com/tsp under the Health, Medicine & Biotechnology category****.* *ARL-0186*

Aerion Progresses on the Supersonic AS2 with Help From Airbus

The joint engineering efforts that Aerion and Airbus Group have dedicated to the AS2 supersonic business jet since 2014 have taken on even more importance as it was announced in mid-November that the aircraft has received its first firm order for 20 from Flexjet.

Carrying eight to 12 passengers, the AS2 will have an intercontinental-capable range of 4750 nmi at supersonic speed, saving three hours across the Atlantic vs. subsonic aircraft and more than six hours on longer trans-Pacific routes. The three-engine jet will make its first flight in 2021 and enter service in 2023.

"We see Aerion's technology and the AS2's performance capabilities as potential game-changers for business travel," said Flexjet Chairman Kenn Ricci. Flexjet offers fractional jet ownership and leasing. Aerion and Flexjet will work together to design the interiors for the AS2s

In terms of Airbus and Aerion working together, the two companies have been proceeding "quietly, but steadily" on the Mach 1.5 AS2 since the first joint engineering team meeting in 2014.

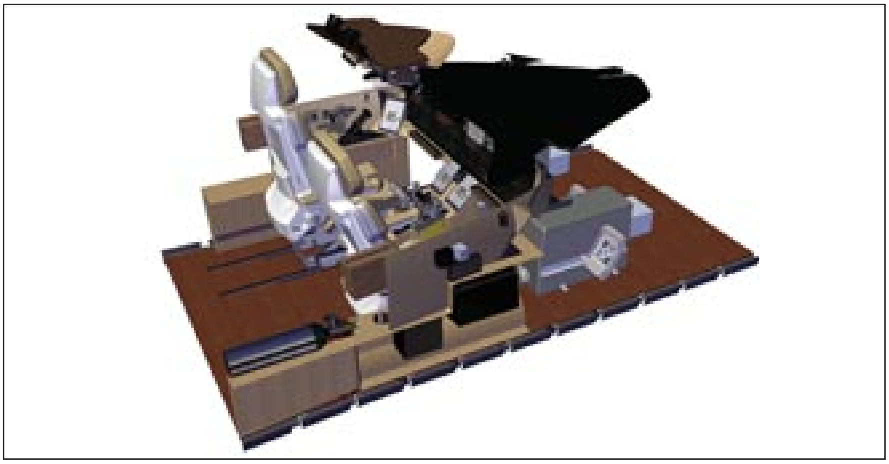
Airbus Defence & Space (Airbus DS) out of Spain has made progress in the engineering of airframe structures, the AS2's fly-by-wire flight control system, its integrated fuel system, and landing gear. Some of the company's accomplishments include preliminary designs for a 10-spar carbon fiber wing structure, fuselage and empennage structures, an articulating main landing gear system that minimizes space requirements in the fuselage when stowed/retracted, and a fuel system that is integrated with the digital fly-by-wire system for control of center of gravity.

The aircraft's flight control design will take advantage of small, powerful actuators that can be housed in the AS2's thin flying surfaces. To supplement the design process, Airbus DS built a sample titanium wing leading-edge section for evaluation and is testing composite material specimens to optimize material properties.

Aerion is the lead for other systems, such as avionics, electrical, environmental control, hydraulics, and auxiliary power. In conjunction with Airbus DS, Aerion had made preliminary space allocations for every system with weight and balance considerations in mind. Candidate suppliers have been identified and the supplier selection process has begun.

This past September, senior engineering staff from Aerion, Airbus DS, Airbus

Since entering into a collaborative relationship in 2014, Aerion and Airbus Group engineering teams have been deeply engaged in designing aircraft structures and systems. Airbus Defence & Space has taken the lead in the design of airframe structures, digital flight controls, an integrated fuel system, and the landing gear system. Aerion is responsible for all other systems, including avionics, environmental control, auxiliary power, hydraulics, electrical system, cabin systems, and more. The two companies share responsibility for aerodynamics and flight sciences.



The flight deck of the AS2 is being designed to maximize situational awareness through a combination of advanced avionics, natural line of sight, and ergonomics. Aerion will craft the flight deck with considerable attention to day/night illumination, making the cockpit environment as inviting as the cabin.

