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Australian Government
Department of Defence
Defence Science and Technology Organisation

SAMAP INTERNATIONAL
Submarine Air Monitoring Air Purification

Review of Submarine Exhaust and Induction Mast Designs

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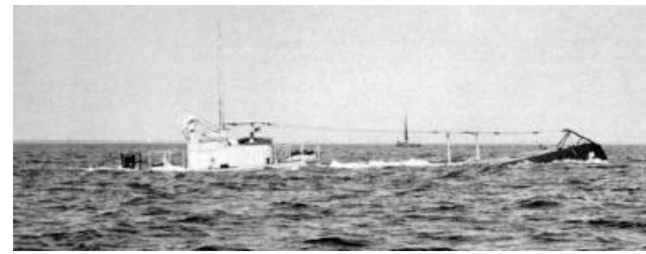
DSTO Science and Technology for Safeguarding Australia

Aim of Review

- Navies have been continuously researching better submarine exhaust and induction mast designs post WW II
- Better stealth and endurance capabilities
- Exhaust is a system of SAM, AP and ES systems
- DSTO SAMAPES Review
  - Modern submarine project (2025)
  - Better understanding of exhaust bubble characteristics
  - Better exhaust design

History

- First designed by Italian Navy for Sirena Class (1934 – Taranto Naval Base Museum)
  - Retractable intake with fixed exhaust mast
  - No perceived operational need
  - J. Military History 2005 (Jones)



- RNL Navy developed first telescopic snorkel
  - 1938 in O19 and O20
  - Captured by Germans in 1940
  - O21 escaped to UK, but RN perceived operational risks
  - Kriegsmarine was winning Battle of Atlantic
    - No benefit running diesel engines underwater

Adoption by U-Boats

- Mounting U-boat losses in 1943
  - Kriegsmarine experimented with folding mast snorchel
  - Fragile mast slowed U-boats to 6 knots
    - Frequent damage and Vulnerable
    - Vibrations of diesel engines

- Type XXI U-Boat (1945)
  - Modern submarine design with radical technologies
    - Undetected
  - Noise reduction,
  - Telescopic induction integrated with engine operation
  - Exhaust discharge under water
  - Commissioned into Allied Navies (Snort trials by RN Truant and USN Irex)

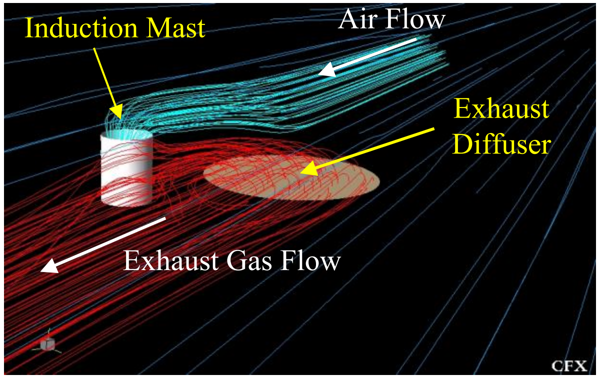
Post WW II Designs

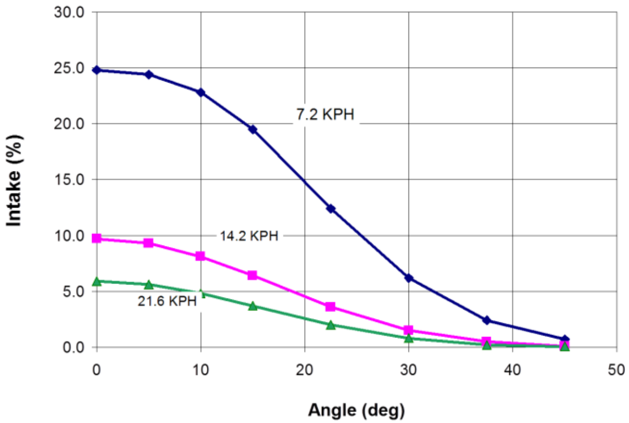
- Myriad of Designs
  - Underwater snorting
  - *Disperse bubble plume widely*
  - Angled exhausts to disperse bubbles with trajectory
  - Side exhausts to disperse wide and deep
  - *Reduce profiles* of exhaust crowns and domes

- Categories of Exhaust designs
  - Wide angle deflector fin (WAD)
  - Open cavity angled exhaust and Flow assisted (FOCEAN)
  - PORSCHE by HDW
  - Plenum chamber (RNL Navy)
  - AIP designs (Scorpene and Soryu)
  - Aim of DSTO - PASCOE with small bubbles widely dispersed leaving no wake at surface

