LPI, Inc. Consulting Engineers

Advanced Analysis & Fitness for Service
Failure & Materials Evaluation
Nondestructive Engineering

Est. 1885

Performance of In-pavement Runway Light Fixture Assemblies

October 20, 2015

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Background

- Incidents involving dislodged in-pavement runway lights

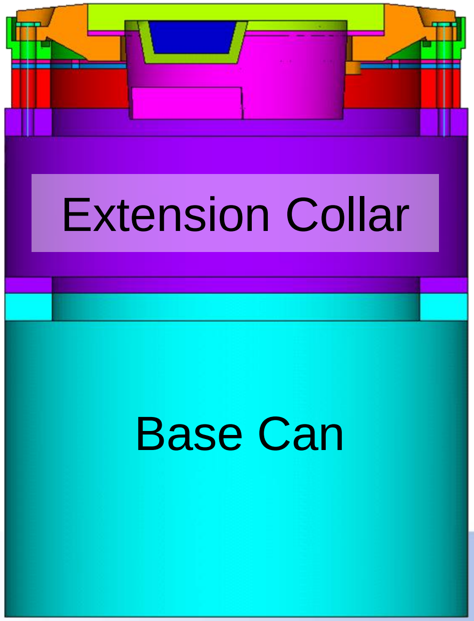
- Comprehensive engineering assessment performed in order to mitigate future light fixture issues

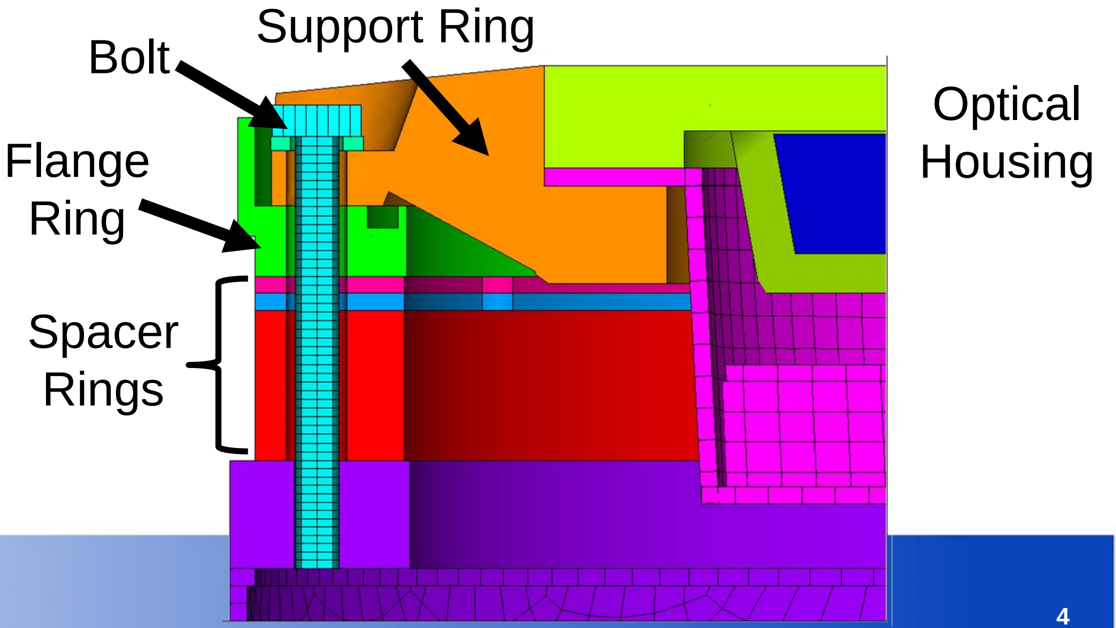
LPI Evaluation Overview

- Light Fixture and Bolt Failure Analyses
- Sampling Program
- Finite Element Analyses
- Torque Testing
- Instrumentation
- Recommendations and Findings

Light Fixture Assemblies

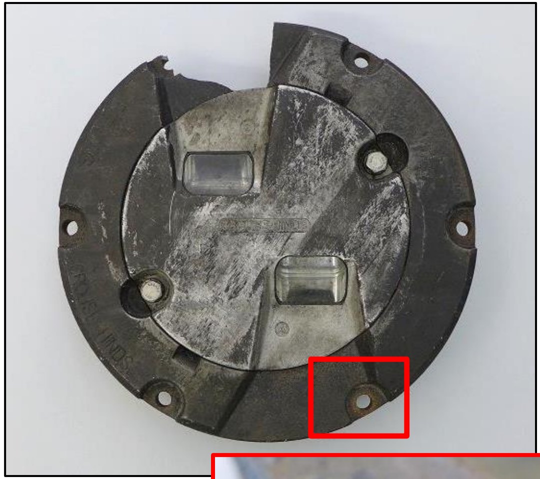
- 8-in. optical housing with 12-in. support ring
- Type 304 SS, Type 410 SS, coated carbon steel bolts

