MoreVision
Excel in Engineering

Bolt Technology in a Digital Age

By John Doyle

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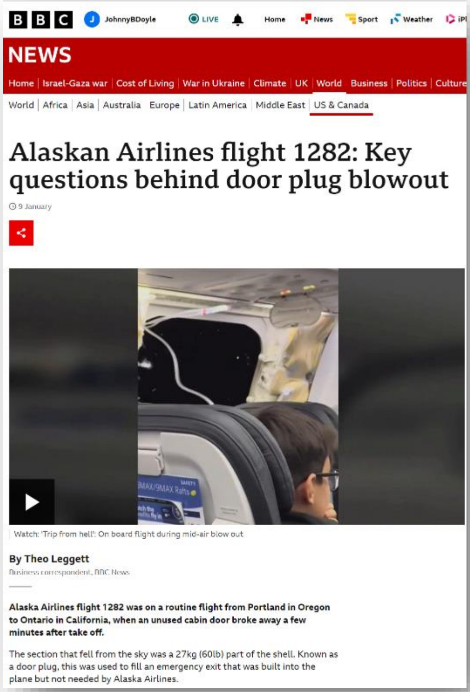
1 Abstract

MoreVision specialises in engineering analysis, testing, and software development. MoreVision founder John Doyle discusses the value of digital records for preventing bolt failures. He advises storing all records related to bolts in a digital format for easy tracking. John uses his broad engineering experience and gives examples and insights of bolt failures. He introduces digital tools like ExcelCalcs, which shares bolting analysis knowledge, and ExcelWraps, which creates production workflow records. Last year ExcelWraps established data exchange with a digital torque wrench server using an API connection. This both programs your wrench to any tightening mode and extracts the bolt tightening records for insertion to the production workflow records. All you need to use this technology is simply your existing Excel skills.

He reflects on the application of this technology in the light of the most recent headline bolt failure incident, the Alaskan Airlines door plug explosion in January 2024.

2 Introduction



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Alaskan Airlines flight 1282: Key questions behind door plug blowout

9 January

Watch: 'Trip from hell': On board flight during mid-air blow out

By Theo Leggett

Business correspondent, BBC News

Alaska Airlines flight 1282 was on a routine flight from Portland in Oregon to Ontario in California, when an unused cabin door broke away a few minutes after take off.

The section that fell from the sky was a 27kg (60lb) part of the shell. Known as a door plug, this was used to fill an emergency exit that was built into the plane but not needed by Alaska Airlines.

On January 9, 2024, a door plug exploded on an Alaskan Airlines flight, due to a bolting failure. Boeing had to investigate the design, testing, manufacturing, installation, and maintenance of the bolts to understand and remedy the root cause of the problem.

Before jumping into the body of this report consider how your own organisation would react to a bolt failure resulting in potential loss of life.

3 Bolting Case Studies

Ten case studies from nearly 40 years of handling bolt issues:

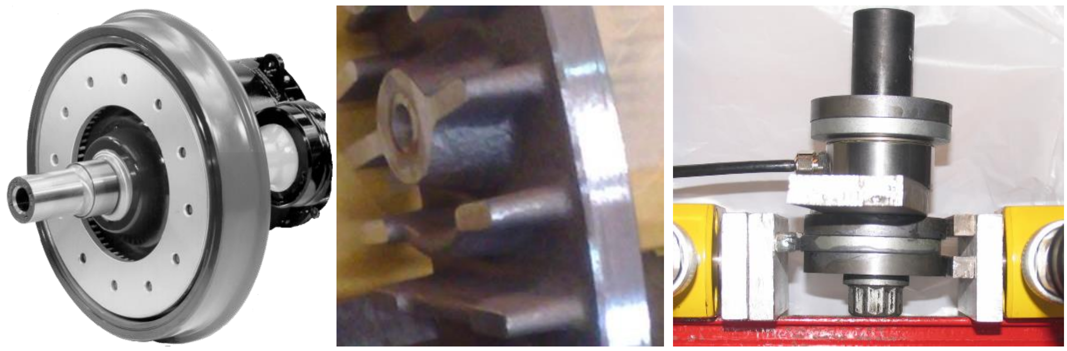


Figure 1 – Bolted brake disk missing bolts. Pretension/slip tests and effect of movement under thermal expansion and contraction.

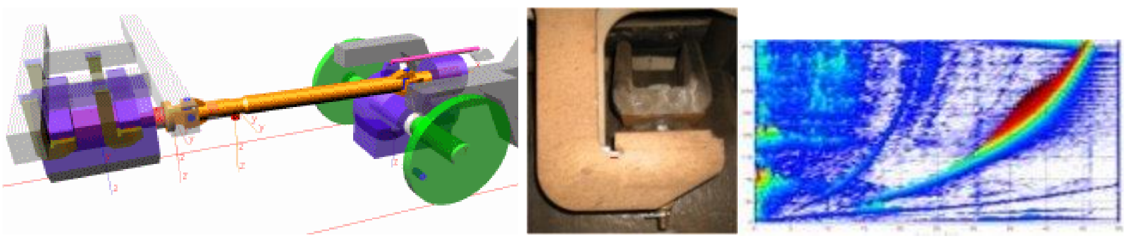


Figure 2 – Traction motor mounting bracket fatigue failure featuring resilient mount thermal hardening. Digital signal processing software shows that the stiffened mount moves the maximum response frequency to coincide with the railway vehicle running speed.

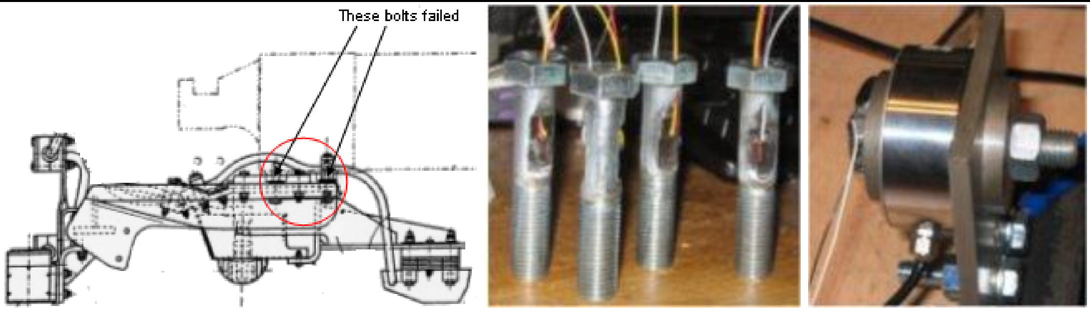


Figure 3 – Bogie mounted antennae resonance induced loading not considered in design.

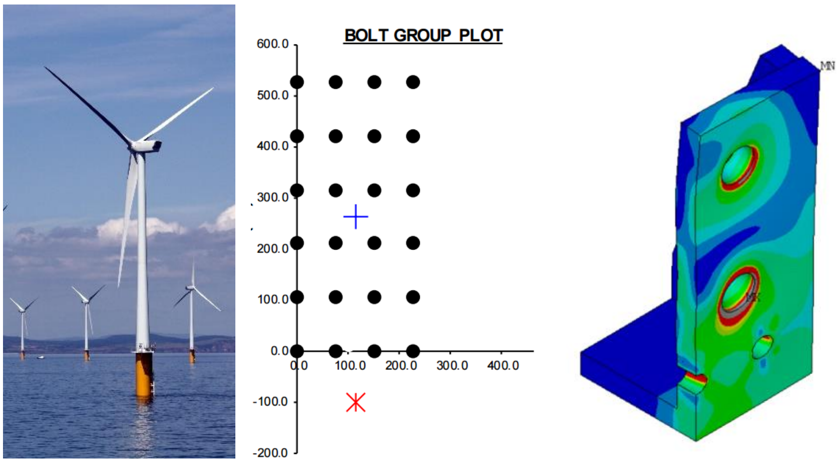


Figure 4 – Wind turbine tower connection to pile. Design change from bolts to dowels to maximise shear capacity.

Figure 5 – Change of bolt supplier projects, generally allowed provided preload is not degraded and backed up with preload testing.

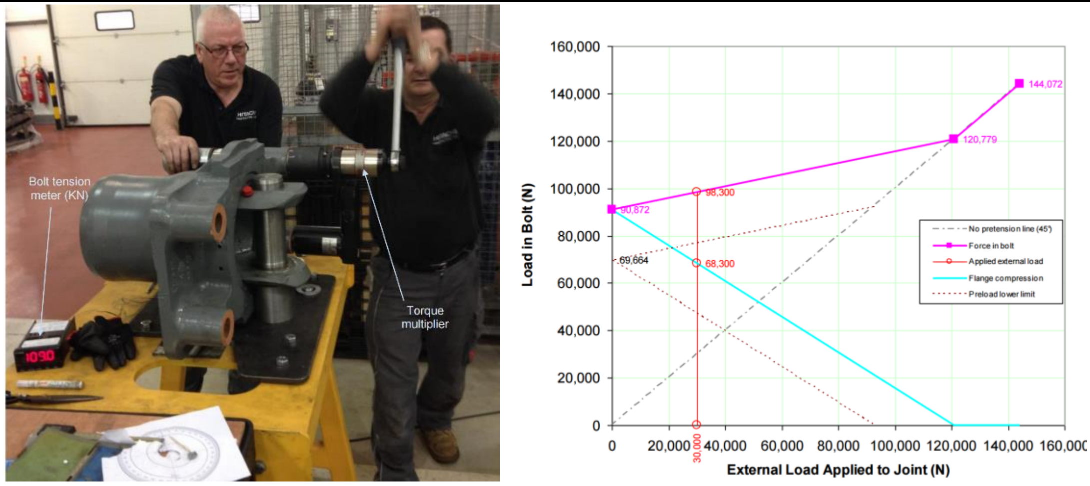


Figure 6 – Bolt reuse projects. Allowed providing torque tightening is replaced with angle tightening procedure.

