

**DTFAC-16-C-00047**

**IN-PAVEMENT LIGHT FIXTURE TESTING  
AND ANALYSIS**

**FINAL SUMMARY PRESENTATION**

**IESALC Fall Technology Meeting  
Government Contacts Subcommittee**

**Dallas, TX – October 23, 2017**

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# OUTLINE

- General Material Information
- Key Points from current version of EB83
- Overview of Testing
  - Test procedures
  - Test results
  - Take-aways and observations





# GENERAL MATERIAL INFORMATION



## Bolt Specifications:

ASTM F593-13a – “Standard Specification for Stainless Steel Bolts, Hex Cap Screws, and Studs”

F593C - Austenitic Alloy Group 1 (includes 304SS, and others)

- Condition CW1 (cold worked)

F593P - Martensitic Alloy Group 5 (includes 410SS, and others)

- Condition H (hardened and tempered)

SAE J429 – “Mechanical and Material Requirements for Externally Threaded Fasteners”

Grade 2 - Carbon Steel, heat treatment not required

Grade 5 – Quenched and Tempered Carbon Steel



# GENERAL MATERIAL INFORMATION



Nominal Size	Description	ASTM F593	SAE J429		ASTM F593		SAE J429			
					table 4		calculated	table 5	75% of	
		yield strength (psi)	proof strength (psi)	tensile strength (psi)	stress areas(in^2)	yield load(lbs)	proof load(lbs)	proof load(lbs)	proof or yield	ultimate load(lbs)
3/8"	SAE J429 Grade 2 CS (Coated)	NA	55,000	74,000	0.0775	NA	4263	4250	3197	5735
3/8"	SAE J429 Grade 5 CS (Coated)	NA	85,000	120,000	0.0775	NA	6588	6600	4941	9300
3/8"	ASTM F593C Grade 304 SS	65,000	NA	100,000	0.0775	5038	NA	NA	3778	7750
				150,000						11625
3/8"	ASTM F593P 410 SS-black oxide	90,000	NA	110,000	0.0775	6975	NA	NA	5231	8525
				140,000						10850
7/16"	SAE J429 Grade 5 CS (Coated)	NA	85,000	120,000	0.1063	NA	9036	9050	6777	12756
7/16"	ASTM F593P 410 SS-black oxide	90,000	NA	110,000	0.1063	9567	NA	NA	7175	11693
				140,000						14882



# GENERAL MATERIAL INFORMATION



3/8" Head Markings



Grade 2



Grade 5



F593C



F593P

7/16" Head Markings







## GENERAL MATERIAL INFORMATION

### Light Fixtures:



#### Ductile Cast Iron Rings

Ultimate Tensile Strength and 0.2% Yield Strength Measured  
3 specimens from 3 different rings



#### Aluminum Forgings

Ultimate Tensile Strength and 0.2% Yield Strength Measured  
3 specimens from 3 different light fixture forgings





## GENERAL MATERIAL INFORMATION



### Marine Grade Anti-Seize





## GENERAL MATERIAL INFORMATION



### Bolt Torqueing

Star Pattern

Done twice for all test conditions

Holes 5 and 6 were always threaded  
fixture removal holes.







## GENERAL MATERIAL INFORMATION

### Material Re-use:

No material was re-used after application of failure torque

Some re-use was done for non-destructive tests

No bolts or washers were re-used

All material was labeled and retained for future examination



## FAA ENGINEERING BRIEF 83



Torque versus tension relationship (2.1)

$$T = K * D * F_p$$

185inlbs maximum for a dry 18-8, should not use that torque for 18-8 with anti-seize (1.0a)

Dry grade 2 bolt:  $K=0.2$  (239inlbs to achieve 3188lbs (75% of proof)) (2.1)

185inlbs yields 2466 lbs (assuming  $K=0.2$ ) (2.1.1)

$\mu = 0.45$  (static friction coefficient for aluminum light on steel base) (2.1.1)

$K = 0.1$  to  $0.12$  for fluoropolymer coated bolts



## FAA ENGINEERING BRIEF 83



$$T = K * D * F_p$$

### F593C bolt Recommendations:

Section 3.1:

$$T = K * D * F_p = K * 0.375 * 2466 \text{ lbs} = \text{range of 141 to 159 inlbs}$$

### Grade 2 fluoropolymer coated bolt Recommendations:

Section 8.1:

$$T = K * D * F_p = 0.1 * 0.375 * 2500 = 93.75 \text{ inlbs}$$

“Rounded” to 120 inlbs





## OVERVIEW OF TESTING

### 4.1.1 Preliminary Test - Develop Torque - Tension Relationships

- 32 test conditions, 3 bolts each
- go to 75% of yield strength or proof load in 5 ftlb increments  
(from applicable standards)
- one extra bolt from each type was taken to failure to show how the K value changes.



# OVERVIEW OF TESTING



## 4.1.1 Preliminary Test - Develop Torque - Tension Relationships





# OVERVIEW OF TESTING



## 4.1.1 Preliminary Test - Develop Torque - Tension Relationships

- Test configuration
  - Must simulate installation as close as possible
  - Sliding interfaces are the key
    - Bolt – washer
    - Washer – Light Fixture
    - Bolt threads – Flange Threads
- Skidmore-Wilhelm Model J Bolt Tension Calibrator
  - Initial verification
- Operator variations







## OVERVIEW OF TESTING

### 4.1.1 Preliminary Test - Develop Torque - Tension Relationships

#### TEST RESULTS:

K values have a limited range where they are consistent

Marine Grade Anti-seize provides a very consistent K value

Black Oxide K values vary greatly

K value is dependent on all associated material's properties





## OVERVIEW OF TESTING

### 4.1.1 Preliminary Test - Develop Torque - Tension Relationships

#### TEST RESULTS:

Bolt	75% of proof or yield (lbs)	Light Fixture	Light Base Extension	Average K	Torque (inlbs)
3/8" SAE J429 Grade 5 (Red)	4941	LSA	IA	0.160	296.5
3/8" SAE J429 Grade 5 (Red)	4941	DIR	IA	0.166	307.6
3/8" SAE J429 Grade 5 (Red)	4941	LSA	IB	0.158	292.8
3/8" SAE J429 Grade 5 (Red)	4941	DIR	IB	0.162	300.2
3/8" SAE J429 Grade 2	3197	LSA	IA	0.198	237.4
3/8" SAE J429 Grade 2	3197	LSA	IB	0.199	238.6
3/8" SAE J429 Grade 2	3197	DIR	IB	0.197	236.2
3/8" SAE J429 Grade 2	3197	DIR	IA	0.216	259.0
3/8" F593P-black oxide(anti-seize)	5231	LSA	IA	0.212	415.9
3/8" F593P-black oxide(anti-seize)	5231	LSA	IB	0.215	421.7
3/8" F593P-black oxide(anti-seize)	5231	DIR	IA	0.198	388.4
3/8" F593P-black oxide(anti-seize)	5231	DIR	IB	0.215	421.7
3/8" F593C (anti-seize)	3778	DIR	IB	0.157	222.4
3/8" F593C (anti-seize)	3778	DIR	IA	0.172	243.7
3/8" F593C (anti-seize)	3778	LSA	IA	0.155	219.6
3/8" F593C (anti-seize)	3778	LSA	IB	0.153	216.8



## OVERVIEW OF TESTING



### 4.1.1 Preliminary Test - Develop Torque - Tension Relationships

#### TEST RESULTS:

Bolt	75% of proof or yield (lbs)	Light Fixture	Light Base Extension	Average K	Torque (inlbs)
7/16" SAE J429 Grade 5 (Red)	6777	LSA	IA	0.152	451.2
7/16" SAE J429 Grade 5 (Red)	6777	LSA	IB	0.157	466.0
7/16" SAE J429 Grade 5 (Red)	6777	LSA	IA (GARDSERT)	0.178	528.4
7/16" SAE J429 Grade 5 (Red)	6777	DIR	IA (GARDSERT)	0.166	492.7
7/16" SAE J429 Grade 5 (Red)	6777	DIR	IA	0.159	472.0
7/16" SAE J429 Grade 5 (Red)	6777	DIR	IB	0.176	522.4
7/16" F593P-black oxide(anti-seize)	7175	LSA	IA	0.239	751.1
7/16" F593P-black oxide(anti-seize)	7175	LSA	IB	0.257	807.7
7/16" F593P-black oxide(anti-seize)	7175	DIR	IA	0.208	653.7
7/16" F593P-black oxide(anti-seize)	7175	DIR	IB	0.251	788.8
7/16" F593P-black oxide(anti-seize)	7175	LSA	IA(GARDSERT)	0.252	791.9
7/16" F593P-black oxide(anti-seize)	7175	DIR	IA(GARDSERT)	0.255	801.4

