

Consideration and Testing in Support of a Potential Standardized Perforator Hole Size Test

IPS 16-46

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AGENDA/INTRODUCTION

- Testing Background
- Need For Testing
- Feasibility Testing
- Test Method
- Test Results
- Test Discussion
- Conclusion
- Future Work
- Questions and Discussion

TESTING BACKGROUND

STANDARDIZED API TESTS

- Currently the only test that provides phased hole size data for a perforating charge/system is an API RP 19B Section 1 Test
- This limits the standard casing options for each perforating system
- Test design is used to determine system interference by measuring penetration and hole size
- Due to the penetration requirements of modern DP charges concrete targets must be large in diameter, between 96" and 156" in size
- Extremely cost prohibitive to shoot multiple tests

NEED FOR TESTING

CURRENT METHODS

- Currently hole size data can be collected by several methods, each having pros and cons

Method	Pro	Con
QC/Coupon Test	Cost effective, quick, easy	Limited data, lacks boundary constraints
Barrel Test	Cost effective, easy	Limited data, still requires concrete target
Gun Test	Cost effective, quick, easy, large amount of data	Lacks formation confinement constraints
Section 1 Test	Accurate well scenario test	Expensive, time consuming
Computer Simulation	Cost effective, quick, easy	Potentially inaccurate due to limited input data

- Is there a potential solution to provide a cost effective and accurate test for the industry?

BENEFITS OF A HOLE SIZE SPECIFIC TEST

- A standardized test creates customer confidence in data
 - The manufacturer can provide a better answer to the question of charge performance
- It aids in development and focus on frac or specific/consistent entry hole size charges
- Collection of hole size data eventually allows for better modelling and simulation software
- Lastly, it allows for comparison of charge performance in similar scenarios

RECOMMENDED TEST METHOD

- This topic is currently in initial talks within the API RP 19B subcommittee members consisting of Operators and Manufacturers
- Several iterations have been addressed and examined
- Currently, the test method allows:
 - Deep Penetrating and Good Hole Design style of charges to be used
 - Big Hole charges have been left out
 - BH tests are orders of magnitude less than DP due to target size
 - BH charges are far more dependent on the concrete confinement around the casing for performance
 - Conduct gun test in fluid or air
 - Suspend multiple casing strings on the gun carrier, minimum of 12 shots or 2' consecutive perforating
 - Centralized or Decentralized
 - One string must be the same as the valid Section 1 test for a comparison of data for accuracy
 - Testing Company can choose alternate casing sizes, weights, grades, and orientations as they see fit for their needs, and potentially test through multiple casing strings

FEASIBILITY TESTING CONDUCTED

TEST SETUP

- 21' perforating gun
- 6spf
- 60deg phasing
- 2' of captured perforations
- 4 different casing string sizes
- No perforations captured within 3" of casing boundary



