Inclosure 2

DEVELOPMENT AND PROOF SERVICES
ABERDEEN PROVING GROUND
MARYLAND

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METHODS OF COMPUTING BALLISTIC LIMITS FROM FIRING DATA

I. V_{min} BALLISTIC LIMIT

A. CP and PP within 50 fps, with Confirming Partials

1. Firing Method - Obtain 3 PP below and within 50 fps of low CP. (Minimum number of rounds, such as 10, may be specified.)

2. Method of Computation - Average of the velocities of the low CP and the high PP below that.

3. Uses - Principally TB4-10A program.

4. Number of Rounds Involved - Generally 6 to 14.

5. Comments - Presents armor at its poorest. Data can not be combined with V_{50} data. Reproducibility unknown.

II. $V_{biased\ low}$ BALLISTIC LIMIT

A. CP and PP within 50 fps

1. Firing Method - Employ up and down method until a PP is obtained below and within 50 fps of low CP.

2. Method of Computation - Average of the velocities of the low CP and the high PP below that.

3. Uses - a. Old armor test programs.
b. Tests of hulls and turrets of tanks (due to limited area available for testing).
c. Acceptance testing of armor (with the optional provision that two additional PP be obtained above specification requirements).

4. Number of Rounds Involved - Generally 3 to 6

5. Comments - Poorest reproducibility of any method, but suitable when projectile-plate combination would normally give a small zone of mixed results. Ballistic limit can be obtained with a minimum number of rounds.

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III. V_{50} BALLISTIC LIMITS

A. 3 CP and 3 PP within 150 fps

1. Firing Method - Employ up and down method until 3 CP and 3 PP are obtained within a spread of 150 fps.

2. Method of Computation*- Average of the velocities of the 3 lowest CP and the 3 highest PP.

3. Uses - Most armor development programs other than TB4-19A; also projectile test programs.

4. Number of Rounds Involved - Generally 7 to 10.

5. Comments - Probably gives better reproducibility for number of rounds fired than method IA. Permissable velocity spread may be modified to, for example, 100 fps.

B. 5 CP and 5PP within 125 fps

1. Firing Method - Employ up and down method until 5 CP and 5 PP are obtained within a spread of 125 fps.

2. Method of Computation*- Average of the velocities of the 5 lowest CP and the 5 highest PP.

3. Uses - Tests of body armor materials (because a large number of projectiles may be fired at one panel).

4. Number of Rounds Involved - Generally 10 to 17

5. Comments - Requires the firing of a large (relatively) number of rounds. Permissable velocity spread may be modified.

* For the special case when the zone of mixed results exceeds the permissable velocity spread, no definite overall policy has been established. For body armor, the tentative specification requires that should this situation develop, the permissable spread will be increased to the size of the zone of mixed results and firing will be continued until 7 CP and 7 PP are obtained within the zone of mixed results. Another suggestion is that the permissable velocity spread be applicable only to the highest CP considered and the lowest PP considered, and the ballistic limit still be based upon an equal number of the highest PP's and the lowest CP's even though the zone of mixed results may be greater than the permissable velocity spread.

C. 3 CP and 3 PP within 100 fps, per Frankford (AP Shot Test Program Request #8)

1. Firing Method - Employ up and down method until 3 CP and 3 PP are obtained within a spread of 100 fps. If zone of mixed results is greater than 100 fps, fire additional rounds to obtain a minimum of 3 CP and 3 PP in the mixed zone.

