HELICOPTER EW SELF-PROTECTION

From Femtoseconds to Operational Capability

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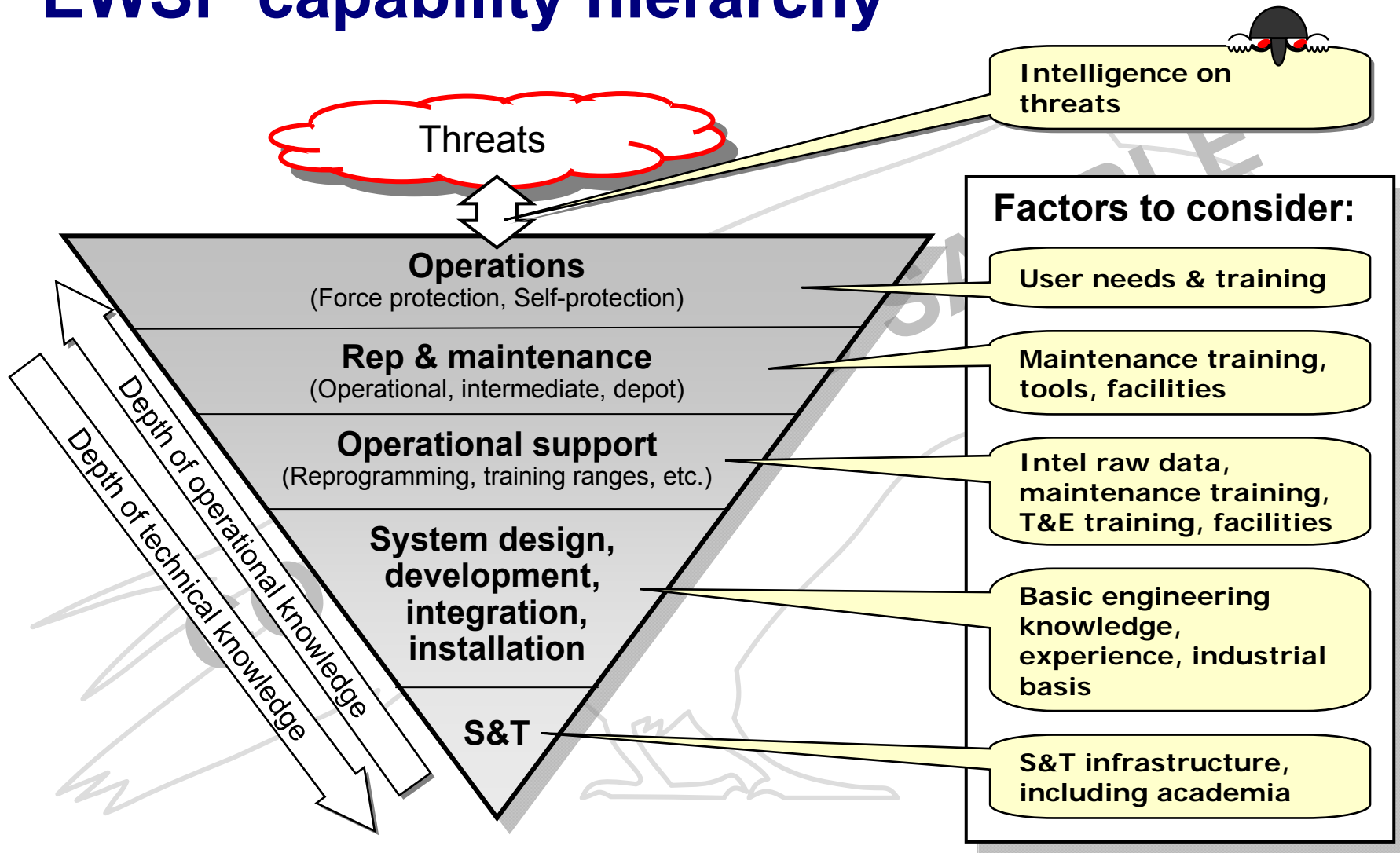**URL: http://www.heikell.fi**

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Dr.EW

EWSP capability hierarchy[1]

Intelligence on threats

Threats

Operations
(Force protection, Self-protection)

Rep & maintenance
(Operational, intermediate, depot)

Operational support
(Reprogramming, training ranges, etc.)

System design, development, integration, installation

S&T

Depth of operational knowledge

Depth of technical knowledge

Factors to consider:

User needs & training

Maintenance training, tools, facilities

Intel raw data, maintenance training, T&E training, facilities

Basic engineering knowledge, experience, industrial basis

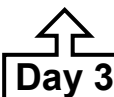**S&T infrastructure, including academia**

1) Adapted from Reynolds, M.: *EW as a Priority Industry Capability*, Presentation at the Australian EW and IO Convention 2010. Legend: S&T = science & technology.

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Seminar outline

1. **Introduction**
2. **Military thinking and the role of helicopters**
3. **Helicopter survivability and EWSP**
4. **Threats & environment**
5. **RF EW refresher**
6. **EO EW refresher**
7. **Platform-specific EW & survivability topics**
8. **Operational-tactical issues in helicopter survivability**
9. **Helicopter EW in the life cycle framework**
10. **Infrastructure of helicopter EWSP**
11. **EWSP in the coalition setting**
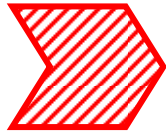12. **Concluding remarks**

Day 1
Day 2
Day 3
Day 4

Outline of four-day seminar *Helicopter EW, from Femtoseconds to Operational Capability*. Lectures last for approx. 50 minutes, followed by a 10-minute break.
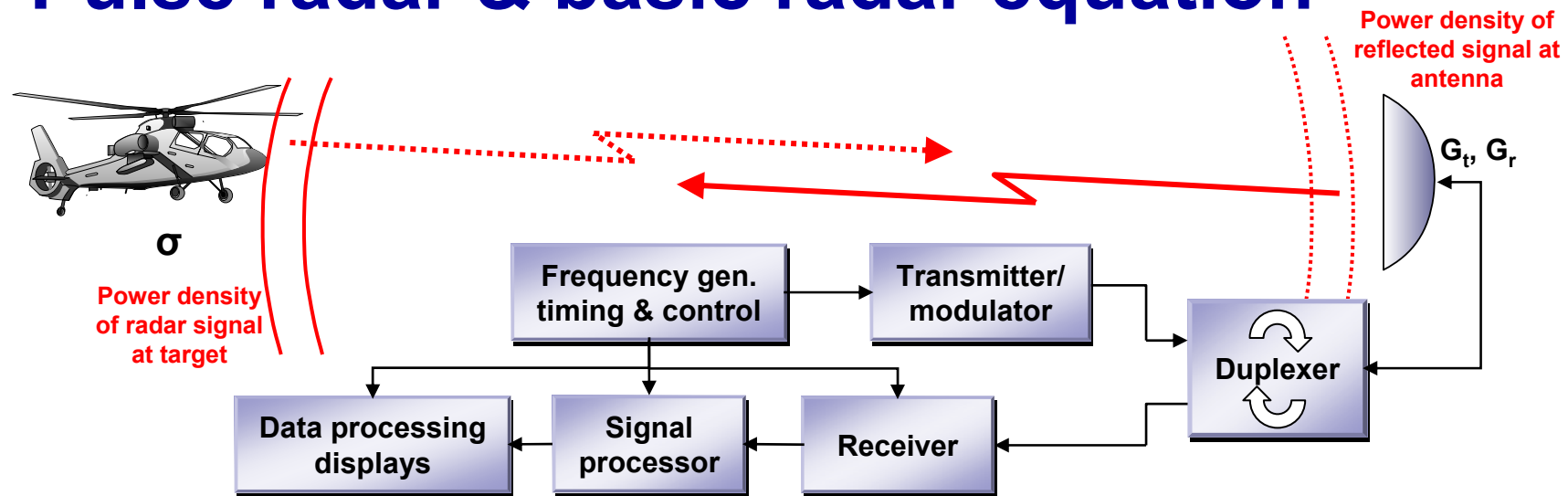
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Part 5

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Pulse radar & basic radar equation[1,2]

Power density of reflected signal at antenna

G_t, G_r

σ

Power density of radar signal at target

Frequency gen. timing & control → **Transmitter/ modulator** → **Duplexer**

Data processing displays ← **Signal processor** ← **Receiver** ← **Duplexer**

$$SNR = P_t \cdot \frac{1}{4\pi R^2} \cdot G_t \cdot \frac{1}{L_a} \cdot \sigma \cdot \frac{1}{4\pi R^2} \cdot \frac{1}{L_a} \cdot \frac{G_r \lambda^2}{4\pi} \cdot \frac{1}{L_r} \cdot \frac{1}{kT_oFB_n}$$

Signal-to-noise ratio of radar receiver

Density of radar signal at target

Propagation losses ($L_a > 1$)

Radar cross section of target

Effective antenna area (A_e)

Losses in the antenna-receiver chain ($L_r > 1$)

Thermal noise

Power density of reflected signal at antenna

Signal power picked up by radar antenna

For a receiver bandwidth of 1 MHz at 290 K the thermal noise floor kT_oB_n is -144 dBW. The noise level is increased in practical receivers by the noise figure F.

1) The most popular textbook on radar engineering is Skolnik, M.I.: *Introduction to Radar Systems*, now in its third revised edition (2001) from McGraw-Hill. 2) There are numerous variations of the radar equation, see e.g. [Barton, Leonov 1998, pp. 378-379].