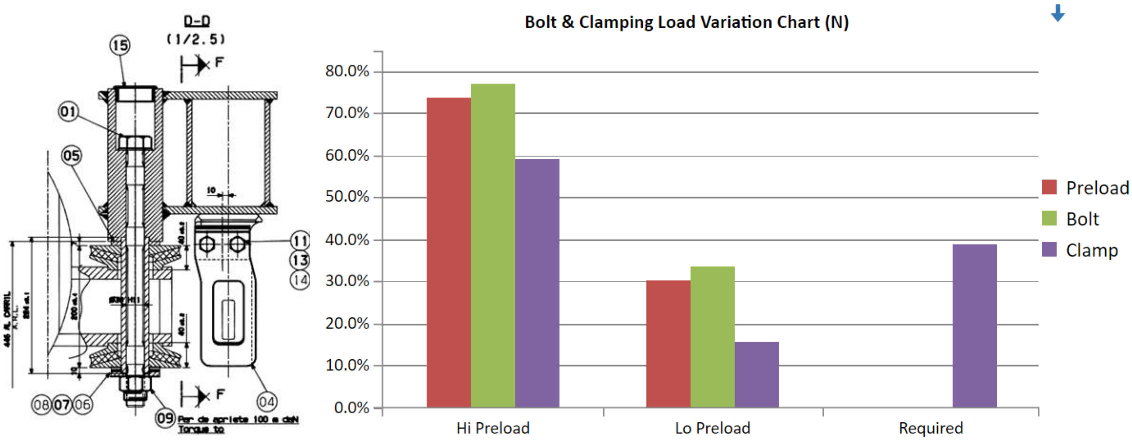


Figure 7 – M30 Bolt replacement showing BoltExpert load variation chart.

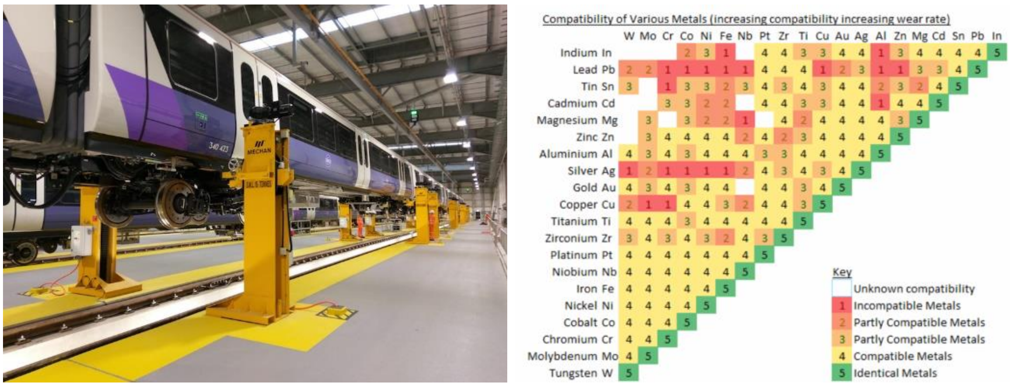


Figure 8 – Train lift accident investigation due to screw jack wear and deficiency in safety nut design as dynamic loading not accounted for. Bonus: insurance case reports and structural repair of permanently deformed bodyshell.

Figure 9 – Line buffer stop fails to arrest low speed train. Bent bolt indicates that bolt was not sufficiently tightened to provide clamping force. Bonus: crash assessment of train/buffer collision and structural repair of damaged bodyshell.

Figure 10 – Bolt design calculations for theme park equipment. Failure to predict impact loads. Bonus: visits to the Disney back lot to witness Snow White on a 'fag' break.

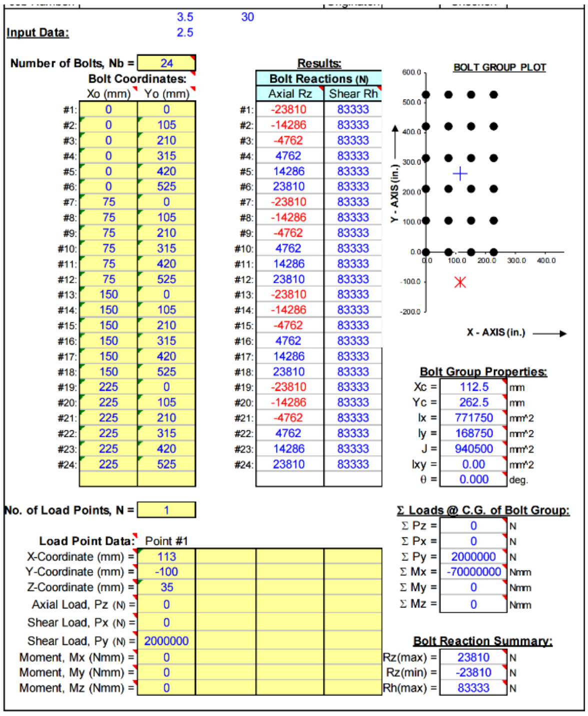
Reviewing the case studies, it is possible to place each into one of the following broad categories:

1. **Missing bolts –** Scatter in bolt pretension means some bolt joints slip under shear loads providing a mechanism for loosening in high vibration environments.
2. **Short Bolts –** the simplest thing to avoid but the most common problem we see.
3. **Under estimating bolt loads –** effect of resonance, strain gauged bolts and on track testing. Digital signal processing of test results in the frequency domain can illuminate the problem.
4. **Not following tightening procedure –** Bolt not pretensioned at all. Over tightening or an additional tug on the wrench after the torque wrench has clicked.
5. **Inadequate slip strength** - Solutions include surface preparation or introducing pins, dowels, or spiral dowel bushings.
6. **Bolt reuse/life extension** - Determining if bolts can be reused by switching to angle tightening procedures.
7. **Bolt replacement –** Using cheaper bolts may introduce new bolt failures.
8. **Fatigue** - Utilising the good fatigue resistance of bolts compared to welds.
9. **Assessment of bolt groups –** check that design requirements are satisfied using classical calculations or finite element methods. Also calculating the Ultimate strength of bolt groups to assist in failure investigations.
10. **Unconventional use of a bolt –** A bolted joint that allows slip on the clamped interface.

When an investigation begins it becomes clear that generally bolting is rarely well understood in the service environment and it is almost treated as some kind of black art. Certainly the design intent of the bolt is lost, and all kinds of rumours and madcap theories abound.

The author advocates digitally capturing all records pertaining to bolts, including design, testing, manufacturing, installation, and maintenance data. This information would be accessible for anyone needing to investigate a failure. Though few companies currently take advantage of digitisation, the technology is readily available.

4 2005 - ExcelCalcs Digital Library – Capture the Design Intent.



Input Data: 3.5 30 2.5

Number of Bolts, Nb = 24

Bolt #	Xo (mm)	Yo (mm)		Bolt #	Axial Rz	Shear Rh
#1:	0	0		#1:	-23810	83333
#2:	0	105		#2:	-14286	83333
#3:	0	210		#3:	-4762	83333
#4:	0	315		#4:	4762	83333
#5:	0	420		#5:	14286	83333
#6:	0	525		#6:	23810	83333
#7:	75	0		#7:	-23810	83333
#8:	75	105		#8:	-14286	83333
#9:	75	210		#9:	-4762	83333
#10:	75	315		#10:	4762	83333
#11:	75	420		#11:	14286	83333
#12:	75	525		#12:	23810	83333
#13:	150	0		#13:	-23810	83333
#14:	150	105		#14:	-14286	83333
#15:	150	210		#15:	-4762	83333
#16:	150	315		#16:	4762	83333
#17:	150	420		#17:	14286	83333
#18:	150	525		#18:	23810	83333
#19:	225	0		#19:	-23810	83333
#20:	225	105		#20:	-14286	83333
#21:	225	210		#21:	-4762	83333
#22:	225	315		#22:	4762	83333
#23:	225	420		#23:	14286	83333
#24:	225	525		#24:	23810	83333

Bolt Group Properties:

Xc =	112.5	mm
Yc =	262.5	mm
Ix =	771750	mm^2
Iy =	168750	mm^2
J =	940500	mm^2
Ixy =	0.00	mm^2
θ =	0.000	deg.

