Implementing a Comprehensive Plan for In-pavement Lighting Reliability Improvements

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October 25, 2016

Regional Transportation System –
Port Authority of New York and New Jersey

Airports (5)

- Newark Liberty International (EWR)
- John F. Kennedy International (JFK)
- LaGuardia (LGA)
- Teterboro (TEB)
- Stewart International (SWF)

Marine Terminals (4)

Interstate Tunnels and Bridges (6)

Commuter Rail System (1)

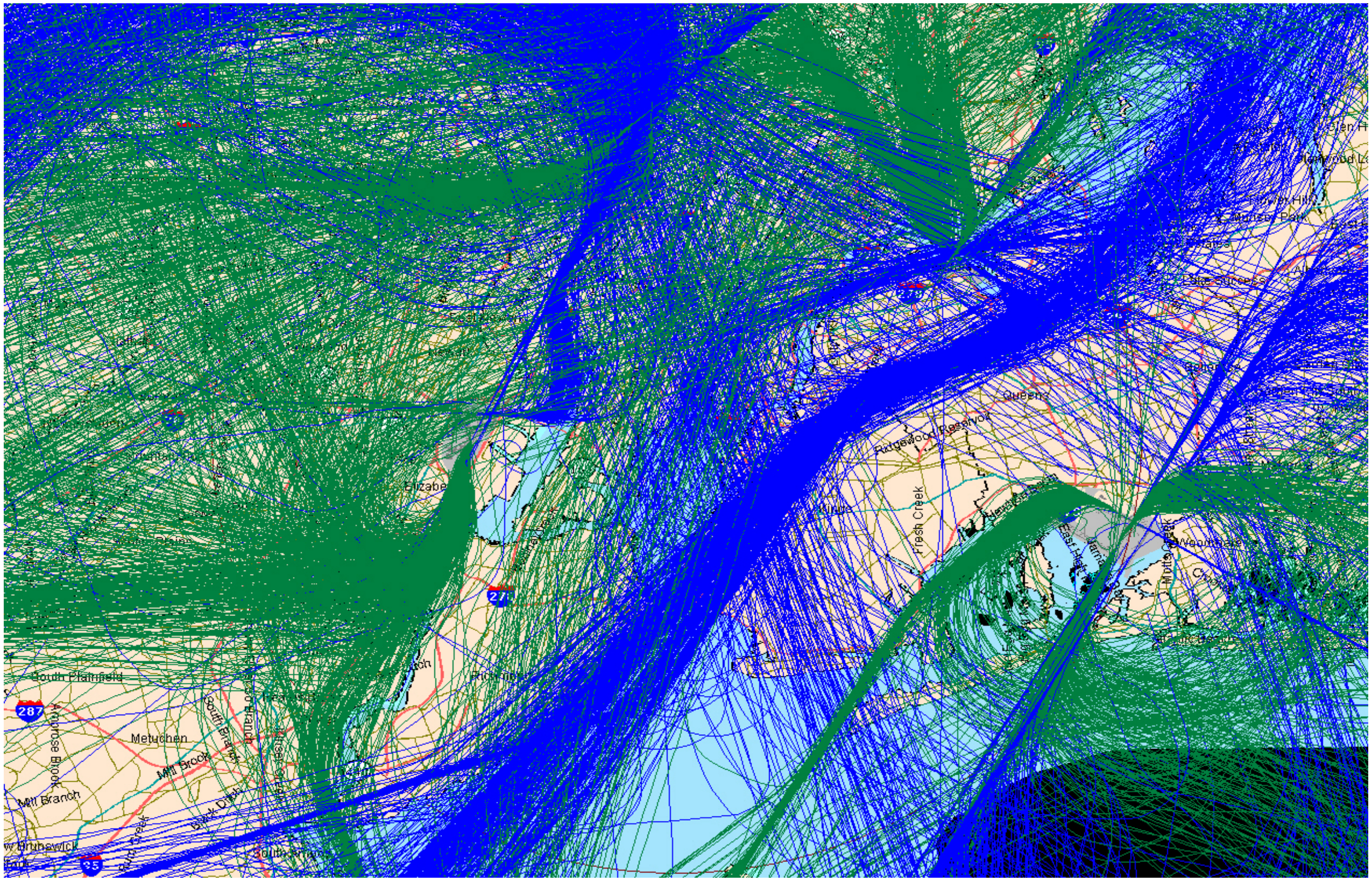
Bus Terminals (3)

World Trade Center

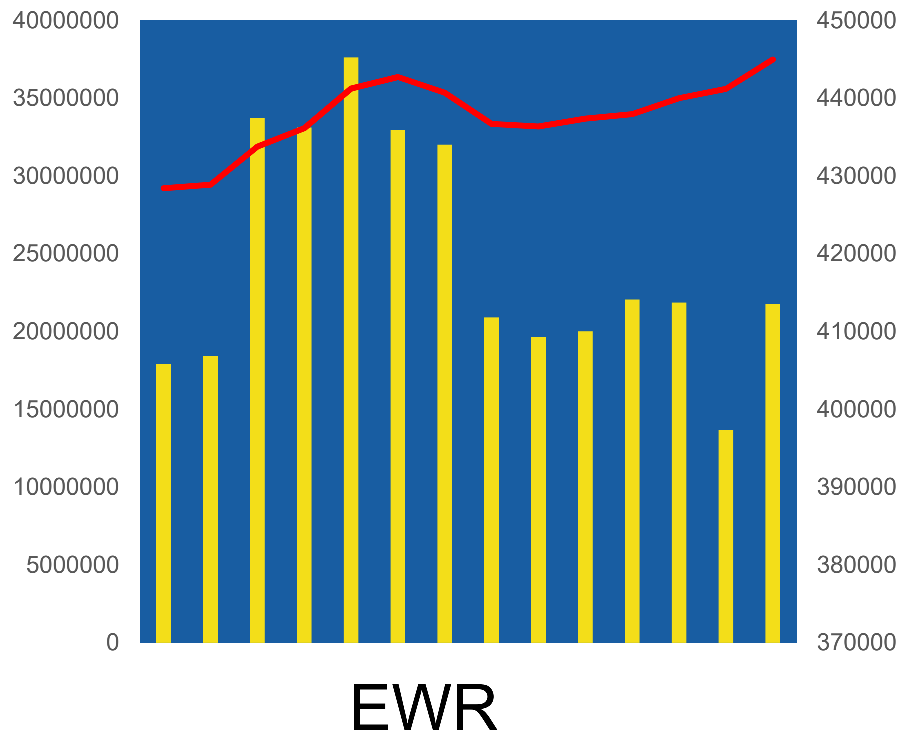
Regional passenger demand requires more of airport infrastructure

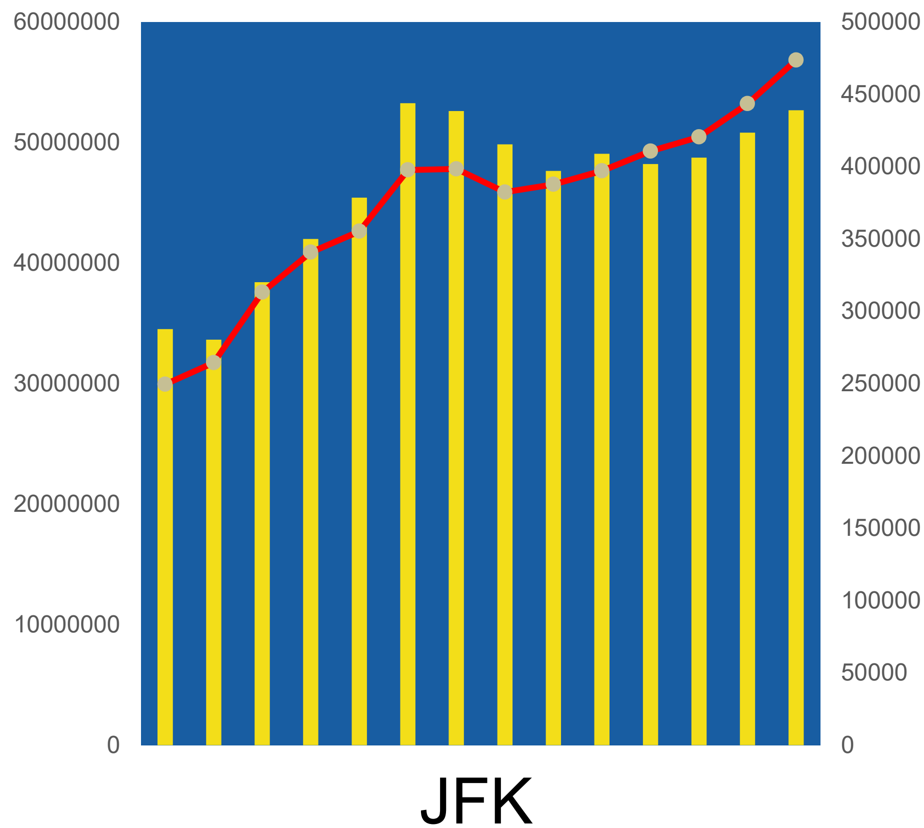
<u>Regional Passenger Demand</u>

- 2005: 100 million
- 2014: 114 million
- 2024: 146 million
- 2034: 187 million



OVER TIME, LARGER/HEAVIER AIRCRAFT: PASSENGER INCREASE RELATIVE TO OPERATIONS





Red Line shows increasing number of total passengers
Yellow Bars show total operations decreased (EWR)
or moderate increase (JFK)

An integrated airport system is required to meet the regional demand

John F. Kennedy International

International Gateway For Passengers & Cargo

Stewart International

Gateway to the Hudson Valley

Newark Liberty International

Int'l/Transcontinental & Small-Package Hub

Atlantic City International

Gateway to Southern New Jersey

LaGuardia

Premier Short-Haul Domestic Airport

Teterboro

Corporate Reliever

As activity has grown over the years, the number of bolt failures have increased

JFK – December 2000 – MALSR fixture struck a DC-9

EWR – November 2009 – MALSR fixture ingested Boeing 737

JFK – April 2014 – Fixture struck Boeing 737

EWR – April 2014 – Fractured bolts

JFK – May 2014 – Fixture embedded in Boeing 747 fuselage during take-off

LGA – October 2014 – Loosening bolts

EWR – Feb 2015 – Fixture dislodged, found during inspection - snow plow impact

JFK – Feb 2015 – Raised centerline fixture – ovalized base can, found during inspection

EWR – May 2016 – Fixture dislodged, found during inspection

EWR – October 2016 – Fractured bolt found, found during inspection

In 2014, the Aviation Director Initiated Airfield Electrical Maintenance Improvement Program

1. Completion of Corrective Maintenance Backlog
2. Standardize and update preventive and corrective maintenance using the existing Computerized Maintenance Management System (CMMS)
3. Conduct maintenance audits
4. Implement a new state-of-the-art CMMS, Maximo, using mobile technology
5. Engineering analysis of system/component failures
6. Update construction oversight standards
7. Update engineering design standards

Preliminary output of the engineering analysis modified, maintenance practices along with design and construction standards.

The review of existing procedures by consultant (LPI) resulted in revised criteria for bolt installation

In order to maximize the achieved clamping force:

- Mounting base holes must be degreased, cleaned, and dried prior to bolt installation. *Best maintenance practice*
- All mating surfaces from the base to the fixture must be degreased, cleaned and dried prior to installation. *Improved friction connection - No silicone*
- Apply marine grade antiseize (K=.18) *Maximize bolt pre-load*
- Torque bolts with a calibrated torque wrench in a “star” pattern.*
- Immediately re-torque the bolts in the same “star” pattern. *
- Re-torque bolts within 2-weeks of the initial installation. *

* Best maintenance practices for bolt tightening

LPI, Inc. Consulting Engineers

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

Est. 1885

Performance of In-pavement Runway Light Fixture Assemblies

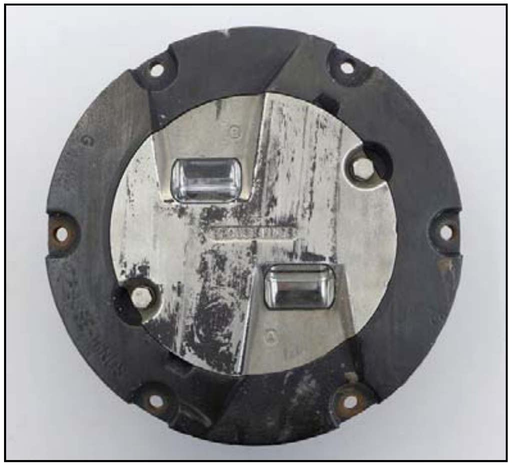
IESALC Fall Technology Meeting 2016

October 25, 2016

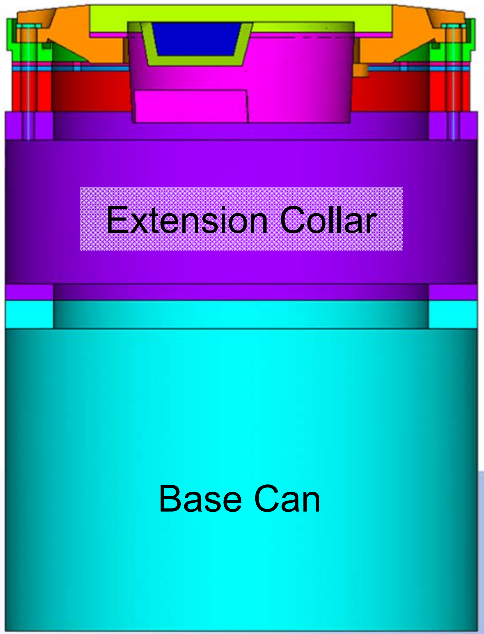
Eric Cheifet

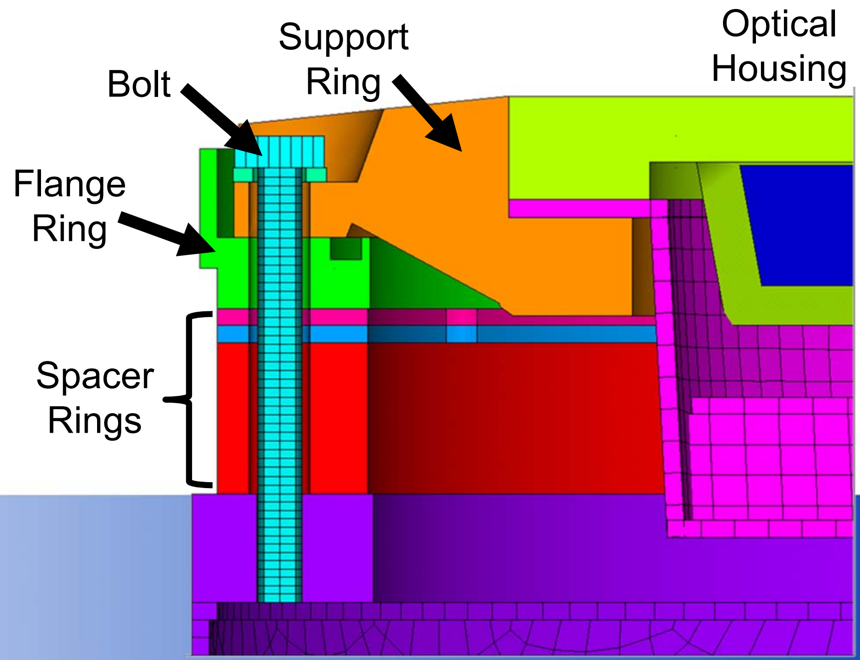
Senior Engineer

Background



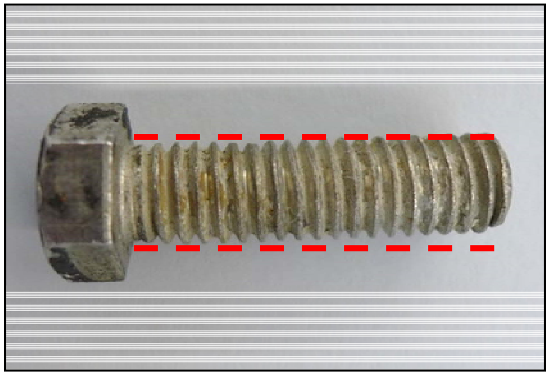
- Incidents involving dislodged in-pavement runway light fixtures
- Comprehensive engineering assessment performed to mitigate future fixture issues