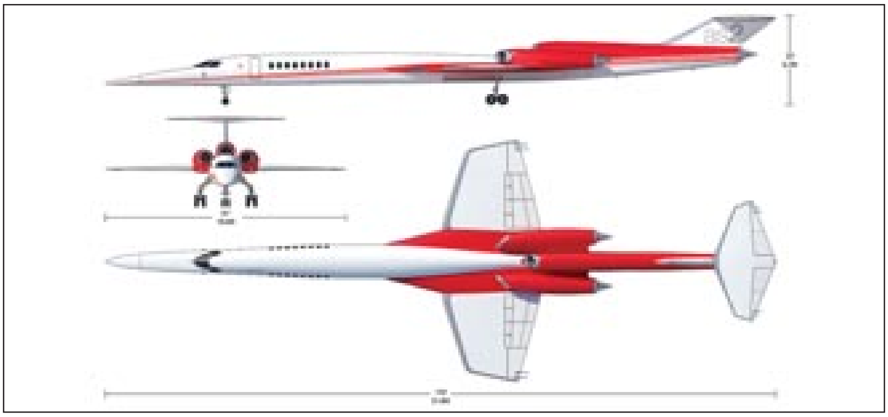
Full-scale engineering mockup for the AS2's cockpit and cabin design at Design Q in Redditch, England.

Group, and other Tier 1 equipment suppliers gathered at Aerion headquarters in Reno for a four-day technical and program review, covering engineering accomplished to date on all structures and aircraft systems.

"The take-away from the design review and the effort this past year is that we have moved out of the conceptual design phase into commercializing Aerion technology," said Aerion Senior Vice President for Aircraft Development Mike Hinderberger, "We are doing the engineering work today that will allow us to build and fly a supersonic jet at the turn of the next decade."

As it stands, the engine will be the pacing element for the first flight of the AS2 in 2021. The original design specified the JT8D engine from Pratt & Whitney, and the engineers are now looking at more modern engines.

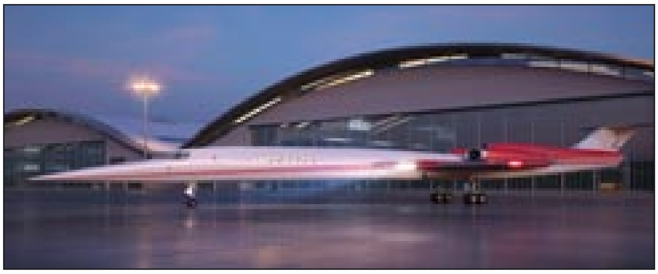
"We are targeting the first half of 2016 to select a propulsion system, which will



Basic dimensions of the AS2.

Aerion expects to announce the location of the assembly site of the supersonic AS2 in the first half of 2016 upon formal launch of the AS2 program, and break ground in 2018.


Aerion AS2's preliminary cabin renderings from INAIRVATION and Design Q-Night.


"We are targeting the first half of 2016 to select a propulsion system, which will enable us to formally launch the program shortly thereafter," said Doug Nichols, Aerion CEO.

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Aerion has identified existing core engines suitable for adaptation to the needs of supersonic flight.

"We will proceed with an engine that allows us to meet our performance goals with the minimum changes required," said Nichols. "Aerion is focused on an engine solution that meets Stage 4 noise standards while preserving long-range supersonic performance. This is a significant challenge with a low-bypass supersonic engine, but solutions are in sight with today's engine technology."

Aerion says the jet will operate efficiently within the current regulatory environment, including rules regarding supersonic flight over land. This takes advantage of the ability of the AS2 to operate efficiently just below the speed of sound at Mach 0.95 to 0.98, and at speeds up to Mach 1.5 over water and other areas where supersonic flight is permitted. "This is a very good airplane at subsonic or supersonic speeds," said Hinderberg, adding that he considers the aircraft "almost more like a fighter than a commercial airliner."

When the partnership began, Airbus was particularly interested in Aerion's proprietary laminar flow software tool for analyzing high-speed airflow and for airframe optimization. In fact, said, Hinderberg, the program's "two top goals were optimizing for natural laminar flow and optimizing for wave drag."