Losses in the radar process

The radar equation above considers only two loss types (L_a and L_r). Accurate calculations require that additional losses be considered, e.g.:[1]

- **Transmission losses L_t**; occur between the transmitter and transmitting antenna.
- **Beam-shape losses L_b**; account for the fact that the beam shape is not constant ("top hat") but rounded off—usually considered to be Gaussian.
- **Matched filter losses L_m**; recognize that the matched filter of the receiver is not ideal.[2]
- **Integration losses L_i**; depend on the type of pulse integration (coherent or non-coherent) used to improve SNR.
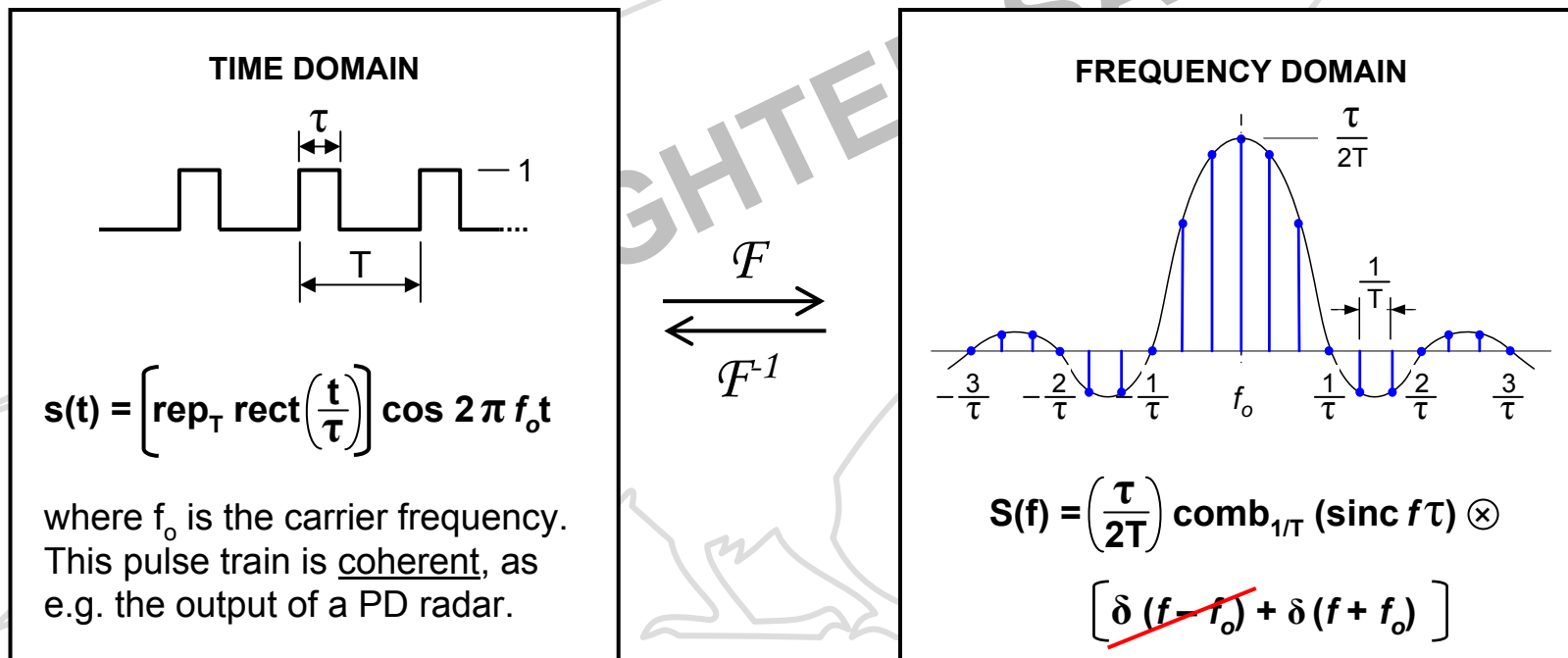- **Signal processing losses L_s**; due to data quantization, approximations, etc.

> **Radar literature define some 50 loss factors, divided into four groups: 1) Antenna and propagation losses; 2) Transmit RF losses; 3) Receive RF losses, and 4) Receiver-processor losses. [Barton & Leonov 1998]**

1) [Neri 1991, pp. 58-62]. 2) A matched filter is one that maximizes the SNR at the output of the filter.

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Frequency content of a pulse train

Fourier analysis reveals that a pulse train is composed of numerous (infinite) discrete frequencies. In practice, we filter out all but frequencies containing the bulk of signal energy.[1]

TIME DOMAIN

$$s(t) = \left[\text{rep}_T \, \text{rect}\left(\frac{t}{\tau}\right) \right] \cos 2\pi f_o t$$

where f_o is the carrier frequency. This pulse train is <u>coherent</u>, as e.g. the output of a PD radar.

FREQUENCY DOMAIN

$$S(f) = \left(\frac{\tau}{2T}\right) \text{comb}_{1/T} \, (\text{sinc } f\tau) \otimes$$
$$\left[\delta\,(f - f_o) + \delta\,(f + f_o) \right]$$

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1) See [Brandwood 2003] for the use of Fourier analysis in radar engineering. The book discusses Fourier transforms based on Woodward's "rules and pairs" [Woodward 1953].

Bandwidth

Bandwidth (BW) has important implications e.g. for radar range accuracy[1] and pulse integration, but it is an elusive concept with no universal definition. Two concepts are of major interest to us:

- **Null-to-null BW** (B_{NN}): Frequencies that fall within the first nulls of the sinc function. Stated otherwise: $B_{NN} = 2/\tau$.

- **3 dB BW** (B_{3dB}): Half power bandwidth. For pulse radars $B_{3dB} \sim 1/\tau$.

- Typically B_{3dB} is taken as the radar bandwidth. For a receiver with a rectangular filter it is also the noise bandwidth B_n.[2]

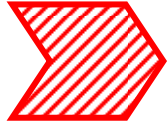**3dB & NULL-TO-NULL BANDWIDTH**
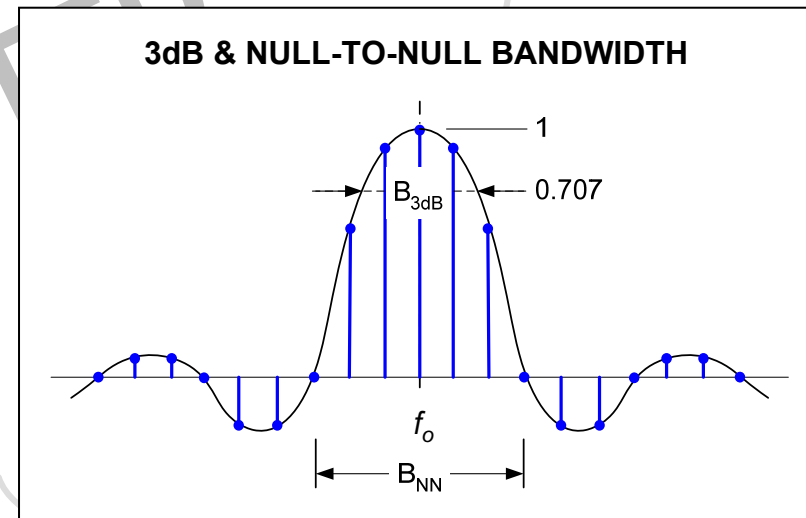
1) Note that range accuracy does not depend on pulse length *per se* but on **radar bandwidth**, which, in turn, varies with pulse length [Kingsley, Quegan 1992, p. 131-134]. 2) However, the bandwidth may be selected higher to preserve the square shape of the pulse and provide better resolution of closely spaced targets [Barton & Leonov 1998].

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Part 6

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Why is this important?

The EW specialist needs sound understanding of EO EW, since with the rapid development of MANPADS and other EO systems this area has become the premier threat to battlefield helicopters.

Archimedes conducting an EO/DEW attack against Roman ships during the siege of Syracuse in 212 B.C.

The basic aim of Part 6 is to refresh the seminar participant's memory on EO EW issues. In addition, it is hoped that the presentation will present details that are not normally covered in basic EW courses.

A comprehensive review of the subject is given in Vol. 7 of *The Infrared and Electro-Optical Systems Handbook*, ERIM/SPIE, 1993. The seminal work on the subject—still of interest—is Hudson, R.D. jr.: *Infrared System Engineering*, John Wiley & Sons, Inc., 1969.[1]

1) Basic reading on EO EW can also be found in e.g. Neri, F.: *Introduction to Electronic Defense Systems*, 2nd ed., Artech House, 2001; and Schleher, D.C.: *Electronic Warfare in the Information Age*, Artech House, 1999.

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IR missile seekers (1/11)
Development of IR guided missiles[1]

Will IR seekers with HOJ capability be reality in the 2020's?[2]

Some 500,000+ MANPAD missiles exist world-wide, thousands are in the hands of terrorist groups.

2010
2nd Gen Spectral Imagers (Gen V+)

2005
1st Generation Imagers (Gen V)

2000 Scanning Imagers (Gen V-)

Gen IV

CM: Femto-second lasers?

1980s/90s
Cross Array/Rosette Flare CCMs (Gen III/IV)

1970/80
Cooled Con Scan (Gen II)

1960s
Uncooled Spin Scan (Gen I)

Mockup of Japanese Type 91 "Keiko", regarded as one of the most advanced MANPAD missiles. (Wikipedia)
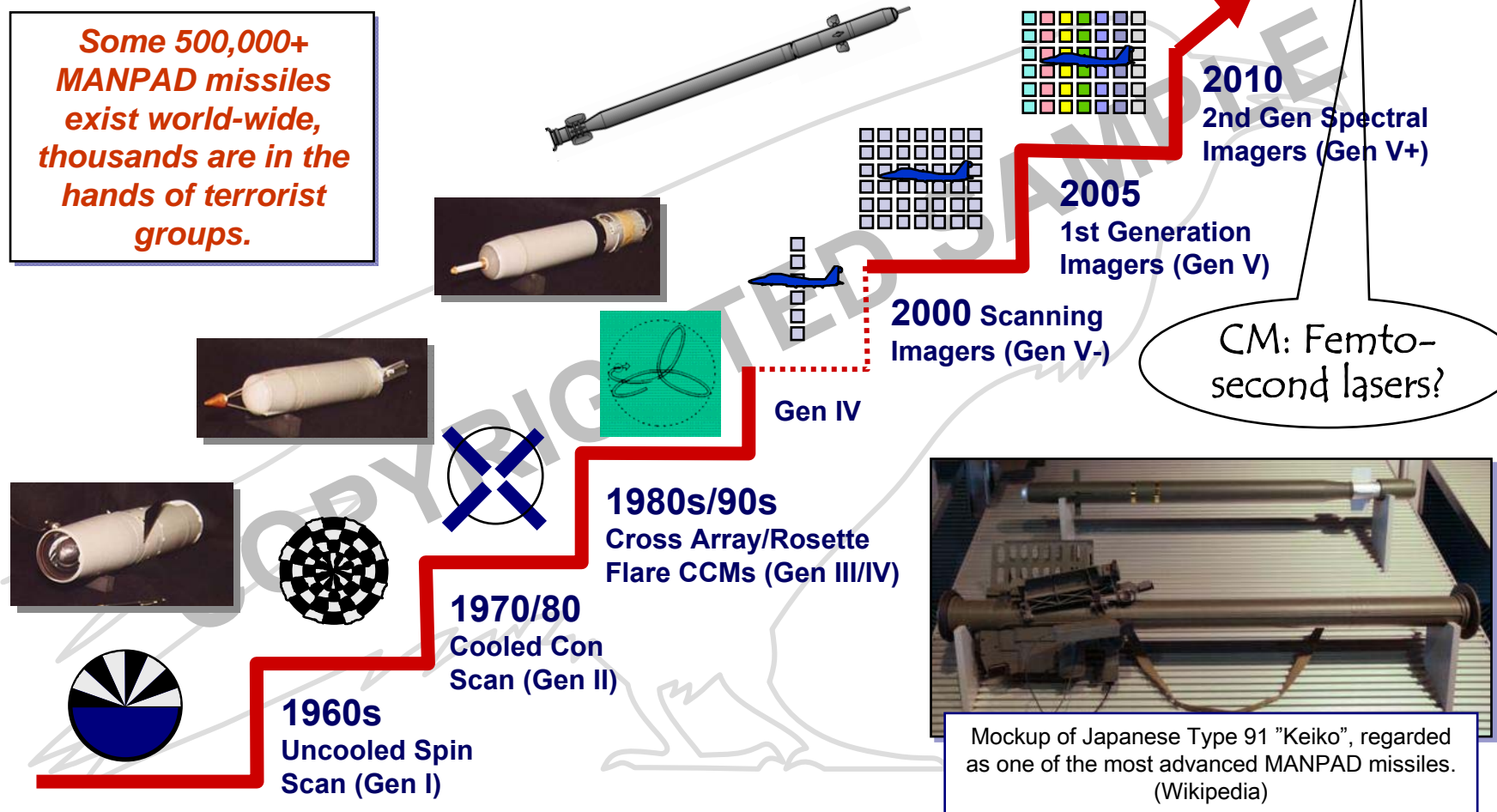
1) The graphic knowingly originates with the LAIRCM SPO, AFRL, although there are many variants in circulation. 2) See [European Patent EP 0 882 941], [German Patent DE 198 05 850], and [EP 0 822 383] for DIRCM-resistant solutions. Rosette scanning seekers are claimed to have intrinsic HOJ capacity [Rafilov 2009].

