

# Marine Corps Operational Test and Evaluation Activity



## Enhanced Combat Helmet Test Protocol

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# Agenda

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- Objective of the Analysis
- Background
- Analysis Approach
- Analysis
- Results
- Conclusion



# Objective of the Analysis

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- Develop a test methodology to support the follow on characterization of the Enhanced Combat Helmet (ECH) to validate the current First Article Testing (FAT).
- The current protocol allows for the aggregation of the FAT results across helmets size, environmental conditions, and helmets shot location.



# Objective of the Analysis

## 9mm Resistance To Penetration (RTP)/Ballistic Transient Deformation (BTD): Current ECH FAT Protocol Aggregation

- 96 shots (Trials) – 48 Helmets across helmets size, environmental condition, and helmets shot location per stratified sampling.
- Based on legacy Kevlar based helmet test protocol.

## 9mm Resistance To Penetration (RTP)/Ballistic Transient Deformation (BTD): Non-Aggregation

- 1760 shots (Trials) - 880 Helmets across helmets size, environmental condition, and helmets shot location – full factorial design.

Was utilizing the stratified sampling protocol valid for ECH?

90/90 statistical standard



# Objective of the Analysis

## 9mm RTP/FTP : Current ECH FAT Protocol Aggregation

### Helmet Test Matrix

9 mm Resistance to Penetration/Ballistic Transient Deformation  
(Enhanced Combat Helmet)

Size	Helmet	Ambient		Hot		Cold		Seawater	
		Shot 1	Shot 2	Shot 1	Shot 2	Shot 1	Shot 2	Shot 1	Shot 2
Small	#1	Cr	B	L	F	Cr	B	L	F
	#2	L	F	Cr	B	R	F	Cr	B
	#3	Cr	B	R	F	Cr	B	R	F
Medium	#1	R	F	Cr	B	R	F	Cr	B
	#2	Cr	B	R	F	Cr	B	L	F
	#3	L	F	Cr	B	L	F	Cr	B
Large	#1	Cr	B	R	F	Cr	B	R	F
	#2	R	F	Cr	B	L	F	Cr	B
	#3	Cr	B	L	F	Cr	B	L	F
X-Large	#1	L	F	Cr	B	L	F	Cr	B
	#2	Cr	B	L	F	Cr	B	R	F
	#3	R	F	Cr	B	R	F	Cr	B

#### Key:

F=Front

B=Back

R=Right

L=Left

Cr=Crown

All shots at 0° obliquity

## 9mm RTP/FTP : Aggregation

Environment	Size	Crown	Left Side	Right Side	Front	Back
Ambient	Small	22	22	22	22	22
	Medium	22	22	22	22	22
	Large	22	22	22	22	22
	X-Large	22	22	22	22	22
Hot	Small	22	22	22	22	22
	Medium	22	22	22	22	22
	Large	22	22	22	22	22
	X-Large	22	22	22	22	22
Cold	Small	22	22	22	22	22
	Medium	22	22	22	22	22
	Large	22	22	22	22	22
	X-Large	22	22	22	22	22
Seawater	Small	22	22	22	22	22
	Medium	22	22	22	22	22
	Large	22	22	22	22	22
	X-Large	22	22	22	22	22