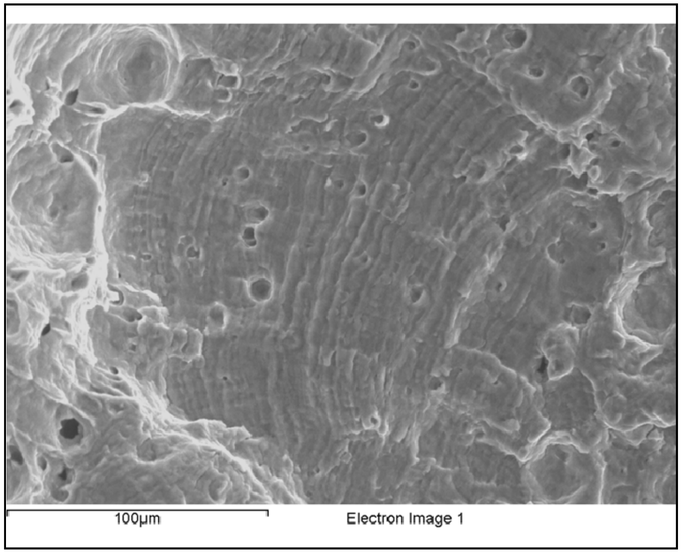




Light Fixture Failure Analysis

- Thread impressions in fixture clearance holes
- Bent bolts and bolt fatigue failures





Evidence of repeated excessive lateral movement of light fixture

Bolt Preload and Proof Load

- Preload – The tension created in a fastener as it is tightened
- Proof Load – The maximum load a bolt can take before it yields
- Rule of Thumb – Preload should be 75% of proof load

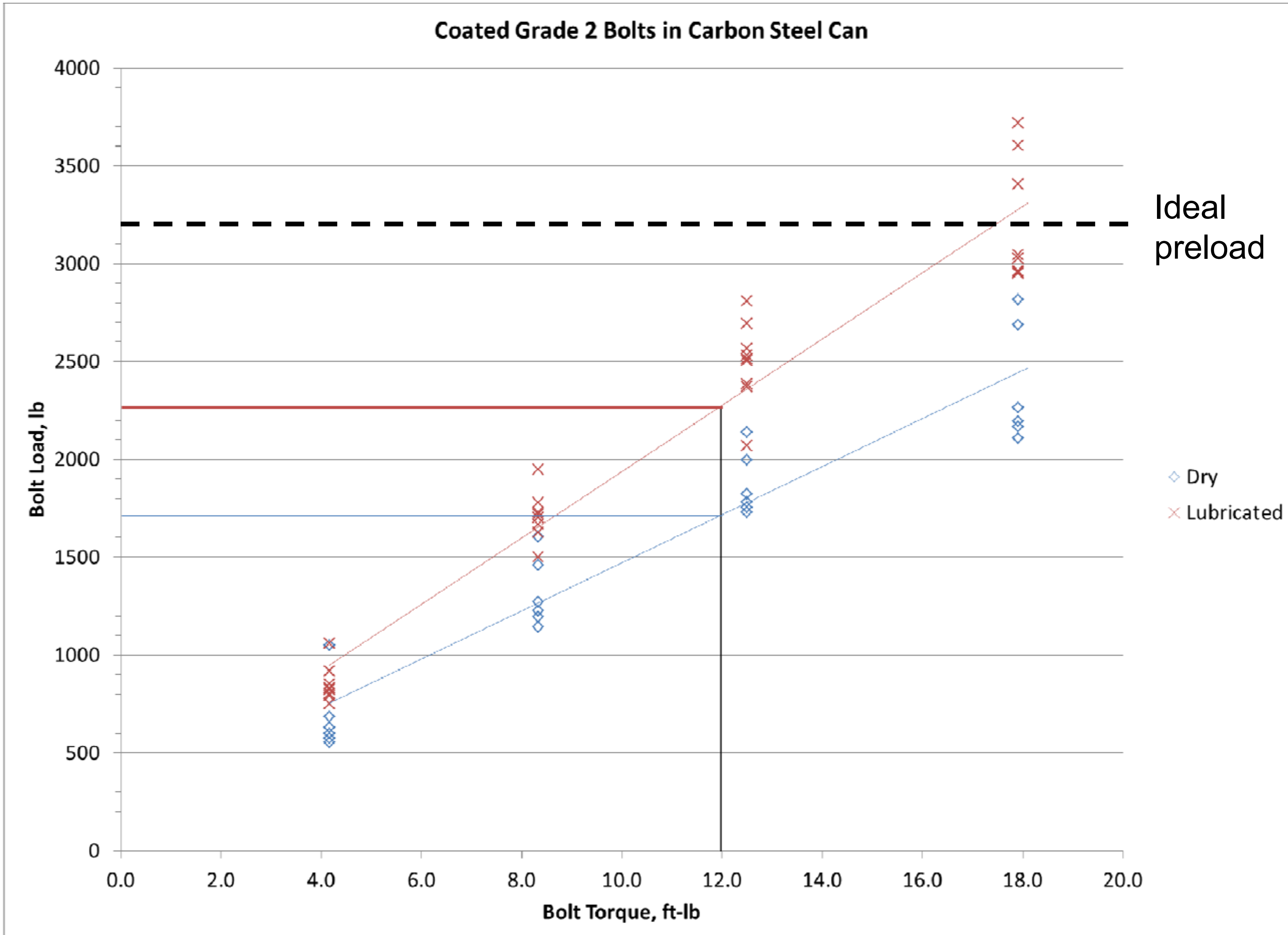
Bolt Torque Testing

- Bolt torque vs. bolt preload testing performed utilizing instrumented bolts
- Recommended manufacturer torque values do not ensure bolt is at ~75% of proof load
- Documented that scatter is inherent in achieved preload

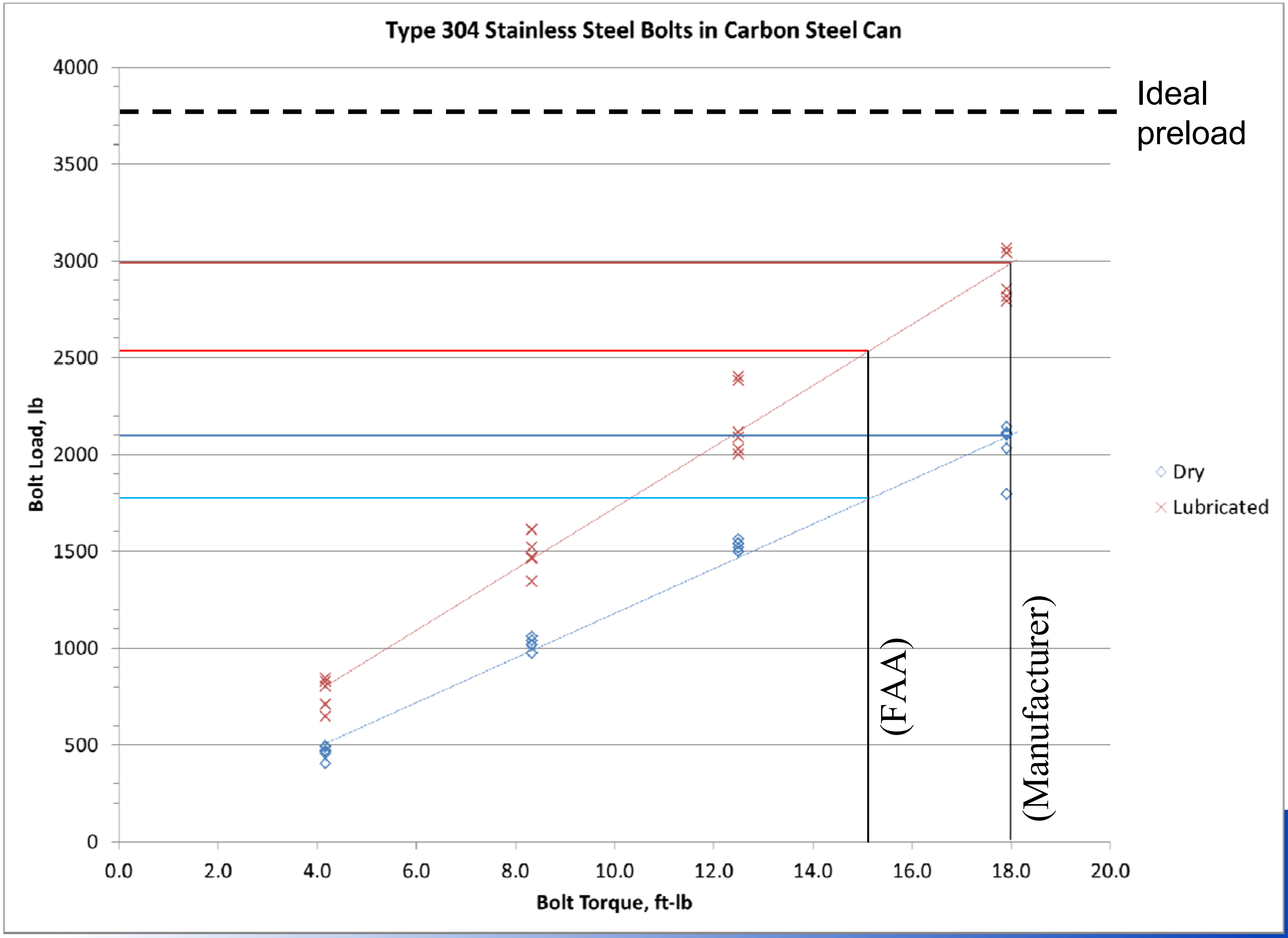
$$T_{in} = F_P \times D \times K$$

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

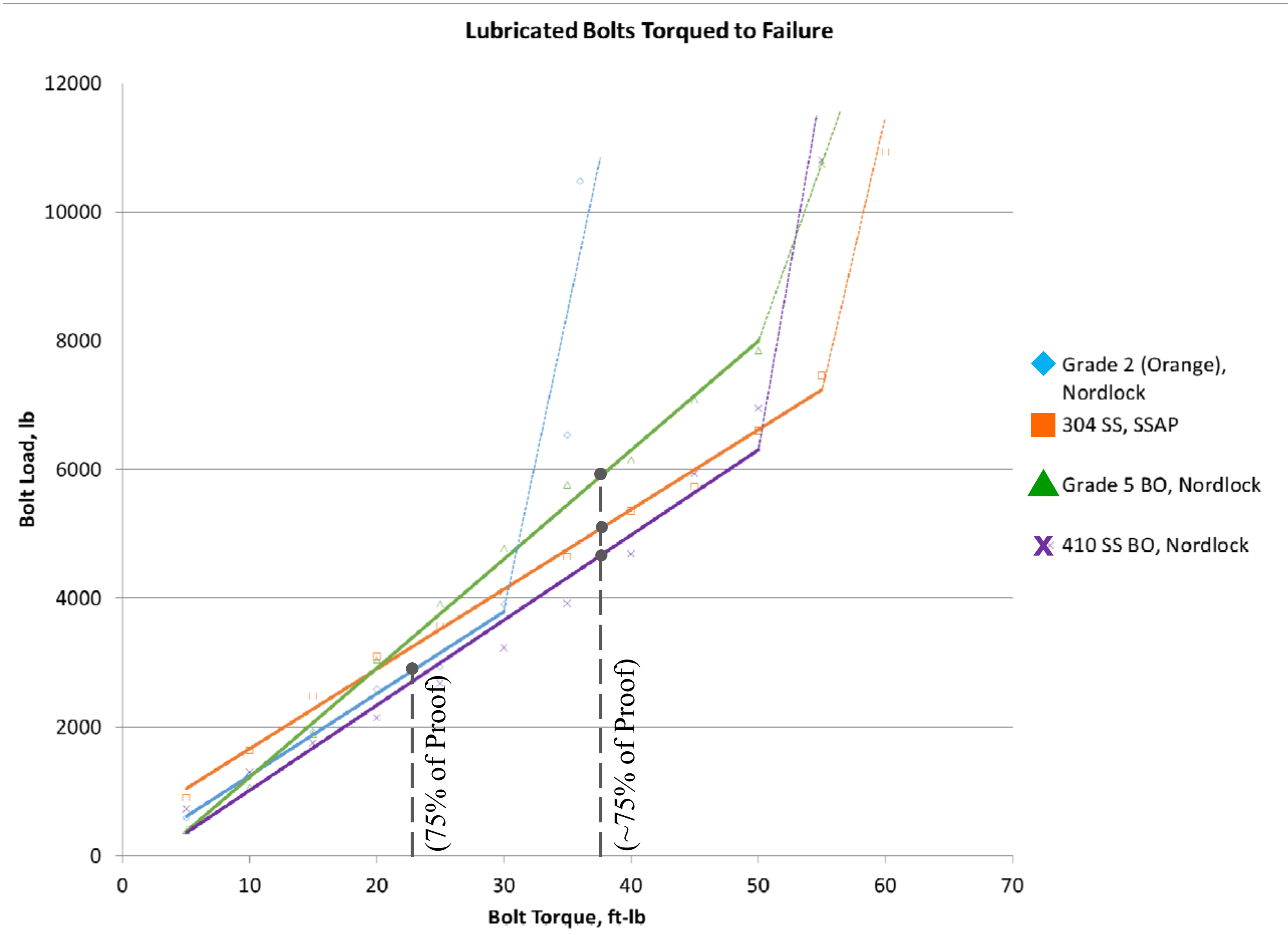
Torque Test Results – Coated Grade 2



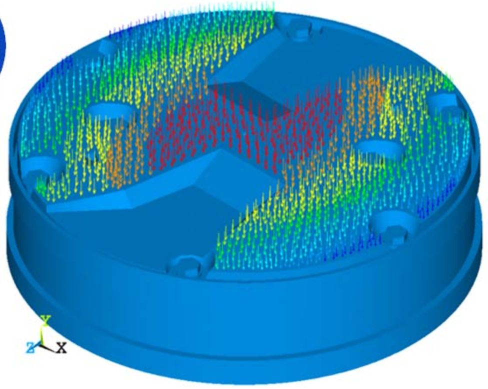
Torque Test Results – Type 18-8 SS



Torque Testing to Yield

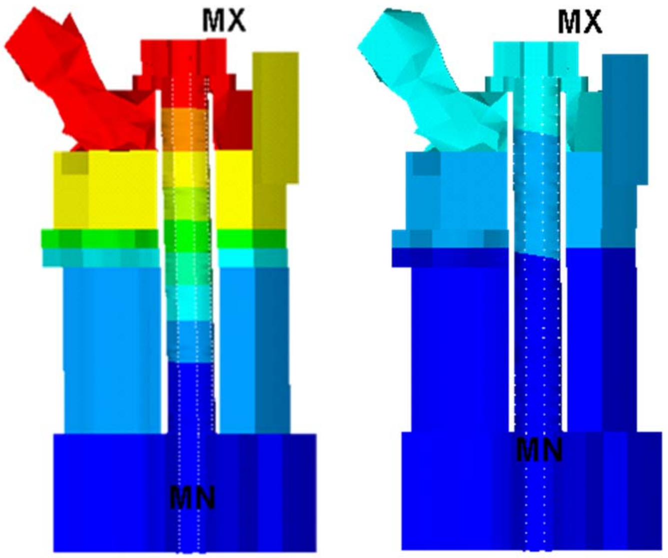


Finite Element Analysis (FEA)



