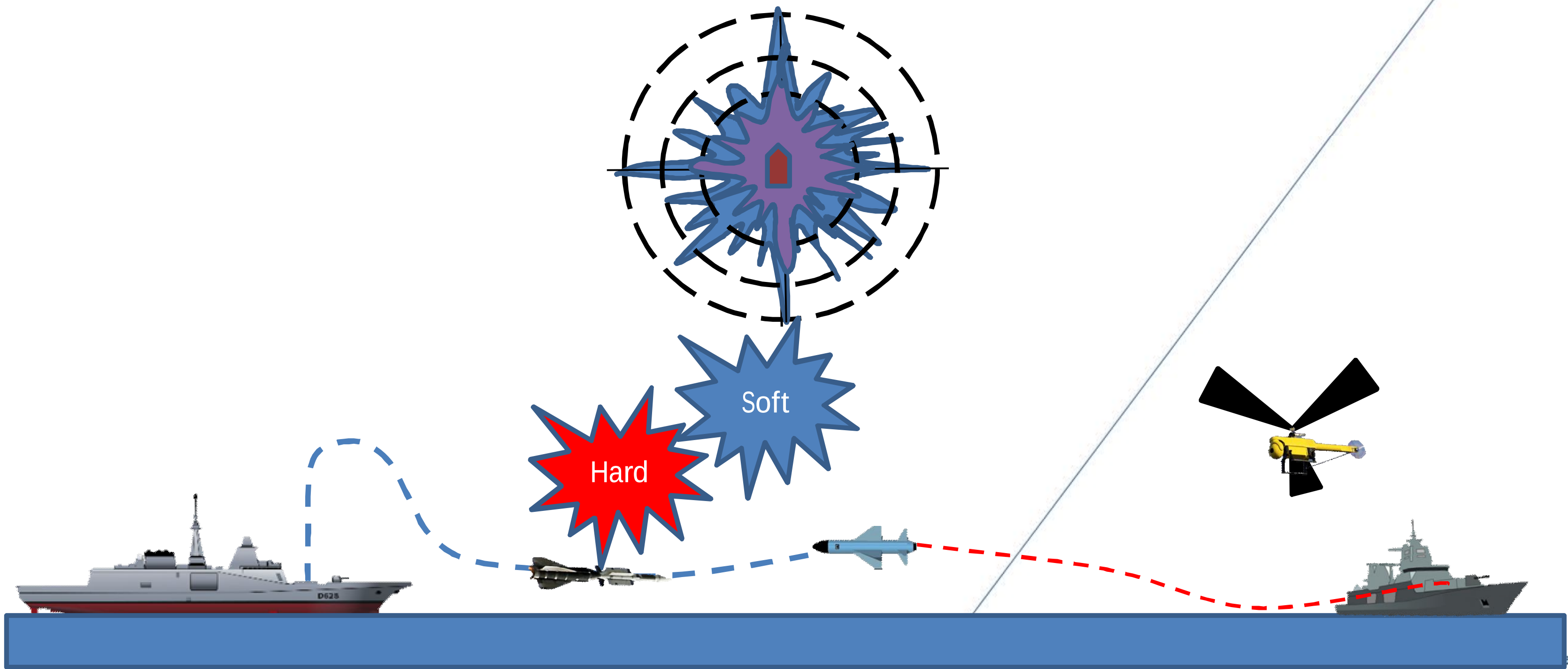
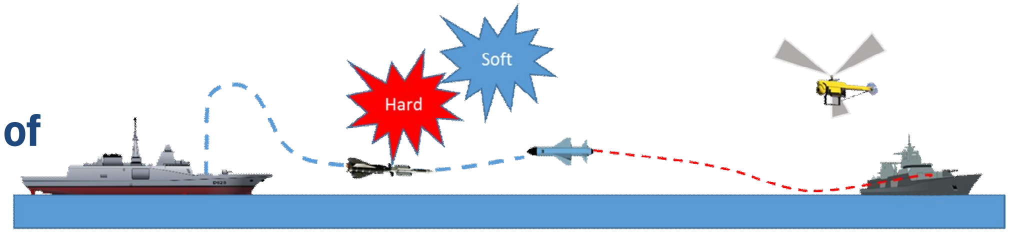
ELETTRONICA
MIND IS THE FIRST DEFENCE

The Defence of the Naval Unit through the best trade-off fra RCS, Soft e Hard Kill

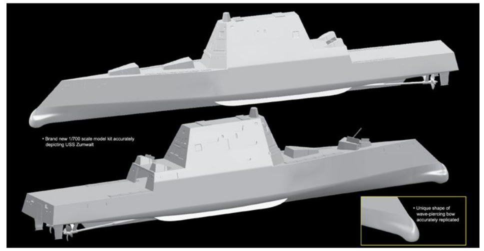


Purpose of the analysis

- to suggest a methodology to find a reasonable comprise among RCS reduction, Soft Kill enhancement and hard kill availability, so that:



- an acceptable effectiveness immunity of the warship from missile attacks is obtained



- the RCS reduction feasibility using well proven reduction methods (Shaping and Radar Absorbing Materials) is assured

- the costs to be sustained to reduce radar signature is “reasonable” respect to the total ship costs

Platform Immunity: the US point of view

FIRST	Not to be seen	(i.e. detected by the opponent weapon system)
SECOND	Not to be tracked	(i.e. classified, identified, tracked by the opponent weapon system)
THIRD	Not to be engaged	(i.e. detected, discriminated, tracked by the launched weapon)
FOURTH	Not to be hit	
FIFTH	Not to be damaged	