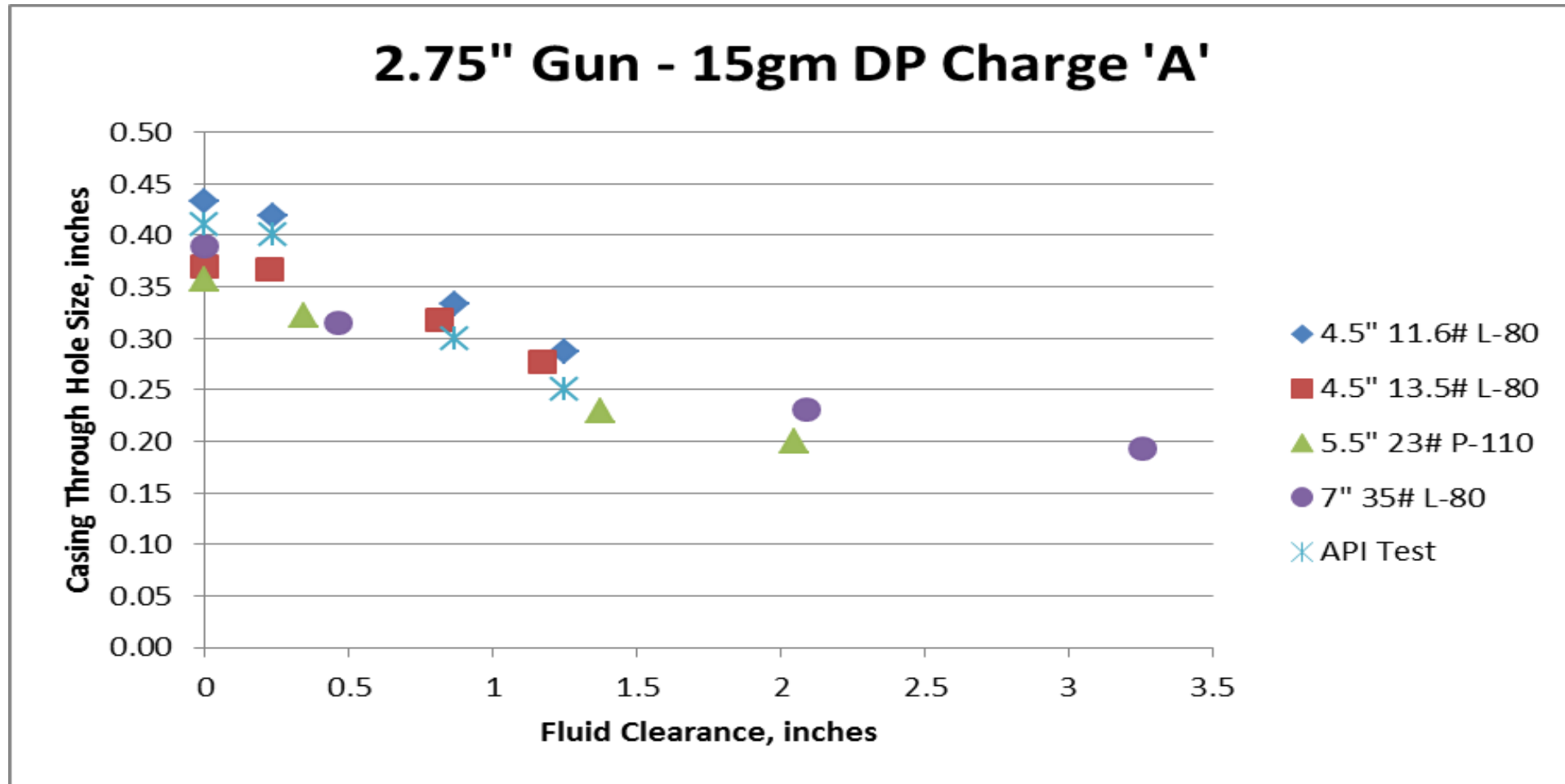
TEST SETUP

- Examine 4 different style DP charge designs that have Section 1 data to compare against
- Examine 1 charge that can be shot in multiple gun sizes to determine system effects
- Test in one casing that was the same as Section 1
- Test in 3 other casings that vary in weight, wall thickness, grade, and diameter
- At least one casing size that have extreme far water clearances

15 Gm DP Charge 'A'	2.75"	4.5" 11.6# L-80	4.5" 13.5# L_80	5.5" 23# P-110	7" 35# L-80
21 gm DP Charge 'B'	3.125	4.5" 11.6# L-80	5.5" 23# P-110	7" 35# L-80	9.625" 53.5# P-110
	3.375				
21 gm DP Charge 'C'	3.125				
25 gm DP Charge 'D'	3.375				

