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The Application of Survivability to Warship Design in the Modern Naval Environment

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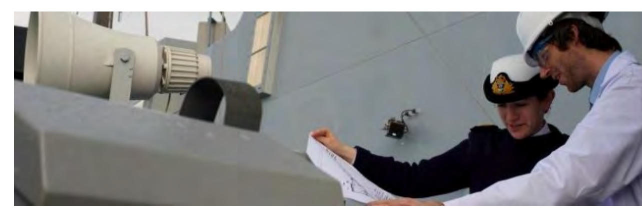
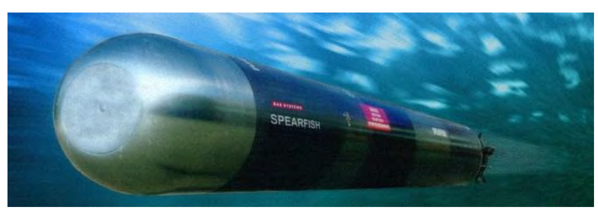




Survivability

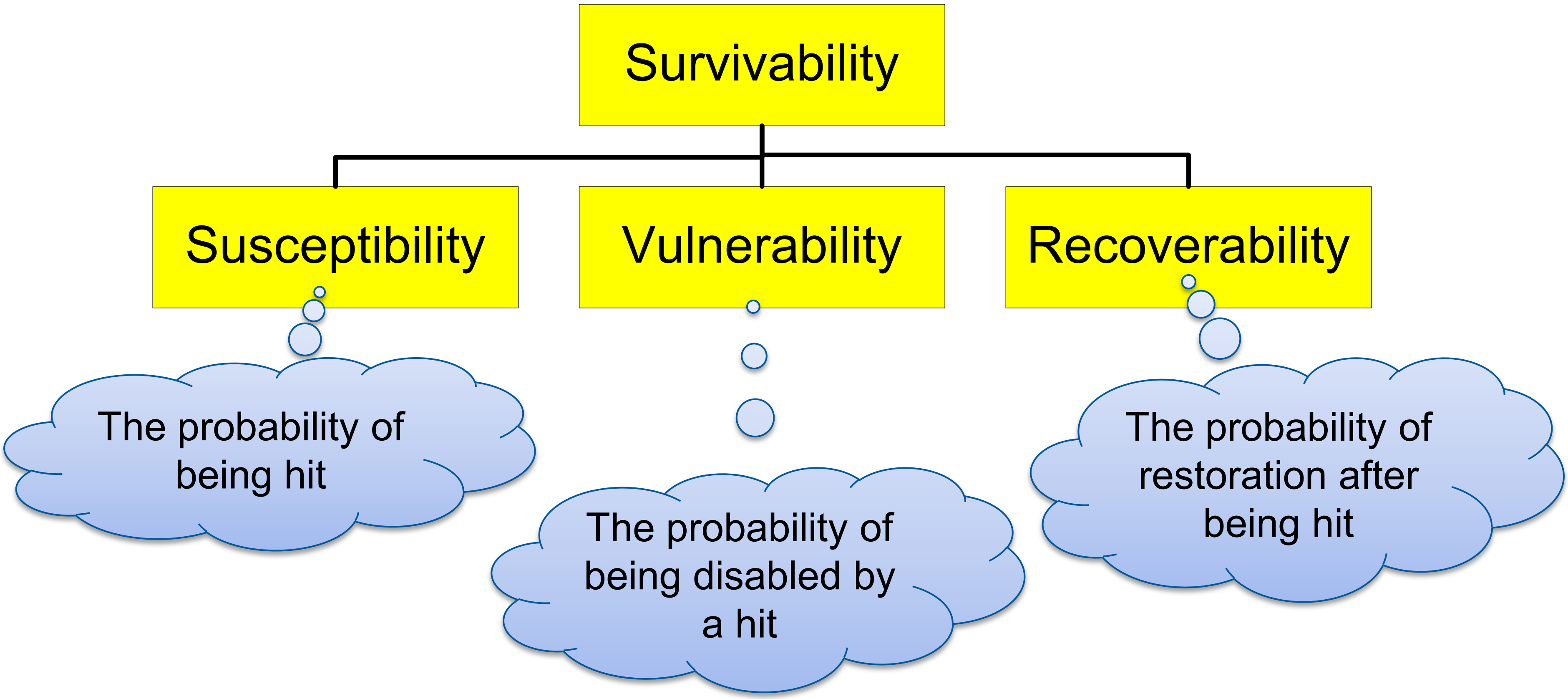
Survivability is a key requirement in warship design

- Definition of survivability
- BAE Systems early design approach
- Effect on naval platform

Survivability

What is Survivability?

- Survivability is commonly expressed as a function of three factors:



