Countermeasure Development and Validation of On-Board Countermeasure System including the Directed Infrared Countermeasure System.

Miro Dubovinsky
Jeff Vesely
Electro-Optic Countermeasures Group
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Scope of the talk

- **Customer focus**
- **Evolution of Onboard Countermeasure systems**
- **Countermeasure development and validation process**
  1. Modelling and simulations (M&S)
  2. Validation and verification
  3. Field trials
- **Underpinning research**
  1. Laser through the plume propagation studies
  2. Retro-reflection measurements
- **Conclusions**

Customer focus: Defence Materiel Organisation-New acquisition: (ASPSPO, AIR projects have EW programs)

ADF-Force-in-being: Air (mature/educated process); Navy/Army (developing process, understands importance)

Other ADO agency inputs to CMD&V
Customer Focus:  
PRIORITY  
Large Aircraft Acquisition Projects  

DMO  
- Transport (Lockheed-Martin)  
- Air-to-Air Refueler (AIRBUS),  
- Airborne Early Warning and Control (Wedgetail) (BOEING)  
- (and ASPSPO-Echidna)  

Transport C17-Globemaster  
MRTT- A330  
AEW&C - B737  
Echidna
Customer Focus:
PRIORITY
Large Aircraft Acquisition Projects

- ADF: JEWOSU: Amberley/Williamtown/Richmond Air Force Bases,
- The AACT activities,
  1. Development of a jam code, complex mathematical approach.
  2. Investigation into the synergy between flares and DIRCM systems
  3. Sustainment plan is imperative to maintain capability effectiveness
  4. Building relationships with stakeholders (inc. industry)

The Australian Airborne Countermeasure Team is a combination of JEWOSU and EWRD personnel responsible for managing and conducting CMD&V activities. The AACT is responsive to a Management Body but with individual members remaining accountable to their own chain of command.

The JEWOSU personnel coordinate ADF units and assets for Test and Evaluation and the EWRD oversee and design test and evaluation techniques to meet scientific and operational requirements.

The EWRD personnel undertake M&S and capability and infrastructure development in support of CMD&V outcomes.
Customer Focus: Large Aircraft Acquisition Projects

- Develop and Evolve On-board Evaluation Suite
  1. Radiometer
  2. Laboratory laser (DEOS)
  3. Stimulator (IR source(s)/MALLINA)
  4. Simulation environment for Countermeasures Development
  5. Sustainment plan for evolving and emerging requirements

- Future R&D
  1. OSAR – Optical Scattering and Retro-reflection
  2. Countermeasures to Imaging systems – modeling, and experimentation with commercially available Focal Plane Arrays
  3. Propagation of laser beams through the plumes
First generation IR jammers have a fixed Field of View (FOV), use incandescent sources and operate continuously albeit covert to the naked eye; with no requirement for indication of missile launch, direction or type; totally open loop jamming.
Evolution of Onboard Countermeasure systems

- Lamp/Laser
- Modulated
- All aspects
- Band I/II/IV
- High J/S

ATIRCM

- Lamp/Laser
- Modulated
- All aspects
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- High J/S

MOTS

NEMESIS

Directional IR Countermeasure (DIRCM) systems track the missile but provide no indication of missile type. This can be considered as semi closed loop jamming. Consequently generic jam codes rather than codes optimised for the threat are generally used. The DIRCM's narrow beam (lamp or laser) results in high J/S values and enables generic waveforms to be effective against a large range of missile systems.

Developed by BAe Systems, the ATIRCM/CMWS uses electro-optic MAWS sensors to detect the presence of incoming missiles by sensing the energy emitted by their rocket motors. Once detected, missiles are tracked by the system. The seekers on the missiles can then be jammed using electromagnetic emissions from the ATIRCM’s directed infra-red countermeasure system.