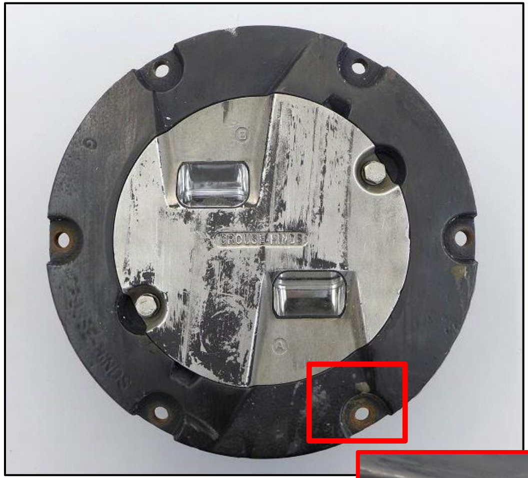




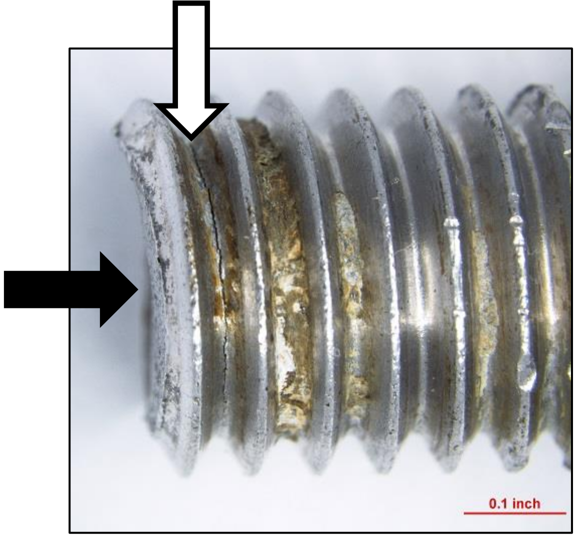
Incident Light Fixture Failure Analysis

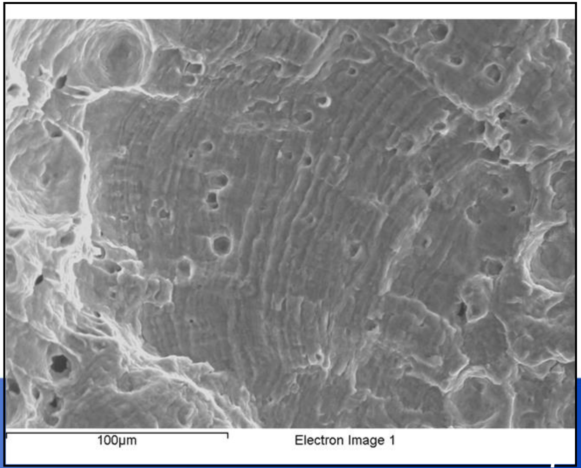
Incident Light Fixtures



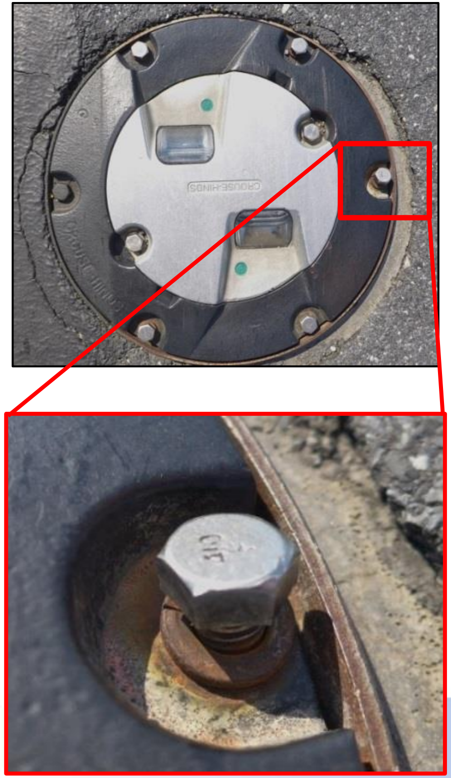


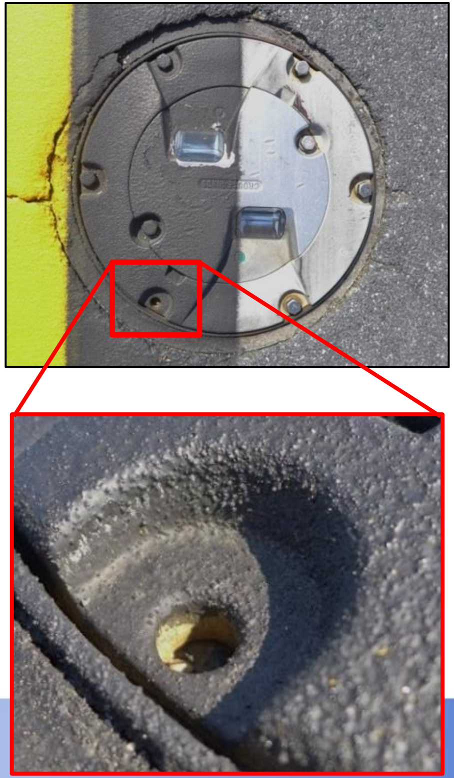
Fractured Bolts

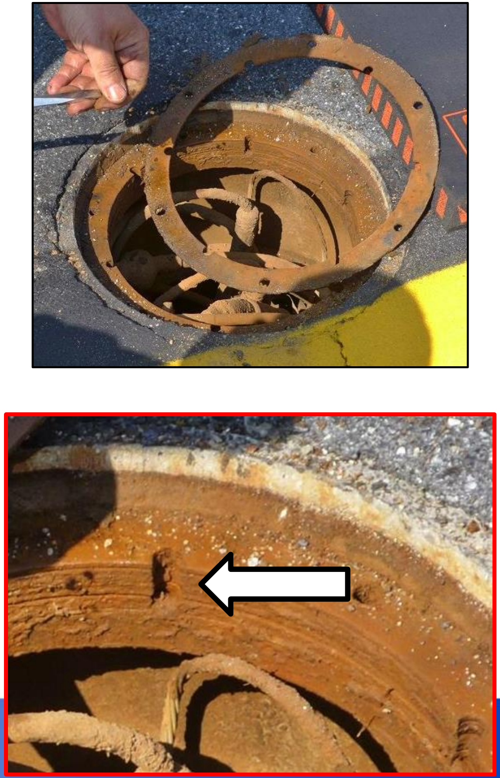




Airport Site Inspections







Sampling Program

Sampling Program Protocol

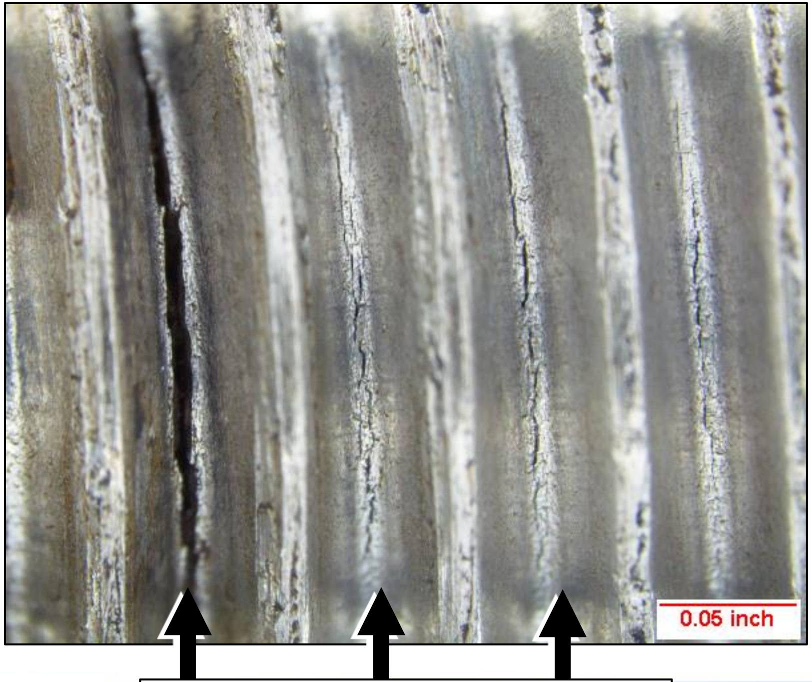
- 30 light fixtures selected per runway for inspection:
  - Runways: 9
  - Fixtures: 270
  - Bolts: 1620

- Protocol for Sampling Program included:
  - Visual examination of light fixture
  - Removal of bolts for examination at LPI
  - Visual examination and count of spacer rings
  - Visual examination of bolt holes in extension or base mounting can

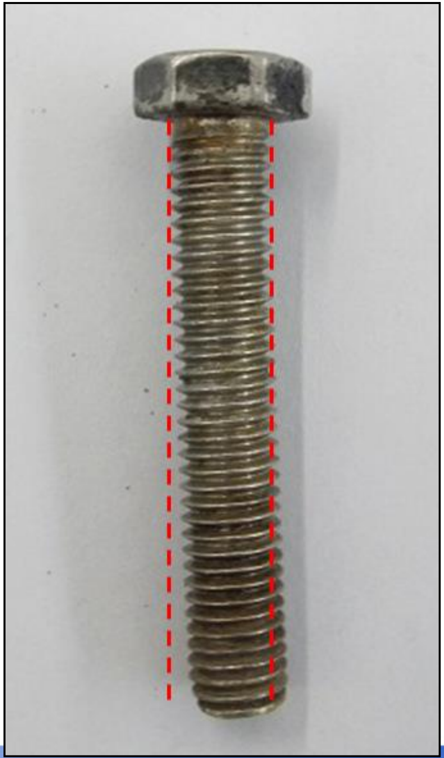
Sampling Program Findings

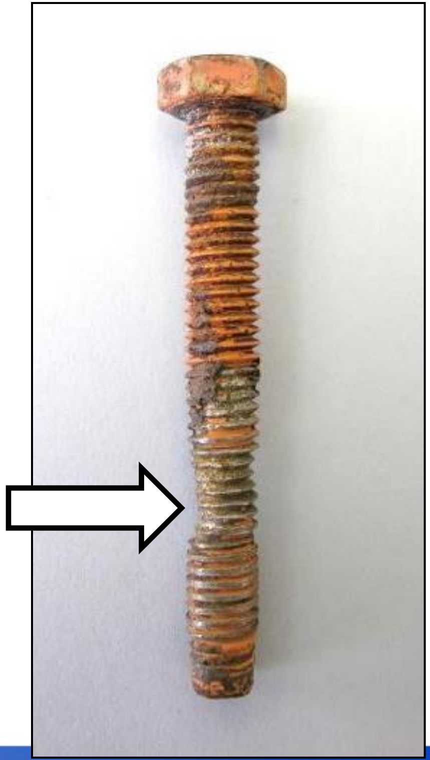
- 22 cracked bolts found
  - Consistent with low-cycle, high-stress fatigue
- 36 bent bolts (Type 304 and Grade 2) found
- Some coated carbon steel bolts exhibited extensive corrosion
- 25 to 50% of support ring holes exhibited thread impressions
- Six extension collars exhibited missing bolts
  - Three base cans exhibited ovalization
- 30 to 45% of light fixtures had more than three spacer rings