Not taken
into account

Susceptibility and Immunity

$$P_H = P_D \times P_{T/D} \times P_{L/T} \times P_{H/L}$$

Where

- P_D is the probability that the vessel is discovered
- $P_{T/D}$ is the probability that the vessel is tracked and identified once discovered
- $P_{L/T}$ is the probability the threat weapon is in lock on the vessel once identified
- $P_{H/L}$ is the probability the vessel is hit once locked

P_{NH} is the vessel **Immunity** i.e. the Probability the vessel is not hit

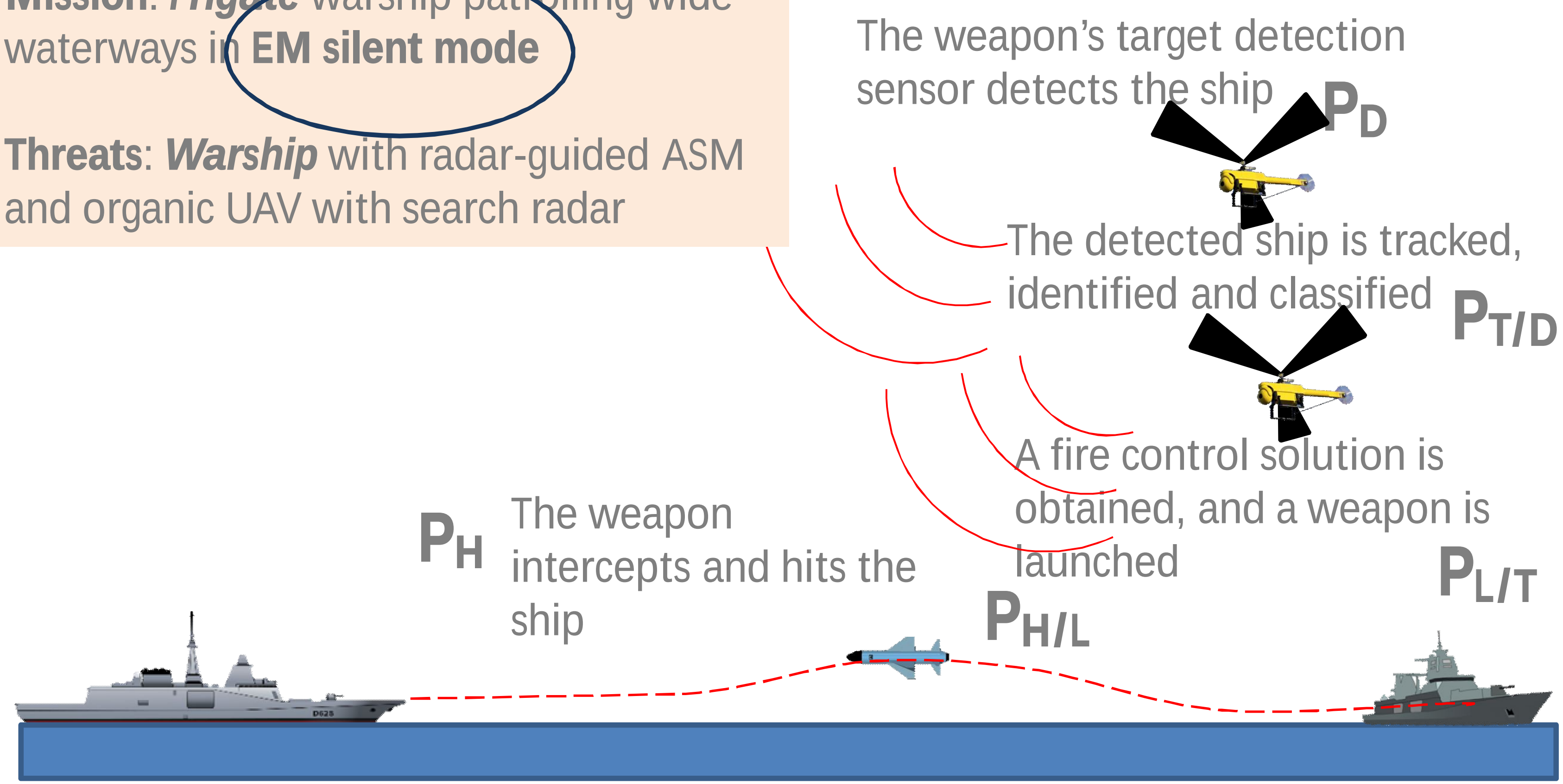
$$P_{NH} = 1 - P_H$$

[1] "NAVAL SURVIVABILITY AND SUSCEPTIBILITY REDUCTION STUDY—SURFACE SHIP"
Steven Loke Yew Kok _Naval Postgraduate School _ September 2012

Referred scenario

Mission: ***Frigate*** warship patrolling wide waterways in **EM silent mode**

Threats: ***Warship*** with radar-guided ASM and organic UAV with search radar



$$P_H = P_D \times P_{T/D} \times P_{L/T} \times P_{H/L}$$

Killability Reduction= Susceptibility Reduction

Reduction of P_H	Signature	Soft-Kill	Hard-Kill
Reduction of threat Detection Range	x		
Reduction of Probability of Acquisition	x	x	
Reduction of Launch Probability	x	x	
Increasing Threat Warning		x	
Increasing Threat Suppression		x	x
Threat effectiveness reduction/minimization	x	x	