The AACT Electronic Warfare Self Protection kit (ATIRCM and CMWS) has been fully integrated in a portable, compact trolley unit, which can be moved to different trials locations at short notice.
Evolution of Onboard Countermeasure systems

- RF pumped CO2
- COTS
- High PRF

DEOS – Coherent (R&D workhouse)

• Multiple bands (Band I/II/IV)
• MOTS
• Solid state

MURLIN AT

AACT’s AT-MURLIN research tool

The Advanced Tactical-MUlti-band Research Laser, Infrared (AT-MURLIN) is a multi-band DIRCM solid-state laser.

DSTO last year received delivery of the second of two AT-MURLIN systems from Tenix Defence, representing the completion of yet another significant milestone in five years of collaborative development between DSTO and Tenix under the PA10 program.

The AT-MURLIN laser is an outstanding achievement of Australian military capability development, in which a complex laboratory-based laser system produced for DIRCM research has then been semi-ruggedised, robustly packaged and designed and optimised for flight trials.

The laser is based on a patented DSTO Nd: YAG slab laser that is frequency-converted into the mid-infrared spectral region with cascaded optical parametric oscillators. It has full built-in-test capabilities and is software controlled.
This is the countermeasure process undertaken by the AACT to develop effective countermeasures.

Defence Instruction (General) OPS 13-13 describes the CMD&V administration process which allows countermeasure work to be adequately resourced and prioritised.
The EOCM Jam Lab is designed to present to the EO simulator with both a in-band target (S) to track and a LASER for Jamming (J). It consists of:

**Laser:** A selection of laser sources (for different wavelengths) can be set up to focus at the focus of a collimating mirror.

**Attenuator:** Used to keep the incident laser radiation in the linear region of the EO detector.

**Beam Combiner:** Used to combine both target and Laser

**Lenses:** For beam expanding and focusing to match the collimator.

**Collimator (Off-axis Parabola - OPA):** The collimator is used to simulate the far field that the optical device views and allows the device to focus at infinity. A large OPA will provide a uniform plane wave at the optical device and avoid spherical aberrations at the focal plane.
Optical laboratory

The IR track is perturbed  IR tracker is losing the lock from the target
Miss distance has two components, one due to path perturbation (\(M_p\)) and the other due to gravity drop (\(M_G\)). Miss distance due to perturbation is estimated by assuming that the missile continues on in the direction of its velocity vector at time of LOL:

\[
M_p = \tau V_N
\]

\[
M_G = \frac{1}{2} g \tau^2
\]

where \(V_N\) is the velocity component normal to the ideal trajectory. It is assumed the missile continues with its velocity at the instant of LOL and is not affected by the direction of the body axis. It is further assumed that there are no guidance demands after LOL.

Some missiles have a track rate bias, to push the track towards the body axes and the intercept point ahead of the plume. Typically the bias is only enabled of the look angle exceeds a set value. The acceleration developed and resulting deviation from the ideal flight path depends on the magnitude of the bias and the look angle (since bias ceases when seeker boresight is driven into alignment with the body axes). This can induce a high acceleration on LOL, and lead to larger miss distances than estimated in the study.

Although the simulation computes miss distance in only one dimension, the results can be generalized to a 2-D miss distance circle, by taking the perturbation amplitude to be the radius of the miss distance circle. Another assumption is that there is no limit to missile acceleration.
The Hardware-in-the-loop facility enables simulated hardware to be tested as if it was performing in a real environment. The real environment is presented by injecting signals into the simulated hardware from representative software models. The aim is use simulated hardware, with software modeling the scene and flight.

The advantage? Compared to an in-the-field experiment it is cheaper (cost per run) as many runs can be tested time and time again.

Is it accurate? Final verification is done with sample scenario’s that are run in-the-field and compared to the results given by the simulated HWIL runs.

The diagram shows two control loops. The first loop is the tracking of the target via simulated steering of the simulated hardware. The second is the steering of the software missile body; which is de-coupled from the hardware simulator.
Coverage diagrams and miss distance interpretation.

How safe is the platform? Scenarios are developed where the aircraft flies at a constant altitude and speed. This diagram is for such a case. A threat missile of interest can be fired at any point on the polar plot. The plane sits in the middle, nose to the top of the page. For example a shot taken from behind the plane, as the plane flies away, will not reach the plane if fired at a distance of 3nmi or more. The self-destruct, yellow areas, show this.

