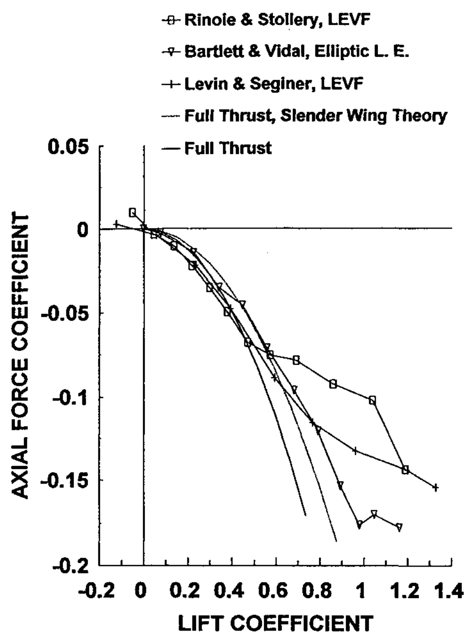


**Fig. 3 Effect of leading-edge devices and shape on axial force coefficient.**


## Summary

A comparative study was undertaken to evaluate the effectiveness of vortex flaps when compared to a geometrically similar blunt-edged delta wing. The study shows that for the data presented in this Note, a planar blunt-edged wing is capable of matching the performance of a similar wing equipped with a vortex flap at low to moderate $C_L$. Furthermore the blunt-edged wing is seen to retain higher levels of axial force or thrust at high lift coefficients. Nonetheless, at high $C_L$, drag of the LEVF is lower than the blunt wing because of enhanced lift through vortex suction.

The LEVF concept would offer superior flexibility if the flap were movable, such that its deflection could be optimized for the particular operating conditions. If the blunt-edged wing were modified with a conventional leading-edge flap or slat, it is likely that the performance of the wing so modified, and a movable LEVF would be similar, as it has been shown that for optimum LEVF performance, separation is suppressed.[5]


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# Ring Wing for an Underwater Missile


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## Introduction

BY providing stealth capabilities to advanced torpedoes and scout-like unmanned underwater vehicles (UUVs), their mission success can be enhanced. Under a Defense Advanced Research Projects Agency (DARPA) contracted effort, a study was performed to evaluate the potential benefits in underwater flight performance that an extendable, novel ring wing and wraparound tail control surfaces may provide to a conventional heavyweight torpedo. With wrapped ring wing and tail surfaces, this bullet-like configuration is conducive to naval vessels having tubular launching systems. Once launched, the free-flight vehicle is reconfigured with extendable ring wing and wraparound tails.[1] These deployable lifting surfaces are activated by self-energizing materials including aluminum, steel, and composite structural members having internal spring-like qualities.

## Ring Wing Benefits for an Advanced Torpedo

Hughes Aircraft has performed exploratory wind-tunnel studies of compressed carriage missile designs having extendable ring wing and wraparound tail control surfaces. These force and moment data show that significant improvements in a missile's lift and aerodynamic efficiency can be realized.

Low-speed test results of these data provided incompressible flow characteristics that were used to estimate potential improved hydrodynamic benefits that a ring wing and wraparound tail surfaces can bring to a novel torpedo design. Estimates of improved underwater flight performance for a heavyweight ring wing torpedo (4000 lb) were made.

By providing standoff capability to U.S. Navy submarines and surface ships, their survivability and mission success can

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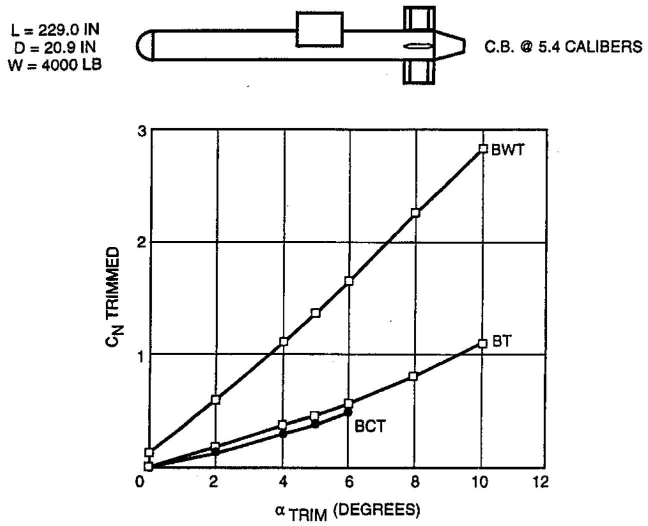


