43RD ANNUAL ARMAMENT SYSTEMS:
GUN & MISSILE SYSTEMS CONFERENCE

Gun-Barrel Vibrations of Rapid-Fire Medium Caliber Guns

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U. S. Naval Academy

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with support from
NAVSEA Naval Gunnery Project Office
and
Naval Surface Warfare Center Dahlgren

I. Background

Barrel Vibrations

- Barrel vibrations can affect accuracy of both slow firing and rapid firing guns by causing positive or negative “muzzle jump”during projectile launch.
- Vibrations can arise from gravity-caused barrel droop or barrel curvature from manufacturing… or both.
- Possible enhanced effect with rapid-fire guns where vibrations from one round continue to exist and can be reinforced by subsequent rounds.

Present Interest

… in rapid-fire *medium-caliber* gun mounts and the effects of barrel vibrations on their accuracy.

Motivation

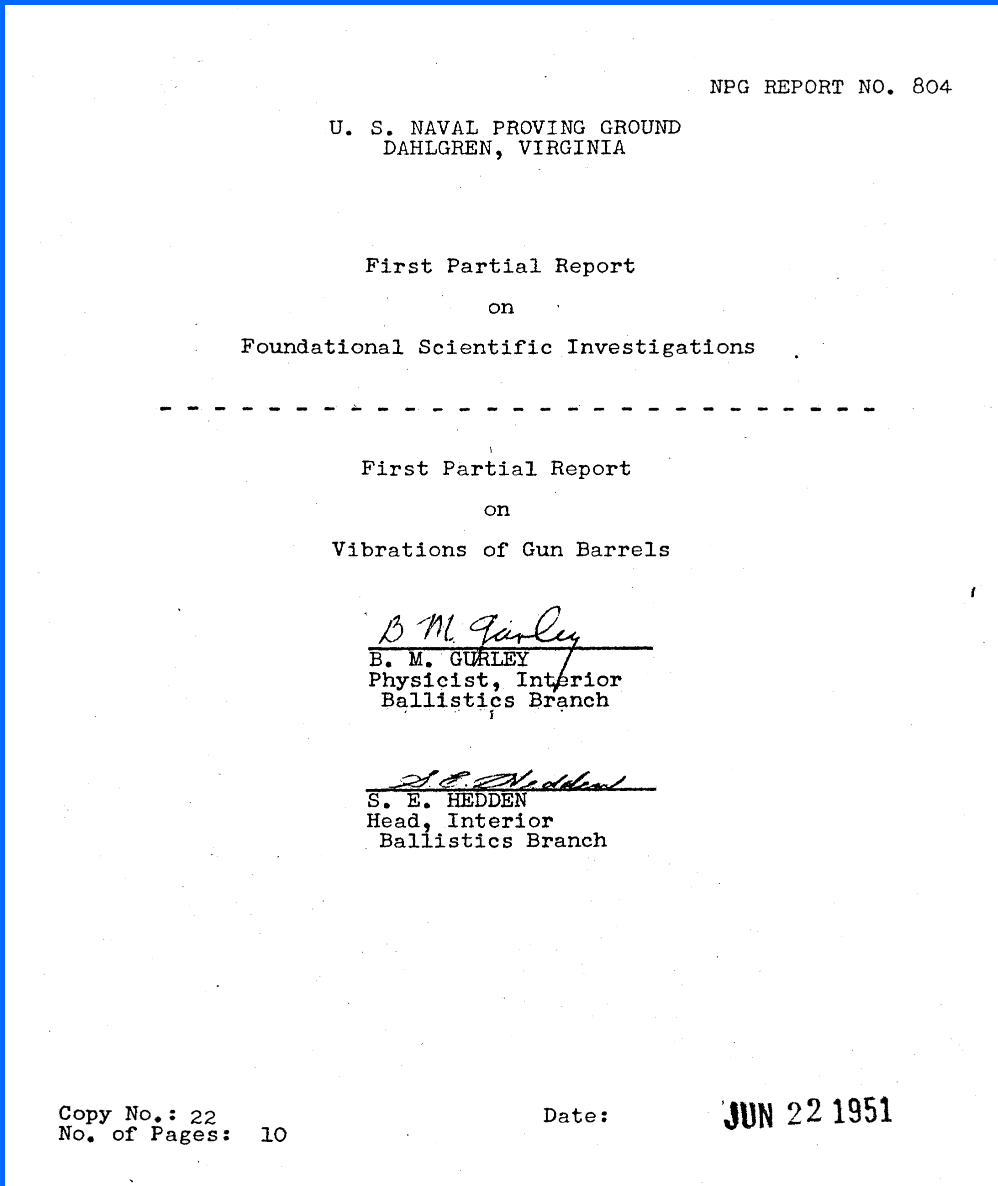
…generated by evaluation and selection of gun mounts for the new Littoral Combat Ships and for other similar Navy needs

Early Navy Work

Near-muzzle barrel vibrations of 3-in/70 Gun Mount during travel of projectile through the barrel

-Single Firings

Dahlgren Report of 1951



NPG REPORT NO. 804

U. S. NAVAL PROVING GROUND
DAHLGREN, VIRGINIA

First Partial Report

on

Foundational Scientific Investigations

- -

First Partial Report

on

Vibrations of Gun Barrels

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Physicist, Interior
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Copy No.: 22
No. of Pages: 10

Date: JUN 22 1951

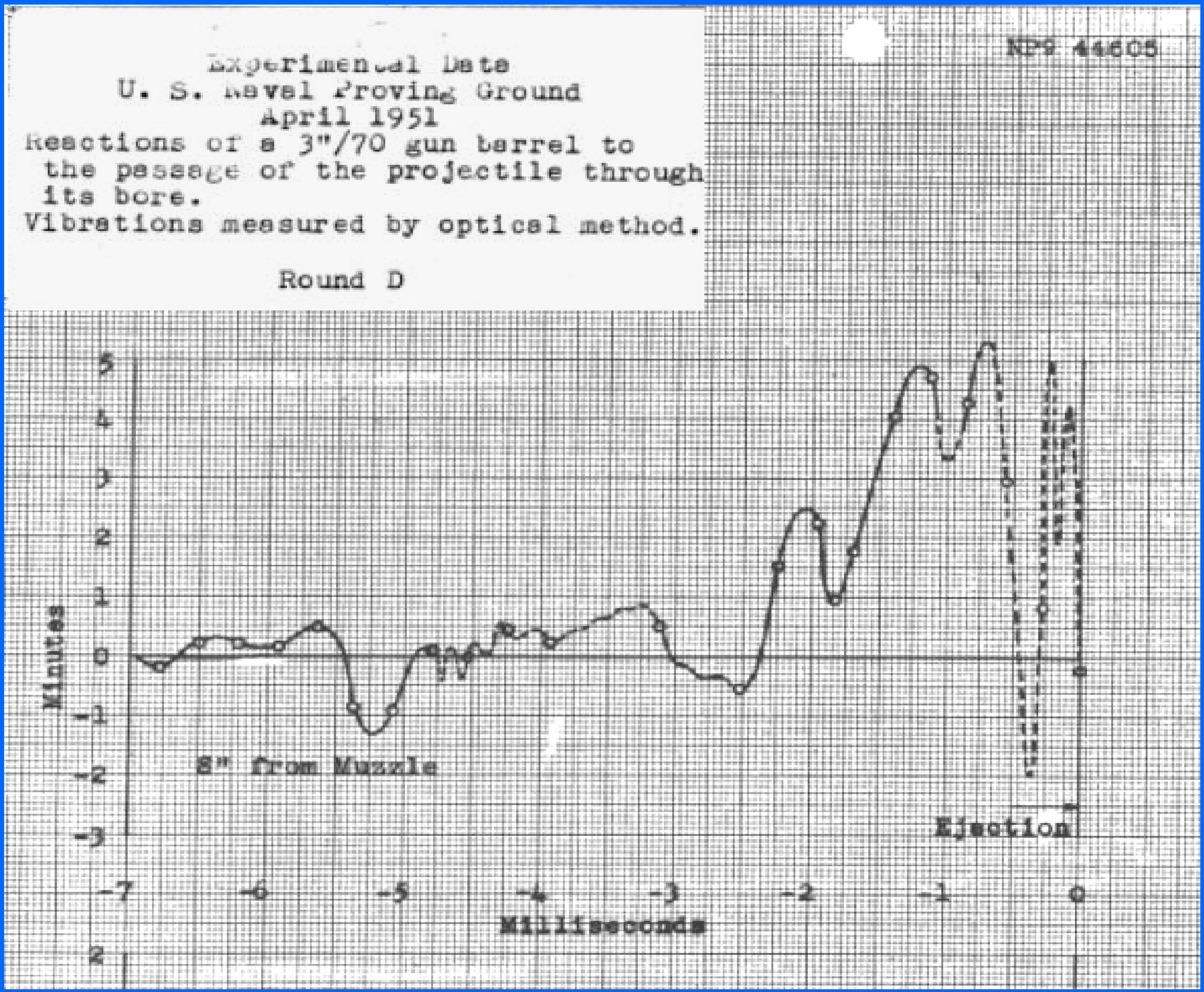
B. M. Gurley

&

S.E. Hedden

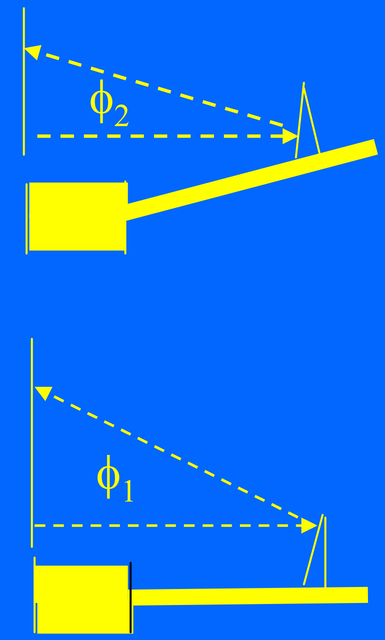
Novel use of optical reflections and “Fastax” camera to measure rotations (slopes) of barrel section near muzzle during projectile launch

