Engineering, Operations & Technology
Boeing Research & Technology

cWorks – Corrosion Control System

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Report Documentation Page

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14. ABSTRACT

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What is cWorks?

- **What is cWorks?**
  - Disciplined process to select corrosion resistant systems

- **Why do we need it?**
  - Current practices rely on engineering guidelines along with the expertise of Material & Process engineers
  - Process entails an assessment of the effects of surface protection, direct material-to-material contact, heat, ultraviolet light, moisture, size and location of components, repeated loading, and a multitude of other contributory parameters
  - Process is not systematic, nor quantitative, and lacks a common reference set of corrosion parameters

How does it work?

- **RELATIVE CORROSION INDEX (RCI)** is calculated using the parameters that make up a material system

- What is the **RCI**?
  - The **relative** potential of the material system to corrode or experience corrosion on a scale of one to 100
  - One is the most corrosion resistant and 100 the least

Base Material Corrosion Ranking

How do the materials that we use on aircraft stack up to each other with regard to corrosion?

R = 10 (very corrosion resistant) to
R = 60 (poor corrosion resistance)
Group No. = Galvanic Ranking from
1 (Active) to 18 (Noble)

Material	Group	Alloy	Product	Temper	R
Stainless Steel	11	15-5PH			22.5
		PH13-8	Forging	H1000	25.625
				H1050	25.625
			Bar		25.625
		A286			22.5
		300 Series			19.375
Alloy Steel	6	H-11			41.25
		300M			41.25
		4340	160 ksi or below		41.25
			180 ksi and above		47.5
		HY-TUF			41.25
Nickel Alloys	16	MP159			16.25
		Inconel	625		16.25
			718		16.25
Titanium	17	All	All		10
Copper Alloys	15	Be-Cu			28.75
Tungsten Alloys	10	Tungsten Carbide			10

Material	Group	Alloy	Temper	Alclad	R
Aluminum	4	2024	T3	Alclad	53.75
				Bare	60
			T351		60
			T3511		60
			T81		60
		2090	T8E41		60
		2117	T4		60
		2219	T62	Alclad	53.75
				Bare	60
			T81	Alclad	53.75
				Bare	60
			T851		60
			T852		60
		7050	T73		53.75
			T74		53.75
			T7451		53.75
			T74511		53.75
			T6*		53.75
			T651*		53.75
			T6511*		53.75
		7075	T6 t<=0.188	Alclad	47.5
				Bare	53.75
			T6 t>0.188*	Alclad	47.5
				Bare	53.75
			T73		53.75
			T7351		53.75
			T76	Alclad	47.5
				Bare	53.75
		7150	T7751		53.75
			T77511		53.75
		7475	T761	Alclad	47.5
				Bare	53.75
			T7651		53.75
		A357	Castings		47.5
		D357			47.5
		KO1			60
		5052	Honeycomb		44.375
		6061	T6		44.375

Surface Treatment Effectivity

Organic Coatings

Fastener	Primer Material	Primer Type	Topcoat Material	Topcoat Type	H
No	None	N/A	None	N/A	1.0
			Polyurethane	Heat resistant	0.4
			Fuel Tank Coating	N/A	0.3
			Rain Erosion Tape		0.5
	Epoxy	Regular	Polyurethane	Gloss	0.3
		Fluid Resistant	None	N/A	0.3
			Fluid Resistant Epoxy		0.4
		Impact Resistant	Polyurethane	N/A	0.4
			Impact Resistant Epoxy	Regular	0.4
				Walk-on	0.4
				Erosion	0.4
Yes	None	N/A	None	N/A	1.0
			Dry Film Lube		0.8
			Hi-Kote		0.6

Inorganic Coatings

Material	Type	T
Aluminum	Clean/none	1.00
	Chromic acid anodize	0.30
	Cadmium plate	0.60
	Nickel plate	1.10
Stainless Steel	Clean/none	1.00
	Cadmium plate	1.20
	Nickel plate	0.40
	Chrome plate	0.20
	Silver plate	0.80
Titanium	Clean/none	1.00
	Anodize	0.20
	Nickel plate	0.50
	Chrome plate	0.20

Material	I
None	1.00
Sealant	0.10
CPC	0.20
Sealant & CPC	0.02

Sealant

$$\Omega_{Base} = R \cdot I \cdot T \cdot H$$

Baseline Corrosion Potential = Ω_{Base}

Environmental and Chemical Attack

- Three types of environmental - chemical attack
  - Environmental Attack of the Organic Surface Finish
    - Salt Spray
    - Anti-ice
    - Blue Water
    - UV
  - Organic Surface Finish Damage
    - Sand
    - Gravel
    - Engine Exhaust
    - Maintenance
  - Environmental Attack of the Parent Material
    - Salt Spray
    - Anti-ice
    - Blue Water
    - UV