No. of Load Points, N = 1

Load Point Data:	Point #1
X-Coordinate (mm) =	113
Y-Coordinate (mm) =	-100
Z-Coordinate (mm) =	35
Axial Load, Pz (N) =	0
Shear Load, Px (N) =	0
Shear Load, Py (N) =	2000000
Moment, Mx (Nmm) =	0
Moment, My (Nmm) =	0
Moment, Mz (Nmm) =	0

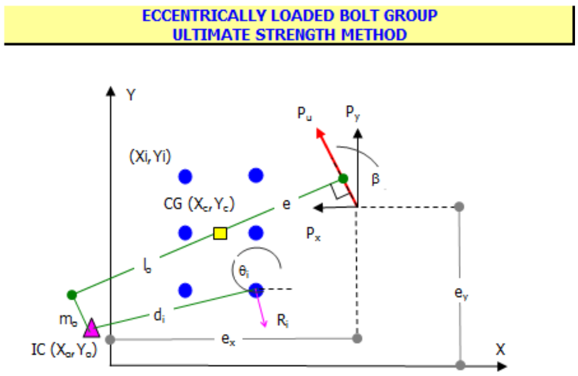
Σ Loads @ C.G. of Bolt Group:

Σ Pz =	0	N
Σ Px =	0	N
Σ Py =	2000000	N
Σ Mx =	-70000000	Nmm
Σ My =	0	Nmm
Σ Mz =	0	Nmm

Bolt Reaction Summary:

Rz(max) =	23810	N
Rz(min) =	-23810	N
Rh(max) =	83333	N

http://www.excelcalcs.com/repository/machines/bolts-and-threads/boltgrp.xls/ version 2.5



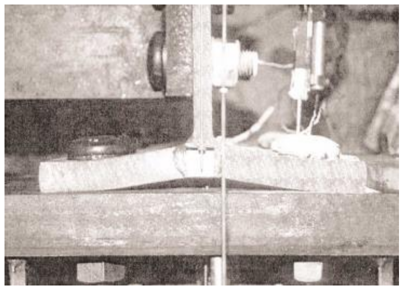


Figure 11 – ExcelCalcs examples to determine loads on bolted joints working in a bolt group or subject to prying loads.

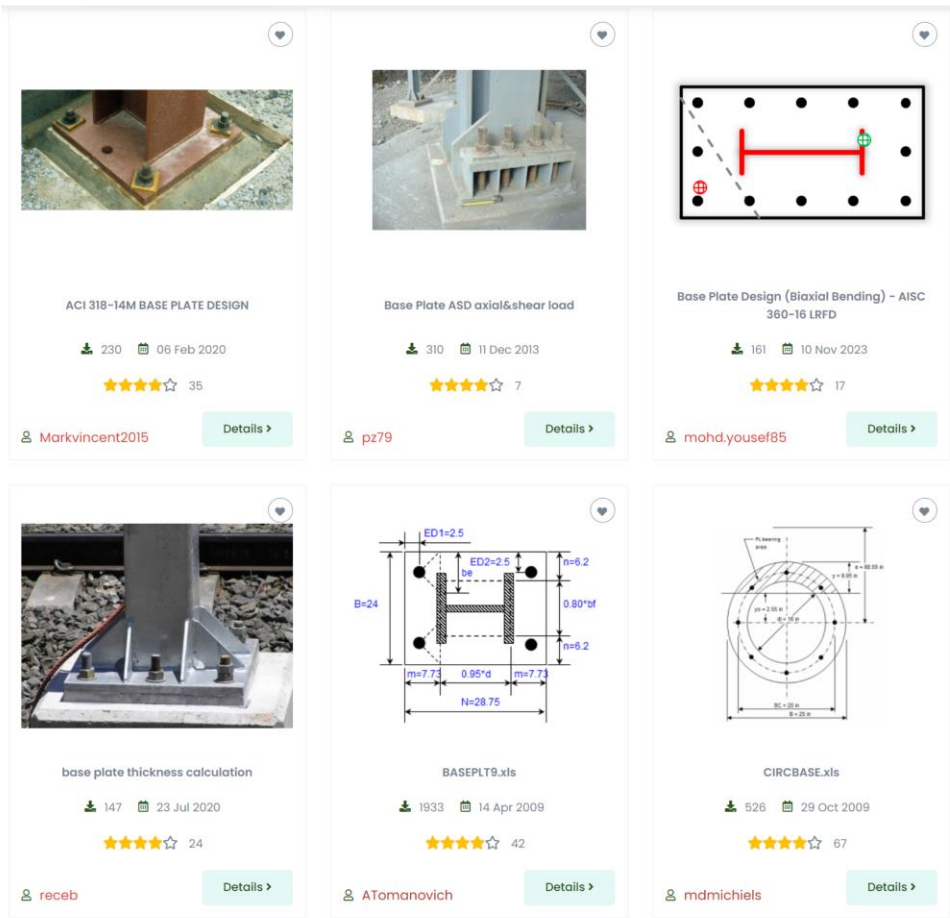
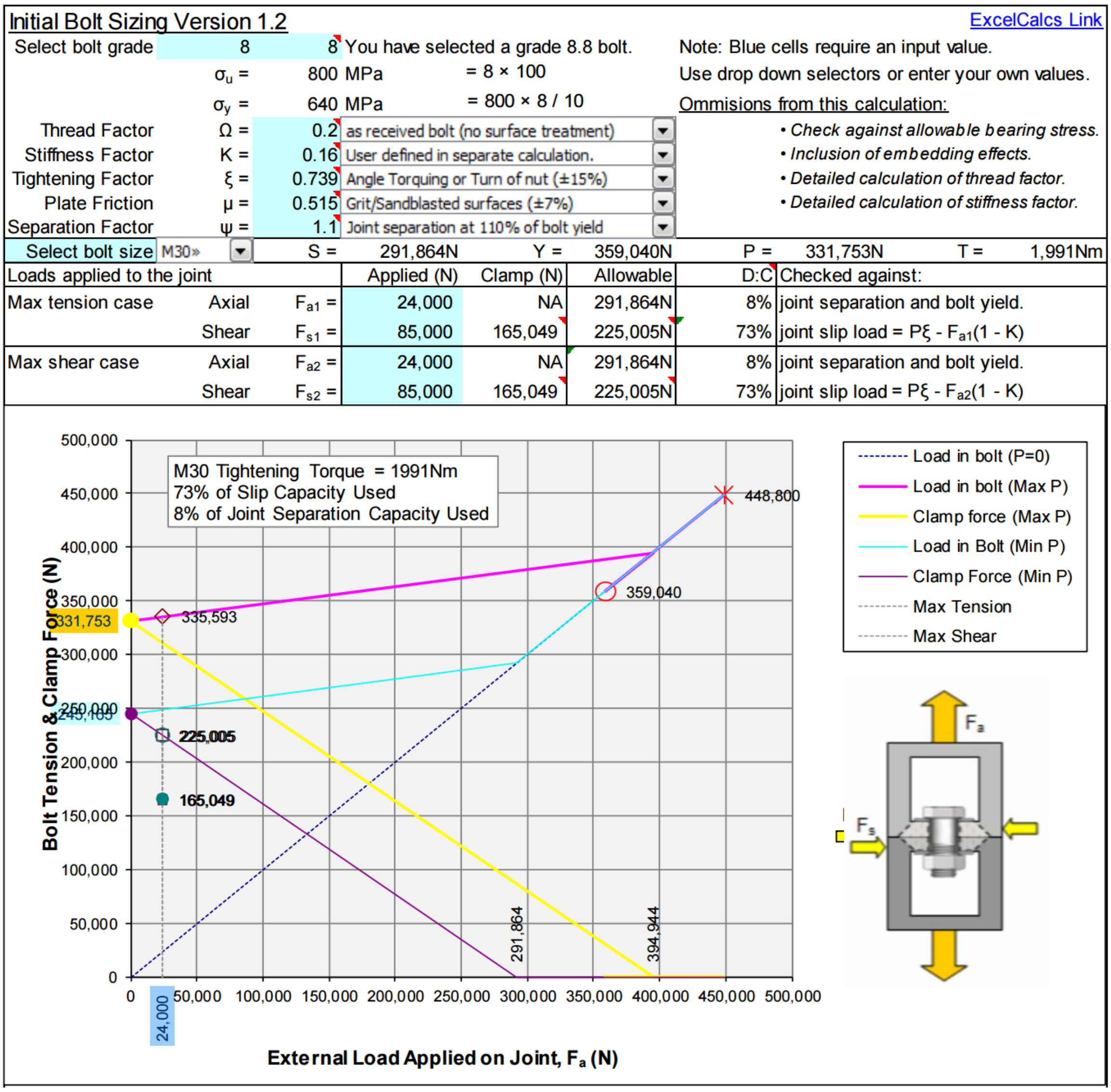


Figure 12 – Examples of structural details found on the ExcelCalcs website.



http://www.excelcalcs.com/repository/machines/bolts-and-threads/quick-and-dirty-bolt-sizing-calculation.xls/ Version 1.2

Figure 13 – ExcelCalcs example for bolted joint assessment.