…and Early Record of Barrel Vibrations



Section Rotation

$\Delta\phi = \phi_1 - \phi_2$



Early Army Work

- Dispersion of machine-gun fire as influenced by firing rate.
- Increased dispersion measured when firing rate near fundamental barrel vibration frequency - or twice that frequency.
- Basis for design criterion that: *barrel frequency in cycles/sec should generally be 4 (or more) times the firing rate in rounds/sec.*

1955 Report on Barrel Vibrations

AN INVESTIGATION OF THE EFFECT OF THE NATURAL FREQUENCY OF VIBRATION OF THE BARREL UPON THE DISPERSION OF AN AUTOMATIC WEAPON

U. S. ARMY ORDNANCE EXPERIMENT STATION

PURDUE UNIV LAFAYETTE IN

01 APR 1955

D. E. Wente

R. L. Schoenberger

B. E. Quinn

Contract No. DA 11-022-ORD-38

Ordnance Corps Project No. TS3-3039

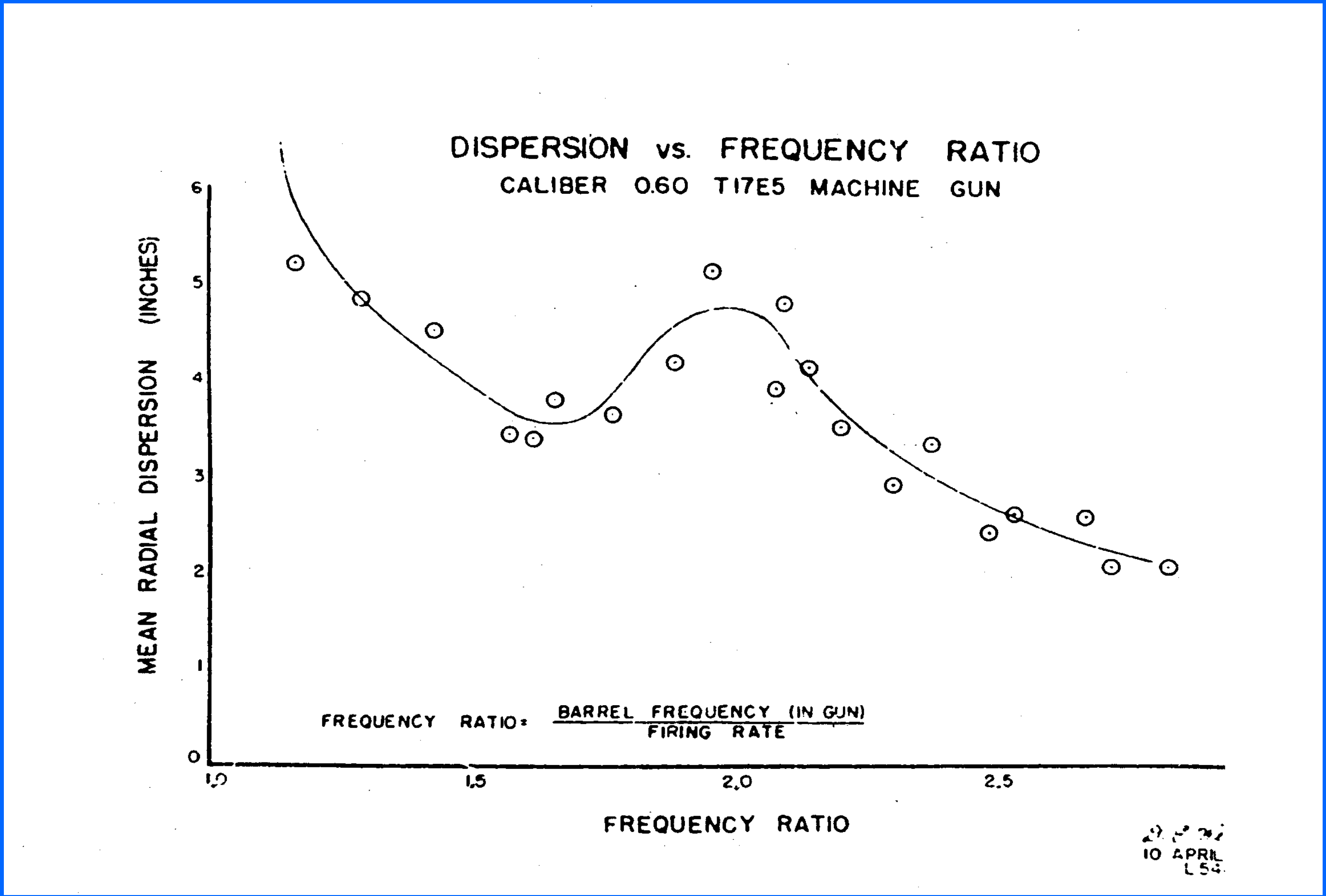
D. E. Wente

R. L. Schoenberger

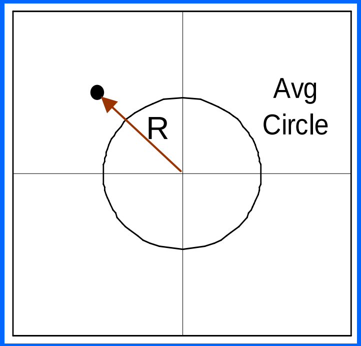
B. E. Quinn

First study of dynamic amplification of barrel vibrations from “tuned” firing rates

Dynamic Amplification of Barrel (from 1955 Army Report)



Dispersion



Barrel curvature from manufacture

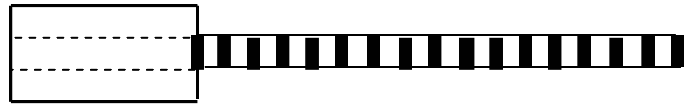
Previous Numerical Work on Barrel Vibrations

Numerical studies were carried out at the Army's Watervliet Arsenal during 1970's (and onward) *with attention restricted to barrel vibrations before projectile exit: No multiple firings.*

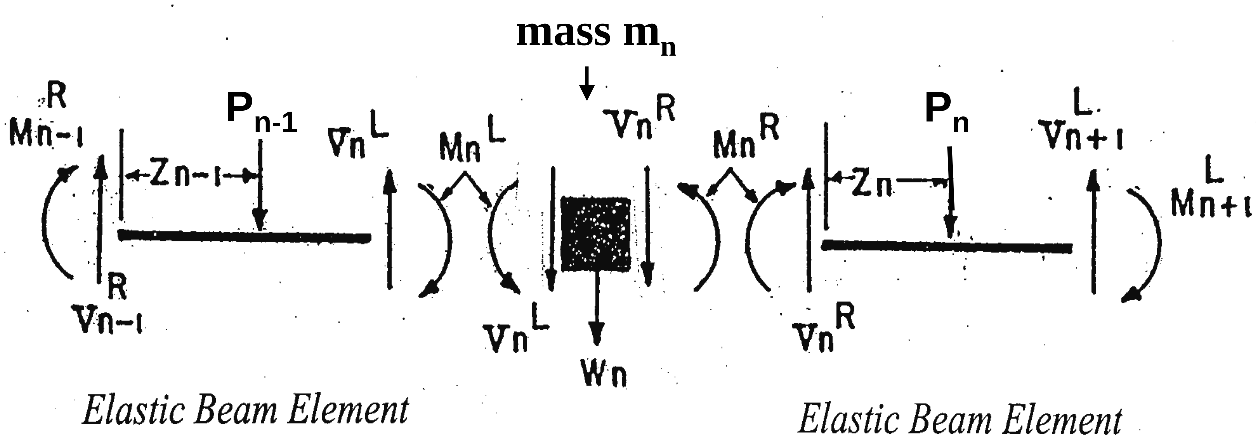
II. Computer Model

Lumped-Mass Model & Mechanic

V's & M's depend on v's at n-1, n, n+1 & projectile load P (if between n-1 and n+1)



