



ARL-TR-8558 • OCT 2018



Canard Enhancement with Gurney Flaps

by Ilmars Celmins

Approved for public release; distribution is unlimited.

NOTICES

Disclaimers

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of manufacturer's or trade names does not constitute an official endorsement or approval of the use thereof.

Destroy this report when it is no longer needed. Do not return it to the originator.



Canard Enhancement with Gurney Flaps

by Ilmars Celmins

Weapons and Materials Research Directorate, ARL

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY) October 2018		2. REPORT TYPE Technical Report		3. DATES COVERED (From - To) 1 August 2018–30 September 2018	
4. TITLE AND SUBTITLE Canard Enhancement with Gurney Flaps				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Ilmars Celmins				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) US Army Research Laboratory ATTN: RDRL-WML-E Aberdeen Proving Ground, MD 21005				8. PERFORMING ORGANIZATION REPORT NUMBER ARL-TR-8558	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT This report provides an initial exploration of the effectiveness of Gurney flaps in improving canard performance on guided munitions. It is shown that the canards with Gurney flaps have both aerodynamic and physical advantages over a baseline NACA-0015 airfoil. Initial aerodynamic testing indicates the Gurney flap canards exhibit improved stall characteristics over the baseline canard, with a 50% increase in lift. The Gurney flaps also reinforce the delicate airfoil trailing edge, thereby reducing the likelihood of physical damage during handling and assembly of the munition.					
15. SUBJECT TERMS canard, Gurney flap, HMA, lift enhancement, guided munition					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 19	19a. NAME OF RESPONSIBLE PERSON Ilmars Celmins
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (Include area code) (410) 306-0781

Contents

List of Figures	iv
1. Introduction	1
2. Gurney Flaps	1
3. HMA and Quad-Canard Actuation System (Q-CAS)	2
4. Wind Tunnel Setup	4
5. Wind Tunnel Configurations	5
6. Wind Tunnel Results	7
7. Summary, Conclusions, and Future Work	9
8. References	11
List of Symbols, Abbreviations, and Acronyms	12
Distribution List	13

List of Figures

Fig. 1	Gurney flaps, single and double (shown in red)	1
Fig. 2	The 83-mm, gun-launched HMA showing the four independently controlled canards near the projectile nose	2
Fig. 3	Q-CAS canard core and shell, with and without Gurney flap	3
Fig. 4	Q-CAS solid model and bench test assembly	3
Fig. 5	Photo of canard blade with damaged trailing edge	4
Fig. 6	Photo of the model in the wind tunnel	5
Fig. 7	Experimental canard profiles	6
Fig. 8	Canard dimensions (mm)	6
Fig. 9	Coefficient of lift vs. angle of attack as measured in wind tunnel (M = 0.16)	7
Fig. 10	Coefficient of drag vs. angle of attack (M = 0.16, shown for reference only; drag measurements are inconsistent)	8
Fig. 11	L/D ratio vs. angle of attack (M = 0.16, shown for reference only; drag measurements are inconsistent)	9

1. Introduction

Canards are a common method used to steer guided munitions. Typically, the canard is pivoted so that its angle of attack changes relative to the airflow. This generates a lifting force on the canard, which in turn increases the projectile angle of attack. The resulting overall lift force then causes a change in the trajectory of the munition.

One of the limitations on canard effectiveness is aerodynamic stall. When the canard angle of attack exceeds the stall angle, the flow separates and the lift coefficient of the canard decreases. This effect limits the total projectile angle of attack that can be achieved and thus limits the projectile's maneuverability.

This report provides an initial exploration of the effectiveness of Gurney flaps in improving canard performance on guided munitions.