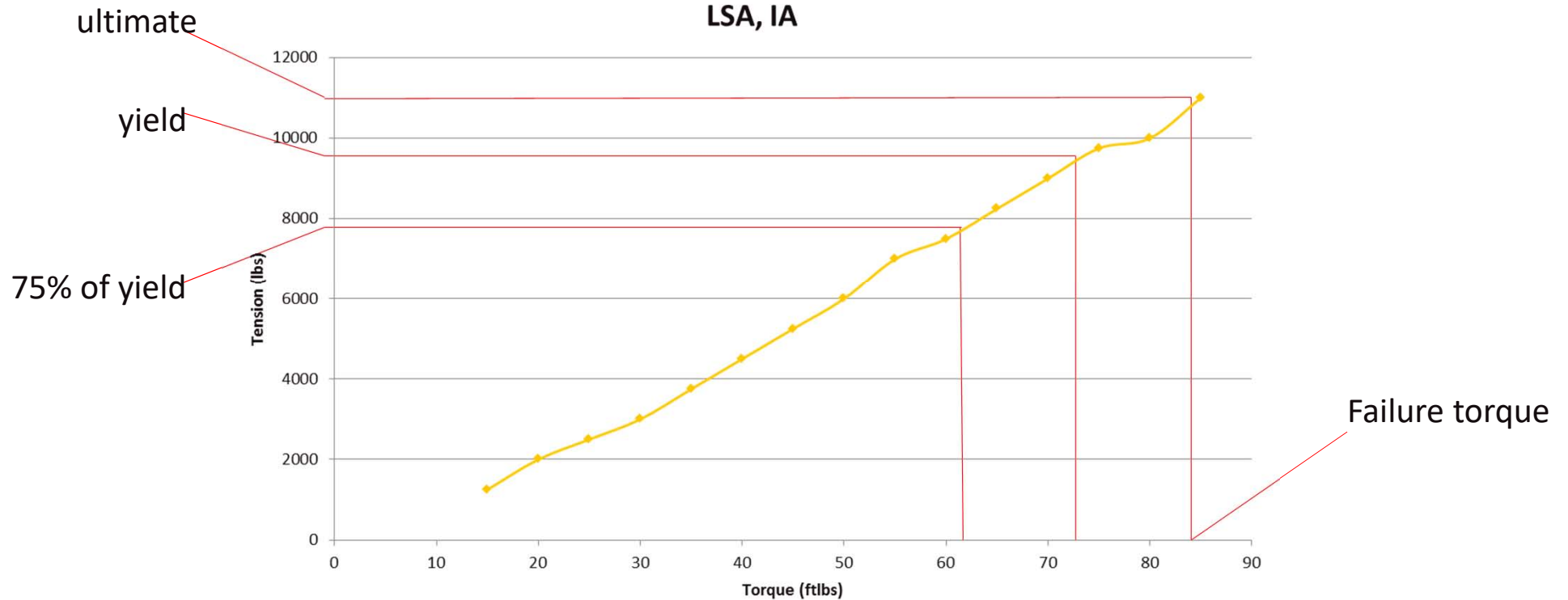


# OVERVIEW OF TESTING



## 4.1.1 Preliminary Test - Develop Torque - Tension Relationships

7/16" Black Oxide F593P  
LSA, IA



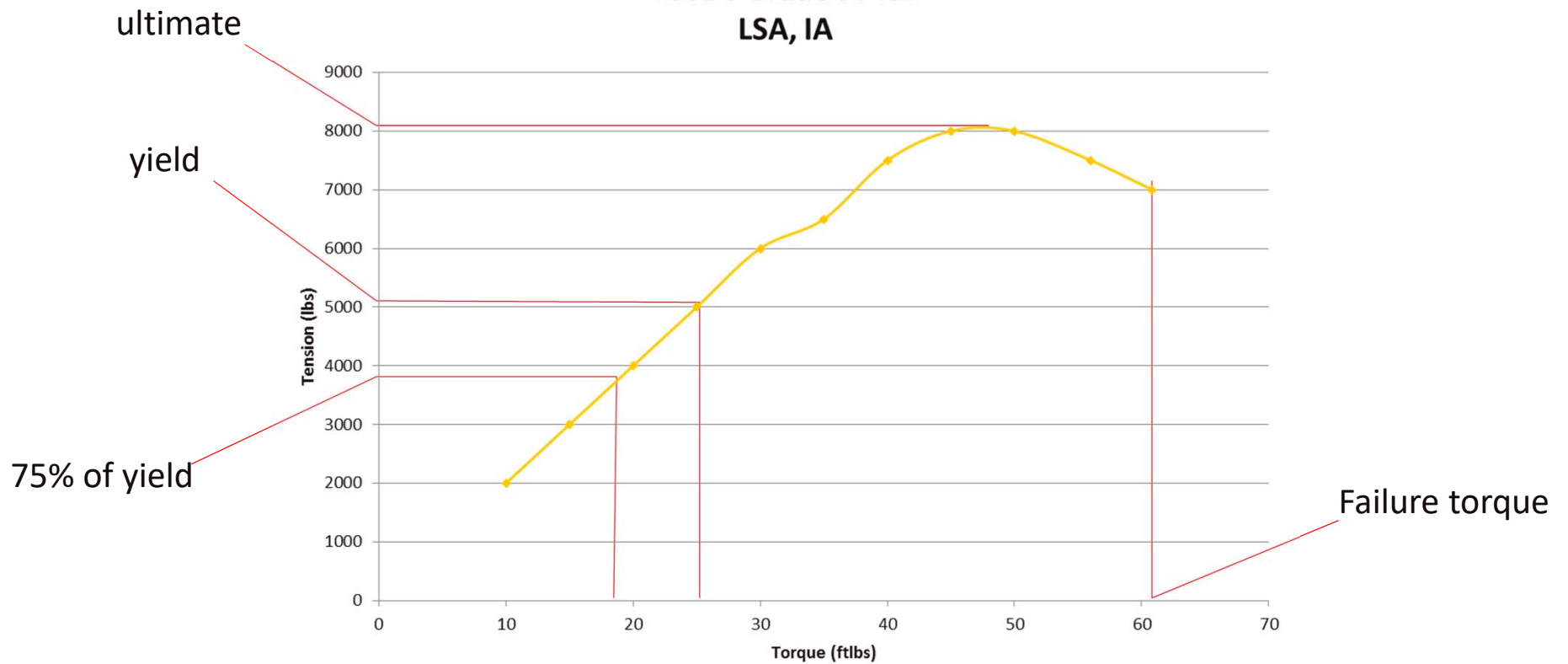


# OVERVIEW OF TESTING



## 4.1.1 Preliminary Test - Develop Torque - Tension Relationships

F593C Grade 304SS  
LSA, IA

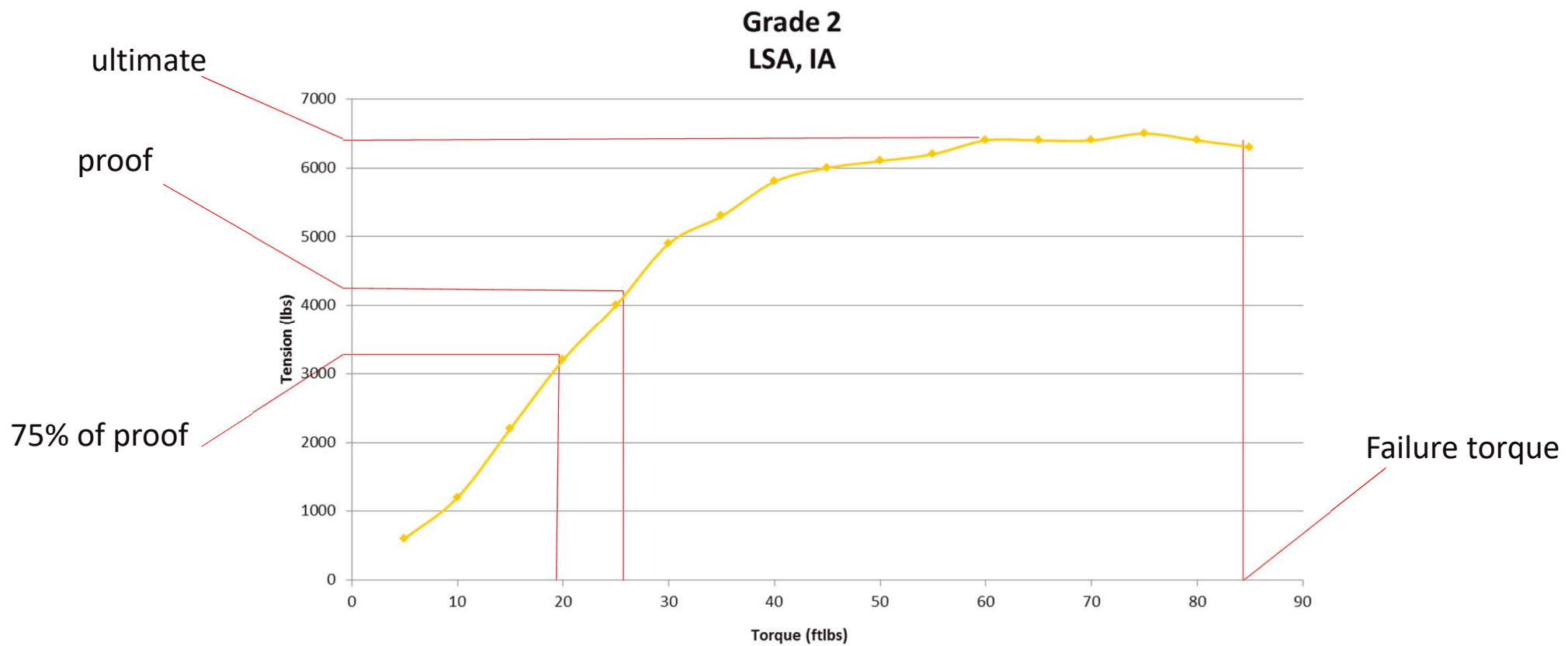




# OVERVIEW OF TESTING



## 4.1.1 Preliminary Test - Develop Torque - Tension Relationships





## OVERVIEW OF TESTING



### 4.1.2 Test 1 - Basic Test

- 24 test conditions, 6 bolts each
- Torque in 5ftlb increments until failure torque
- Failure torque is defined as peak torque or the point at which “the bolt is no longer able to generate additional installation torque.”
- Testing was continued until complete bolt failure.
- Peak force was calculated using the K value at bolt failure determined in the Preliminary Test.
- Test intended to show what part of the system is the “weak link”.



## OVERVIEW OF TESTING



### 4.1.3 Test 2 - Spacer Ring

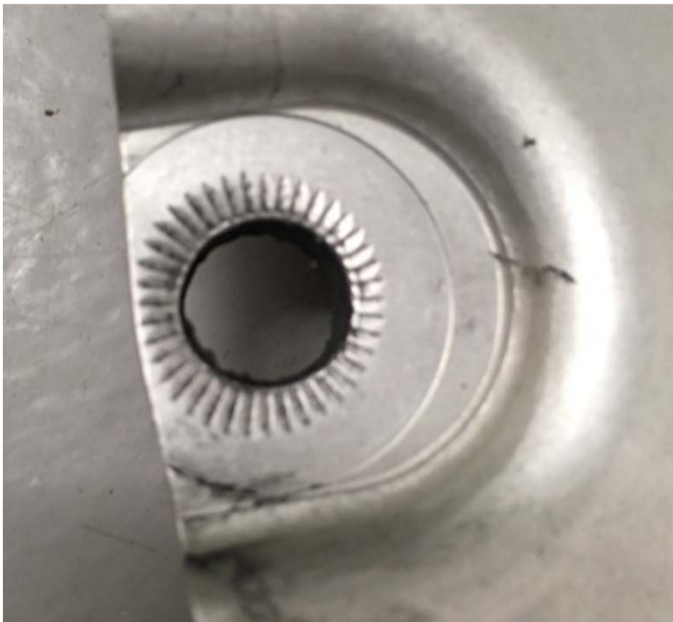
- 72 test conditions, 6 bolts each
- 3 combinations of 1/16", 1/2", 1" spacers (SS and CS)