16 mass model



Governing Equations for Deflection v_n of Mass m_n

If P between n-1 and n
P_{n-1} = F
Otherwise 0

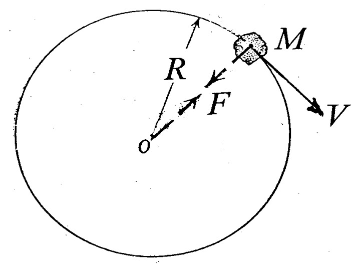
$$m_n \frac{d^2 v_n}{dt^2} = -(V_n^L + V_n^R) - w_n$$

$$M_n^L + M_n^R = 0$$

If P between n and n+1
P_n = F
Otherwise 0

Projectile Forces on Barrel

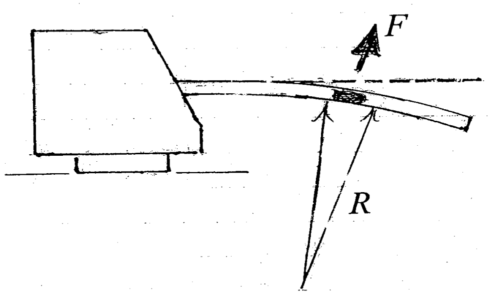
Centrifugal Forces



Constant radius

$$F = \frac{MV^2}{R}$$

Simple Example

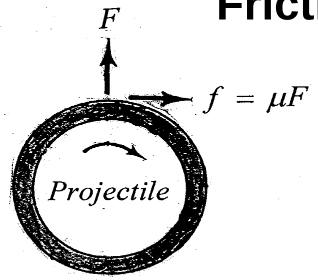


Instantaneous radius of curvature

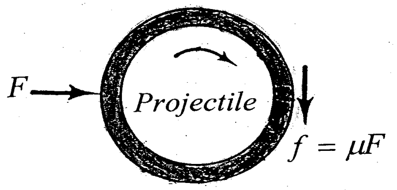
$$F = MV^2 \frac{\partial^2 y}{\partial x^2}$$

Actual Case

Friction Forces



Vertical Centrifugal Force



Horizontal Centrifugal Force

Typical

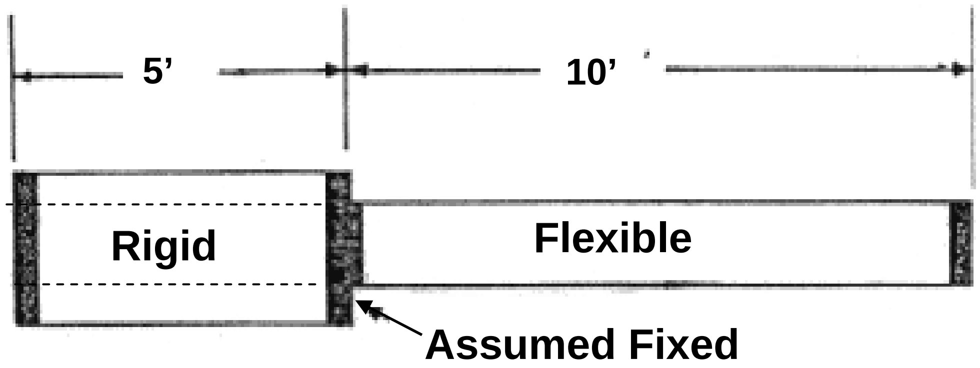
Coeff of Friction

$\mu \approx$ 0.20 to 0.30

III. “Generic” 3in /60 Gun Mount (Firing 14 lb Projectiles)

Generic Barrel

Barrel (No attachments)



Flexible Length

Inside Dia = 3 in

Outside Dia = 4 in

vibration frequencies

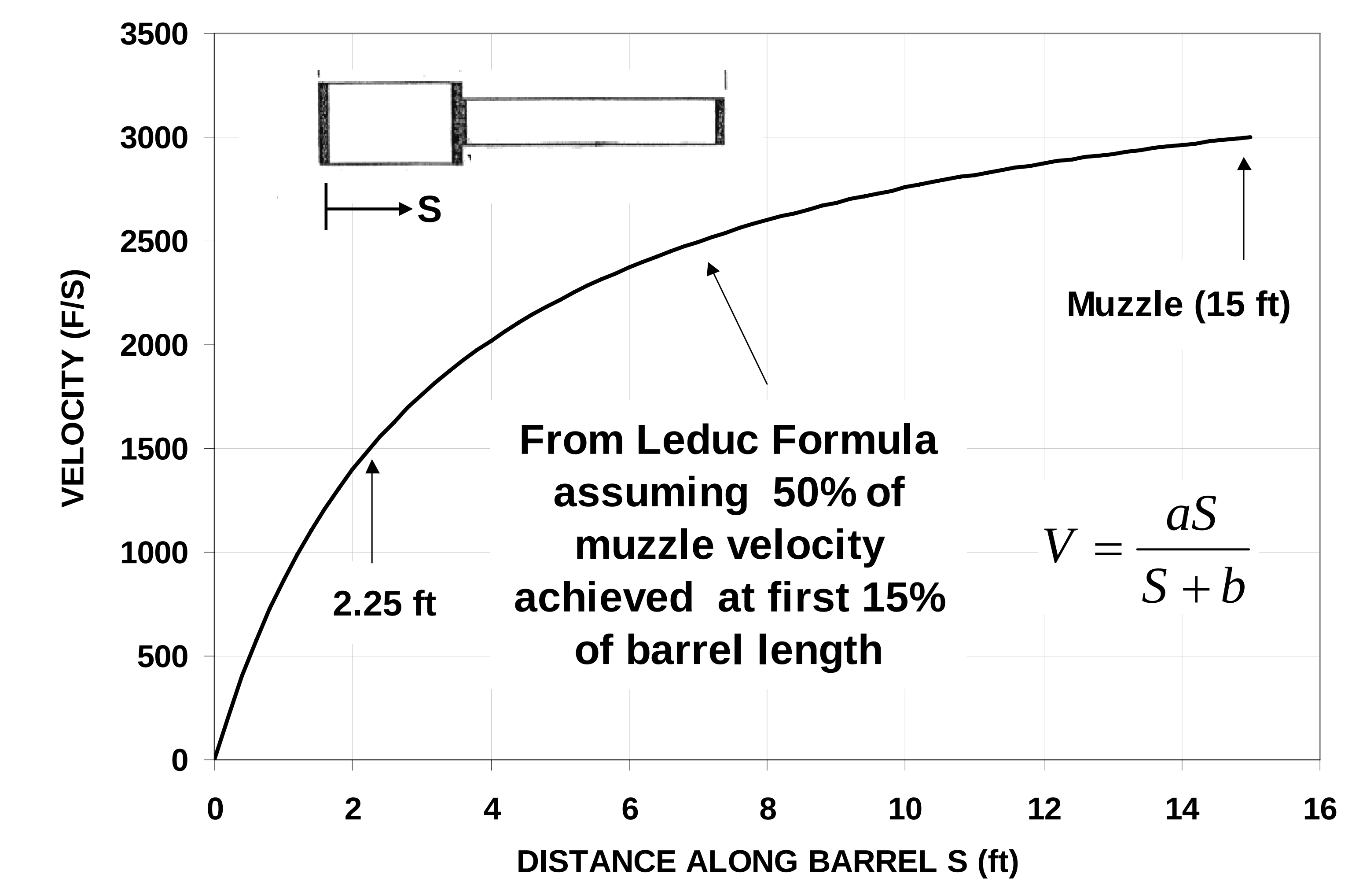
$\omega_1 = 62.0$ rad/sec = 9.87 cycles/sec

$\omega_2 = 387$ rad/sec = 61.6 cycles/sec

etc

Flexible section divided into 16 lumped masses. Accuracy checked by increasing number to 32 and then to 48 …
as shown in the following