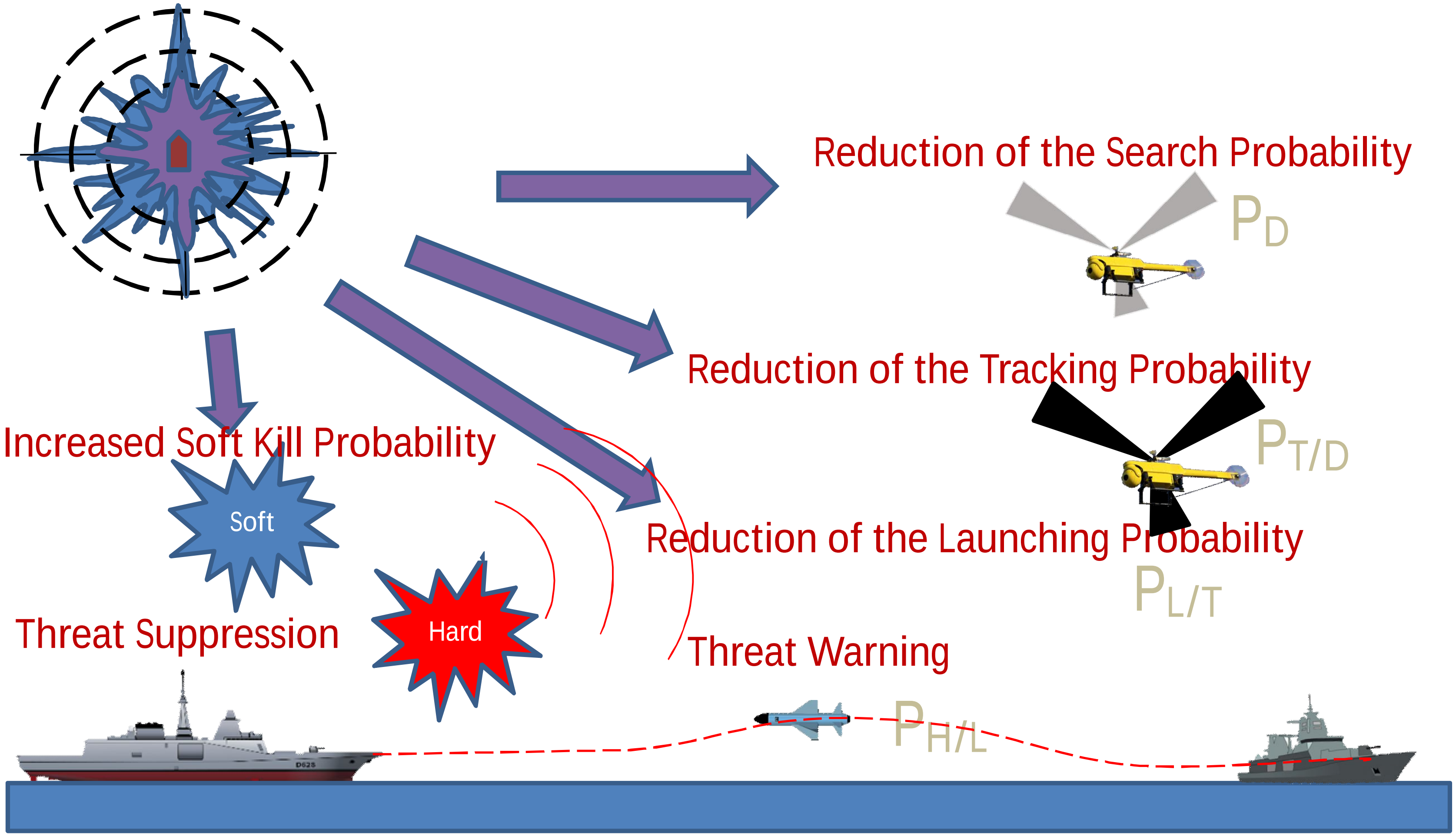
Not taken into account

Signature = cross section (passive) + on board transmissions (active)

Soft-Kill= manouvers + EW (on-board, off-board)

Among all the ship "signatures" (radar, IR, EO, magnetic, acoustic), only the Radar-Cross-Section will be consider hereafter.
Similar analysis can be performed for the other cases.

Susceptibility Reduction



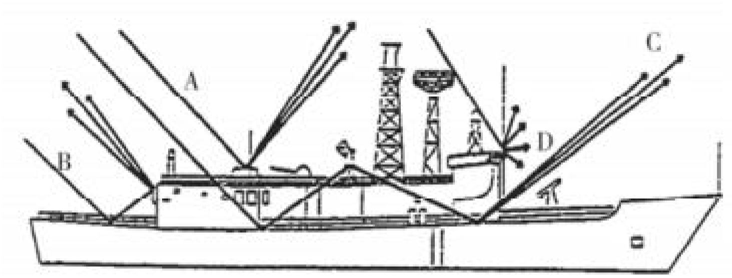
Ship RCS Table

Target Ship			Median radar cross section of target vessel, m²								
Type	Overall length (m)	Gross tonnage	10	100	1.000	10.000	100.000	1.000.000	10.000.000	approx. min. RCS	approx. max. RCS
Inshore fishing vessel	9	5	Q							3	10
Small coaster	40-46	200-250		S	B/Q					20	800
Coaster	55	500		nS		B/Q				40	2.000
Coaster	55	500			S	BW/Q				300	4.000
Coaster	57	500				Q	BW			1.000	10.000
Large Coaster	67	836-1.000				BW Q				1.000	5.000
Collier	73	1.570			nB	BW				300	2.000
[redacted]											
Cargo liner	114	5.000				BW	Q			10.000	16.000
Cargo liner	137	8.000				BW/Q	Q			4.000	16.000
Bulk carrier	167	8.200			BW	B/Q				400	10.000
Cargo	153	9.400				BW BW				1.600	12.500
Cargo	166	10.430			BW		Q			400	16.000
Bulk carrier	198	15.000-20.000				nB	B/Q			1.000	32.000
Ore carrier	206	25.400				BW	nB			2.000	25.000
Container carrier	212	26436**					BW Q/B/BW			10.000	80.000
Medium tanker	213-229	30.000-35.000				nB	Q			5.000	80.000
Medium tanker	251	44.700					nB		B	16.000	1.600.000