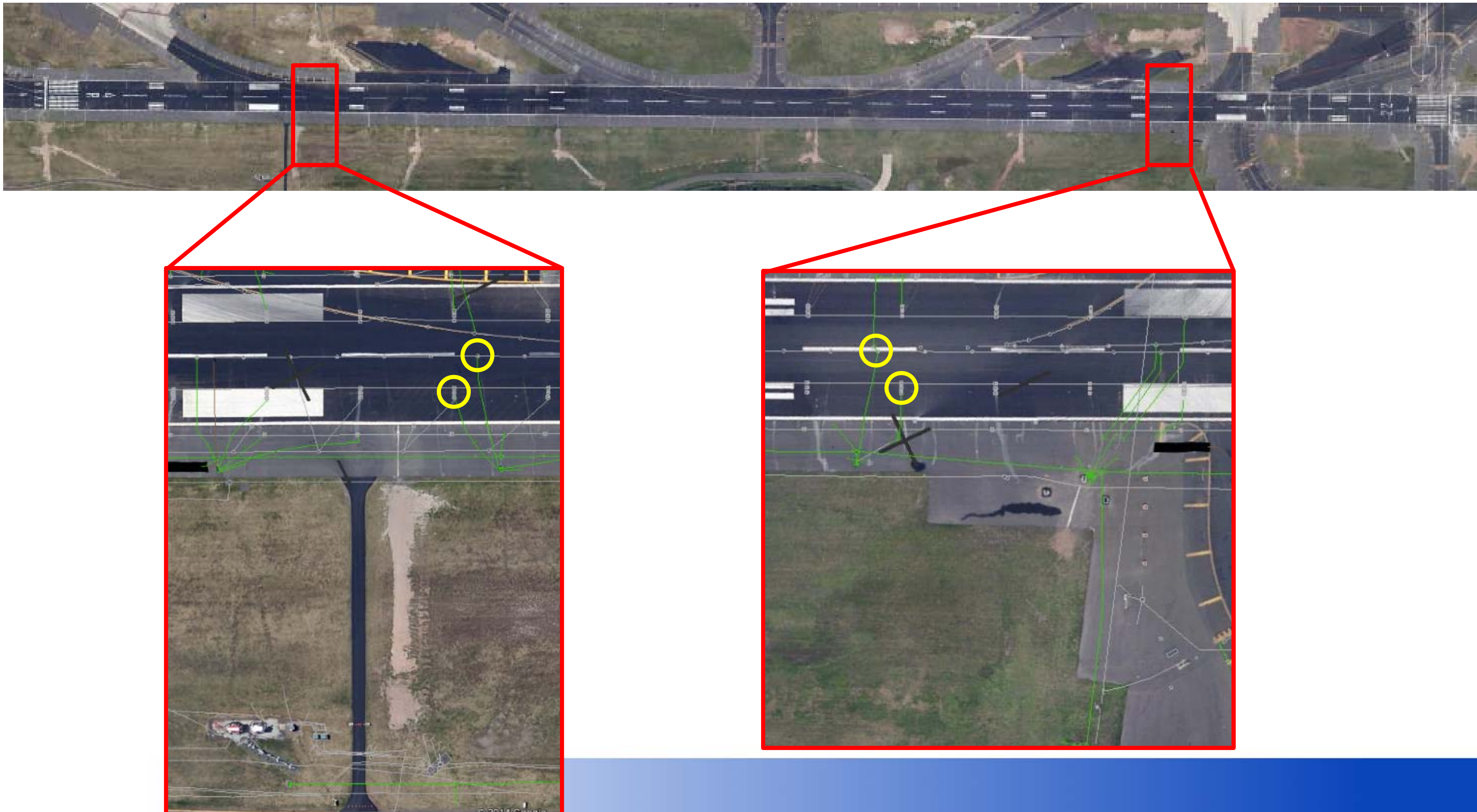
- Evaluate aircraft wheel roll-over
- Loads derived from Aircraft Characteristics documents
- Low preload allows slip at Support Ring / Flange Ring / Spacer Ring interfaces and bending of bolts

Bolt Preload (lb) →	2000	5000
Bending Stress [ksi]	181.2	33.6
Bolt Lateral Disp. [in.]	.0398	.0070



2000 lb   5000 lb

Instrumentation and Analysis



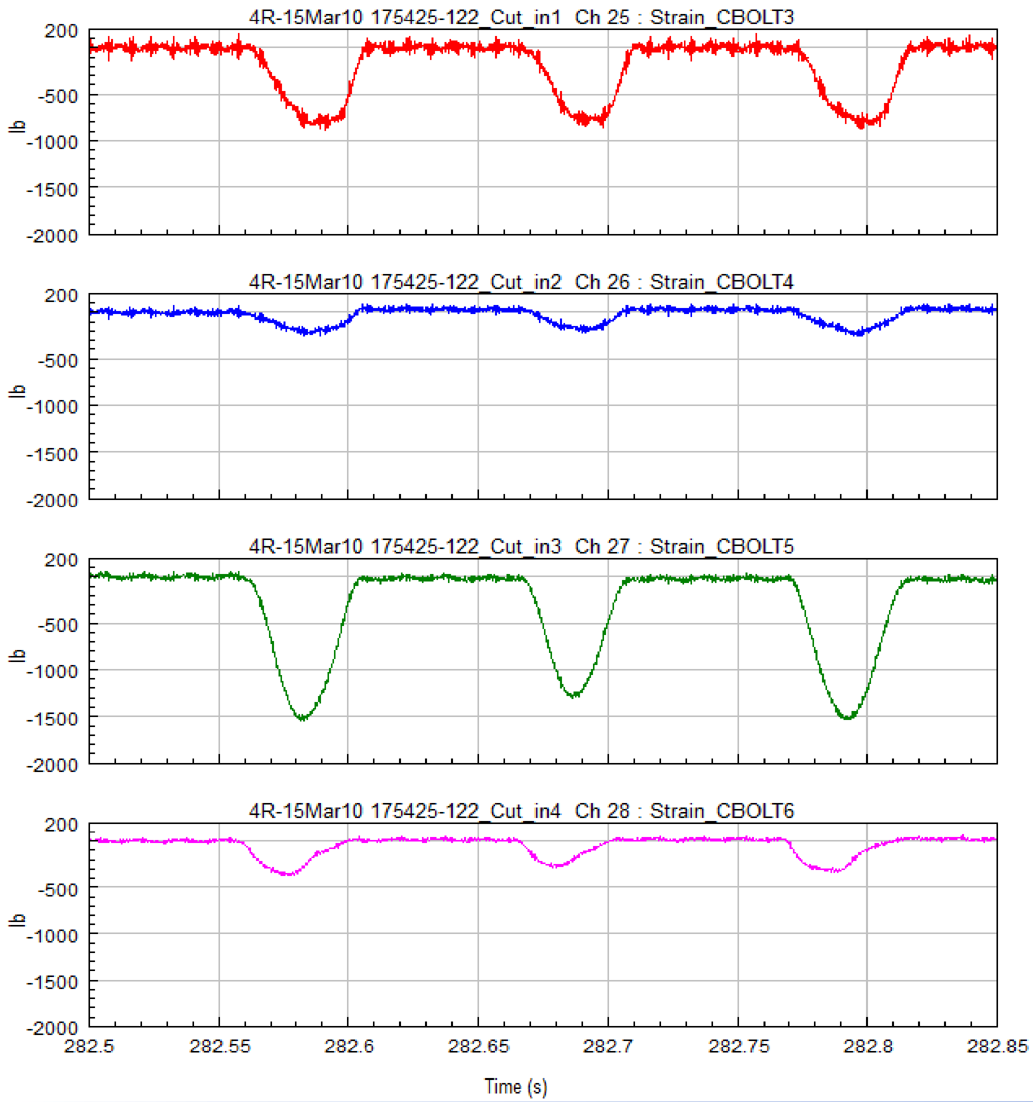
Instrumentation and Analysis

- Bolts repeatedly experience significant relaxation/unloading

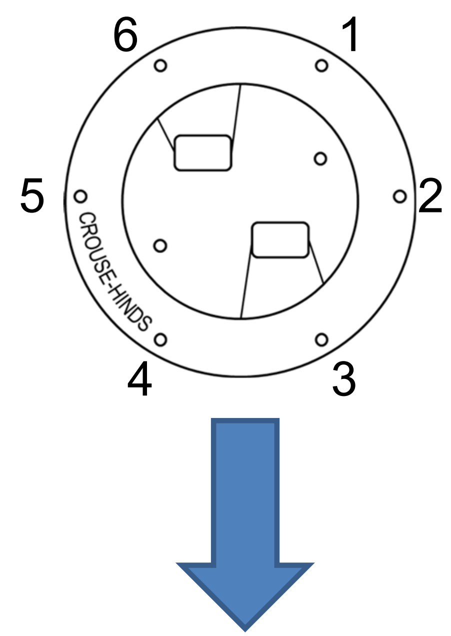
- Results indicate aircraft ***does not*** have to contact light fixture in order to induce cyclic strain response
  - No indication of direct impact, but good results obtained from "rolling end" of runway

Instrumentation and Analysis

- 777 after landing (all wheels down)



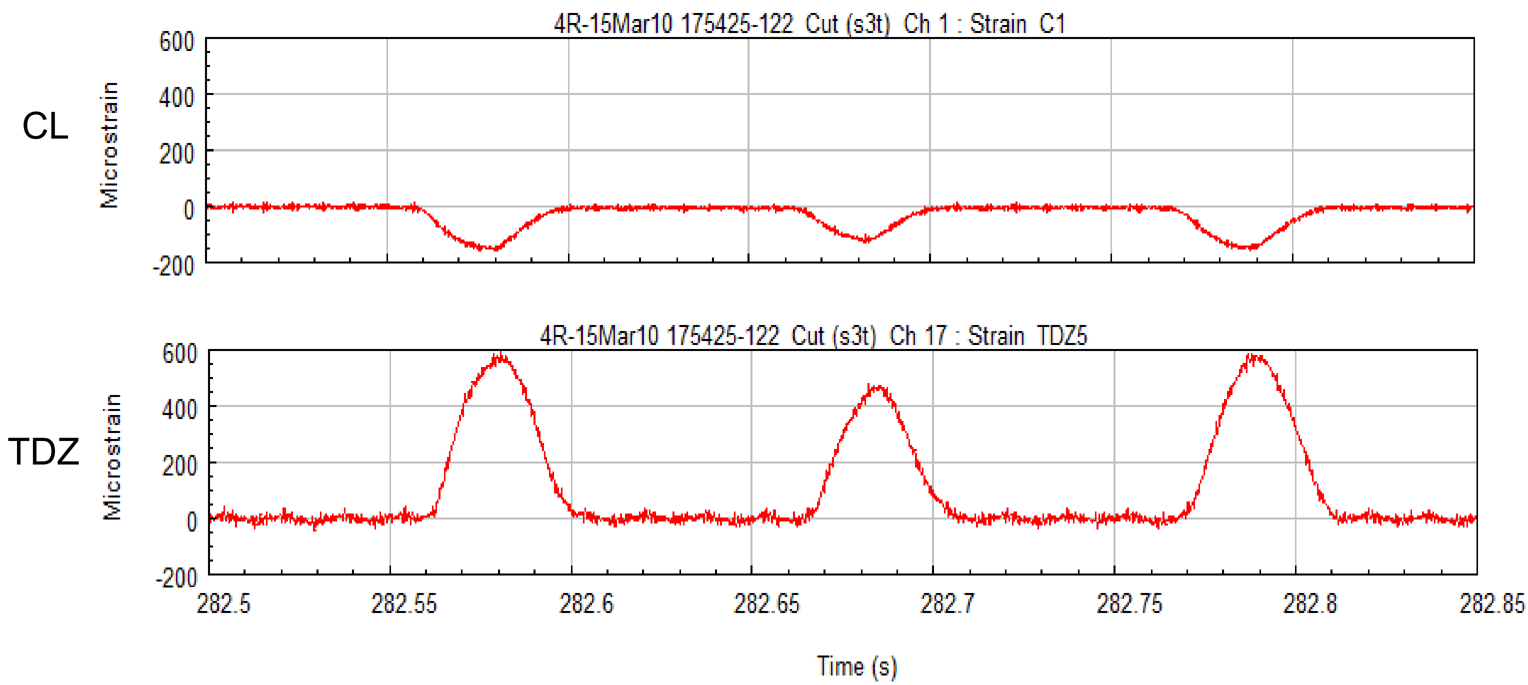
Centerline bolt strain gages

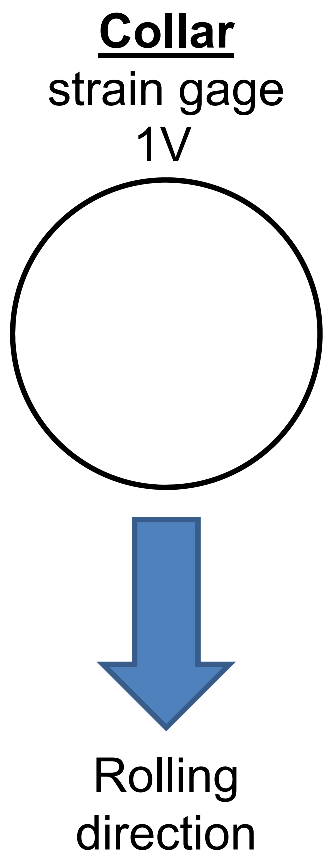


Rolling direction

Instrumentation and Analysis

- Simultaneous response at centerline and touchdown zone





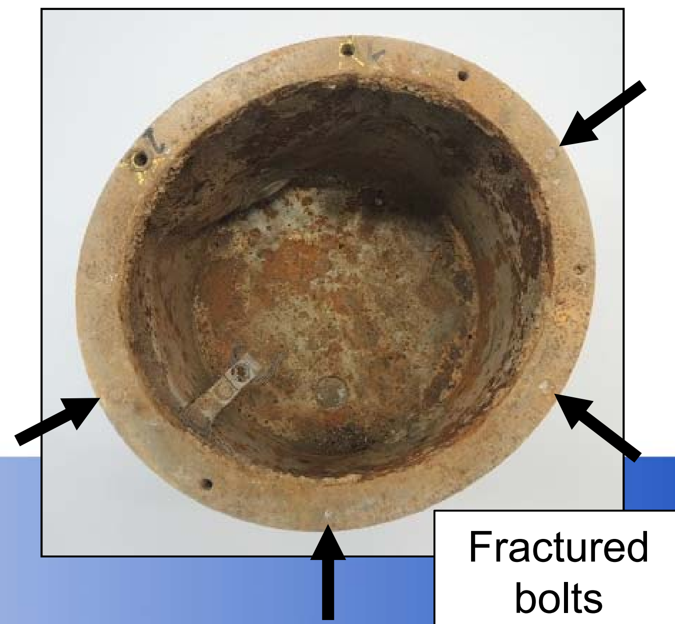
High-speed Turn-off Analysis

- Additional type of incident highlighting influence of pavement / light fixture interaction

- High-speed turn-off fixtures experience braking forces and lateral turning forces