"This is Aerion's jet and Aerion's program, with substantial benefits for Airbus Group," said Ken McKenzie, Senior Vice President for Strategy and Corporate Development at Airbus Group. "We gain new technology and tools, and through our collaboration will be expanding engineering knowledge and refining processes such as digital manufacturing. The AS2 program will be an incubator for innovation in design, engineering, and manufacturing."

Nichols says that "Aerion has begun a formal search for a U.S. manufacturing location" for the AS2.

"We're looking for a state-of-the art campus of more than 100 acres on a major airport with a minimum 9000-ft runway, and other special geophysical requirements," he said. Among them will be a location within 200 nmi of a supersonic flight test area, most likely one offshore.

Aerion will evaluate numerous factors including: airport suitability, road and rail infrastructure, proximity to a deep-water port for shipped structures and equipment, local aerospace workforce, state and local regulations, quality of life, and regional educational institutions.

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Airbus Group will provide major components and Aerion will conduct final assembly. Both companies envision a long-term relationship for ongoing technical support. Aerion will draw on expertise from Airbus Group for establishing the new Aerion production facility.

Jean L. Broge

Uncovering Safer Solutions for Aircraft Corrosion Prevention

Working with aircraft maintainers at the Ogden Air Logistics Complex, researchers from the Air Force Research Laboratory's Environmental Technology (EnviroTech) Program and Coating Technology Integration Office have identified and tested a variety of non-chromium sealers to anodize aluminum aircraft landing gear components to reduce and prevent corrosion.


An F-15 outer piston is anodized and sealed with new potassium permanganate sealer at Ogden Air Logistics Complex. AFRL researchers identified and tested this non-chromium sealer as a safer alternative to chromium-based products, and it is now fully incorporated into OO-ALC's coating process. (U.S. Air Force)

AFRL's EnviroTech Program executes development and demonstration of alternative environmentally preferred technologies. The EnviroTech mission is to scope and develop technologies to meet user requirements, progress solutions through Technology Readiness Levels, and highlight technology transition activities for U.S. Air Force enterprise use.

Non-chromium coatings and materials are increasingly important to the USAF because of the harmful nature of chromate-based products. Chromium is listed on the U.S. EPA's list of industrial toxic chemicals due to its toxicity to humans if inhaled or otherwise ingested. In 2009, a U.S. DoD directive restricted the use of chromium-based compounds on military vehicles and weapon systems.

To find a suitable alternative material, AFRL researchers identified non-chromate materials that would perform similarly to the traditionally used sodium dichromate sealers. They tested various types of sealers by coating test panels and landing gear components and anodizing the components using the same process as maintenance depots. They also performed additional tests that were specific to the needs of OO-ALC.

After testing four different products, AFRL researchers identified a permanganate-based sealer now being marketed as SafeGard CC-5000 by Sanchem, Inc. that met, and in some cases, exceeded, the necessary criteria. They then presented the data to OO-ALC, where it was approved for use on landing gear wheels, brakes, and struts. In September 2015, the sealer was transitioned to OO-ALC and fully incorporated into the coating process.

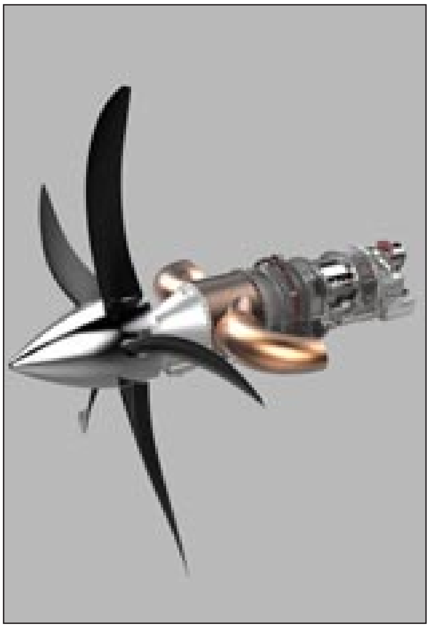
According to Dr. Elizabeth Berman, AFRL Senior Materials Research Engineering, "The transition and full implementation of this material is critical as it moves toward more environmentally and health-conscious maintenance solutions. This safer material provides the same protection as the old materials."