2. Gurney Flaps

Gurney flaps are simple lift enhancement devices attached to the rear of an airfoil. An excellent overview is offered by Lombardi: "The Gurney Flap was named after racecar driver Dan Gurney, who devised it to increase the aerodynamic downforce helping a racecar hold the road. It's nothing more than a small tab, angled at 90 degrees to an airfoil and mounted at its trailing edge (see Fig. 1). Although seemingly insignificant, its effect can be great. A Gurney Flap simply 'bends' the airflow around a surface in such a way that it makes the surface act as if it were a different size or shape."¹

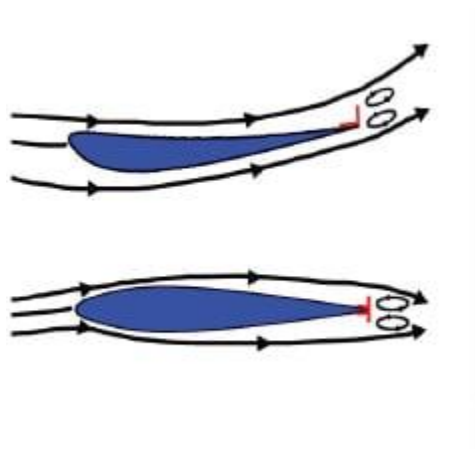


Fig. 1 Gurney flaps, single and double (shown in red)¹

Additional information on single and double-sided Gurney flaps can be found in Neuhaert and Pendergraft² and Cavanaugh et al.³

Double-sided Gurney flaps (or “T-strips”) have several features that make them attractive for canards on maneuvering munitions. These will be illustrated when applied to the US Army Research Laboratory’s High Mobility Airframe (HMA).

3. HMA and Quad-Canard Actuation System (Q-CAS)

Figure 2 illustrates the HMA, used for technology demonstration purposes. The munition is 83 mm in diameter and 420 mm long, weighs about 3.3 kg, and flies in the subsonic regime after experiencing up to 10,000 g’s of acceleration during gun launch. The vehicle features eight fixed fins in the rear for stabilization and four moveable canards toward the nose for control.⁴

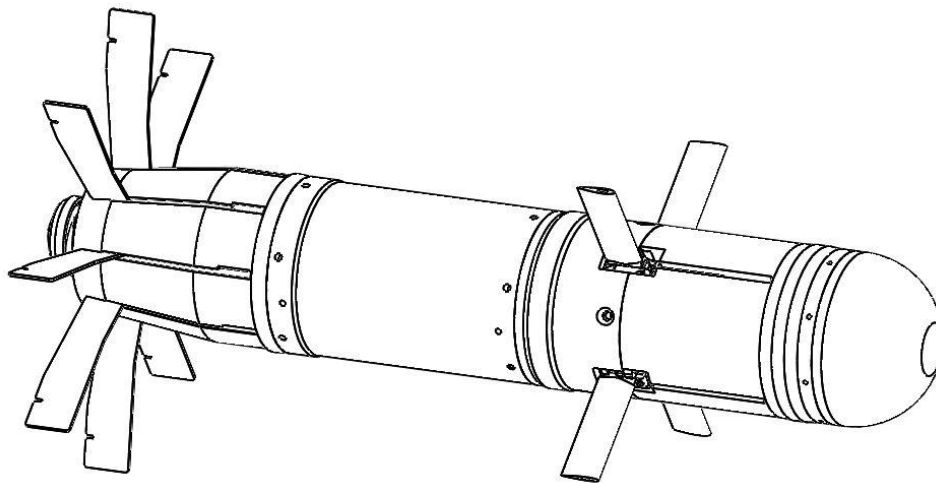


Fig. 2 The 83-mm, gun-launched HMA showing the four independently controlled canards near the projectile nose

The canard blades consist of a waterjet cut 7075-T6 aluminum core, with an additively manufactured shell that has a NACA-0015 profile with a chord of 18.86 mm, shown in Fig. 3. The canard shells are fabricated by the Rapid Technologies and Inspection Branch of the Advanced Design and Manufacturing Division of the Edgewood Chemical Biological Center, located at the Edgewood Area of Aberdeen Proving Ground, from DSM SOMOS 11122 WaterShed-XC on the 3D-system’s SLA-Viper.