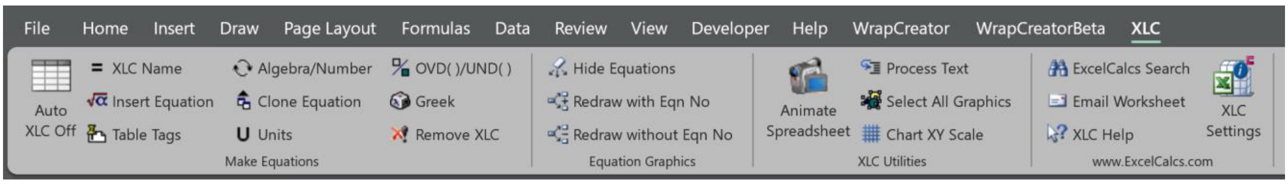


Figure 14 – XLC add-in for Excel available at ExcelCalcs

[ExcelCalcs](http://www.excelcalcs.com) features a software add-in for Excel called 'XLC' that makes Excel into a calculation pad for engineers. It can display mathematical equations that show the method behind the numbers and verify the formulas in the cells. Mathcad, Mathematica, and Maple have symbolic algebra features but are not accessible by everyone. Excel is almost universally used so giving it symbolic math capabilities makes a great way to share engineering knowledge widely.

[ExcelCalcs](http://www.excelcalcs.com) is a site that offers more than 1500 calculations for various engineering topics, including bolting, publishing about 10 new calculations each month. Each calculation has a system to track changes and can serve as an internet reference point. You can follow calculations that you have an interest in and use them to standardise the technical approach to common engineering problems. It is a great learning resource and calculations are shared with an expert community, consisting of 80,000 registered members, who give their own review comments and feedback. The author publishes calculations on ExcelCalcs regularly and the same calculations are used time and time again for new bolting investigations and studies.

5 2012 - BoltExpert Web App – Bolt Investigation/Learning Tool

BoltExpert
A MoreVision Venture

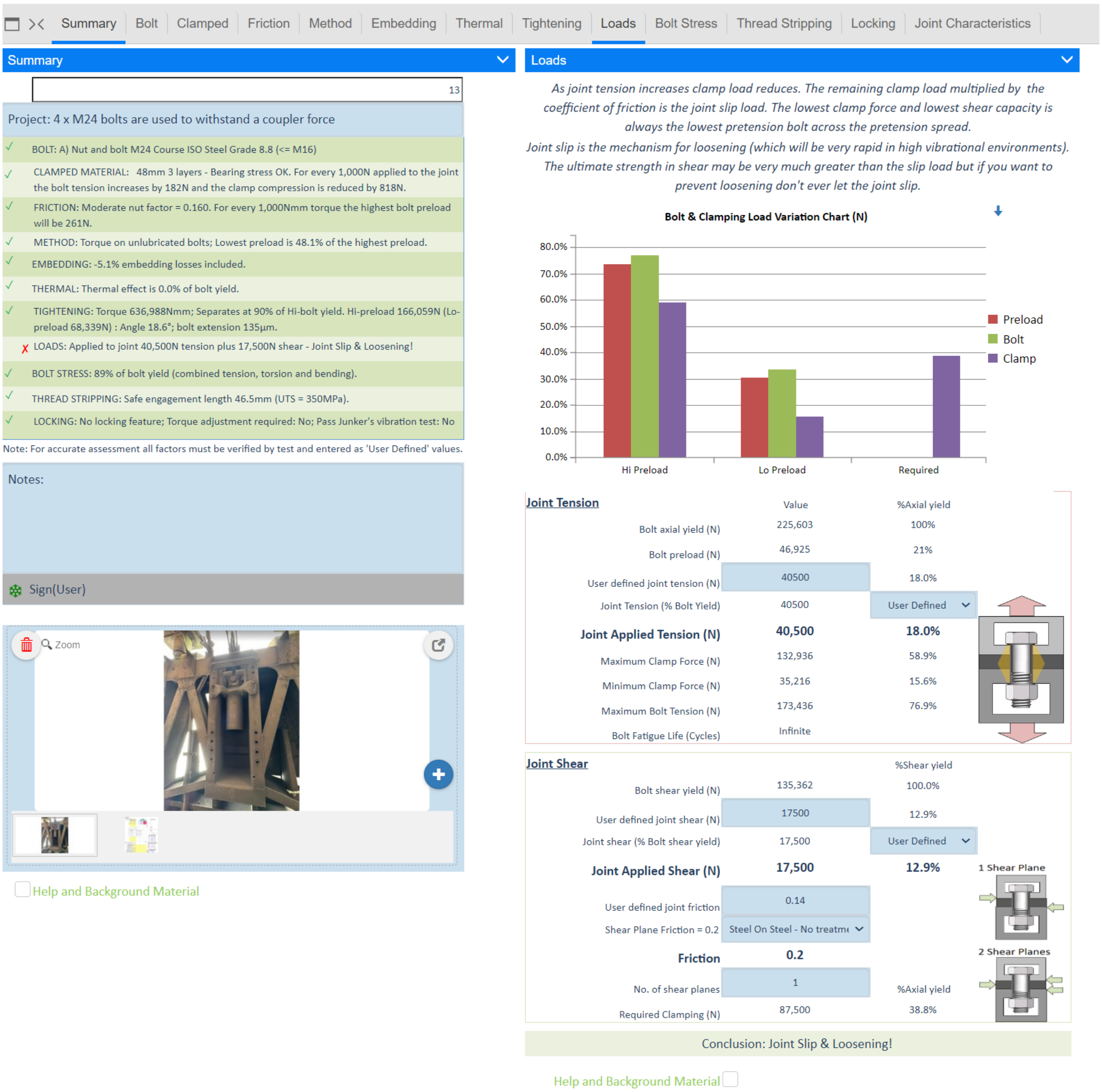


Figure 15 – BoltExpert shows that this joint fails under the "Loads" Tab as the required preload is greater than the minimum preload and this joint will be prone to slip and vibrational loosening.

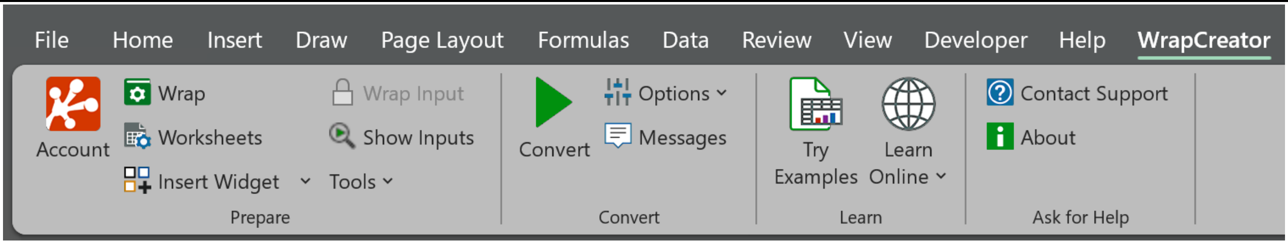
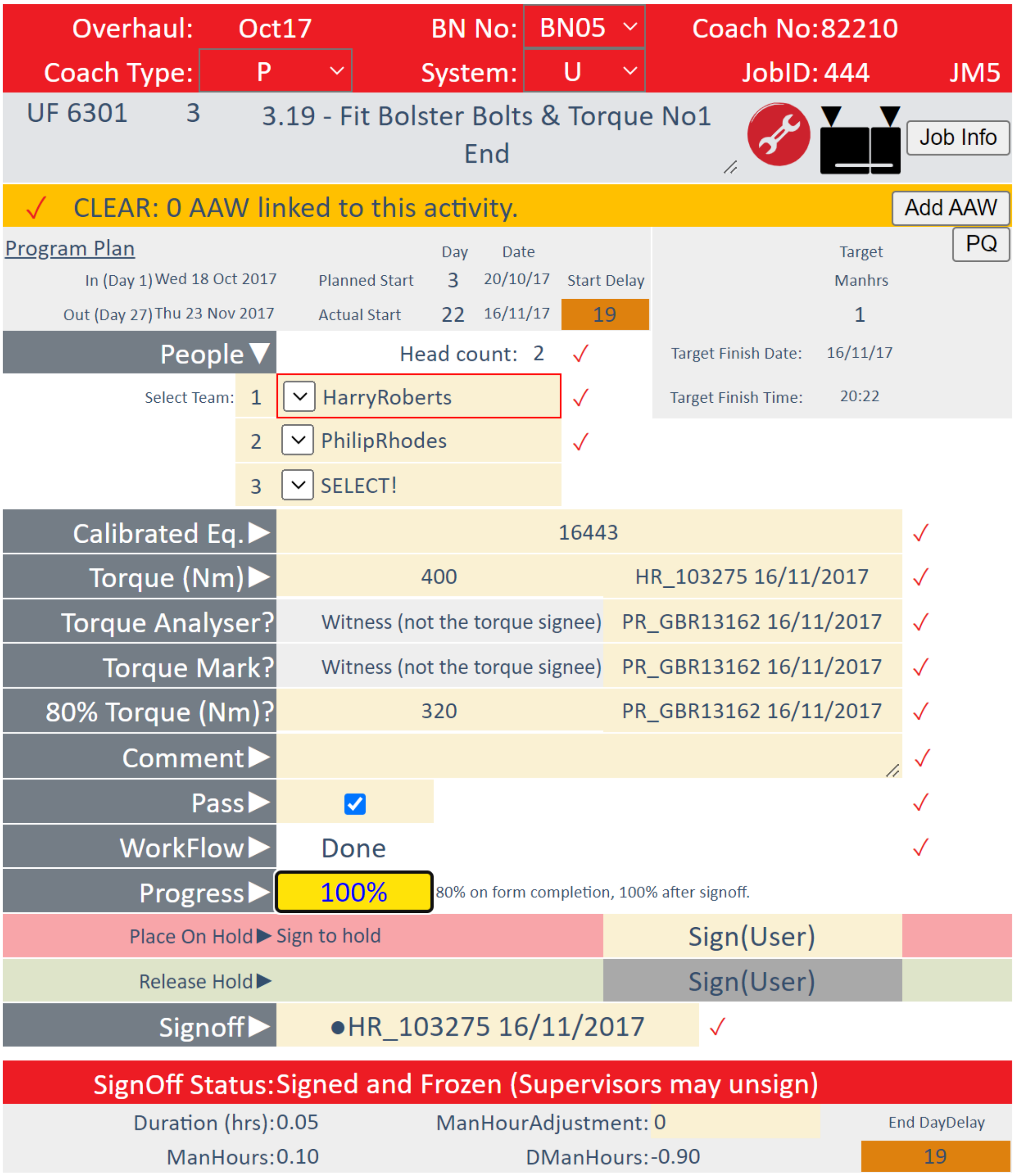