Jean L. Broge

GE's Clean-Sheet Turboprop Engine to Launch with Textron Aviation

Textron Aviation has opted for GE Aviation's all-new turboprop engine to power its single engine turboprop (SETP). The 1300 shaft horsepower (SHP)-rated turboprop engine will be the first entry in GE's new family of turboprop engines designed specifically for business and general aviation aircraft in the 850- to 1600-SHP range.

Brad Mottier, Vice President and General Manager of GE Aviation's Business & General Aviation and Integrated Systems division, said during the recent announcement that "this new engine features an industry-best 16:1 overall pressure ratio (OPR), enabling the engine to achieve up to 20% less fuel consumption and 10% more cruise power compared to competitor offerings in the same size class, which usually feature an OPR of 9:1. It also has 4000-6000 hour MTBO," - or mean time between overhauls - which is about 30% longer than with existing engines.



GE Aviation's new 1300-SHP-rated turboprop engine is the first entry in GE's new family of turboprop engines aimed at business and general aviation aircraft in the 850- to 1600-SHP range. It features some technology based on the T700/CT7 turboshaft such as a ruggedized, modular architecture and cooled turbine blades. It also features a titanium, 3D aero compressor design for lightweight and efficient power generation and an integrated electronic propulsion control for optimized single-lever engine and propeller control.

As an advantage of being part of GE, says Mottier, "We don't have to pay for research; we just go to the GE store for proven technologies from GE's large commercial and military engines and props. For example, we didn't have to pay hundreds of millions of dollars into research for stator vanes."

Other new design and manufacturing technologies leveraged from GE's latest military and commercial engines include an all-titanium, 3D aero compressor design for lightweight and efficient power generation and additive manufacturing capabilities pioneered for the CFM LEAP turbofan.

"For the past five years, GE conducted design studies and actively researched the turboprop market to identify and integrate the best of our next-gen commercial and military technologies at the lowest cost and risk to our business aviation customers," said Mottier. "Our mission is to make the operation of this engine look just like a jet."

"Our SETP will combine the best of both clean-sheet aircraft and new engine designs," said Christi Tannahill, Senior Vice President, Turboprops and Interior Design at Textron Aviation. "We expect it to outperform the competition in critical areas ranging from cabin size and acquisition cost to performance capability and fuel savings."

Textron Aviation's new aircraft is expected to have a range of more than 1500 nmi and speeds higher than 280 knot. Part of the enablers to those statistics are key features of the new turboprop engine that include a ruggedized, modular architecture based on the T700/CT7 turboshaft, and cooled turbine blades that enable higher thrust and fuel efficiency, also leveraged via technology from the T700/CT7. In the latter case, multi-stage turbines take air out of the compressors to cool the blades.

The engine also features integrated electronic propulsion control for optimized single-lever engine and propeller control. The new engine could be retrofit on older aircraft, though there would have to be changes in the cockpit to accommodate it. There's no official word yet on whether the propellers for the engine are being designed and sourced from GE's Dowty.

There is no prototype of the engine running today, though GE expects to conduct the detailed design review (DDR) for the new turboprop in 2017 followed by the first full engine test in 2018, for which the company has dedicated about 200 engineers, according to Mottier. It is expected to weigh about 535 lb.

Continued development, testing, and production of the new turboprop engine will occur at GE Aviation's new turboprop Center of Excellence in Europe, announced this past September. The new facility will represent an investment exceeding $400 million and ultimately support 500-1000 new jobs. "All the engine systems will be integrated outside of the U.S." said Mottier.

GE Aviation is combining the expertise gained from its Walter Engine turboprop facility in the Czech Republic with its other military and commercial jet engine technologies in its quest to pursue additional turboprop engines. GE research continues on a new 5000-SHP turboprop engine for the regional market that will leverage GE's new GE38 turboshaft military helicopter engine (for the U.S. Marines' CH53-K heavy lift helicopter), as well as technologies across GE's more broad jet engine portfolio.

GE Aviation claims to have the largest development engine portfolio in the jet propulsion industry and invests more than $2 billion annually in research and development. GE employs 8000 engineers, with about 3000 outside of the U.S., said Mottier.

Jean L. Broge

Application Briefs

Satellite System

Hughes Network Systems
Germantown, MD
301-428-5539
http://defense.hughes.com

Hughes Network Systems, LLC (Hughes) recently unveiled a new HM Satellite System, engineered around its novel software-definable modem (SDM) technology and scrambled code multiple access (SCMA) waveform. Hughes is launching with three commercial-off-the-shelf (COTS) products for government applications.

