Guided Munitions for Aerial Gunnery; Increased Mission Effectiveness and Large Cost Savings

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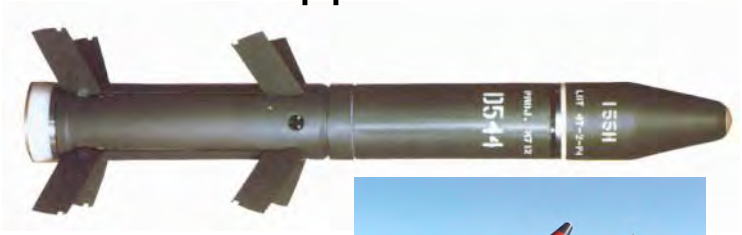
- Introduction
  - Guided Hard Launch Munitions (GHLM)
- Concept of Operations
- Aerial Applications
  - F-15
  - FAC-130
  - F-35
- Future Work

M712 Copperhead 1975



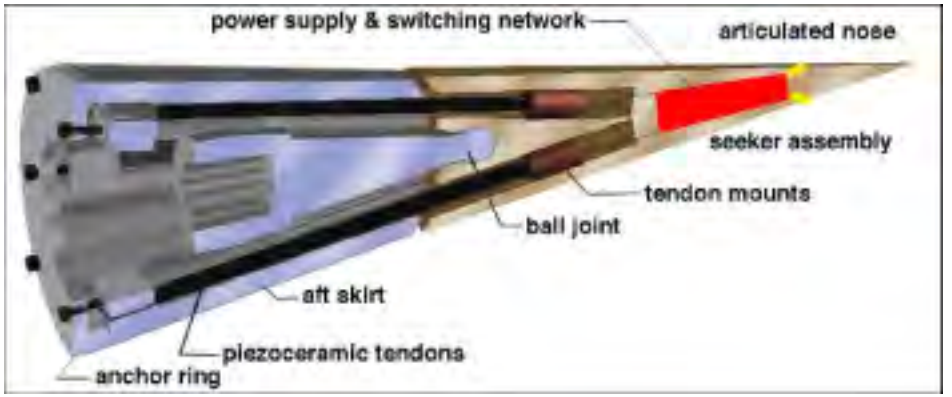
XM 982 Excalibur
& ERGM

Barrel-Launched Adaptive Munition (BLAM) Program 1995 - ’97

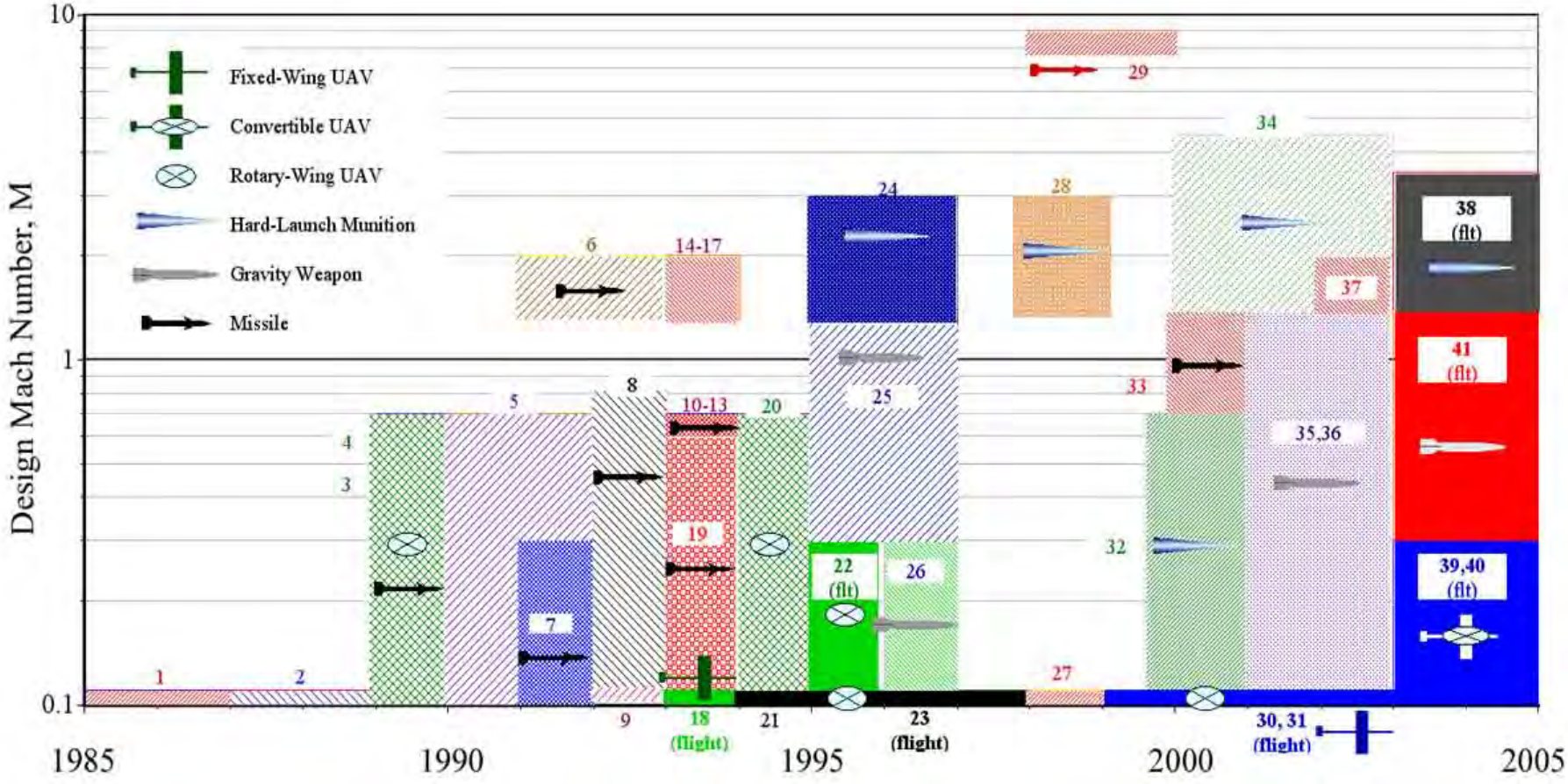
USAF/AFRL-MNAV

- Aerial Gunnery (20 - 105mm)
- Extend Range w/2g maneuver
- (Eglin AFB tests ‘97)

  (Mach 3.3 tests ‘96-’97)
- Increase hit probability
- Increase probability of a kill given a hit
- Reduce total gun system weight fraction



