DESIGN OF EXPERIMENTS (for a Precision Guided Weapon)

D.1 Design of Experiments (DOE) Definitions

This appendix uses terminology specific to DOE; the following definitions should be applied while reading.

- Initial Factor – A factor determined to potentially impact the performance of the precision guided weapon system in which the weapon system operates. Initial factors are pulled from the test design framework developed by the Operational Test Activity (OTA) or from subject matter expert inputs. Initial factors are accepted on their own, combined with other initial factors and accepted, placed in recordable status, determined to be a demo item, or eliminated from consideration for the DOE design.
- Accepted Factor – a factor accepted as a standalone from an initial factor or through the combination of multiple initial factors. Accepted factors were input into JMP[1] software to create the DOE. Accepted factors are given levels.
- Level – the regions or levels that would be input into JMP software to create the DOE tables. Each accepted factor has a minimum of two levels.
- Recordable (Non-DOE) factor – a factor for which data are recorded during testing, but is not included in the DOE design. Factors that cannot be controlled, but might impact the performance the weapon system are placed into this category. These factors and their values will be recorded and compared against the performance of the weapon system to determine the impact they may have on the system.
- Demo Items – a factor or particular capability that will be tested against but is not incorporated into the DOE design created with JMP software. Demo items will be tested in standalone events if deemed to impact response variable, or incorporated into the DOE events when deemed to not impact response variable.
- Strike Warfare (STW) – the precision guided weapon system when used against Stationary Land Targets (SLT).
- Surface Warfare (SUW) – the precision guided weapon system when used against Moving Maritime Targets (MMT).

D.2.0 Overarching DOE Strategy

The precision guided weapon system effectiveness will depend on its ability to conduct two primary missions:

- Surface Warfare (SUW) against MMTs, and

[1] JMP (http://jmp.com/) is the registered trademark for a statistical software package that can assist with experimental design. Design Expert (http://www.statease.com/dx8descr.html), can also be used for DOE.

- Strike Warfare (STW) against SLTs

Design of Experiments was used to develop the DT&E, integrated test events, and the IOT&E. A significant amount of data from previous testing of this precision guided weapon system exists, which helped to refine the test design. Captive carry testing will be used to execute the majority of the testing. The captive carry testing uses a precision guided weapon system digital simulation consists of high fidelity guidance and electronics unit (GEU) and seeker models coupled with a target scene generator. The scene generator creates a perspective projection of the infrared target scene as presented to the seeker optics; the scenes are developed from empirical data and incorporate environmental effects such as time of day, sea state, humidity, and atmospheric conditions. Seeker imagery and GEU performance data captured during previous captive carry flight testing has been used to successfully validate the all digital precision guided weapon system simulation. The T&E WIPT consisting of the Technical Program Office, Lead Test Engineers, Systems Engineers, OTA testers, and DOE Subject Matter Experts determined that the appropriate response variables for evaluating the effectiveness of the system are:

- ***Aim point delta***: the distance between seeker aimpoint and the preplanned aimpoint at the final seeker aimpoint refinement. This response variable applies to both the captive carry (CC) and free flight (FF) live fire tests.
- ***Miss distance***: the distance between the preplanned aimpoint and the actual impact point for FF live fire shots.

Additionally, the T&E WIPT determined and defined the initial set of factors selected for both SUW and STW missions. These factors were then ranked based on their predicted impact to the response variable and their intended use in the design. Tables D.1 – D.2 provide the overall DOE strategy for each test objective (assessing weapon system effectiveness for SUW Missions and STW Missions).

Table D.1: Overview of DOE Strategy for Surface Warfare (SUW) Against Moving Maritime Targets (MMT)

		Test Phase		
		DT	**IT**	**IOT**
Critical Responses		**Aim Point Delta**	**Aim Point Delta**	**Aim Point Delta** **Miss Distance**
Factors	**Factor Levels**			
Sun Elevation	4 Levels	SV*	SV	SV
Target Type	4 Levels	SV	SV	SV

Target Range	Continuous	Record	Record	SV
Target Aspect	4 Levels	SV	SV	SV
Location Defenses	Maneuvering, RFCM, GPS Jamming	SV (Target Maneuver only)	SV(Target Maneuver only)	SV
Seeker Defenses	IRCM, Camouflage, Shipping Presence	Demo	Demo	SV