* Displacement
** Considerable deck cargo

S = stern on
Q = quarter
B = broadside
BW = bow
BWO = bow on
n = near

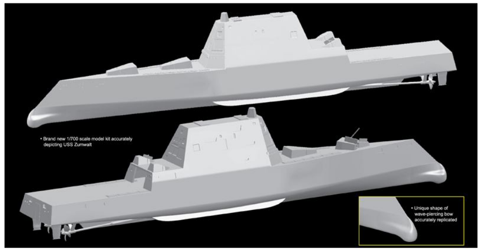
RCS reduction methods



A = Single reflection B = Double reflection
C = Triple reflection D = Edge diffraction

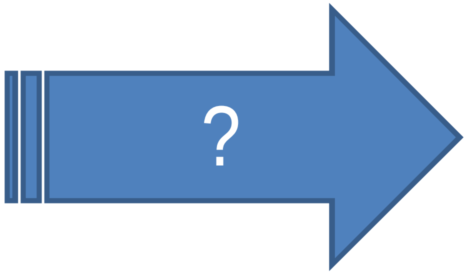
Main scattering mechanisms on naval ships

Management of Shaping



RAM (Radar Absorbing Material)

Management of Shaping



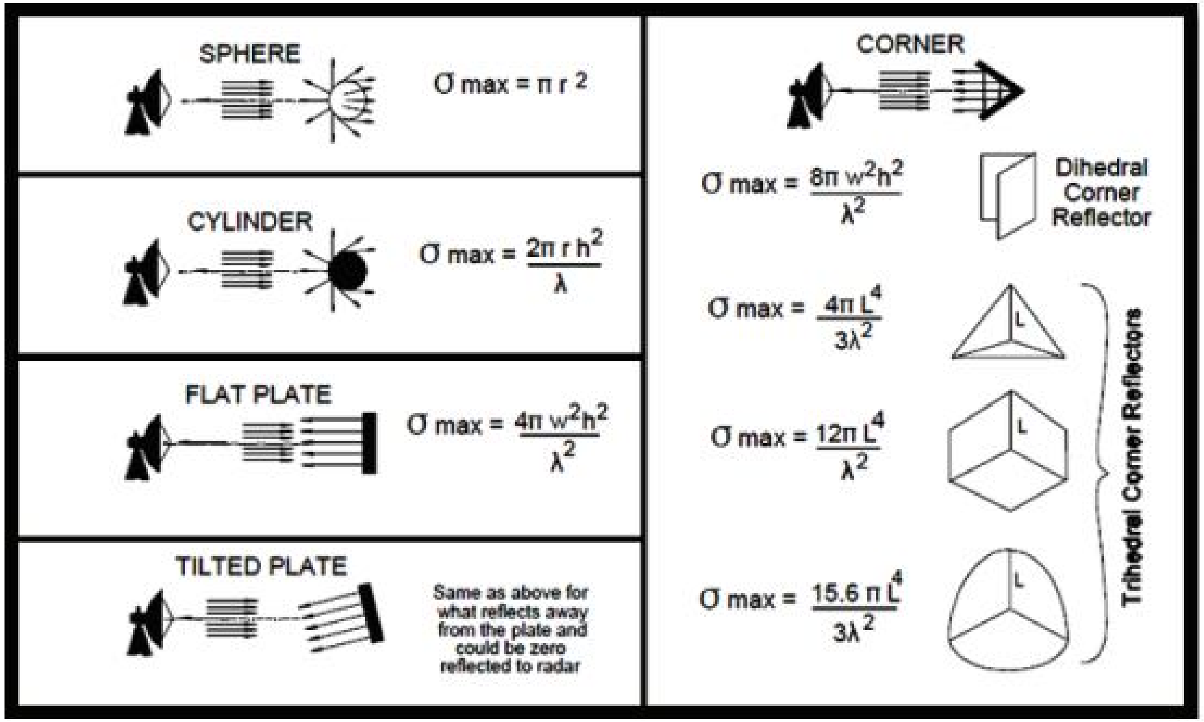
The question is: how much stealth is convenient to reach through management of shape ?

Facts to be considered:

- **Sensors require surface**
- **Weapons require room**
- **The ship has to accomplish its own mission using both the above systems**

For these reasons, the management of shape can contribute to the overall RCS reduction up to 15 dB (average datum, experienced).

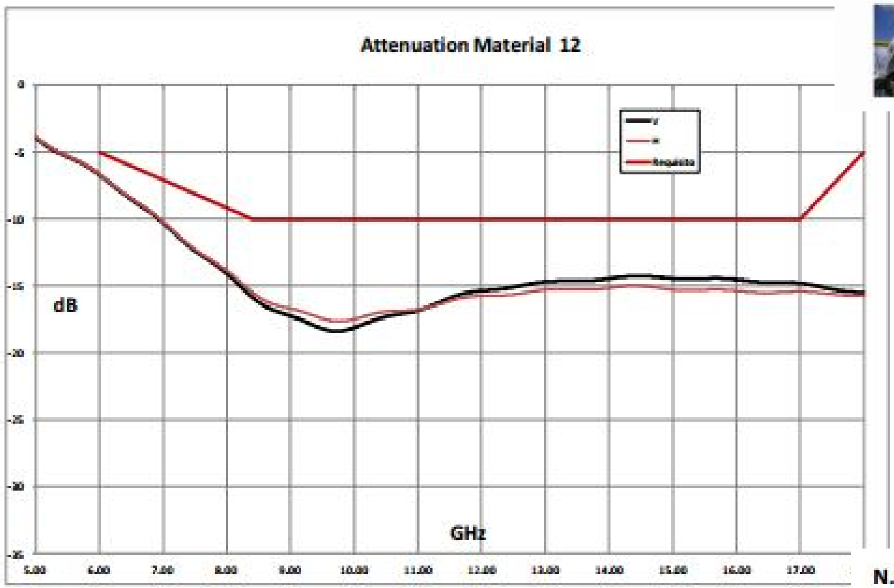
RAM (Radar Absorbing Material) and RCS Reduction [1]



$$\sigma_{max} = \frac{4\pi A^2}{\lambda^2}$$

Quadratic dependence between A and σ $_{max}$

RAM (Radar Absorbing Material) and RCS Reduction [2]



Nuova CONNAVI s.r.l.