High-speed Turn-off Analysis

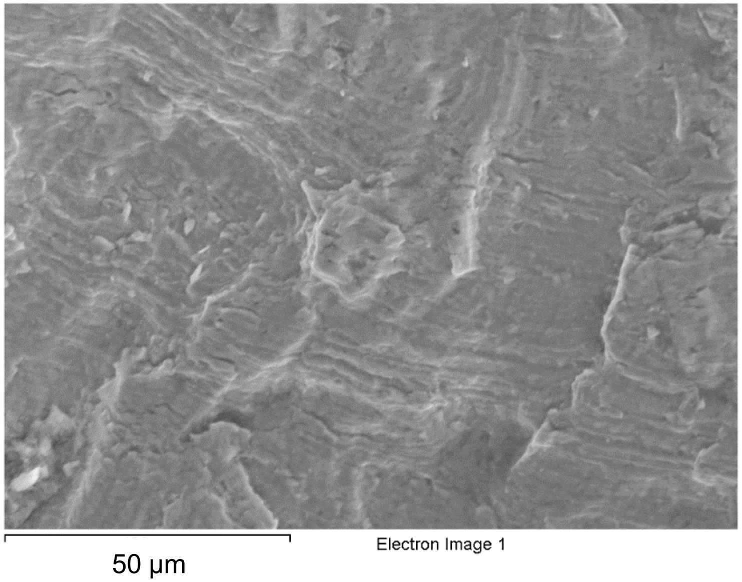
- Numerous lead-off light fixture assemblies for high-speed taxiways discovered with:
  - Cracked / fractured extension collars
  - Ovalized base cans
  - Severely deformed / cracked / fractured bolts



High-speed Turn-off Analysis

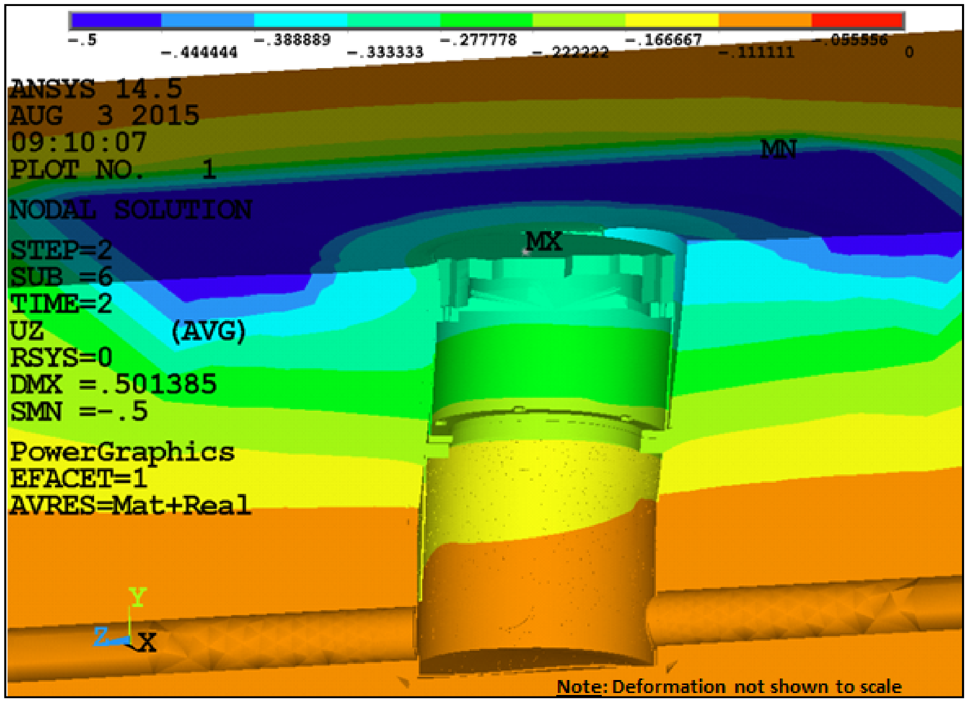
- Extension collar exhibited evidence of fatigue cracking at lower flange

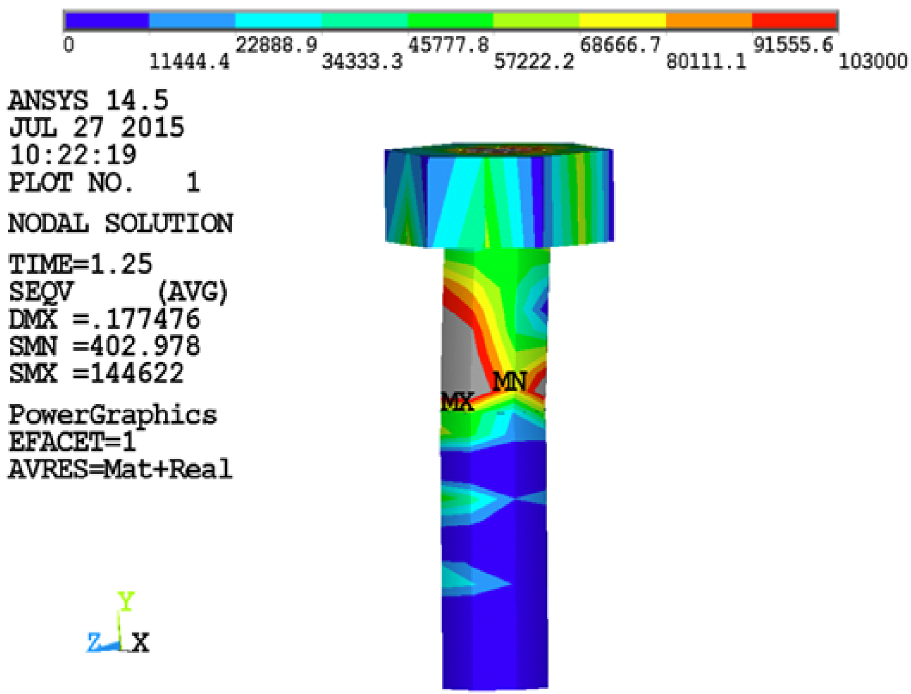
- Bolt segments in base can exhibit evidence of bending fatigue



High-speed Turn-off Analysis

- Finite element analysis validated findings under scenarios of asphalt pavement displacement





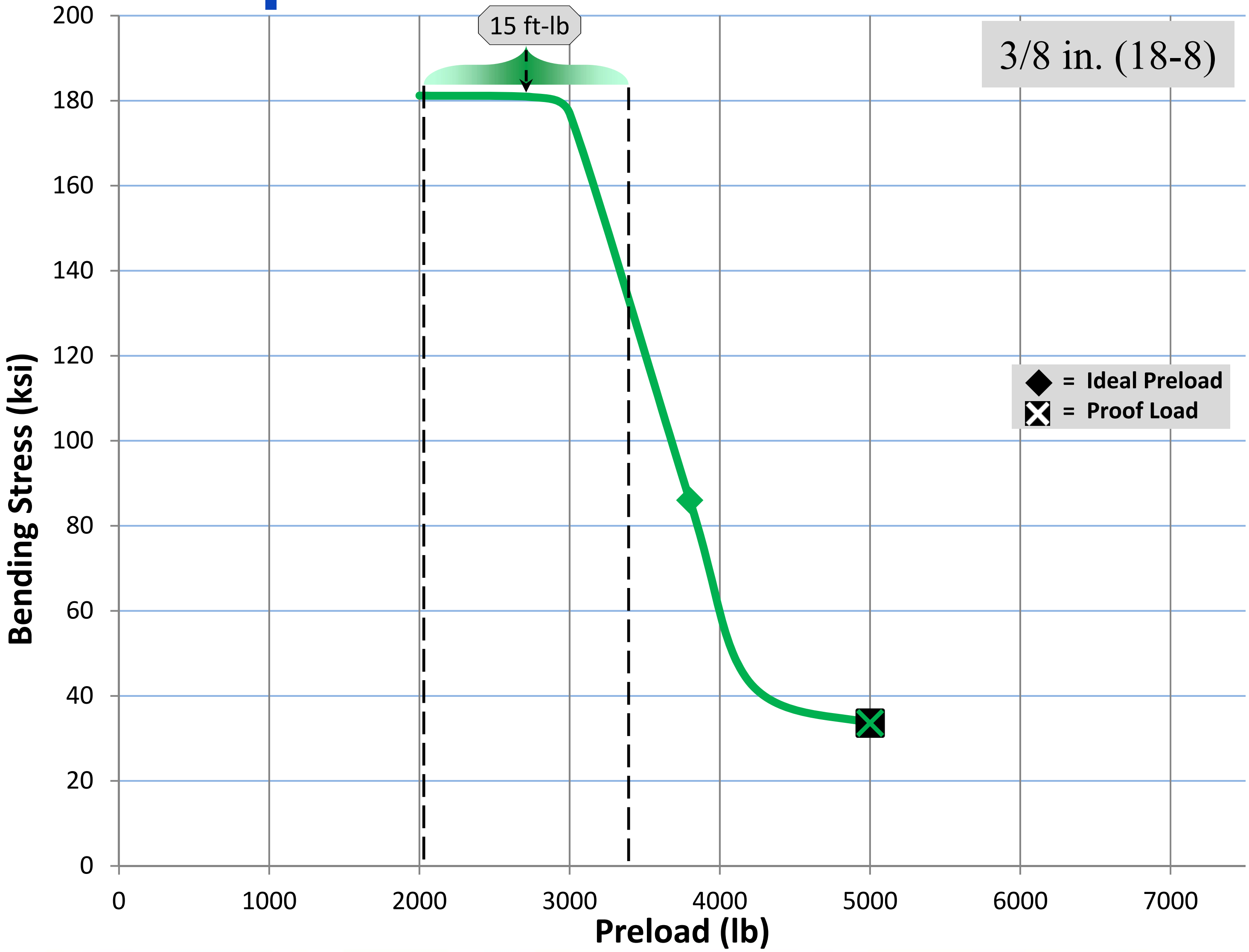
LPI Evaluation Findings

- Bolts experience **repeated** unloading cycles due to pavement acting as a system
- Current torque levels **are not sufficient** to prevent movement due to passing aircraft
- High-speed turn-off fixtures experience unique pavement / fixture loading interactions

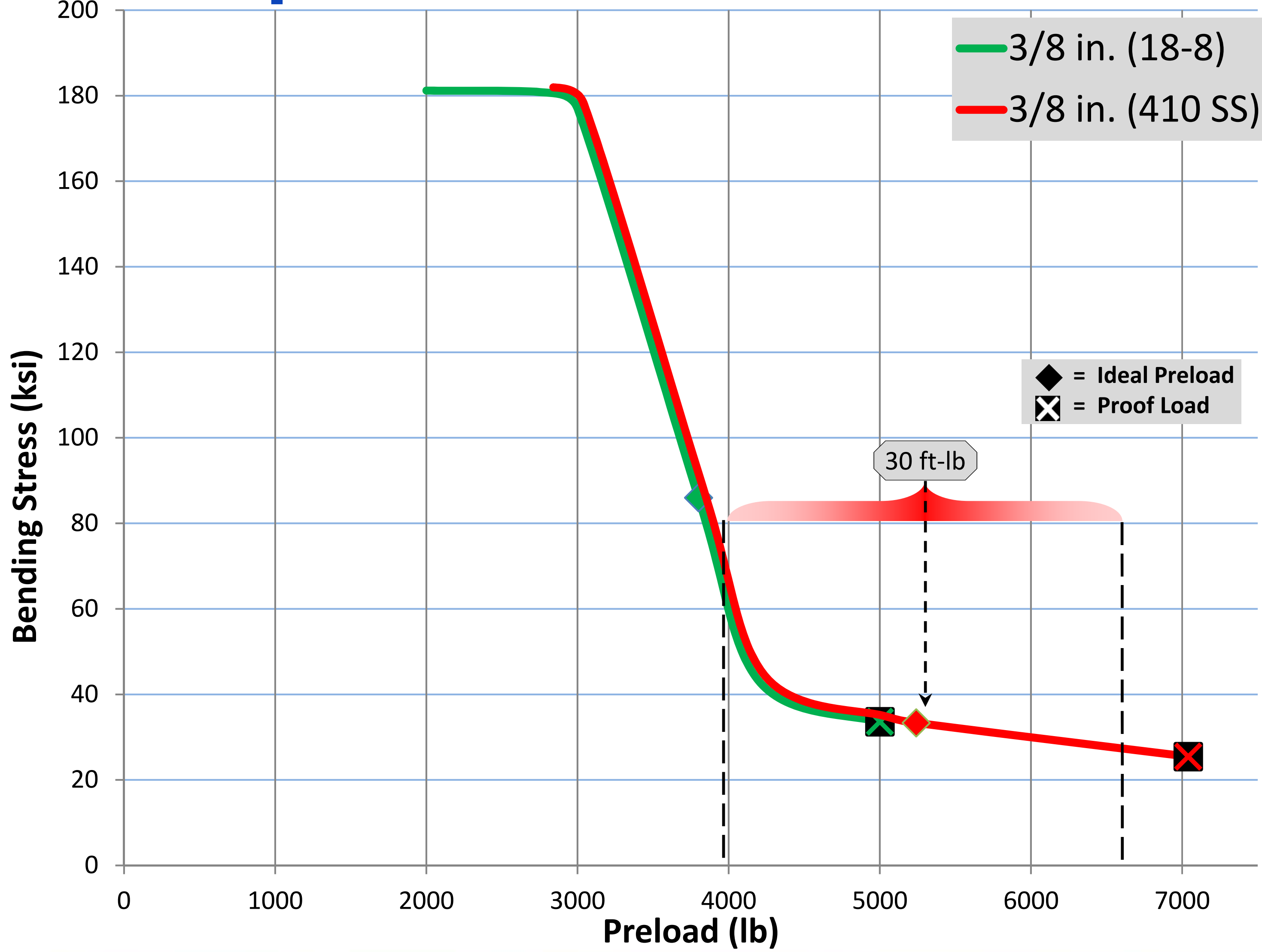
LPI Bolt Recommendations

- Interim recommendation
  - Type 410 stainless steel bolts (ASTM F593P)
  - 30 ft-lb
  - Loctite marine grade anti-seize
  - Two-piece lock washer (wedge-locking style)
- Next phase recommendation
  - Further increase possible clamping force
  - Feasibility study: Increase bolt size to 7/16 in.
  - Modify existing infrastructure