Sampling Program Findings



Thread root cracks





Sampling Program Findings

Extension Collar to Base Can Bolt

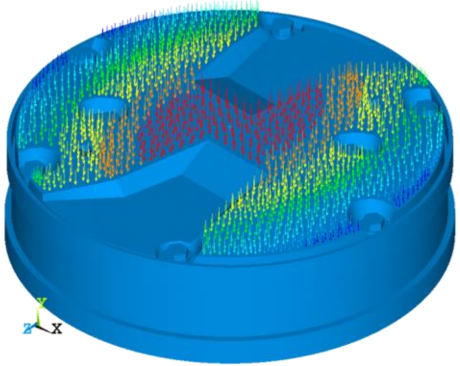
Finite Element Analyses

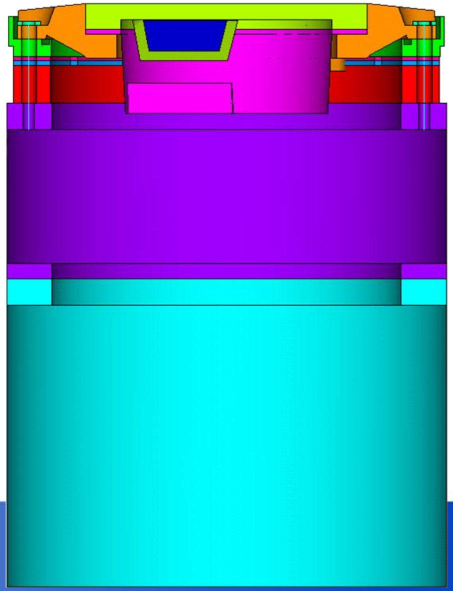
Finite Element Analyses

- Evaluate effect of aircraft roll-over on light fixture and support ring bolts

- FEA model created for light fixture assembly

- Loads derived from Aircraft Characteristics documents
  - Considered conservative





FEA Results

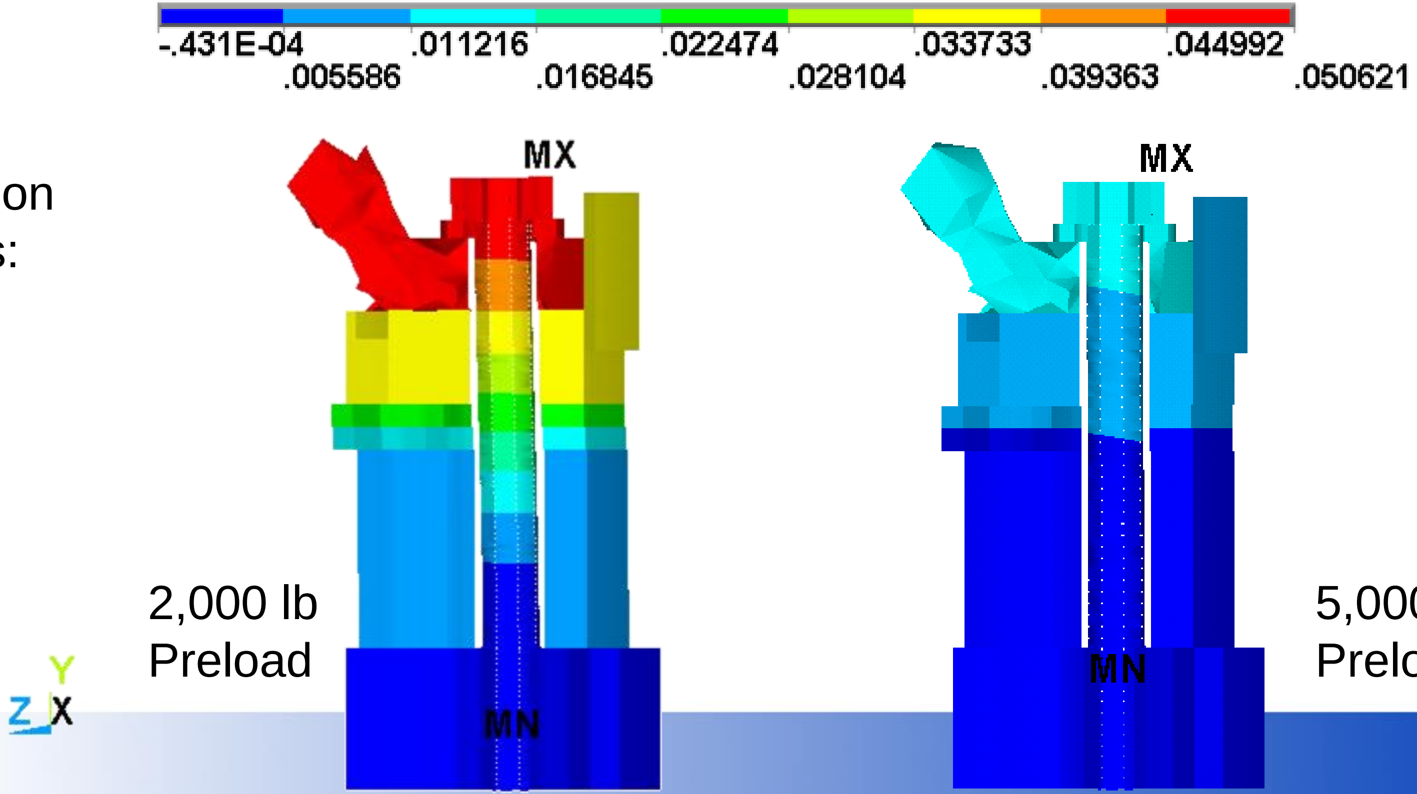
	With Foundation Stiffness			Without Foundation Stiffness		
Bolt Preload (lb) →	2000	3000	5000	2000	3000	5000
Axial [lb]	3029	3849	5033	3311	4067	5156
Shear [lb]	411.3	250.0	71.9	491.0	244.2	117.0
Moment [lb-in.]	476.2	283.4	82.1	558.1	278.1	133.1
Bending Stress [ksi]**	156.5	93.1	27.0	183.4	91.4	43.8
Bolt Z-Disp. [in.]	0.0346	0.0203	0.0065	0.0394	0.0201	0.0103

** Note: This is an “apparent” stress and is only listed for comparison purposes. Once the bolt starts to yield, the linear relationship no longer holds.

- Low preload allows slip at Support Ring / Flange Ring interface

FEA Results

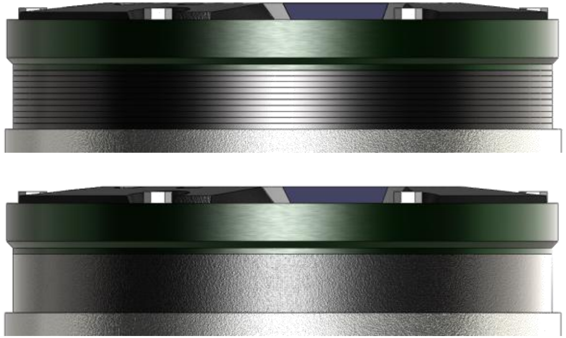
Without foundation stiffness:



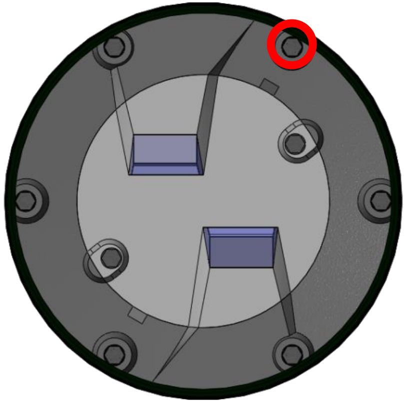
2,000 lb Preload

5,000 lb Preload

Additional FEA Studies



- Effect of spacer rings
  - Bolt displacement and bending stress increases with number of rings



- Effect of missing bolt
  - One missing bolt results in higher stresses in remaining bolts