**Fig. 1 Trimmed normal force coefficient for novel torpedoes.**

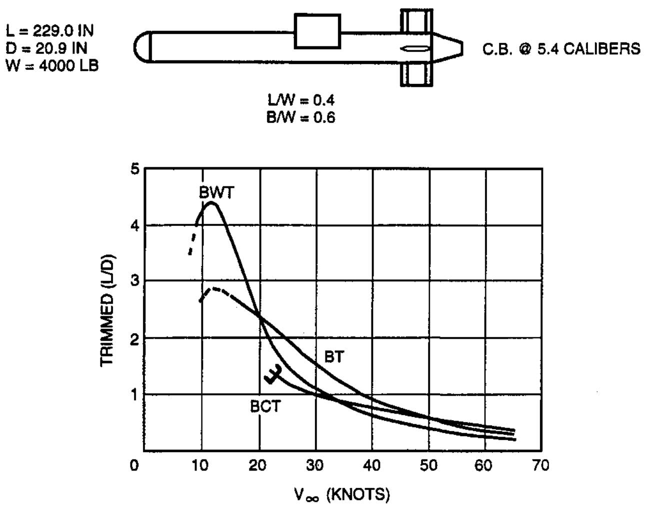


**Fig. 2 Equilibrium hydrodynamic efficiency for novel torpedoes.**

be enhanced. DARPA and the Office of Naval Technology recognize that advanced unmanned underwater vehicles launched from conventional naval vessels can perform scouting roles as well as carry warheads against enemy targets. Through fiber optic linkage, intelligence gathered in real time by UUVs about submerged enemy vehicles and potential minefield encounters can be communicated back to their carriage vehicles. Relative to these threats, this extended visibility will provide our military personnel and naval vessels with needed information allowing them to take evasive action; thereby ensuring a posture of safety.

## Predicted Flight Performance of an Underwater Missile

Preliminary estimates of improved level flight performance of an advanced torpedo having large wraparound tail surfaces [body–tail configuration (BT)], and a novel wing with large wraparound tail surfaces [body–wing–tail configuration (BWT)] relative to a 4000-lb baseline torpedo system [body–conventional tail configuration (BCT)] were made. The bouyancy force of this underwater missile is 2400 lb, and 1000 lb of on-board fuel was assumed.

Based on low transonic speed aerodynamic wind-tunnel test results under a Hughes IR&D ring wing missile project at the AEDC 4-ft transonic wind-tunnel facility,[2] hydrodynamic characteristics for advanced heavyweight torpedoes including a ring wing missile design were estimated. Although the wind-tunnel test results were taken at Mach 0.6, it was determined that these aerodynamic results were representative of incompressible flowfield characteristics. Significant advantages in trimmed normal force coefficient $C_N$ and equilibrium hydrodynamic efficiency lift-to-drag ratio $L/D$ are shown in Figs. 1 and 2.

Compared to a typical torpedo design, it was determined that the unique extendable surfaces can provide significantly greater contributions to lift relative to a conventional underwater vehicle design. Further, it was found that these novel wing and larger tail surfaces introduce longitudinal and lateral static and dynamic stability to the torpedo. In addition, these unique surfaces provide much greater control effectiveness to these underwater vehicles in pitch, yaw, and roll authority. Propulsion characteristics typical of a conventional torpedo including its thrust, horsepower, specific fuel consumption, and

EQUILIBRIUM CONDITION @ 150 FT DEPTH: $W_{TOTAL}$ = 4000 LBS, $W_{FUEL}$ = 1000 LBS, B/W = 0.6

FACTORS RELATIVE TO BASELINE

| CONFIGURATION/ FLOW CONDITION | TRIMMED L/D | EXPENDED HORSEPOWER | MAXIMUM RANGE | ENDURANCE | JETPUMP RPM |
|---|---|---|---|---|---|
| BASELINE, $V_\infty$ = 23 KNOTS, $\alpha = 6^o$ | 1.2 | 1.0 | 1.0 | 1.0 | 1.0 |
| BODY - TAIL, $V_\infty$ = 15 KNOTS, $\alpha = 10^o$ | 2.7 | 0.3 | 1.7 | 2.5 | 0.7 |
| BODY - WING - TAIL, $V_\infty$ = 9 KNOTS, $\alpha = 10^o$ | 4.2 | 0.1 | 1.9 | 4.8 | 0.4 |