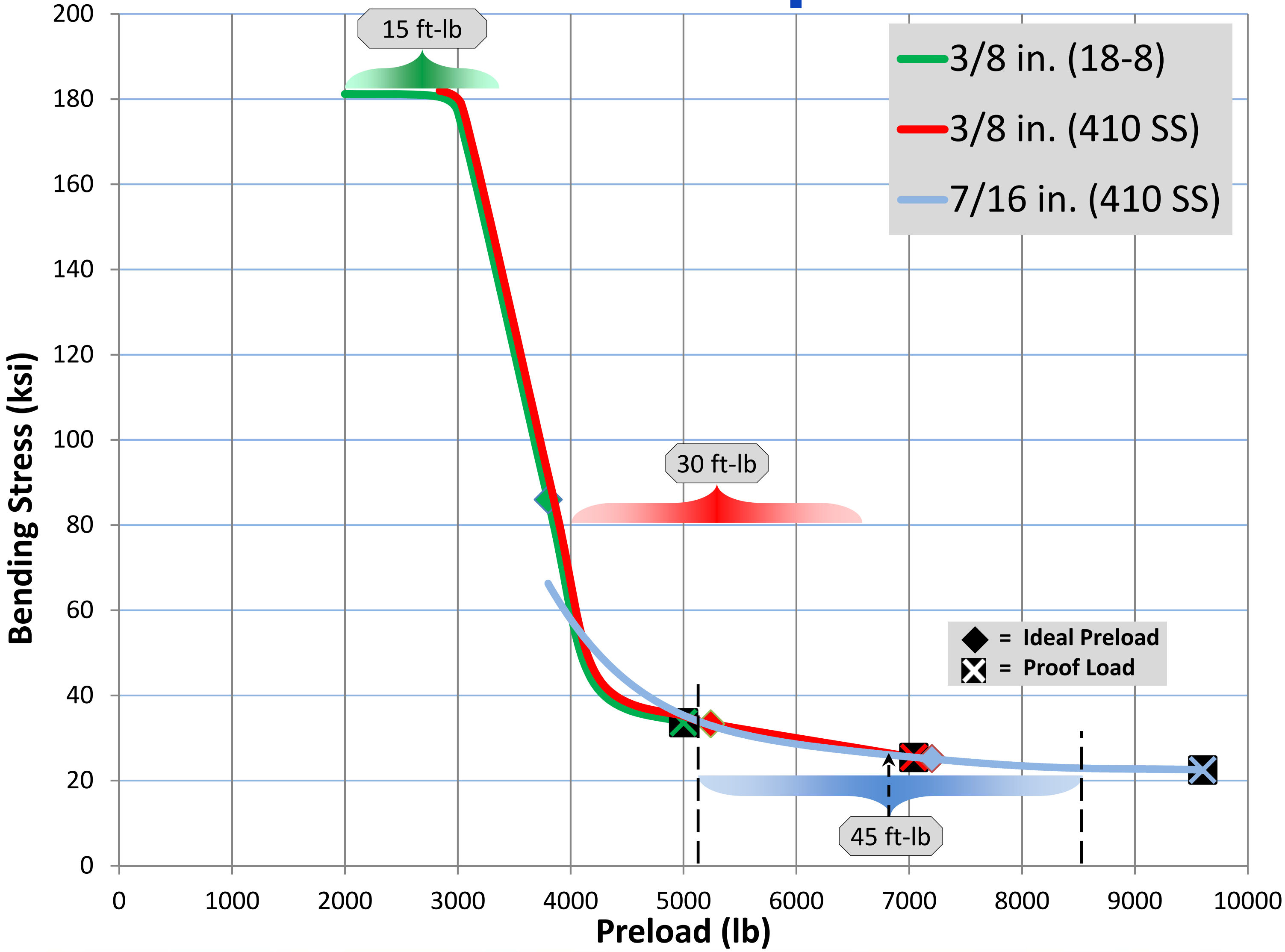
Torque Effect on Bolt Stress



Torque Effect on Bolt Stress



Bolt Size Comparison



Future Work

- Field instrumentation and analysis of modified 7/16 in. light fixtures
  - One asphalt runway, one concrete runway
  - Same fixtures as previously instrumented
- Validation of finite element analysis
- Help determine torque maintenance requirements

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nsuring the integrity of today's critical infrastructure for tomorrow's world.

Based on these findings by LPI, this Improvement Program became Phase I

1. Completion of Corrective Maintenance Backlog
2. Standardize and update preventive and corrective maintenance using the existing Computerized Maintenance Management System (CMMS)
3. Conduct maintenance audits
4. Implement a new state-of-the-art CMMS, Maximo, using mobile technology
5. Update construction oversight standards
6. Engineering analysis of system/component failures
7. Update engineering design standards

Phase II recommendation includes bolt replacement program with 3/8" - 410 stainless bolts

- Use fully threaded, 3/8-16, 410 Stainless Steel, black oxide coated bolts with a hardness range of 20-30 HRC with two-piece lock washer (wedge-locking style). Maximize bolt strength and avoid "gall"
- Mounting base holes must be degreased, cleaned, and dried prior to bolt installation.
- All mating surfaces from the base to the fixture must be degreased, cleaned and dried prior to installation.
- Apply marine grade antiseize (K=.18)
- Torque bolts to 30 ft-lbs with a calibrated torque wrench in a "star" pattern. Adjust for 75% of proof load
- Immediately re-torque the bolts in the same "star" pattern.
- Re-torque bolts within 2-weeks of the initial installation.

A three phase plan was developed to enhance safety and improve reliability

Phase I – Update the AOA Electrical preventive maintenance program

Phase II – Maximize clamping force with existing light fixtures

- LPI Recommendation: 410 Stainless – black oxide torqued to 30ft-lbs
- C-H Adjustment: 410 Stainless – localized stress on fixture limited torque to 23ft-lbs

Phase IIA – Adapt fixtures to upgrade to larger bolts

Phase III – Promote redesign of the entire assembly

Aircraft Loading Effects on Load-bearing Inset Lights

John Schneider
Director of Engineering

EATON
Powering Business Worldwide

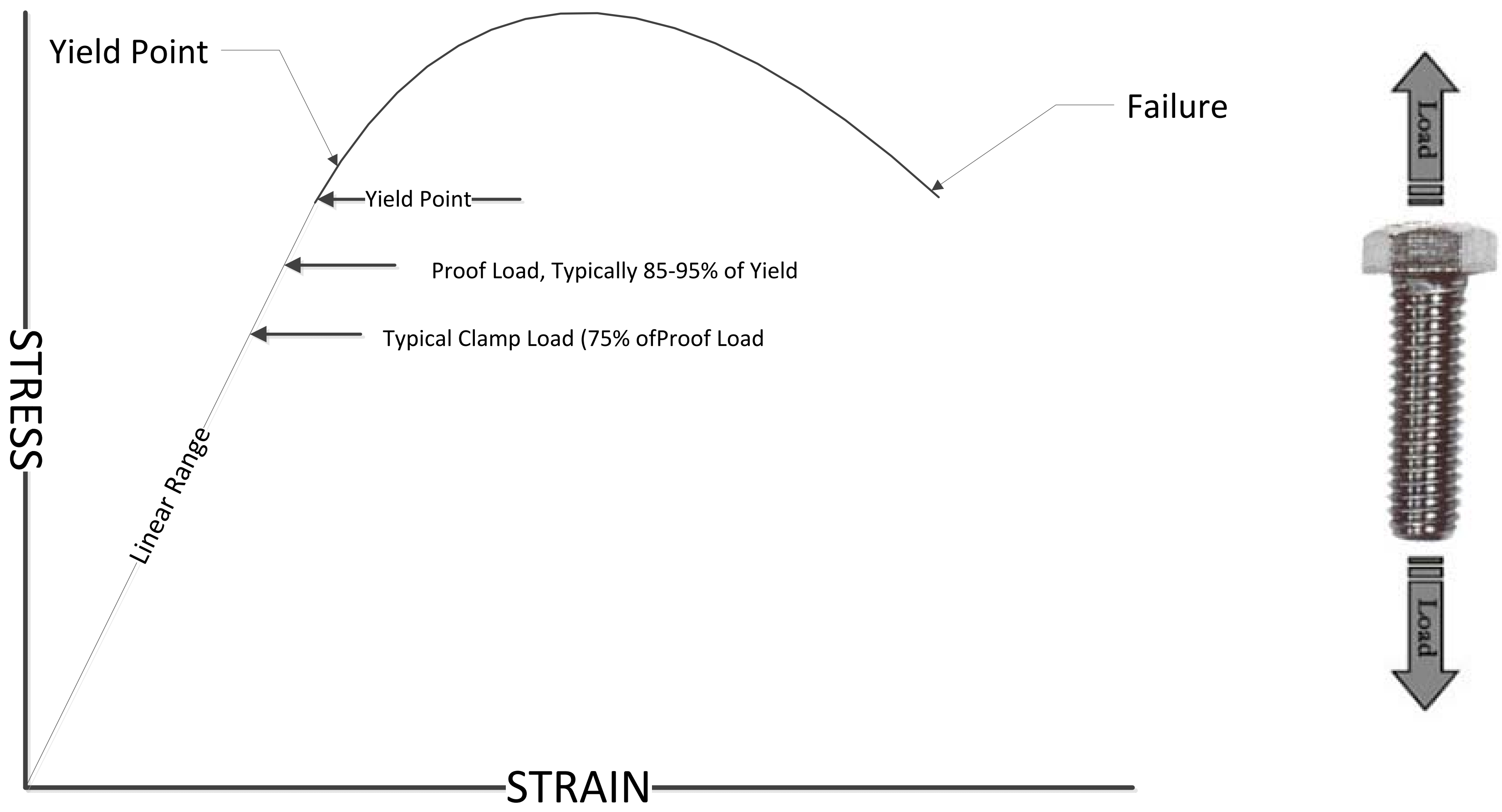
20160922

Goal

To understand the effects of aircraft loading (instantaneous braking) on inset fixtures.

Are six 3/8” 18-8 bolts sufficient?

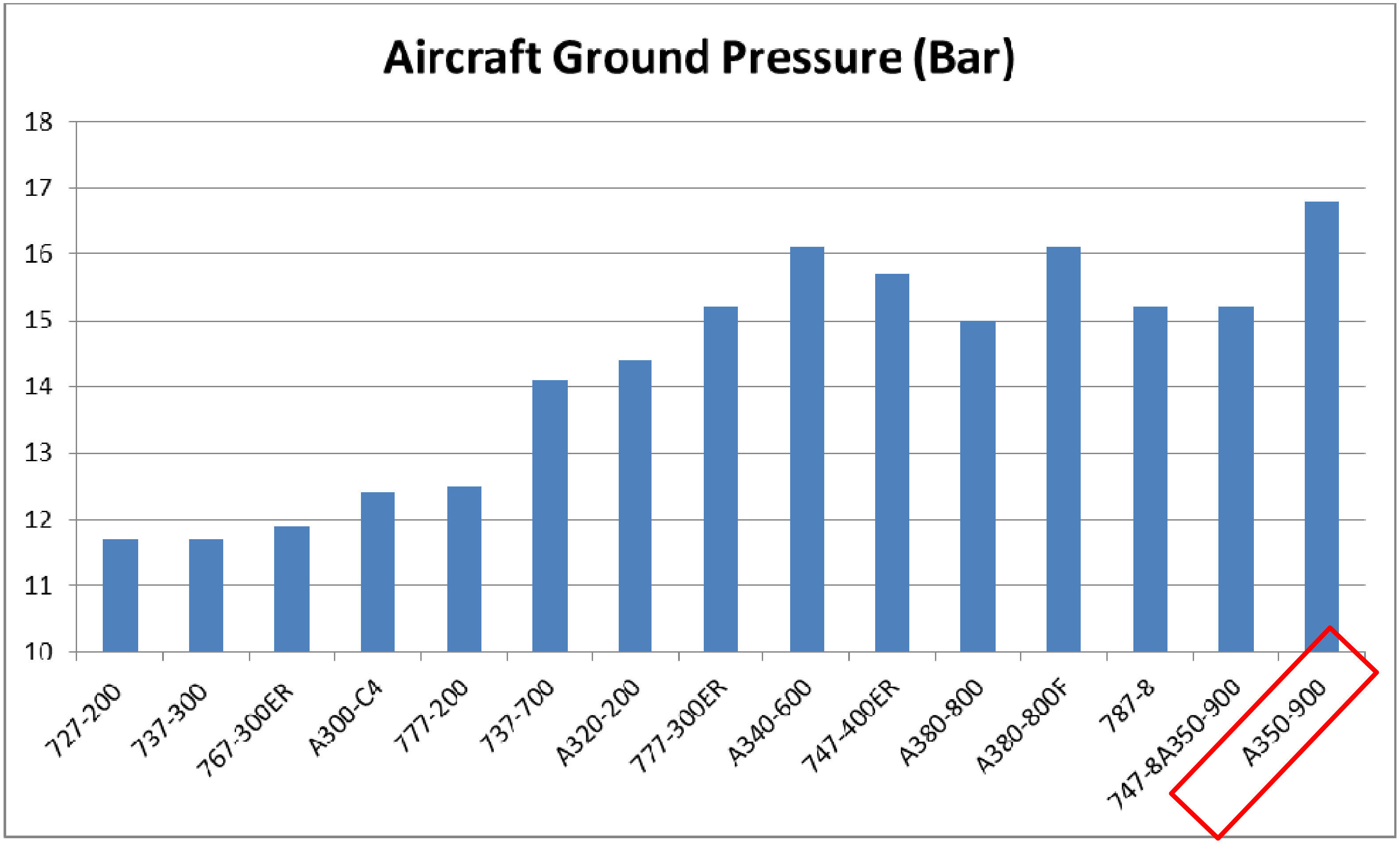
Assumption: 75% proof-load tensile limit[7]



Assumption: full main-gear contact

Click for video of cross-wind landings.[3]

Aircraft Pavement Contact Pressure



[1]

A350-900 Main Strut Data (each)[2]

Max Static Load (lbs)	Instantaneous Braking Force (lbs)
277,700	222,150

Analysis Case General Assumptions

So, for the main strut of a A350-900 aircraft[2]

69,500 lb downforce per tire

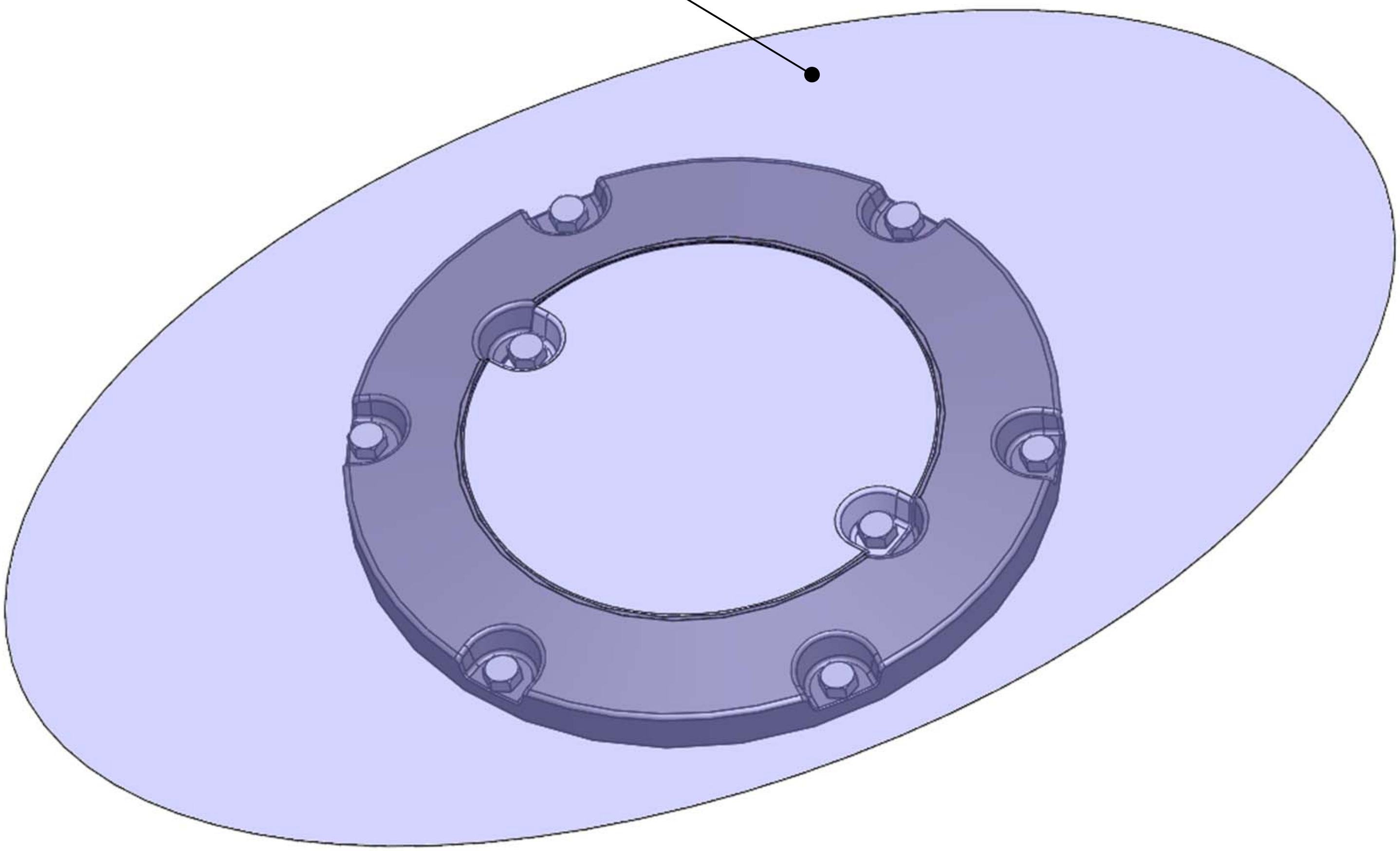
55,600 lb horizontal (shear) force per tire