2. Method of Computation

a. If no mixed zone is obtained - Average of the velocities of the lowest CP and the highest PP.

b. If mixed zone is less than 100 fps - Average of the velocities of the 3 lowest CP and the 3 highest PP.

c. If mixed zone ranges from 100 to 250 fps -

(1) And the number of PP in mixed zone exceeds the number of CP, then:

$$BL = V_A + \frac{(N_P - N_C)}{(N_P + N_C)} (V_{HP} - V_A)$$

(2) And the number of CPin mixed zone exceeds the number of PP, then:

$$BL = V_A - \frac{(N_C - N_P)}{(N_C + N_P)} (V_A - V_{LC})$$

3. Uses -

4. Number of Rounds Involved - Generally 7 to 14

5. Comments -

D. V_{50} with K Factor, per Navy

1. Firing Method - Employ up and down method with 50 fps increments; zone method also suitable.

V_A - Average of all velocities in mixed zone
N_P - Number of PP in mixed zone
N_C - Number of CP in mixed zone
V_{HP} - Velocity of the highest PP
V_{LC} - Velocity of the lowest CP

2. Method of Computation - Plot curve showing frequency of CP's at each velocity interval. Draw straight line through straight line section of curve. Difference in velocities between that at which the straight line intersects the 100% CP line and that at which it intersects the 0% CP line, is equal to 2K. Apply formula:

$$BL = \frac{SV + (Np - Nc)\,K}{Np + Nc}$$

SV = The sum of the velocities of all rounds in the range extending 20 fps above and below the zone of mixed results.

3. Uses - Used a few times in old programs.

4. Number of Rounds Involved - Probably an absolute minimum of 50.

5. Comments - Requires more rounds than is normally practical. Frequency curves are not as smooth in practice as they are theoretically. If enough rounds are fired, method III C probably more satisfactory.

E. V_{50} with K Factor, per Navy, Modified by APG

1. Firing Method - Employ up and down method.

2. Method of Computation - Same as III D except that K is considered to be one-half the zone of mixed results obtained in firing.

3. Uses - Occasional use in special tests when the zone of mixed results is large.

4. Number of Rounds Involved - Generally 12 to 20.

5. Comments - Requires fewer rounds than method III D. Suitable when a large zone of mixed results exists and a moderate number of rounds have been fired.

F. Method of Maximum Likelihood, per BRL Technical Note No. 151

1. Firing Method - Employ up and down method.

2. Method of Computation - Maximum likelihood method described in BRL Technical Note No. 151.

3. Uses - Suitable for all data, provided a zone of mixed results is obtained. At present, used principally as a check on other methods and when the most accurate determination possible is desired.

4. Number of Rounds Involved - Generally 5 to 20.

5. Comments - This is the only statistically sound method available for

use when a small or moderate number of rounds have been fired. Provides a standard deviation as well as a ballistic limit, though the standard deviation may not be very accurate as far as the particular plate-projectile combination is concerned. Requires two to four hours of computation to obtain ballistic limit and standard deviation, but a specially designed computing machine should be able to supply answers in an insignificant amount of time. When no zone of mixed results is obtained in firing, no standard deviation can be obtained and the ballistic limit can only be estimated. Checks to date have shown that ballistic limits obtained by this method differ only very slightly from ballistic limits obtained by the 3 and 3 method or the 5 and 5 method.

G. Probability Curves

1. Firing Method - Employ up and down method or zone method.

2. Method of Computation - Plot curve showing frequency of CP's at various velocity intervals on either linear or probability graph paper. Pick off V_{50} point from curve.

3. Uses - To set up specification requirements for body armor materials, and for other special tests.

4. Number of Rounds Involved - Generally 150 or more rounds are necessary.

5. Comments - Suitable only when a large number of rounds can be fired at the same target. May also furnish reliable standa rd deviation. Most accurate of all methods.

H. Average of Velocities in Zone of Mixed Results, per Navy

1. Firing Method - Employ up and down method.

2. Method of Computation - Use formula below:

$$BL = \frac{\Sigma V}{N_C + N_P}$$

ΣV - The sum of the velocities of all rounds in the zone of mixed results.
N_C - Number of CP in zone of mixed results.
N_P - Number of PP in zone of mixed results.

3. Uses - Normal development firing by Navy.

4. Number of rounds Involved - Generally 9 to 15.

5. Comments -