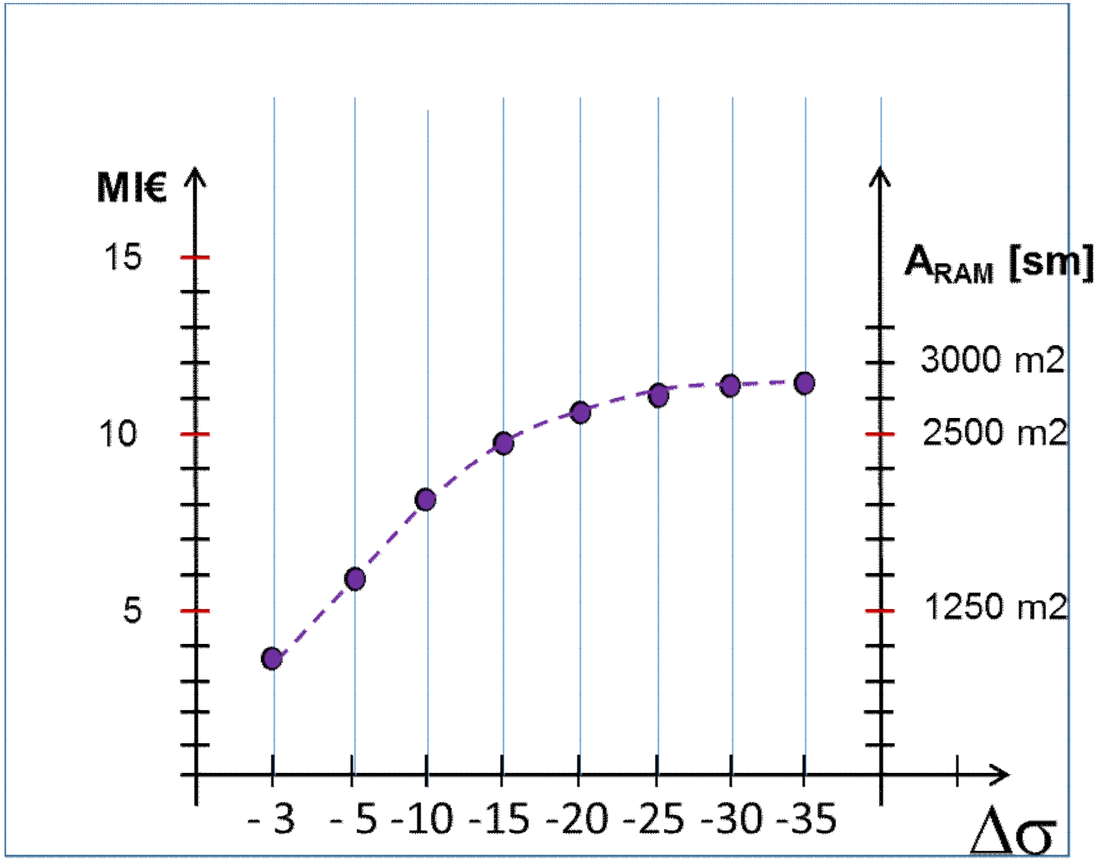
N.B.

Nuova Connavi certifica che gli stessi pannelli sono stati consegnati a MARITELERADAR il quale ci ha comunicato verbalmente di avere ottenuto le medesime attenuazioni contenute nel presente documento.

- **Cost per square meter (installed) = 4.000 €/m2**
- **Weight per square meter ≅ 6 Kg**