[13]

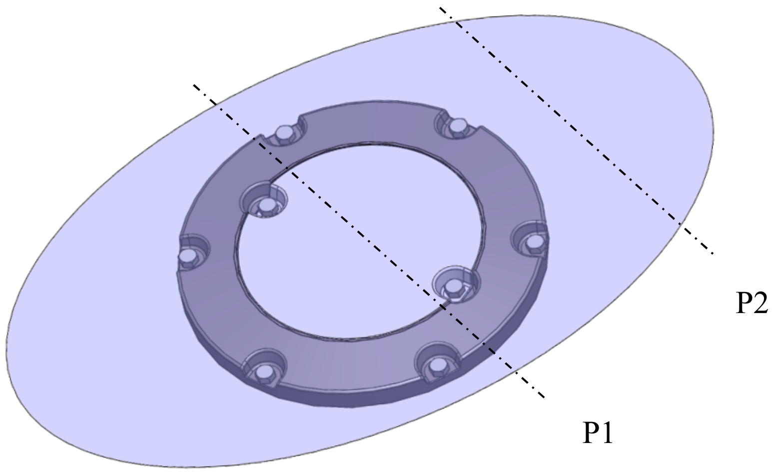
Powering Business Worldwide

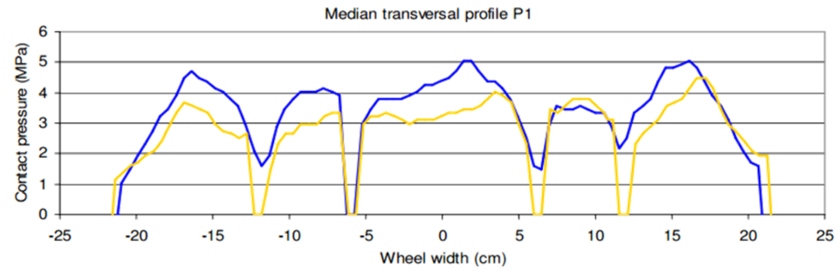
Assumption: full main-gear contact

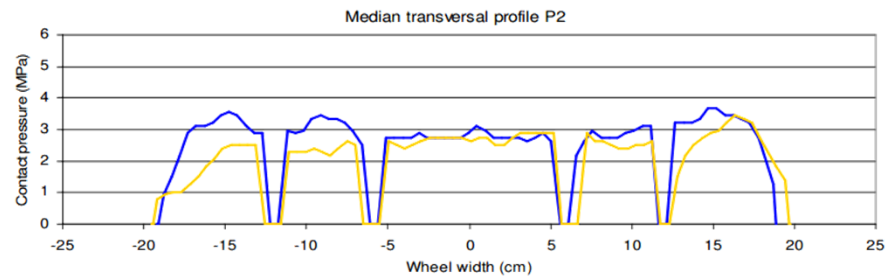
A350-900 Tire Contact Patch, 290in^2 [4]

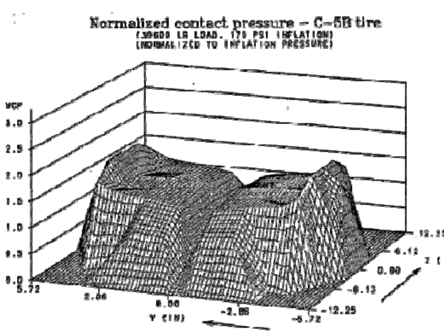


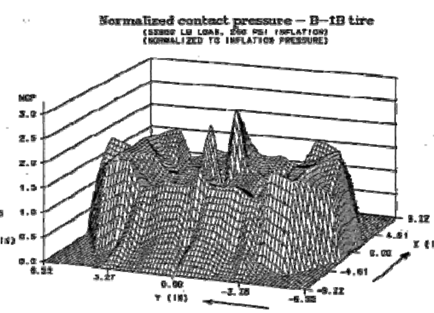
Assumption: 150% x average loading

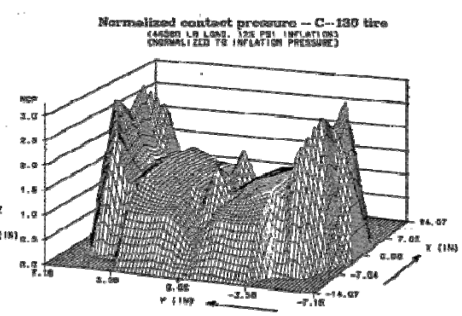


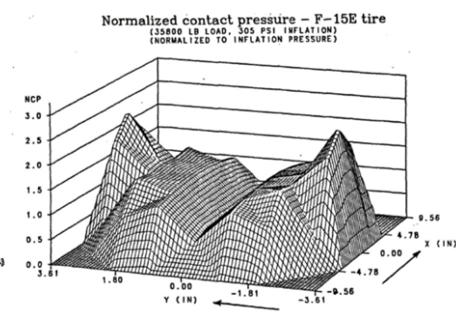






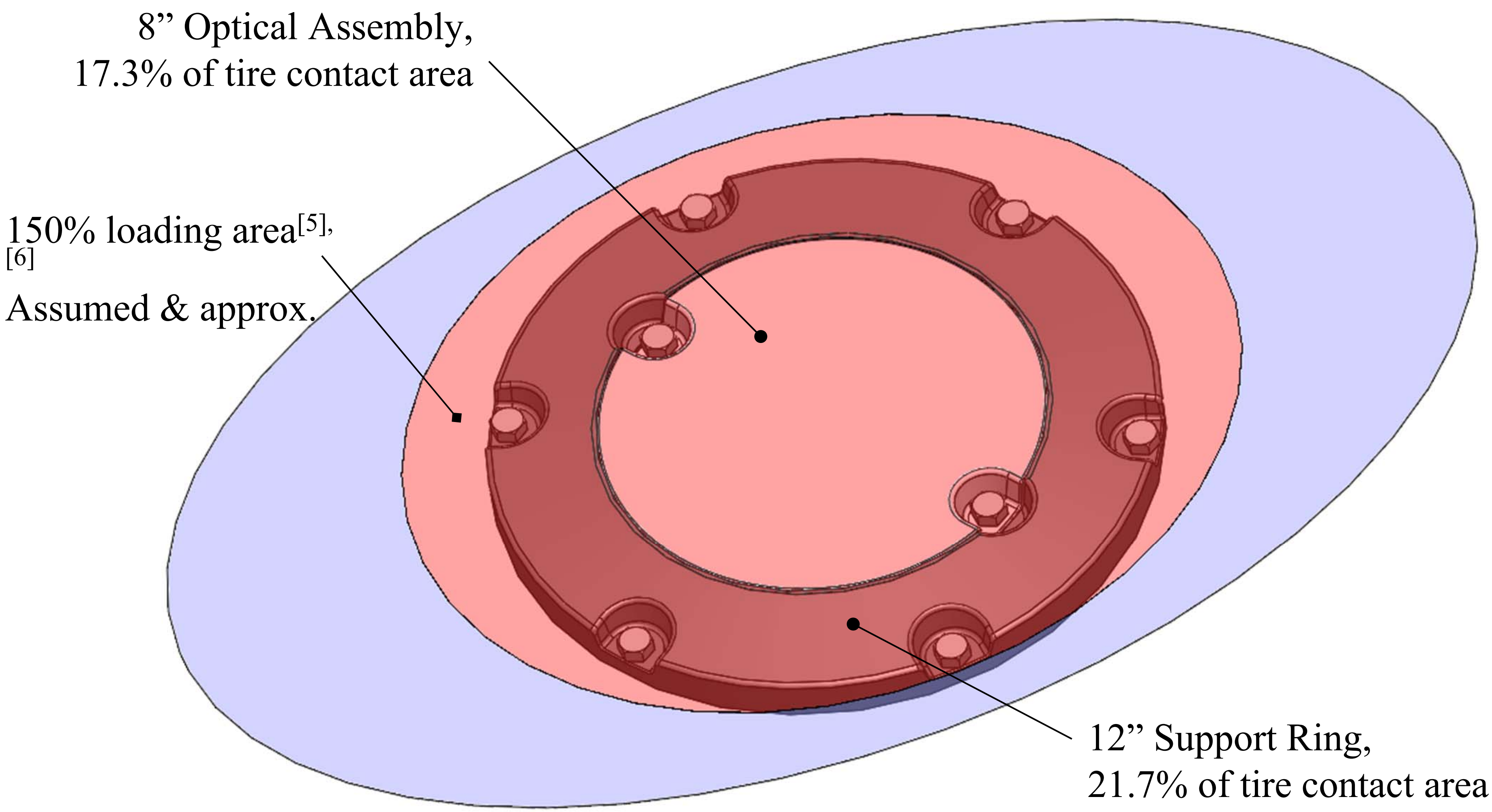






Boeing and Airforce test data[5] [6] (above) shows uneven contact pressure distribution across the length of an aircraft tire patch

Fixture contact area



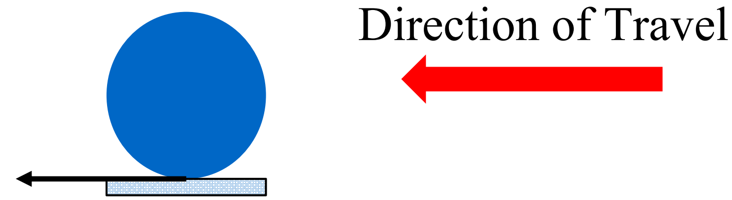
Remaining Assumptions

- Maximum instantaneous vertical and horizontal (shear) forces[2] occur simultaneously

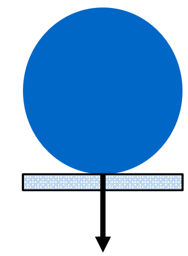
- 0.45 coefficient of friction on fixture-to-base mating surfaces[9] (from FAA brief EB83), actual COF may vary

- Controlled bolted-joint K value of .18 (marine grade anti-seize)[10]

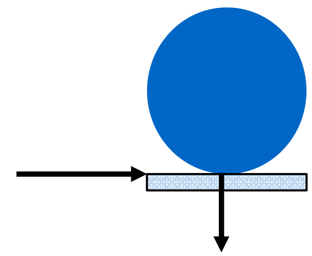
A350-900 Minimum Required Bolt Tensile Load Calculations



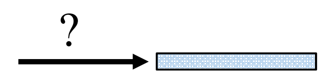
<u>A350-900 Braking Shear Load on 12” fixture</u>
Shear load applied to fixture w/ support ring =
(222,150 lb / 4) x 150%[5], [6] x (17.3% + 21.7%) = 32,489 lb



<u>A350-900 Down Force on 12” fixture</u>
A350-900 down-force applied to 12” fixture =
(277,700 lb / 4) x 150%[5], [6] x (17.3% + 21.7%) = 40,614 lb

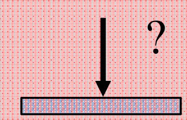


<u>A350-900 Self-applied Shear Resistance on 12” fixture</u>
40,614 lb x $.45_{COF}$[9] = 18,276 lb shear resistance



<u>Minimum Required Bolting Shear Resistance for 12” fixture</u>
32,489 lb – 18,276 lb = 14,212 lb min

<u>Minimum Required Bolt Clamp Load to Resist 14,212 lb Shear w/ $.45_{COF}$</u>
14,212 lb / $.45_{COF}$[9] = 31,584 lb min total clamp load
31,584 lb / 6 bolts = 5,264 lb min clamp load per bolt



Current FAA Certification Requirements (AC…46E)

Current FAA Certification Requirements (AC…46E):

[11]

4.5.1.3. Horizontal Shear Test.

This test simulates the shearing load applied to the top of any in-pavement fixture by a braking aircraft tire.

a. A bar must be attached (welded) to the top of the fixture so it is parallel to the runway centerline when the light is installed.

b. The ends of the bar should extend beyond the edges of the fixture to facilitate loading.

c. The light fixture, attached to a base receptacle or facsimile, and torqued to manufacturer's specifications, must be installed in a press with the attached bar in line with the piston of the press.

d. A load of 3,000 pounds (1,360.70 kg) must be applied to the end of the bar by the press. The load must be applied and release 20 times to each end of the bar.

e. Any structural damage, movement of any part, or loosening of fasteners must be cause for rejection.

Worst case A350-900 analysis (i.e. this analysis):

Minimum Required Bolting Shear Resistance for 12" fixture

32,489 lb – 18,276 lb = 14,212 lb min

Current FAA Recommendations (EB83)

1.0 Recommended Industry Best Practice. [9]

a. A **maximum of 185 in lbs.** of torque for a **dry 18-8 bolt** is recommended. A torque of 185 in. lbs. **should not** be used for a 18-8 bolt with anti-seize compound applied to the threads. With anti-seize compounds and coated bolts, less torque is required to achieve the clamping forces required to offset fixture movement in the presence of opposing forces. Always consult the light fixture manufacturer's installation instructions for proper bolt torque.

2.1.1 Determination of Clamp Force from Bolt Torque. [9]

If the light fixture manufacturer's recommended torque of 185 in. lbs. is used, the clamping force of the light fixture to the light base can be verified. Algebraically solving the equation in 2.1 for F_p and using a dry bolt (K =0.2):

NOTE: The friction coefficient K will be explained in later text.

$F_p = T / K * D$

Substituting the numbers:

F_p = 185 in. lbs. / 0.2 * 0.375 = 185/0.075 = 2,466 lbs. clamping force.

It then follows that the total clamping force for a light fixture to a light base is 6 times 2,466 lbs. (six bolts in the light fixture) or 14,796 lbs.