Red areas show the angles and distances at which the plane is not safe. The missile will hit if fired at these positions.

The scenarios can be run with and without countermeasures enabled to determine the effectiveness of the countermeasures.
Modelling and Simulation
Computer Simulation Laboratory
Interpreting Results

• For flares, once the IR seeker is seduced, it tends to follow the flare – outcome is generally hit or miss
  – “usual” hit-miss (flare view) is not adequate for analysing DIRCM performance

• For DIRCM jamming:
  - Interaction between perturbation of the IR seeker & missile performance
  - Thus, Computer simulation is only reliable way to analyse DIRCM jamming

• Miss distance embodies time to breaklock and continued jammer efficiency in deviating threat from target.
  - Graded “miss” outputs for computer simulation
Modelling and Simulation
Advantages and Disadvantages

- Computer models
  - Advantages: Cheap, repeatable, fine grain, flexible, secure
  - Disadvantages: Validation, believability
- Optical test bed (beam combiner)
  - Advantages: Cheap, repeatable, secure
  - Disadvantages: Limited scenarios
- Hardware in the loop (HWIL)
  - Advantages: Cheap, repeatable, fine grain, minimises simulation, secure
  - Disadvantages: Validation
- Field trials
  - Advantages: Believable, validation
  - Disadvantages: Expensive, security, limits to scenarios, repeatability

Cost: cents to thousands of dollars
On-board Countermeasure Field trials

- Good climate
- Littoral
- Humidity

Littoral views or desert views

Hint: LCDR Mayes
On-board Countermeasure Field trials

- To be ready for the protection of the Large Transport Aircraft
- Each mount 2 or 4 sensors,
- Scaleable & larger mount options.

Proven and established capability for flare effectiveness testing.
Need to get all the equipment in the circle.
better pixs around
veselyj, 17/04/2008
On-board Countermeasure Field trials

Single band DIRCM Test Set

- Radiometric
- High data collection frame rate
- Bandpass matched
- Energy limiting
- High sensitivity

PA10 Outcome

This capability allows us to measure and quantify the output from On-board Countermeasure systems. The applications ranges from the laboratory to the flight trials.

A new capability on the drawing board will allow dual band measurement.
On-board Countermeasure
Flight Trials
Test objectives(1)

- DIRCM performance test
  1. Testing of the obscuration path
  2. Radiometric Output Measurements
  3. Beam quality and pointing accuracy
  4. Effectiveness evaluation

Rolling out the capability in time for the C17 LAIRCM IOC 2008/2009
The AACT will test the end to end response of the DIRCM installation.
MALLINA -> AAR54 -> JAM HEAD operation -> LASE -> effectiveness test
Under-pinning Research

DIRCM Laser propagation

1. Plume propagation studies
2. Optical scattering and reflection (OSAR)
3. Retro-reflection
4. Atmospheric propagation studies
   i. Scintillation
   ii. Absorption

DSTO work in support of CMD&V and the AACT activities.
Under Pinning Research
Plume Propagation (1)

Parametric study to determine the significance of certain parameters on laser beam propagation through a jet engine plume

1. Temperature
2. Cell size
3. CO2 levels
4. Turbulent intensity
5. Laser beam wavelength
6. Laser beam diameter
7. Refractive indices

To predict the degradation on a laser beam for given jet engine conditions and beam propagation incident angle

We would like to predict the degree of divergence and dispersion of the laser beam as it passes through a jet plume. To do this an understanding of the exhaust gas structure and its influence is needed. There are parameters such as temperature, carbon dioxide, turbulence intensity and length scales as well as the laser beam wavelength and beam size that will effect the beam movement. A parametric study under controlled conditions in a laboratory was undertaken to examine these effects. The results at visual and IR wavelengths will be presented in open literature later this year. Quantifying the parametric effects at high temperatures will assist with the development of a parametrically based laser beam propagation model.
Laser-based Directed Infra-Red Countermeasures (DIRCM) systems are foremost among new technologies being developed to protect aircraft from IR-guided missiles.