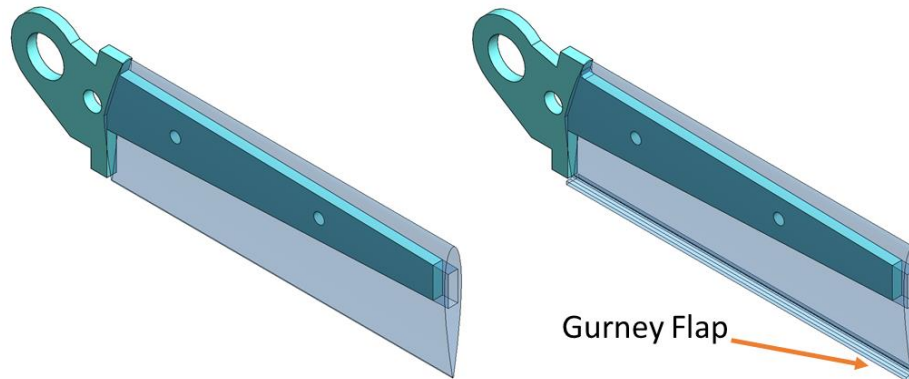


Fig. 3 Q-CAS canard core and shell, with and without Gurney flap

The Q-CAS (Fig. 4) is the mechanism that deploys and moves the canard blades. Each blade is independently actuated and has a $\pm 10^\circ$ range of deflection, driven by a servo. The canards are held inside the projectile body prior to launch by a retention mechanism. The launch acceleration pivots the canard blades inwards away from the retention arms and unlatches the retention mechanism, which then rotates via a torsion spring. When the projectile exits the gun, the acceleration load is removed and the canards are deployed by compression springs.

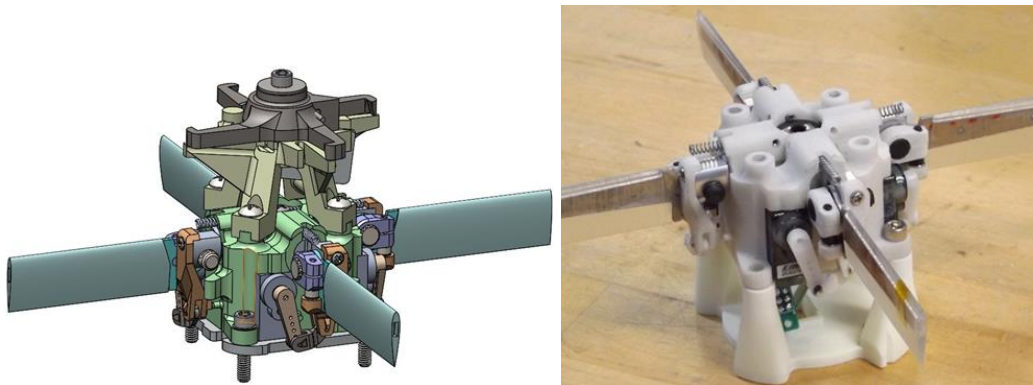


Fig. 4 Q-CAS solid model and bench test assembly

If the retention mechanism is manually unlatched without first pulling the canard blades in (e.g., during assembly or bench testing), then the retention arms are dragged across the delicate trailing edge of the canard blades, potentially resulting in damage. Figure 5 is a photograph of a canard with a damaged trailing edge.

This leads to the first potential advantage of a Gurney flap for this application. Having a T-strip on the canard trailing edge would substantially increase the robustness, making the trailing edge less likely to chip. Additionally, this would serve to stiffen the canard blade.