# Background

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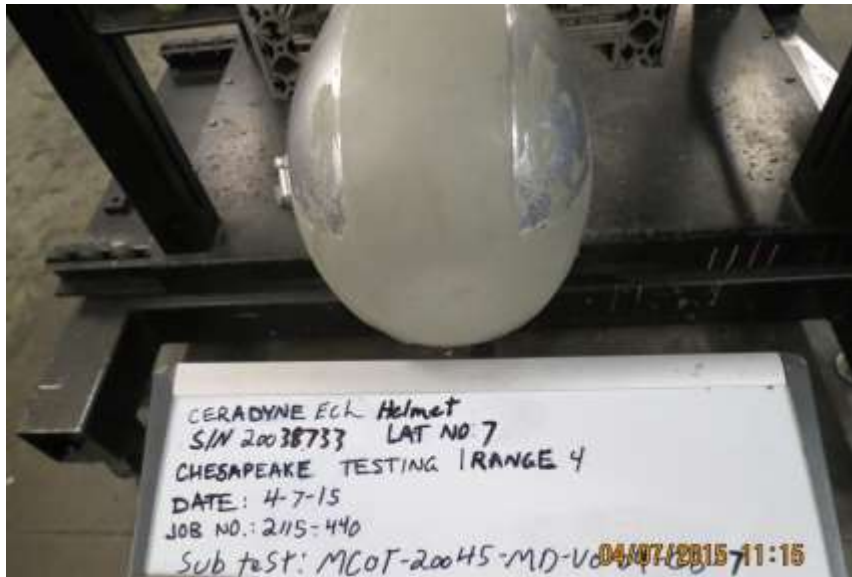
- Urgent Needs Statement (UNS) for the ECH: 2009
  - Threat M RTP
  - 9mm RTP and BTD
- The ECH uses Ultra High Molecular Weight Polyethylene (UHMWPE) Technology
- Developmental Testing – Life Fire Testing: June 2010 - May 2013
- Production / Fielding: Commenced in FY 2014
  - Lot Acceptance Testing for each Lot
  - Independently oversighted by OTA (MCOTEA)
- Follow-On characterization is pending (FY 16).



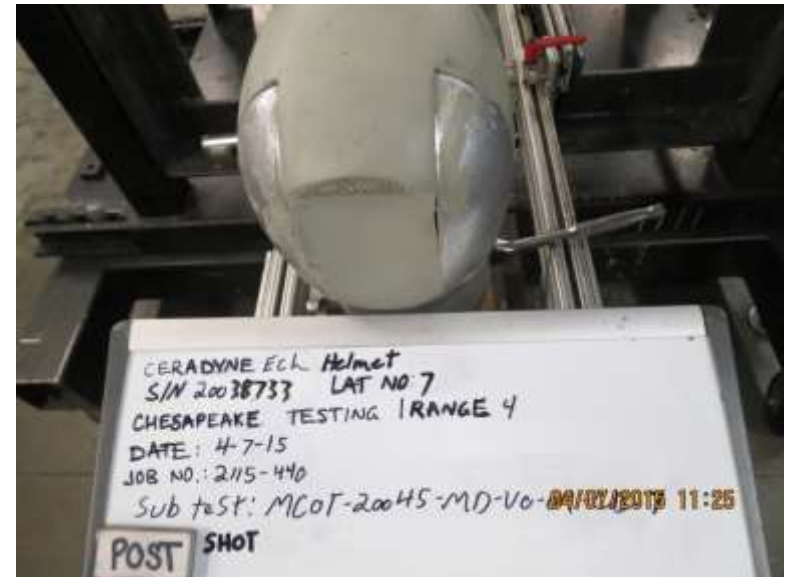
# Background

## 9mm BTD Test Description

Pre Shot



Post Shot





# Lot Acceptance Testing

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- LAT began in Early 2014
- LAT required for each lot; each Lot is approximately 1,000 helmets
  - 47 helmets ballistically tested out of the lot (randomly sampled)
- Each lot is a singular sized lot
  - Small, Medium, Large, or Extra-Large
  - 13 helmets (26 trials) tested for 9mm RTP/BFD for each LAT
- Ongoing LATs provided additional data at Ambient environmental condition
  - 1493 LAT data points for 9-mm RTP/BTD

***Given the additional data in hand from LAT; and short of conducting a full factorial test series, what is the most efficient test regime to pursue for follow-on characterization?***