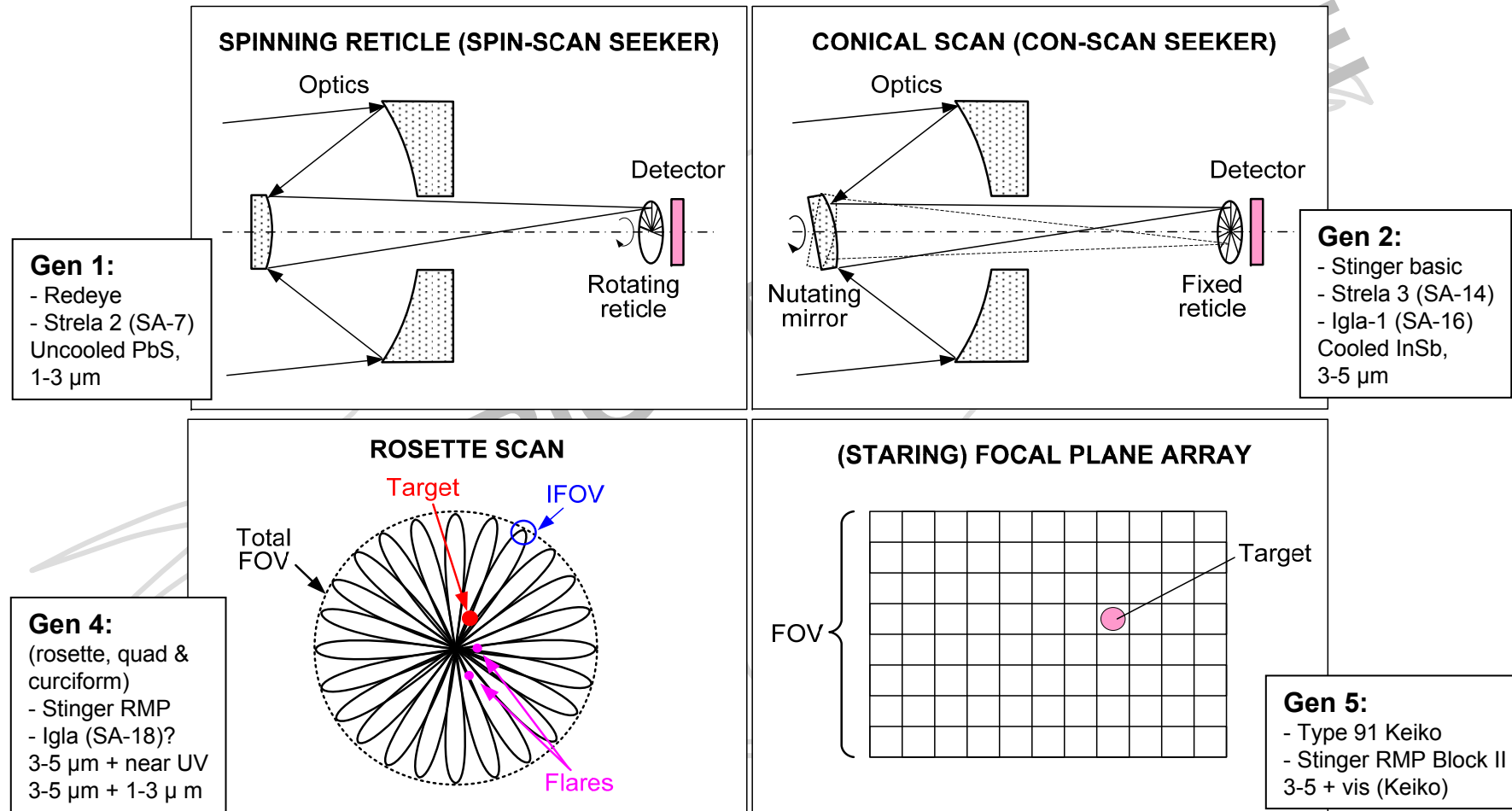# IR missile seekers (2/11)
Four of five seeker generations (Gen 5+ is coming)[1,2]

SPINNING RETICLE (SPIN-SCAN SEEKER)

Optics

Detector

Rotating reticle

Gen 1:
- Redeye
- Strela 2 (SA-7)
Uncooled PbS,
1-3 µm

CONICAL SCAN (CON-SCAN SEEKER)

Optics

Detector

Nutating mirror

Fixed reticle

Gen 2:
- Stinger basic
- Strela 3 (SA-14)
- Igla-1 (SA-16)
Cooled InSb,
3-5 µm

ROSETTE SCAN

Target

IFOV

Total FOV

Flares

Gen 4:
(rosette, quad & curciform)
- Stinger RMP
- Igla (SA-18)?
3-5 µm + near UV
3-5 µm + 1-3 µ m

(STARING) FOCAL PLANE ARRAY

Target

FOV

Gen 5:
- Type 91 Keiko
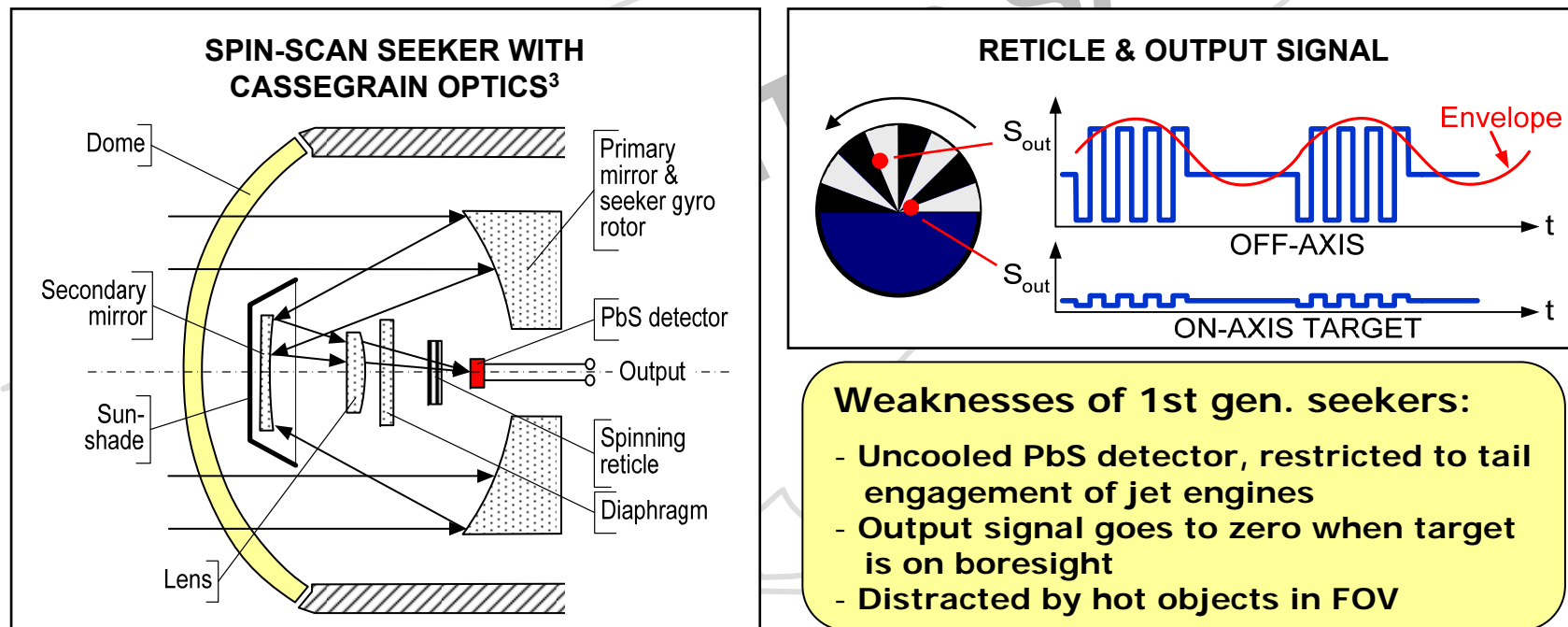- Stinger RMP Block II
3-5 + vis (Keiko)

1) According to [Glasgow, Bell 1999], the time delay from the first 128x128 pixel FPAs being available commercially until such an FPA emerged in military systems was 13 years, and a similar lag must be expected for multicolor FPAs. 2) Data on missile types from [Heck 2002].