Fig. 5 Photo of canard blade with damaged trailing edge

4. Wind Tunnel Setup

Several different Gurney flap canard configurations were fabricated and tested in a wind tunnel at the US Army's Edgewood Chemical and Biological Center. The tunnel is a continuous flow, in-draft wind tunnel and was operated at a Mach number of approximately 0.16 with a test section of 0.76 m wide $\times$ 0.61 m high. An internal strain gage balance with a 14-mm diameter and 5-axis capability (no roll moment) obtained the aerodynamic loads in this tunnel. The balance was fixtured to a sting that suspended the model in the test section. It should be noted that the balance that was used was not optimal for the models being tested since the measured normal force loads were only approximately 2% of the balance capacity, and axial loads were 0.5% of capacity. This balance was used because it was installed and set up in the tunnel for an ongoing HMA experiment. The canard evaluation was performed as a piggyback test using the same setup in order to quickly get some preliminary feasibility measurements.

Figure 6 shows one of the models mounted in the wind tunnel. The models were fabricated as a single piece via additive manufacturing using the same process and materials as the standard HMA canard shells. The canard blades also were built to the same size as the actual HMA canards. Using the same scale, material, and process allows a realistic evaluation of fabrication resolution that would be encountered when building actual canard shells with integral Gurney flaps. The acrylic clear tube behind the model was attached in order to shield the delicate balance components from the airflow.

The model consists of a 26-mm-diameter body with a hemispherical nose and two identical canard blades extending from opposite sides of the body. The model is mounted so that the canard blades are vertical because this tunnel sweeps the sting in the horizontal plane. The angle of attack was varied from -15° to $+15^\circ$ and readings were taken at 1° increments.

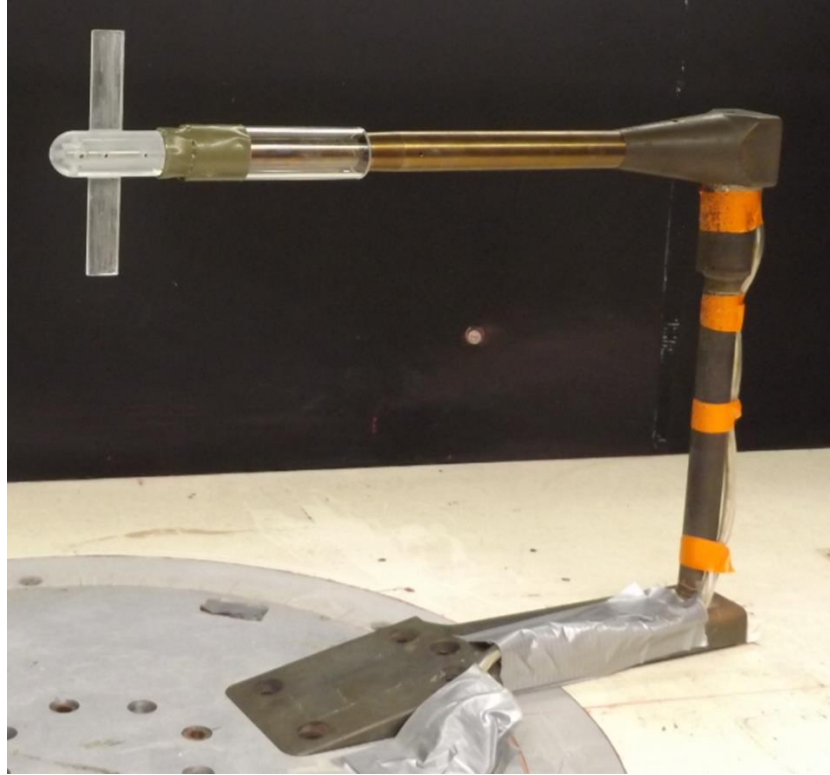


Fig. 6 Photo of the model in the wind tunnel

5. Wind Tunnel Configurations

Five different canard profiles were fabricated and tested. Figure 7 shows the profiles, and Fig. 8 gives dimensions. The Gurney canards have the same NACA-0015 profile as the baseline. The Gurney flaps are added with the rear of the flap coincident with the baseline trailing edge. Two different flap heights were tested. The Gurney 1 flap height extends to 7.6% of the canard chord on each side, and the Gurney 2 flap extends 5.5%. Both of these are somewhat higher than what is commonly used for a Gurney flap (1% to 3%). According to Jain et al., “Lift enhancement is achieved for greater heights but at the expense of increased drag. The rate of lift increment decreases for greater heights and drag increases rapidly for $H > 2\%$.”⁵

The main reason for the larger flaps was concern that they could be adequately printed in a small scale. The canard chord was 18.86 mm and the Gurney 2 flap height was only 1 mm on each side. Fabrication of smaller flaps can be attempted if further testing is performed.