Environmental Attack – Organic Surface Finish

Coating					A_i							
Fastener	**Primer Material**	**Primer Type**	**Material**	**Type**	**UV**	**Salt Spray**	**Anti-Ice**	**Blue Water**	**Engine Exhaust**	**Heat**	**De-Ice**	**Leak**
No	None	N/A	None	N/A	100%	100%	100%	100%	100%	100%	100%	100%
			Polyurethane	Heat resistant	100%	76%	76%	59%	100%	100%	59%	92%
			Dry film lube	N/A	50%	65%	65%	50%	40%	20%	50%	65%
			Hi-Kote	N/A	50%	76%	76%	59%	46%	24%	59%	85%
			Fuel tank coating	N/A	25%	87%	87%	67%	46%	27%	67%	85%
			Rain Erosion Tape	N/A	100%	87%	87%	67%	43%	27%	67%	79%
	Epoxy	Regular (2104)	Polyurethane	Gloss	100%	100%	100%	77%	55%	27%	77%	100%
				APC	100%	87%	87%	67%	40%	31%	67%	73%
		Fluid Resistant	None	N/A	25%	100%	100%	38%	35%	15%	38%	65%
			Fluid-resistant epoxy	N/A	25%	76%	76%	100%	46%	40%	100%	85%
		Fluid Resistant - Two Coats	None	N/A	25%	100%	100%	38%	35%	15%	38%	65%
		Impact Resistant	Polyurethane	APC	100%	87%	87%	67%	40%	31%	67%	73%
			Impact-resistant	Regular	100%	100%	100%	77%	46%	27%	77%	85%
				Walk-on	100%	100%	100%	77%	46%	27%	77%	85%
				Erosion	100%	100%	100%	77%	46%	27%	77%	85%
Yes	None	N/A	None	N/A	100%	100%	100%	100%	100%	100%	100%	100%
			Dry Film Lube	N/A	100%	85%	85%	85%	87%	85%	100%	100%
			Hi-Kote	N/A	100%	100%	100%	100%	100%	100%	85%	80%

Environmental attack reduces the resistance of the organic finish – but not below that of the parent material.

Environmental attack factors negate the coating factor, H:

$$E = 1 + (H - 1) \cdot A_0 \cdot A_1 \cdots A_n \qquad 0.2 \leq E \leq 1.0$$

Organic Surface Finish Damage

Coating Damage		
Location	**Type**	**B**
External	None	1.00
	Sand	0.75
	Gravel	0.50
	Engine Exhaust	0.75
	Maintenance damage	0.25
	Erosion	0.75
Internal	None	1.00
	Galley	0.25
	Cargo area	0.75
	Fuel tank	0.50
	Maintenance damage	0.25

$0.25 \leq B \leq 1.0$

Finish damage reduces the resistance of the organic finish – but not below that of the parent material.

Surface protection factor, C, takes into account the benefit of the coating system (organic & inorganic finish, sealant, & CPC) and the detriment of coating damage:

$$C = 1 - B\left(1 - E \cdot T \cdot I \cdot Y\right)$$

Where Y accounts for exposure resistance provided by an interference fit fastener:

Fasteners	Y
Clearance Fit	1.0
Interference Fit	0.3

$0.3 \leq Y \leq 1.0$

Environmental Attack – Parent Material

Material	D_i							
	UV	Salt Spray	Anti-Ice	Blue Water	Engine Exhaust	Heat	De-Ice	Leak
Aluminum	1.00	1.43	1.43	2.00	1.21	2.00	2.00	1.21
Stainless Steel	1.00	1.07	1.07	1.29	1.04	1.07	1.29	1.07
Alloy Steel	1.00	1.21	1.21	2.00	1.21	1.14	2.00	1.21
Nickel Alloys	1.00	1.03	1.03	1.14	1.04	1.00	1.14	1.03
Titanium	1.00	1.00	1.00	1.14	1.04	1.00	1.14	1.00
Copper Alloys	1.00	1.10	1.10	1.29	1.21	1.14	1.29	1.10
Tungsten Alloys	1.00	1.04	1.04	1.14	1.04	1.00	1.14	1.04
Plastics	1.43	1.01	1.01	1.14	1.21	2.00	1.14	1.01
Composite Prepreg	1.43	1.03	1.03	1.03	1.03	1.03	1.03	1.03
Composite Core	1.43	1.03	1.03	1.03	1.03	1.03	1.03	1.03