2.75" SYSTEM DATA

15 GRAM CHARGE 'A'



2.75" SYSTEM DATA

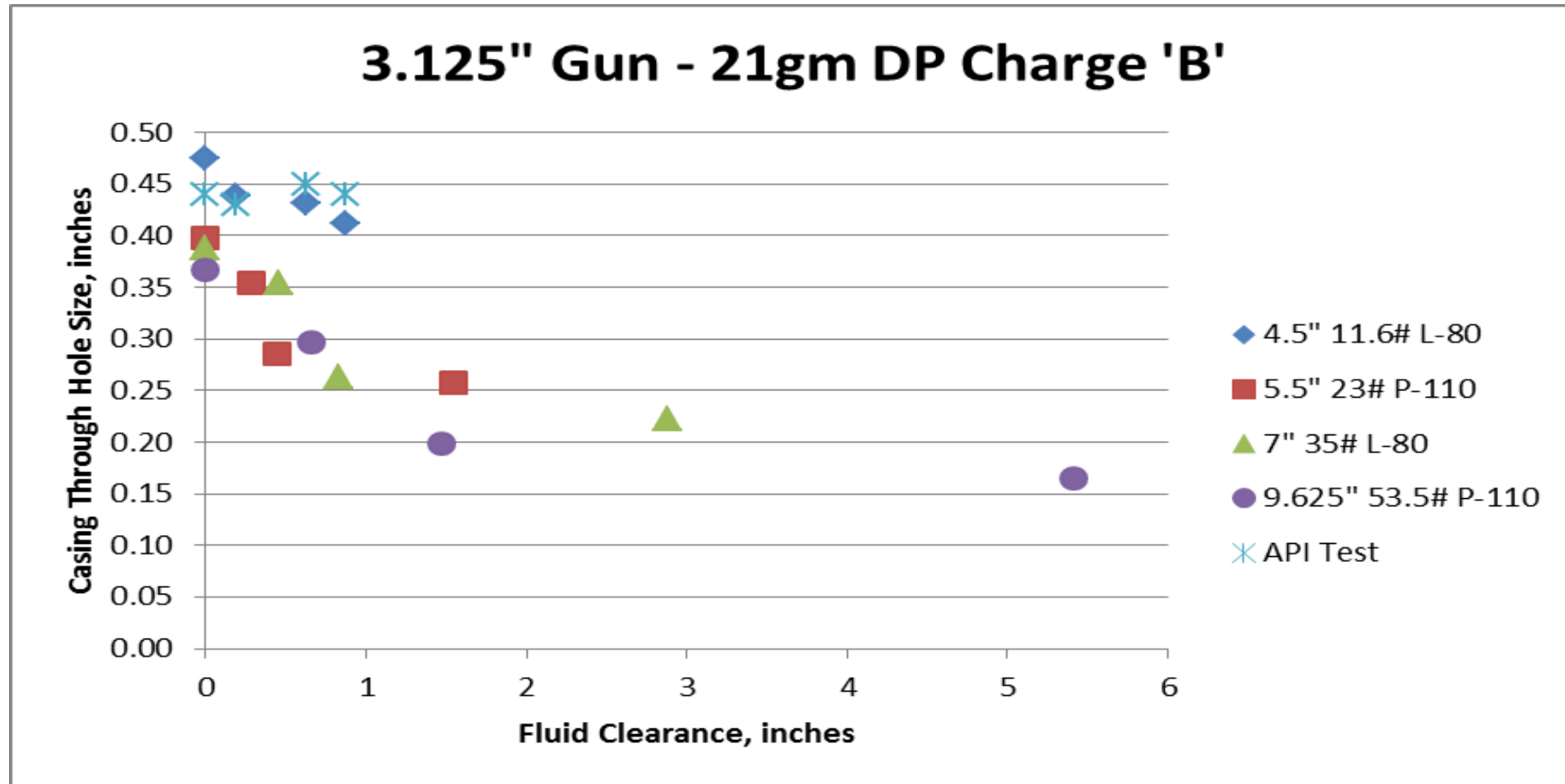
15 GRAM CHARGE 'A'

- API Confined vs Unconfined showed 8.5% larger hole size with no confinement
- Average simulation error was 14.4%
- Minimum simulation was -43% below actual results
- Maximum simulation was 58% over actual results

Performance Results																									
Method	API TEST DATA 4.5" 11.6#					4.5" 11.6#					4.5" 13#					5.5" 20#					7" 35#				
	0	60	120	180	Avg	0	60	120	180	Avg	0	60	120	180	Avg	0	60	120	180	Avg	0	60	120	180	Avg
Test Data	0.41	0.40	0.30	0.25	0.34	0.43	0.42	0.33	0.29	0.37	0.37	0.37	0.32	0.28	0.34	0.36	0.32	0.23	0.20	0.28	0.39	0.32	0.23	0.19	0.28
Simulation 1	0.40	0.42	0.41	0.38	0.41	0.40	0.42	0.41	0.38	0.41	0.39	0.40	0.4	0.37	0.39	0.39	0.41	0.36	0.3	0.37	0.39	0.41	0.36	0.3	0.37
Simulation 2	0.40	0.40	0.30	0.25	0.34	0.40	0.40	0.30	0.25	0.34	0.38	0.36	0.24	0.16	0.29	0.38	0.36	0.24	0.16	0.29	0.40	0.36	0.15	0.13	0.26
Simulation 1 Error	-2%	5%	37%	52%	18%	-7%	0%	24%	31%	10%	5%	8%	25%	32%	16%	8%	28%	57%	50%	33%	0%	28%	57%	58%	33%
Simulation 2 Error	-2%	0%	0%	0%	0%	-7%	-5%	-9%	-14%	-8%	3%	-3%	-25%	-43%	-14%	6%	13%	4%	-20%	4%	3%	13%	-35%	-32%	-8%