Figure 16 – WrapCreator add-in for Excel

The BoltExpert web app was made in the early days of the development of ExcelWraps. WrapCreator is an Excel add-in that turns a workbook into a standalone web application. We used the knowledge accumulated at ExcelCalcs to make a web application for assessment of bolted joints. It works on any device including your smart phone and aids understanding of joint mechanics and disseminates bolting knowledge to a layman. It checks for different possible issues and points out problems. Some key features are:

- Summary page showing pass/fail status of many joint considerations.
- Simple drop-down inputs for bolts, clamped material, friction, and tightening method.
- Checks for issues like embedding, thermal effects, vibration loosening and bolt stress.
- Repeatable analyses and bolt knowledge sharing.



Overhaul: Oct17 BN No: BN05 Coach No:82210
Coach Type: P System: U JobID: 444 JM5
UF 6301 3 3.19 - Fit Bolster Bolts & Torque No1 End
Job Info
✓ CLEAR: 0 AAW linked to this activity.
Add AAW
PQ

Program Plan			Day	Date		Target	
In (Day 1)	Wed 18 Oct 2017	Planned Start	3	20/10/17	Start Delay	Manhrs	
Out (Day 27)	Thu 23 Nov 2017	Actual Start	22	16/11/17	19	1	

People ▼	Head count: 2		✓
Select Team: 1	HarryRoberts		✓
2	PhilipRhodes		✓
3	SELECT!		
Calibrated Eq. ▶	16443		✓
Torque (Nm) ▶	400	HR_103275 16/11/2017	✓
Torque Analyser?	Witness (not the torque signee)	PR_GBR13162 16/11/2017	✓
Torque Mark?	Witness (not the torque signee)	PR_GBR13162 16/11/2017	✓
80% Torque (Nm)?	320	PR_GBR13162 16/11/2017	✓
Comment ▶			✓
Pass ▶	☑		✓
WorkFlow ▶	Done		✓
Progress ▶	100%	80% on form completion, 100% after signoff.	
Place On Hold ▶	Sign to hold	Sign(User)	
Release Hold ▶		Sign(User)	
Signoff ▶	●HR_103275 16/11/2017		✓

Target Finish Date: 16/11/17
Target Finish Time: 20:22

SignOff Status:Signed and Frozen (Supervisors may unsign)

Duration (hrs):0.05 ManHourAdjustment: 0 End DayDelay
ManHours:0.10 DManHours:-0.90 19

Figure 17 – Excel used to design the production workflow for attachment of underframe equipment, capturing torque wrench serial number and digital signatures for the operator and the buddy checks. Only people with the specified competence can sign. All this data is stored in an online database.

ExcelWraps is used to create web apps to digitise production data. The benefits are:

- **Elimination of paper** – any Excel user can create them.
- **Provides easy access to captured data** – filtered tables and charts from database records.
- **Competence** - Ensures only qualified personnel can complete tasks.
- **Compliance** – Guarantees success of quality assurance audits.
- **Time and Motion** – task timing tracked for project management where the full project is mapped on a Gantt chart and compared with the base plan.

ExcelWraps creates a morphing signoff sheet so that a single wrap can capture data for any job. It uses web app show and hide logic to achieve this. This is not a one-to-one replacement of paper workflows it is a one-to-many replacement. This make setting up an ExcelWraps production workflow system very quick to roll out. Around 10% of jobs have custom 'wraps' appended to the signoff wrap, this allows for special form layouts to help operators undertake more complex jobs (e.g. brake checks can follow a layout mirroring the axle and wheel positions on a train). The morphing signoff sheet must be completed correctly to achieve 100% progress on a job.

Several wrap solutions are linked to cover all aspects of production. For example:

a) A separate wrap solution for a calibrated tool database can be linked to create drop down selection of 'in-calibration' tools.
b) A wrap solution for document control can be linked so that only the latest issue of a job can be viewed.
c) A wrap solution for production/client queries so that they can be easily raised and monitored.
d) A wrap solution for unplanned work or arising work (AW) keeps track of an expanding work scope. It requires an "instruction to proceed" with a client's digital signature to avoid any argument over additional work at the end of a contract.

ExcelWraps has a library of 30 such solutions that are freely available for clients to use and customise.

	OH	Unit	Car	System	Station	JobNo	Task	Competence	RemHrs	Team	SignOff	AW	Comment	Start	LastModified
☐	co(May1!	co(BN2'	eq(B)	eq(U)				ne(mech)							
sum									0.0			10			
☐	May19	BN21	B	U	3	U~ 0105	Underframe Mounted Equipment - Examine (Air Conditioning Module)	Staff	0	DavidEvans AndzejRyt	AndzejRyt	0		15/05/2019 12:21:56	15/05/2019 13:22:18
☐	May19	BN21	B	U	3	U~ 0105	Underframe Mounted Equipment - Examine (Brake Module)	Staff	0	DavidEvans AndzejRyt	AndzejRyt	0		15/05/2019 12:22:50	15/05/2019 13:23:06
☐	May19	BN21	B	U	3	U~ 0105	Underframe Mounted Equipment - Examine (Static Converter Module)	Staff	0	DavidEvans AndzejRyt	AndzejRyt	0		15/05/2019 12:23:30	15/05/2019 13:23:47
☐	May19	BN21	B	U	3	U~ 0105	Underframe Mounted Equipment - Examine (Control Equipment Module)	Staff	0	DavidEvans AndzejRyt	AndzejRyt	0		15/05/2019 12:24:34	15/05/2019 13:24:53
☐	May19	BN21	B	U	3	U~ 0105	Underframe Mounted Equipment - Examine (Battery Box Module)	Staff	0	DavidEvans AndzejRyt	AndzejRyt	0		15/05/2019 12:25:21	15/05/2019 13:25:41
☐	May19	BN21	B	U	3	U~ 0105	Underframe Mounted Equipment - Examine (Auxiliary Equipment Module)	Staff	0	DavidEvans AndzejRyt	AndzejRyt	0		15/05/2019 12:26:00	15/05/2019 13:26:15
☐	May19	BN21	B	U	1	UB 0105	Retractable Hydraulic Buffer - Examine Non Drivers Side	Mech	0	AndzejRyt	MarkBrennan	0	done by andy ryt	16/05/2019 08:19:01	16/05/2019 09:19:20
☐	May19	BN21	B	U	1	UB 0105	Retractable Hydraulic Buffer - Examine Drivers Side	Mech	0	AndzejRyt	MarkBrennan	0		16/05/2019 08:19:41	16/05/2019 09:20:00
☐	May19	BN21	B	U	1	UB 0108	Vestibule Buffer - Overhaul	Mech	0	BenKnox-Leet EricPanther GeorgeCarroll PhilipRhodes KeithWard	GeorgeCarroll	0		07/05/2019 18:40:51	11/05/2019 07:17:34
☐	May19	BN21	B	U	1	UB 0108	Vestibule Buffer - Refit	Mech	0	KeithWard GeorgeCarroll	KeithWard	1		09/05/2019 12:21:31	09/05/2019 13:25:56
☐	May19	BN21	B	U	1	UB 0108	Vestibule Buffer - Remove	Staff	0	GeorgeCarroll PhilipRhodes	PhilipRhodes	0		07/05/2019 09:12:58	07/05/2019 10:13:26
☐	May19	BN21	B	U	1	UC 0115	Drophead Buckeye Coupler - Overhaul	Mech	0	KeithWard GeorgeCarroll	KeithWard	0		09/05/2019 12:26:27	09/05/2019 13:27:55
☐	May19	BN21	B	U	1	UC 0124	Coupler Pins - Examine No1 End - Diameter of Pin MM	Mech	0	AndzejRyt DavidEvans	DavidEvans	0		07/05/2019 18:22:41	07/05/2019 19:23:26

Figure 18 – MyWraps report to show all overhaul jobs on the underframe, on unit B21, coach B. It shows the repeated use of the morphing signoff wrap to cover all jobs.