IR missile seekers (3/11)
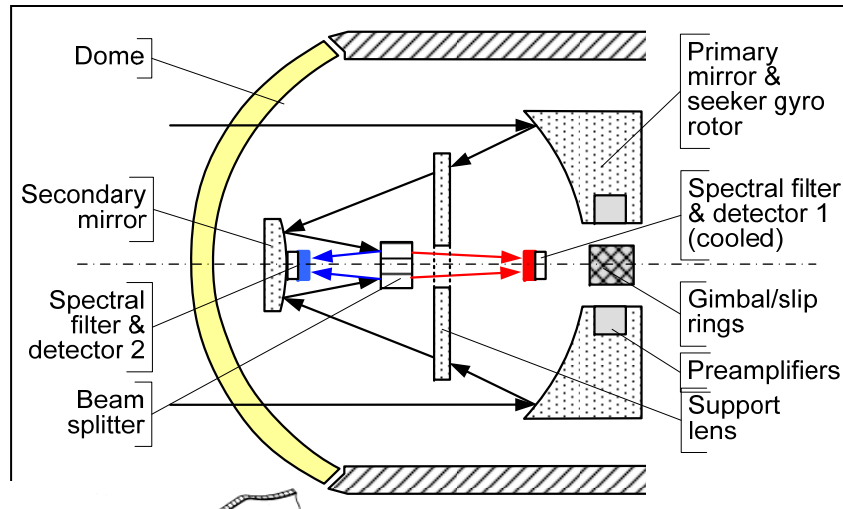## Anatomy of the basic seeker

First generation IR seekers, introduced with the Sidewinder air-to-air missile in 1956,[1] used spin-scan modulation based on a rotating reticle. The output signal was AM modulated.[2]

SPIN-SCAN SEEKER WITH CASSEGRAIN OPTICS[3]

- Dome
- Secondary mirror
- Sun-shade
- Lens
- Primary mirror & seeker gyro rotor
- PbS detector
- Output
- Spinning reticle
- Diaphragm

RETICLE & OUTPUT SIGNAL

S_{out}

Envelope

OFF-AXIS

S_{out}

ON-AXIS TARGET

Weaknesses of 1st gen. seekers:

- Uncooled PbS detector, restricted to tail engagement of jet engines
- Output signal goes to zero when target is on boresight
- Distracted by hot objects in FOV

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1) The first Sidewinder model to become operational was subsequently known as AIM-9B. Modulation of the field-of-view (FOV) by reticles to extract angular target data was first devised by German scientists during WW II. 2) [Schleher 1999, pp. 429-450]. 3) [Rogalski, Chrzanowski 2002].
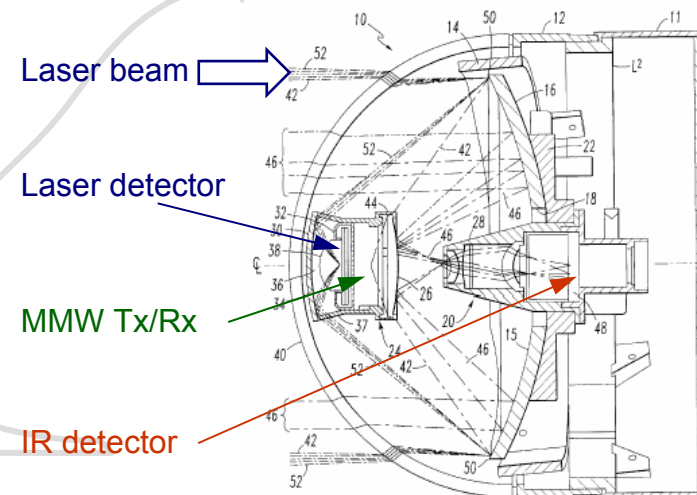
IR missile seekers (4/11)

Anatomy of multispectral seekers[1]

Dome

Primary mirror & seeker gyro rotor

Secondary mirror

Spectral filter & detector 1 (cooled)

Spectral filter & detector 2

Gimbal/slip rings

Preamplifiers

Beam splitter

Support lens

Left: Typical two-color seeker optical layout [Glasgow & Bell 1999] and requirements on IR missile domes. Motivations for longer wavelength detectors (3.2-4.8 µm or more) are to achieve lower dome emission and to escape solar radiation reflected from sunlit clouds [Harrris 1999, Hudson 1969 p. 238]. According to [Doo et al. 2002] the optimal UV band in a combined UV/IR seeker is 0.37-0.43 µm; i.e., on the border between the visual and UV regions. Solutions for rosette scanning seekers can be found e.g. in [Knight 2001] and [Voigt & Gordon 2000].
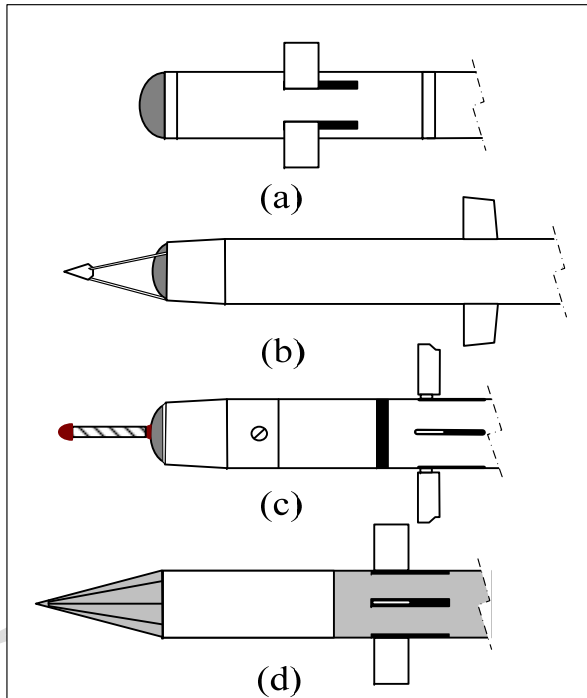
FIG.1
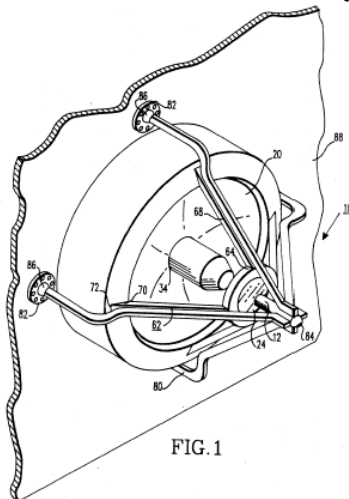
Left: Arrangement of a dual-band MMW/IR seeker. The struts of the reflector/horn antenna are the four waveguides for the MMW monopulse radar.[2] **Right:** Tri-mode seeker (MMW/IR/laser). The laser detector is located within the reflector arrangement, which also holds the MMW transmitter/receiver assembly.[3]

Laser beam

Laser detector

MMW Tx/Rx

IR detector

1) For a general discussion on imaging IR seekers, see [Bell & Glasow 1998], and [Glasow & Bell 1999]. 2) U.S. Patent 5,214,438. 3) U.S. Patent 6,606,066. The American Joint Surface-to-Air Missile (JSAM) will have a tri-mode seeker.

IR missile seekers (5/11)
Seeker domes[1]

> "At elevated temperature, it is emission, not absorption, that limits the performance of an optical window. (….)
> A long wave infrared seeker can tolerate much greater emittance from the dome than can a midwave seeker" (Harris)

The dome:

Aerodynamic heating of the dome is a major source of noise in IR seekers, particularly at sea level. At Mach 3 the dome temperature rises above 500 °C. Improvements are the aerodynamic spike on the Iglas (SA-16/SA-18) and the octagonal cone of the Mistral. Long wavelength detectors tolerate more dome emittance. Popular dome materials are MgF_2 and Al_2O_3 (sapphire); other acceptable materials are GaP, ZnS, and ZnSe. Diamond domes are under development and expected to be superior at long wavelengths (mechanical strength, transmittance).

(a)

(b)

(c)

(d)

Dome architectures: a) Stinger, b) Igla-1 (SA-16), c) Igla (SA-18, KP-SAM Shingung similar), d) Mistral (similar solution in the Chinese FN-6). Of the most advanced MANPAD missiles today Stinger and Keiko retain the aerodynamically inefficient hemispherical dome.
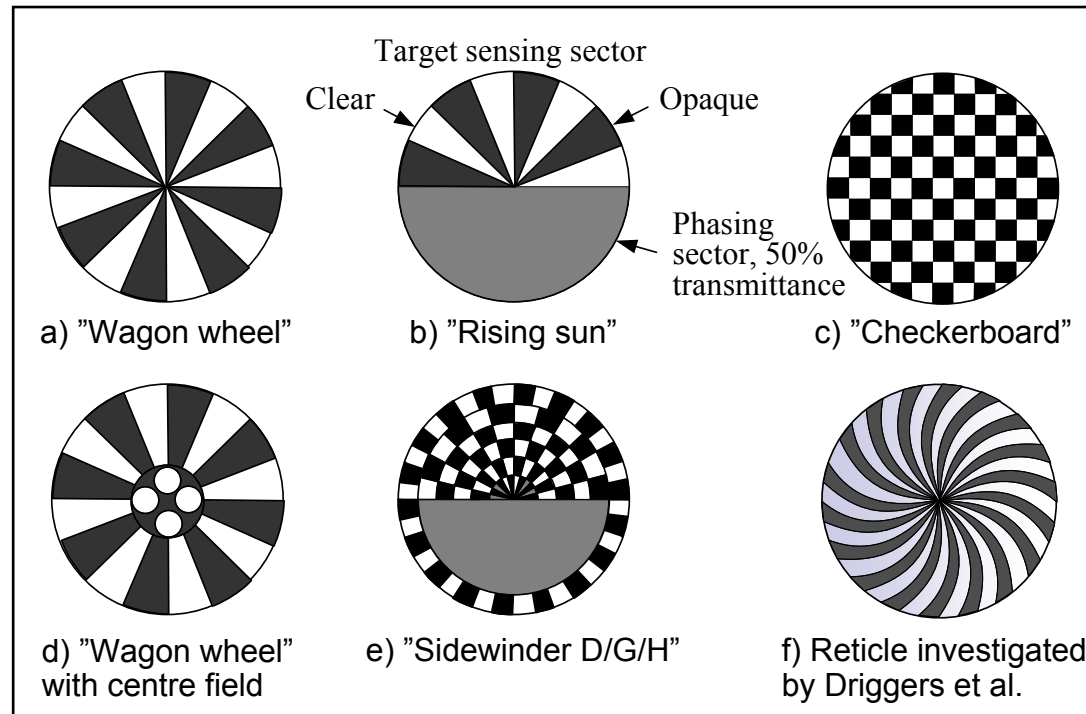
The aerodynamic spike of Igla (SA-18) is glued to the dome. (Source: Dr.EW)

1) The most comprehensive information source on IR missile dome materials is Harris, D.C.: *Materials for Infrared Windows and Domes: Properties and Performance*, SPIE Optical Engineering Press, 1999.

IR missile seekers (6/11)
Reticles and seeker scan methods[1,2]

Target sensing sector
Clear — Opaque
Phasing sector, 50% transmittance

a) "Wagon wheel"
b) "Rising sun"
c) "Checkerboard"
d) "Wagon wheel" with centre field
e) "Sidewinder D/G/H"
f) Reticle investigated by Driggers et al.

Explanation to shown reticles:
a) The basic episcotister or "wagon wheel" is susceptible to confusion by extended background sources like sunlit clouds or terrain [May83]. Symmetric spokes produce an AM output signal for circular scan, and FM output with asymmetric spokes [Car63, Ger85 p.22/40].
b) The "rising sun" developed by Bieberman and Estey to comply with their findings that there are no background signals beyond the eight harmonic [Hud69 pp.239-243].
c) The "checkerboard" is usually inserted in the center field of a "wagon wheel" [May83].
d) Modified "wagon wheel" that can be used with nutating scanning. Its output is either AM or FM modulated [Ols92,94].
e) Simplified presentation of reticle used in some Sidewinder models [Hoi95 p.5b/15]. Other claimed Sidewinder reticles can be found in Craubner [Cra80] and May and Van Zee [May83].
f) Reticle investigated in detail by Driggers et al. [Dri91].

Except for some special cases there is no closed form mathematical solution to reticles. Their operation therefore has to be investigated e.g. by hardware-in-the-loop simulations or similar methods. [Olsson 1992, 1994] provides insight into a method for simulating the behavior of reticle seekers.