- torque in 5ftlb increments until failure torque
- bolt tightening process the same as the basic test
- torque required to cause bolt failure was compared for all spacer combinations



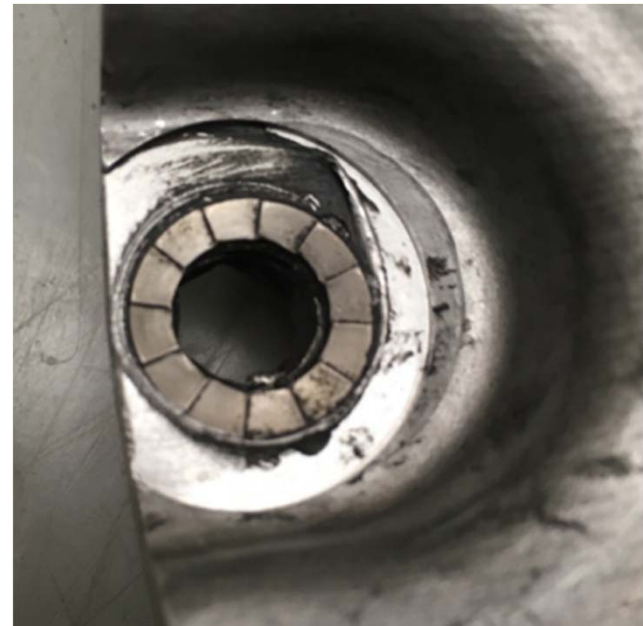


## OVERVIEW OF TESTING

### 4.1.3 Test 1 and Test 2 – Basic and Spacer TEST RESULTS



washer teeth abrasion - LSA



washer embedment - LSA



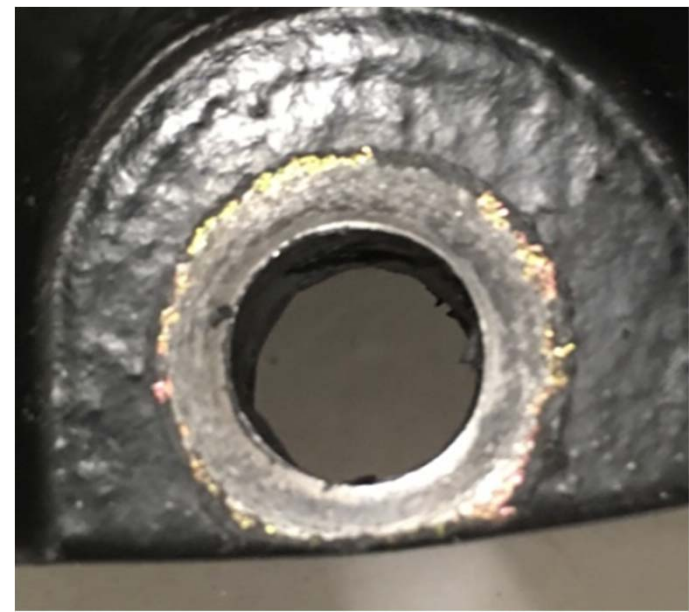
## OVERVIEW OF TESTING



### 4.1.3 Test 1 and Test 2 – Basic and Spacer TEST RESULTS



heavy machining and hole bulging - LSA



paint removal and abrasion - DIR





## OVERVIEW OF TESTING

### 4.1.3 Test 1 and Test 2 – Basic and Spacer

#### TEST RESULTS



Light machining of bolt hole - LSA



## OVERVIEW OF TESTING



### 4.1.3 Test 1 and Test 2 – Basic and Spacer

#### TEST RESULTS:

Peak forces determined through testing were consistent with specified ultimate forces for each bolt type.

The damage noted to system components was not just related to the clamping forces and material ultimate strength.

- Bolt hole clearance

- Material hardness

- Bolt “wandering”

No noticeable trend between the number of spacers and the torque required to cause bolt failure.