DSTO Work 2004

- CFD simulations of getting your own back





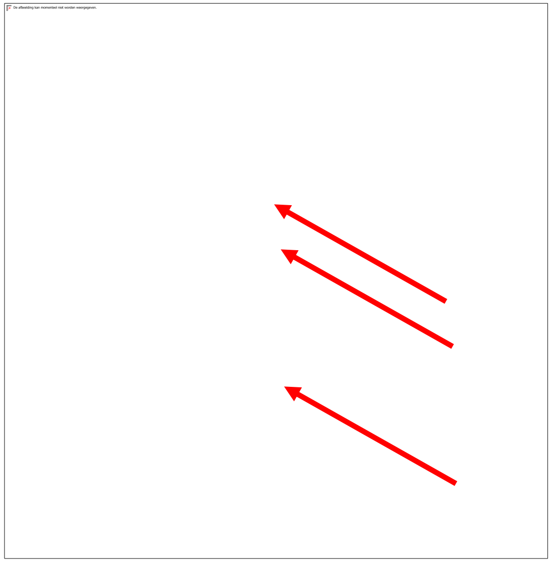
- Salt water modelling
  - Good agreement with CFD

DSTO Work Bubble Outgas Model

- Large bubbles from present submarines
  - Maximum CO_2 release at surface
  - Return of asphyxiant to induction mast
  - Large CO_2 plume signature

- Small bubbles
  - No CO_2 release at surface
  - Snorting capability in shallow waters
  - RNL Navy efforts to produce small exhaust bubbles

Wide Angle Deflector



- HDW 1967
- Designed to deflect bubble plume
- *Wide dispersal,* large bubble splitter
- Small engine backpressure
- But expect large bubble burst and crown

Song Class

- Same principle as WAD
- *Honeycomb* exhaust (RNL Navy)
  - Disperse bubbles sideways
- Deflector - *greater depth from surface*

- Larger engine backpressure
  - Less efficient snorting

Open Cavity Angled Exhausts (OCEAN)

- Agosta Class
- Small angled cavity
    - To reduce exhaust volume
    - Overcome by engine backpressure
- *Downward* exhaust trajectory
    - Wider dispersal of exhaust plume
- Expect large bubble burst at surface
    - Little dispersal due to big bubbles

Flow Assisted OCEAN (FOCEAN)

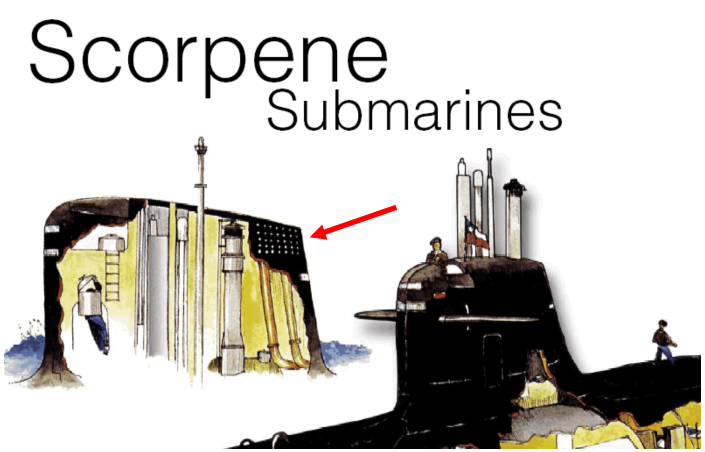
- Taiwan Navy
  - Improved Dutch Zwarvdis
- Similar to Agosta design
- Scoop at rear of exhaust
  - Assists hydrodynamic flow
  - Wider and longer path dispersal of exhaust plume
- Expect large bubble crown at surface

PORSCHE (TWIN PIPE)

- HDW 1990s
- Exhaust pipe extends along top of sail
  - 2 joints to avoid backpressure from other engine exhaust
- Low snort depth
  - Low hydrostatic pressure
- Collins variant
  - Slots for bubble breakup
  - Bubbles further aft
- Expect large bubble plume
  - High dome or crown

Yuan Class and Chile Scorpene

- Grille to split bubbles
- Similar to RAN Oberon Class exhaust design
- Different shapes
- Expect large bubbles



RNL Navy PC_PORSCHE

- Double chamber with bubble diffuser
- Small bubbles but coalesce to medium sized bubbles
- Fast bubble rise
- Lower bubble dome at surface