Threats

Above Water

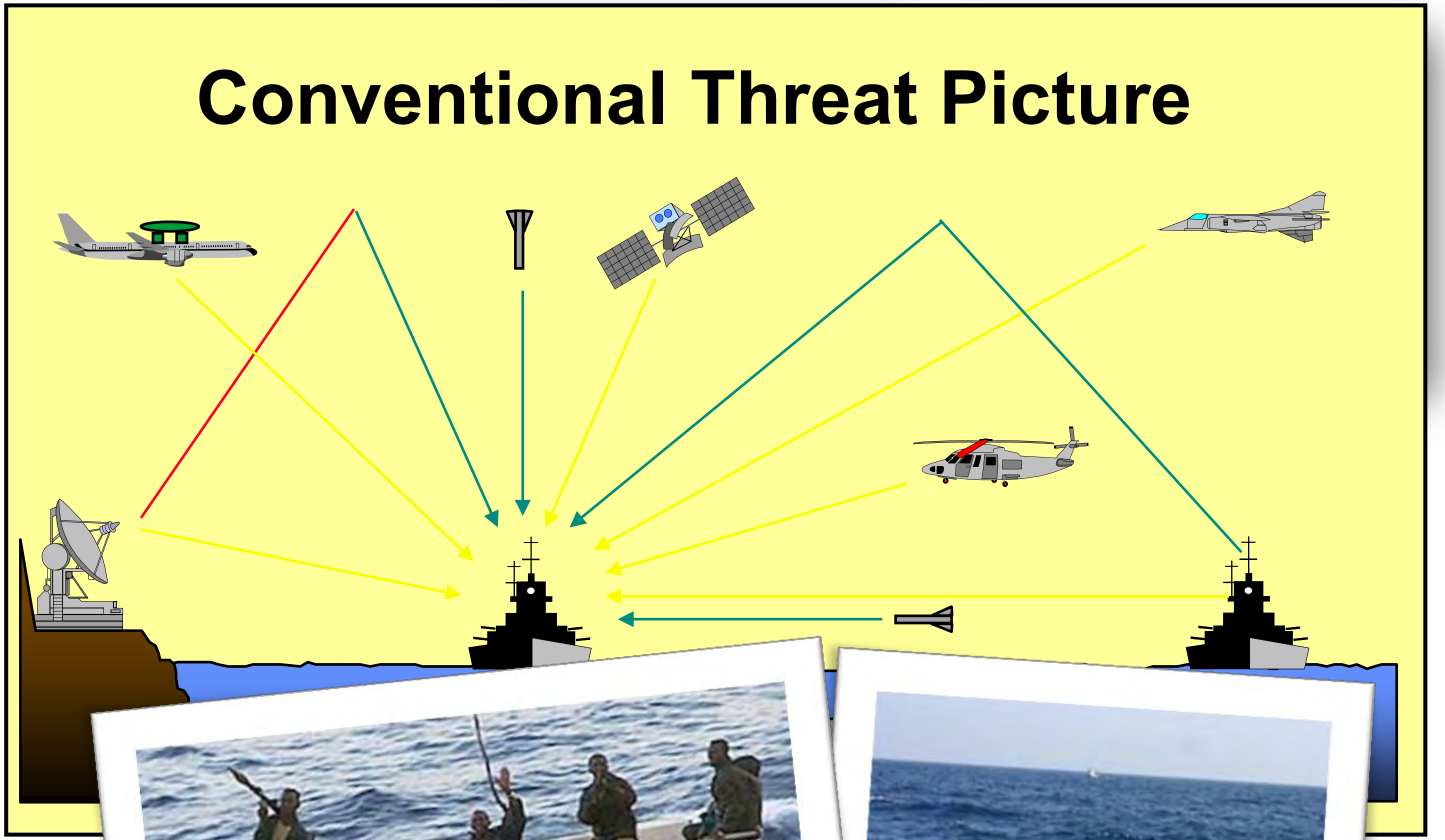
- Missiles
- Bombs
- Shellfire
- Gunfire

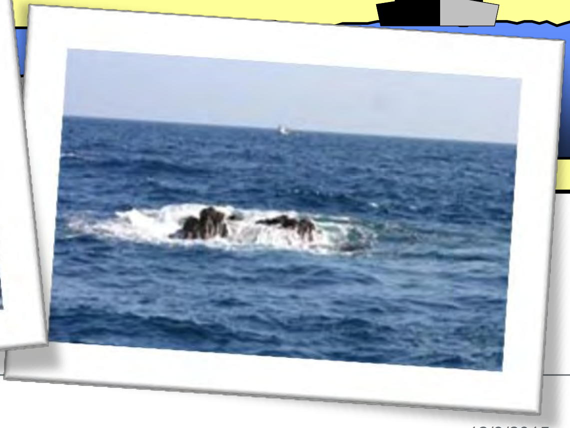
Underwater

- Torpedoes
- Mines

Asymmetric

- Anything else!