Table D.2: Overview of DOE Strategy for Surface Warfare (STW) Against Stationary Land Targets

		Test Phase		
		DT	IT	IOT
Critical Responses		Aim Point Delta	Aim Point Delta	Aim Point Delta
Factors	Factor Levels			
Terrain	4 Levels	Operational Testing will be used solely to determine system performance against the less challenging STL		SV
Target Orientation	4 Levels			SV
Contrast	Continuous			SV
Sun Elevation	4 Levels			SV
Defenses	Camouflage, IRCM, GPS Jamming			Demo

D.3.0 Developmental and Integrated Testing

Developmental and integrated testing will focus on the prioritized surface warfare (SUW) scenario against moving maritime targets (MMTs). The factors investigated in DT&E and IT are highlighted in more detail in table D-3 below.

D.3.1 DT/IT Power, Confidence, and Matrix for DOE Runs (MMT)

Using the accepted factors and assuming a normal distribution, the test design was created with JMP software for MMT using a D-optimal design for main effects and two-way interaction estimates. The matrix created includes 60 runs and using 80% confidence and provides sufficient a power to test for main effects. The power for detecting a 2 sigma shift difference in the response for Target Type is 80 percent, for Target Aspect is 63 percent, for Target Manuver is 98 percent, and for Sun Elevation is 51.5 percent. The lower power for Sun Elevation is due to the five levels of the factor and acceptable because it is expected that not all five levels will result in significantly different performance. The data will be collected during 60 captive carry runs. In addition to these 60 (30 DT&E, 30 IT&E) data runs, there will be 8 (4

DT&E, 4 IT&E) captive carry dress rehearsals and 4 (2 DT&E, 2 IT&E) free flight live fire runs where the data will be recorded during the MMT DT/IT testing.

Table D-3. MMT DOE for DT&E and IT&E

MMT DOE FACTORS (DT/IT)		
INITIAL FACTORS	**ACCEPTED FACTORS**	**LEVELS**
Thermal Contrast Day/Night Glint	Sun Elevation	≤ 1/2 Peak Rising - 1 > 1/2 Peak Rising - 2 > 1/2 Peak Setting - 3 ≤ 1/2 Peak Setting - 4 Night - 5
Target Speed Target Size	Target Type	Small (≤ ft) & Slow (≤ knots) Small (≤ ft) & Fast (> knots) Large (> ft) & Slow (≤ knots)
Target Aspect	Target Aspect	Head (0) Beam (90/270) Qtr (45/135/225/315) Tail (180)
TGT Maneuvering	TGT Maneuver	Evasive S Turn Non-maneuvering (constant course and speed)
RECORDABLE (NON-DOE)		
Sea State	Thermal Crossover	Humidity
DEMO ITEMS		
Multi Weapons Weapon Datalink	Datalink Source IRCM	Search Altitude WPN/Datalink RNG

The overall average miss distance will be compared against threshold values for the system to support the evaluation of the precision guided weapon system CPD requirements. ANOVA and regression analysis will also be performed based on the results. The analysis will provide additional evaluation understanding of overall system capabilities and limitations.

D.4.0 Operational Test DOE Development

In order to better evaluate precision guided weapon system performance in the STW and SUW operational environments, two distinct mission-based DOEs were developed: one for engaging stationary land targets (SLT) and one for engaging MMTs. Since the STW and SUW missions and requirements for precision guided weapon system employment are so different, one combined DOE would not adequately test the system.

STW requires the delivery platform to fly to the release point and launch the precision guided weapon system with prelaunch coordinates entered into the weapon. When the weapon approaches the target, the seeker will refine the flight profile to ensure the precision guided weapon system strikes the desired impact point on a stationary target. The precision guided weapon system incorporates a new seeker design.

SUW requires the delivery platform to detect the target with either a radar or targeting sensor, fly to the release point, and launch the precision guided weapon system. The delivery platform provides IFTU support to get the precision guided weapon system as close as possible to the MMT. As the weapon approaches the MMT, the seeker takes over, refining the flight profile in the final miles to ensure the precision guided weapon system strikes at the desired impact point on a moving target. These two distinct missions are described in detail below.