1) See chapters 17 and 22 in [Wolfe, Zissis 1985] for basic theory of reticles and IR tracking systems. The seminal text on optical modulation is presented in Hudson, R.D. jr.: *Infrared Systems Engineering*, John Wiley & Sons, 1969, pp. 235-263. 2) Information on basic parameters of early American IR reticle seekers can be found in [U.S. Patent 6,429,466].

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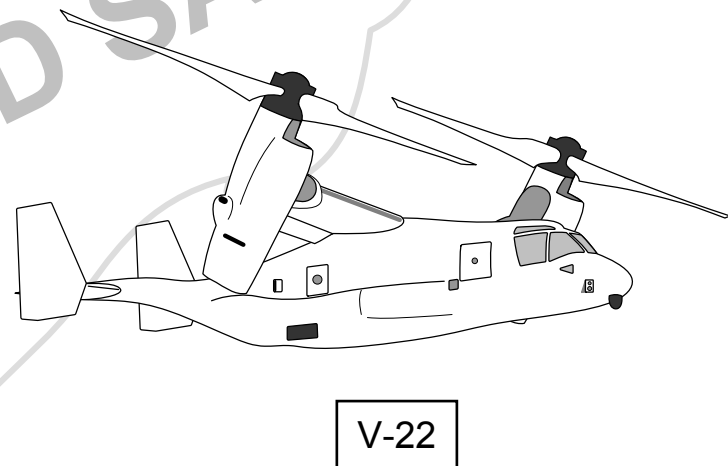
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Part 7

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SECTION 3: PLATFORM INSTALLATION
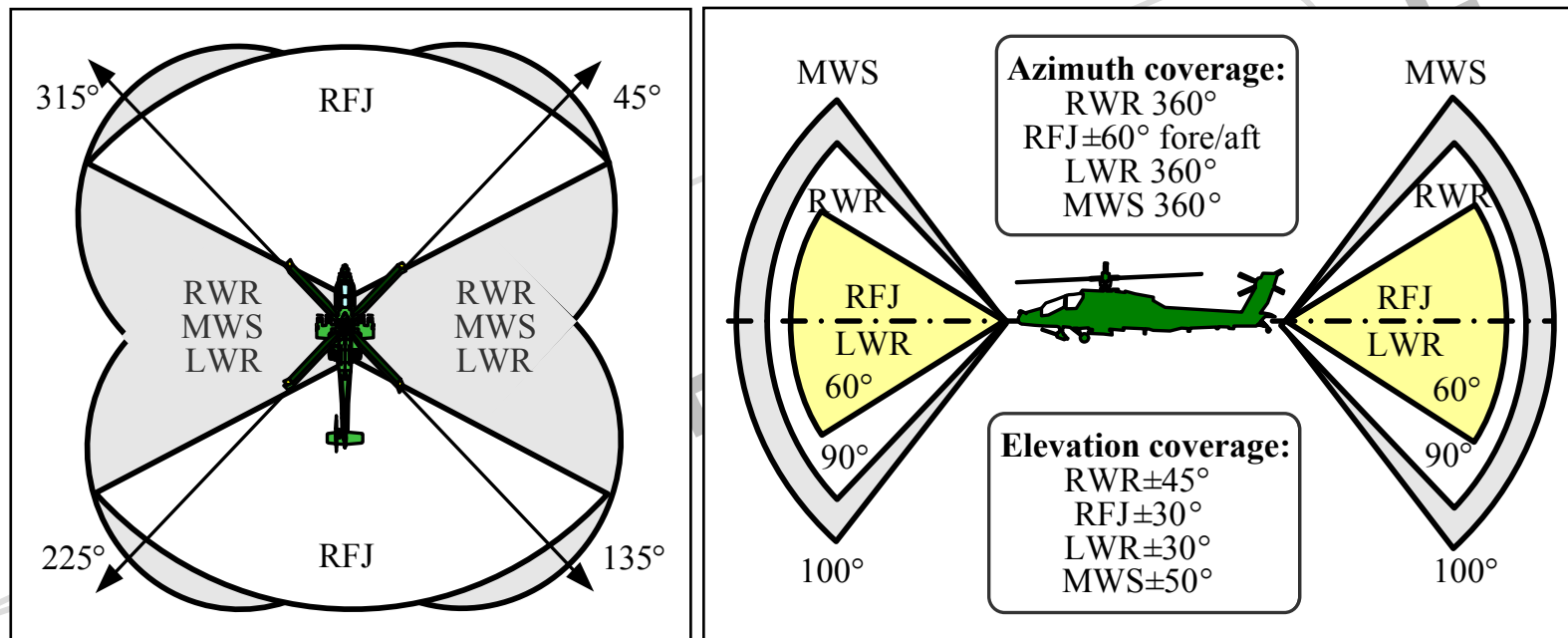
Once an EWSP suite has been developed, it has to be installed on the platform. Suitable locations must be found for the various subsystems, they must be interconnected and supplied with power and cooling, and they must be compatible and interfaced with the platform's other electronic equipment.

V-22

"You can have it good, fast, or cheap: pick any two." The Project Manager's Maxim.

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EWSP installation on helicopters (1/10)

Spatial coverage of warning systems

Azimuth coverage:
RWR 360°
RFJ±60° fore/aft
LWR 360°
MWS 360°

**Elevation coverage:**
RWR±45°
RFJ±30°
LWR±30°
MWS±50°

An EWSP suite typically covers only a part of the sphere. With the advent of top-attack weapons it must be asked if the entire upper hemisphere has to be covered? It should also be noted that the coverage is not extensive in the indicated sectors. Tail boom, rotors, winglets, pods, etc., block certain directions. These will introduce blind zones from which the threat can approach without being detected or countered.

The indicated solution has been proposed for export versions of the AH-64 Apache and is not used on U.S. Army Apaches [Oeh 1998]. A rear-looking RF-jammer would be exceptional on a helicopter.

EWSP installation on helicopters (2/10)
Antenna architecture for AOA measurement

Four-quadrant amplitude-comparison direction finding with spiral antennas is the most common AOA measurement technique in EWSP.[1]
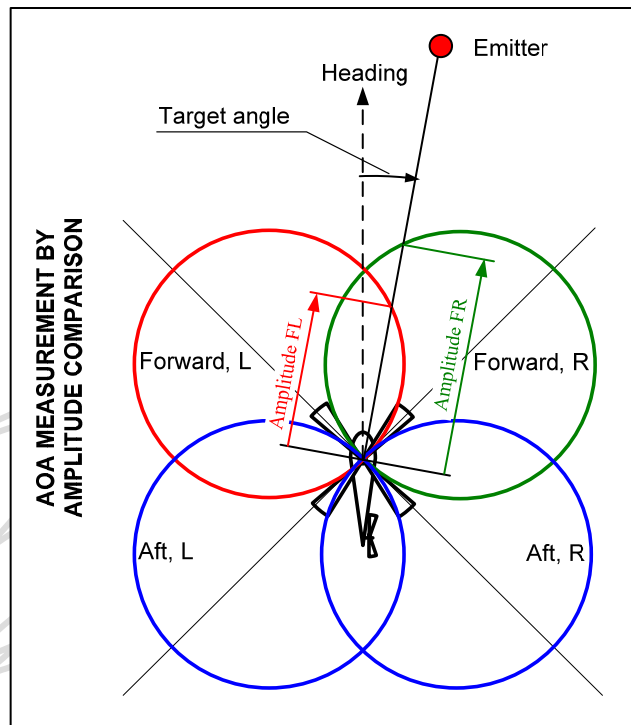
- Preferably antennas with circular/ elliptic lobe pattern, typically spiral antennas with circular polarization.
- Must find unobstructed antenna locations on the helicopter (nose, tail boom, etc.).
- Requires antenna lobe correction tables that compensate for installed lobe asymmetries.
- Antennas require a ground plane, e.g. metallic fuselage.
- External objects on the helicopter can influence antenna pattern and worsen AOA measurement accuracy.
- Improved accuracy with more antennas (antenna lobe has best symmetry in the middle).

1) The advantages are simplicity, reliability, and low cost. The disadvantages are poor accuracy and sensitivity. Both accuracy and sensitivity can be improved by expanding the number of antennas. [Schleher 1986, p. 100] Typically amplitude correction tables are used, but the antenna lobe pattern changes when external pods, weapons, etc. are installed on the platform.

EWSP installation on helicopters (3/10)
## Spatial coverage of antennas and apertures

RWR antennas:
Symmetric and overlapping antenna lobes allow optimal AOA measurement by amplitude comparison. The lobe pattern of a practical spiral antenna (blue dotted line) is not a perfect circle.[1]
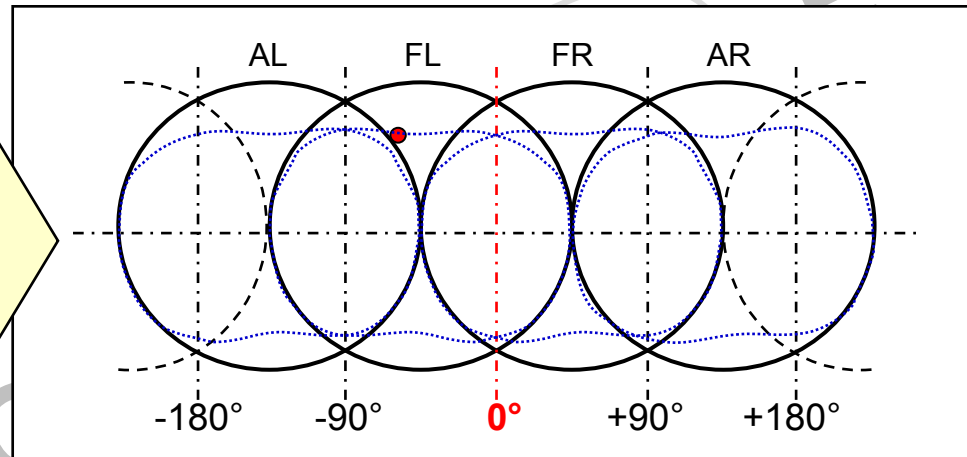
EO apertures:
Some FOV overlap is necessary to compensate for installation errors and to avoid blind zones. The overlaps give ambiguous detections that SP must delineate. Frame alignment by software should be provided in addition to mechanical adjustment.
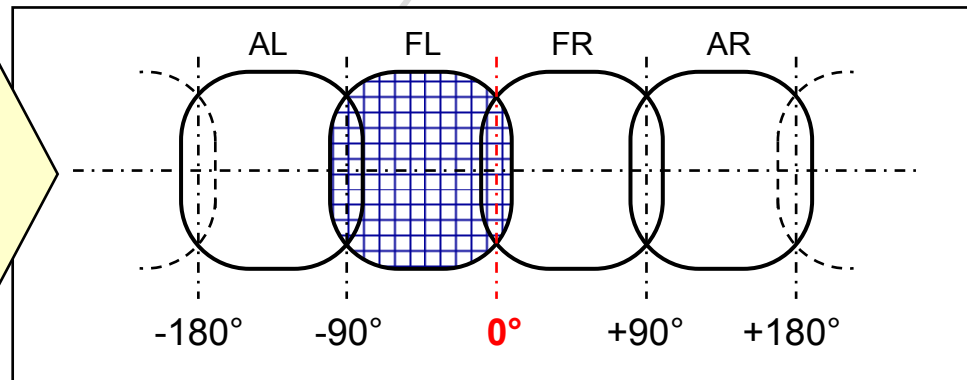
1) For a examples of spiral antenna lobe patterns, see [DuHamel, Scherer 2001]. A four-arm cavity backed spiral antenna when excited in dual mode by a beam-forming network can generate simultaneous sum and difference patterns [Schleher 1986, p 478]. However, it is unknown to which extent this has been exploited in practical RWR systems.