France Scorpene

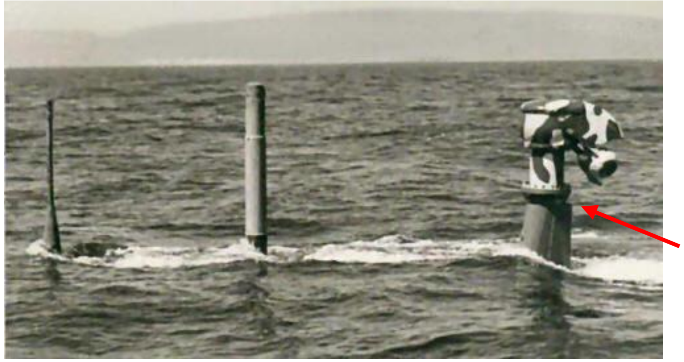
- Improved Agosta design
- Large rear exhaust

- Side exhaust with small holes
  - Side dispersal of bubbles

- Mixture of large, small and medium sized bubble plume (Complex)
- Streamlined sail

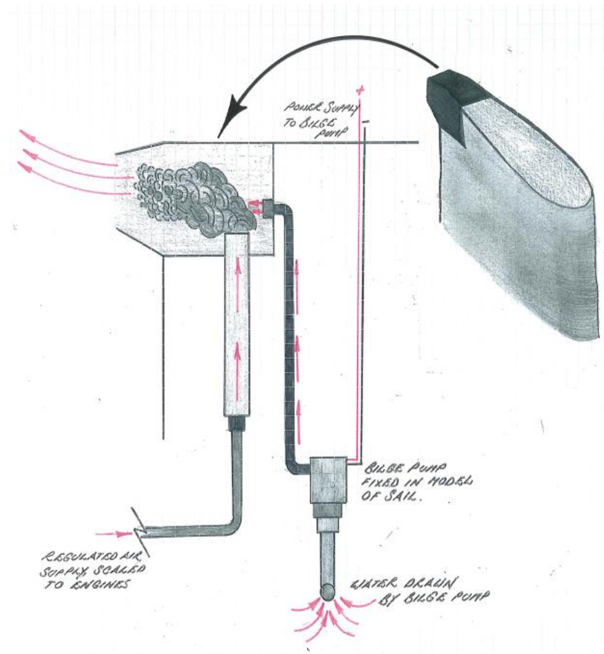
Soryu Class

- Absence of exhaust on sail
- Telescopic induction within exhaust pipe
  - Similar to RN combined induction - exhaust
  - Advantage avoiding getting your own back
  - Better air quality



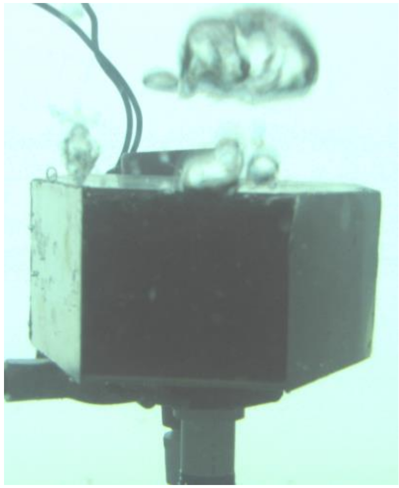
- Has room for modifications

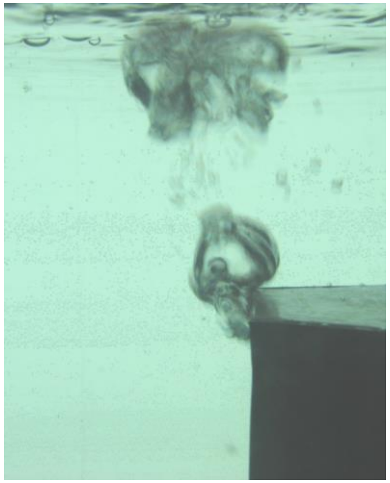
Simulations Using Box Model

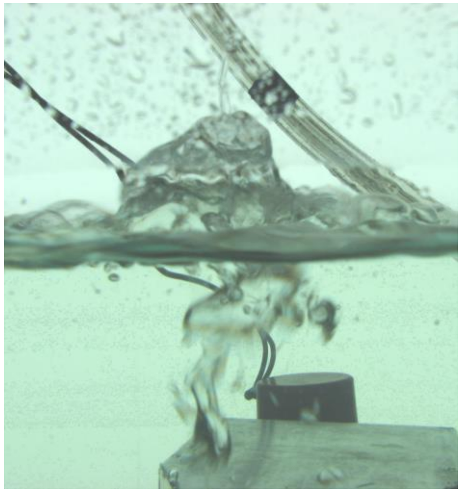


- Not scale model
- Simulations at low cost
  - Not quantitative or rigorous
  - But, Good quality visualisations
- Reproducible conditions
- Easy comparison with CFD modelling
- Rapid assessment of design effects
- Rigorous methods
  - Paralysis by analysis