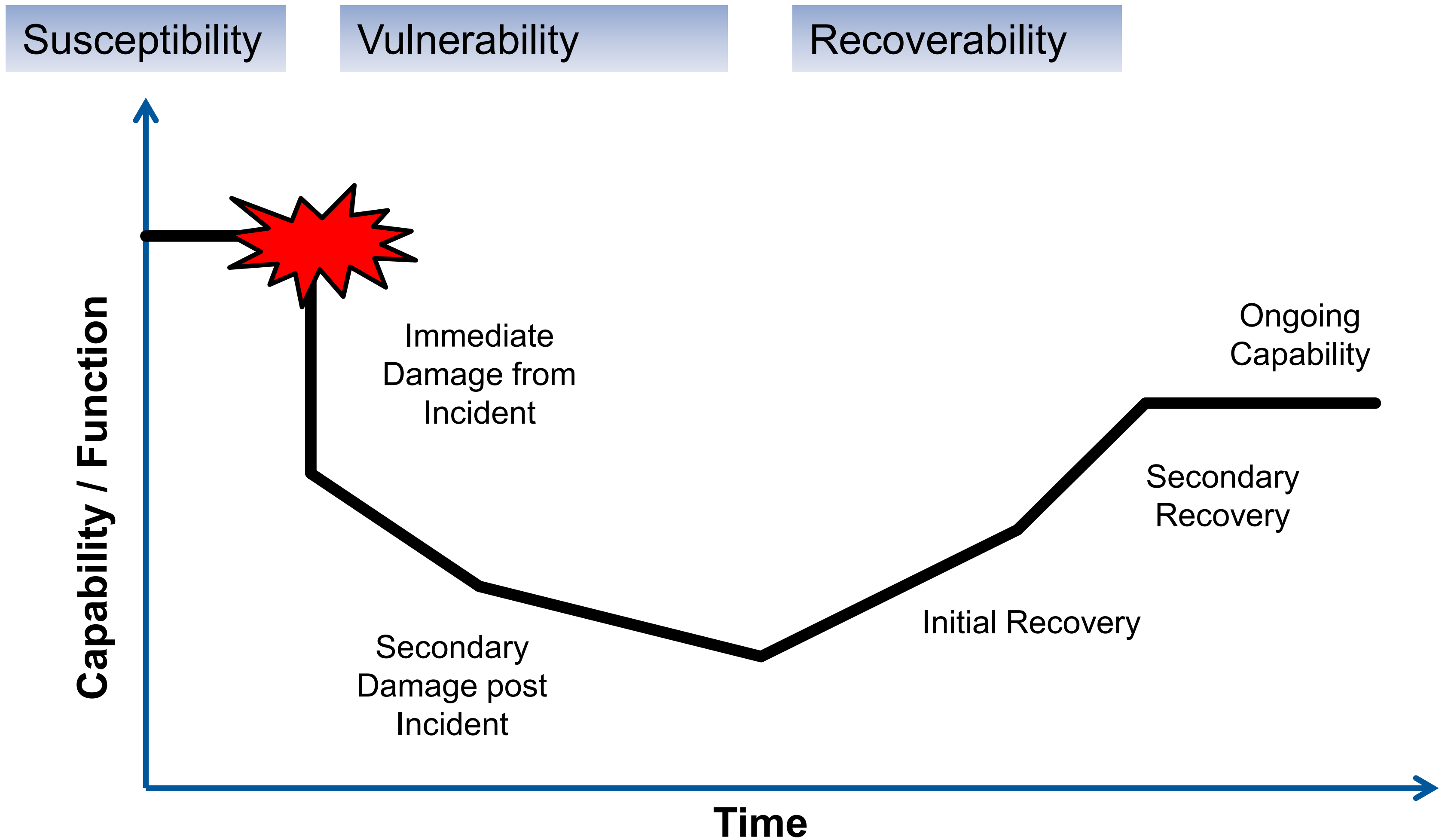


INS Hanit - 2007 (Missile)

ROKS Cheonan – 2010 (Torpedo)

USS Cole - 2000 (Explosive charge in close proximity)

Survivability Timeline of Incident



SUSCEPTIBILITY

Platform Susceptibility

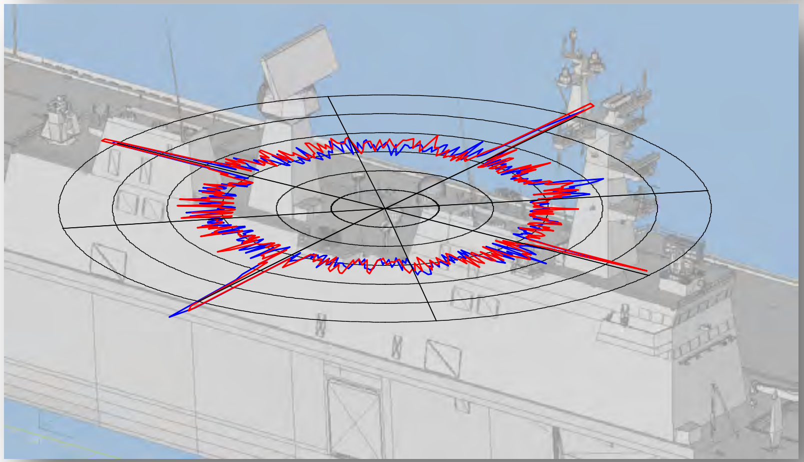
Focussed around signatures:

- Radar
- Infra Red
- Noise / Acoustic
- Electromagnetic / Magnetic
- Pressure
- Wake
- Visual
- Decoys

Radar Signature Control

1. Sectional Shaping
   - Construct ship from large flat panels.
   - Angle topside panels at least ± 5° to vertical.
   - Avoid reflective dihedrals - all internal angles >= 97°.
   - Ensure bridge windows are radar reflective
   - Use modelling to optimise signature

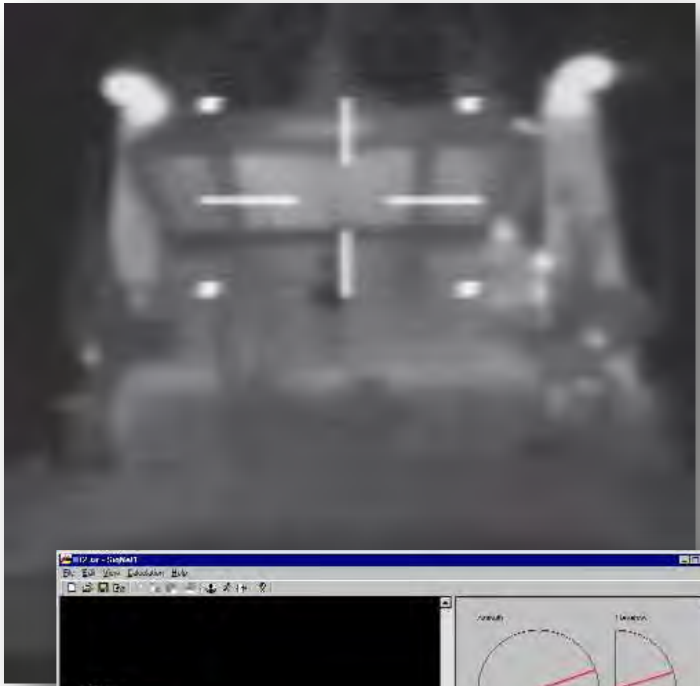
2. Micro-geometry reduction
   - Install an "integrated" mast.
   - Enclose/screen mooring decks.
   - Relocate upper deck equipment inside the superstructure e.g. junction boxes.
   - Install bulwarks to hide equipment that can not be relocated.
   - Use radar transparent material
     e.g. GRP deck stanchions and ladders
   - Screen openings and recesses with doors

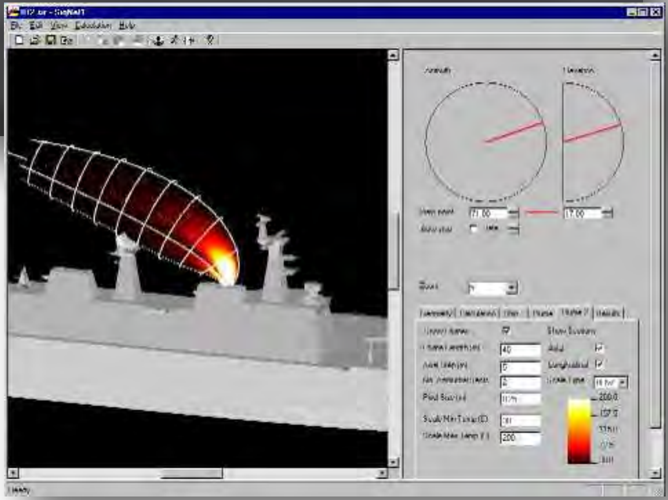


3. Radar Absorbent Materials
   - Must be used with modelling to get most benefit
   - Can be used to reduce reflections from own radar
   - Expensive and makes structure repair difficult