The new HM System employs a commercially-based, open standards architecture and frequency band-agnostic platform that enables affordable, resilient solutions to meet a wide variety of mobility and portability requirements for government users. In addition to supporting fixed applications, the HM System provides satellite-on-the-move capabilities for airborne, maritime and land mobility solutions, including a complete, ultra-compact and portable terminal for small teams reliant on quick-deploy connectivity. The first gateway was installed and became fully operational in September 2015. The Hughes Airborne SATCOM System featuring the new HM200 Modem has already been successfully installed on a NorthStar Aviation Bell 407 Multi-role Helicopter.

According to a Hughes spokesperson, the basis of the new HM System is advanced waveform technology based on very low-rate coding and new multiple access techniques. The waveform utilizes advanced software-definable SCMA technology enabling high-throughput, as well as secure and efficient sharing of bandwidth.

The three HM System product solutions based on the new waveform technology include:

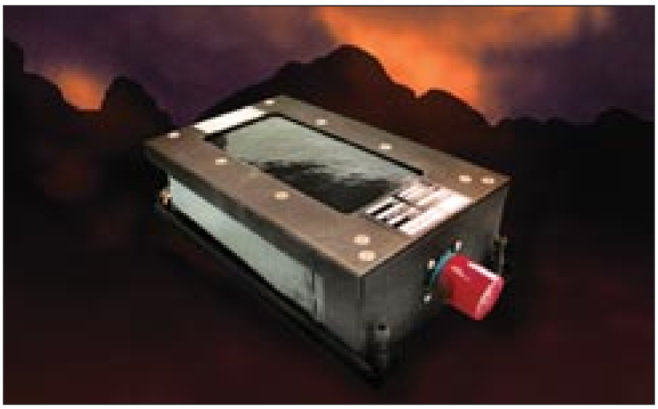
- HM100: Enterprise Application Modem – A universal rack-mounted hub that is transportable and offers high-throughput to support ground station SATCOM operations.
- HM200: Satellite-on-the-Move (SOTM), Ruggedized Modem – A mobile, ruggedized modem for any communications-on-the-move (COTM) scenario, with real-time situational awareness and beyond-line-of-sight (BLoS) capabilities. Target applications include land mobile, maritime, and airborne platforms. The HM200 offers faster acquisition time, low power requirement, carrier-in-carrier capabilities, MIL-SPEC connectors, internal power supply and separate data and M&C ports.
- HM300: Ultra-Compact, Portable Terminal – An ultra-lightweight man-packable communications solution that allows fast deployment and recovery while enabling up to 512 kbps of voice and data and is suitable for use in harsh environments. A complete terminal, the HM300 offers X-band communications with a small antenna footprint in a compact, low power package. The HM300 will launch as the portable terminal of choice for the XEBRA Service from Airbus Defence & Space.

Suitable applications for the HM System include intelligence-surveillance-reconnaissance (ISR), border patrol, search and rescue, disaster response, wildfire monitoring, oil platform communications, cellular backhaul and airborne BLOS communications.

For Free Info Visit http://info.hotims.com/61058-507

Lithium Battery Pack

Tadiran Batteries
Lake Success, NY
800-537-1368
www.tadiran.com



When designing an unmanned aerial vehicle (UAV), engineers must continually seek to reduce size and weight wherever possible in order to improve aerodynamics and free up critical space to deploy additional sensors and instrumentation.

Miniaturization and weight reduction were forefront on the minds of the engineers responsible for designing an air reconnaissance UAV's emergency recovery system deployed in Iraq

Cov ToC

and Afghanistan. A back-up power supply was designed to provide redundant guidance control in case of main system failure, enabling the UAV to glide to a safe landing. The back-up capability provided an ideal opportunity to deploy a new generation of high-power lithium metal oxide batteries.

Constructed with a carbon-based anode, a multi-metal oxide cathode, organic electrolyte, and a shut-down separator, TLM Series lithium metal oxide cells from Tadiran Batteries feature a high energy-to-size ratio. A AA-size lithium metal oxide cell, for example, delivers up to 2 Wh of energy with a nominal voltage of 4V, a discharge capacity of 1,100 mAh, and both 15A pulses and 5A continuous current.