**Fig. 3 Torpedo flight performance from novel wing and tails.**

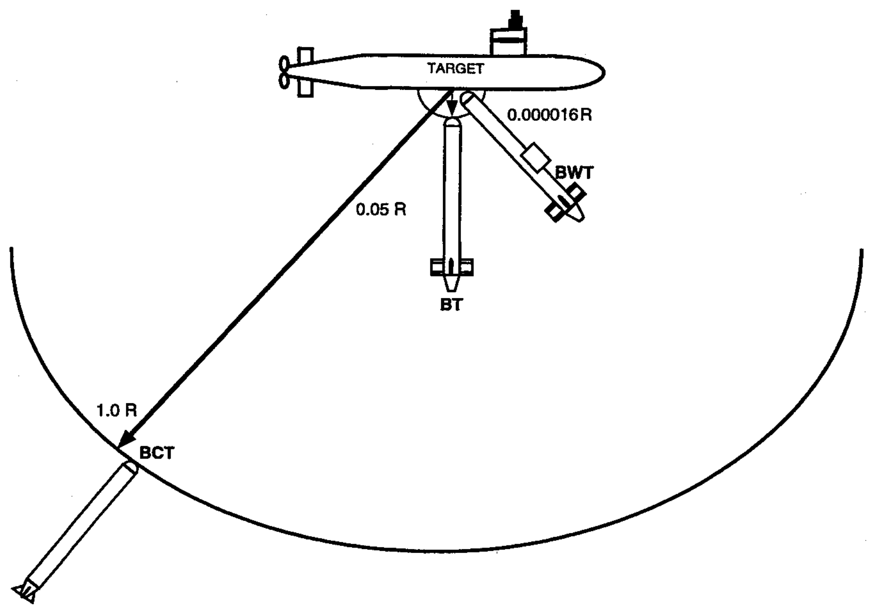


**Fig. 4 Counter detection range from novel wing and tails.**

jetpump rotor rates were used in this evaluation of its flight performance.

A three-degree-of-freedom flight performance analyses code was used to predict maximum range and endurance of the ring wing and baseline vehicles. For simplicity, only relative underwater flight performance factors are shown in Fig. 3. The torpedo design with the novel tails significantly improves its range and endurance. These gains are further enhanced for the case of the novel wing and wraparound tails torpedo design. Also, it was estimated that this innovative torpedo design would provide the needed lift (1600 lb) for sustaining underwater level flight of this heavyweight vehicle at considerably reduced speeds (less than 10 kn). In addition, jetpump rotor rates needed to sustain the indicated low speeds are largely reduced. Consequently, propulsive as well as body noise generation can be significantly reduced because of the favorable hydrodynamic lifting characteristics of the novel torpedo surfaces that permit reduced speeds while maintaining equilibrium flight. As the speed of the torpedo is reduced, turbulent boundary-layer velocity fluctuations and pressure perturbations as well as vortex shedding contributions to noise intensity are largely alleviated.[3]

## Estimate of Noise Reduction for Underwater Vehicles

Estimates of counter detection range reductions that a submerged enemy target would suffer because of the improved flight efficiency of a ring wing underwater vehicle were made and these findings are dramatically depicted in Fig. 4. The isolated novel tail modification permits the torpedo to gain a significant advantage against the target by reducing its minimum undetected range by more than an order of magnitude. By utilizing the novel wing and tails, detectability of the approaching underwater missile by the target is virtually avoided and its escape is thereby prevented.

## Summary of Results

Compared to a baseline heavyweight torpedo of 4000 lb, a tube-launched, advanced torpedo design having an extendable ring wing and wraparound control surfaces is capable of providing significantly extended underwater flight performance in range and endurance. This is achieved by the generation of higher lift by the wing at much reduced speeds where the unbouyed normal force needed for maintaining equilibrium level flight (1600 lb) is met and the angle of attack is correspondingly raised to that for nominally achieving maximum *L/D* ratio. Correspondingly, the effected speed reduction yields largely reduced radiated noise stemming from pressure disturbances within the torpedo's turbulent boundary layer. In this manner, a significant advantage in stealth qualities may also be realized by a ring wing torpedo.

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# Aircraft with Synchronically Deployed Wings

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## Introduction

THE dynamic behavior of an aircraft with single axis, aerodynamically deployed wings was analyzed by Djerassi and Kotzev.[1] Two configurations of such aircraft, designated LD and UD, were considered, comprising a fuselage A and wings B and C, all regarded as rigid bodies. These configurations differ from one another in the path transversed by the wings during deployment, and consequently, in their aerodynamical behavior. In particular, simulations presented in Ref. 1 indicate that deployment of the LD configuration is more

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