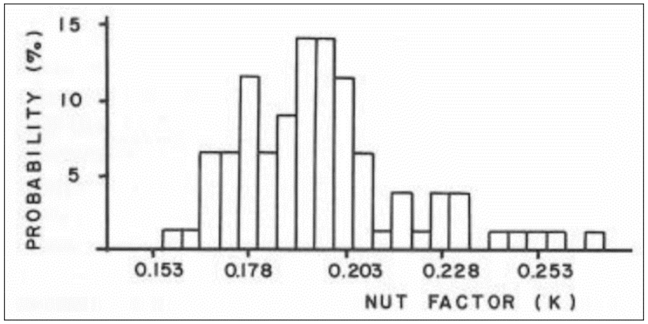
Worst case A350-900 analysis (i.e. this analysis):

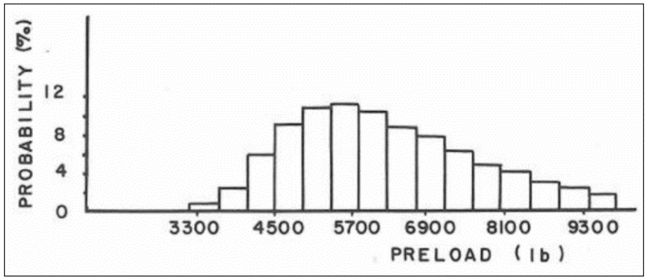
Minimum Required Bolt Clamp Load to Resist 14,212 lb Shear w/ $.45_{COF}$

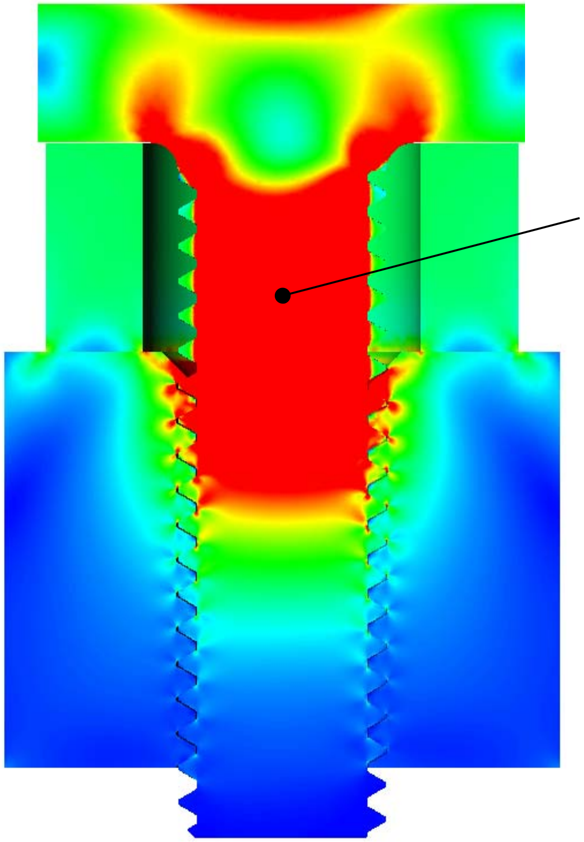
14,212 lb / $.45_{COF}$[9] = 31,584 lb min total clamp load

31,584 lb / 6 bolts = 5,264 lb min clamp load per bolt

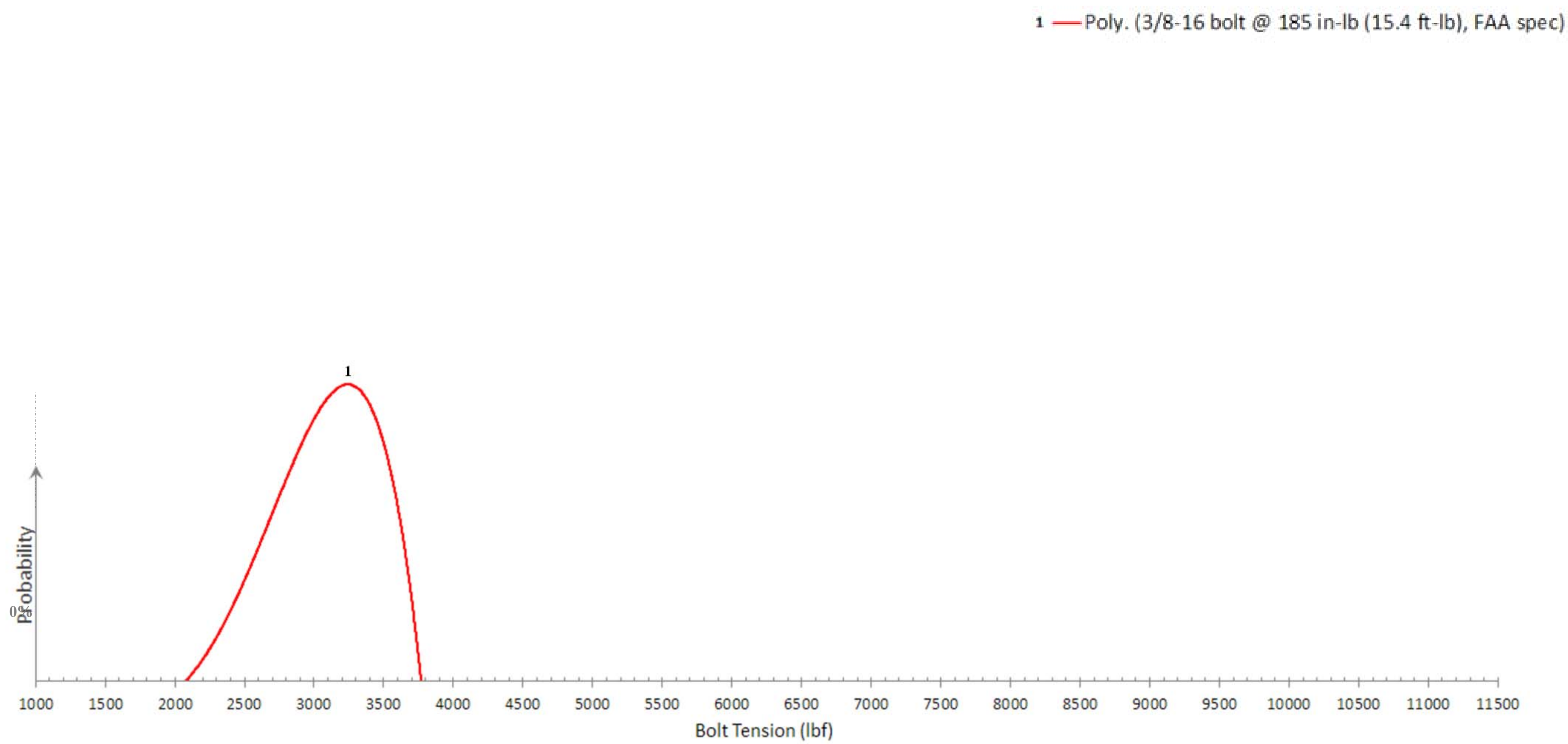
Assumption: ±25% tensile load uncertainty[8]







Torque & Probable Bolt Tension[8], K=.18[10]



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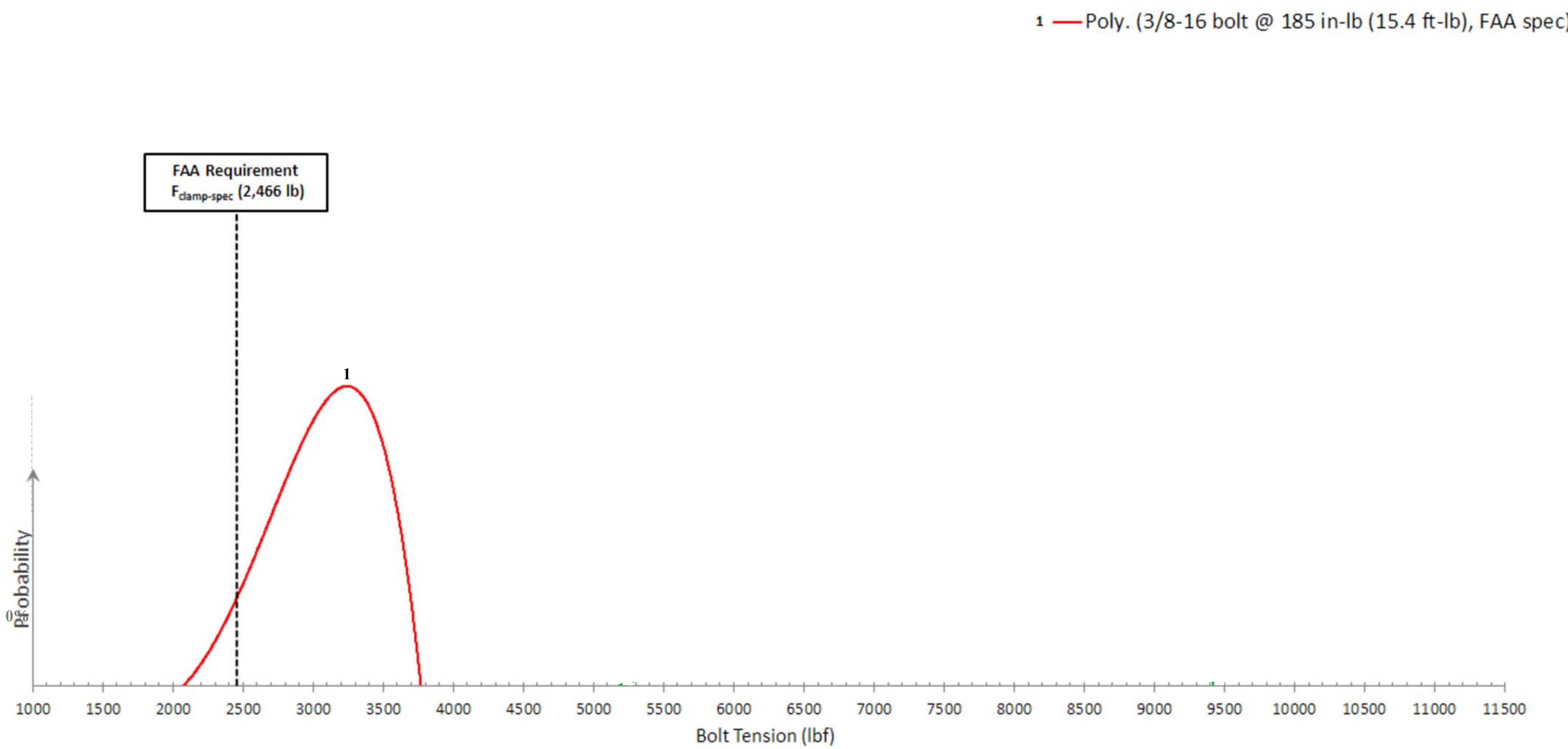

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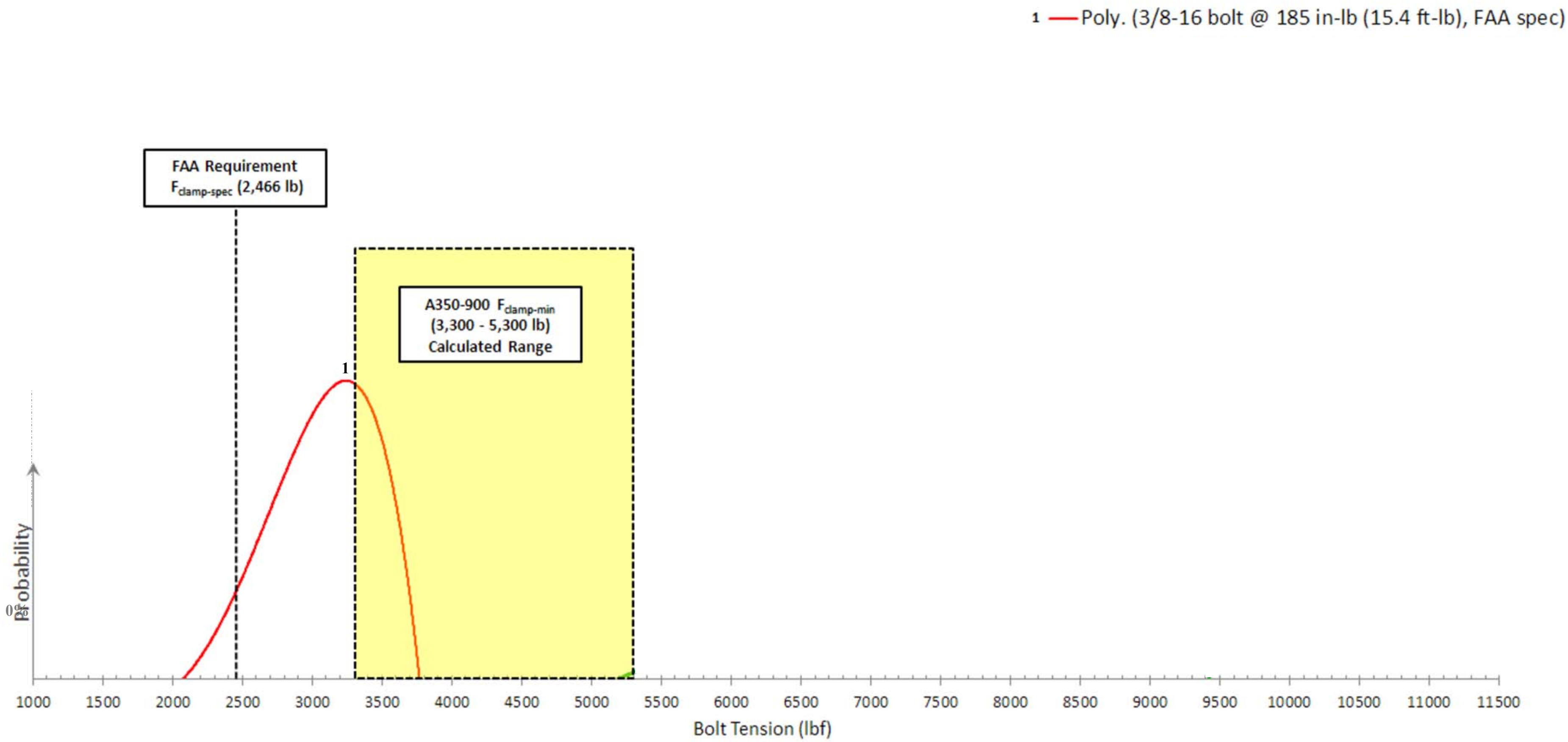

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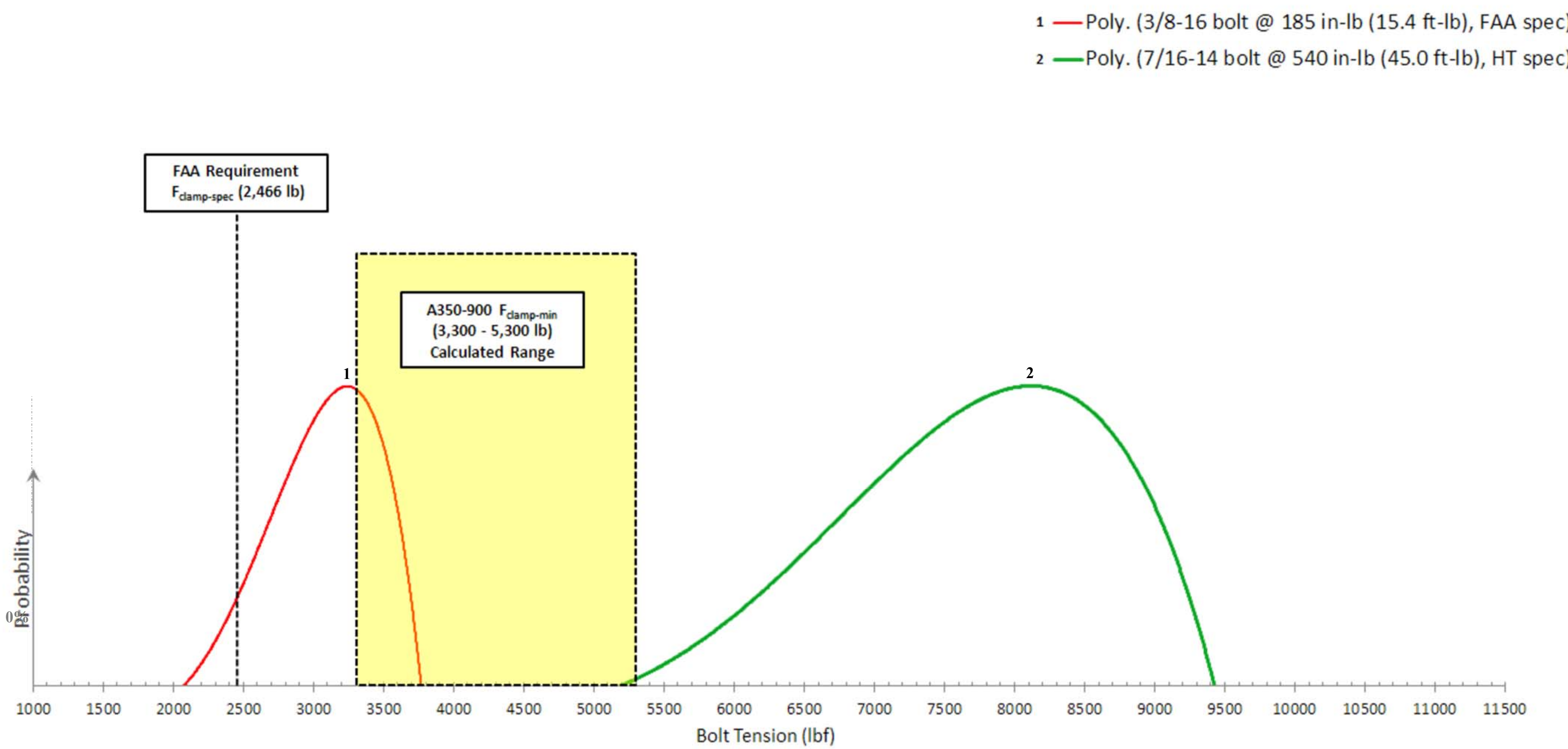