# Analysis Approach

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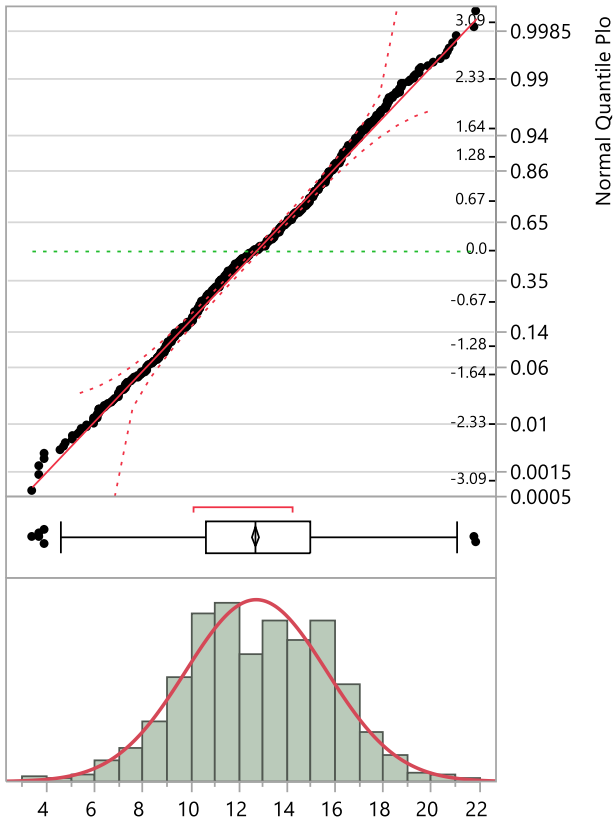
- Use statistical analysis of historical data to identify those helmet test points most likely to be out of specifications (potential risk areas)
  - An Analysis of Variance (ANOVA) was performed to test differences in BTD between group means of ECH
- Dataset
  - Collected from ECH testing conducted in 2013 - 2014
  - 1589 Valid Trials (96 FAT + 1493 LAT trials) [796 helmets]
  - Response: BTD due to 9-mm shot
  - Factors: Environmental Condition; Helmet Size; and Shot Location
- Factor Levels
  - Environmental Condition – Ambient, Hot, Cold, and Seawater
  - Helmet Size – Small, Medium, Large, and X-Large
  - Shot Location – Crown, Sides, Front, and Back



# Analysis - Summary Statistics

BTD = Ballistic Transient Deformation

BTD (mm)



Normal(12.7146,2.93702)

BTD (mm)	Legacy ECH						
	Sample Size	Mean	Std. Dev	90% LCB	90% UCB	Skewness	Kurtosis
Overall	1589	12.71	2.94	12.62	12.81	-0.07	-0.20

### Summary of Fit

RSquare	0.71552
RSquare Adj	0.708921
Root Mean Square Error	1.58457
Mean of Response	12.7146
Observations (or Sum Wgts)	1589

### Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	36	9801.322	272.259	108.4324	
Error	1552	3896.859	2.511		
C. Total	1588	13698.181			<.0001

### Effect Tests

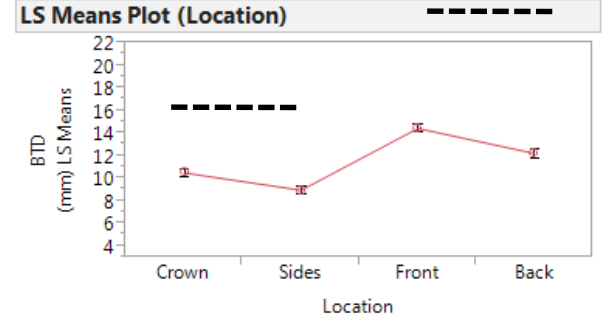
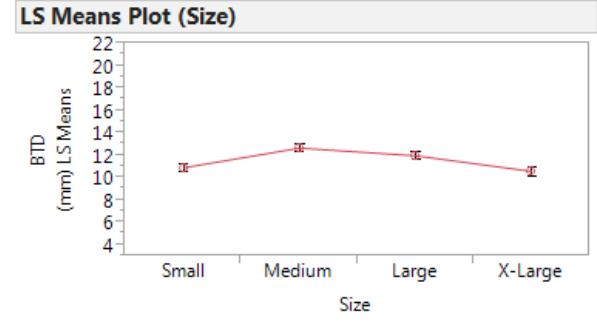
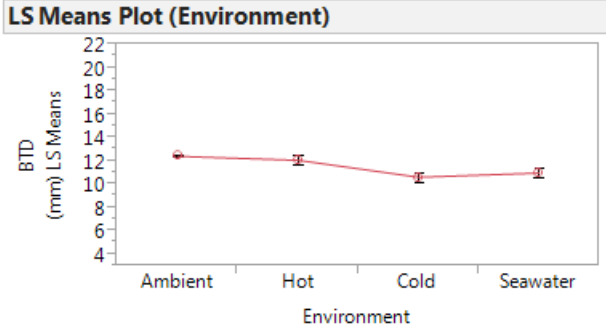
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Environment	3	3	121.4042	16.1172	<.0001
Size	3	3	87.6554	11.6368	<.0001
Location	3	3	524.6401	69.6494	<.0001
Environment*Size	9	9	25.7189	1.1381	0.3320
Environment*Location	9	9	52.2862	2.3138	0.0139
Size*Location	9	9	1153.0384	51.0244	<.0001