Infrared Signature Reduction

- Utilise existent ship systems
  - Use Ship's own NBC wash-down system to reduce signature
- Insulation
  - Insulate ship sides and deck instead of machinery spaces
- Heat reflective paint
  - Solar reflective paints
  - IR reflective paints
- Exhaust temperature reduction
  - Side exhaust with water injection (not always suitable for smaller vessels due to engine backpressure)
  - Direct exhaust cooling





Acoustic Signature Reduction

Main sources of underwater radiated noise (URN)

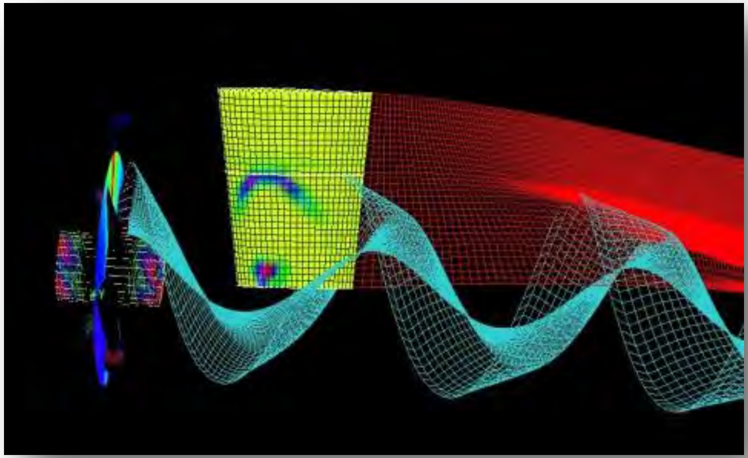
1. Airborne noise
    - Reduce radiating noise sources
    - Install acoustic insulation or enclosures
2. Structureborne noise
    - Isolate rotating machinery using flexible mounts
    - Consider double mounting equipment on rafts
3. Fluid noise
    - Eliminate unsteady flow around hull
        - Avoid knuckles and steps in hullform
        - Consider flow around sea inlets, thruster tunnels, sonars etc.
        - Use paint flow tests and CFD modelling to highlight areas of flow instability and separation
        - Ensure all hull appendages are accurately aligned with the local flow
    - Eliminate unsteady fluid flow within system pipework e.g. HPSW

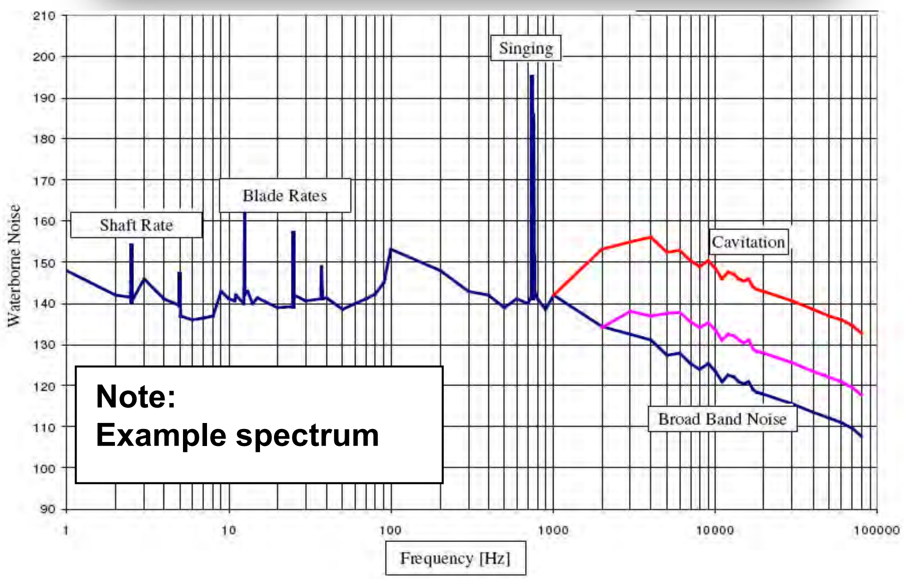
Acoustic Signature Reduction

4. Propeller noise
    - Ensure steady wake field in the propeller disk
    - Minimise shaft / bracket wake shadows
    - Align shaft bracket struts with the flow
    - Reduce pressure pulses
        - generous hull clearance
        - blade skew
    - Limit cavitation
        - blade sections
        - blade finish and accuracy
    - Eliminate singing
        - trailing edge geometry