## OVERVIEW OF TESTING

### 4.1.4 Test 3 - Horizontal Shear Force Test

- 96 test conditions, 6 bolts each
- 75% of yield or proof load
- J429 Grade 2 testing repeated at EB 83 recommended torque
- F593C 304 SS testing repeated at EB 83 recommended torque







## OVERVIEW OF TESTING

### 4.1.4 Test 3 - Horizontal Shear Force Test

Procedure:

- 20 loadings at 3000lbs in the test direction
- Increase in 500lb increments until slippage of at least 0.020"
- Slip force used to calculate slip coefficient recorded at 0.020" slippage.
- Slippage of light fixture is measured with respect to the light base  
0.0001" resolution

Stopped test at full diameter clearance of bolt holes





## OVERVIEW OF TESTING



### 4.1.4 Test 3 - Horizontal Shear Force Test

Bolt Hole Clearance Measurements					
Clearances for 3/8" Nominal Bolts to Fixture Bolt Holes (inches)					
	Grade 2 (Star)	Grade 5 (GBA)	F593C (Viraj Logo)	F593C (THE)	F593P (LSF)
LSA	0.032	0.027	0.027	0.024	0.022
DIR	0.067	0.062	0.062	0.059	0.057
	F593P (SW)	F593P (VFM)			
LSA	0.032	0.027			
DIR	0.067	0.062			

Clearances for 7/16" Nominal Bolts to Fixture Bolt Holes (inches)					
	Grade 5 ( $\Delta$ )	Grade 5 (JH)	Grade 5 (WT)	F593P (LSF)	F593C (CNL)
LSA	0.037	0.038	0.033	0.036	0.036
DIR	0.031	0.032	0.027	0.030	0.030





## OVERVIEW OF TESTING

### 4.1.4 Test 3 - Horizontal Shear Force Test

3/8" Throat Projection to Base ID Clearances (inches)		
--	LSA	DIR
1A	0.052	0.049
1B	0.048	0.045

7/16" Throat Projection to Base ID Clearances (inches)		
--	LSA	DIR
1A	0.032	0.037
1B	0.028	0.033