AAL: Building Adaptive Actuators for Hard-Launch Munitions since 1995

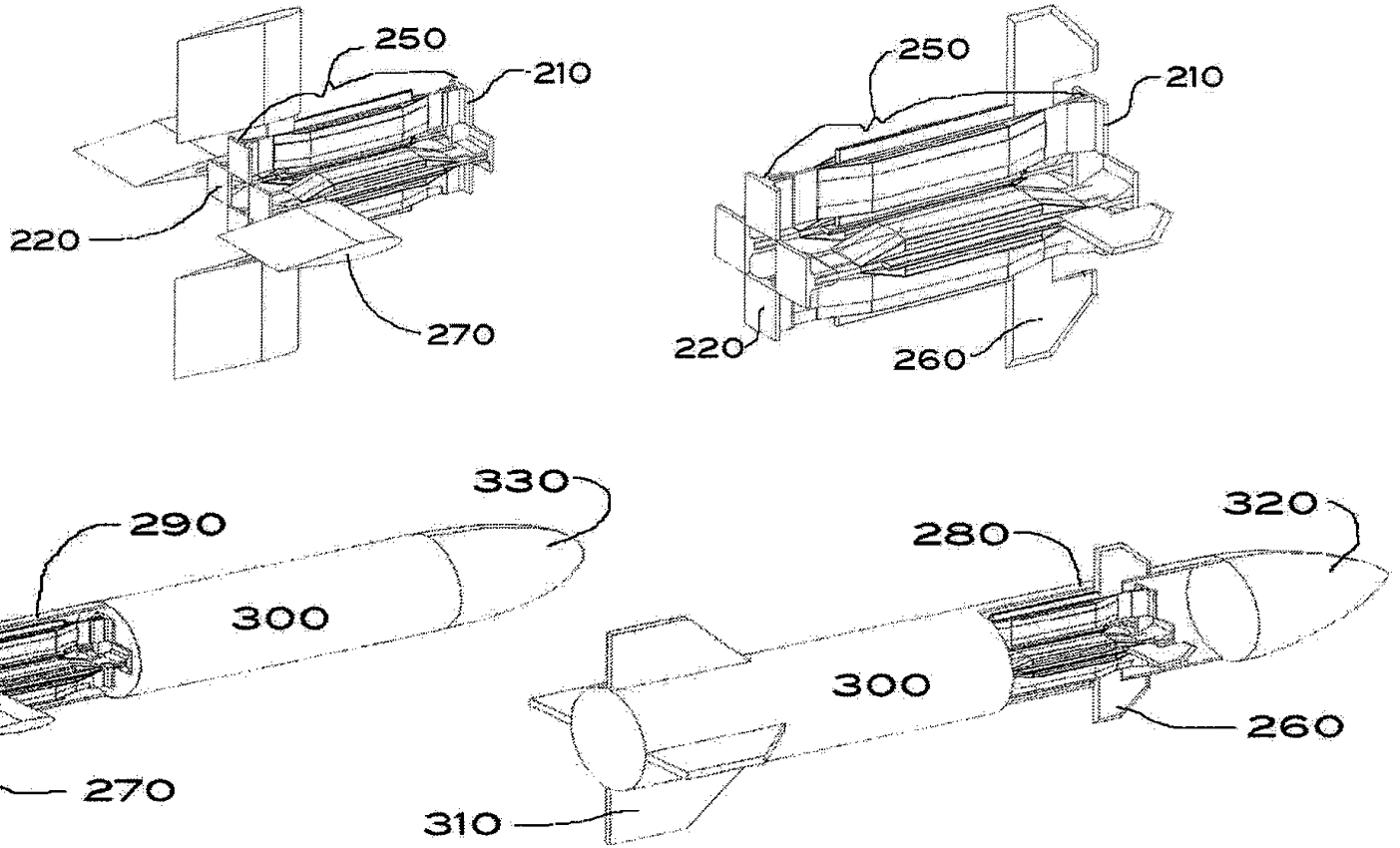


Historic Guided Hard-Launch Munitions

- Copperhead: 155mm, USA Armament Research
  - 1970's indirect fire against hardened targets
- Adaptive Guided Munitions Programs
  - Barrel Launched Adaptive Munition (BLAM), 1995, conical round, USAF Armament Directorate
  - Hypervelocity Interceptor Test Technology (HITT), 1998, USA Space and Missile Defense Command
  - Range-Extended Adaptive Munition (REAM), 1998, sniper round, derivative—SCREAM, USA Armament Research, Development, and Engineering Center
  - Light Fighter Lethality Adaptive Round (LFLAR), subsonic, USA Armament Research
- Extended Range Guided Munition (ERGM), Raytheon
  - Rocket Assisted Projectile (RAP), 5 in diameter, 13-54nmi (Cancelled)
- Extreme Accuracy Tasked Ordnance (EXACTO), DARPA
  - DARPA initiative, small caliber guided sniper round, live fire tests in 2015
- M982 Excalibur, Raytheon
  - 155mm GPS and inertial guided munition for close-support
- Multi-Azimuth Defense Fast Intercept Round Engagement System (MAD-FIRES), DARPA
  - DARPA initiative, medium caliber guided rounds

AAL: Issued patents & 2 decades of test data up to: Mach 11, 1kHz, 100,000g's

PBP-Class Hard-Launch Capable Full-Proportional Actuator FCS Units:



Application to Aerial Platforms: Retrofit

- Increased Number of Targets
- Expanded Engagement Range Envelope
- Airframe Defense with Maneuver Overmatch
- Decreased Cost per Kill

Guided Hard-Launch Munitions
0-100+ mi

- Reduced Observables (RF, IR & Acoustic)
- Increased Airframe Performance
  - Reduction in platform weight, wetted area, and total volume