5. Important to set noise budgets!

6. Use modelling to manage and track progress against budget(s)

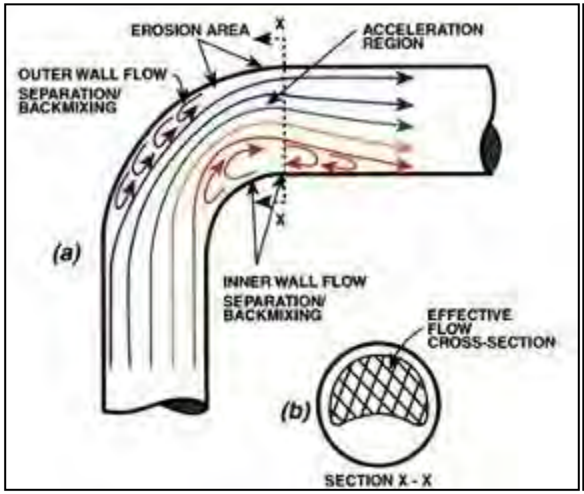


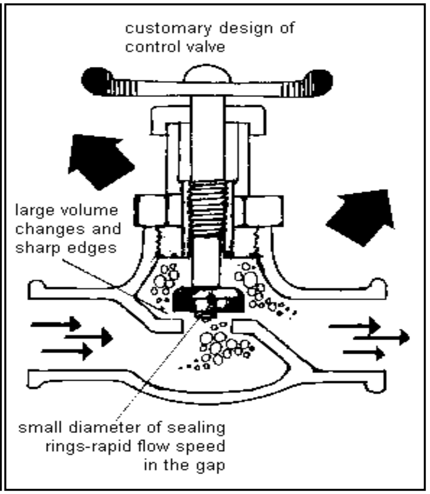


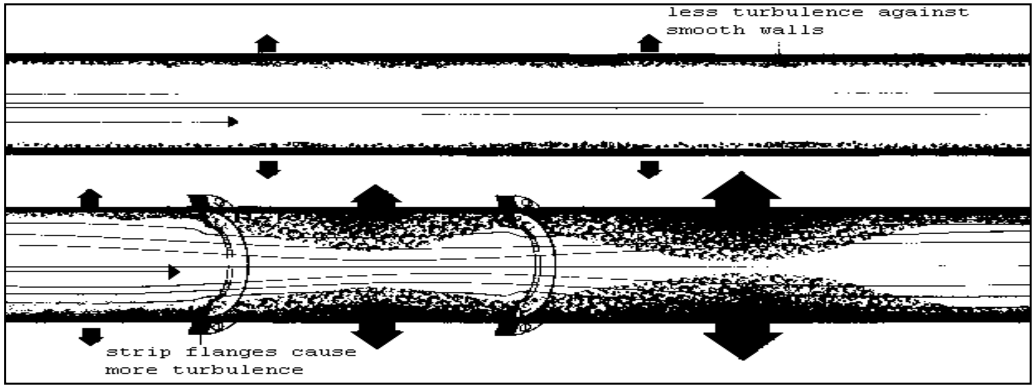
Note:
Example spectrum

Example - Fluid Flow Noise Sources

- When fluid flows through pipes, noise is generated
- When flow becomes turbulent, noise increases
- If a tight elbow is encountered then as flow separates from pipe wall, a rapid pressure drop created that leads to cavitation
- Most valves will generate cavitation and flow noise, under certain conditions
- Pipe wall discontinuities will cause cavitation and poor flow, in certain circumstances







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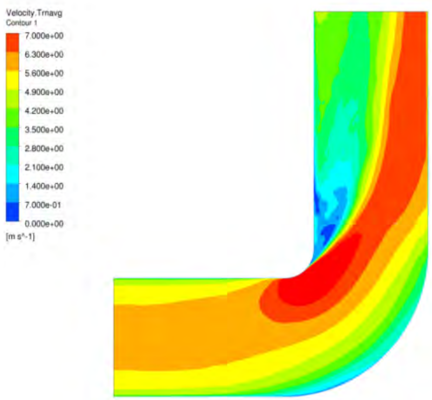
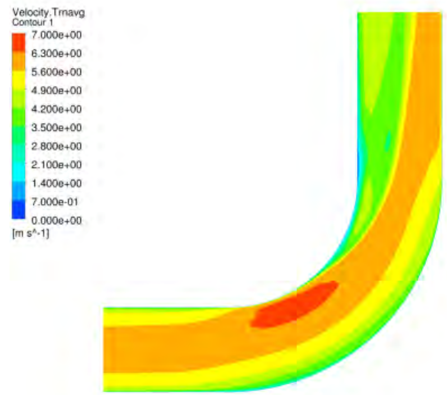
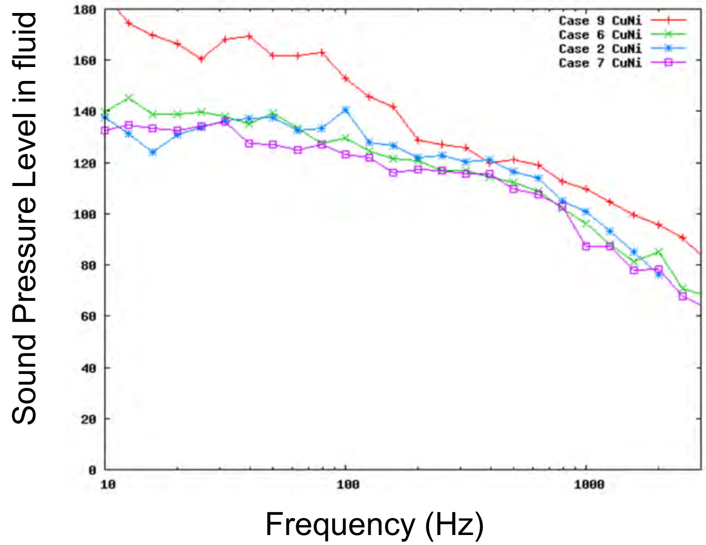
Example - Noise from Pipe Bend







- Empirical formulae used for initial analysis of pipework features such as bends - generally larger bend radii improve URN
- Conditions of flow velocity & bend radii of specific features modelled using CFD
- Analysis provides the basis for informed design trade offs between pipe diameter, bend radius and flow velocity.
- Minimises the impact on platform design without compromising URN performance.

Electromagnetic/Magnetic Signature Reduction

- Signature reduction systems include
  - Magnetic treatments - reduce the ship's signature. Although not permanent
    - Wiping
    - De-perming
  - Degaussing systems
    - 2D or 3D systems
    - Magnetometer or gyro control
  - Impressed current cathodic protection (ICCP)
    - Balancing this system can be used to minimise the magnetic signature
  - Active shaft grounding systems
    - Used to reduce the alternating magnetic and electric fields generated by the interaction between the ICCP and the rotating shaft / propeller blades
- Systems have to work together

VULNERABILITY

Vulnerability

The intrinsic capability to resist damage within the moment of the incident.

Effects include:

- Blast
- Fragments
- Residual Strength
- Shock
- Fire / Smoke

Mitigated by design.