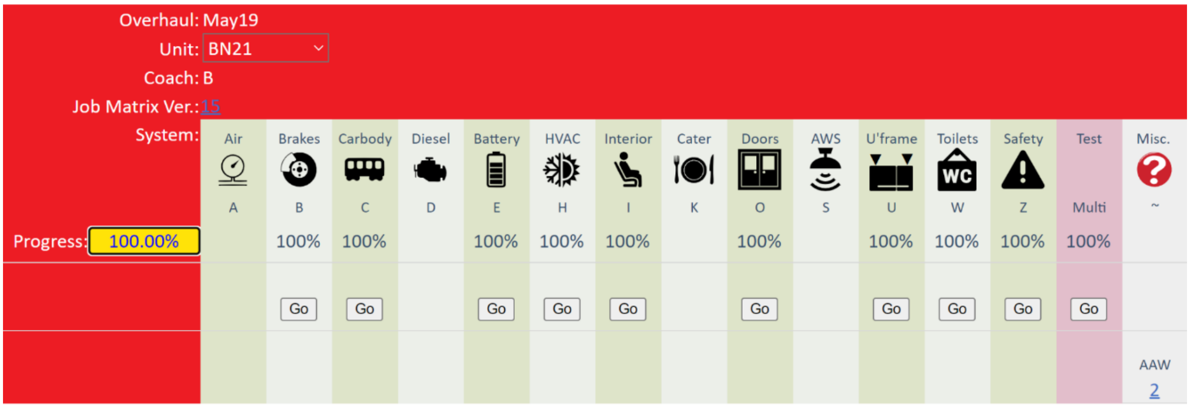


Figure 19 – A dashboard showing % completion of all systems on coach B and the number of additional arising work tasks (AAW). The "Go" button opens the list of remaining jobs on that system.

OVERHAUL: May19		Start Date:	02/05/2019	Matrix: 15			
UNIT: BN21		Day:	1223.43	27	20%		
	AVERAGE UNIT PROGRESS:		100.00%		0	296	Live AW All
ORDER	COACH	COACH No.	PROGRESS	RAG	Live AW	All AW	
PMK	B [TOE]	12222	100.00%		0	23	Live AW B
PMK							
PMK	C [TO]	12461	100.00%		0	27	Live AW C
PMK							
PMK	D [TO]	12441	100.00%		0	24	Live AW D
PMK							
PMK	E [TO]	12476	100.00%		0	24	Live AW E
PMK							
PMK	F [TOD]	12323	100.00%		0	28	Live AW F
PMK							
PMK	H [SV]	10330	100.00%		0	41	Live AW H
PMK							
PMK	K [POP]	11244	100.00%		0	32	Live AW K
PMK							
PMK	L [POD]	11321	100.00%		0	21	Live AW L
PMK							
PMK	M [PO]	11421	100.00%		0	28	Live AW M
PMK							
PMK	P [DVT]	82227	100.00%		0	38	Live AW P
PMK							
		All [Rake]	100.00%		0	10	Live AW Rake

Figure 20 – A unit dashboard to show the overhaul % completion of each coach on the unit and 296 arising work tasks raised. Clicking % progress takes you to the individual coach dashboard.

It is easy to see that all work is 100% complete and that there are no remaining jobs to be done. The final digital signature can only be completed when all jobs are finished, and this provides a "certificate of conformance" so the client can return the train back into passenger service safely.

The internet allows your production workflows to be used by your sub-contractors. This means that all the relevant information for your project is gathered in your database and automatically reports on the progress of a subcontractor. In one case where both the main contractor and the sub-contractor had an ExcelWraps system, the subcontractor maintained their own records and scripts are used to transfer the information to the main contractor's system automatically.

At the end of a contract a pdf copy of all wraps is bound in a single pdf volume. This is very important to clients who need a universally accessible record of the work done, with no dependency on ExcelWraps at all. As the main contractor, with an ExcelWraps system, you have the added advantage of database access to create reports about every job, every measurement and every KPI and compare them over an entire fleet of trains.

Figure 21 show how the technology has been successfully applied to many engineering activities.

Train MRO (Maintenance, Repair & Overhaul)	SF-1	Maintenance
	SF-2	Overhaul
	SF-3	Modifications
	SF-4	Fleet Checks
	SF-5	Fault Trees
	SF-6	Tools and calibration
	SF-7	Smart tool API connectors
	SF-8	Dynamic work scope
	SF-9	Core work
	SF-10	AW - Planned change to core work
	SF-11	AAW - Unplanned change to core work
	SF-12	Technical Query
	SF-13	Concessions
	SF-14	Quarantine
Train Presentation	SF-15	Cleaning Scorecards
	SF-16	Carpet Stain Management
	SF-17	Damage and Vandalism Management
	SF-18	Paint Repair Management
	SF-19	Passenger Defect Reports
Train Audits	SF-20	Delivery - fleet introduction
	SF-21	Redelivery - Fleet operator change
Train Compliance	SF-22	Competence Management
	SF-23	Office Procedures
	SF-24	Alerts and Acknowledgements
	SF-25	Document Control
Train Experts	SF-26	Exam Analytics
	SF-27	Software Experts
	SF-28	Suspension Expert
	SF-29	Structural Expert
	SF-30	Bolt Expert

Figure 21 – SmartFleet Solutions are free for clients to copy/customise. Features include image markup, pdf docpacks, Alerts, simultaneous editing, scheduled KPI reports and API connections to other applications.

7 2022 - ExcelWraps Integration with Digital Torque Wrenches

Intelligent torque wrench

Min (Nm)	Target (Nm)	Max (Nm)	Batch size	TCI	Wrench
35	36	37	8	113935	2 | 180Nm

Send torque data to wrench — Send Job

Send torque results to wrap — Get Data

	Torque (Nm)	Angle
1	36.32	7
2	35.58	6
3	35.36	7
4	35.95	7
5	35.66	7
6	35.92	9
7	35.54	8
8	36.49	10
	Torque average (Nm)	**Batch completed**
	35.8525	8

Figure 22 – Extract of a wrap production workflow dealing with the records for fastening of 8 bolts. The tightening method applies a snug torque then applies a turn through a specific angle.

ExcelWraps API (Application Programming Interface) connectors were developed to exchange data from other software applications. ExcelWraps is given a machine login to a partner's website to allow a two-way flow of information between ExcelWraps and the partner's software. The first test of the API connector technology was a connection to a digital torque wrench server. This allows our production workflow wraps to:

“Send Job” – The production workflow wrap sends tightening method and control parameters to the operator’s digital torque wrench via the digital torque wrench server.

“Get Job” – The production wo rkflow wrap retrieves tightening information for 8 bolts from the digital torque wrench server.

Formatted key-value pairs 1	JSON object keys	JSON object values w/o ""
"id":"113935"	id	113935
"ip":"192.168.0.101"	ip	192.168.0.101
"port":"4546"	port	4546
"adapterId":"0"	adapterId	0
"adapterLength":"0"	adapterLength	0
"angleMaximum":"360"	angleMaximum	360
"angleMinimum":"5"	angleMinimum	5
"angleThreshold":"17.5"	angleThreshold	17.5
"auditAngle":"0"	auditAngle	0
"batchSize":"8"	batchSize	8
"control":"1"	control	1
"cycleEndTime":"7"	cycleEndTime	7
"finalAngleTarget":"180"	finalAngleTarget	180
"mode":"1"	mode	1
"parameterSetId":"1"	parameterSetId	1
"parameterSetName":"36Nı	parameterSetName	36Nm x 8
"rotationDirection":"1"	rotationDirection	1
"tciSerial":"113935"	tciSerial	113935
"torqueFinalTarget":"36"	torqueFinalTarget	36
"torqueMaximum":"37"	torqueMaximum	37
"torqueMinimum":"35"	torqueMinimum	35
"torqueThreshold":"17.5"	torqueThreshold	17.5
"optionalParams":{"contract	optionalParams	"contract":"C180541100","sub_cwo":"

wrenchapipostholder - this is the JSON job string sent to the Crane server

{"id":"113935","ip":"192.168.0.101","port":"4546","adapterId":"0","adapterLength":"0","angleMaximum":"360","angleMinimum":"5","angleThreshold":"17.5","auditAngle":"0","batchSize":"8","control":"1"
,"cycleEndTime":"7","finalAngleTarget":"180","mode":"1","parameterSetId":"1","parameterSetName":"36Nm x
8","rotationDirection":"1","tciSerial":"113935","torqueFinalTarget":"36","torqueMaximum":"37","torqueMinimum":"35","torqueThreshold":"17.5","optionalParams":
{"contract":"C180541100","sub_cwo":"B800XH0399","sub_type":"KH-244 - pos 2","sub_no":"63UA201","job_no":"540","wrapid":"1049533"}}

Figure 23 - Wrench programming is simplified using Excel like wrap tables. Data is concatenated into a single JSON block and sent to the digital torque wrench server which directs the program to the appropriate wrench.