Assumed Projectile Velocity in Barrel

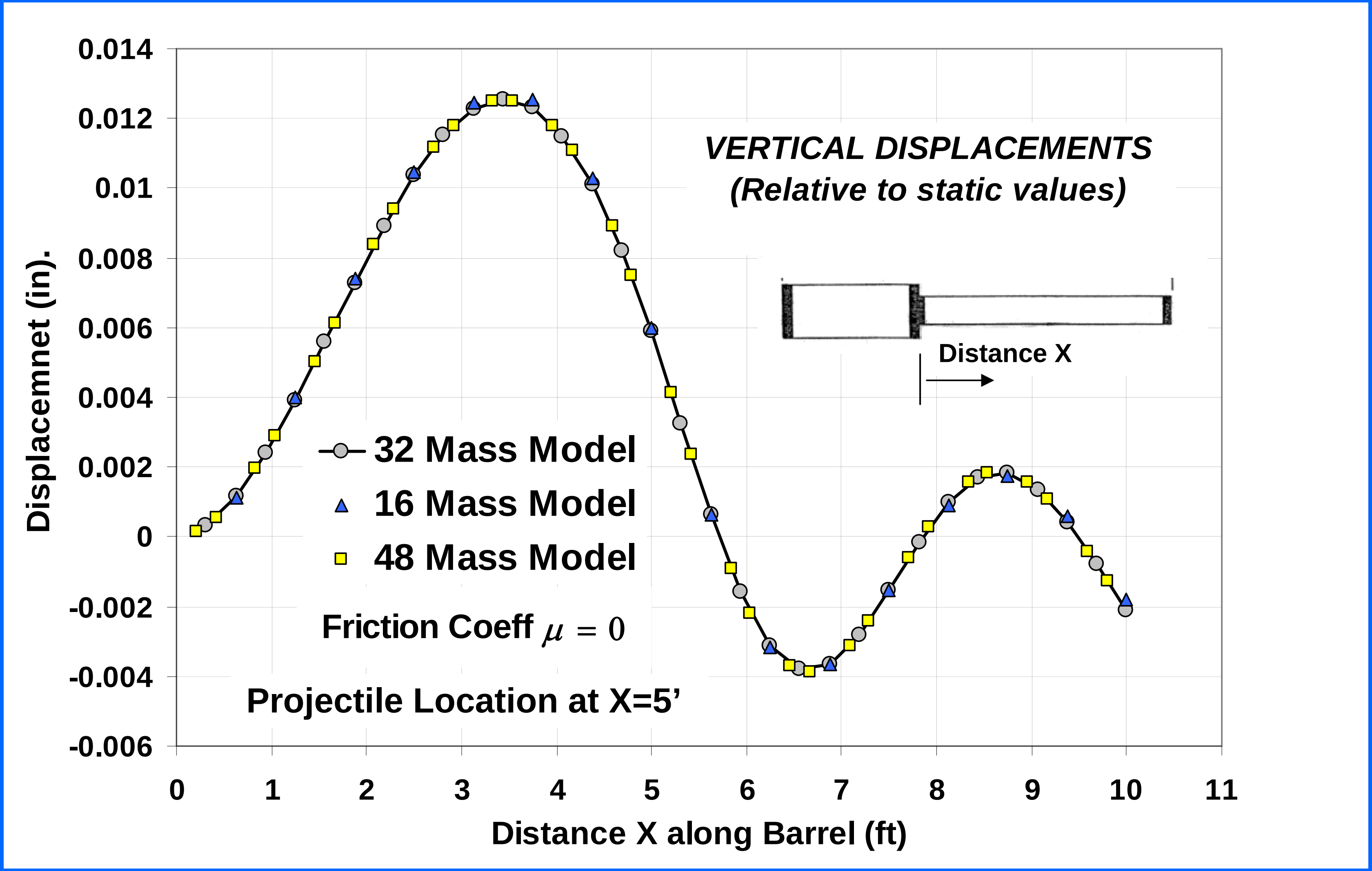


Demonstration of Adequacy of Lumped-Mass Model

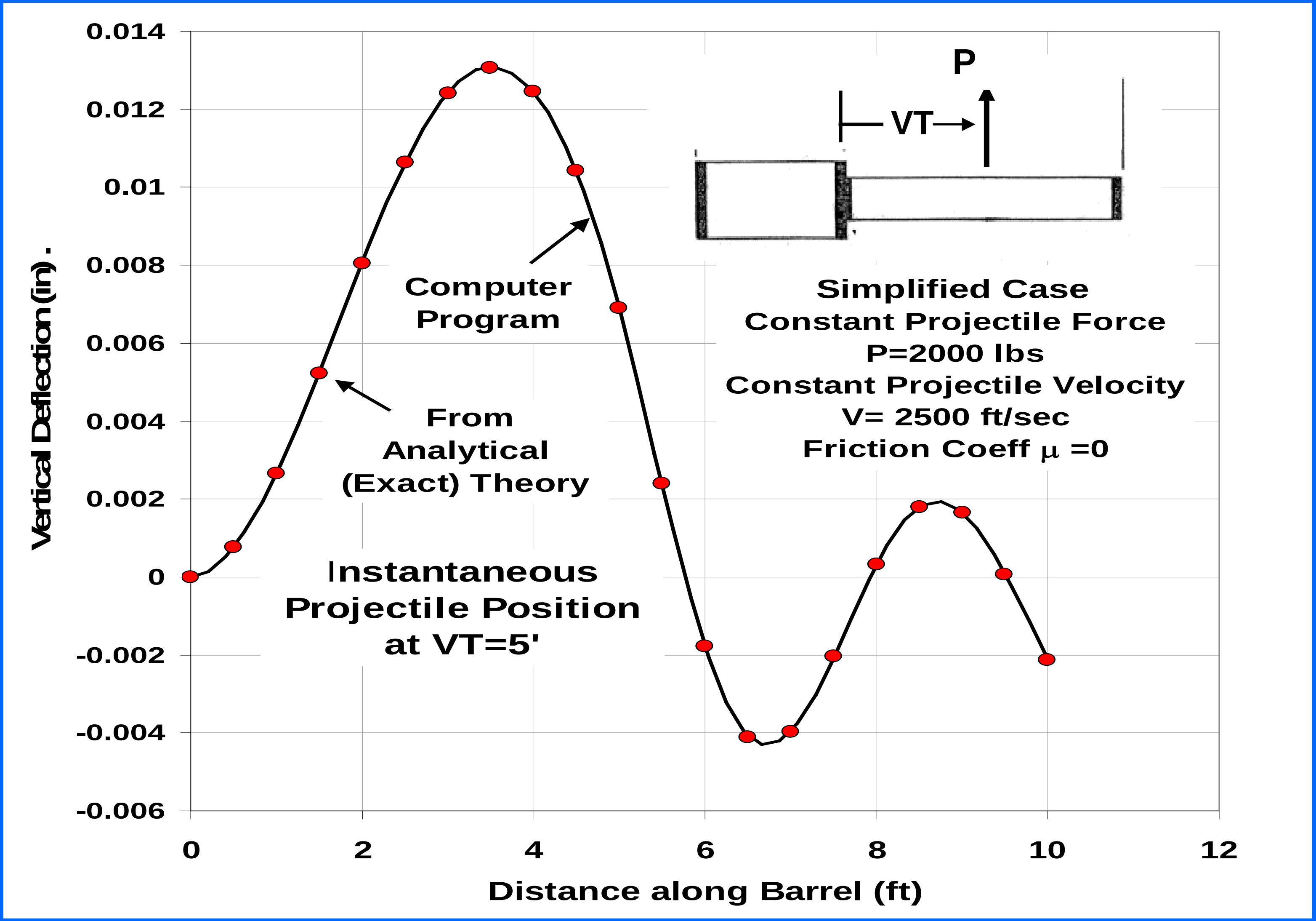
- Idealized Case-

Negligible Friction between Spinning Projectile and Barrel

Convergence with number of mass elements