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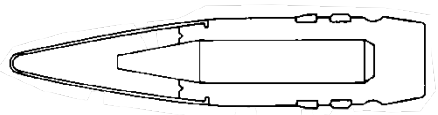
- Energy based analysis: interior and terminal ballistics
- 6 DOF ballistic model
- Simplified intercept in simulated atmosphere

$$\Phi_w(\omega) = \frac{2\sigma_w^2 L_w}{\pi V} \frac{\left(1 + \frac{8}{3} * \frac{2.678 L_w \omega}{V}\right)^2}{\left(1 + \left(\frac{2.678 L_w \omega}{V}\right)^2\right)^{\frac{11}{6}}}$$

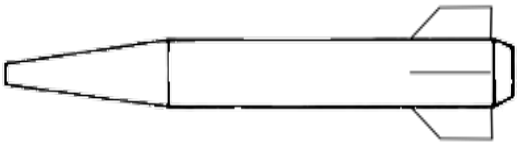
$$\frac{d\bar{V}}{dt} = -\frac{\rho V S C_D}{2m}\bar{V} + \frac{\rho S C_{L_\alpha}}{2m}(V^2\hat{x} - (\bar{V}\cdot\hat{x})\bar{V}) + \bar{g}$$

$$\frac{d\bar{h}}{dt} = \frac{\rho V S d^2 C_{l_p}}{2I_y}(\bar{h}\cdot\hat{x})\hat{x} + \frac{\rho V^2 S d \delta_F C_{l_\delta}}{2I_y}\hat{x} + \frac{\rho V S d C_{M_\alpha}}{2I_y}(\bar{V}\times\hat{x})$$

- Increase impact kinetic energy at Effective Range:
  - PGU-14 E_{impact}/E_{muzzle} ~ 51%