wrenchapiholder - this is the JSON result string received from the Crane server

{"optionalParams":{"job_no":"540","sub_cwo":"B800XH0399","wrapid":"1049533","sub_no":"63UA201","sub_type":"KH-244 - pos
2","contract":"C180541100"},"port":"4546","ip":"192.168.0.101","results":
[{"torqueMinimumLimit":"35","pSetNumber":"2","tighteningId":"154","torqueControllerName":"crane","torqueMaximumLimit":"37","torque":"36.32","torqueFinalTarget":"36","angleMaximumLimit":"36
0","dateTimeOfLastChangeInPSetSettings":"2000-01-
01:00:00:00","finalAngleTarget":"180","batchCounter":"1","vinNumber":"","angle":"7","channelId":"1","torqueStatus":"1","peakTorque":"","angleStatus":"1","angleMinimumLimit":"5","cellId":"1","tighte
ningStatus":"1","timeStamp":"2023-10-26:08:01:36","secondaryStatus":"","batchSize":"8","batchStatus":"2","jobNumber":"0"},
{"torqueMinimumLimit":"35","pSetNumber":"2","tighteningId":"155","torqueControllerName":"crane","torqueMaximumLimit":"37","torque":"35.58","torqueFinalTarget":"36","angleMaximumLimit":"360
","dateTimeOfLastChangeInPSetSettings":"2000-01-
01:00:00:00","finalAngleTarget":"180","batchCounter":"2","vinNumber":"","angle":"6","channelId":"1","torqueStatus":"1","peakTorque":"","angleStatus":"1","angleMinimumLimit":"5","cellId":"1","tighte
ningStatus":"1","timeStamp":"2023-10-26:08:01:51","secondaryStatus":"","batchSize":"8","batchStatus":"2","jobNumber":"0"},
{"torqueMinimumLimit":"35","pSetNumber":"2","tighteningId":"156","torqueControllerName":"crane","torqueMaximumLimit":"37","torque":"35.36","torqueFinalTarget":"36","angleMaximumLimit":"360
","dateTimeOfLastChangeInPSetSettings":"2000-01-
01:00:00:00","finalAngleTarget":"180","batchCounter":"3","vinNumber":"","angle":"7","channelId":"1","torqueStatus":"1","peakTorque":"","angleStatus":"1","angleMinimumLimit":"5","cellId":"1","tighte
ningStatus":"1","timeStamp":"2023-10-26:08:14:03","secondaryStatus":"","batchSize":"8","batchStatus":"2","jobNumber":"0"},
{"torqueMinimumLimit":"35","pSetNumber":"2","tighteningId":"157","torqueControllerName":"crane","torqueMaximumLimit":"37","torque":"35.95","torqueFinalTarget":"36","angleMaximumLimit":"360
","dateTimeOfLastChangeInPSetSettings":"2000-01-
01:00:00:00","finalAngleTarget":"180","batchCounter":"4","vinNumber":"","angle":"7","channelId":"1","torqueStatus":"1","peakTorque":"","angleStatus":"1","angleMinimumLimit":"5","cellId":"1","tighte
ningStatus":"1","timeStamp":"2023-10-26:08:14:18","secondaryStatus":"","batchSize":"8","batchStatus":"2","jobNumber":"0"},
{"torqueMinimumLimit":"35","pSetNumber":"2","tighteningId":"158","torqueControllerName":"crane","torqueMaximumLimit":"37","torque":"35.66","torqueFinalTarget":"36","angleMaximumLimit":"360
","dateTimeOfLastChangeInPSetSettings":"2000-01-
01:00:00:00","finalAngleTarget":"180","batchCounter":"5","vinNumber":"","angle":"7","channelId":"1","torqueStatus":"1","peakTorque":"","angleStatus":"1","angleMinimumLimit":"5","cellId":"1","tighte
ningStatus":"1","timeStamp":"2023-10-26:08:14:38","secondaryStatus":"","batchSize":"8","batchStatus":"2","jobNumber":"0"},
{"torqueMinimumLimit":"35","pSetNumber":"2","tighteningId":"159","torqueControllerName":"crane","torqueMaximumLimit":"37","torque":"35.92","torqueFinalTarget":"36","angleMaximumLimit":"360
","dateTimeOfLastChangeInPSetSettings":"2000-01-
01:00:00:00","finalAngleTarget":"180","batchCounter":"6","vinNumber":"","angle":"9","channelId":"1","torqueStatus":"1","peakTorque":"","angleStatus":"1","angleMinimumLimit":"5","cellId":"1","tighte
ningStatus":"1","timeStamp":"2023-10-26:08:14:58","secondaryStatus":"","batchSize":"8","batchStatus":"2","jobNumber":"0"},
{"torqueMinimumLimit":"35","pSetNumber":"2","tighteningId":"160","torqueControllerName":"crane","torqueMaximumLimit":"37","torque":"35.54","torqueFinalTarget":"36","angleMaximumLimit":"360
","dateTimeOfLastChangeInPSetSettings":"2000-01-
01:00:00:00","finalAngleTarget":"180","batchCounter":"7","vinNumber":"","angle":"8","channelId":"1","torqueStatus":"1","peakTorque":"","angleStatus":"1","angleMinimumLimit":"5","cellId":"1","tighte
ningStatus":"1","timeStamp":"2023-10-26:08:15:14","secondaryStatus":"","batchSize":"8","batchStatus":"2","jobNumber":"0"},
{"torqueMinimumLimit":"35","pSetNumber":"2","tighteningId":"161","torqueControllerName":"crane","torqueMaximumLimit":"37","torque":"36.49","torqueFinalTarget":"36","angleMaximumLimit":"360
","dateTimeOfLastChangeInPSetSettings":"2000-01-
01:00:00:00","finalAngleTarget":"180","batchCounter":"8","vinNumber":"","angle":"10","channelId":"1","torqueStatus":"1","peakTorque":"","angleStatus":"1","angleMinimumLimit":"5","cellId":"1","tight
eningStatus":"1","timeStamp":"2023-10-26:08:15:30","secondaryStatus":"","batchSize":"8","batchStatus":"2","jobNumber":"0"}],"slot":"4546","id":"113935"}

Figure 24 - Tightening data for 8 bolts is retrieved from the digital torque wrench server as a JSON block. The production workflow wrap splits the data and inserts it into the relevant wrap workflow

cells. This will be kept in a central database along with all other measurement and data related to that job.

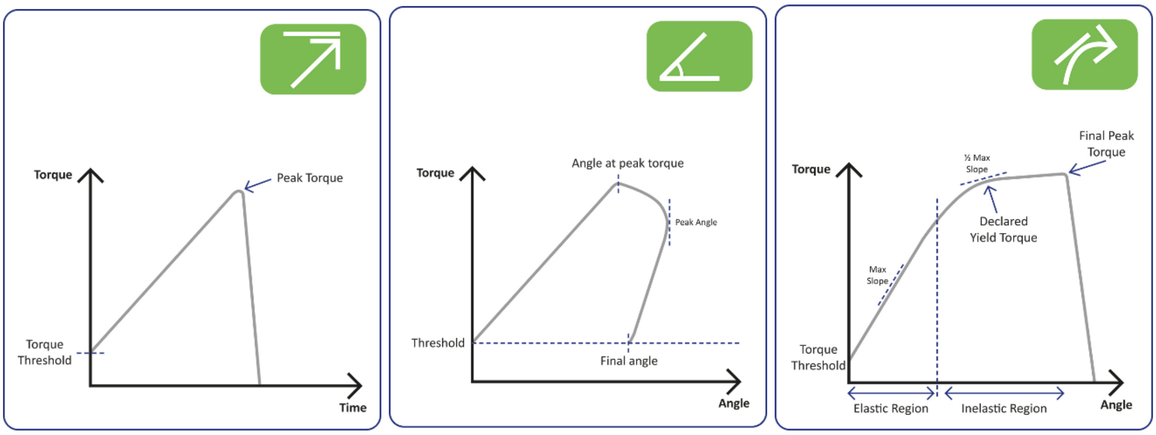
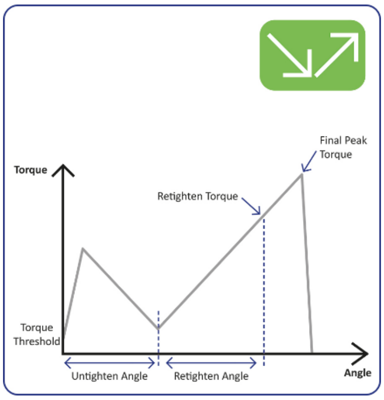


Figure 25 – Peak Torque, Angle and Yield modes of tightening for a digital torque wrench. Many other modes are available like Click Mode, Pulse Mode, Audit Mode, MoveOn Mode, MoveOn Advanced Mode, and Force Mode.

A tightening accuracy factor is a measure of how accurately you can achieve a particular bolt clamping force for different tightening methods. For example:

- **Peak torque tightening** - on unlubricated bolt gives a tightening accuracy factor of ±35% or ±25% for lubricated bolts.
- **Angle tightening –** a tightening accuracy factor of ±25%.
- **Yield tightening** – a tightening accuracy factor of ±8%. The use of this method is restricted to joints carrying high shear load with low tension loads.



Digital torque wrenches can also be used in a “retightening” mode for recovery of embedding losses. Embedding losses occurs over the first few hours of tightening as the contact surfaces in the joint settle. This may account for around 5% to 10% depending upon material and joint configuration.

Figure 26 – Retightening mode can be used to reduce bolt embedding losses.

Tightening accuracy factor and recovery of embedding losses is managed by the BoltExpert app (or calculations in the ExcelWraps repository). They calculate the variation of clamping force in a batch of bolts due to accuracy of the tightening mode. Usually, the bolt with the least clamping force needs to be checked for joint slip, as this provides a mechanism to drive bolt vibrational loosening (this can be seen in the “bolt and clamping load variation chart” in Figure 15).