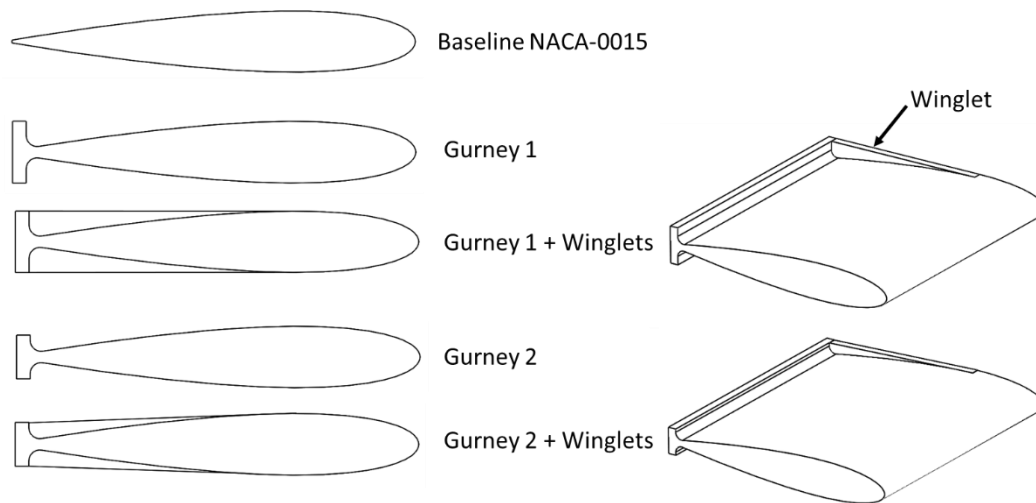


Fig. 7 Experimental canard profiles

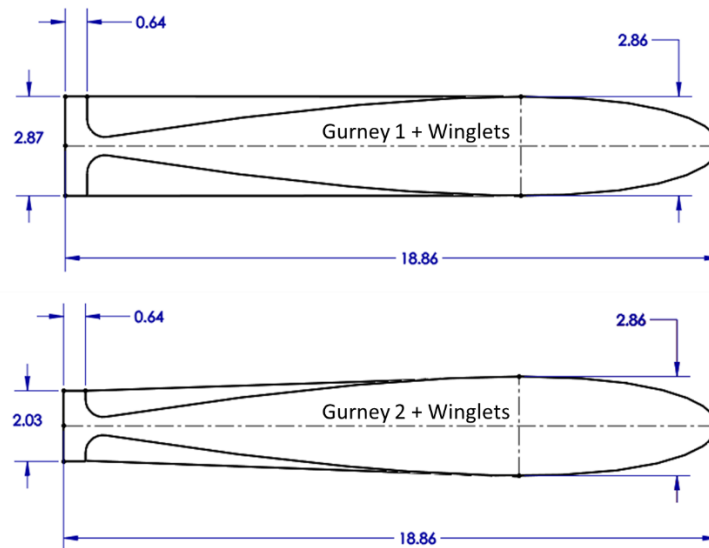


Fig. 8 Canard dimensions (mm)

A simple winglet or wing tip fence was also fabricated in addition to the standard Gurney flap. This can be seen in Figs. 7 and 8. It basically fills in the space between the Gurney flap and the canard profile at the wing tip. The purpose was to both improve the structural rigidity and to potentially reduce wingtip vortices to some extent.

No attempt was made to isolate canard forces in this current round of experiments; there was no body-alone configuration. The purpose was to get an initial comparison of the baseline canard to canards with Gurney flaps to see if there was a substantial difference in performance that would warrant further investigation.