3.125" SYSTEM DATA

21 GRAM CHARGE 'B'



3.125" SYSTEM DATA

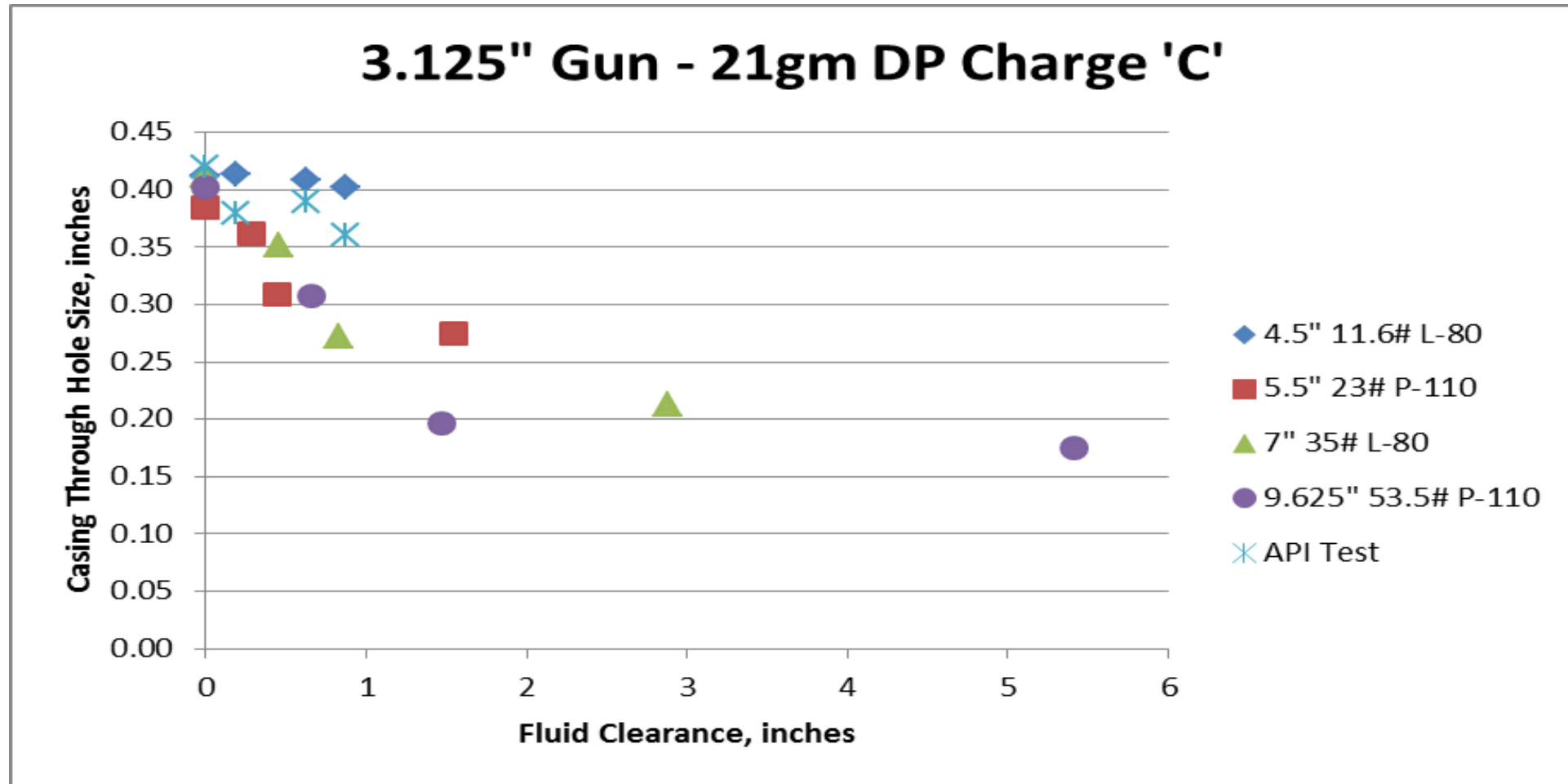
21 GRAM CHARGE 'B'

- API Confined vs Unconfined showed no change in performance
- Average simulation error was 8.3%
- Minimum simulation was -41% below actual results
- Maximum simulation was 40% over actual results

Performance Results																									
Method	API TEST DATA 4.5" 11.6#					4.5" 11.6#					5.5" 23#					7" 35#					9.625" 53.5#				
	0	60	120	180	Avg	0	60	120	180	Avg	0	60	120	180	Avg	0	60	120	180	Avg	0	60	120	180	Avg
Test Data	0.44	0.43	0.45	0.44	0.44	0.48	0.44	0.43	0.41	0.44	0.40	0.35	0.29	0.26	0.32	0.39	0.36	0.26	0.22	0.31	0.37	0.30	0.20	0.17	0.25
Simulation 1	0.46	0.43	0.42	0.39	0.43	0.46	0.43	0.42	0.39	0.43	0.44	0.41	0.35	0.29	0.38	0.46	0.42	0.27	0.18	0.34	0.44	0.40	0.15	0.10	0.27
Simulation 2	0.41	0.45	0.44	0.38	0.43	0.41	0.45	0.44	0.38	0.43	0.36	0.42	0.20	0.20	0.30	0.38	0.45	0.28	0.21	0.34	0.36	0.42	0.2	0.2	0.30
Simulation 1 Error	5%	0%	-7%	-11%	-3%	-4%	-2%	-2%	-5%	-3%	10%	17%	21%	12%	17%	18%	17%	4%	-18%	9%	19%	33%	-25%	-41%	9%
Simulation 2 Error	-7%	5%	-2%	-14%	-3%	-15%	2%	2%	-7%	-3%	-10%	20%	-31%	-23%	-6%	-3%	25%	8%	-5%	10%	-3%	40%	0%	18%	20%