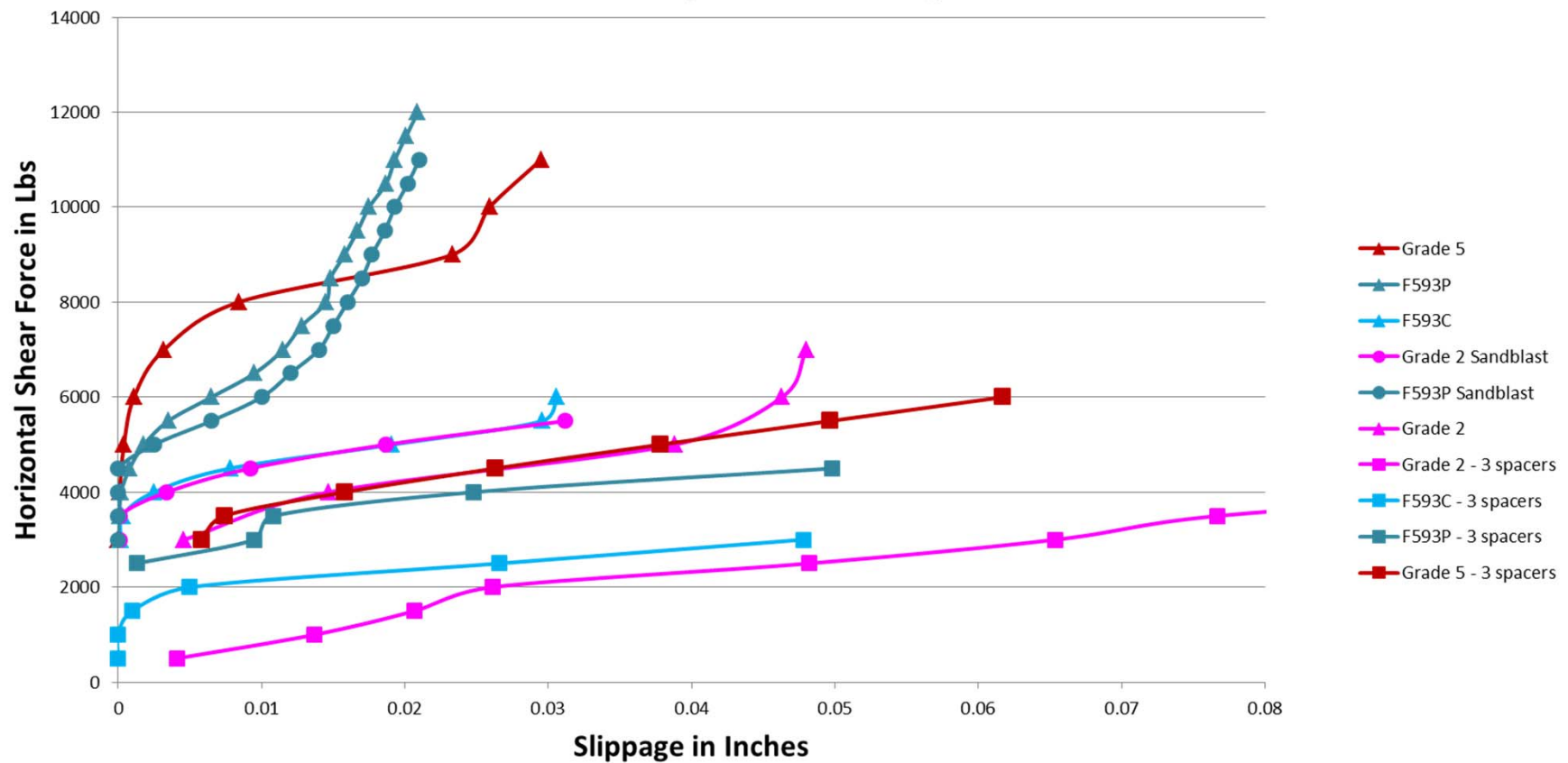


## OVERVIEW OF TESTING



### 4.1.4 Test 3 - Horizontal Shear Force Test

3/8" Bolts with LSA light fixture / IA light base extension



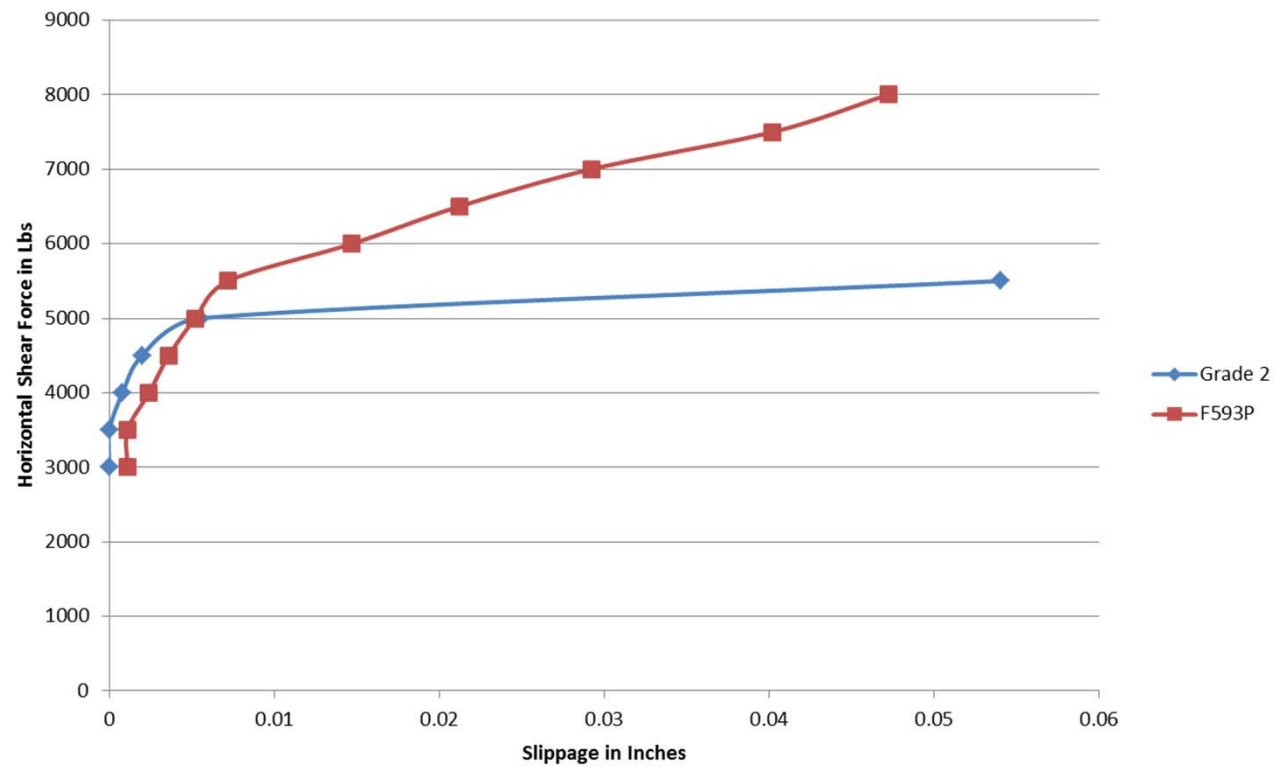


## OVERVIEW OF TESTING



### 4.1.4 Test 3 - Horizontal Shear Force Test

3/8" Bolts, Machined Ductile Iron Ring /  
Raw Carbon Steel Flange



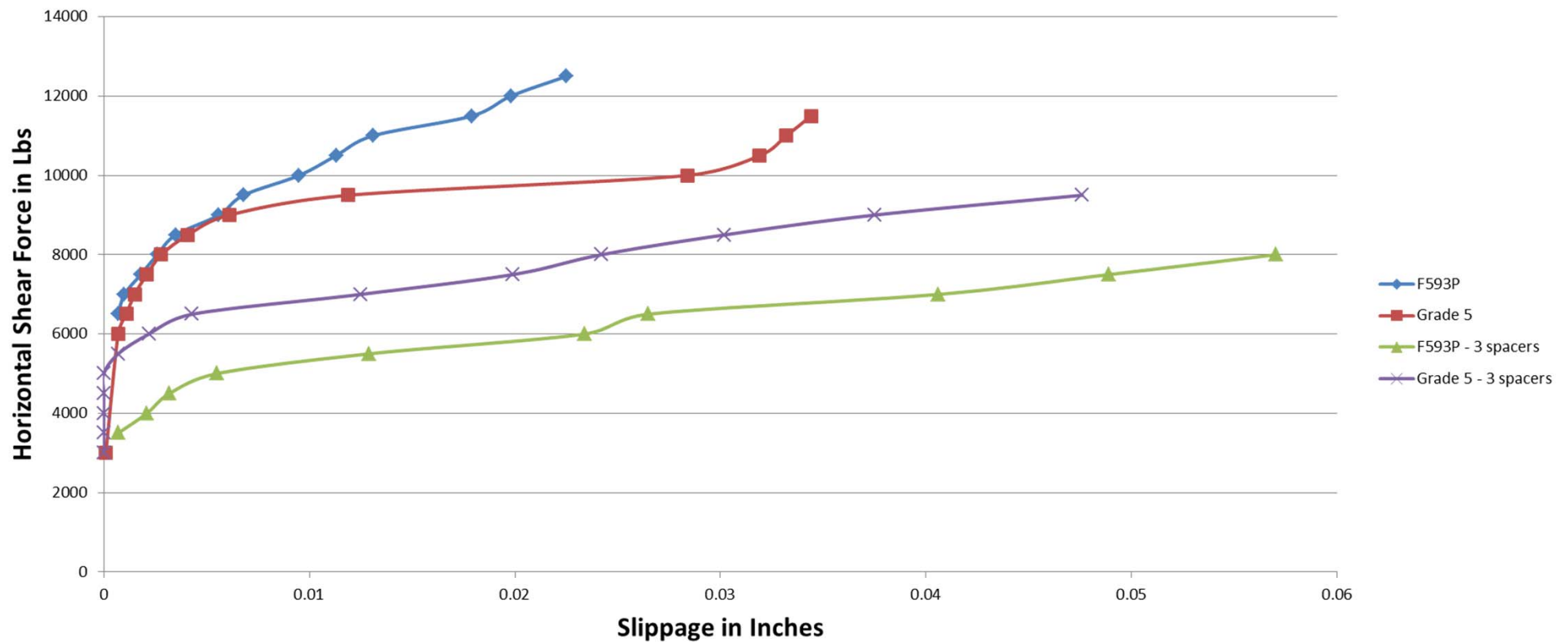




## OVERVIEW OF TESTING

### 4.1.4 Test 3 - Horizontal Shear Force Test

7/16" Bolts with LSA light fixture / IA light base extension







## OVERVIEW OF TESTING

### 4.1.4 Test 3 - Horizontal Shear Force Test

#### TEST RESULTS:

Did not successfully support aircraft loading as a slip-critical connection.

Spacer rings drastically reduce the slip coefficient in all cases.

Slip coefficients with aluminum light fixture generally better than with ductile iron ring

#### DISCUSSION POINT:

Is this bolted connection a slip-critical connection or a bearing connection?



## OVERVIEW OF TESTING



### 4.1.4 Test 3 - Horizontal Shear Force Test

TEST RESULTS:

TEST CONDITIONS (no orange highlighted conditions except where shown)	average slip coefficient	standard deviation
LSA with class IA base	0.286	0.038
LSA with class IB base	0.274	0.038
DIR with class IA base	0.217	0.056
DIR with class IB base	0.232	0.053
LSA with class IA base - 1/16" spacer	0.232	0.036
LSA with class IB base - 1/16" spacer	0.245	0.031
DIR with class IA base - 1/16" spacer	0.200	0.038
DIR with class IB base - 1/16" spacer	0.226	0.051
LSA with class IA base - 3 spacers	0.133	0.034
LSA with class IB base - 3 spacers	0.145	0.036
DIR with class IA base - 3 spacers	0.134	0.020
DIR with class IB base - 3 spacers	0.163	0.035
LSA with IA base (sandblasted flange)	0.311	0.034
DIR (machined interface) with IA base (raw flange)	0.247	0.056