D.4.1 Operational Test DOE (STW)

Using DOE, the OT team leveraged the knowledge base from previous precision guided weapon system testing in developing the streamlined STW test design. The following assumptions provided the foundation for selecting the factors and levels for the test design:

- the weapons procedures for employment against SLT remained unchanged from the legacy precision guided weapon system;
- the weapon Launch Area Region (LAR), release and separation characteristics from the launch aircraft, and warhead capabilities remained the same;
- the new seeker capabilities and limitations will be compared against the legacy precision guided weapon system seeker; and
- the same target set will be used for the comparison of seeker performance data as much as possible.

The DOE factors considered known capabilities and limitations of the legacy precision guided weapon system seeker.

The precision guided weapon system test design was created primarily for Captive Carry (CC) runs. Replication was used to increase the understanding of the effects size and variability of data for specific test runs while increasing the statistical power and confidence of the test. The breadth of the design, coupled with the ease of performing multiple CC runs in a short period of time against SLTs in STW scenarios, facilitated replication in a cost efficient matter. With targets grouped together in a target area it is possible to fly against three or four different targets during an event, but not possible to transit to a new area during the course of one flight. It was deemed effective and efficient to fly three runs against each target in the target area, allowing nine runs or greater to be performed during each flight.

Outside of the primary DOE for CC runs, a robust test against Global Positioning System (GPS) jamming and Infra-red Countermeasures (IRCM) was also developed. This test will be used to demonstrate the specific effects of GPS denial, IRCM, and camouflage on the precision guided weapon system seeker. The performance of the precision guided weapon system will be compared directly against the legacy system in this same environment.

In addition to the CC STW DOE matrix and the CC test against GPS jamming/IRCM described above, data from two Free Flights (FF)/live fire (performed in IT) will be evaluated and compared with the results from the CC runs. Each of the FF/live fire shots will have CC dress rehearsal runs performed prior to the weapon release. These CC dress rehearsal runs will occur on a flight prior to the actual FF event to run through the FF scenario and ensure pilot familiarization with the event. The data gathered during the CC dress rehearsal and the CC runs just prior to the launch will also be used to compare with previous data gathered during the CC DOE and CC test against GPS jamming.

Table D-4 presents the factors for STW during OT&E. Table D-5 and D-6 provide the test matrix.

Table D-4. OT&E Factors and Levels for STW

STW DOE FACTORS (OT)		
INITIAL FACTORS	ACCEPTED FACTORS	LEVELS
Terrain	Terrain	Desert Mountain Urban Littoral
Target Orientation	Target Orientation	Horizontal Face Vertical Face
Clutter Civil Structures Snow	Contrast	High Low
Thermal Contrast	Sun Elevation	<1/2 peak AM or PM >1/2 peak AM or PM
RECORDABLE (NON-DOE)		
Thermal Crossover		Humidity
DEMO ITEMS		
IRCM	Camouflage Day/Night	GPS jamming

D.4.1.1 Operational Test Power, Confidence, and Matrix for DOE Runs (STW)

Using the factors above and assuming a normal distribution, the design was created with JMP for STW using a full factorial design for main effects and two-way interaction estimates. The matrix created includes 32 runs, which will each be replicated three times, for a total of 96 runs. The replications are a result of efficient use of flight sortie time by repeating runs rather than repeating flights. This design used 80 percent confidence level and yielded a power of test of greater than 95 percent to detect a 1 sigma change in performance across all main effects and greater than 85 percent power for all two-factor interactions. The runs are displayed in Table D-3.