3.125" SYSTEM DATA

21 GRAM CHARGE 'C'



3.125" SYSTEM DATA

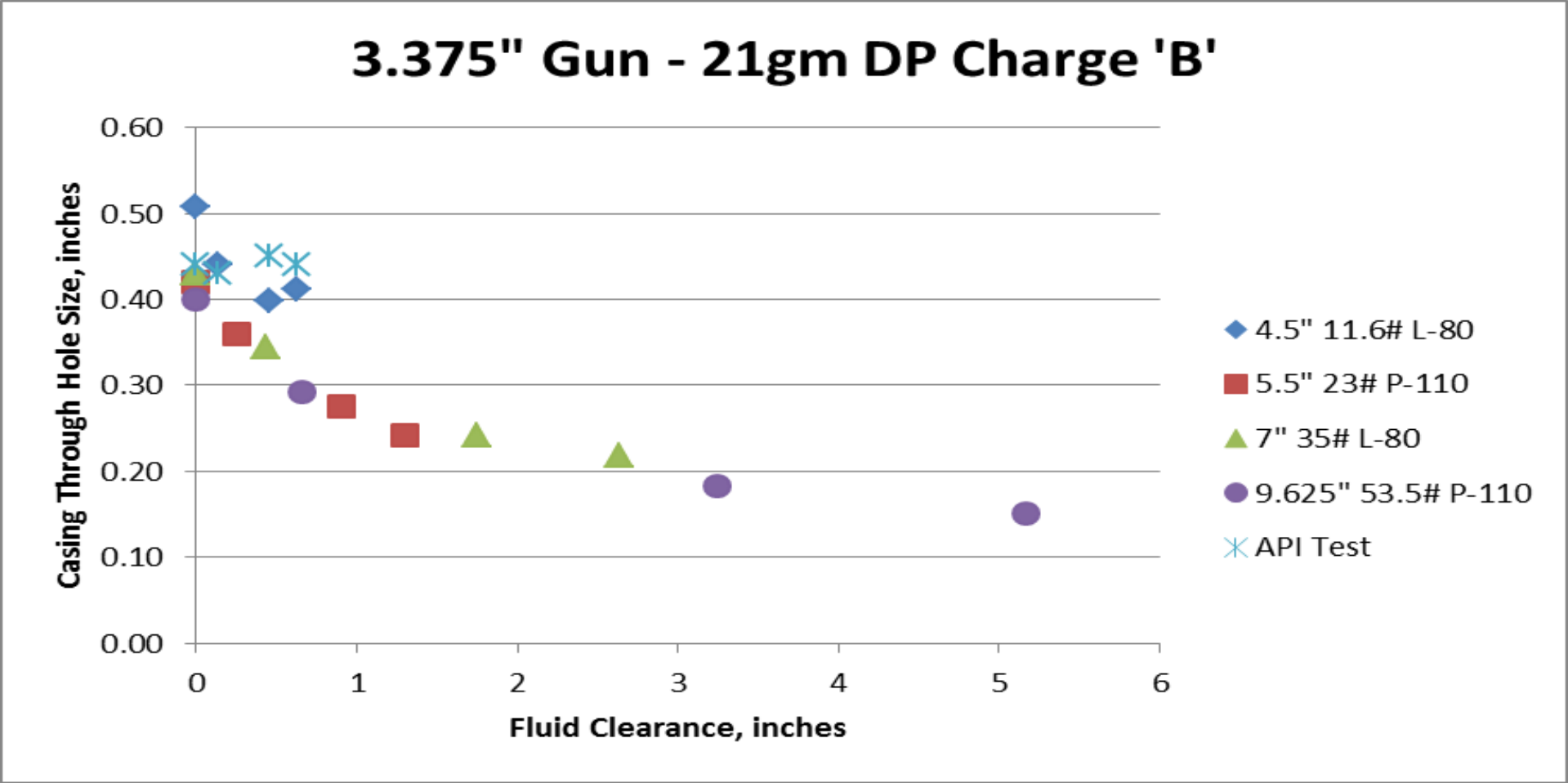
21 GRAM CHARGE 'C'