Lithium metal oxide batteries also offer a 20-year storage life due to a low annual self-discharge rate (less than 1% per year). The little cells withstand extreme temperatures (-40°C to 85°C) and comply with MIL-STD 810G specs for vibration, shock, temperature, salt fog, altitude, acceleration (50,000 gn), and spinning (30,000 rpm). The components also meet UN 60086 standards for crush, impact, nail penetration, heat, over-charge, and short circuit.

To power the UAV's emergency recovery system, a 32V/480W custom battery pack and enclosure was developed using 96 AA-size lithium metal oxide batteries. The resulting compact power supply, including the metal enclosure, weighed 2 kilograms — a far less bulky option than a battery pack constructed of D-size primary lithium batteries.

High-energy lithium metal oxide batteries are currently being deployed in numerous applications, including avionics, ordinance fuses, missile systems, GPS tracking and emergency/safety devices, shipboard and oceanographic devices, automatic external defibrillators (AEDs), and surgical power tools.

For Free Info Visit http://info.hotims.com/61058-509

Digital Optical Comparator

VISIONx
Pointe-Claire, Quebec, Canada
514-694-9290
www.visionxinc.com

VISIONx's VisionGauge® Digital Optical Comparator 700 Series, featuring 5-axis inspection, has allowed aerospace supplier Paradigm Precision to improve the inspection process of its 16 different heat shields.

The heat shields, made of Single Crystal Super alloy materials, provide maximum strength and tolerance in the high-heat environment of turbine engines. Paradigm uses EDM drilling machines to drill the heat shield cooling holes, ranging in size from 0.016 to 0.076 inches. Hole quantities span from over 50 to nearly 400, at different locations and angles into the assorted heat shields. The cooling holes must line up precisely where the OEM specifies via CAD files and prints.

The company was originally using a Coordinate Measuring Machine (CMM) and pin gauges to perform part inspection to ensure the holes were in the right locations. The pin gauges needed to be positioned perfectly or else the CMM probe could deflect off the pins. However, because the holes are so small and the angles of the pin gauges so precarious, they could not use the CMM to directly probe the holes and the CMM was unable to validate hole sizes below .030 inch.

The CMM inspection process was also awkward, taking Paradigm inspectors up to six hours to fully inspect 365 holes on one part. To reduce inspection time, they were measuring just two holes per side using Mylars™ to determine if the checked cooling holes fell within an acceptable range. Paradigm Precision determined that this inspection process was not accurate enough nor acceptable, so they researched inspection options that didn't include contact probing.

The VisionGauge® Digital Optical Comparator 700 Series enabled the viewing of heat shield holes from all sides and angles. Unlike the CMM, which only rotated on the head, the VisionGauge could locate on the X-Y plane as well as the Z.

The 700 series has linear axes with 0.25-micron resolution and a 0.005-inch resolution on the rotary axis. For both round and shaped holes, the VisionGauge 700 Series automatically verifies precise hole presence and accurately measures hole location — typically achieving repeatability of ±0.0001 inch.

The VisionGauge 700 Series requires no contact with the parts, which reduces the risk of marking or material deformation. The digital optical comparator also works directly with the parts' CAD data and does not require any overlays, Mylars, or templates, which can result in increased errors.

Paradigm inspectors now view the heat shield holes in 20x optical magnification in a 38-inch diagonal image viewing area, which allows them to easily and accurately locate holes in all different angles. Furthermore, the VisionGauge Digital Optical Comparator allows users to compare a part to its CAD data in real time, fully automated, which eliminates human error and speeds up the process of the hole inspection.

For Free Info Visit http://info.hotims.com/61058-572

New Products

Low-PIM Cable Assemblies

San-tron, Inc, (Ipswich, MA) a manufacturer of RF coaxial connectors and cable assemblies, offers a growing line of advanced, outdoor, low-PIM cable assemblies and innovative new pressurized solutions to overcome environmental challenges.