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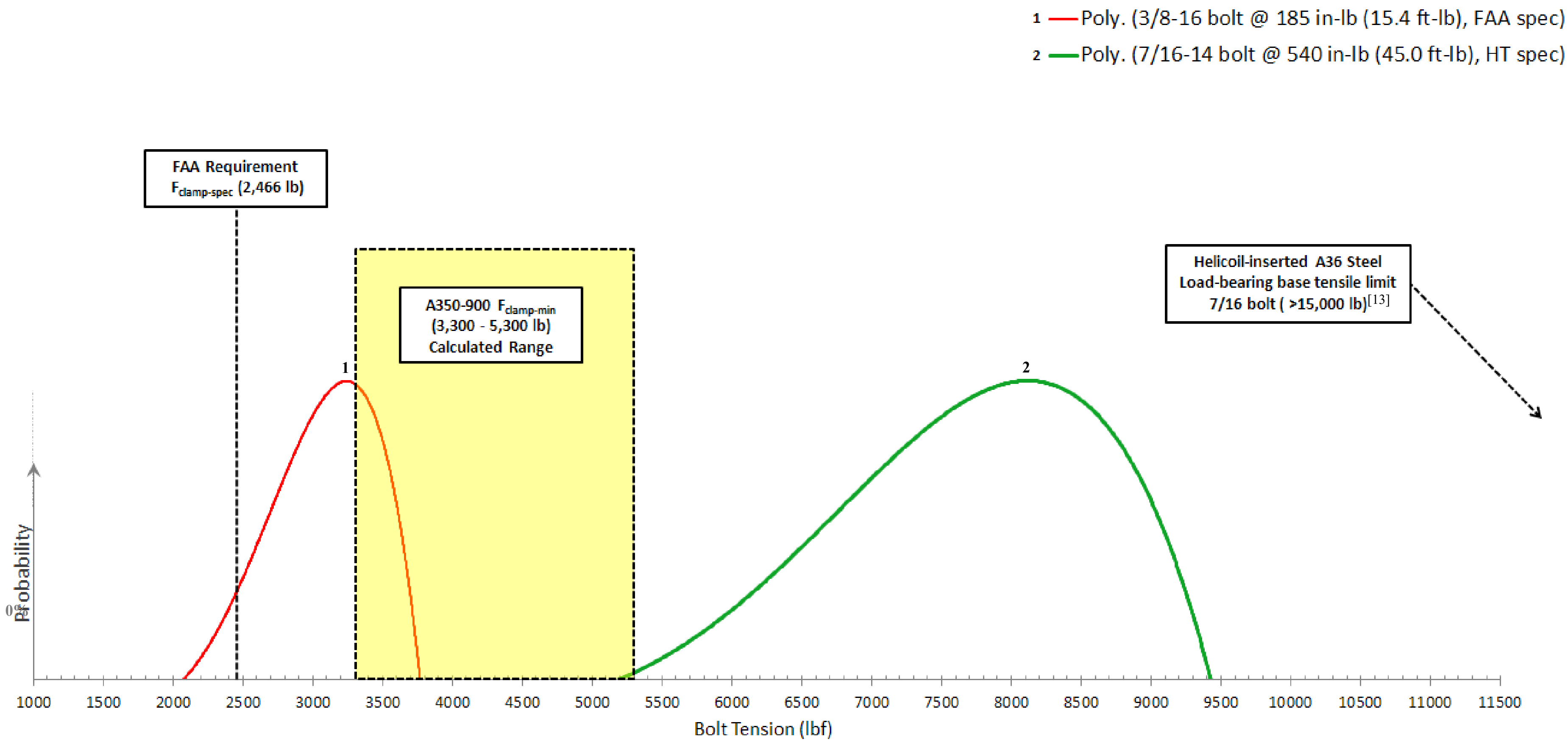
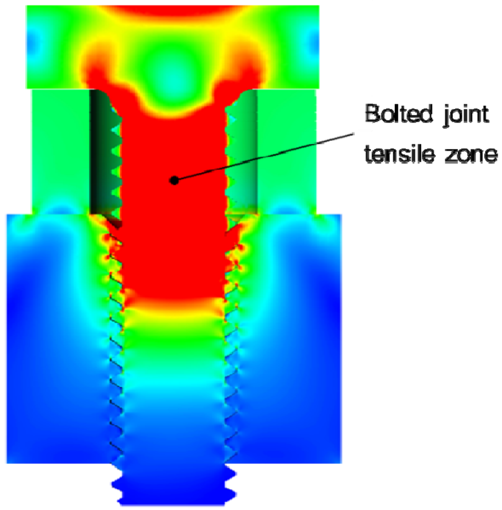
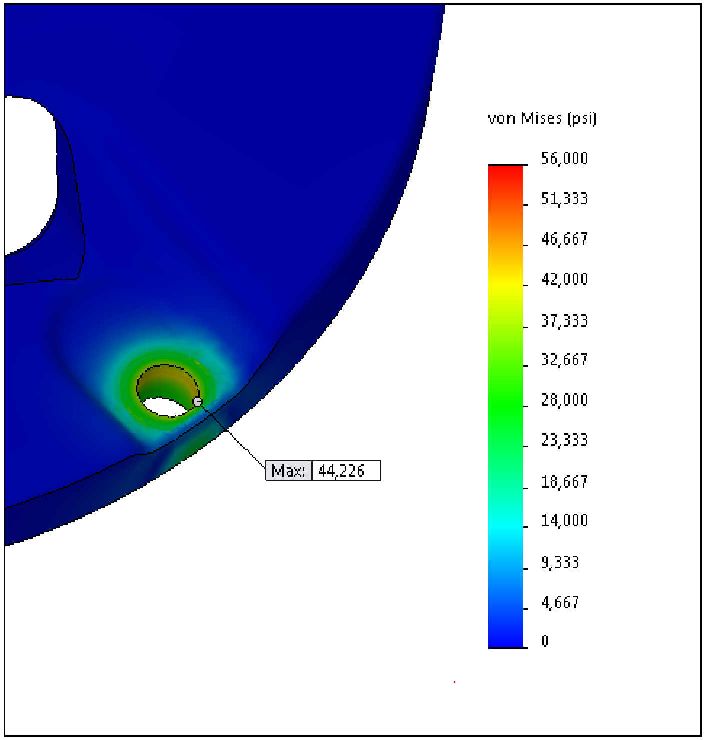
Torque & Probable Bolt Tension[8], K=.18[10]



Bolt System Considerations (3/8” & 7/16”)





- Bolt yield
- Fixture compression
- Base can pull out ✓
- Lock washer loading
- (Threaded insert) pull-out strength

Options & Recommendations

Approach	Pro's	Con's
6 x 3/8" 18-8 Stainless, increased torque (40+ ft-lb)	• Uses existing hardware • No change to current configuration • Provides required clamp load (but no margin)	• Will statistically create bolt stresses in the range of ultimate tensile stress. Safety issue. • May overload optical housing.
12 x 3/8" 18-8 Stainless (15 ft-lb)	• Uses existing hardware • No changes to base cans	• Doubles the amount of hardware • Light fixtures need redesign • Offers slightly less than required clamp force
6 x 3/8" Grade 8 (130ksi) Coated Steel (40+ ft-lb)	• No changes to light fixtures or base cans	• Coated bolts susceptible to abrasion/flaking and corrosion • May overload lock washers • May overload aluminum housings
7/16" Stainless (90ksi) (45 ft-lb)	• Provides required clamp load (but no margin) • Minimal changes to light fixtures (enlarged clearance holes)	• Need to re-tap (or install inserts) base-cans, or replace can extensions • Requires new hardware
1/2" Stainless (90ksi) (68 ft-lb)	• Exceeds required clamp load with sufficient margin (>30%) for the foreseeable future	• System redesign (light fixture and base-can)
Add shear pins?		

Automotive Approach

½ Ton Chevy Truck → Six 7/16" Lugs

Inputs		
Calculated		

		units
Curb Weight =	3300	lb
Load capacity =	0.5	ton
# of wheels =	4	n/a
# of bolts per wheel =	5	n/a
Acceleration/Decceleration =	3	g
Shear force per wheel =	3225	lbf
Shear force per bolt =	645	
COF =	0.45	n/a
Min required clamping force =	1433.3	lbf/bolt
Typical 7/16 lug nut torque =	85	ft-lb
Min 7/16 lug nut clamp =	8000	lbf
Clamp Factor of Safety =	5.6	

Time for a system upgrade?

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Summary

Airports should work with the FAA to determine the best path forward and obtain approval if it deviates from specifications until the next generation solution is defined.

References

[1] **Aircraft Pavement Load:** *Airport Compatibility, Opportunities and Challenges* *http://www.aci-na.org/static/entransit/Cohen-Nir.pdf*

[2] **A350-900 Maximum Pavement Loads:** Airbus A350-900 *Aircraft Characteristics, Airport & Maintenance Planning, Rev Jun 01/13*

[3] https://youtu.be/FAGtkcsvR-w

[4] **Tire contact area:** *Calculation Tire Contact Area* *http://www.boeing.com/assets/pdf/commercial/airports/faqs/calctirecontactarea.pdf*

[5] **Tire Pressure Distribution:** *Full-Scale Aircraft Tire Pressure Tests* *http://www.airporttech.tc.faa.gov/ATT2010/Pavements/Session9a/Fabre-Full%20Scale%20Aircraft%20Tire%20Pressure%20Tests.pdf*

[6] **Tire Pressure Distribution:** *Aircraft Tire/Pavement Pressure Distribution, AD-A279 100, Department Of The Air Force, 1989*

[7] **Tensile Stress-Strain Diagram:** Fastenal *Bolted Joint Design* https://www.fastenal.com/content/feds/pdf/Article%20-%20Bolted%20Joint%20Design.pdf

[8] **Preload Uncertainty:** NSTS 08307 NASA *Space Shuttle Criteria For Preloaded Bolts, Rev A*

[9] **Coefficient of friction, Recommended Industry Best Practice, Determination of Clamp Force from Bolt Torque:**
Engineering Brief 83 *http://www.faa.gov/airports/engineering/engineering_briefs/media/eb-83.pdf*

[10] **Anti-seize K Factor:** *https://tds.us.henkel.com/NA/UT/HNAUTTDS.nsf/web/6BD116165490B5A0852577450068FB29/$File/MARGASL-EN.pdf*

[11] **Horizontal Shear Test:** AC150-5345-46D *http://www.faa.gov/documentLibrary/media/advisory_circular/150-5345-46D/150_5345_46d.pdf*

[12] **Helicoil Assembly Tensile Strength:** *Tensile Strength of Threaded Insert Assembly, Technical Bulletin 68-2*

[13] **A350 landing:** http://www.airbus.com/presscentre/pressroom/high-res-photos/filter/a350-xwb-family/cache/0/

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Implementation of Phase IIA is more complex for a number of reasons.

Modification of multiple fixture assembly components

- Base cans
- Spacers
- Fixtures

Clear departure from FAA Circulars that prescribe 3/8” bolts

Two Conditions: Retrofit and New

The retrofit alternative required has to compare modification or replacement of extension collar

Replacement of the extension collar with 3/8” bolt holes on the bottom flange and 7/16” bolt holes on the top.

Modification of the base can or extension collar in place will require a tool to drill out existing bolt holes.

The target schedule for the Phase IIA 7/16” bolt alternative is March, 2017

1. LPI will perform field testing with instrumented cans and bolts at JFK; 1st with 3/8” followed by 7/16”.
2. LPI updating the finite element analysis and performing additional lab testing of the bolts, inserts, extension collars, and base cans.
3. PA will be submitting findings by LPI and Eaton, requesting concurrence that the proposed plan meets or exceeds applicable circular criteria.
4. Installation work will begin in 2017 prioritizing: 1.High-speed turn-offs, 2. Balance of runways, 3. Taxiways
5. Where possible, work with be timed with planned capital projects with the balance being performed by in-house staff.

Airport operators and manufacturers should evaluate their programs for similar reliability enhancements

Improve Installation QA/QC

Update PM program

Develop customized implementation plan to increase clamping force considering:

- Fixture assembly materials (carbon steel vs. stainless)
- Bolt material and target preload (evaluate gall risk)
- Evaluate light fixtures, extension collars, and base cans for higher stresses (avoid moving the problem)
- Prepare implementation plan based on: risk-based priorities, scheduled capital projects, and resource constraints

Engaging Airport Industry to Date & Future Plan

Advisory Circular (AC) Comment Process

- 9/16/2015 – PANYNJ commented on AC 150/5345-42G "Specification for Airport Light Bases, Transformer Housings, Junction Boxes, and Accessories"(replaced by 42H)

FAA Atlantic City Tech Center Meetings

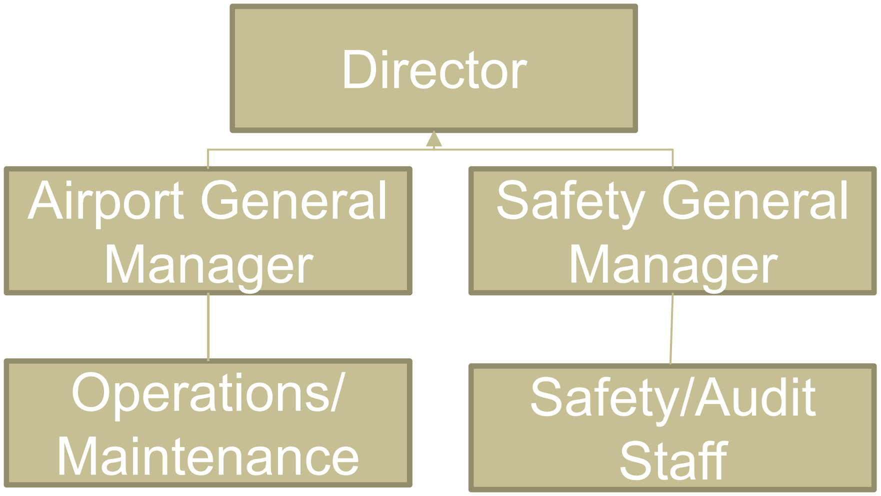
Engagement with Airport Associations

- 11/21/2016 – AAAE North East Chapter Webinar
- 3/28-30/2017 – 2017 Airports Conference, Hershey, PA
- Winter 2016/17 – AAAE National/World Webinar
- Winter 2016/17 – ACI National/World Webinar

Moving Forward – Key Elements to a Successful Improvement Program

Safety Assurance

- Independent from airport
- Audit procedures & reports
- Follow-up



Safety Promotion

- Defined job responsibilities
- Training (classroom, manufacturer and OJT)
- Meetings and communication
  - o Scheduled (quarterly, weekly)
  - o Immediate (email new findings)

Questions?