Review of Submarine Exhaust and Induction Mast Designs

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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 snorkel
  - 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 (RLN 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\textsubscript{2} release at surface
  - Return of asphyxiant to induction mast
  - Large CO\textsubscript{2} plume signature

- Small bubbles
  - No CO\textsubscript{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 Scorpène

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

- 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
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