- API Confined vs Unconfined showed 5.0% larger hole size with no confinement
- Average Simulation error was 4.8%
- Minimum simulation was -50% below actual results
- Maximum simulation was 26% over actual results

Performance Results																									
Method	API TEST DATA 4.5" 11.6#					4.5" 11.6#					5.5" 23#					7" 35#					9.625" 53.5#				
	0	60	120	180	Avg	0	60	120	180	Avg	0	60	120	180	Avg	0	60	120	180	Avg	0	60	120	180	Avg
Test Data	0.42	0.38	0.39	0.36	0.39	0.41	0.41	0.41	0.40	0.41	0.39	0.36	0.31	0.28	0.33	0.41	0.35	0.27	0.21	0.32	0.40	0.31	0.20	0.18	0.26
Simulation 1	0.38	0.43	0.40	0.33	0.40	0.38	0.43	0.40	0.33	0.40	0.37	0.43	0.27	0.20	0.33	0.38	0.43	0.17	0.13	0.29	0.37	0.38	0.12	0.09	0.24
Simulation 2	0.39	0.41	0.39	0.35	0.39	0.39	0.41	0.39	0.35	0.39	0.33	0.37	0.35	0.31	0.35	0.35	0.40	0.30	0.22	0.33	0.33	0.39	0.20	0.20	0.29
Simulation 1 Error	-10%	13%	3%	-8%	2%	-7%	5%	-2%	-18%	-4%	-5%	19%	-13%	-29%	-1%	-7%	23%	-37%	-38%	-11%	-8%	23%	-40%	-50%	-6%
Simulation 2 Error	-7%	8%	0%	-3%	1%	-5%	0%	-5%	-13%	-5%	-15%	3%	13%	11%	5%	-15%	14%	11%	5%	3%	-18%	26%	0%	11%	10%

3.375" SYSTEM DATA

21 GRAM CHARGE 'B'



3.375" SYSTEM DATA

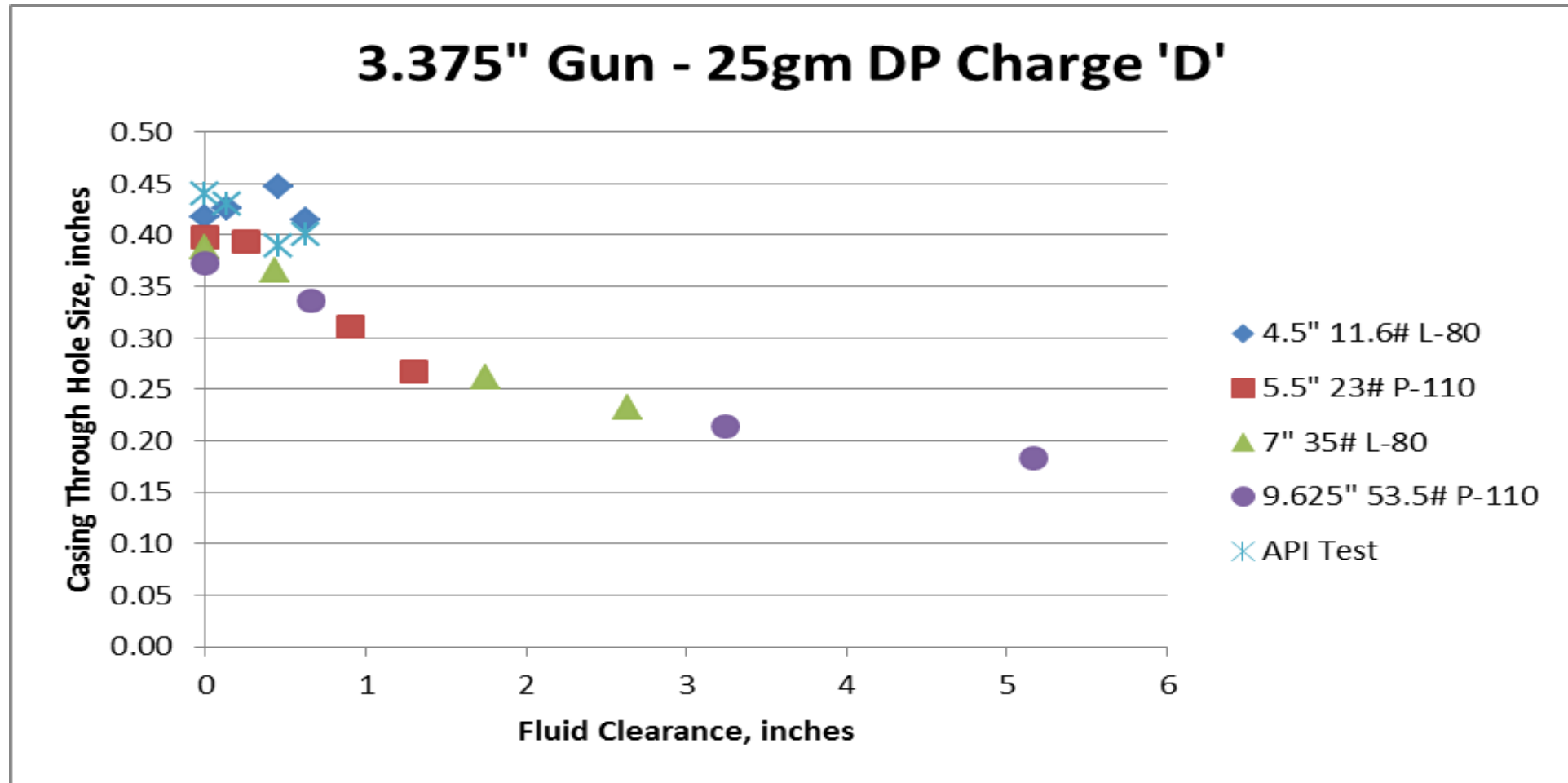
21 GRAM CHARGE 'B'