Bolt Torque Testing

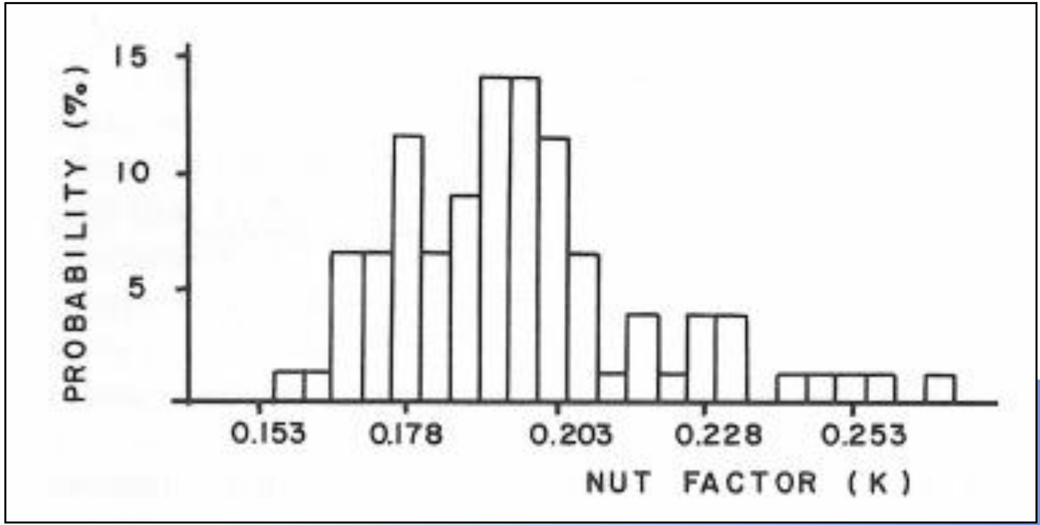
Bolt Torque Specifications

- FAA AC 150/5345-42, 150/5340-26, 150/5340-30
  - Torque per manufacturer's recommendations
  - 185 in.-lb *(15 ft-lb)*, 230 in.-lb *(18 ft-lb)*
- FAA Engineering Brief No. 83
  - 18-8 bolt (dry): 185 in.-lb *(15 ft-lb)* maximum
  - Coated Grade 2 bolt (dry): 120-144 in.-lb *(10-12 ft-lb)*
- FAA AC 150/5345-46
  - Light fixture bolts must withstand shear load of 3000 lb

Design Torque vs. Bolt Preload

$$T_{in} = F_P \times D \times K$$

where T_{in} = input torque (in.–lb)
F_P = achieved preload (lb)
D = nominal diameter (in.)
K = nut factor



Nut Factor "K"

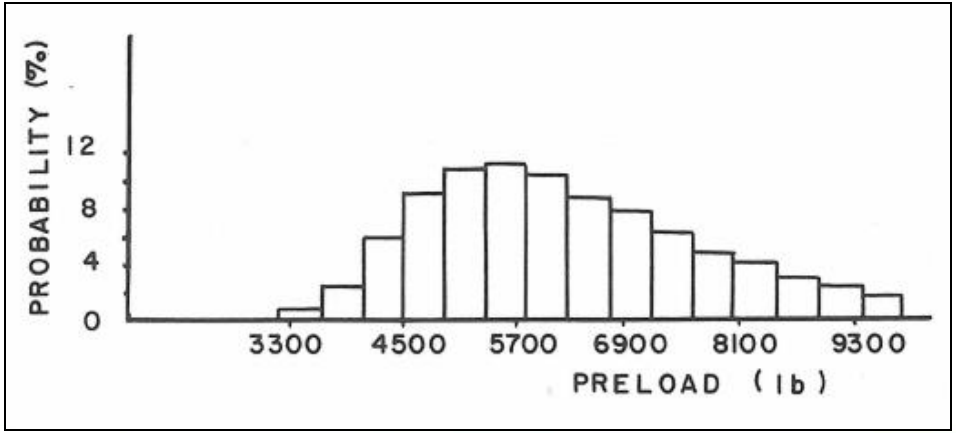
Experimental constant

- Steel (dry) = 0.2
- Steel (lubricated) = 0.1-0.2

Bickford, John H. *An Introduction to the Design and Behavior of Bolted Joints*. 3rd ed. New York: Marcel Dekker, Inc., 1995. Print.

Design Torque vs. Bolt Preload

- Scatter in preload achieved at a uniform torque level



Bickford, John H. *An Introduction to the Design and Behavior of Bolted Joints*. 3rd ed. New York: Marcel Dekker, Inc., 1995. Print.

- Preload uncertainty (Γ) documented in NASA NSTS 08307

Torque-measurement of unlubricated bolts	$\Gamma = \pm 35\%$
Torque-measurement of lubricated bolts	$\Gamma = \pm 25\%$

Design Torque vs. Bolt Preload

- 3/8 in.-16 Grade 2 carbon steel
  - 75% of proof load = ~ 3200 lb
  - Torque required to achieve 3200 lb pre-load (dry bolt) = 20 ft-lb

- 3/8 in.-16 Type 304 stainless steel
  - 75% of yield load = 3780 lb
  - Torque required to achieve 3780 lb pre-load (dry bolt) = 23 ft-lb

- 3/8 in.-16 Type 410 stainless steel
  - 75% of yield load = 5230 lb
  - Torque required to achieve 5230 lb pre-load (dry bolt) = 32 ft-lb

Torque Test Set-up

- Strain-gaged bolts tested in light fixture assembly

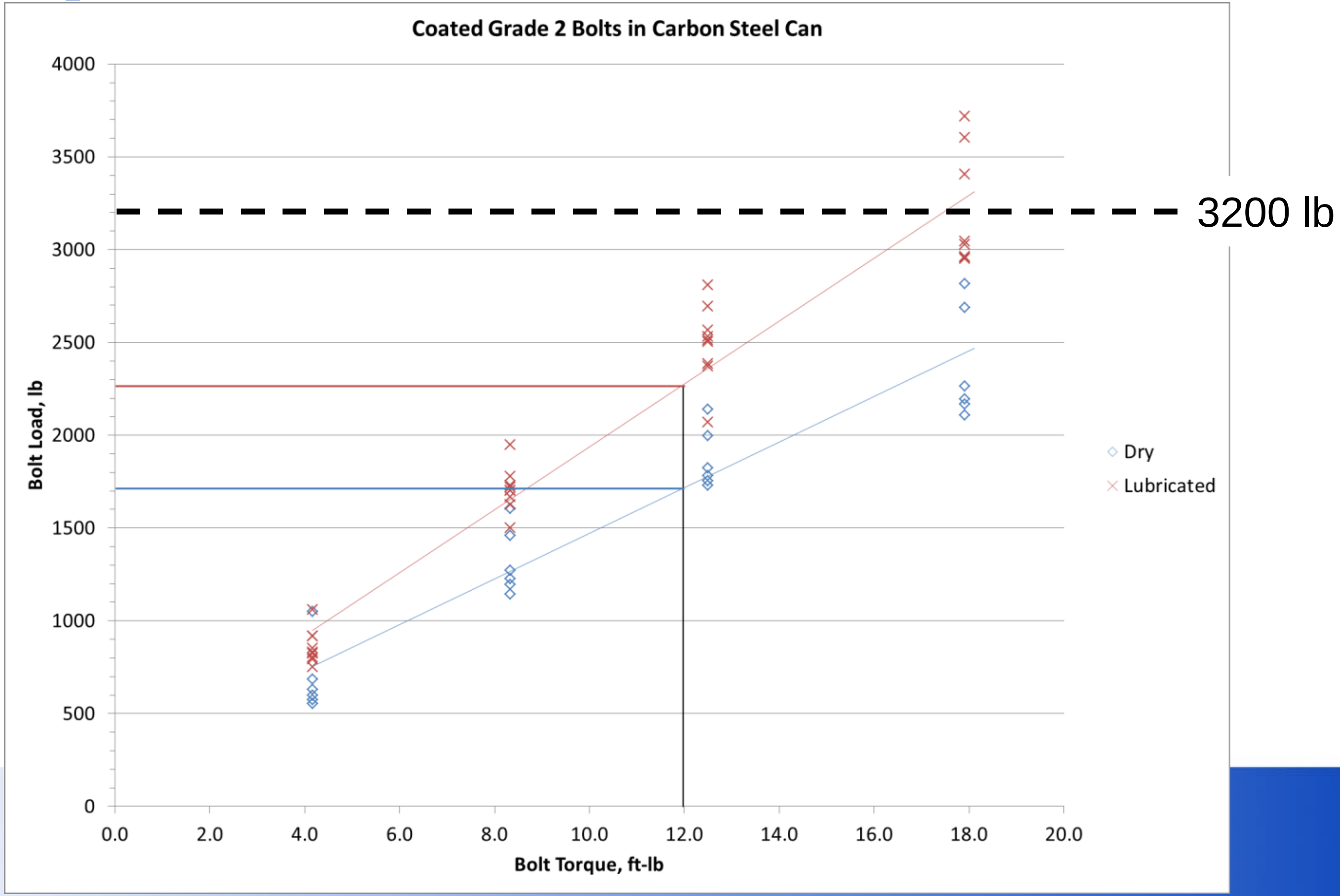
Types of bolts tested:

- Coated Grade 2 carbon steel 
- Type 304 stainless steel 
- Type 410 stainless steel 
- Grade 5 carbon steel  

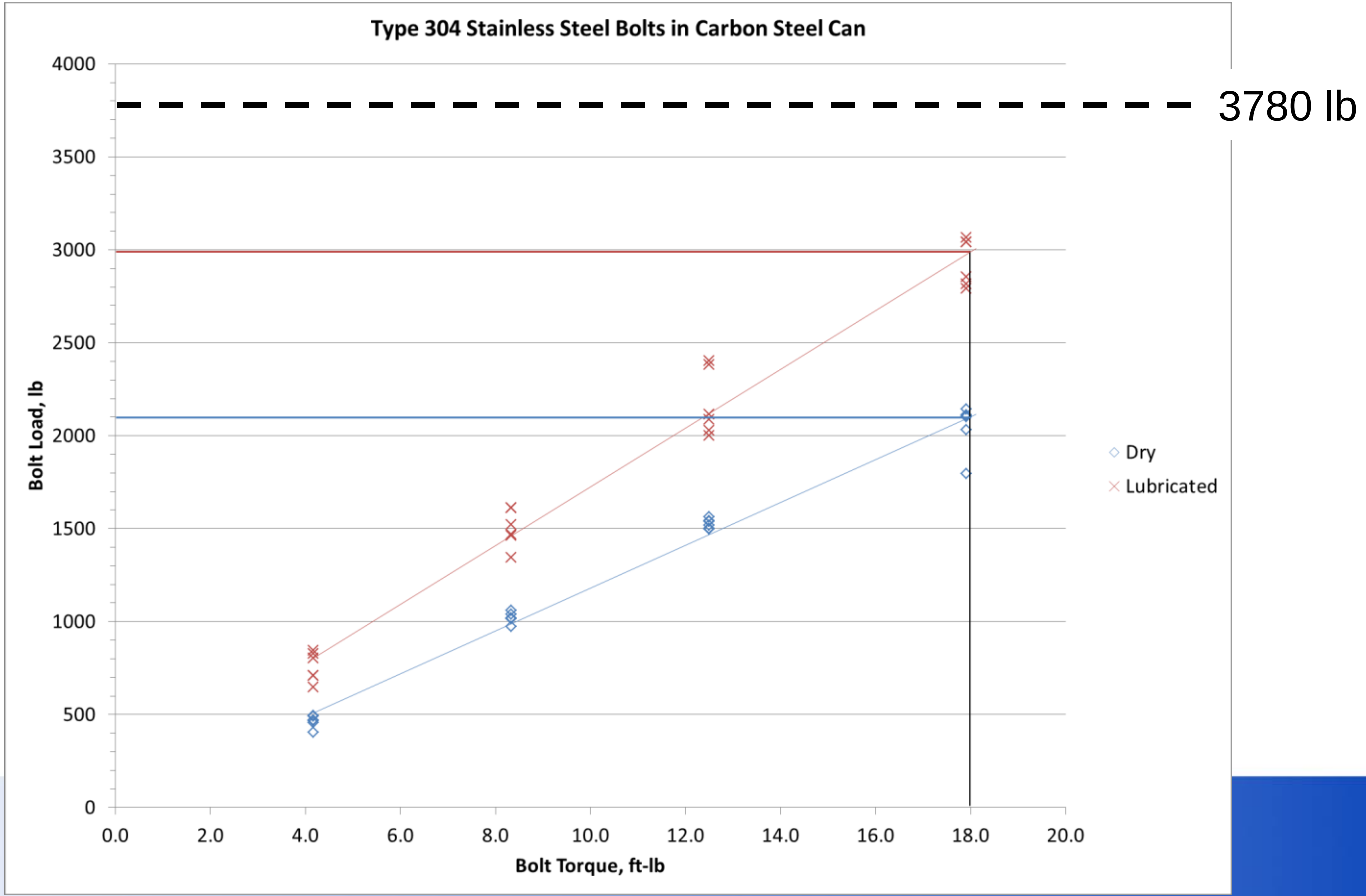
Types of light bases tested:

- L-868 Class IA and IB

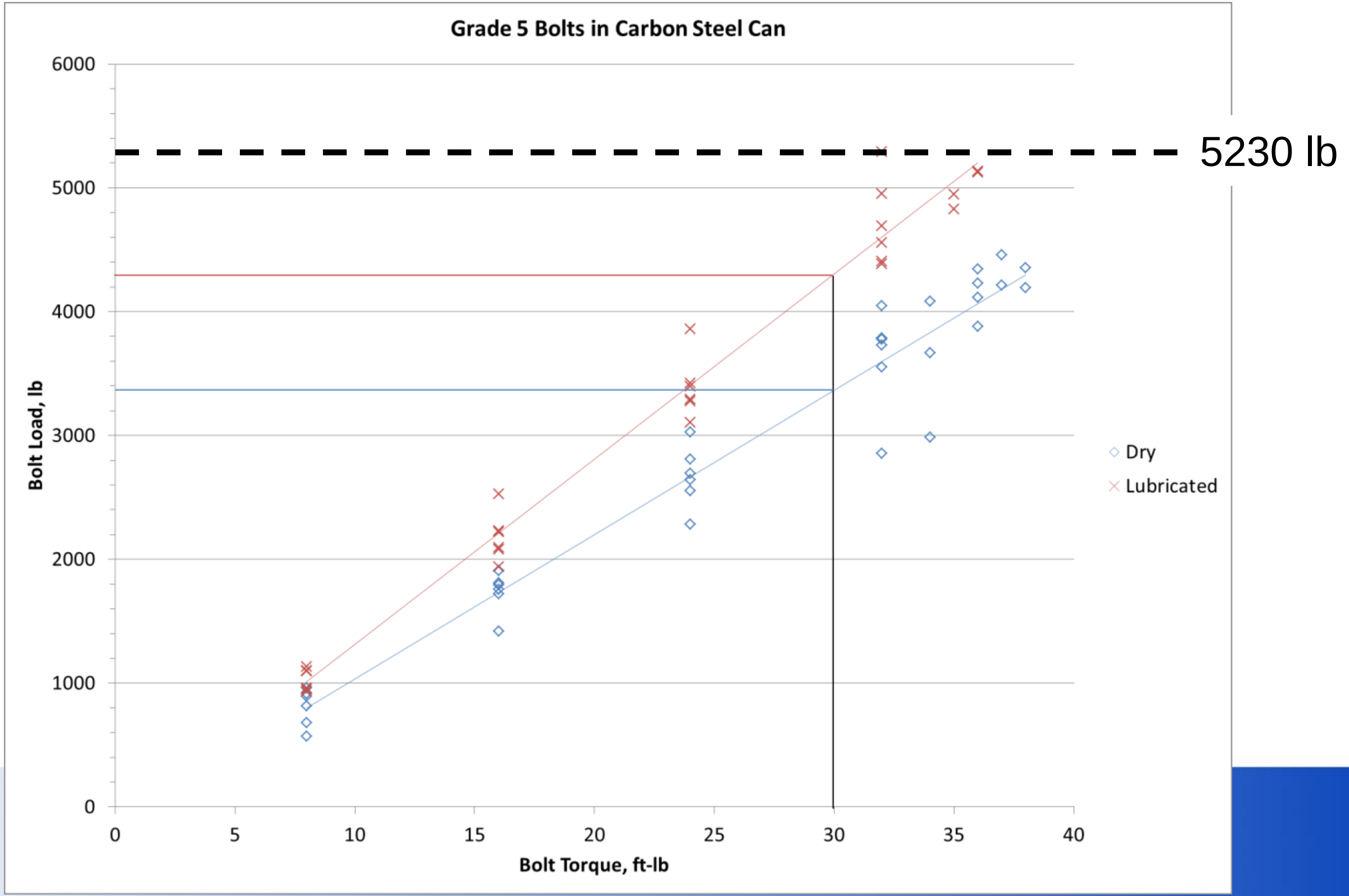
Torque Test Results – Grade 2



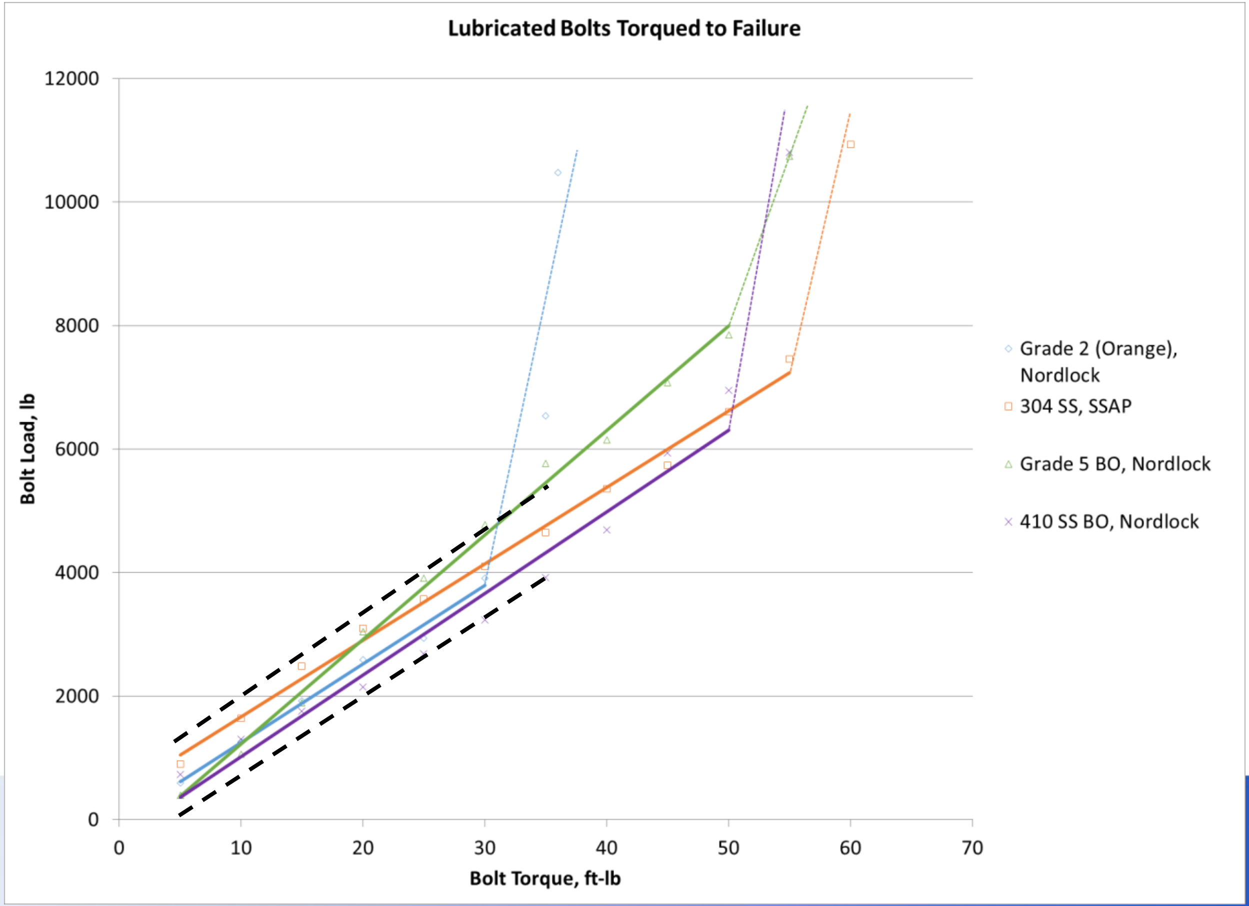
Torque Test Results – Type 304



Torque Test Results – Grade 5



Torque to Failure



Light Fixture Bolt Recommendations

Bolt Recommendations

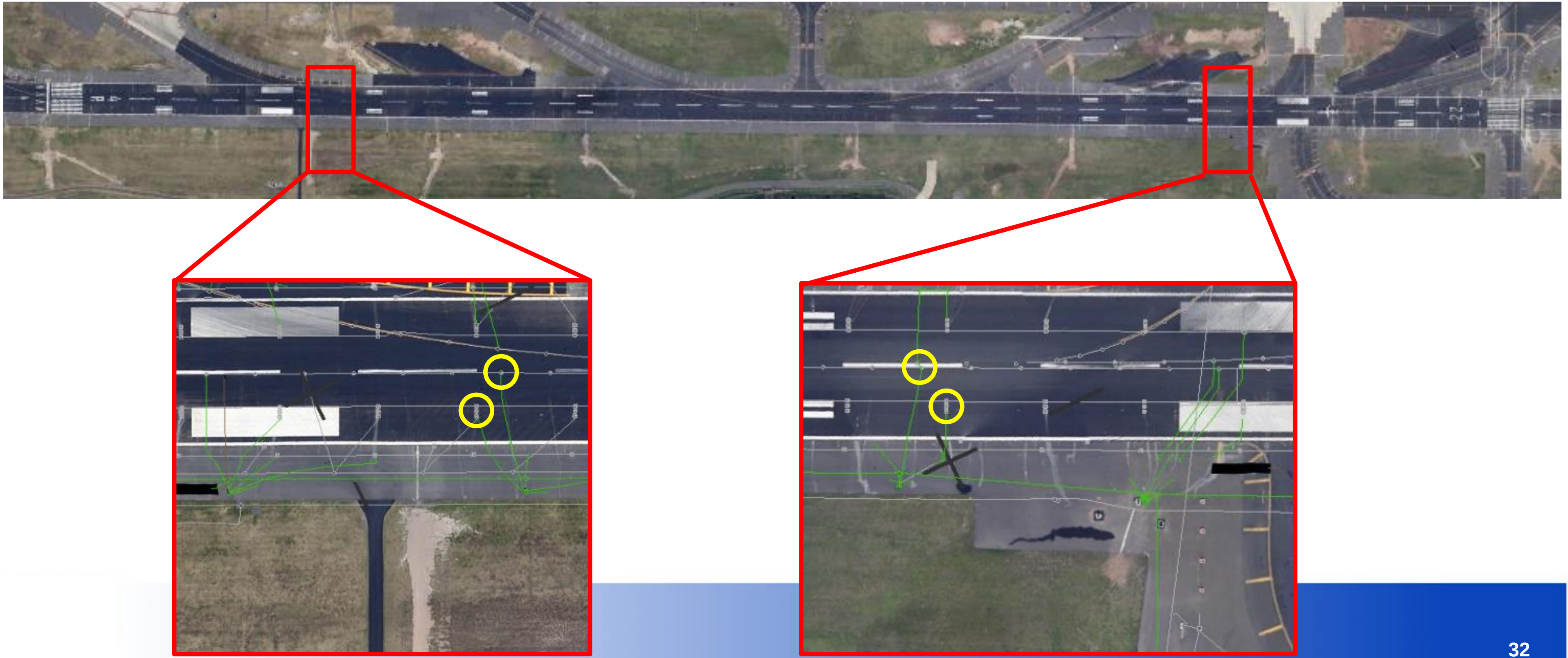
- Type 410 stainless steel bolts (ASTM F593P)
  - 23 ft-lb
  - Torque bolts in star pattern
  - Loctite marine grade anti-seize
  - Two-piece lock washer (Nord-lock type)