6. Wind Tunnel Results

Figure 9 shows the measured lift coefficient versus angle of attack for the different configurations. Drag and lift coefficients are calculated based on the wind tunnel model body diameter (26 mm). It is immediately obvious that the baseline canard performance is significantly different from that of the various Gurney flap configurations. At low angles of attack the lift curve slope is steeper for the baseline canard. Above stall (at about 9°) the lift of the baseline canard drops slightly and then plateaus at a constant value. The lift for the Gurney flap canards continues to increase with angle of attack after the baseline canard has stalled, although there is a change in slope of the lift curve. This results in a post-stall lift increase of up to 50% over the baseline canard when Gurney flaps are added.

The differences between the various Gurney configurations are not as large as the difference from the baseline. Also, they do not exhibit completely consistent behavior when comparing positive and negative angles of attack. One would expect to see symmetry in the measurements since the models were symmetrical. Some of this effect could be due to the use of an oversized balance. The peak normal force measurements were only 2.5% of the balance capacity, so it is likely that the signal-to-noise ratio of the readings is low.

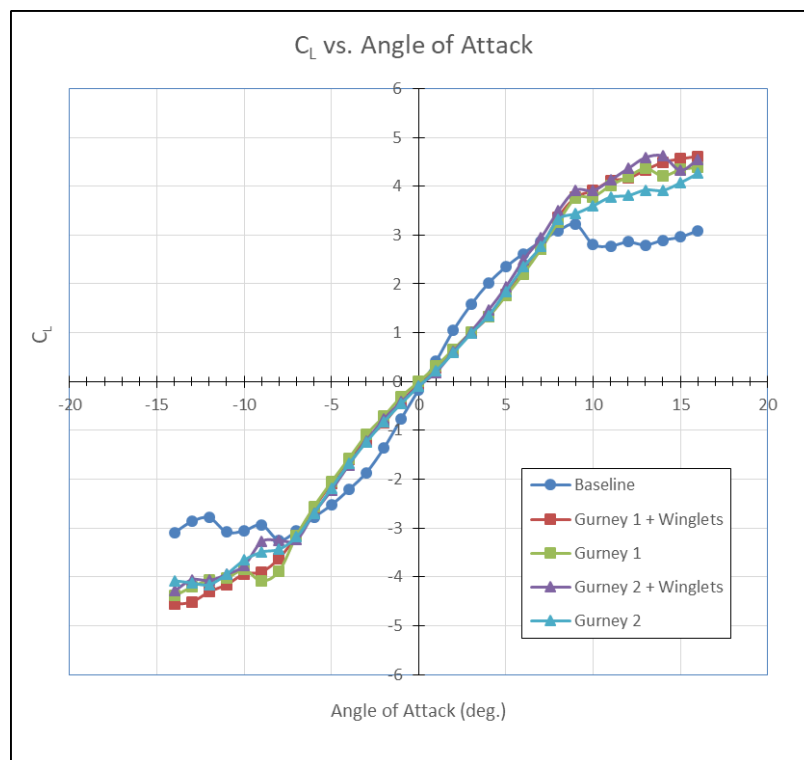


Fig. 9 Coefficient of lift vs. angle of attack as measured in wind tunnel ($M = 0.16$)

Drag force was also measured and the coefficient of drag is shown in Fig. 10. The quality of the readings was significantly less consistent than the normal force readings. There is a large asymmetry between positive and negative angle of attack values for each configuration. The axial force was approximately 0.5% of balance capacity so the readings could be approaching the measurement resolution. There could also be some unaccounted for factor in the test setup. However, the curves do show an overall trend in that the baseline canard has consistently lower drag than the Gurney flap configurations. Also, the Gurney 2 drag is lower than the Gurney 1. Note that no drag data were obtained for the “Gurney 2 + Winglets” configuration due to instrumentation problems.