EWSP installation on helicopters (4/10)
Apertures on the AH-64 Apache

RF jammer receiver antenna (ALQ-136(V)5)

Radar frequency interferometer (APR-48(V))

RWR spiral antenna (APR-39(V)1)

RF jammer transmit antenna (ALQ-136(V)5)

IR jammer transmitter (ALQ-144A(V)3)

RWR spiral antenna (APR-39(V)1)

LWR detectors (AVR-2A(V)1)

RWR blade antenna (APR-39(V)1)

Chaff dispenser (M-130)
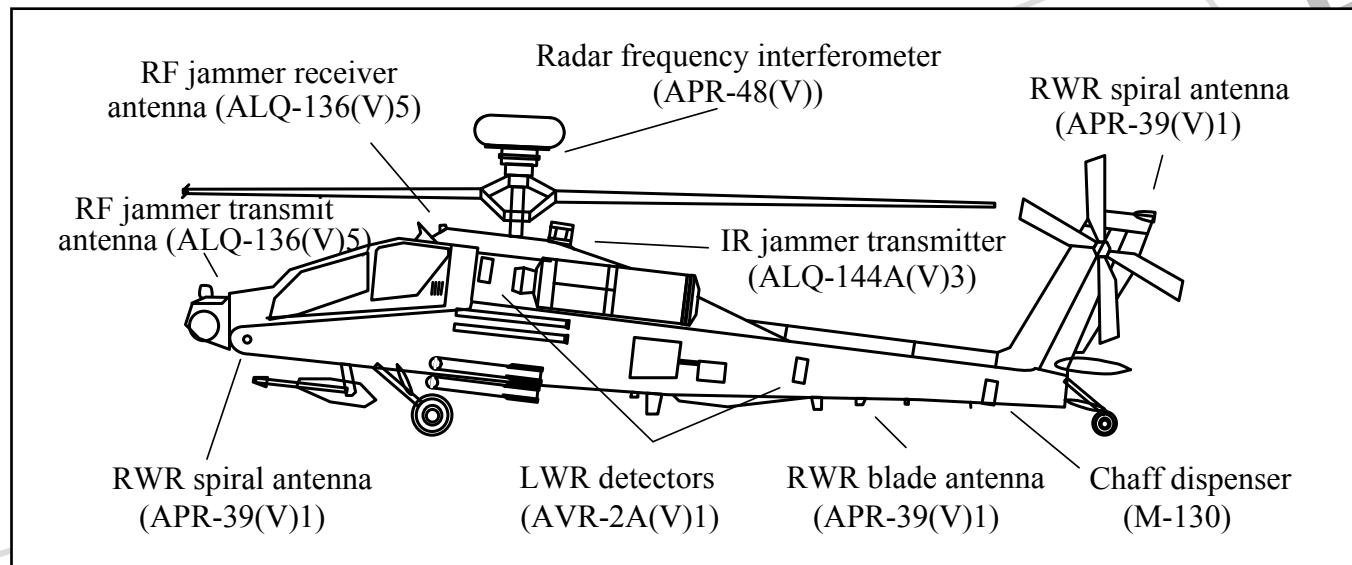
Requirements on apertures: Sensor antennas & detectors should overlap for full coverage. Location should not be too low to avoid clogging by dirt and snow, particularly on transport helicopters that have to land on the battlefield. The spatial coverage of the RWR should be at least that of the RF jammer, including its receiver. If tail rotor glitches are a problem to the rear-looking LWRs, part of their FOV may have to be blocked.
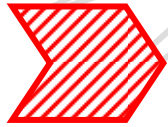
The shown EWSP suite (top) is partly obsolete and about to be replaced. Note that the ALQ-136 RF jammer has antennas (Rx/Tx) only in the forward direction, and that there is no MWS since the ALQ-144 is used preemptively.

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Part 10

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SECTION 1: INTELLIGENCE
The second oldest profession….

Intelligence on different levels—including reconnaissance and surveillance—is an absolute necessity for EWSP effectiveness. The EW support center is tightly connected to intelligence—including the research function—that transforms intelligence data[1] to operational utility.

Note: The term "intelligence" is used for brevity. More accurately, the following discussion focuses on scientific and technical intelligence.[2]

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1) The word "data" is used here in a broad sense and includes all forms of information, samples, etc. that are of use when developing countermeasures. 2) The term "Scientific and Technical Intelligence" was popularized by R.V. Jones in his book *Most Secret War* (published as *The Wizard War* in the U.S.).

The road to susceptibility reduction
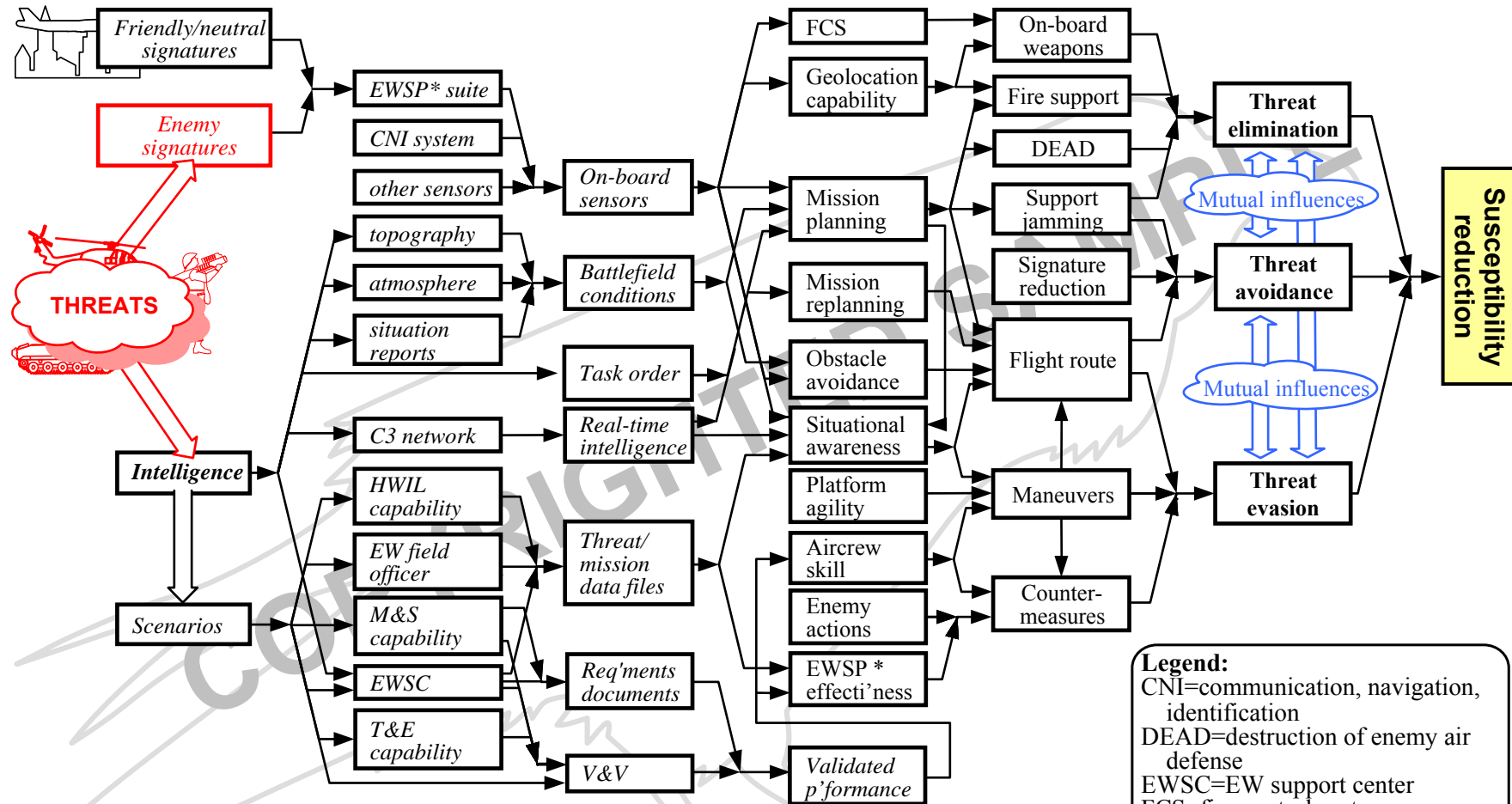
Factors contributing to helicopter mission susceptibility. The EWSP block (*) has been split to ease drawing. The term "situation reports" covers EOB (electronic order of battle) and other tactical intelligence used for mission planning. "Real time intelligence" covers all types of in-flight information that are received over the C3 network. Validation is interpreted in its broadest sense and has also an influence on aircrew skills. HWIL capability required for threat data file generation/testing is separated from general T&E capability.

Legend:
CNI=communication, navigation, identification
DEAD=destruction of enemy air defense
EWSC=EW support center
FCS=fire control system
HWIL=hardware-in-the-loop
M&S=modeling and simulation
OAR=open air range
T&E=test and evaluation
V&V=verification and validation

Recall the Sankey diagram in Part 9 and its message about political issues, financial constraints, human skills, etc.

Intelligence (1/10)[1]

Major intelligence factors. The input ("raw data") is supplied by a number of sources. In many cases the same sources are also the users of the intelligence produced by the "National Intelligence Machine". From the perspective of helicopter EW the main users of intelligence are the armed forces and national defense industry. The main sources of data are open literature, allies, airborne assets/electronic intercept, and agents.

USERS

NATIONAL INDUSTRY

POLITICAL DECISION MAKERS

ARMED FORCES

INTELLIGENCE TO USERS

DIPLOMATIC CORPS

OTHER GOVERNMENT BODIES

SOURCES

SPACE ASSETS

AIRBORNE ASSETS

GROUND ASSETS

MARITIME ASSETS

AGENTS, DIPLOMATS

RAW DATA

"NATIONAL INTELLIGENCE MACHINE"

RAW DATA

SOURCES

UNDERWATER SENSORS

ELECTRONIC INTERCEPT

OPEN LITERATURE

ALLIES

DEFECTORS

INTANGIBLE FACTORS

COUNTER-INTELLIGENCE

FACTOR "X"

ACTIVE MEASURES

PASSIVE MEASURES

TRAINING

PERSONNEL

EXPERIENCE

PAST PERFORMANCE

INTELLIGENCE DATA BASE

DECEPTION

PHYSICAL SECURITY

PERSONNEL SECURITY

DISINFOR-MATION

Factor "X" = The ability to be in the right place at the right time, to be lucky.