Blast Resistance

- Austenitic welding
  - All watertight bulkheads
  - High value compartments operations, machinery control rooms etc.
  - High risk compartments gunbays and, magazines etc.

- Blast Resistant Bulkheads
  - Minimum - All zone bulkheads
  - Measures <u>must</u> be used conjunction with blast resistance doors

Fragmentation Damage

- Ballistic protect compartments where
  - High numbers of crew are located
  - High value / skilled crew are located
  - Equipment essential to the ships mission

- Typical compartments
  - Operations room, mission spaces, bridge, radar & chart rooms
  - Communications equipment and offices
  - Main, mission and air weapons magazines
  - Machinery control room (as this normally also doubles as the DCHQ)
  - Weapons related electrical and mechanical equipment rooms
  - Gunbay (because of locally stored ammunition)
- Use layout to protect compartments
  - Difficult to achieve on OPV due to lack on beam
  - Ensure magazines are as low as practical

Residual Strength - Box Girders

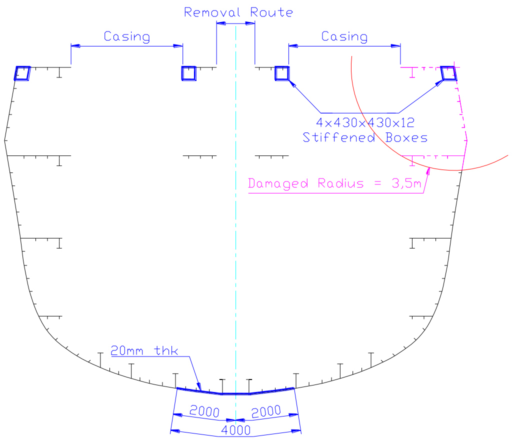
- An OPV can only realistic withstand small to medium missile strike i.e. Sea Suka or Hell Fire

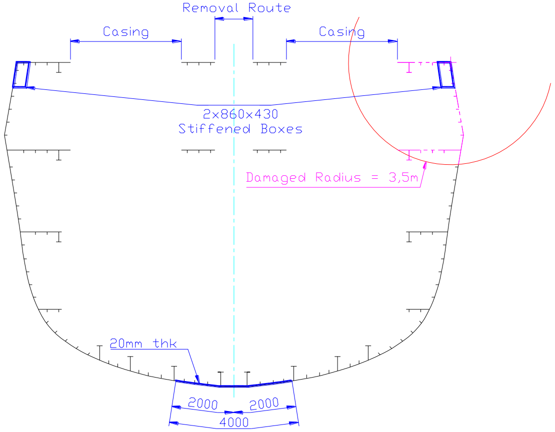
- To be effective the box girders must
  - Extend over at least 60% of ship's length
  - Be effectively tied into the ship's structure
  - Constructed from high strength steel (yield stress 390 MPa)

- Difficult to replace transverse moment

- Box keel considered impractical on OPV

- Weight increase in the region of 40te





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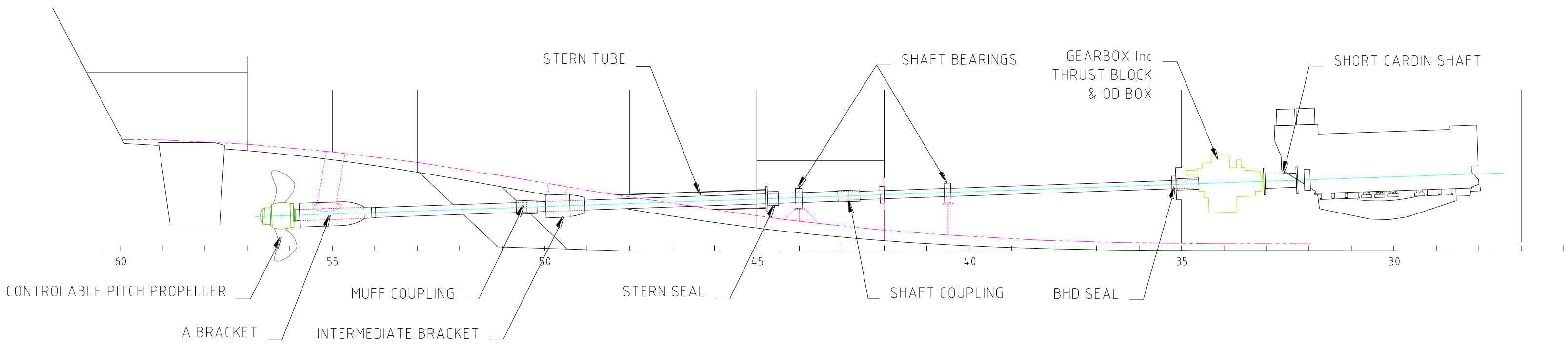
Shock Resistance

- Shock mounting
  - May be detrimental to underwater radiated noise signature
  - Requires flexible connections
- Shock hardening
  - Avoid the use of grey cast iron and other brittle materials
  - Avoid cantilevered or overhanging components (turbocharges etc.)
- Raft mounting
  - Multiple components on single raft
  - Increased space and weight requirements