Two factor interactions (Environment\*Location & Size\*Location) are shown to be significant at the alpha value of 0.10 (90% confidence)



# Summary Statistics by Factor

BTD Threshold (mm)	
Sides / Crown	16.0
Front / Back	25.4



BTD (mm)	Legacy ECH			
	Sample Size	Mean	Std. Dev	90% UCB
Environment				
Ambient	1517	12.78	2.92	12.88
Hot	24	12.23	3.17	13.08
Cold	24	10.50	3.33	11.40
Seawater	24	11.14	2.32	11.76

BTD (mm)	Legacy ECH			
	Sample Size	Mean	Std. Dev	90% UCB
Size				
Small	128	12.10	3.49	12.49
Medium	571	13.41	2.84	13.57
Large	762	12.55	2.75	12.68
X-Large	128	11.18	3.05	11.53

BTD (mm)	Legacy ECH			
	Sample Size	Mean	Std. Dev	90% UCB
Location				
Crown	428	10.89	1.93	11.01
Sides	372	10.23	2.04	10.36
Front	364	15.60	1.74	15.72
Back	425	14.25	2.00	14.38

% of Threshold BTD

Crown	0.6882
Sides	0.6477
Front	0.6189
Back	0.5661

Potential risk performer

Level	Least Sq Mean
Ambient A	12.438583
Hot A	12.087955
Seawate B	11.000455
Cold B	10.637045

Levels not connected by same letter are significantly different.

Level	Least Sq Mean
Medium A	12.672853
Large A	11.986988
Small B	10.910477
X-Large B	10.593720

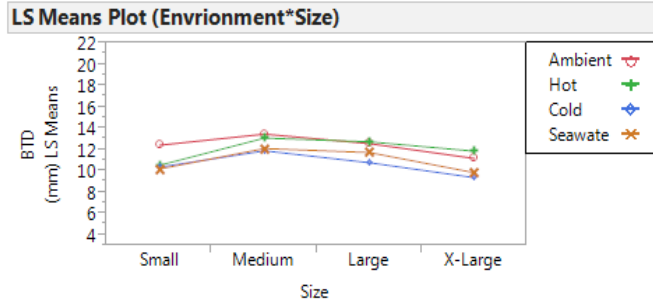
Levels not connected by same letter are significantly different.

Level	Least Sq Mean
Front A	14.452775
Back B	12.227215
Crown C	10.511112
Sides D	8.972936

Levels not connected by same letter are significantly different.



# Statistics by Environment & Size



Level	Least Sq Mean
Ambient,Medium A	13.494894
Hot,Medium A B C D	13.121517
Hot,Large A B C D E	12.771083
Ambient,Large B	12.601870
Ambient,Small B D	12.449582
Seawater,Medium A B C D E F	12.146517
Cold,Medium A B C D E F G	11.928483
Hot,X-Large A B C D E F G	11.891893
Seawater,Large A B C D E F G	11.762750
Ambient,X-Large C E F G	11.207985
Cold,Large B C D E F G	10.812250
Hot,Small C D E F G	10.567327
Cold,Small C E F G	10.399339
Seawater,Small E F G	10.225661
Seawater,X-Large F G	9.866893
Cold,X-Large G	9.408107