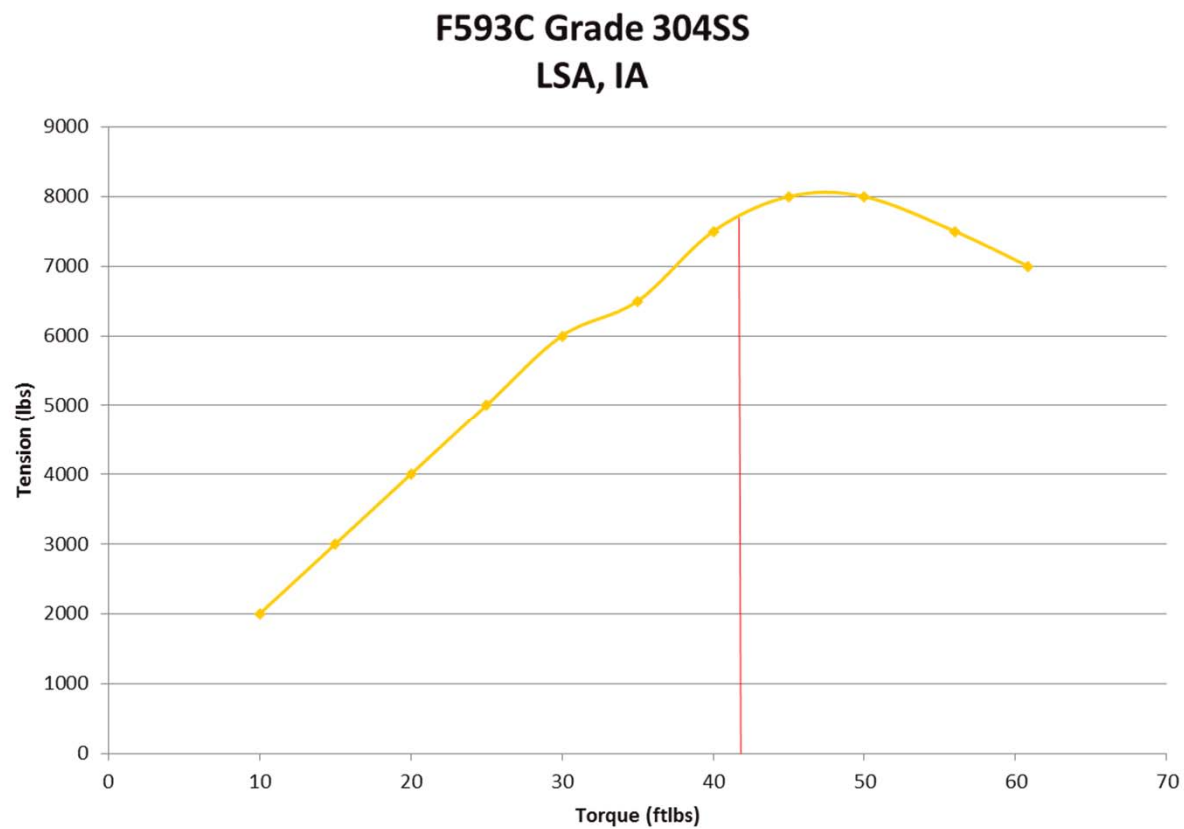




## OVERVIEW OF TESTING

### 4.1.4 Test 3 - Horizontal Shear Force Test (Supplemental Tests)

500 inlb shear tests with F593C bolts







## OVERVIEW OF TESTING

### 4.1.4 Test 3 - Horizontal Shear Force Test (Supplemental Tests)

500 inlb shear tests with F593C bolts

Bolt clamping force (lbs)	total clamping force (lbs)	light fixture	light base extension	spacers	0.020" slip force (lbs)	Slip Coefficient
7797	46782	LSA	IA	none	8000	0.17
6768	40608	LSA	IB	none	7000	0.17
7797	46782	DIR	IA	none	10000	0.21
7797	46782	DIR	IB	none	7000	0.15

Change in slip coefficient appears to be due to entering the plastic deformation region of the bolts.





## OVERVIEW OF TESTING

### 4.1.4 Test 3 - Horizontal Shear Force Test (Supplemental Tests)

Sandblasted L-868 IA top flange

Slight increase in slip coefficient.

TEST CONDITIONS (no orange highlighted conditions except where shown)	average slip coefficient	standard deviation
LSA with class IA base	0.286	0.038
LSA with IA base (sandblasted flange)	0.311	0.034

Research needed into different finishes.







## OVERVIEW OF TESTING

### 4.1.4 Test 3 - Horizontal Shear Force Test (Supplemental Tests)

Raw steel base flange with machined ductile iron

No large change in slip coefficients (slight increase).

TEST CONDITIONS (no orange highlighted conditions except where shown)	average slip coefficient	standard deviation
DIR with class IA base	0.217	0.056
DIR with class IB base	0.232	0.053
DIR (machined interface) with IA base (raw flange)	0.247	0.056







## OVERVIEW OF TESTING

### 4.1.4 Test 3 - Horizontal Shear Force Test (Supplemental Tests)

Aircraft Loading:

A380-800 aircraft (28,194 lb normal force and 22,556 lb traction force)

Ductile Iron Ring on Class IA light base extension ( $\mu = 0.217$ )

Calculated required horizontal shear force = **16,438 lbs**

7/16" F593P Test Results:

10962 lbs clamping force per bolt

1065 inlb (from  $K = 0.222$ )

Measured slip force = **14,000 lbs**





## OVERVIEW OF TESTING

### 4.1.4 Test 3 - Horizontal Shear Force Test (Supplemental Tests)

Aircraft Loading:

A380-800 aircraft (28,194 lb normal force and 22,556 lb traction force)

LSA light fixture on Class IA light base extension ( $\mu = 0.286$ )

Calculated required horizontal shear force = **14,493 lbs**

7/16" F593P Test Results:

7175 lbs clamping force per bolt

654 inlb (from  $K = 0.208$ )

Measured slip force = **12,500 lbs**





## OVERVIEW OF TESTING

### 4.1.4 Test 3 - Horizontal Shear Force Test (Supplemental Tests)

Precision flange ID to match light fixture throat projection

Cast Iron Ring - Machined Bottom Throat Projection OD (inches)	9.920
Class 1A - Precision Smaller Machined ID (inches)	9.947
Throat Projection Clearance (inches)	0.027
Bolt Hole Clearance (inches)	0.062

LSA Throat Projection OD (inches)	9.943
Class 1A - Precision Smaller Machined ID (inches)	9.947
Throat Projection Clearance (inches)	0.004
Bolt Hole Clearance (inches)	0.027





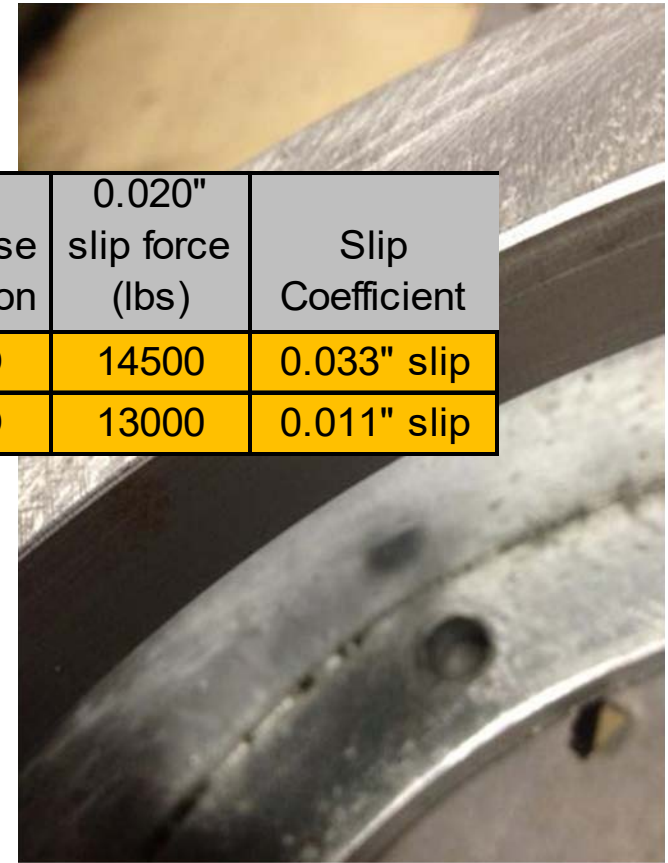
## OVERVIEW OF TESTING



### 4.1.4 Test 3 - Horizontal Shear Force Test (Supplemental Tests)

Precision flange ID to match light fixture throat projection

Bolt	Bolt clamping force (lbs)	total clamping force (lbs)	light fixture	light base extension	0.020" slip force (lbs)	Slip Coefficient
3/8" F593C (anti-seize)	3778	22668	DIR	IA *ID	14500	0.033" slip
3/8" F593C (anti-seize)	3778	22668	LSA	IA *ID	13000	0.011" slip







## OVERVIEW OF TESTING

### 4.1.4 Test 3 - Horizontal Shear Force Test (Supplemental Tests)

Shear testing to failure

Bolt	Bolt clamping force (lbs)	total force (lbs)	light fixture	light base	spacers	0.020" slip force (lbs)	Slip Coefficient
3/8" SAE J429 Grade 5	4941	29646	DIR	IA	1/16"+1/2"+1"	32000	test fixture broke
3/8" SAE J429 Grade 2	3197	19182	LSA	IA	none	47000	bar weld cracked
3/8" SAE J429 Grade 2	3197	19182	LSA	IA	1/16"+1/2"+1"	22500	6 broken bolts
3/8" F593P-black oxide(anti-seize)	5231	31386	LSA	IA	1/16"+1/2"+1"	31000	6 broken bolts







## OVERVIEW OF TESTING

### 4.1.5 Test 4 - Compressive Loading Test

- 32 test conditions, 6 bolts each
- 75% of yield or proof load
- J429 Grade 2 testing repeated at EB 83 recommended torque
- F593C 304 SS testing repeated at EB 83 recommended torque





## OVERVIEW OF TESTING



### 4.1.5 Test 4 - Compressive Loading Test

- 42H load procedure (3 loadings)
- start at 450psi (~51,000lbs for 12" fixture)
- increase incrementally until loss of preload or fixture damage
- loss of pre-load determined by torque verification between loadings



## OVERVIEW OF TESTING



### 4.1.6 Test 5 - Bolt Diameter Test

- 8 test conditions, 6 bolts each
- Used Gardsert threaded inserts  
model for 7/16" (pictured on the right)
- torque in 5ftlb increments until failure torque
- same procedure as the basic test
- Results are summarized with the basic test