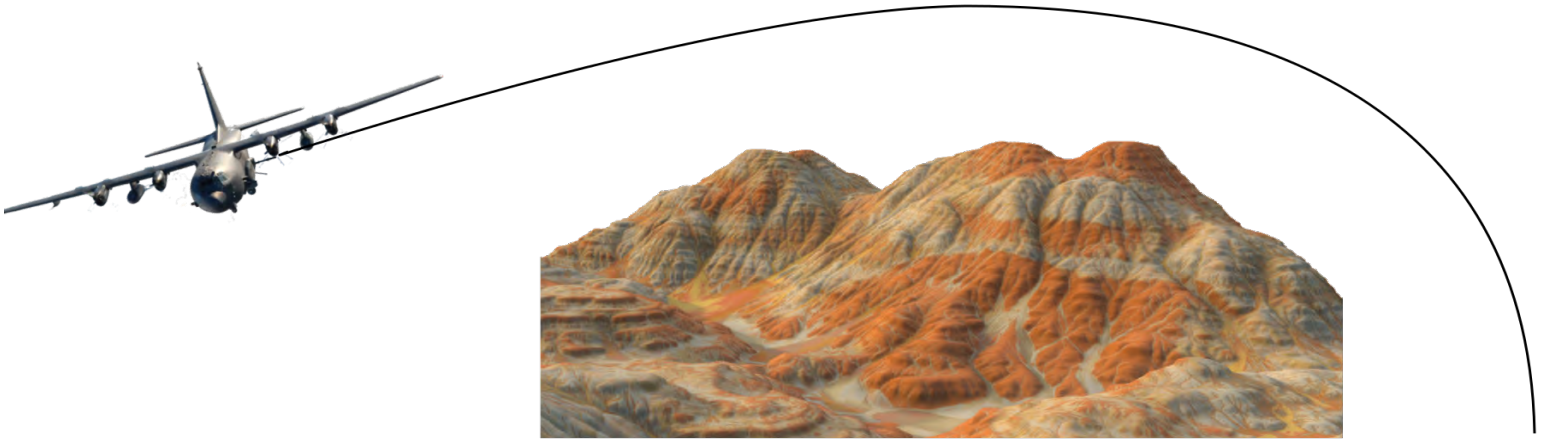


  - MASS GHLM E_{impact}/E_{muzzle} ~ 89%



- MASS Guided Variants

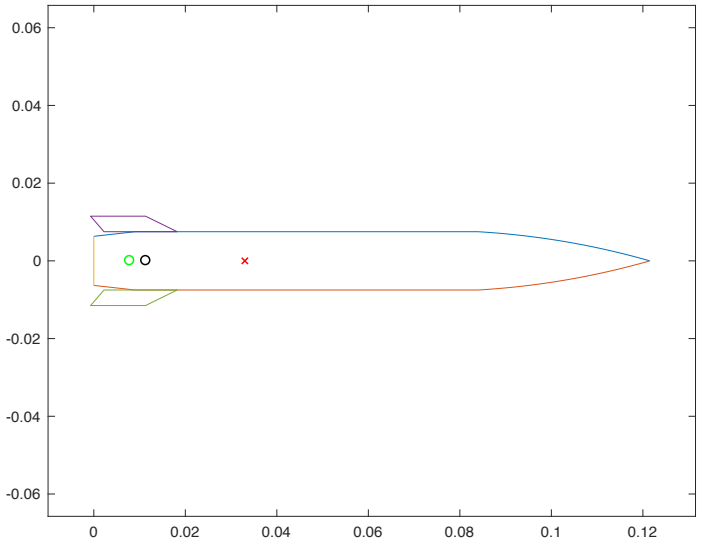
- MASS Guided Indirect Fire