Certificato da Mariteleradar nel IV° trimestre 2014

RAM Costs and Area covered vs.$\Delta\sigma$



Total Area of the Frigate
~3000 m2

$$\sigma_{max} = \frac{4\pi A^2}{\lambda^2}$$

Quadratic dependence between A and σ_{max}

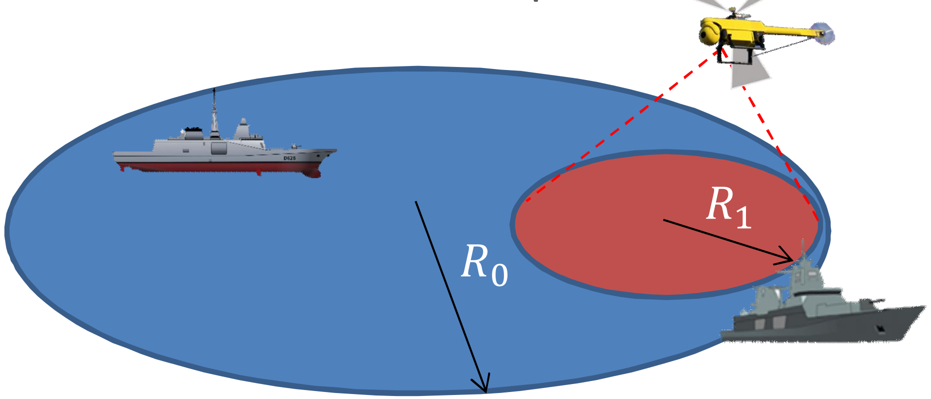
Reduction of threat Detection Range

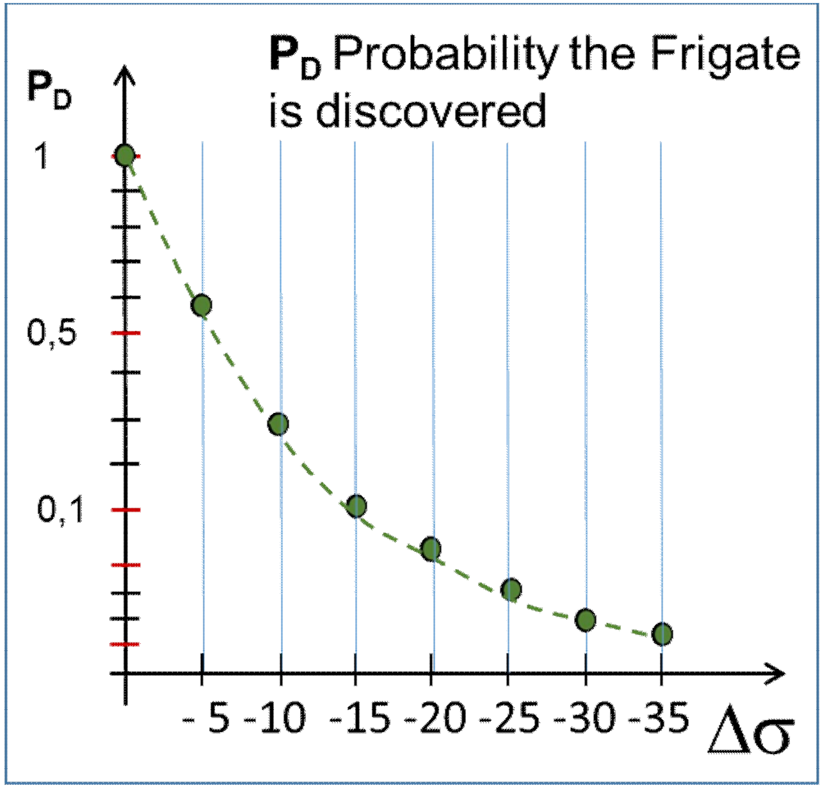
The Radar Range is dependent on RCS according to:

$$R = \mu \sqrt[4]{\sigma}$$

The Threat Search Radar at constant pulse Pd and Pfa has a Search Area proportional to:

$$A_i \equiv R_i^{\ 2} \equiv k \sqrt[2]{\sigma_i}$$





Reduction of Probability of Acquisition and Launch Probability

As we have supposed the detection Range at constant Pd and Pfa, the Probability of Acquisition and the Launch Probability are assumed constant:

$$P_{T/D} = 0{,}9$$

And

$$P_{L/T} = 0{,}9$$

The degradation of Tracking and Lock-on are considered in the Soft Kill probability of the Frigate reaction

Increasing Threat Warning

Threat warning (in silent mode, i.e. using Electronic Support Measures) is the stronger mean to:

- Enhance the readiness of the crew and the own defence system
- Allow a more convenient manoeuvre
- Reduce the overall reaction time vs. attacks

Threat Warning and Threat Suppression (Hard & Soft Kill)

The threat suppression by the Hard Kill is not dependent on its RCS. A typical Hard Kill probability P_{hk} = 0.8 is assumed

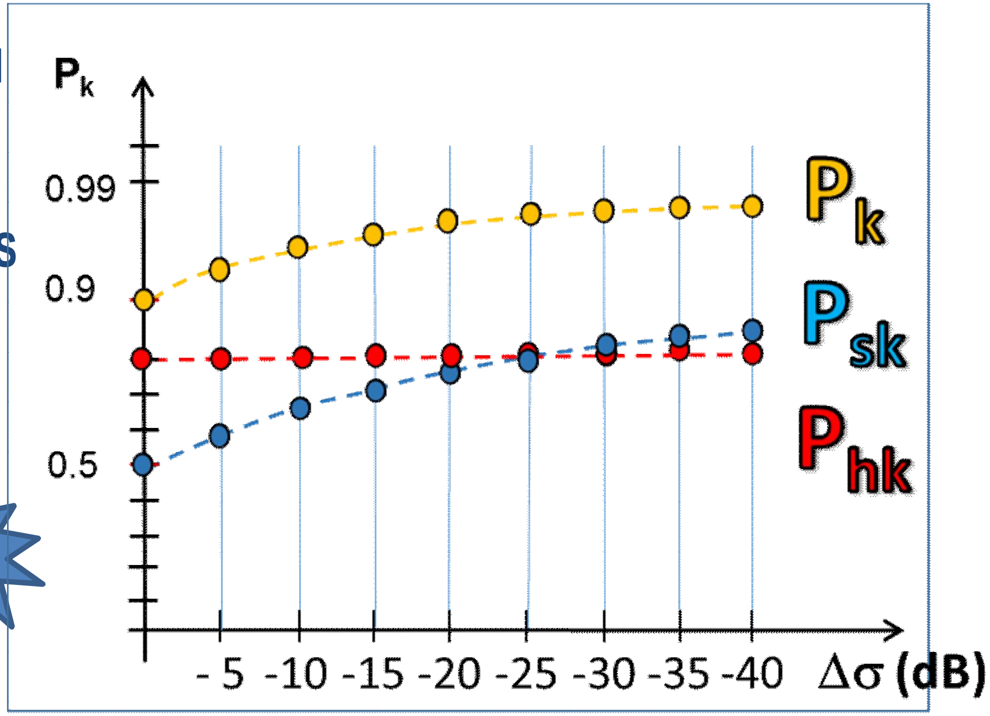
Threat Warning is obtained by ESM Radar Warning function and Laser Warning function.