Table D-5. OT&E STW Run Matrix

OT STW Matrix Full Factorial						
High Humidity Det						
Run	Sun Elevation	Orientation	Contrast	Humidity	Terrain	Actual Target
1-3	<1/2 max	Horizontal	Low	High	Littoral	Corpus Christi Command Center Wall
4-6	<1/2 max	Horizontal	High	High	Littoral	Corpus Christi Hangar
7-9	<1/2 max	Vertical	Low	High	Littoral	Corpus Christi Small Building on Pier
10-12	<1/2 max	Vertical	High	High	Littoral	Corpus Christi Tower
13-15	<1/2 max	Horizontal	High	High	Urban	Orange Grove Roof of NE Bldg
16-18	<1/2 max	Horizontal	Low	High	Urban	Orange Grove Airfield Arresting gear building
19-21	<1/2 max	Vertical	Low	High	Urban	Orange Grove ILS Radar
22-24	<1/2 max	Vertical	High	High	Urban	Target TBD
25-27	>1/2 max	Horizontal	Low	High	Littoral	Corpus Christi Command Center Wall
28-30	>1/2 max	Horizontal	High	High	Littoral	Corpus Christi Hangar
31-33	>1/2 max	Vertical	Low	High	Littoral	Corpus Christi Small Building on Pier
34-36	>1/2 max	Vertical	High	High	Littoral	Corpus Christi Tower
37-39	>1/2 max	Vertical	High	High	Urban	Orange Grove Roof of NE Bldg
40-42	>1/2 max	Horizontal	Low	High	Urban	Orange Grove Airfield Arresting gear building
43-45	>1/2 max	Vertical	Low	High	Urban	Orange Grove ILS Radar
46-48	>1/2 max	Horizontal	High	High	Urban	Target TBD
Low Humidity						
Run	Sun Elevation	Orientation	Contrast	Humidity	Terrain	Actual Target
49-51	<1/2 max	Horizontal	High	Low	Mountain	Independence Courthouse Multi level Building
52-54	<1/2 max	Horizontal	Low	Low	Mountain	Independence Jailhouse Large building
55-57	<1/2 max	Vertical	Low	Low	Mountain	Independence Microwave Tower
58-60	<1/2 max	Vertical	High	Low	Mountain	Target TBD
61-63	<1/2 max	Horizontal	Low	Low	Desert	Trona Large Yellow Building
64-66	<1/2 max	Horizontal	High	Low	Desert	Trona Movie Theater
67-69	<1/2 max	Vertical	High	Low	Desert	Trona Post Office Wall
70-72	<1/2 max	Vertical	Low	Low	Desert	Ballarat Radar/R2508
73-75	>1/2 max	Horizontal	High	Low	Mountain	Independence Courthouse Multi level Building
76-78	>1/2 max	Horizontal	Low	Low	Mountain	Independence Jailhouse Large building
79-81	>1/2 max	Vertical	Low	Low	Mountain	Independence Microwave Tower
82-84	>1/2 max	Vertical	High	Low	Mountain	Target TBD
85-87	>1/2 max	Horizontal	Low	Low	Desert	Trona Large Yellow Building
88-90	>1/2 max	Horizontal	High	Low	Desert	Trona Movie Theater
91-93	>1/2 max	Vertical	High	Low	Desert	Trona Post Office Wall
94-96	>1/2 max	Vertical	Low	Low	Desert	Ballarat Radar/R2508

The overall average miss distance will be compared against threshold values for the system to support the evaluation of the precision guided weapon system CPD requirements. ANOVA and regression analysis will be performed as well, based on the results. The analysis will provide additional understanding of overall system capabilities and limitations.

D.4.1.2 Matrix for Demo and Countermeasure Runs (STW)

The STW demonstration items (IRCM, GPS jamming, GPS availability, and camouflage) will be demonstrated during the following 30 runs, which are displayed in Table D-6.

Twelve runs versus GPS jamming in mountainous terrain (six against co-altitude jamming)

Twelve runs in R-2505 versus multiple countermeasures in the White Sands area

Six runs in R-2505 versus multiple IR countermeasures.