Adequacy of Computer Solution



Detailed Results
-Actual Case-

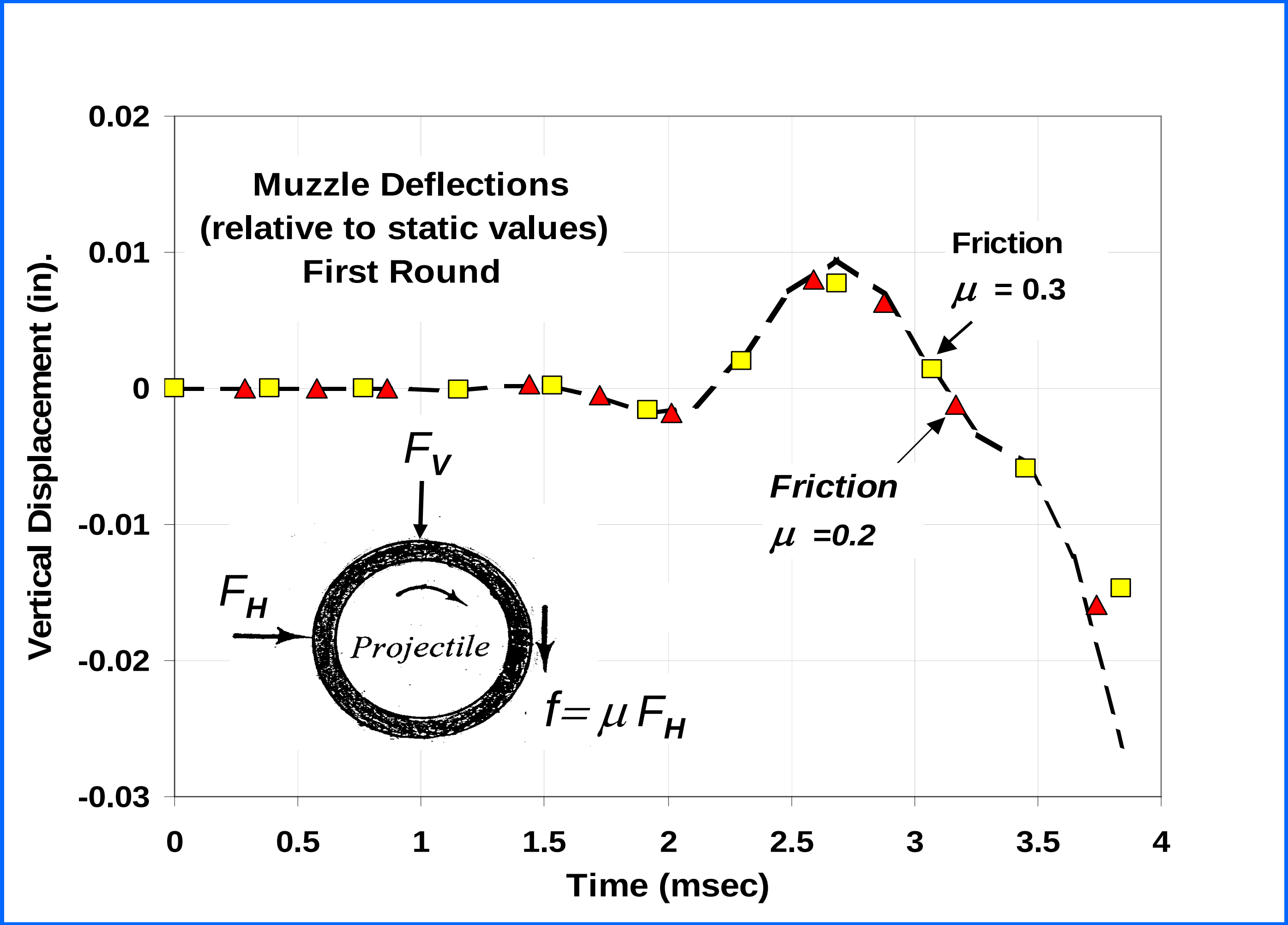
First-Round Barrel Response

Free Vibrations following First Round

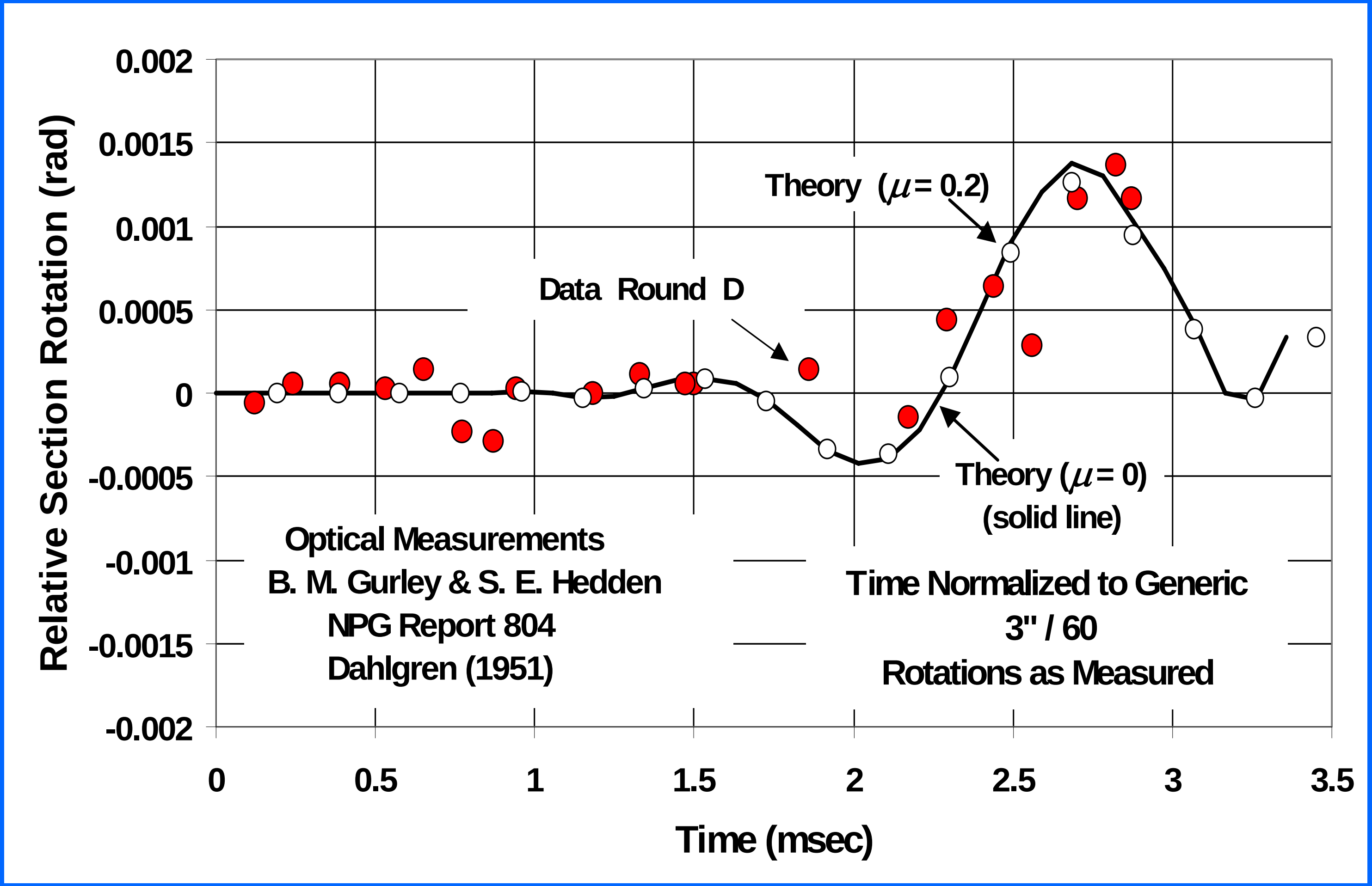
Response Characteristics after Multiple Rounds