Water Tank Experiments – Open Exhaust



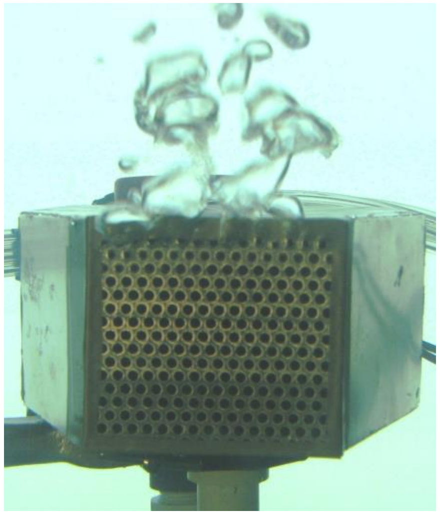


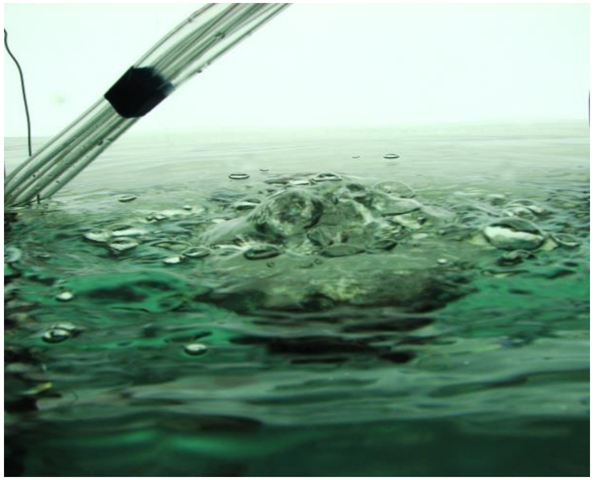


Bubble Characteristics

- Adhesive attraction forces on wetted surfaces
  - Delayed rise to surface
  - At air-liquid interface, minimum free energy and surface area
  - But liquid-solid contact area is maximum for adhesion
  - Diminishes for larger bubbles
- Bubble coalescence by cohesive attraction
  - Formation of undesirable larger bubbles
- Shape of bubble burst crown or dome
  - Bubble size
  - Surface tension(salinity, chemical surfactants, temperature)

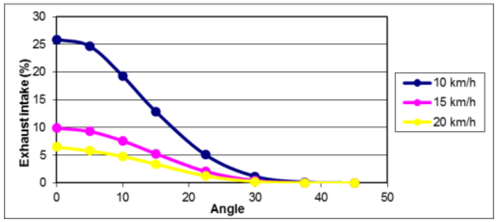
Box Model – RNL Navy Simulation

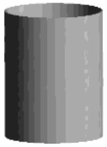




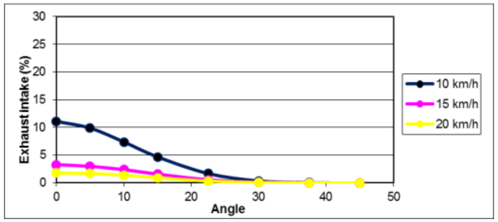
Induction Mast Design

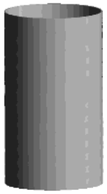
- Exhaust design in tandem with induction mast
- CFD modelling of plume re-entry
- Advanced funnel design concept
  - BP ‘Emerald Green’
  - Plume avoidance of tail wind



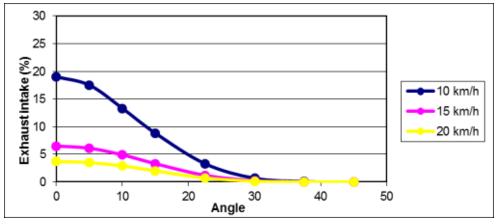


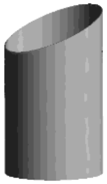
Standard mast





One radius higher than standard mast





One radius higher than standard, angle cut to standard mast height

Future SAMAPES Work

- CFD modelling of exhaust performance
  - Better understanding of bi-phasic (air-liquid) plume behaviour
  - Small bubbles, added momentum (from jet) with smaller Reynolds
  - Trajectory and dispersal visualisation (3-D)
- Scale model development
- Tow tank experiments
- Capability demonstrator model (5 years)
- Possible prototype and trials in Collins
- Collaboration via DEA, MOU