## OVERVIEW OF TESTING



### 4.1.7 Test 6 - Vibration Test

#### Procedure Summary

- 48 test conditions, 6 bolts each
- 75% of yield or proof load
- procedure followed FAA AC 150/5345-46E (3 axis)
- done without spacers and with all 3 spacers
- controlled at the mounting point of base extension





## OVERVIEW OF TESTING



### 4.1.7 Test 6 - Vibration Test

#### Results Summary

- No loss of torque noted
- No material failures noted
- Dynamic response was measured on the fixture and on one bolt

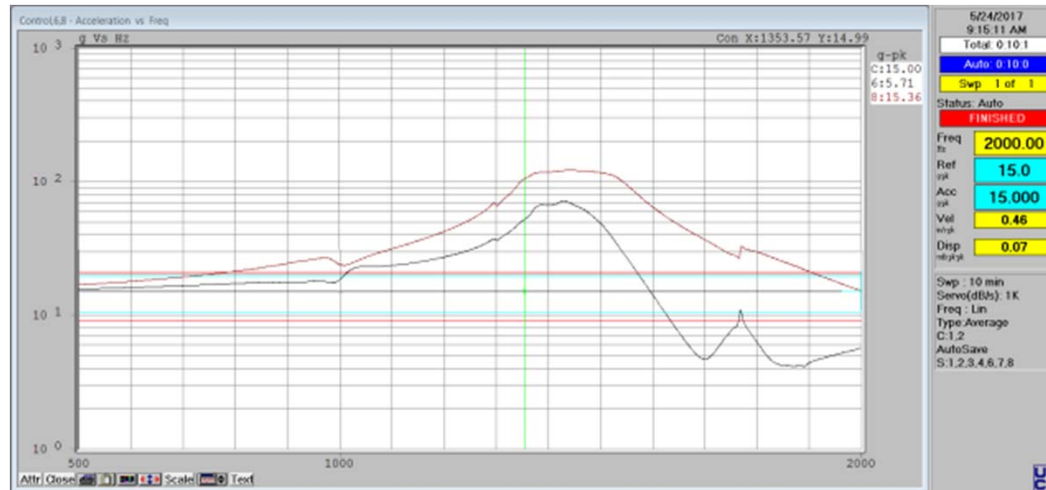




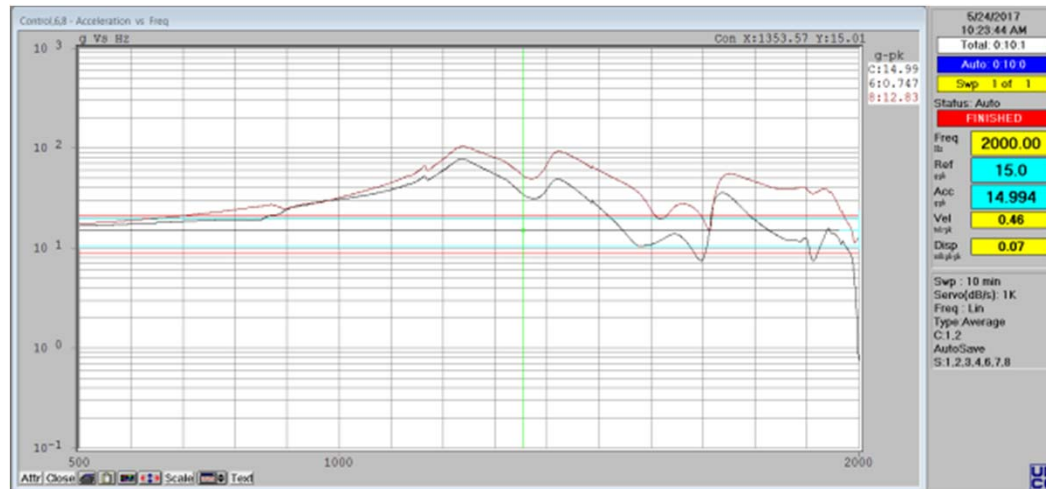
## OVERVIEW OF TESTING

### 4.1.7 Test 6 - Vibration Test Vertical Axis

No Spacers



3 Spacers



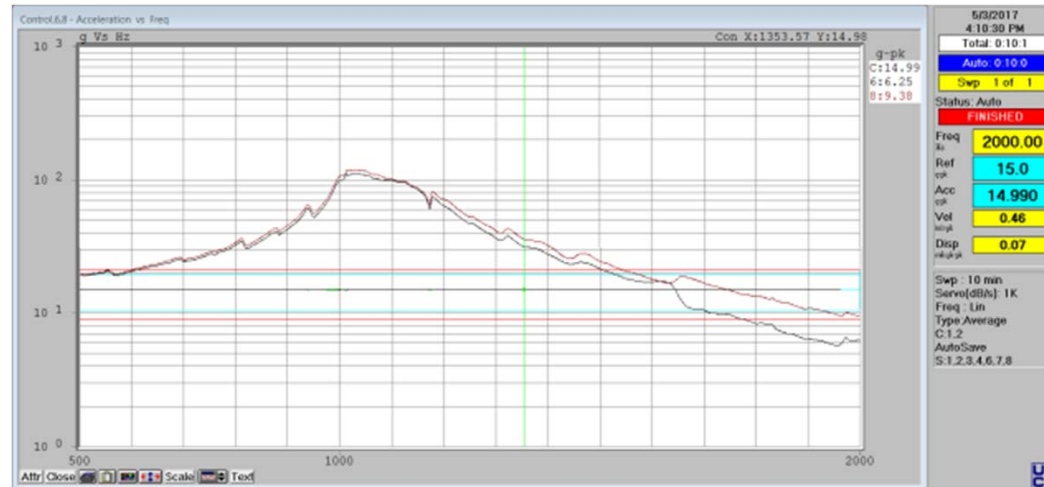




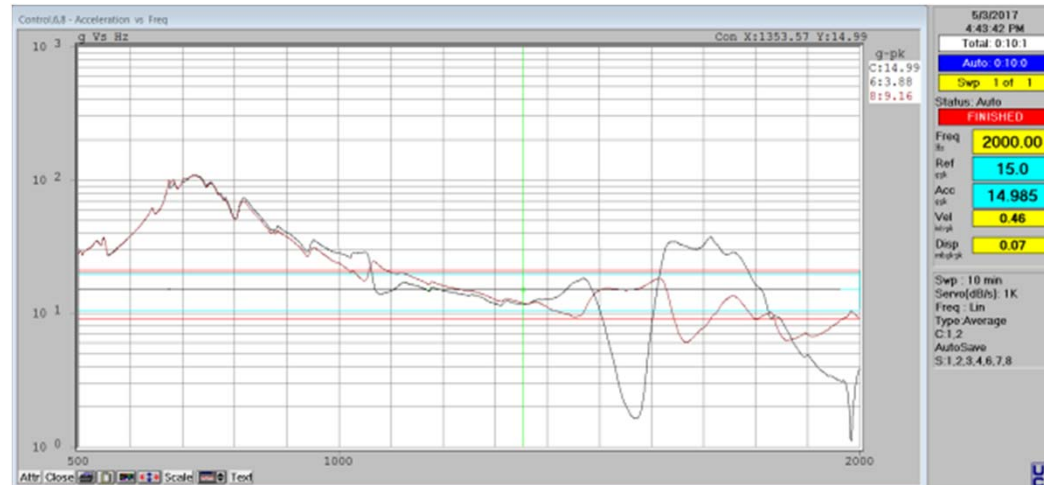
## OVERVIEW OF TESTING

### 4.1.7 Test 6 - Vibration Test Horizontal Axis

No Spacers



3 Spacers



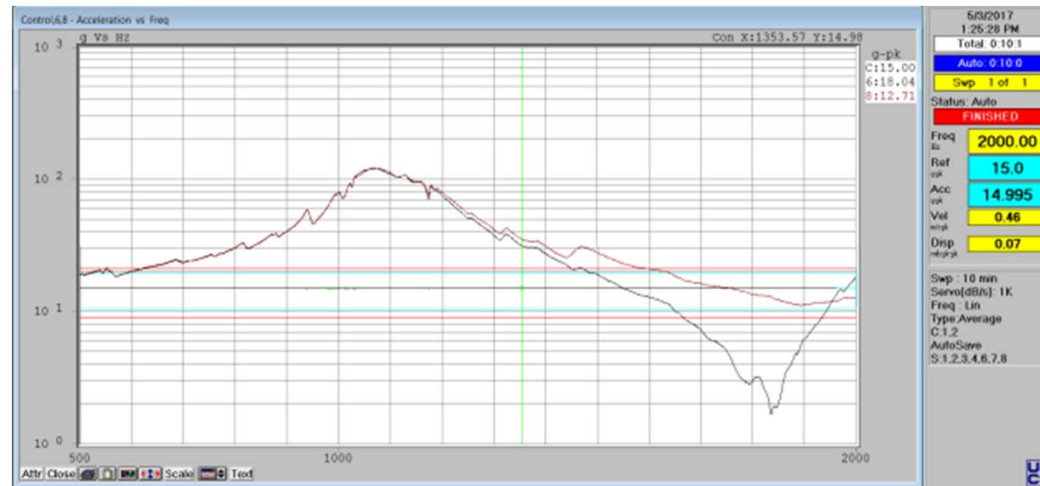




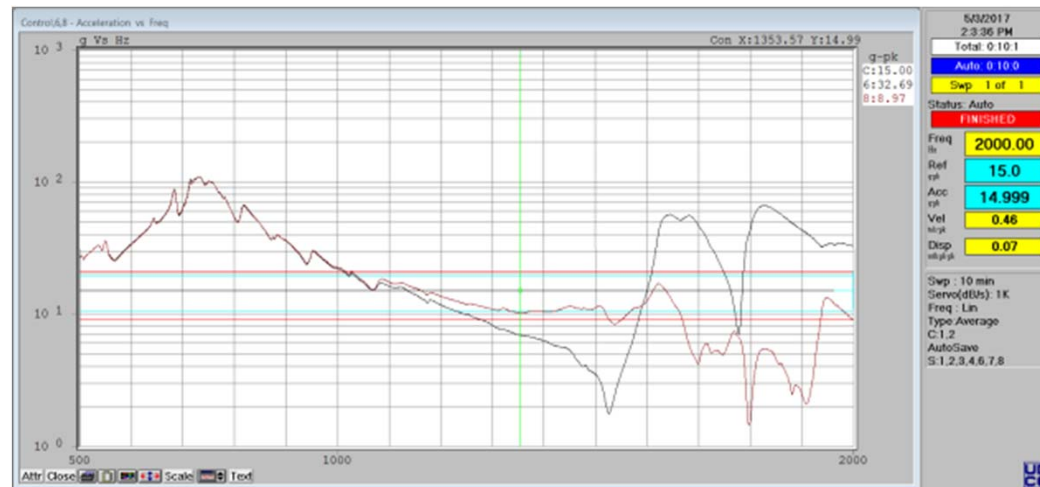
## OVERVIEW OF TESTING

### 4.1.7 Test 6 - Vibration Test Lateral Axis

No Spacers



3 Spacers





## OVERVIEW OF TESTING



### 4.1.8 Test 7 - Bolt Corrosion tests

Potassium Acetate

#### Procedure

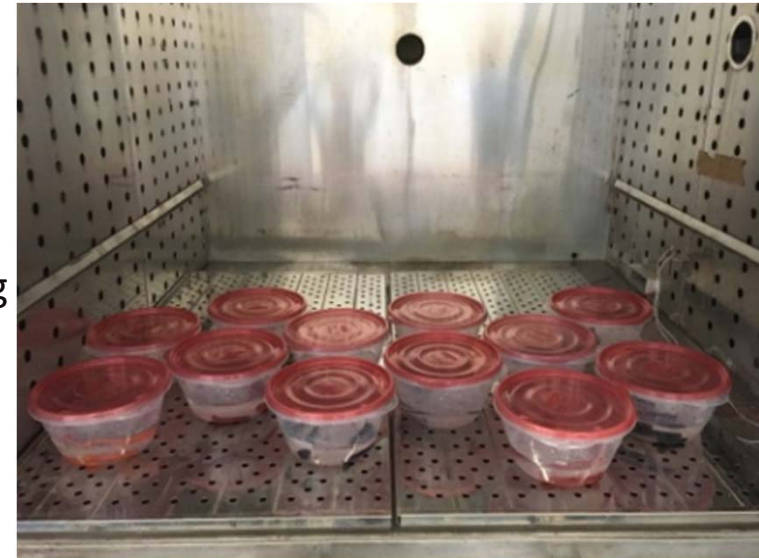
21 days at 90C (bolts submerged)

CRYOTECH E36® 50% aqueous solution

Some bolts were scuffed to remove coating

#### Results

Little to no effect on any bolts