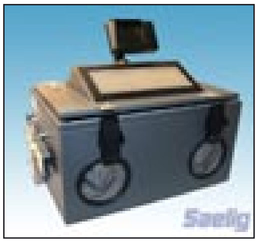
San-tron's SRX™ family of low-PIM solutions includes high performance adapters, connectors (including new 4.1/9.5 mini-DINs) and cable assemblies. They feature intermodulation performance as low as -168 dBc with an eSeries 7/16 connector terminated on flexible-141 cable. Typical performance across the lineup of assemblies terminated with SMA style and Type N style connectors is -158 dBc.

Their pSeries™ pressurized connectors provide low-loss, high stability performance through 30 GHz at ±65 psi. These pressurized connectors, which meet the IP68 standard, feature a simplified, three-piece design – body, center contact, and an innovative dielectric – which eliminates troublesome internal O-rings, gaskets, and silicone greases. These RF-enhanced connectors are available in a variety of different connector types, including 2.92 mm, 3.5 mm, SMA, TNC, and Type N series.

For Free Info Visit http://info.hotims.com/61058-511

Forensic RF Test Enclosure

Saelig Company, Inc. (Fairport, NY) has announced the STE3000FAV2 patented RF Test Enclosure, designed to give forensics technicians a highly isolated bench-top environment to perform electronic device interrogations of electronic equipment. The device is therefore protected from remote kill, lock, or self-destruct commands, as well as being protected from GPS and location tracking.



Attached to the STE3000FAV2 enclosure is a high quality video and audio recorder for downloading evidentiary stored data. When the electronic device (cellphone, laptop PC, etc.) is placed inside this enclosure, it can be viewed through the LED-illuminated RF-proof window and accessed via silver-mesh RF-tight gloves. Whether opening a device, swiping it, turning it on, touching screen icons, changing pages, it can be conveniently operated just as if it were on the open bench. The device maintains total isolation from a carrier network, regardless of the carrier or the frequency bands used. The device is also fully isolated from WiFi signal sources, including both 2.4 GHz and 5.0 GHz, covering all 802.11a/b/g/n/ac protocols.

For Free Info Visit http://info.hotims.com/61058-512

2U Rack PC/Server

Stealth.com (a Sparton company) (Toronto, Canada) has released the new Model SR-2510, a space saving 2U (3.5" high) rackmount computer/server. This compact rack mountable steel chassis is just over 15" in depth allowing it to easily mount into shallow rack cabinets or be deployed into any standard 19" EIA rack cabinet. 4x vertical half height expansion slots give you the ability to install PCIe/PCI expansion cards without the need for a riser card, and removable drive bays come standard with support of up to 8TB of internal storage. Optional solid state drives (SSD) and RAID configurations are also available.

Stealth's SR-2510 rackmount PC/Server is engineered with Intel's 4th Generation (Haswell) i5-4690, i7-4790 & Xeon E3-1276V3 processors delivering high performance for the most processor intense applications. The system can support up to 32GB of DDR3 memory and has a multitude of I/O connectivity built-in such as; Gigabit LAN, 4-USB 3.0, 4 USB 2.0, 1-DVI-D, 1-HDMI, audio and optional onboard 1-Serial/RS232.

For Free Info Visit http://info.hotims.com/61058-510

Day/Night-Vision Data Display

Daisy Data Displays, Inc. (York, PA) has unveiled night-vision technology for displays that provide users with full-color readability in daylight and with night-vision goggles without the need for add-on filters. This technology is appropriate for monitors and terminals that need to be compatible with NVIS goggles that are used in military and flight simulation applications.

Typically, night-vision filters are applied to displays with snap-on clips or adhesive and yield a green or low-color on-screen data view. Daisy's technology eliminates the need for the filter to allow the unit to transition from day to night-time use and allows for full-color, clear, night-vision compatibility with the same screen. The technology is Class B night-vision and MIL-STD-3009 compliant.

For Free Info Visit http://info.hotims.com/61058-519

32-Bit Microcontrollers

Microchip Technology Inc., (Chandler, AZ) announced a new series within its PIC32MZ family of 32-bit microcontrollers (MCUs) that features an integrated hardware floating point unit (FPU) for high performance and lower latency in intensive single and double-precision math applications. This new 48-member PIC32MZ EF series also offers a 12-bit, 18 MSPS analog-to-digital converter (ADC) for a wide array of high-speed, wide-bandwidth applications. Additionally, the PIC32MZ EF supports an extensive DSP instruction set.