  - Semi-ballistic path
  - Terminal Guidance

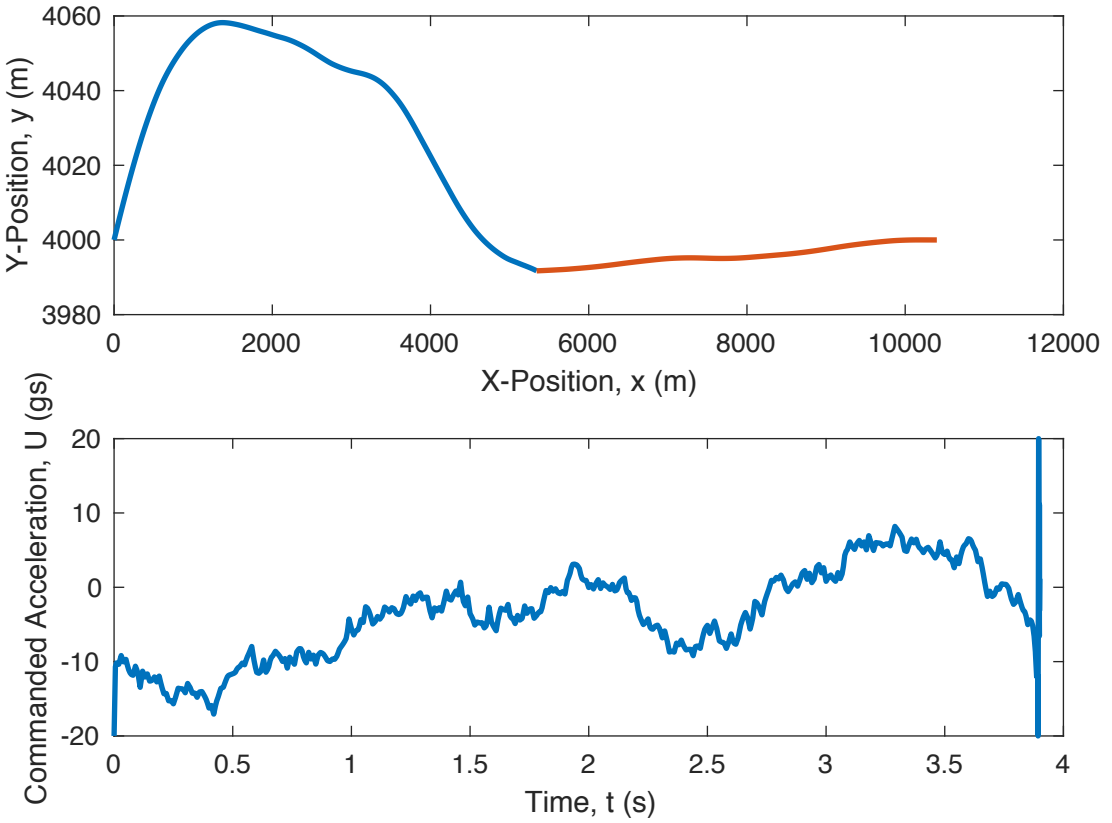


- MASS GHLM IR defense
  - Flying “flare”
- MASS GHLM RF defense
  - Kinetic kill
  - Proximity with debris field