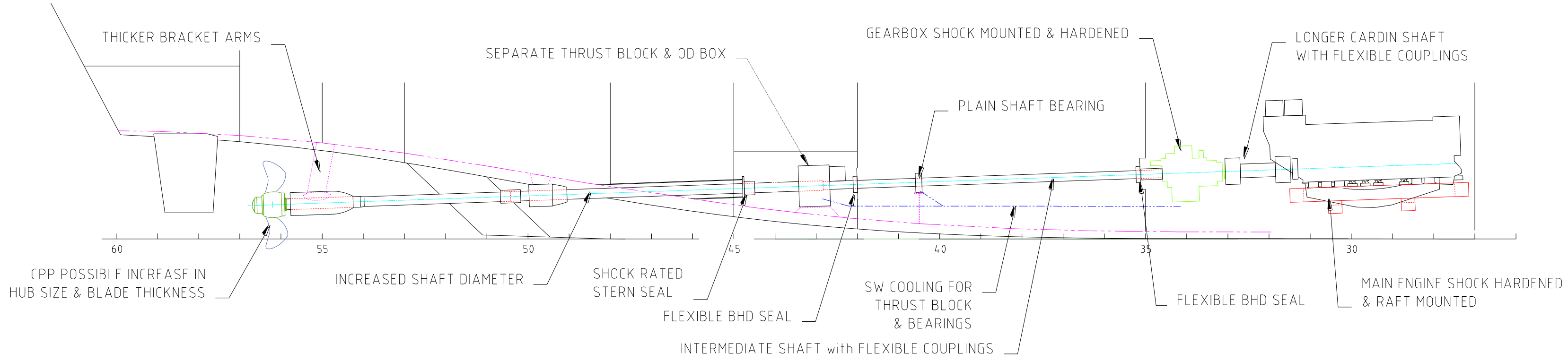
Shock Resistance

- Propulsion System

Typical Shaftline



Shock Hardened Shaftline



Fire Insulation

- Advantages
  - Enhanced fire protection for the ship reducing reliance on crew intervention
  - Increased duty of care to the crew
  - Goes beyond SOLAS to protect high value compartments

- Challenges
  - Very prescriptive regulations
  - Additional boundaries required due to ship layout
  - Additional divisions / fire doors around stairways
  - Need to pay attention to detail - particularly bulkhead penetrations
  - Conflicting rules - NBC air recirculation, boundary cooling

Equipment Redundancy and Separation

- Two totally independent power generation and propulsion systems.
  - Ideally with physical separation
- Physical separation or duplication of command and control systems and compartments.
  - Likely to be of limited effectiveness due to length of ship. Maximum separation only 40m
  - Unlikely to have sufficient room for secondary operation room
  - Split silos, relocate some servers
  - Installation of additional consoles around the ship
  - Duplication and protection of data highways
- Use of multifunction equipment
  - Multifunction and duel use consoles
  - Reversionary modes. Nav. radar providing limited backup to main radar

RECOVERABILITY

Recoverability

The capability to recover functionality following an incident.

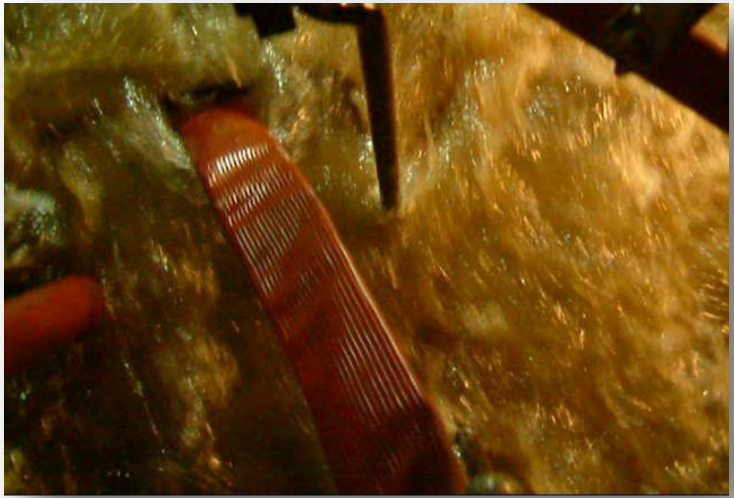
Platform Design

- DCHQ1 and DCHQ2 require to well separated.
- Large displays and integrated communications allows effective co-ordination of information
- Damage control and monitoring systems allow everyone to see the same DC picture
- Prioritisation of recoverability activities

Containment

- Peacetime scenario – Ship not closed down

  versus
- Battle Damage Scenario – Ship closed down
  - Damage Control Zones (A60 Boundaries)
  - Watertight Boundaries
- PMS used to monitor system boundary integrity



Automated Recoverability

Automated recoverability actions following incident include:

- Automated fire protection systems such as CO_2, AFFF and HPFFM spray systems.
- Embedded systems such as fast ACOS can provide an uninterrupted alternate electrical supply to key equipments.
- Electrical management systems to shed loads in order to maintain supply to essential equipments.
- Electrical Propulsion management systems preventing under frequency and the subsequent overall platform failure.
- Intelligent Fluid Systems, such as DINCS, can automatically
  - isolate damage
  - reconfigure fluid systems to supply key equipments
  - maintain a credible fight through capability.

Battle Damage Repair

Manual process whereby:

- Shoring up of the ships structure e.g. bulkheads
- Manual isolation, reconfiguration or reconnection of systems
- Re-establishing electrical power is crucial
- PMS used to monitor system configuration and integrity
- DCHQ - BDR Party communication crucial to success

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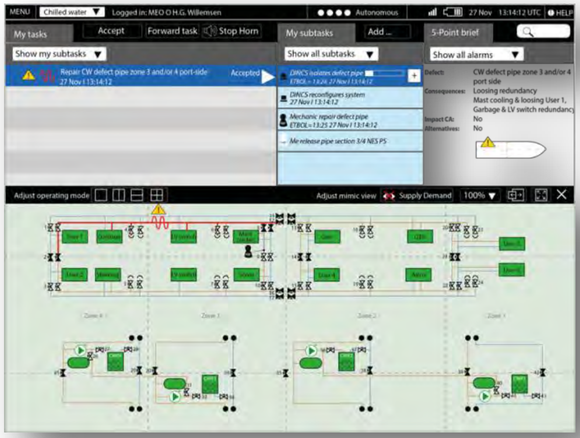
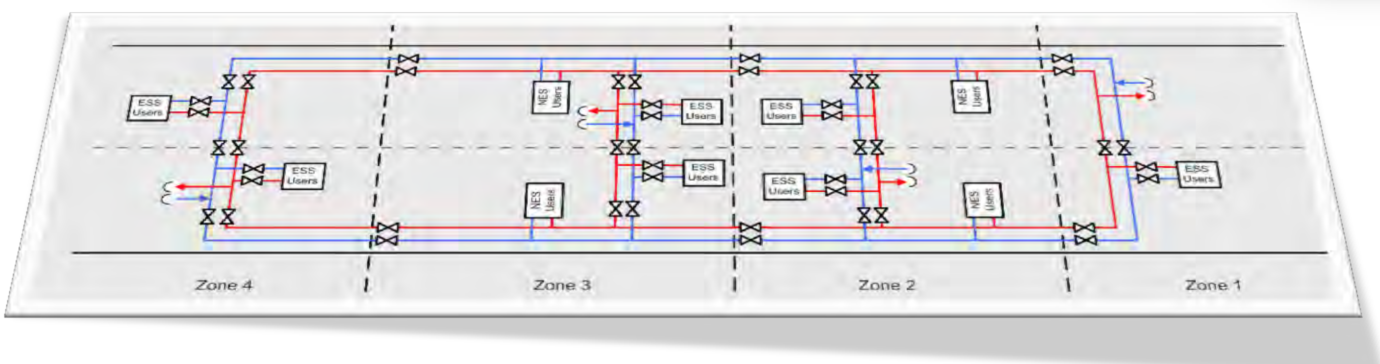
Example - DINCS Automated Recoverability