Table D-6. OT&E STW Demo Run Matrix

Advanced Countermeasures								
Run	Sun Elevation	Orientation	Contrast	Humidity	Terrain	Actual Target	Jamming Profile	Countermeasure
1	>1/2 max	Vertical	High	Low	Mountain	GPS Jamming Parrot Peak Radar dish	25K to 20 degree	
2	>1/2 max	Vertical	High	Low	Mountain	GPS Jamming Parrot Peak Radar dish	25K to 20 degree	
3	>1/2 max	Vertical	High	Low	Mountain	GPS Jamming Parrot Peak Radar dish	25K to 20 degree	
4	<1/2 max	Vertical	High	Low	Mountain	GPS Jamming Parrot Peak Radar dish	Co altitude	
5	<1/2 max	Vertical	High	Low	Mountain	GPS Jamming Parrot Peak Radar dish	Co altitude	
6	<1/2 max	Vertical	High	Low	Mountain	GPS Jamming Parrot Peak Radar dish	Co altitude	
7	>1/2 max	Horizontal	High	Low	Mountain	GPS Jamming Parrot Peak Building roof	25K to 20 degree	
8	>1/2 max	Horizontal	High	Low	Mountain	GPS Jamming Parrot Peak Building roof	25K to 20 degree	
9	>1/2 max	Horizontal	High	Low	Mountain	GPS Jamming Parrot Peak Building roof	25K to 20 degree	
10	<1/2 max	Horizontal	High	Low	Mountain	GPS Jamming Parrot Peak Building roof	Co altitude	
11	<1/2 max	Horizontal	High	Low	Mountain	GPS Jamming Parrot Peak Building roof	Co altitude	
12	<1/2 max	Horizontal	High	Low	Mountain	GPS Jamming Parrot Peak Building roof	Co altitude	
13	<1/2 max	Vertical	Low	Low	Desert	2505 Sams Town T-Building	Point	Multiple/White Sands
14	<1/2 max	Vertical	Low	Low	Desert	2505 Sams Town T-Building	Point	Multiple/White Sands
15	<1/2 max	Vertical	Low	Low	Desert	2505 Sams Town T-Building	Point	Multiple/White Sands
16	>1/2 max	Vertical	Low	Low	Desert	2505 Sams Town T-Building	Point	Multiple/White Sands
17	>1/2 max	Vertical	Low	Low	Desert	2505 Sams Town T-Building	Point	Multiple/White Sands
18	>1/2 max	Vertical	Low	Low	Desert	2505 Sams Town T-Building	Point	Multiple/White Sands
19	<1/2 max	Horizontal	Low	Low	Desert	2505 Sams Small Building 1 Story	Point	Multiple/White Sands
20	<1/2 max	Horizontal	Low	Low	Desert	2505 Sams Small Building 1 Story	Point	Multiple/White Sands
21	<1/2 max	Horizontal	Low	Low	Desert	2505 Sams Small Building 1 Story	Point	Multiple/White Sands
22	>1/2 max	Horizontal	Low	Low	Desert	2505 Sams Small Building 1 Story	Point	Multiple/White Sands
23	>1/2 max	Horizontal	Low	Low	Desert	2505 Sams Small Building 1 Story	Point	Multiple/White Sands
24	>1/2 max	Horizontal	Low	Low	Desert	2505 Sams Small Building 1 Story	Point	Multiple/White Sands
25	<1/2 max	Vertical	Low	Low	Desert	2505 POL Coles Flat	Point	Laser CM and Flames
26	<1/2 max	Vertical	Low	Low	Desert	2505 POL Coles Flat	Point	Laser CM and Flames
27	<1/2 max	Vertical	Low	Low	Desert	2505 POL Coles Flat	Point	Laser CM and Flames
28	>1/2 max	Vertical	Low	Low	Desert	2505 POL Coles Flat	Point	Laser CM and Flames
29	>1/2 max	Vertical	Low	Low	Desert	2505 POL Coles Flat	Point	Laser CM and Flames
30	>1/2 max	Vertical	Low	Low	Desert	2505 POL Coles Flat	Point	Laser CM and Flames

D.4.2 Operational Test DOE (SUW)

Using DOE, the OT team extensively leveraged the knowledge base from previous precision guided weapon system testing in developing the streamlined SUW test design. The following assumptions provided the foundation for selecting the factors and levels for the precision guided weapon system SUW test design:

- the weapon Launch Area Region (LAR), release and separation characteristics from the launch aircraft, and warhead capabilities remained the same;
- the new seeker capabilities and limitations will be compared against the legacy precision guided weapon system seeker.

The DOE factors included limitations of the legacy precision guided weapon system seeker.

The precision guided weapon system SUW test design was created primarily for CC runs. Replication was not used due to the large number of factors to be tested against and the difficulty in performing each run.