First-Round Barrel Response

Muzzle Deflections vs. Time

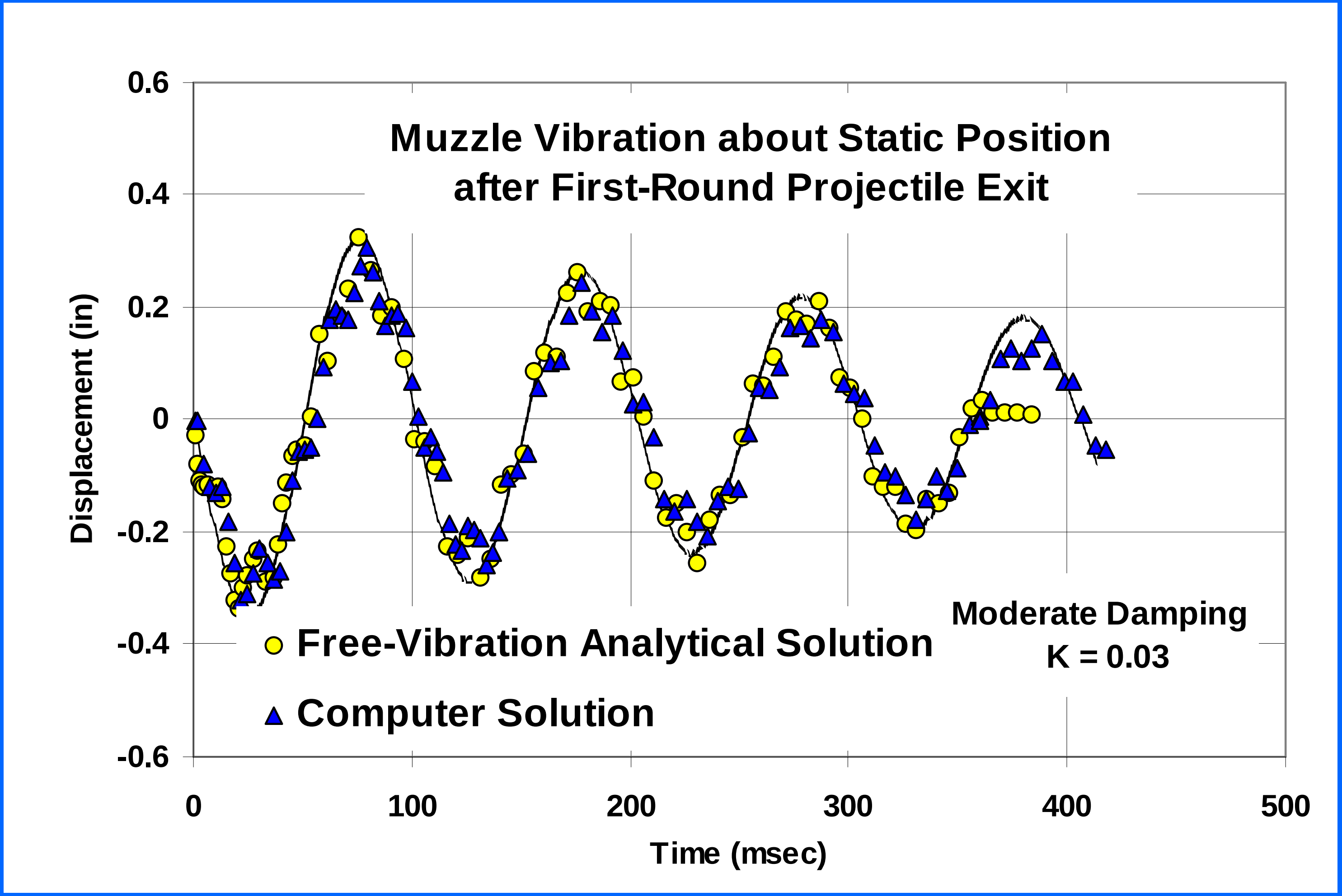


Dynamic Section Rotation Comparison with 1951 Dahlgren Data



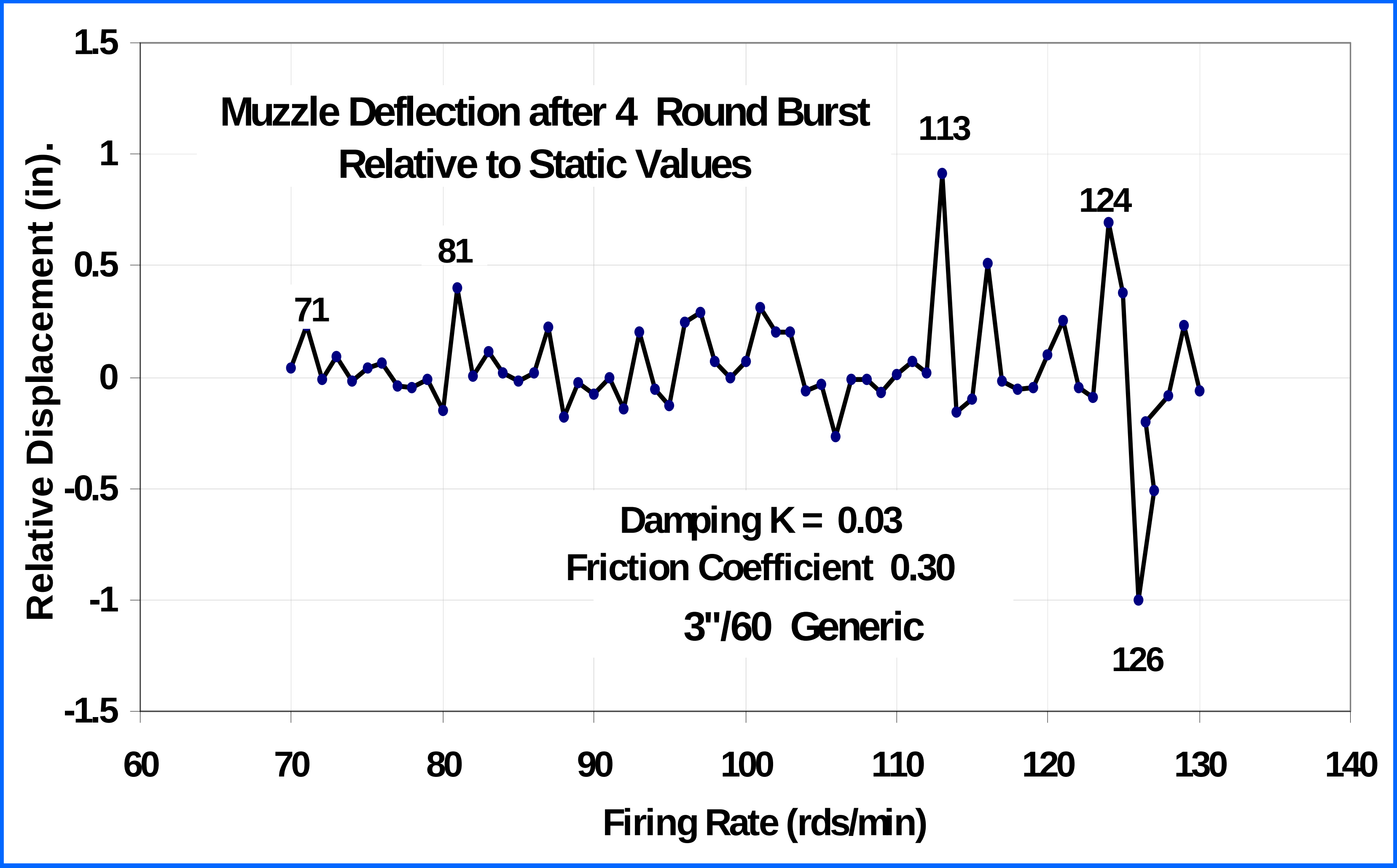
Free Vibrations following First Round

Free Vibration of Muzzle (note check of analytical solution & damping value)