DINCS applied to networked fluid systems will:

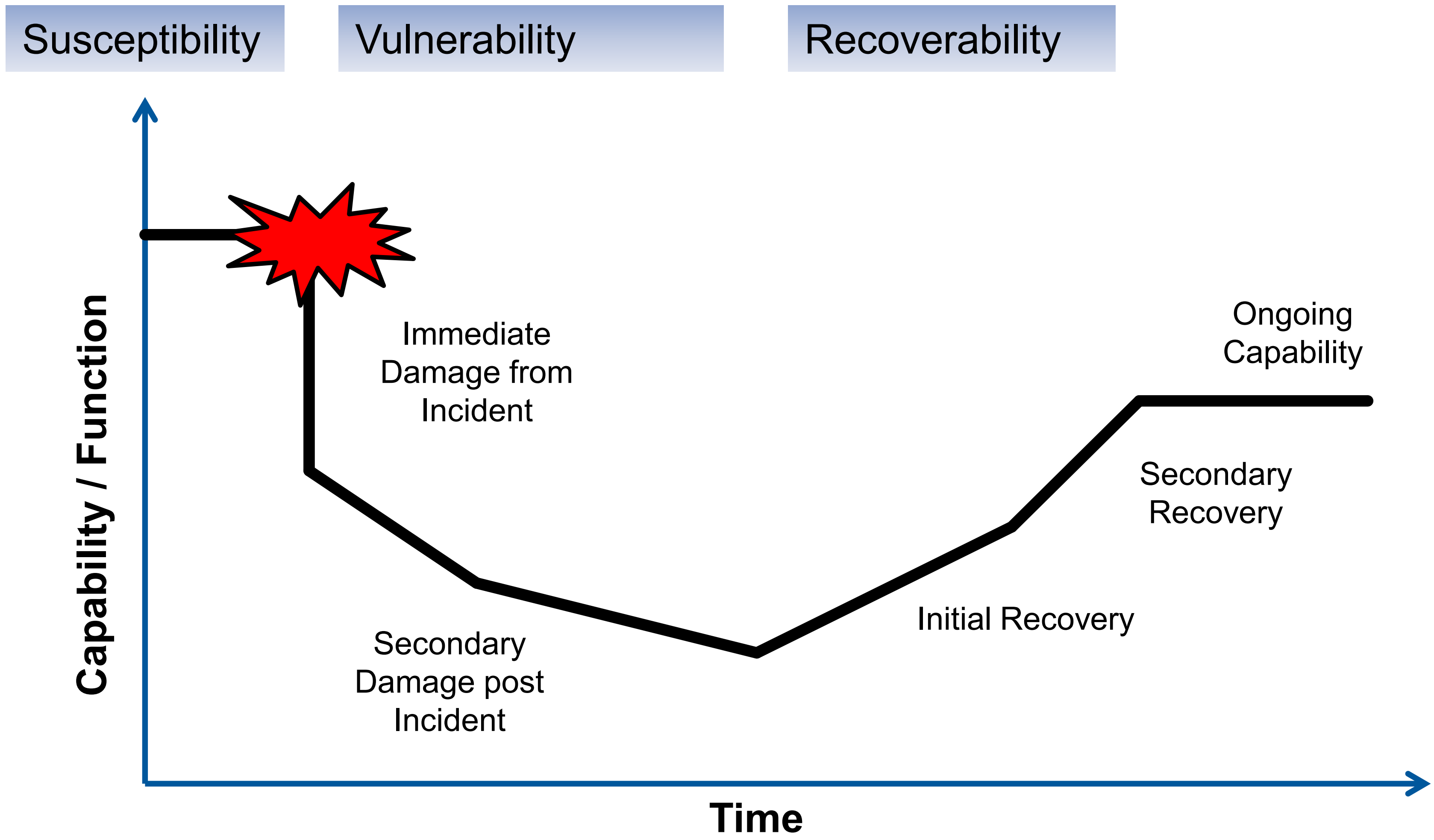
- Reduce operator workload by
  - Detecting and isolating leaks
  - Reconfigure system iaw Command Aim
  - Balancing supply and demand
- Allow autonomous operation iaw Command Aim priorities
- Withstand damage to ship's equipment controls and network





SUMMARY

Survivability Timeline of Incident



Managing Survivability

To maximise a platforms survivability:

Susceptibility: Prevent the platform being hit:

- Minimise signatures
- Eliminate threat - hard kill, soft kill (or both?)

Vulnerability: During hit - minimise impact:

- Redundancy
- Separation
- Blast resistant structure
- Fragment protection

Recoverability: Following hit – maximise fight through capability

- Minimise the time to manually recover functionality
- Automated reconfiguration

In conclusion

- Holistic approach to survivability design and management offers greatest results.
- Survivability design features can be and are being successfully applied to all sizes of naval platform.
- Cost of implementing survivability measures are very moderate compared to the overall capital investment cost.
- BAE Systems has significant experience and knowledge of ship survivability.

Thank you

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