- API Confined vs Unconfined showed **2.3%** smaller hole size with no confinement
- Average Simulation error was 26%
- Minimum simulation was -14% below actual results
- Maximum simulation was 139% over actual results

Performance Results																									
Method	API TEST DATA 4.5" 11.6#					4.5" 11.6#					5.5" 23#					7" 35#					9.625" 53.5#				
	0	60	120	180	Avg	0	60	120	180	Avg	0	60	120	180	Avg	0	60	120	180	Avg	0	60	120	180	Avg
Test Data	0.44	0.43	0.45	0.44	0.44	0.51	0.44	0.40	0.41	0.43	0.42	0.36	0.28	0.24	0.32	0.43	0.34	0.24	0.22	0.30	0.40	0.29	0.18	0.15	0.25
Simulation 1	0.44	0.44	0.47	0.47	0.46	0.44	0.44	0.47	0.47	0.46	0.43	0.43	0.43	0.41	0.43	0.44	0.46	0.4	0.34	0.42	0.43	0.45	0.3	0.2	0.36
Simulation 2	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.42	0.42	0.41	0.41	0.42	0.44	0.44	0.43	0.44	0.44	0.42	0.42	0.43	0.27	0.40
Simulation 1 Error	0%	2%	4%	7%	3%	-14%	0%	18%	15%	6%	2%	19%	54%	71%	33%	2%	35%	67%	55%	39%	7%	55%	67%	33%	42%
Simulation 2 Error	0%	2%	-2%	0%	0%	-14%	0%	10%	7%	2%	0%	17%	46%	71%	30%	2%	29%	79%	100%	46%	5%	45%	139%	80%	59%

3.375" SYSTEM DATA

25 GRAM CHARGE 'D'



3.375" SYSTEM DATA

25 GRAM CHARGE 'D'

- API Confined vs Unconfined showed 4.8% larger hole size with no confinement
- Average Simulation error was 9.3%
- Minimum simulation was -28% below actual results
- Maximum simulation was 44% over actual results

Performance Results																									
Method	API TEST DATA 4.5" 11.6#					4.5" 11.6#					5.5" 23#					7" 35#					9.625" 53.5#				
	0	60	120	180	Avg	0	60	120	180	Avg	0	60	120	180	Avg	0	60	120	180	Avg	0	60	120	180	Avg
Test Data	0.44	0.43	0.39	0.40	0.41	0.42	0.43	0.45	0.42	0.43	0.40	0.39	0.31	0.27	0.35	0.39	0.37	0.26	0.23	0.31	0.37	0.34	0.21	0.18	0.28
Simulation 1	0.52	0.49	0.42	0.41	0.46	0.52	0.49	0.42	0.41	0.46	0.50	0.44	0.4	0.37	0.43	0.52	0.43	0.33	0.23	0.38	0.50	0.4	0.19	0.13	0.30
Simulation 2	0.44	0.43	0.39	0.39	0.41	0.44	0.43	0.39	0.39	0.41	0.42	0.4	0.35	0.32	0.37	0.44	0.39	0.3	0.22	0.34	0.42	0.37	0.19	0.19	0.29
Simulation 1 Error	18%	14%	8%	2%	11%	24%	14%	-7%	-2%	7%	25%	13%	29%	37%	21%	33%	16%	27%	0%	22%	35%	18%	-10%	-28%	8%
Simulation 2 Error	0%	0%	0%	-3%	0%	5%	0%	-13%	-7%	-4%	5%	3%	13%	19%	7%	13%	5%	15%	-4%	10%	14%	9%	-10%	6%	3%