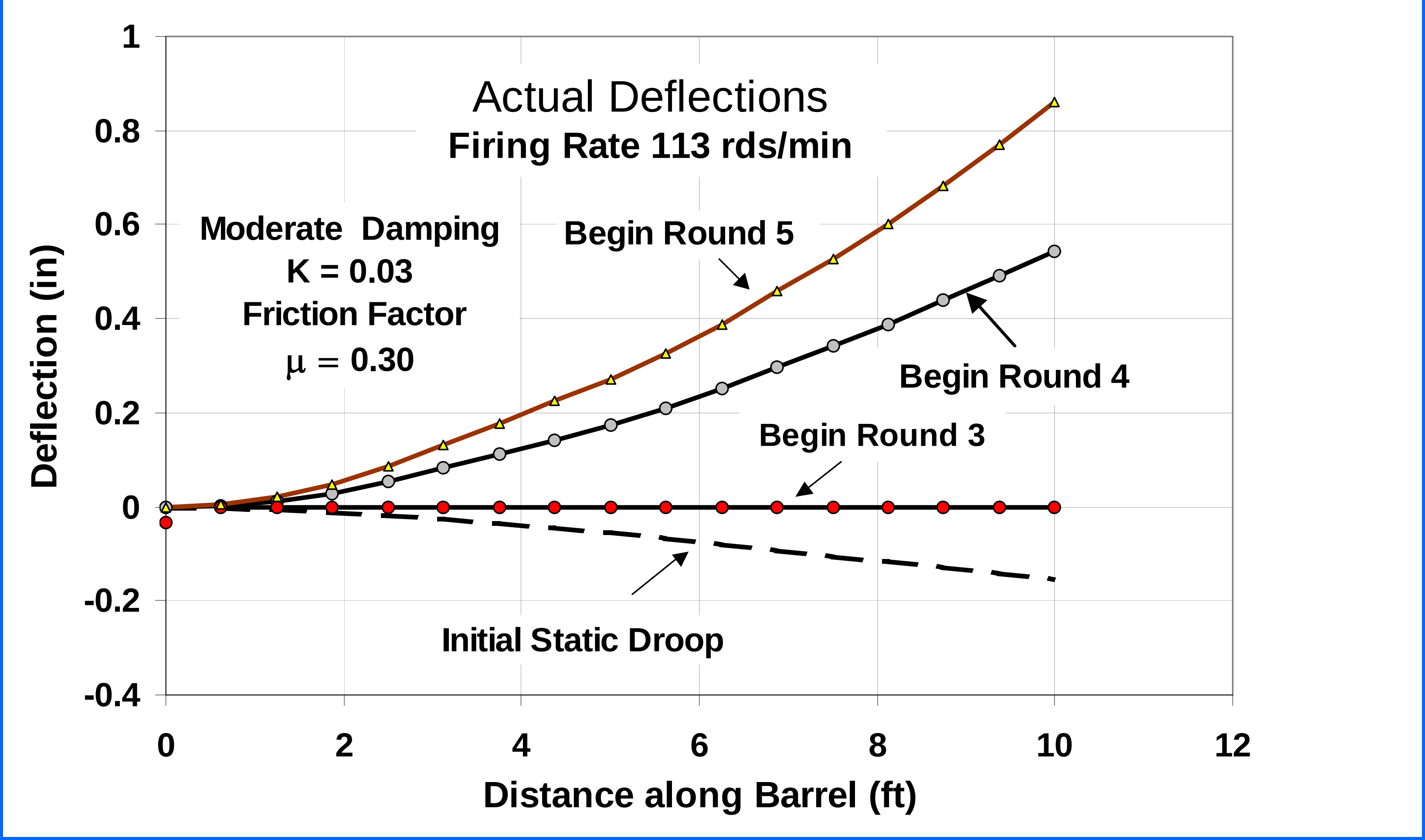


Response Characteristics after Multiple Rounds

Dynamic Amplification



Barrel Deflections
(note continuing input of energy

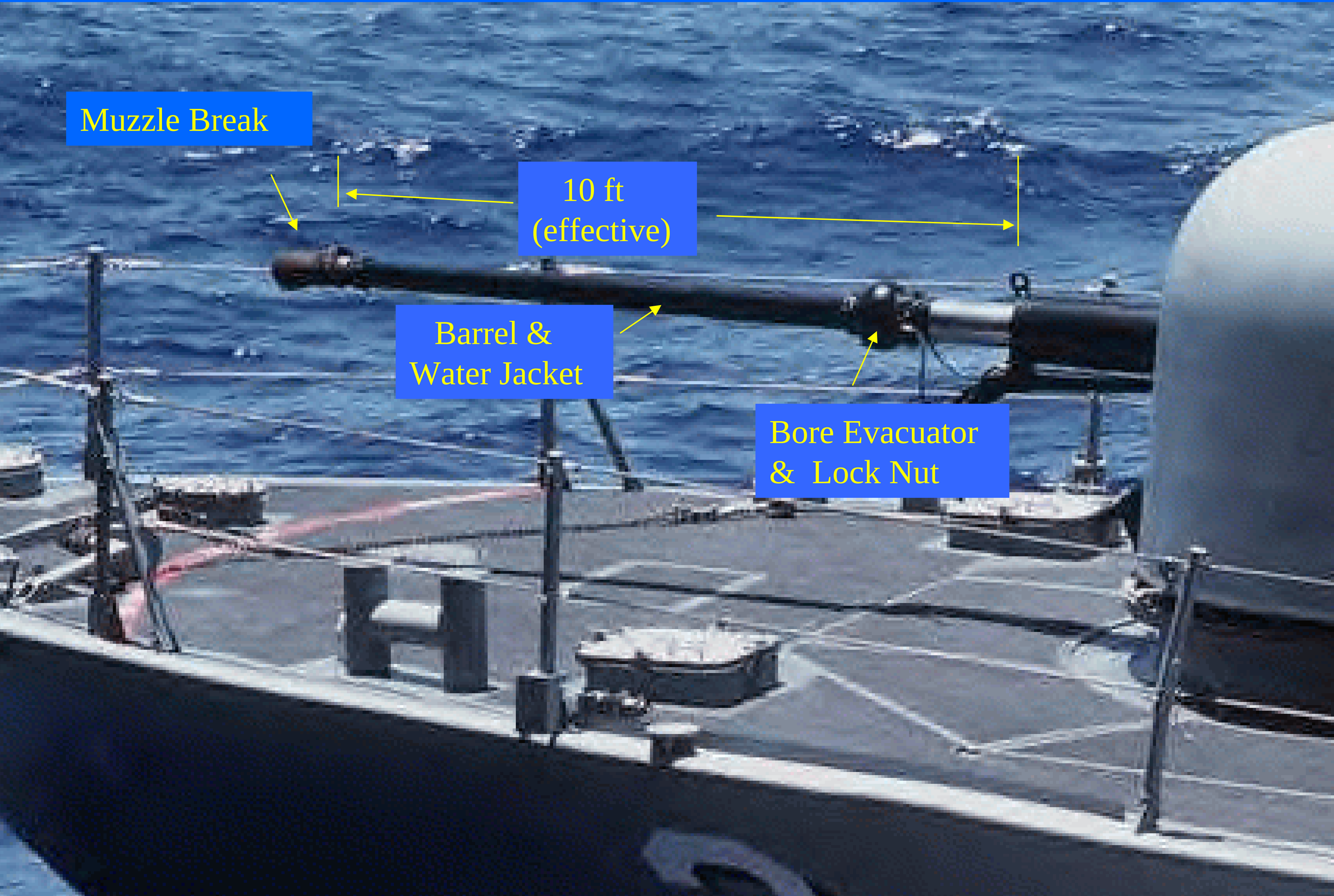


IV. Application to USN Mark 75 (80 rds/min)

Mark 75 3"/62 (80 rds/ min)

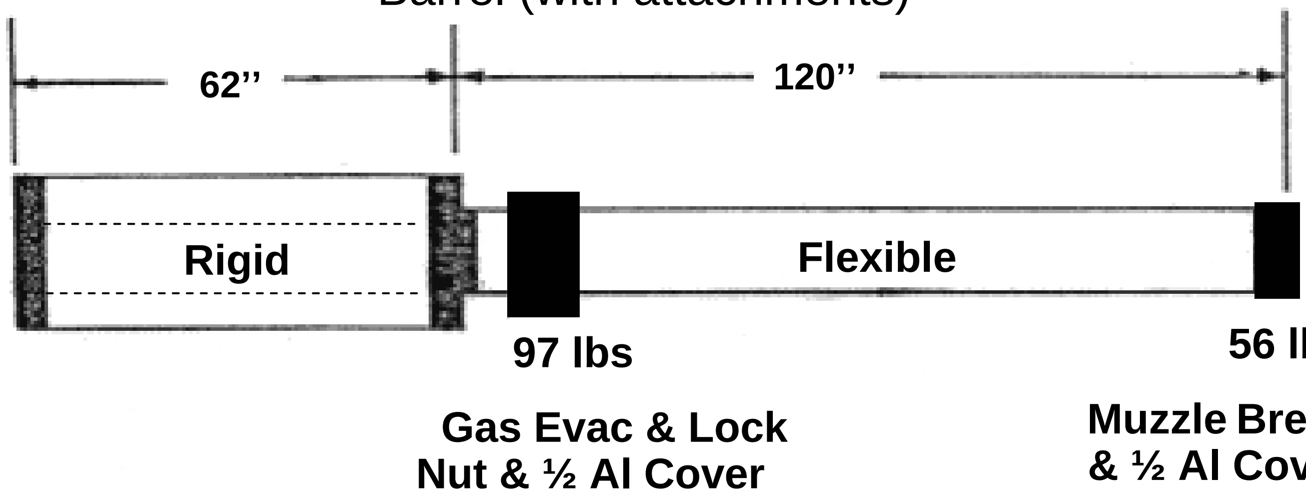
USS Curts FFG 38

Barrel Details –Mark 75 (3in/62) Gun Mount



Mark 75 - Idealized Barrel Description

Barrel (with attachments)



Modal Frequencies

ω_1 = 41 rad/sec (6.5 cycles/sec)

ω_2 = 276 rad/sec (44 cycles/sec)