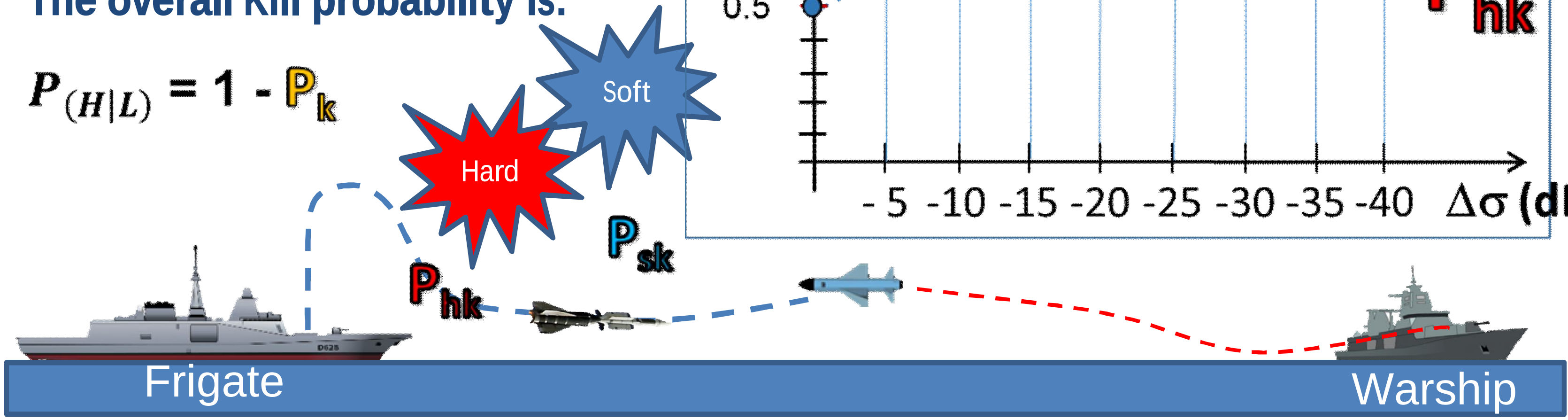
Soft Kill probability depends on RCS

$$P_k = P_{hk} + (1 - P_{hk})\, P_{sk}$$

The overall Kill probability is:

$$P_{(H|L)} = 1 - P_k$$





Soft Kill vs. Hard Kill

	Soft-Kill	Hard-Kill
Survivability in saturating attacks	🟢 (*)	🟡
Reaction time	🟢	🟡
Complexity of planning	🟡	🟢
Complexity of kill assessment	🟡	🟢
Interoperability inside the vessel	🟡	🟢
Risks of collateral damages	🟢	🔴
Availability	🟢	🔴
Life cycle cost	🟢	🔴

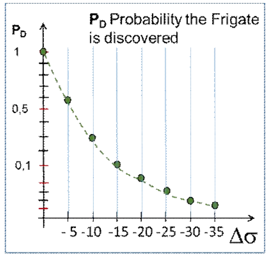
(*) in case of multiple lines of tracking

Immunity P_{NH} vs. $\Delta\sigma$

$$P_{NH} = 1 - P_D \times P_{T/D} \times P_{L/T} \times P_{H/L}$$

Every term of the P_{NH} equation has been computed :