In addition to the CC SUW DOE matrix, data from two FF/live fire shots being performed in IT and data from two FF/live fire shots being performed in OT will be evaluated and compared with the results from CC runs. Each of the FF/live fire shots will have CC runs performed prior to the weapon release. These CC dress rehearsal runs will occur on a flight prior to the actual FF event. During the event for the FF/live fire shot, the profile will be flown CC a few times to ensure everything is working properly. The data gathered during the dress rehearsal and the CC runs prior to the launch will also be compared with previous data gathered during the CC DOE matrix.

Table D-7 presents the factors for SUW during OT&E.

Table D-7. OT&E Factors and Levels for SUW

SUW DOE FACTORS (OT)		
INITIAL FACTORS	ACCEPTED FACTORS	LEVELS
Thermal Contrast Day/Night Glint	Sun Elevation	≤ 1/2 Peak Rising - 1 > 1/2 Peak Rising - 2 > 1/2 Peak Setting - 3 ≤ 1/2 Peak Setting - 4 Night - 5
Target Speed Target Size	Target Type	Small (≤100 ft) & Slow (≤ 15 knots) Small (≤100 ft) & Fast (> 15 knots) Large (>100 ft) & Slow (≤ 15 knots) Large (>100 ft) & Fast (> 15 knots)
Threat WPN Range Target Slant Range	Target Range	≤ 40 nm > 40 nm
Target Aspect	Target Aspect	Head (0) Beam (90/270) Qtr (45/135/225/315) Tail (180)
TGT Maneuvering RFCM GPS Jamming	Location Defenses	Yes
IRCM Camouflage Shipping presence	Seeker Defenses	Yes No
RECORDABLE (NON-DOE)		
Sea State	Thermal Crossover Humidity	Glint
DEMO ITEMS		
Multi-Weapons	Datalink Source	Weapon Datalink

D.4.2.1 Operational Test Power, Confidence, and Matrix for DOE Runs (SUW)

Using these factors and assuming a normal distribution, the design was created with JMP for SUW using a D-optimal design for main effects and two-way interaction estimates. The matrix created includes 80 runs using 80 percent confidence and yields a power of test of 99 percent to detect a 2 sigma change in performance for Target Range, Location Defenses, and Seeker defenses. The power for Target Type and Target Aspect is 68 percent. The power for Sun Elevation is 56 percent. The lower powers for the OT SUW factors are acceptable because the DT&E and IT&E will provide amplifying information to the OT&E. If factors are deemed to be insignificant in testing preceding the OT&E the test design will be revised to optimize power for the remaining factors in OT&E.

D.4.2.2 Additional SUW Runs

In addition to the 80 SUW test runs described above, a minimum of six CC runs will be conducted as dress rehearsal runs for the two free flight/live fire shots against MMT targets and then the two FF/live fire runs. The data will be recorded and compared to CC data. The specifics of these runs will be detailed in the Test Plan. See Table D-8.

Table D-8. OT&E SUW Free Flight

OT SUW Free Flight Matrix								
Run	Sun Elev.	Tgt Aspect	Tgt Type	Datalink Range	Humidity	Location Defenses	Seeker Defenses	Notes
65	2	Tail	Large/Slow	Long	Low	Yes	Yes	Dress
66	2	Tail	Large/Slow	Long	Low	Yes	Yes	Dress
67	2	Tail	Large/Slow	Long	Low	Yes	Yes	Dress
68	2	Tail	Large/Slow	Long	Low	Yes	Yes	Free Flight
69	3	Beam	Small/Fast	Short	Low	Yes	Yes	Dress
70	3	Beam	Small/Fast	Short	Low	Yes	Yes	Dress
71	3	Beam	Small/Fast	Short	Low	Yes	Yes	Dress
72	3	Beam	Small/Fast	Short	Low	Yes	Yes	Free Flight

D.4.3 Operational Test Data Analysis (STW & SUW)

The overall results of the response variable will be compared against threshold values for precision guided weapon system to support the resolution of COIs. ANOVA and regression analysis will be performed based on the results of the OT testing. This analysis will be utilized to understand system performance, the effects of the factors, and to provide tactical recommendations to the fleet operator in employment of precision guided weapon system.