IR guided missiles continue to present the greatest hostile risk to aircraft, causing over seventy per cent of losses. Ever more complex variants of these weapons are becoming available and more widespread every year.

Directed IR lasers allow high jamming powers to be concentrated in the threat missile seeker’s field of view without placing high demands on the aircraft’s power supply, since the energy is concentrated in a very narrow beam.

However, this requires very accurate tracking of the threat missile, and very accurate aiming of the laser, presenting a potential problem for some multi-engined aircraft with large low-slung engines.

The laser tracking and jamming may have to occur through the aircraft’s jet plume with very turbulent air containing fuel droplets that make perfect retro-reflectors for the IR beam. This has the potential to degrade DIRCM performance, particularly against the highest priority threat, the shoulder-fired IR guided missile.

From the outcomes of this research, the Australian and UK researchers will examine measures to minimise degradation of DIRCM performance with future platforms. These measures may include optimisation of the unit’s location, or corrective algorithms for the laser and tracker.
Under Pinning Research
OSAR Mapping (3)

- OSAR is the result of scattering of IR by the imperfections in optical elements in an optical system.
- OSAR effects govern the ability of the jamming laser to enable jamming pulses to reach the detector to create false targets or other aberrations with off-axis energy.
- OSAR measurements/maps are important in verifying OSAR models, which are critical in obtaining the correct seeker response to infrared jammers.
Retro-reflection is predominantly due to specular reflection from the focal plane relies on a semi-reflective surface in or close to the focal plane (IR seekers from a reticle, detector or detector array).

Can be characterised by the Optical Cross Section (OCS)

\[ \sigma_O = \text{Geometric cross section} \times \text{reflectivity} \times \text{losses} \times \text{directivity}. \]

Simplest expression is for a "top hat" profile

\[ \sigma_O = \frac{4 \pi A_O r_O t_O^2}{\omega_B} \]

- \( A_O \) is optical area
- \( r_O \) is reflectivity
- \( t_O \) is optical transmission
- \( \omega_B \) is reflected beam solid angle

Real beam profiles depend on optical configuration, Top Hat and Gaussian profiles are idealisations
Under Pinning Research

Retro-reflection (5)

• Retro-reflection is due to reflections in the focal plane. For infrared seekers this is generally a reticle, for a "simple detector" system

• It generates a strong reflection back along the incident beam and hence has the potential to identify the seeker type and modulation characteristics, range and range rate.

• This provides a basis for selecting a more optimal and hence more potential to monitor jammer effects and provide timing for laser dazzle or damage pulses
Retro-reflection has the potential to identify the missile type, modulation characteristics, range and range rate. This provides a basis for selecting more optimal and hence more effective jam modulation. It also has the potential to monitor jammer effects and provide timing for laser dazzle or damage pulses. However, this depends on reflections being sufficiently strong to be promptly detected and of being sufficiently modulated to enable identification and estimation of modulation parameters.
The atmosphere is made up of layers and pockets of different gas constituents and gas temperatures. As a laser beam front propagates through the atmosphere it passes through these different regions of varying refractive index. The result is the laser beam front is steered and broken-up if the refractive index gradients encountered are not uniform across the beam front.

Placing a detector at a distance to collect energy from the laser we see that the collected energy varies in intensity; moment to moment (based on the dynamic changes in the gases in the atmosphere) and over-time as large scale steering is produced by strong gradients set-up due to solar influences.

The structure constant, $C_n^2$, is a measure of the strength of the refractive index changes and in turn the degree of fluctuations present on the received signal strength from a transmitted laser beam.
Conclusions

- On-board CM test capability built and tested
- Modelling and simulation environment under-development with industry
- Research underway in collaboration with Allies into,
  - Optical Scattering and Retro-reflection
  - Laser propagation under atmospheric effects inc. jet plumes and environmental factors
  - Effectiveness evaluation criteria

Miss distance
Perturbation
End to end timing