P_D →



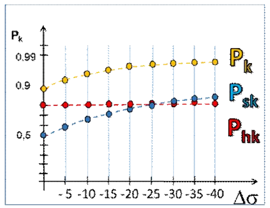
$P_{T/D}$ →
$P_{L/T}$ →

$P_{T/D}$ = 0,9

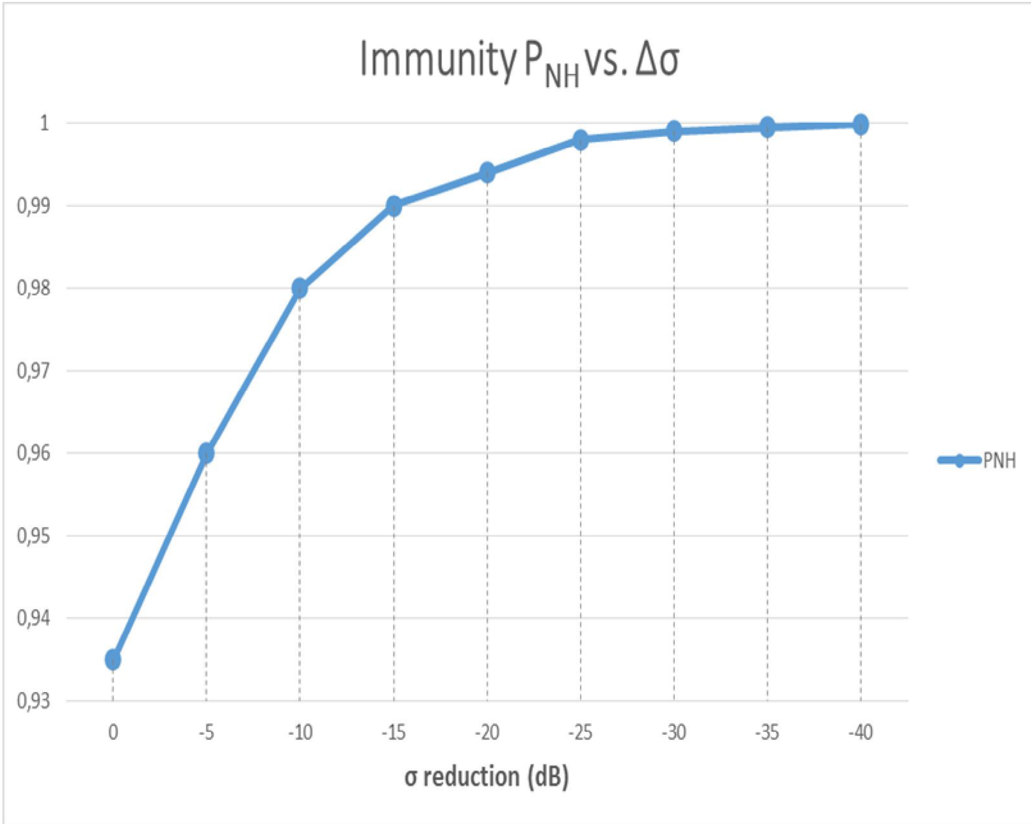
And

$P_{L/T}$ = 0,9

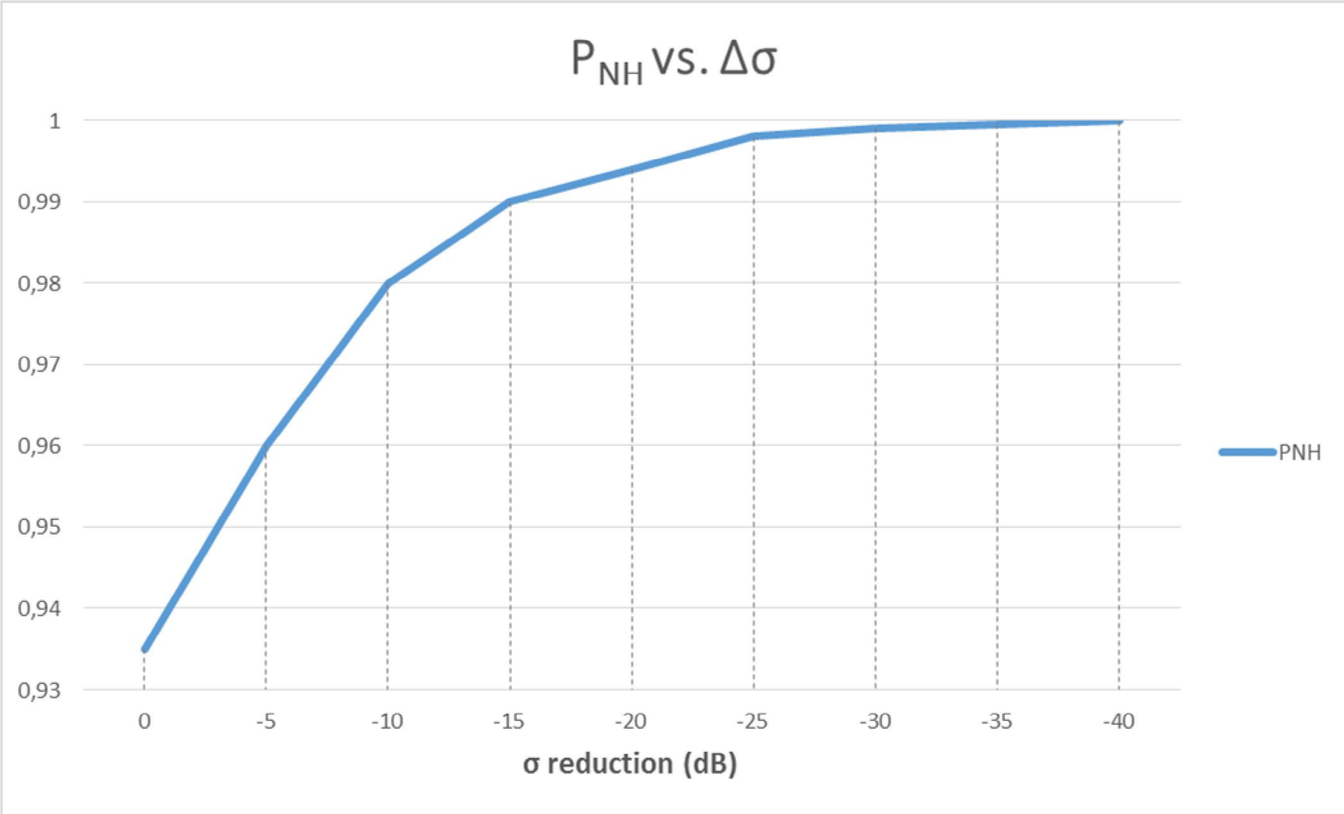
$P_{H/L}$ →



$P_{(H|L)}$ = 1 - P_k



Immunity P_{NH} vs. $\Delta\sigma$



[2] “SYSTEMS ENGINEERING PRINCIPLES AND PRACTICE”: Alexander Kossiakoff and others. JOHN WILEY & SONS, INC. PUBLICATION

Conclusions and Recommendations [1]

Even under severe semplification (conservative) conditions, this preliminary analysis confirms that the survivability of the Frigate depends on a proper combination of signature, soft-kill and hard-kill.

This combination, even if «a priori» calculated, has to be managed dynamically (and in integrated way) along the engagement phases.

This preliminary analysis indicates that an optimal choice in terms of RCS reduction between -10dB and -15dB guarantees the best trade-off immunity vs. costs.

Conclusions and Recommendations [2]

All these considerations are made in case of a SINGLE MISSILE ATTACK.

In case of multiple missiles attack both the hard kill defense and the soft kill one are penalized:

- **the previous one for the number of defensive missiles to be launched (that is a limited number)**
- **the former by the mechanic line of sight that is not able to manage more than one threat at a time, unless an AESA based EW is used.**

Active Electronically Steerable Array (AESA) is an antenna that shifts direction and function by modifying its signal using software algorithms, rather than physically moving.

It is able to produce a number of simultaneous beams in different directions and frequencies instead of only one (several contemporary lines of sight), giving the possibility to counter also multiple missiles attack.

The need to migrate from a mechanically steered antenna to an electronically steered system was the main reason why the US Navy awarded Raytheon the contract for SEWIP program (>290M$) [ref. Journal of Electronic Defence Jan.2015]

Horizon Frigates, FREMM Frigates and Cavour Aircraft Carrier are already equipped with this solution.

Same solution will be on board of next generation Italian vessels.

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