etc

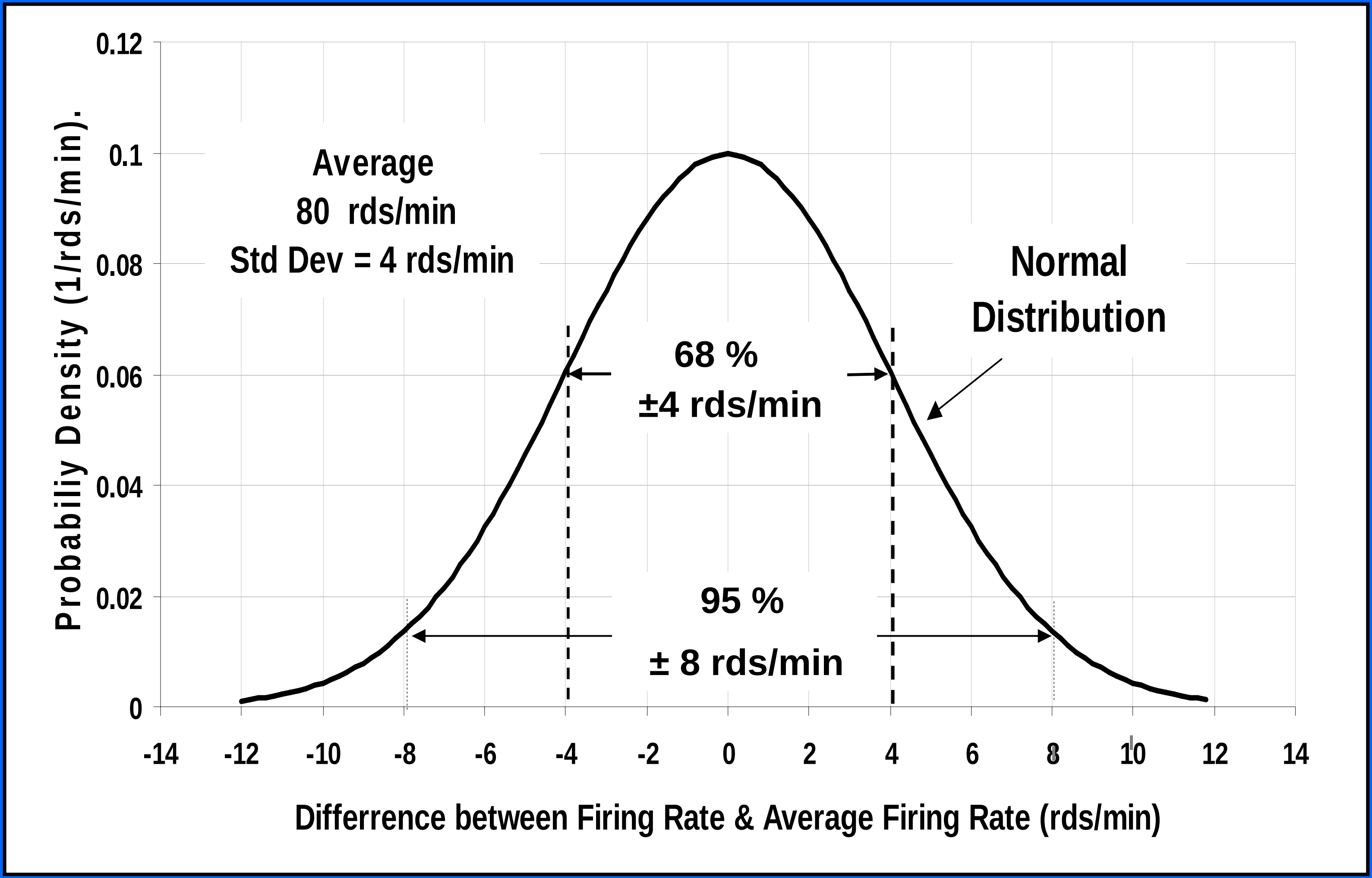
Flexible Length

Inside Dia = 3 in

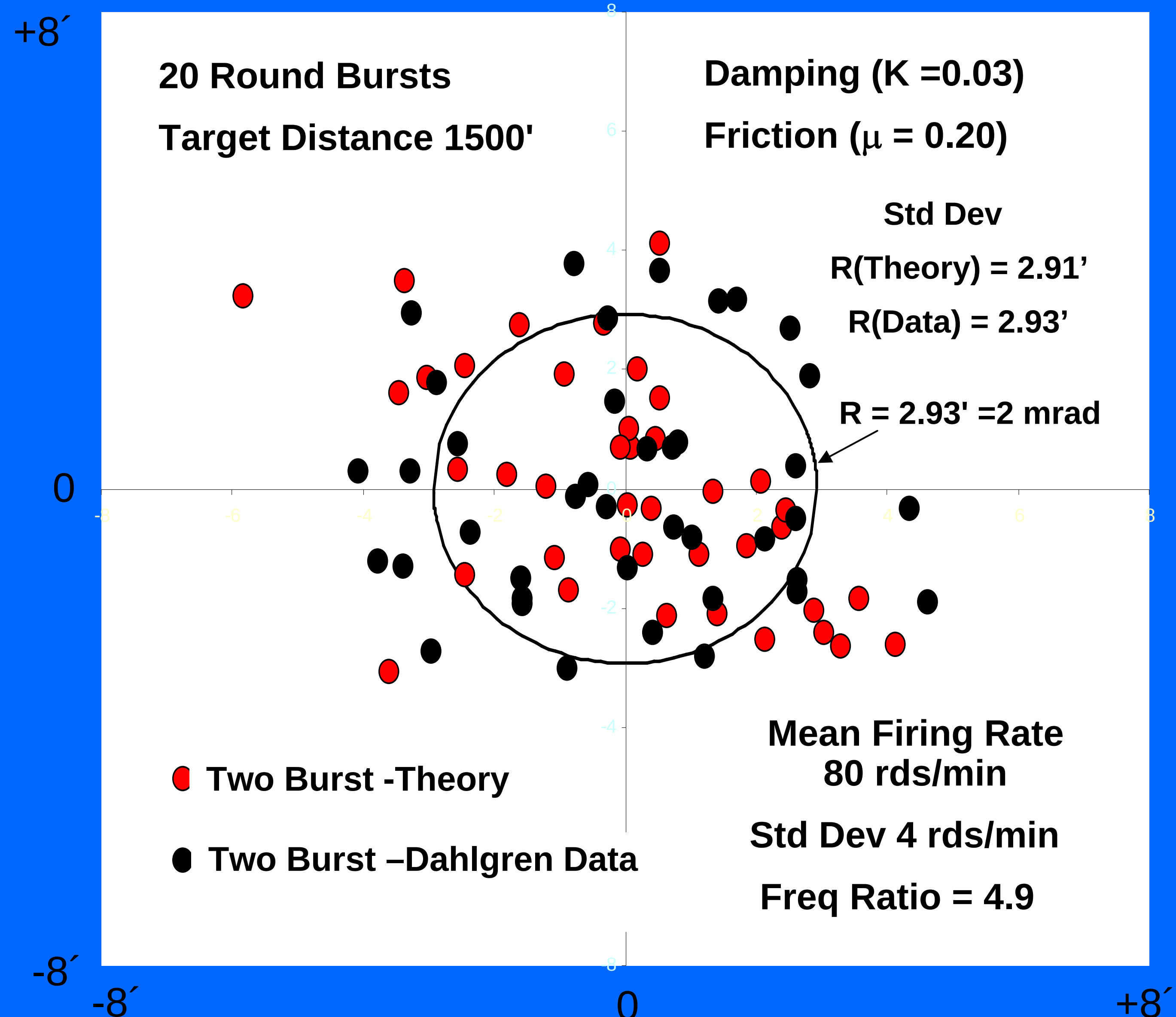
Outside Dia = 4 in

Leduc formula for projectile velocity

Variable Firing Rates
Normal (Bell-Shaped) Distribution



Dispersion: Theory *vs.* Measurement



USN
.Mark 75
3"/ 62
Gun Mount
firing
14 lb
Projectiles

V. Application to Study of Oto Melara 76 mm/62 SR (120 rds/min)

Oto Melara 76mm/62 SR (Super Rapid Gun Mount

Mark 75 *vs* 76mm SR

Mark 75

76mm SR with standard shield

Mark 75 (~1970)	***SR(~2000)***
Firing	
Out of Battery	In Battery
Avg Firing rate	
80 rds/min	120 rds/min
Accuracy (10-rd burst)	
~1.9 *m*rad	0.30 *m*rad*

*Reported on web page

Extracted From Web Page:
Italian 76mm/62 (3″)…

The SR is an improved faster-firing version of the Mark 75…. Accuracy improved partly by reducing the weights of the moving parts. Claims are that these changes have reduced the radial-error standard deviation values to less than 0.3 *m*rad for 10-round burst

Examination with Theory

What if firing rate of Mark 75 is increased 50% to 120 rds/min?

See table. Dispersion increased from about 1.9 mrad at 80 rds/sec to about 6.5 mrad at 120 rd/min (for 10-Rd Bursts)

Mark 75 (modified)

Firing Rate (rds/min)	Radial Dispersion* (Std Dev in mrad)
80	1.9 mrad
120	6.5 mrad

----

* 10 Rd Bursts (avg of 4)

What if weights of gas evacuator & muzzle break are then reduced by 50%?

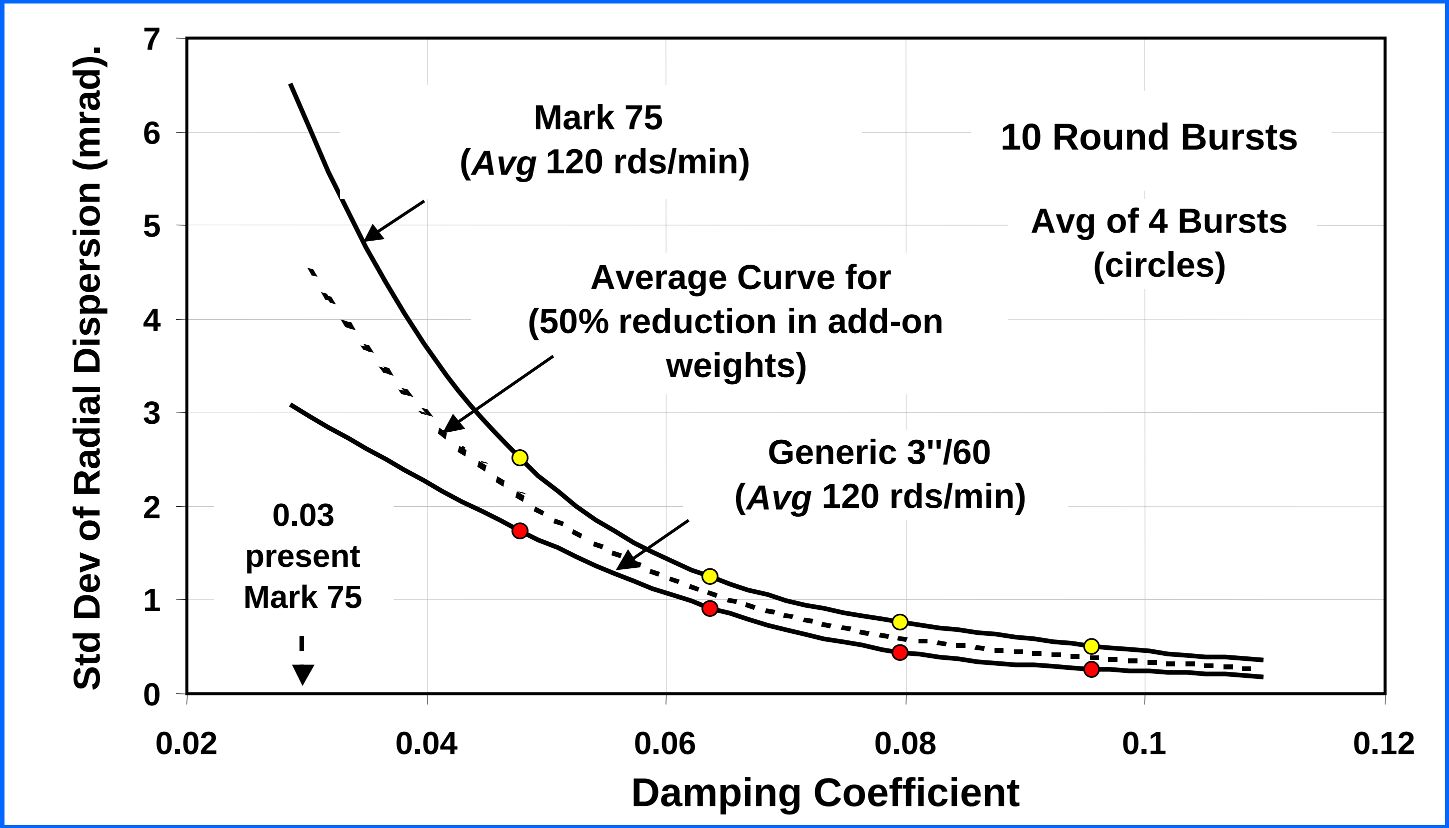
(Avg of data from generic and Mark 75)

Dispersion reduced from about 6.5 mrad to about 4.5 mrad (for 10-rd bursts)

Conclusion: Cannot achieve reported accuracy for 120 mm SR with only a reduction of add-on weights of Mark 75 when modified for 120 rds/min

What if increased damping of barrel vibrations?

See graph below. Dispersion (dashed line) reduced from about 4.5 mrad to about 0.5 mrad for 200% increase in damping.



VI. Concluding Remarks

Barrel Vibrations Work

*A*nalysis can explore performance aspects of rapid fire guns not possible with limited testing. Can be of value in assessing factors for Navy needs when considering cost, accuracy, sensitivity to firing rate, inherent damping of vibrations, age effects, etc.

*B*arrel vibrations can affect gun effectiveness and barrel wear. Longer term implications of work are improved fire control & accuracy and improved maintainability regarding barrel wear…