- Maximum of three spacer rings
  - No silicone sealant

- Check torque after two weeks, then regular maintenance

Light Fixture Instrumentation

Instrumentation and Analysis

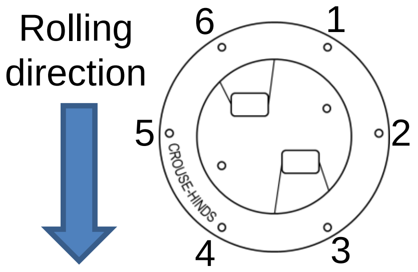


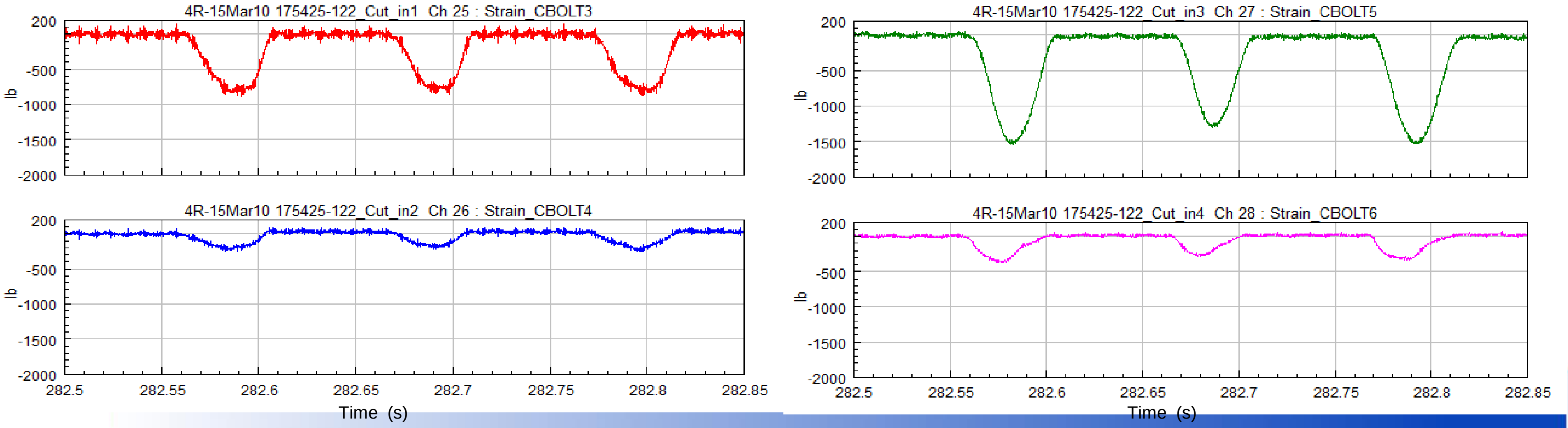
Instrumentation and Analysis

- No indication of direct impact, but good results obtained from "rolling end" of runway
- Results indicate aircraft *does not* have to contact light fixture in order to induce cyclic strain response
- Bolts repeatedly experience 100 to 1500 lb or possibly more relaxation/unloading
  - Utilizing LPI torque vs. preload correlation, 12 ft-lb or more cyclic relaxation/unloading is occurring

Instrumentation and Analysis

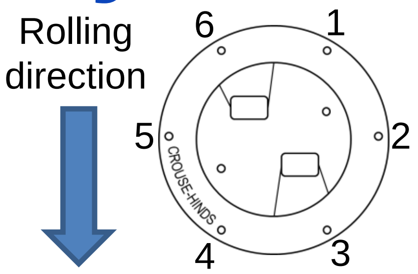
- 777 after landing (all wheels down)
  – Centerline bolt strain gages