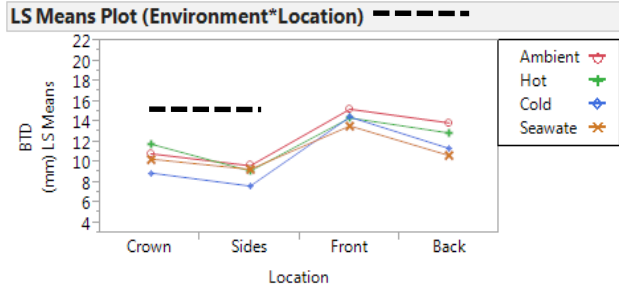
Levels not connected by same letter are significantly different.

BTD (mm)		Legacy ECH			
Environment	Size	Sample Size	Mean	Std. Dev	90% UCB
Ambient	Small	110	12.36	3.41	12.78
	Medium	553	13.45	2.85	13.60
	Large	744	12.57	2.75	12.70
	X-Large	110	11.28	3.01	11.65
Hot	Small	6	10.77	4.17	13.28
	Medium	6	13.03	1.99	14.23
	Large	6	12.65	3.09	14.51
	X-Large	6	12.45	3.41	14.50
Cold	Small	6	9.95	4.00	12.36
	Medium	6	12.27	3.19	14.19
	Large	6	10.68	2.26	12.04
	X-Large	6	9.10	3.61	11.28
Seawater	Small	6	10.68	3.25	12.64
	Medium	6	11.80	1.54	12.73
	Large	6	11.90	1.78	12.97
	X-Large	6	10.17	2.47	11.65



# Statistics by Environment & Location

BTD Threshold (mm)	
Sides / Crown	16.0
Front / Back	25.4



Level		Least Sq Mean
Ambient,Front	A	15.275635
Cold,Front	A B C	14.502035
Hot,Front	A B C	14.410465
Ambient,Back	B	13.915946
Seawater,Front	A B C D	13.622965
Hot,Back	B C D E	12.917915
Hot,Crown	C D E F	11.845495
Cold,Back	D E F G H	11.386251
Ambient,Crown	F H	10.873952
Seawater,Back	E F G H	10.688749
Seawater,Crown	E F G H I	10.349662
Ambient,Sides	G	9.688798
Seawater,Sides	F G H I	9.340445
Hot,Sides	F G H I	9.177945
Cold,Crown	G H I	8.975338
Cold,Sides	I	7.684555

Levels not connected by same letter are significantly different.

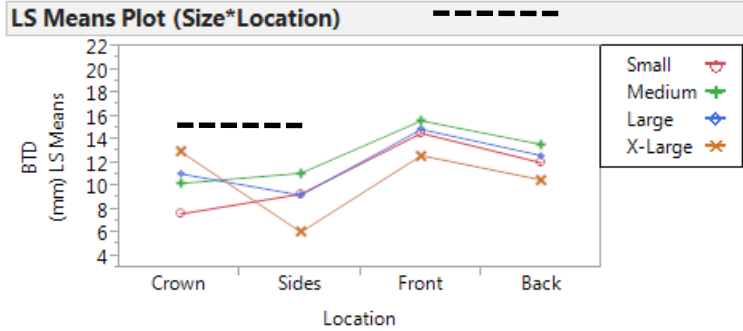
BTD (mm)		Legacy ECH				% of Threshold BTD
Environment	Location	Sample Size	Mean	Std. Dev	90% UCB	
Ambient	Crown	410	10.91	1.89	11.03	0.6891
	Sides	354	10.30	2.00	10.44	0.6525
	Front	346	15.68	1.66	15.79	0.6217
	Back	407	14.37	1.94	14.49	0.5705
Hot	Crown	6	12.33	2.56	13.88	0.8674
	Sides	6	9.18	2.11	10.46	0.6535
	Front	6	14.40	4.05	16.84	0.6631
	Back	6	12.98	1.10	13.64	0.5372
Cold	Crown	6	8.62	2.24	9.97	0.623
	Sides	6	7.55	2.53	9.07	0.5672
	Front	6	14.38	1.91	15.54	0.6116
	Back	6	11.45	1.38	12.28	0.4835
Seawater	Crown	6	10.70	2.34	12.11	0.7569
	Sides	6	9.48	2.00	10.69	0.668
	Front	6	13.75	1.57	14.70	0.5786
	Back	6	10.62	0.91	11.17	0.4396