The PIC32MZ EF series is powered by Imagination's MIPS M-Class™ core at 200MHz/330 DMIPS and 3.28 CoreMarks™/MHz, along with dual-panel, live-update Flash (up to 2 MB), large RAM (512 KB) and the widest selection of connectivity peripherals in the entire PIC32 portfolio, including a 10/100 Ethernet MAC, Hi-Speed USB MAC/PHY and dual CAN ports. Many embedded applications are adding better graphics displays, and the PIC32MZ EF, in the LCCG configuration, can support up to a WQVGA display without the added cost of external graphics controllers. An optional, full-featured hardware crypto engine is also available with a random number generator for high-throughput data encryption/decryption and authentication (e.g., AES, 3DES, SHA, MD5 and HMAC).

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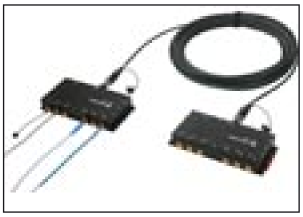
RF-over-Fiber Conversion Modules



HUBER+SUHNER (Pfaffikon, Switzerland) offers a variety of equipment for the defense market including a new series of RF-over-Fiber modules. The company offers three different elements of its RF-over-Fiber solutions: RF-over-Fiber, GPS-over-Fiber and LAN-over-Fiber technologies.

The RF-over-Fiber module converts analog RF signals into fiber signals and vice versa. With a wide frequency range and excellent stability, frequency jitter and phase noise performance, the company's latest solution is rapidly becoming a key part for command & control, naval and airborne applications.

The GPS-over-Fiber connector offers a very high stability in addition to excellent performance in phase noise and frequency jitter in applications such as remote antenna connection in GPS systems.

The LAN-over-Fiber module supports the IEEE802.3 standard 1000 Base-SX fiber. It enables copper connections to interface with fiber connections over a distance up to 500m. It does so by converting copper media into fiber media and vice versa.

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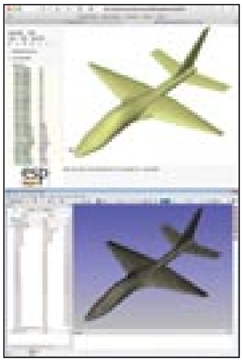
Meshing Software

Pointwise (Fort Worth, TX) has announced the latest release of its meshing software featuring new native interfaces to computational fluid dynamics (CFD) codes. Pointwise Version 17.3 R4 also includes support for ESP, the Engineering Sketch Pad, an open-source, browser-based, constructive solid, CAD system from the team of Dr. John Dannenhoffer (Syracuse University) and Robert Haimes (MIT). ESP targets multi-disciplinary analysis and optimization (MDAO) by aiding computation of the sensitivity of objective functions (lift and drag, for example) with respect to design parameters (wing sweep, for example). ESP is available online at acdl.mit.edu/ESP.



Pointwise software generates structured, unstructured and hybrid meshes; interfaces with CFD solvers, such as ANSYS FLUENT®, STAR-CCM+®, ANSYS CFX®, OpenFOAM, and SU2 as well as many neutral formats, such as CGNS; runs on Windows (Intel and AMD), Linux (Intel and AMD), and Mac, and has a scripting language, Glyph, that can automate CFD meshing.

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Aerospace Gimbals Test Service

A new test service introduced by Bal Seal Engineering, Inc. (Foothill Ranch, CA) offers OEMs verified performance results for Bal Seal spring-energized rotary/face seals used in aerospace and defense gimbal applications. Aerospace gimbals used for targeting, surveillance, and threat detection require precise positioning and must overcome internal drag to function efficiently.

Bal Seal Engineering's gimbal seal test equipment measures friction and leak rate using customer-defined hardware tolerances and operating conditions, including pressure and speed. Fixtures can accommodate seals up to 22 in. OD, and can be modified for larger seal dimensions. The fixtures can produce a wide range of pressures and exert specific frictional forces to accurately simulate a seal's performance under real-world conditions. Rotating plates on the fixtures are connected to digital force testers, which measure the friction of rotation. A vacuum tester simulates air flow over the gimbal during flight. The tester pulls a vacuum across the plates, creating suction inside the seal to measure the leak rate across its surface. Both friction and leak rate are measured simultaneously.

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