Digital retention of the tightening mode and the tightening records of each bolt means that we are always clear of any bolt’s history. This will avoid all the confusion at the start of a bolt investigation.

8 Failure Incident Reporting

NIR 4014 Concluding: Class 331 - Yaw Damper Bracket (New Design) Bodyside Cracks **Defect Date:** 09/01/2024 10:00
Class: 331 (EMU)
Description: Whilst undergoing servicing at Blackpool Train Servicing Point on 09/01/24, cracks have been found in the vehicle body above wheel 13A on unit 331104 within the vicinity of the new yaw damper bracket assembly. Following previous NIR 3757 - "Class 1...

NIR 4006 Initial: Class 710 defective driver's seat **Defect Date:** 05/12/2023 10:30
Class: 710 (EMU)
Description: The back of the driver's seat collapsed backwards after securing bolts at the base had sheared, pictures attached. The driver was falling backwards as a result of this and sustained minor injuries arresting their fall.

NIR 4004 Initial: Class 397 broken traction link (drag link) to axle box bolts. **Defect Date:** 27/11/2023 12:58
Class: 397 (EMU)
Description: During a Light Maintenance (LM) exam and underframe inspections following reports in service of excessive vibration, it was found that both bolt heads connecting the traction (drag) link to the axle box, had sheared on 473005 vehicle at wheel positio...

NIR 4003 Initial: Class 170 Cracked Alternator Body Mounts **Defect Date:** 24/11/2023
Class: 170 (DMU)
Description: Class 170638 suffered from cracks on the alternator body where the mounting brackets are fitted, on all 3 vehicles. These cracks were highlighted by Alstom at Central Rivers on a C4 overhaul, under contract by Porterbrook, and advised to CrossCountry...

NIR 3984 Initial: HST Power Car Drive Link Failure **Defect Date:** 14/09/2023 09:08
Class: 43 (Loco)
Description: 43304 was the leading power car working 1V50 Edinburgh – Plymouth on 14/09/23, on arrival at York there was report of brake pressure gauge for Bogie 2, reading 0 bar. There was no other allegation against the train, and the train continued in servic...

NIR 3947 Concluding: ART17TH MEWP Oscillating Axle **Defect Date:** 10/04/2023 05:40
Class:
Description: MEWPs: The type of Mobile Elevated Working Platforms (MEWPs) involved in the derailment events at Carstairs is the Manitou Art17. Five of these machines were hired to SPL Powerlines from Torrent Trackside. • T141408 • T142118 (2nd and 3rd Derailm...

NIR 3918 Complete: HST Trailer Vehicle Catering PSU Fixing Anomalies **Defect Date:** 13/01/2023 02:30
Class: Mk 3 (LHCS)
Description: ScotRail staff identified fixings discrepancies in the Wabtec supplied documentation for refit of the underframe mounted catering power supply unit (PSU): TI-140306-650-M Issue A. On investigation, Wabtec identified a deficiency in specific Wabtec en...

NIR 3899 Complete: Class 395 Gearbox torque reaction link fixings **Defect Date:** 18/10/2022
Class: 395 (EMU)
Description: On 18th October, during routine maintenance on 395008, Hitachi identified that one wheelset had both gearbox torque reaction link lower fixings missing. One bolt was fully missing and so likely to have come loose. The other bolt was sheared, likely d...

NIR 3895 Initial: Class 720: Axle Earth End Housing Failure **Defect Date:** 04/10/2022 12:10
Class: 720 (EMU)
Description: At 0010 on 04/10/22 it was reported that by a driver that 720537 had a detached axle end earth return assembly had detached. Upon inspection it was found that the M8x8 bolt used to mount the equipment was missing. This was traced back to the bolt h...

Figure 27 – Bolting related incidents on UK railway held on the National Incident Register. Typically, there are 2 to 3 bolting related incidents every month.

A digital register that can be searched quickly is an essential safety service in the UK railway industry. ExcelWraps technology can easily create an incident register. The first step would be to design an incident reporting form in Excel so that they can be saved in a database, and we can generate reports to monitor any number of incidents until they are resolved. This is an important tool used to record service problems and it is used to inform other train operating companies and maintain a record of how they are resolved.

9 Conclusion

Bolt studies have 3 stages, and all are improved if we use digital technologies in design, testing, manufacture, installation, and maintenance.

1. Assess the bolt group loading - determine loads on each bolt working together. ExcelCalcs calculations, FEA models, or load testing with sensors can handle this.

2. Assess the bolted joint - evaluate if the joint can withstand the loads based on factors like bolt properties, clamped materials, friction, tightening method, thermal effects. ExcelCalcs, the BoltExpert app and joint testing can manage this process.

3. Review bolt history - extract digital records capturing the complete bolt history, including manufacturing, batch testing, tightening processes, supplier changes, and failure incident records. ExcelWraps can manage this process.

To try these digital technologies, scan the QR code to get John Doyle’s contact details and ask for:

a) **Bolt Expert App** – we are happy to give you access.
b) **ExcelWraps** - Send a spreadsheet and we’ll wrap it for you (e.g. a production workflow form or your own failure incident form).
c) **See it in action** - Arrange a site visit to an industrial partner to see production workflow wraps with API connector integration to digital torque wrenches.

10 Epilogue and Further Information

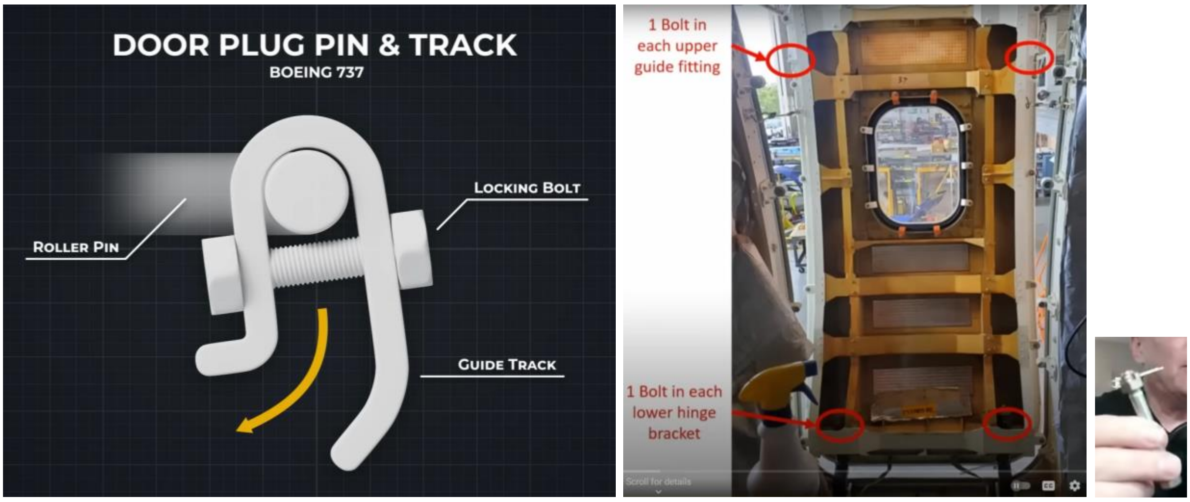


Figure 28 - Boeing 737 door plug track and locking pin with cotter pin locking device.

Regarding the Boeing 737, an update on January 25th: Alaskan Airlines CEO said that numerous loose bolts were found after a fleet check. If they had digital records a fleet check would not have been necessary, the information could have been immediately available by searching digital records.

Boeing's subcontractor, Spirit AeroSystems, makes fuselages and door plugs in Wichita, Kansas, and sends them to Seattle, Washington, for final assembly. The door plugs are not fully installed at first, because Boeing takes them out to adjust interiors for customers and fixes them when they put them back. Misunderstanding between the companies could cause door plugs to be moved wrongly, resulting in improper installation. Spirit AeroSystems quality assurance records indicate that work has been done on the plug door seal, but the Boeing quality assurance system had no records of this. It is possible that they may have skipped their door installation checks altogether. There are also whispers that Boeing may have failed a fuselage pressure test but just reset the pressure switches without alerting anyone. Boeing has also had significant layoffs, particularly reducing the number of quality assurance staff, which has led to confusion over what has been checked and not checked. All these rumours and whispers match the author’s experience of the lack of clarity surrounding failure investigations. It’s still early, and the investigation is continuing, but the root cause is likely to be one of these:

1. No predelivery tests before going into passenger service.
2. Only two bolts fitted.
3. Cotter pins not fitted and vibrational loosening leading to loss of locking bolts.

Regarding the digital technology described in this paper, Boeing and Spirit AeroSystems should have had a clear view of work that had not been completed, particularly if both companies shared data automatically using an API connector.

Further Reading, Useful Links and References.

1) The ExcelCalcs site.
2) The BoltExpert site.
3) The ExcelWraps site.
4) The ExcelWraps help site.
5) Video: The Questionable Engineering of the 737 Max. Video published: Jan 21, 2024. After yet another avoidable accident Boeing has found itself in hot water again over short cuts were made to maximize revenue. Credits: Producer/Writer/Narrator: Brian McManus.
6) Video: Boeing's Quality Management Failure Explained 737-Max-9 Door 24 Jan 2024.