Potential risk performers



# Statistics by Size & Location

BTD Threshold (mm)	
Sides / Crown	16.0
Front / Back	25.4



Level	Least Sq Mean
Medium,Front A	15.650610
Large,Front A B	14.913667
Small,Front A B C	14.582036
Medium,Back B C D	13.613670
X-Large,Crown C D E	13.024564
Large,Back D E F	12.671618
X-Large,Front D E F G	12.664786
Small,Back E F G H	12.043251
Medium,Sides F G H	11.155387
Large,Crown G H I	11.097664
X-Large,Back H I J	10.580322
Medium,Crown H I J	10.271743
Small,Sides I J	9.366147
Large,Sides J K	9.265003
Small,Crown K L	7.650475
X-Large,Sides L	6.105206

Levels not connected by same letter are significantly different

BTD (mm)		Legacy ECH				% of Threshold BTD
Size	Location	Sample Size	Mean	Std. Dev	90% UCB	
Small	Crown	34	8.47	2.13	8.95	0.5594
	Sides	30	10.44	1.65	10.83	0.6770
	Front	30	15.69	2.16	16.21	0.6381
Medium	Back	34	14.02	2.04	14.47	0.5699
	Crown	153	10.55	1.60	10.72	0.6701
	Sides	133	11.76	1.44	11.92	0.7452
Large	Front	132	16.37	1.47	16.54	0.6510
	Back	153	15.16	1.62	15.33	0.6034
	Crown	207	11.17	1.67	11.32	0.7073
X-Large	Sides	179	9.69	1.37	9.82	0.6138
	Front	172	15.43	1.49	15.58	0.6134
	Back	204	14.04	1.86	14.21	0.5593
X-Large	Crown	34	13.14	1.46	13.47	0.8418
	Sides	30	6.41	1.38	6.74	0.4215
	Front	30	13.11	1.06	13.36	0.5260
	Back	34	11.73	1.67	12.10	0.4765

Potential risk performers



# Follow-on Testing DoE

- The proposed Follow-On Testing DoE is to use 40 helmets (sample size) for Threat 9-mm BTB performance against the identified potential risk areas of Size/Location (Medium/Sides and X-Large/Crown) in the environmental conditions (Hot and Cold).

Sample Size = 40 helmets  
Signal-to-Noise Ratio = 1\*

Environment	Size / Location	
	Medium Sides	X-Large Crown
Hot	10	10
Cold	10	10

Power Analysis		
Significance Level	0.1	
Anticipated RMSE	1	
Parameter	Anticipated	
	Coefficients	Power
Intercept	0.5	0.927
Environment	0.5	0.927
Size / Location	0.5	0.927
Environment*Size / Location	0.5	0.927



# Conclusion

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- The proposed follow-on DoE:
  - Enables risk-based testing
  - Results in shorter and less expensive tests.
    - Reduces the number of test articles from 880 to 40
    - Saves approximately \$670,000
  - Is scientifically defensible, and as a result, improves confidence in helmet performance
- LFT&E IPT has reviewed and is incorporating the design
- Periodically revisit the analysis as new data is made available.





# Questions

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Visit our website at <https://hqmc.usmc.afpims.mil/Agencies/MCOTEA.aspx>



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Back-Up



# Acronyms

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- BTDD – Ballistic Transient Deformation
- ECH – Enhanced Combat Helmet
- RTP – Resistance To Penetration
- UNS – Urgent Needs Statement
- UHMWPE – Ultra High Molecular Weight Polyethylene
- UCB – Upper Confidence Bound
- LCB – Lower Confidence Bound
- OTA – Operational Test Agency
- LFT&E – Live Fire Test and Evaluation
- IPT – Integrated Product Team