Concept of Operations: Defensive Overmatch

- Maneuver Specification
- Simulated R-77 intercept

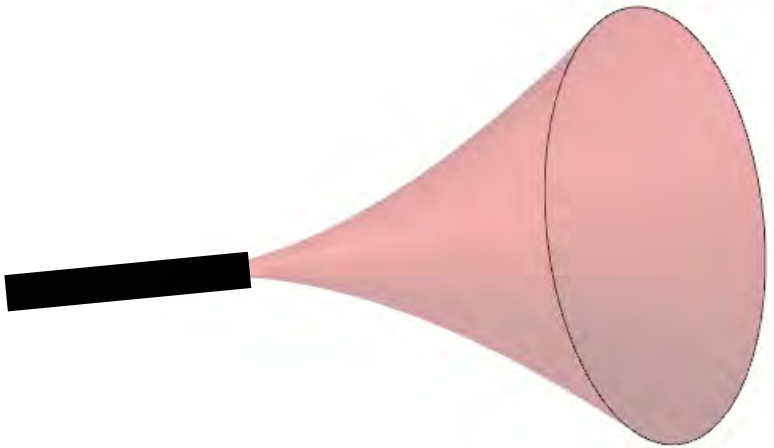




- P_k estimation
  - Cost/kill of MASS GHLM < conventional missile

- Miss radius estimation

$$N = \frac{\ln(1 - P_{k,desired})}{\ln(1 - P_{k,projectile})}$$



$$V_{fragment} = \sqrt{2E}\left(\frac{m_{metal}}{m_{charge}} + \frac{1}{2}\right)^{-\frac{1}{2}}$$

F-15 Application

- Existing Loadout
  - 4 x AIM-9
  - 8 x AIM-120
  - 940 x 20mm
- M61 Vulcan retrofit

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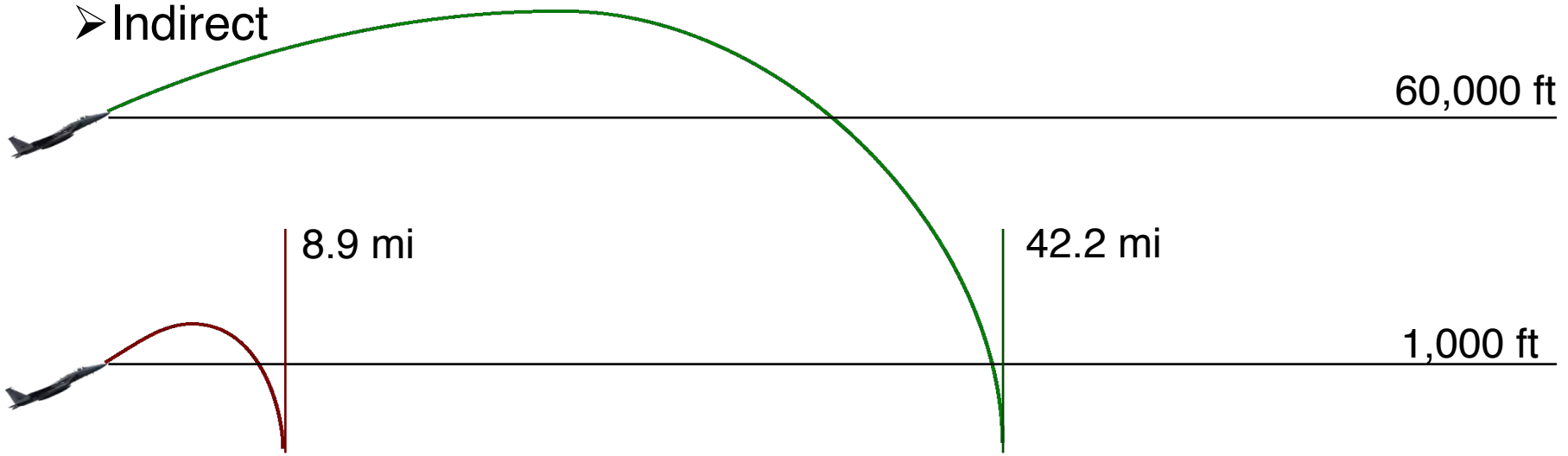
- Simulated retrofit PGU-28 series:
  - Direct fire near sea-level