## OVERVIEW OF TESTING



### 4.1.8 Test 7 - Bolt Corrosion tests

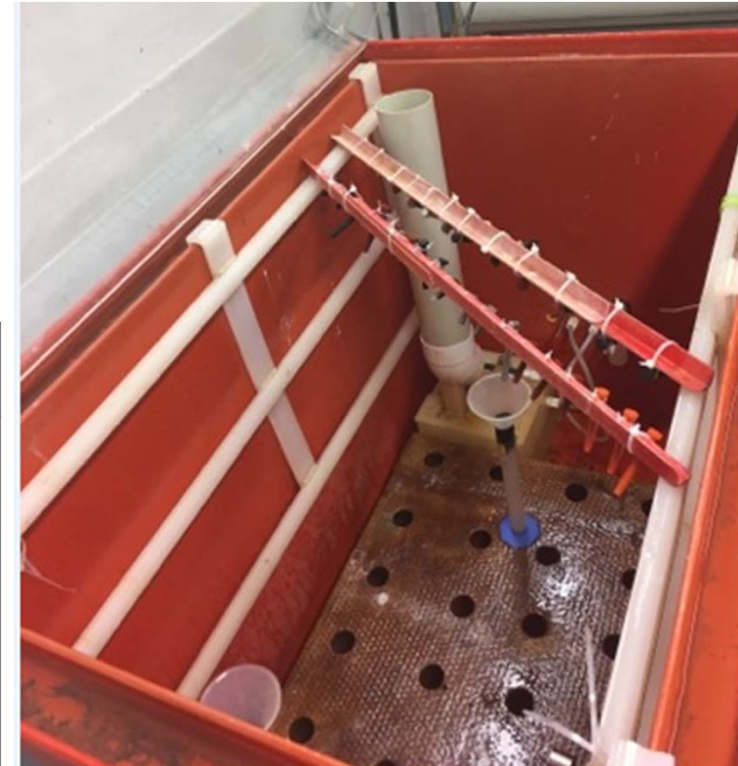
Salt Fog

MIL-STD-810F

4 days

30 bolts

Parameter	Requirement	Measured	
Fall Out Rate	1 - 3mL / 80cm <sup>2</sup> / hr	1.3	mL / hr
Fall Out Rate	1 - 3mL / 80cm <sup>2</sup> / hr	2.5	mL / hr
Salinity	5 ± 1%	5.5	%
Fall Out pH	6.5 - 7.2	6.9	NA
Chamber Temp.	35 ±2°C (95 ±4°F)	35	°C





## OVERVIEW OF TESTING

### 4.1.8 Test 7 - Bolt Corrosion tests

Salt Fog Test Results – Grade 2



Post test (non-scuffed)



Post test (scuffed)





## OVERVIEW OF TESTING



### 4.1.8 Test 7 - Bolt Corrosion tests

Salt Fog Test Results – F593C



Post test (non-scuffed)



## OVERVIEW OF TESTING

### 4.1.8 Test 7 - Bolt Corrosion tests

Salt Fog Test Results – Grade 5 3/8"



Post test (non-scuffed)



Post test (scuffed)





## OVERVIEW OF TESTING

### 4.1.8 Test 7 - Bolt Corrosion tests

Salt Fog Test Results – Black Oxide, 3/8"



Post test (non-scuffed)



Post test (scuffed)





## OVERVIEW OF TESTING

### 4.1.8 Test 7 - Bolt Corrosion tests

Salt Fog Test Results – Grade 5, 7/16"



Post test (non-scuffed)



Post test (scuffed)





## OVERVIEW OF TESTING

### 4.1.8 Test 7 - Bolt Corrosion tests

Salt Fog Test Results – Black Oxide, 7/16"



Post test (non-scuffed)



Post test (scuffed)







Questions?