DATA ANALYSIS

Average Hole Size per Casing String

- Average Simulation error was 15%
- Minimum simulation was -20% below actual results
- Maximum simulation was 59% over actual results

Test Results Summary																				
Gun Size	2.75"				3.125"								3.375"							
Charge	Charge 'A'				Charge 'B'				Charge 'C'				Charge 'B'				Charge 'D'			
Casing Diameter and Weight	4.5" 11.6#	4.5" 13.5#	5.5" 23#	7" 35#	4.5" 11.6#	5.5" 23#	7" 35#	9.625" 53.5#	4.5" 11.6#	5.5" 23#	7" 35#	9.625" 53.5#	4.5" 11.6#	5.5" 23#	7" 35#	9.625" 53.5#	4.5" 11.6#	5.5" 23#	7" 35#	9.625" 53.5#
Avg. Test Hole Size	0.37	0.34	0.28	0.28	0.44	0.32	0.31	0.25	0.41	0.33	0.32	0.26	0.43	0.32	0.30	0.25	0.43	0.35	0.31	0.28
Average Simulation 1 Hole Size	0.41	0.39	0.37	0.37	0.43	0.38	0.34	0.27	0.40	0.33	0.29	0.24	0.46	0.43	0.42	0.36	0.46	0.43	0.38	0.30
Average Error	10%	16%	33%	33%	-3%	17%	9%	9%	-4%	-1%	-11%	-6%	6%	33%	39%	42%	7%	21%	22%	8%
Average Simulation 2 Hole Size	0.34	0.29	0.29	0.26	0.43	0.30	0.34	0.30	0.39	0.35	0.33	0.29	0.44	0.42	0.44	0.40	0.41	0.37	0.34	0.29
Average Error	-8%	-14%	-20%	-8%	-3%	-3%	10%	20%	-5%	5%	3%	10%	2%	30%	46%	59%	-4%	7%	-4%	3%

DATA SUMMARY

- Both simulation methods used showed substantial variation and inconsistencies in the accuracy of their predictions
- There did not appear to be a common over or under prediction in performance
- The simulations showed large errors at a wide range of fluid clearances across the scenarios tested
- Test method showed a maximum of 8.5% variation from published Section 1 performance
- Standard Deviation did not increase substantially due to the reduced confinement effects

Gun Size	Charge	API Section 1 Confined		Unconfined Fluid Test		Hole Size % Difference
		Average Hole Size, in.	Standard Deviation, in.	Average Hole Size, in.	Standard Deviation, in.	
2.75"	Charge 'A'	0.34	0.06	0.37	0.08	8.5%
3.125"	Charge 'B'	0.44	0.02	0.44	0.03	0.0%
	Charge 'C'	0.39	0.04	0.41	0.02	5.0%
3.375"	Charge 'B'	0.44	0.02	0.43	0.04	2.3%
	Charge 'D'	0.41	0.04	0.43	0.02	4.8%

TEST BENEFITS

- Extremely quick and easy to conduct testing
- Does not require aging or curing of targets
- Can test in a wide range of casing sizes with a single gun test
- Can test effects of grade and yield in similar casing sizes while controlling test variables
- So far, has proven to have results that fall in line with Section 1 results and allowable tolerances
- Can be easily witnessed for a registered test
- Offers comparative data to compare against Section 1 data as a baseline metric
- Most importantly, provides a true and tested value to performance that is more accurate than some simulations can achieve

CONCLUSIONS

- Appears to have minimal performance variation in the 4 Deep Penetrating charge designs tested in this research
- Big Hole designs have not been proven out, however this has not been discussed as being necessary for them
- Could be a viable test options for unique multistring perforating designs
- Has been proven in limited testing to be within tolerances to API Section 1 test results
- To date, there has been a growing interest in collecting accurate Hole Size performance data in alternate casings to justify pursuing this initiative
- Section 1 casing recommendations are often not used for the gun sizes found in the standard
- This recommended test method offers a viable, cost effective, timely, and beneficial solution to obtaining shaped charge hole size performance

FUTURE WORK

- This venture will require industry acceptance and to be proven out on a larger scale before it could be recommended as a testing standard
- This method would potentially require testing across several manufacturers to determine the accuracy across a range of perforating designs

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QUESTIONS? THANK YOU!

IPS 16-46

Consideration and Testing in Support of a
Potential Standardized Perforator Hole Size Test