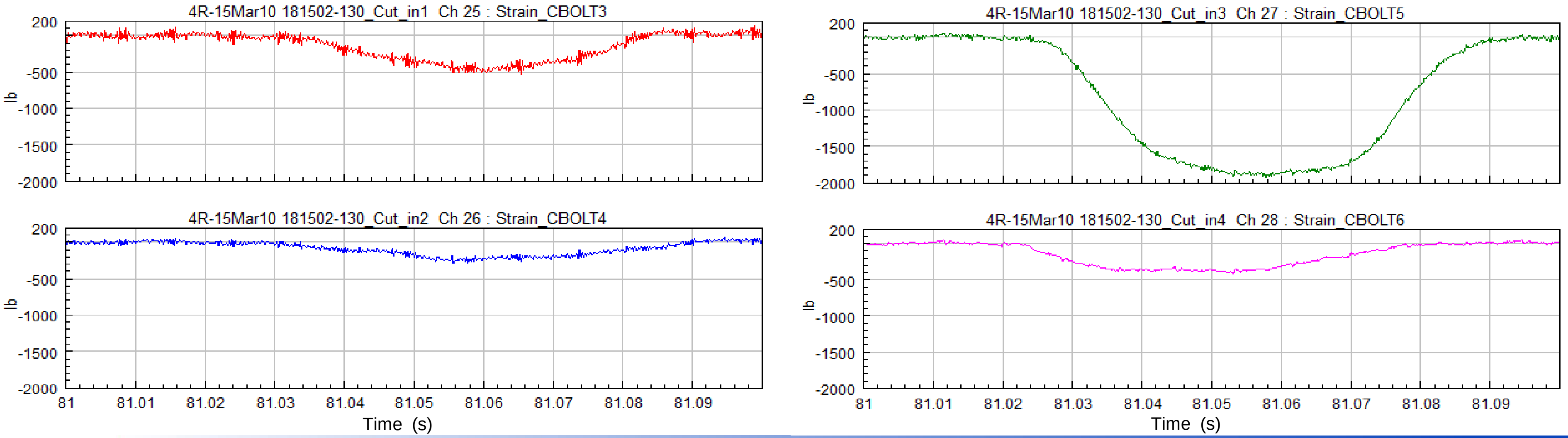




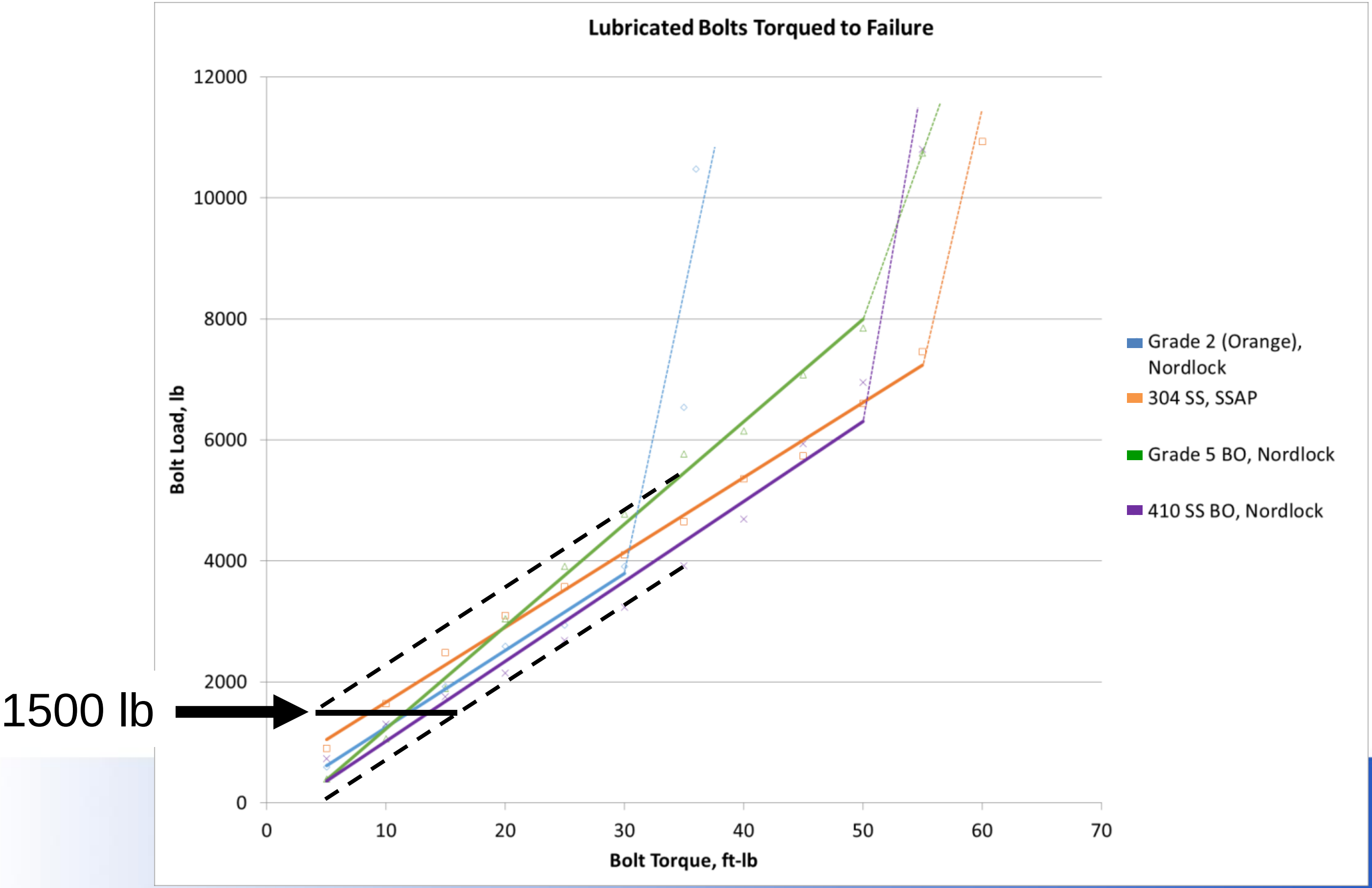
Instrumentation and Analysis

- 737 after landing (all wheels down)
  – Centerline bolt strain gages



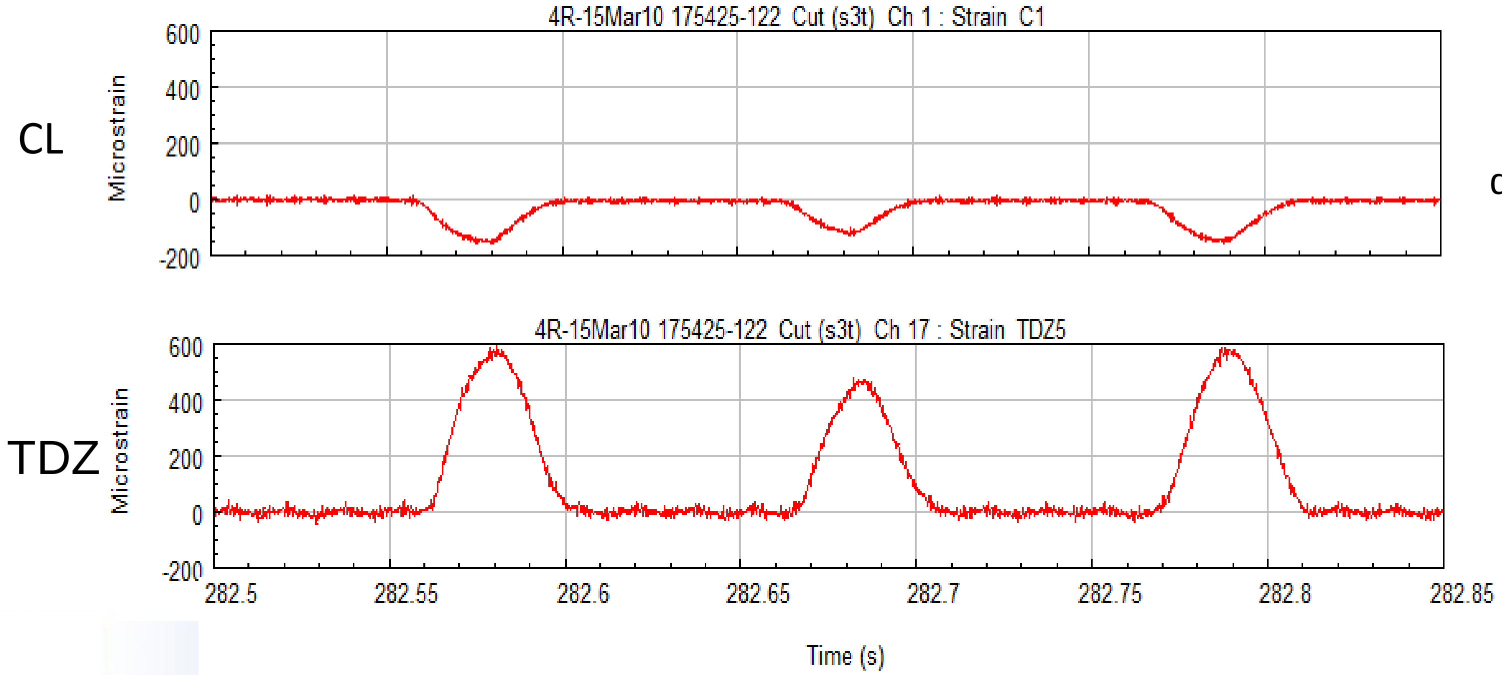


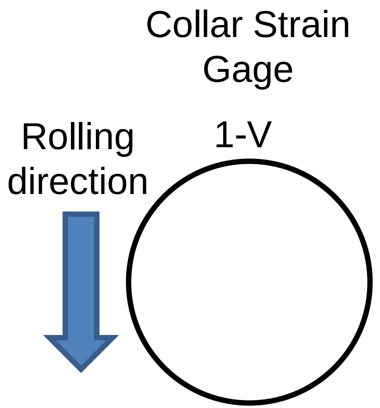
Torque to Failure



Instrumentation and Analysis

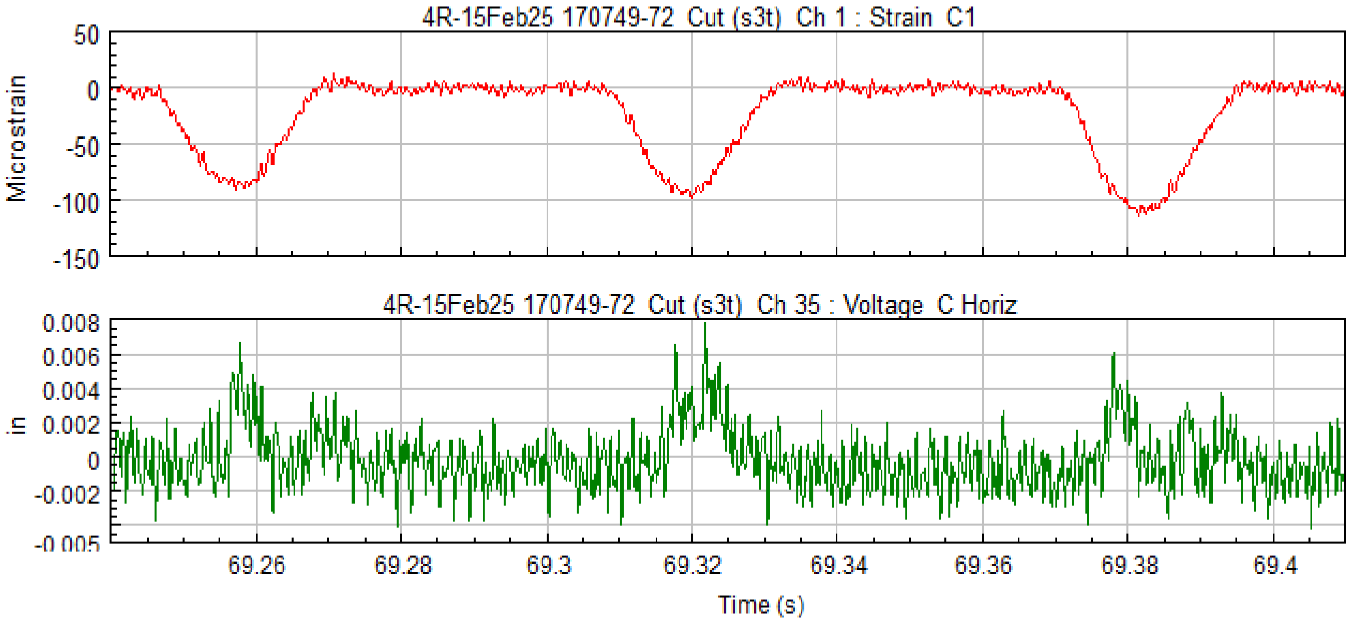
- Simultaneous response at centerline and touchdown zone

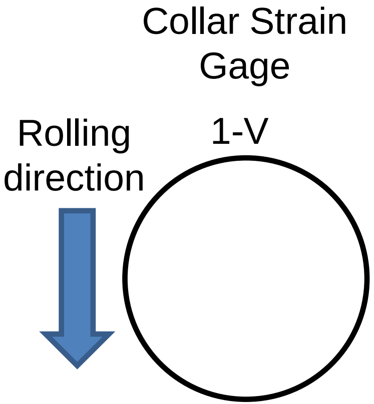




Instrumentation and Analysis

- Centerline horizontal laser transducer
  - Approximately 0.006 in. maximum movement





Instrumentation – Continued Work

- Plan to instrument three additional light fixtures
  - Two runways, one taxiway
  - Data acquisition targeted for late November

- Currently working on pavement and light fixture FEA to further evaluate/validate instrumentation

LPI Evaluation Findings

LPI Evaluation Findings

- Mechanical performance of fixture assemblies
  - Aircraft loading
  - Light fixture installation
  - Maintenance

- Benefit to increasing torque value (preload) of light fixture support ring bolts
  - Recommended torque value should be determined experimentally
  - Maintenance of extension collar to base can bolts

LPI Evaluation Findings

- Light fixture and pavement act as a system
  - Direct wheel contact not required for strain response
  - Continue investigation into light fixture/pavement interaction

- Requires cooperation between airports, FAA, suppliers

Questions?