	PGU-28 A/B	20mm MASS GHLM	% Change
Projectile Mass (kg)	0.11	0.11	~
Effective Range (mi)	1.28	1.90	+48%
Ballistic Coefficient (PGU reference form factor)	1.03	1.87	+81%

  - Indirect



- Existing Loadout AC-130U Spooky II
  - 1 x 25mm GAU-12/U
  - 1 x 40mm L/60 Bofors
  - 1 x 105mm M102

- M102 retrofit

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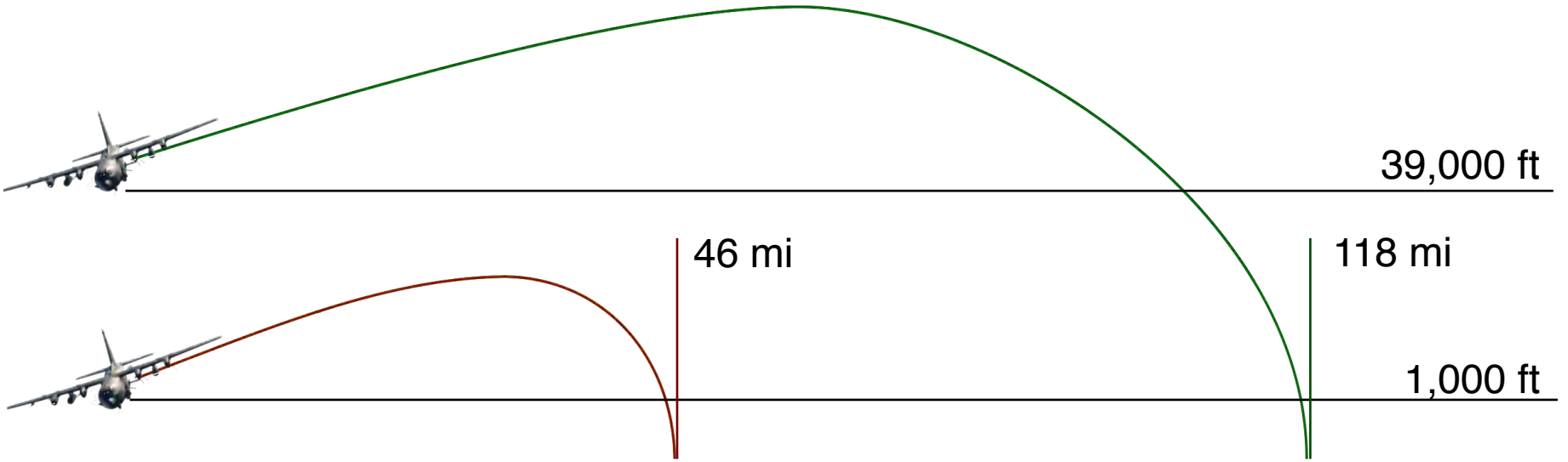
- Simulated retrofit M1 series:
  - Direct fire near sea-level

	M1	105mm MASS GHLM	% Change
Projectile Mass (kg)	18	18	~
Kinetic Energy at Impact (kJ)	607	788	+30%
Ballistic Coefficient (M1 reference form factor)	2.34	3.81	+63%

  - Indirect



- Existing Loadout F-35A
  - 14 x AIM-120
  - 2 x AIM-9
  - 180 x 25mm
- GAU-12/U retrofit