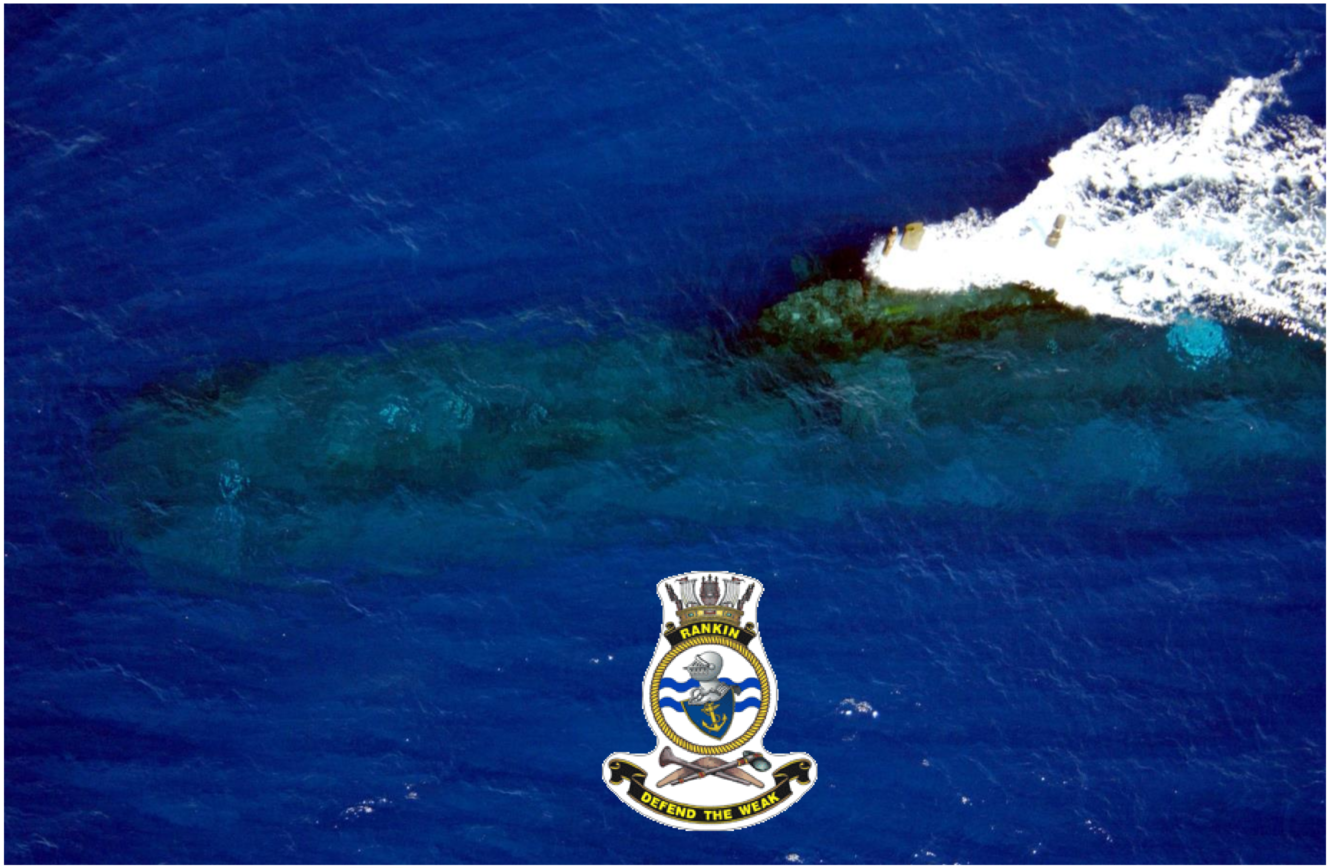
Conclusions

- Review showed great variety of present and past designs
  - *COMPLEX* and *SIMPLE* *(Post WW II to modern)*
  - *Non-powered and flow assisted*
  - *Aim to Disperse bubble plume*
- Open cavity simulated large bubbles and high crown or dome
- Bubble splitters simulated formation of smaller bubbles and low domes at surface

- *Bubbles* influenced by *adhesive* and *cohesive* attraction forces
- Smaller bubbles *coalesce* on *wetted surfaces*, forming larger bubbles

- *Future SAMAPES improvements will focus on small bubble exhausts leaving little or no wake on surface*

Questions



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