The lift-to-drag (L/D) ratio is shown in Fig. 11, although it is contaminated by the questionable drag data. The L/D data are presented solely to show some general trends. For the Gurney flap configurations the L/D ratio was lower than the baseline canards until stall, after which the values converged.

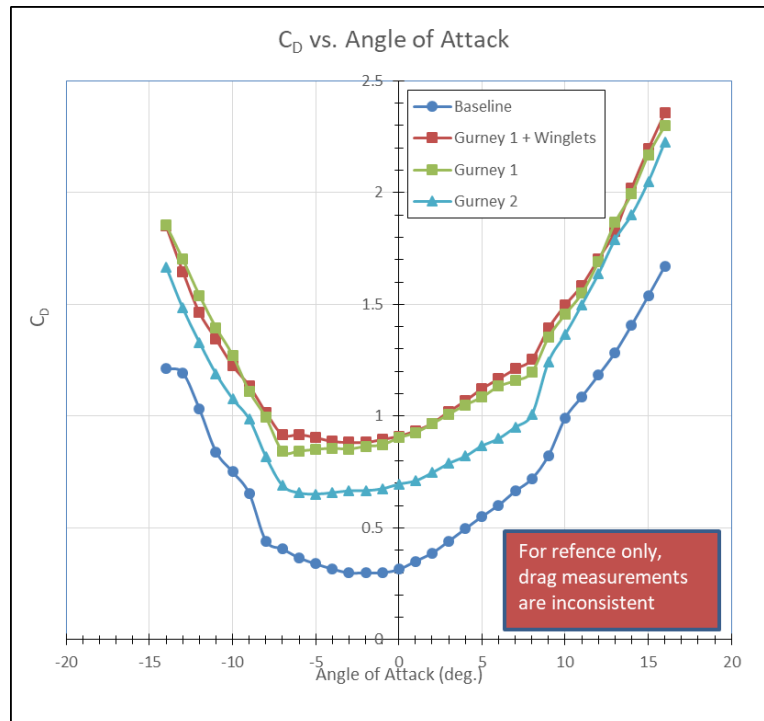


Fig. 10 Coefficient of drag vs. angle of attack ($M = 0.16$, shown for reference only; drag measurements are inconsistent)

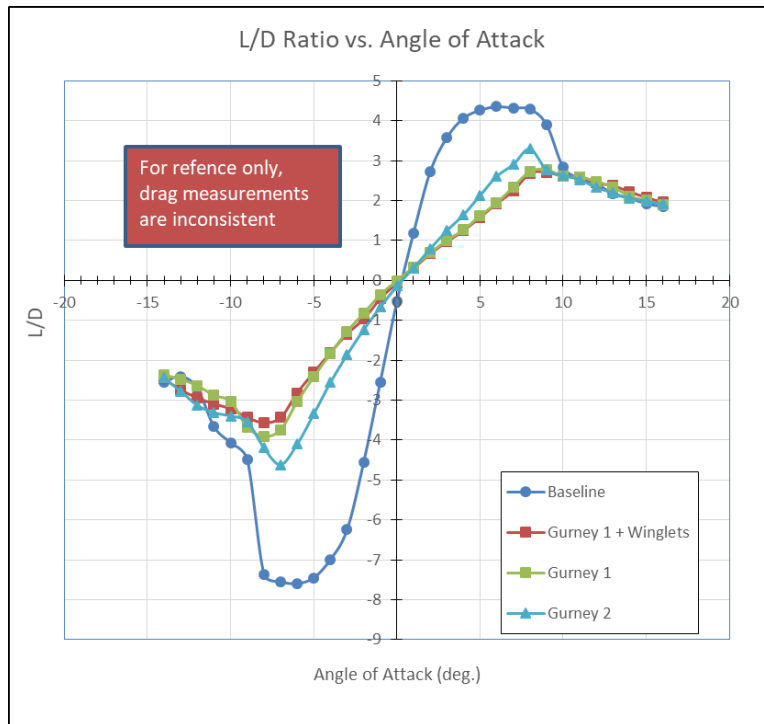


Fig. 11 L/D ratio vs. angle of attack ($M = 0.16$, shown for reference only; drag measurements are inconsistent)