1) Graphics adapted from Kennedy, W.V. (chief author): *The Intelligence War*, Salamander Books Ltd., London, 1983. The role of threat samples as "raw information" for military intelligence is not sufficiently stressed in this representation. 2) For a discussion on Open Source Intelligence and the use of Internet in intelligence, see [Anon 2001c].

Intelligence (2/10)
R.V. Jones & the birth of technical intelligence analysis[1,2]

- In 1939 the British assigned a scientist, physicist R.V. Jones, to the Intelligence Branch of its Air Staff.

- Jones's first scoop was to determine the operation of a German blind (night) bombing navigation aid called "Knickebein."

- On the night of 21 June 1940, an aircraft found the Knickebein radio signals in the frequency range which Jones had predicted.

- Countermeasures could now be developed and Winston Churchill subsequently named Dr Jones "the man who found the beam."
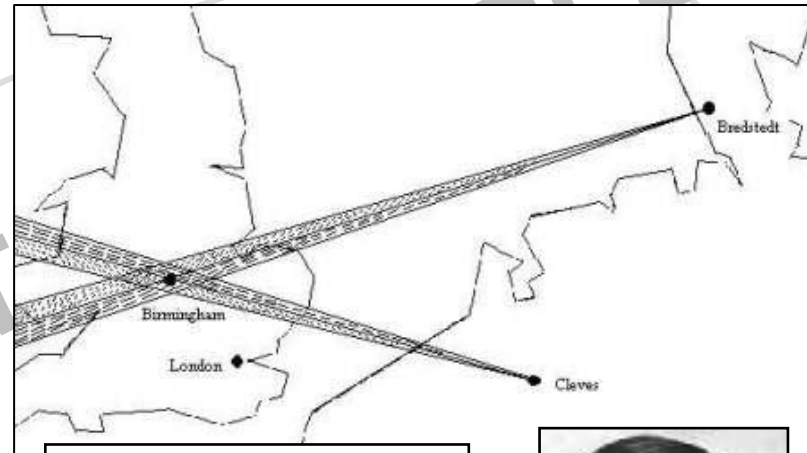
Knickebein, with transmitters in Denmark and Holland and beams pointing at Birmingham

R.V. Jones as professor in Aberdeen, Scotland, after the war

1) R.V. Jones: *Most Secret War*, Wordsworth Editions, 1998 (first published in 1978). Knickebein ("Crocked leg") was based on the Lorenz system for blind aircraft approach. 2) The history is longer still: Egyptians studied captured Hittite iron weapons in the 13th century B.C.

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Intelligence (3/10)
Some SIGINT assets

”The [U.K.] Defence Intelligence Staff learned [during the Falklands War] that electronic warfare details of *allied* missiles—the pulse repetition frequencies (PRF) of the French Exocet anti-ship missile, for example—are every bit as vital as those of Soviet missiles, and often harder to obtain.” [Hughes-Wilson 2004, pp. 305-306]

Swedish Gulfstream IV SIGINT aircraft. (Source: FRA)

Swedish SIGINT ship "Orion". (Wikipedia)

Swiss "Orynx" satellite COMINT station. (Source: David Adair)

Helios II EO intelligence satellite.[1] (CNAS Graphics)

Expensive toys! And all they provide is raw data...

Global Hawk intelligence UAV. (Source: USAF)

Russian A-50 AEW/SIGINT aircraft. (Source: Irkut Corp.)

RC-135 SIGINT aircraft. (Source: USAF)

”European nations need to shift defense intelligence funds from hardware that collects it to the analysts who can divine intent”[2]

1) Helios II is an IMINT asset, but as such it has the ability to supplement data gathered by SIGINT assets. 2) Tigner, B.: *Intel Needs More Thinking, Less Hardware, EDA Official Says*, DefenseNews, April 10, 2006, p. 6. For a discussion on military intelligence collection on the operational level, see FM 2-22.401 (*TECHINT*), June 2006.
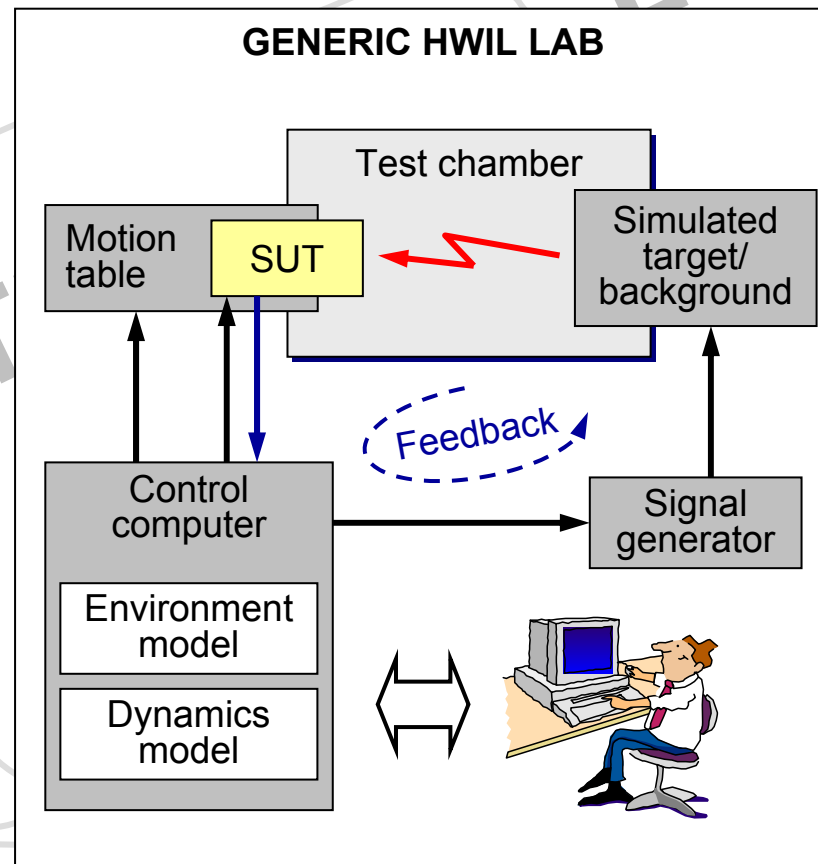
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HWIL tests (1/5)
Characteristics of HWIL[1]

- In HWIL testing an actual system or sensor is part of the simulation process.

- It involves generation of signals in the form they would have at the point where they are injected into the system.

- Typically, it is performed in test chambers with simulated targets and backgrounds and with controlled environmental conditions.

- Generally, it is done for the evaluation and testing of some existing system.

GENERIC HWIL LAB

Test chamber

Motion table | SUT | Simulated target/ background

Feedback

Control computer

Environment model

Dynamics model

Signal generator

1) Baquar, S.: *Low-Cost PC-Based High-Fidelity Infrared Signature Modelling and Simulation*, PhD Thesis, Cranfield University, July 2007, pp. 71-72, <https://dspace.lib.cranfield.ac.uk/handle/1826/2912> (Retrieved 24.1.2009).
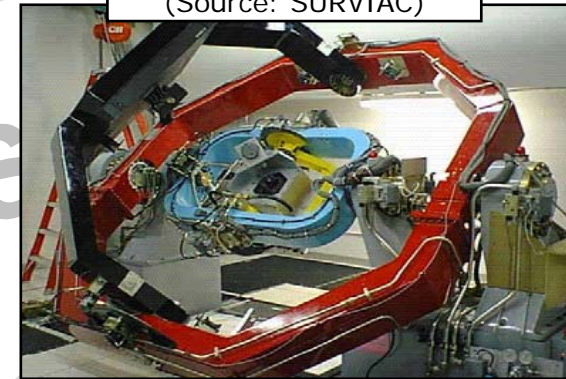
HWIL tests (2/5)
Alternative interpretations of the term "HWIL"

Different types of tests and test setups are referred to as HWIL testing, for instance:

- Seeker-jammer testing on a flight motion table (right, top).
- RWR or seeker testing in an anechoic chamber (right, bottom).
- MWS or seeker testing with a dynamic scene generator.
- Dual mode RF/IR seeker testing in an anechoic chamber.

Recall the earlier description of HWIL facilities: "Common attributes are shielded/screened rooms, test condition repeatability, and high capacity data collecting and recording."[1]

HWIL simulator (flight motion table)[2]
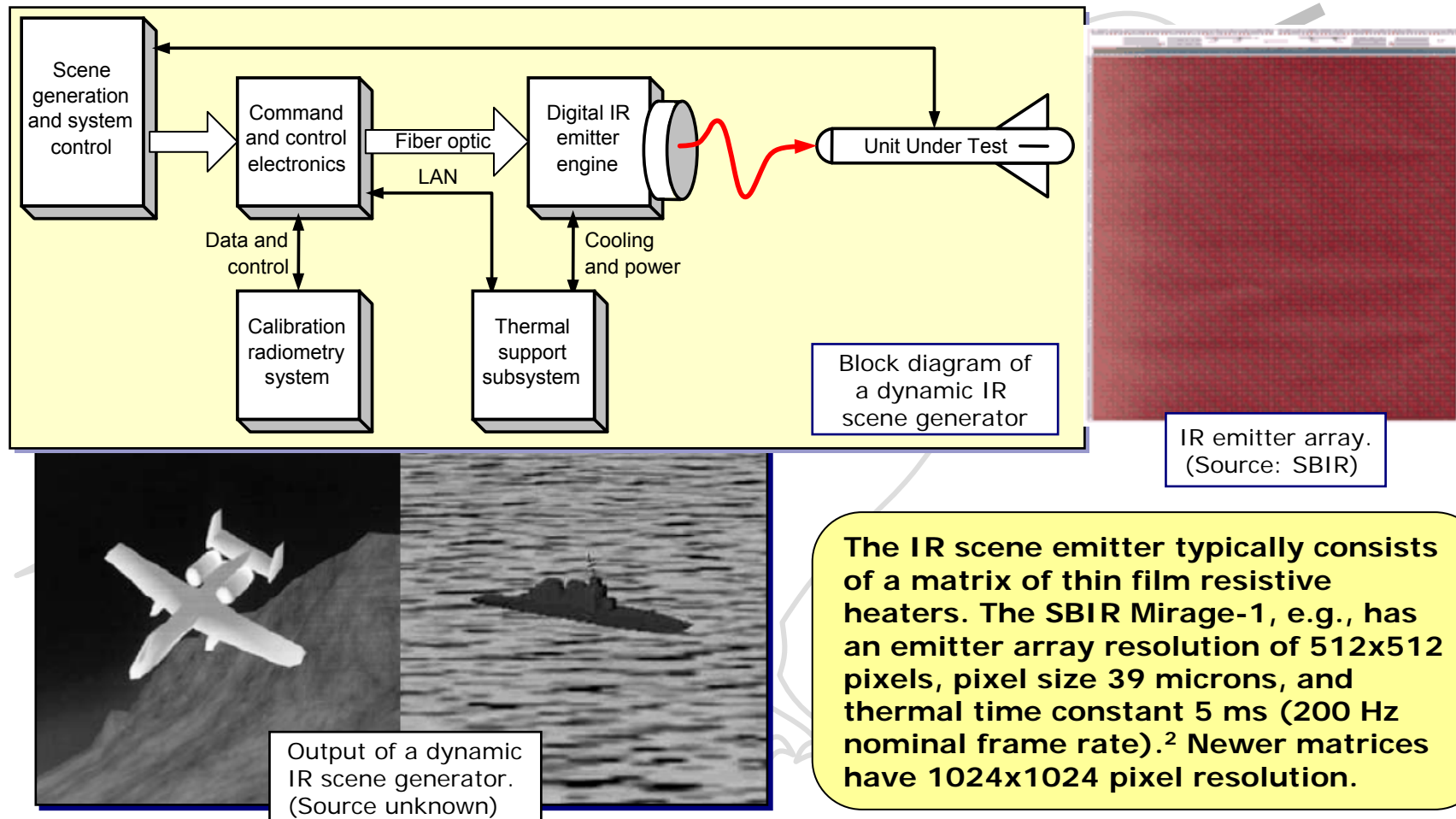(Source: SURVIAC)