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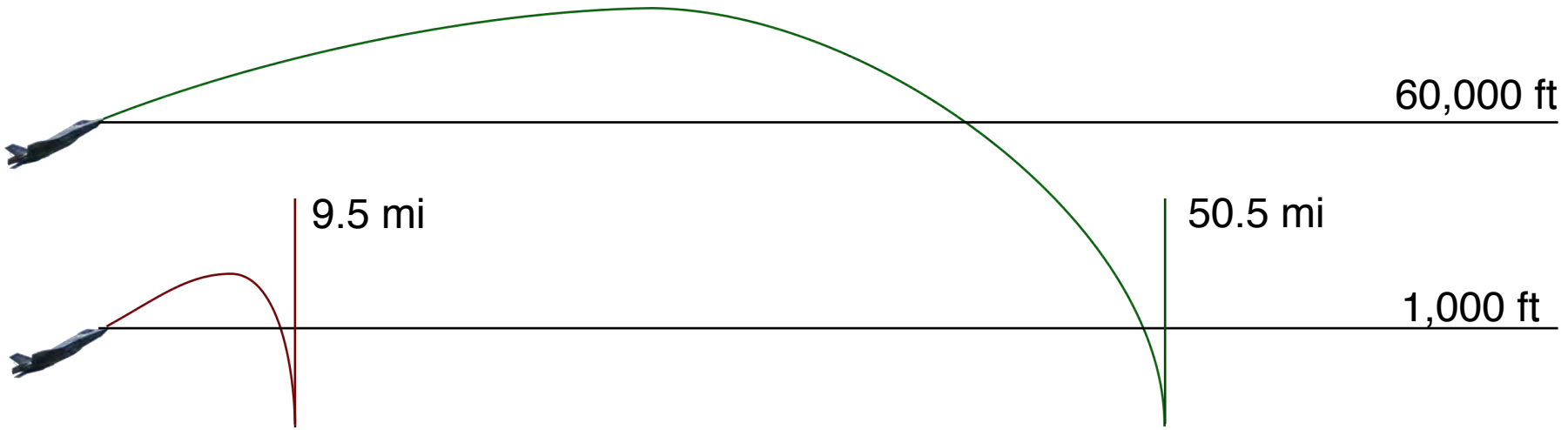
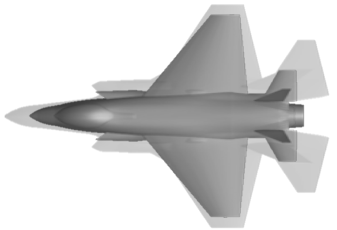
- Simulated retrofit PGU-25 series:
  - Direct fire near sea-level

	PGU-25	25mm MASS GHLM	% Change
Projectile Mass (kg)	0.18	0.18	~
Effective Range (mi)	1.42	2.19	+54%
Ballistic Coefficient (PGU reference form factor)	1.26	2.10	+67%

  - Indirect





- F-35A vs GHLM Equipped Fighter (XF-36)
  - AAA code used for both aircraft, then scaled based on known F-35A procurement cost per airframe. Assumed 1768 airframes at uniform price

Program Level Costs ($ billions)		
	F-35A	XF-36
RDT&E Total	$25.5B	$13.6B
Manufacturing Cost (Program)	$110.4B	$82.2B
Acquisition Cost	$115.9B	$86.3B
Program Operating Cost	$235.5B	$225.5B

Airframe Level Costs		
	F-35A	XF-36
Unit Price (millions)	$ 80.0M	$ 56.5M
Operating Cost per Flight Hour	$ 29,600	$ 28,400

MASS Guided Hard Launch Munition Potential on Aerial Platforms

- Ranges comparable to modern air-to-air missiles
- Expanded engagement range envelope
- Increased number of targets engaged
- Effectively increase caliber of aircraft without retrofit of gunnery system
- Implications for airframe defense and future aircraft design
- Reduced cost/kill
- Enhanced survivability and more rounds allow fewer aircraft to carry out the same mission

Enabling Technology: MASS

- Secure commercial partner for MASS tech. transfer
- Work with commercial partner to capture aerial munitions market

The University of Kansas
Department of Aerospace Engineering

The Madison and Lila Self Graduate Fellowship

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Questions