7. Summary, Conclusions, and Future Work

The stated goal of this round of experiments was to explore whether or not adding a Gurney flap to a canard blade would be advantageous. The results have shown that there is a substantial performance difference when a Gurney flap is added to a canard blade. There is a difference in lift slope at low angles of attack, with the Gurney flap canards exhibiting a lower slope. This may be advantageous from a control perspective in that a small change in canard angle (e.g., going from 1° to 1.5°) results in a smaller body response, thereby reducing the effective gain or sensitivity of the system.

The Gurney flap canards continue to provide increasing lift after stall, whereas the baseline canard lift drops off and plateaus. The Gurney flap canard lift is up to 50% higher than the baseline after stall. This means that the projectile can be better controlled at large angles of attack, resulting in increased maneuverability.

The lift-to-drag ratio of the Gurney flap canards is lower than the baseline, which is not desirable. However, the significance of this effect is mitigated by the fact that the canard contribution to the overall projectile drag is relatively small. The combined drag of the four baseline canards on the HMA is on the order of 5% of the total HMA drag.

Last but not least, the addition of Gurney flaps provides a substantial improvement to the physical robustness of the canard trailing edge, while also increasing the canard stiffness.

The preliminary results suggest some further explorations of Gurney flaps on canards:

- Additional wind tunnel testing with a lower capacity, higher resolution balance, including a body alone configuration to isolate canard contributions.
- Wind tunnel measurements of additional Gurney flap geometries.
- Wind tunnel experiments to measure canard torque and center of pressure location to see how these are affected by the Gurney flaps, as described in Bryson et al.⁶
- Computational investigation of the flow details on Gurney flap canards.
- Exploration of fabrication resolution limits. (How small can Gurney flaps be fabricated?)

8. References

1. Lombardi F. Tail feathers and the Gurney flap. Rotor & Wing International; 2012 Apr 1 [accessed 2018 Oct 15]. <https://www.rotorandwing.com/2012/04/01/tail-feathers-and-the-gurney-flap>.
2. Neuhaert D, Pendergraft O Jr. A water tunnel study of Gurney flaps. Greenbelt (MD): National Aeronautics and Space Administration; 1988 Nov [accessed 2018 Oct 15]. NASA Technical Memorandum 4071. <https://ntrs.nasa.gov/search.jsp?R=19890004024>.
3. Cavanaugh M, Robertson P, Mason W. Wind tunnel test of Gurney flaps and T-strips on an NACA 23012 Wing. 2007 June. AIAA 2007-4175.
4. Fresconi F, Celmins I, Sifton S, Costello M. High maneuverability projectile flight using low cost components. Aerospace Science and Technology. 2015;41:175–188.
5. Jain S, Sitaram N, Krishnaswamy S. Computational investigations on the effects of Gurney flap on airfoil aerodynamics. Hindawi Publishing Corporation International Scholarly Research Notices; 2014 Dec [accessed 2018 Oct 15]. <http://dx.doi.org/10.1155/2015/402358>.
6. Bryson J, Celmins I, Fresconi F. Aerodynamic model for canard control actuation on a subsonic, gun-launched munition. Aberdeen Proving Ground (MD): Army Research Laboratory (US); 2018 Sep. Report No.: ARL-TR-8496.

List of Symbols, Abbreviations, and Acronyms

HMA	High Mobility Airframe
L/D	lift-to-drag
Q-CAS	Quad-Canard Actuation System

1 DEFENSE TECHNICAL
(PDF) INFORMATION CTR
DTIC OCA

2 DIR ARL
(PDF) IMAL HRA
RECORDS MGMT
RDRL DCL
TECH LIB

1 GOVT PRINTG OFC
(PDF) A MALHOTRA

1 ARL
(PDF) RDRL WML E
I CELMINS