RF missile seeker under test in an anechoic chamber.
(Source: DoD)

1) See also [Anon 2000, p. 37]. 2) For a discussion on HWIL simulators with flight motion table, see [Stepp 1994].

HWIL tests (3/5)
Example: Dynamic IR scene generators[1]

Scene generation and system control → Command and control electronics → Fiber optic → Digital IR emitter engine → Unit Under Test

LAN

Data and control → Calibration radiometry system

Cooling and power → Thermal support subsystem

Block diagram of a dynamic IR scene generator

IR emitter array. (Source: SBIR)

Output of a dynamic IR scene generator. (Source unknown)

The **IR scene emitter** typically consists of a matrix of thin film resistive heaters. The SBIR Mirage-1, e.g., has an emitter array resolution of 512x512 pixels, pixel size 39 microns, and thermal time constant 5 ms (200 Hz nominal frame rate).[2] Newer matrices have 1024x1024 pixel resolution.

1) For a discussion on dynamic IR scene generators, see e.g. [Williams 1998] and [Bryant, Solomon 2007]. 2) The time constant means rise time from 10% to 90% intensity. Typically a certain hold time is required, which lowers the effective frame rate.

HWIL tests (4/5)
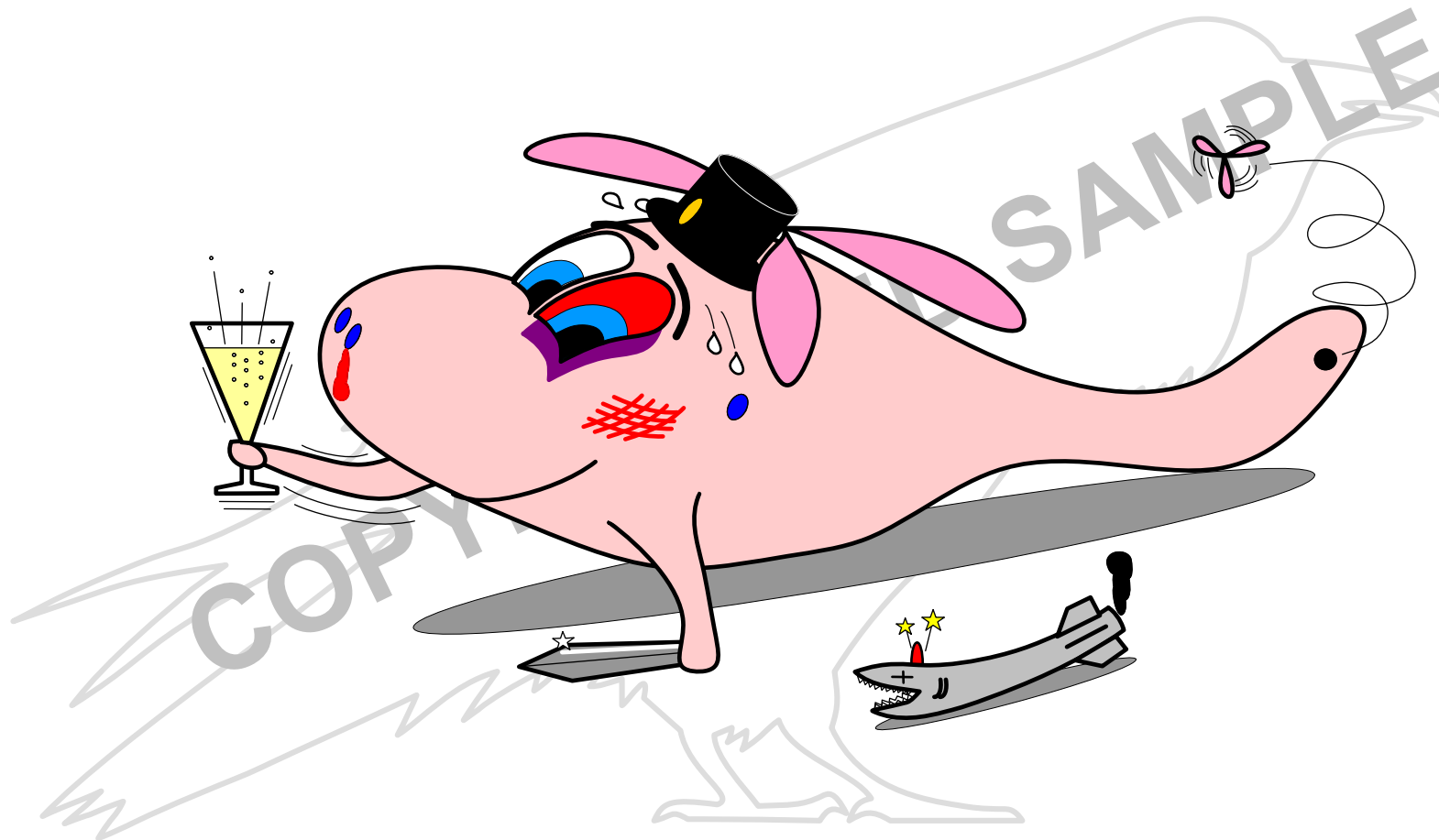## Example: Dual mode RF/IR seeker testing[1]
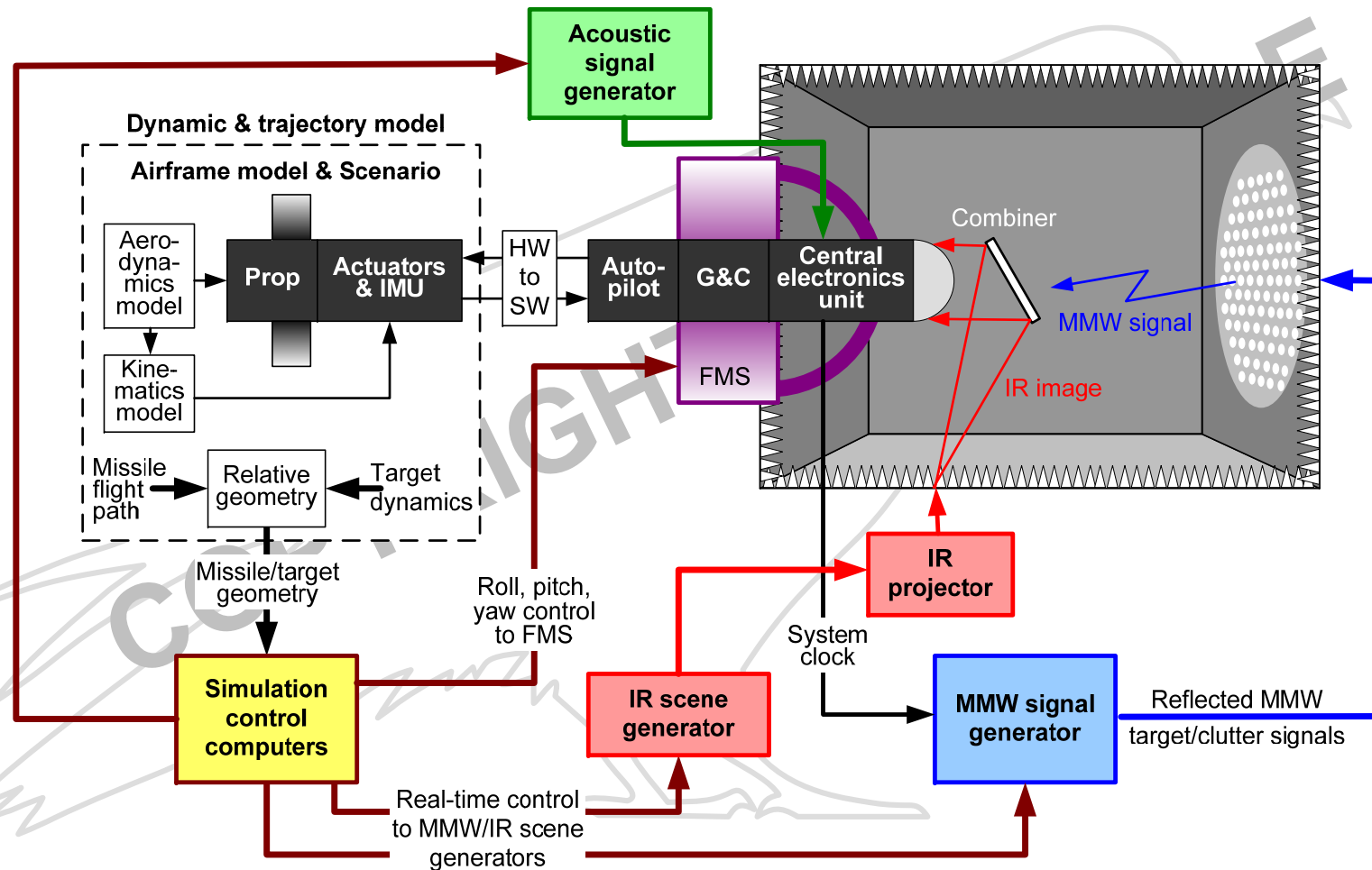
1) Waite, W.F. et al.: *Validation of the Hardware-in-the-Loop (HWIL) and Distributed Simulation System*, Presentation at JHU/APL on October 23, 2002. Legend: FMS = flight motion simulator, IMU = inertial measurement unit.

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That's it, Folks!

"When I think over what I have said, I envy dumb people." Seneca (4 B.C.—A.D. 65).