Chemical attack factors combine per the following:

$$D = D_1 + (D_2 - 1)/2 \cdots (D_n - 1)/n \qquad 1.0 < D \leq 3.09$$

Resultant chemical attack factor interacts with surface protection factor, C:

$$F = C \cdot D \qquad 0 < F \leq 3.09$$

Moisture Intrusion

Location	J
Dry/Ventilated	1.00
Doors	1.17
Low spots	1.33
Bilge	1.50
Sump	1.50
Wheel Well	1.33
Trailing Edge	1.17

Drainage	K
Adequate	1.00
Inadequate	1.17

Moisture Intrusion Factors

Impact potential due to moisture:

$$M = J \cdot K \quad 1.0 \leq M \leq 1.76$$

- The total moisture intrusion risk is dependant on:
  - Location
  - Whether adequate drain paths exist

Beneficial Environments

Environmental Factors	
Condition	**N_j**
None	1.0
Pressurized	0.6
Protected	0.5
Internal	0.7
Fuel	0.4
Oil	0.3

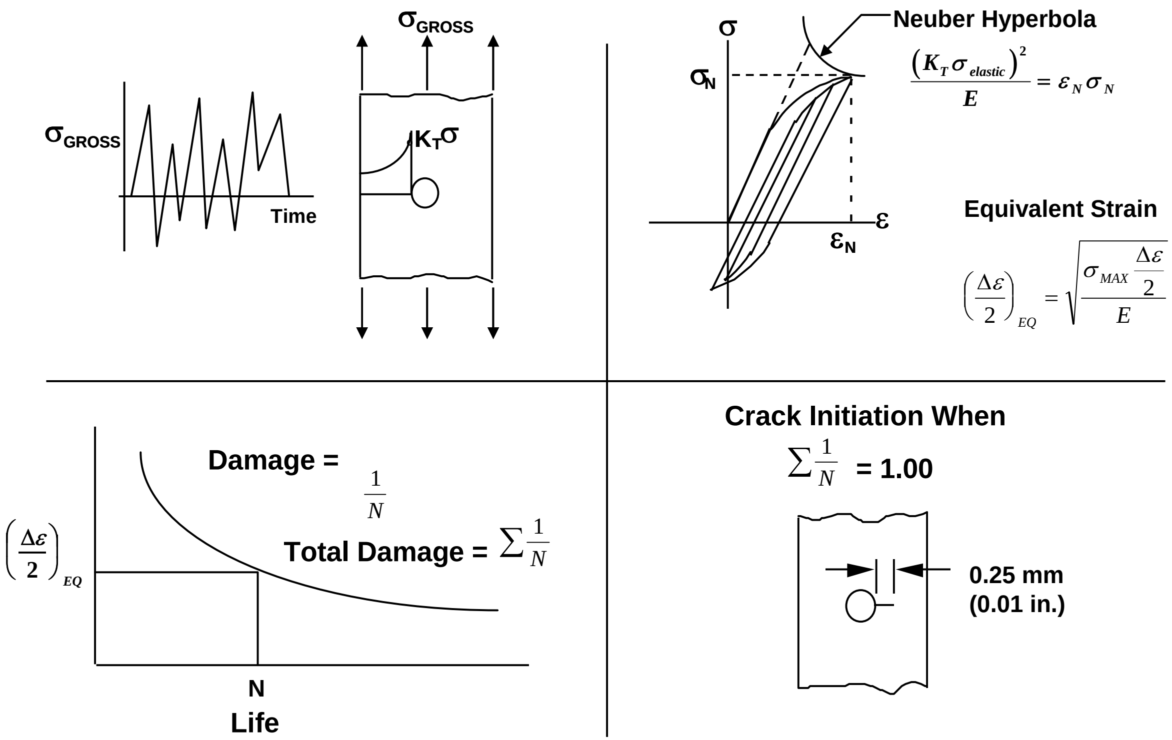
$0.3 \leq N_j \leq 1.0$

Beneficial Environment Impact

Impact potential due to beneficial environment:

$$N = N_1 \cdot N_2 \cdots N_n \qquad 0.15 \leq N \leq 1.0$$

Spectrum Effects



Spectrum Effect	
Life (Hr)	**V**
> 100,000	1.0
50,000	1.2
10,000	1.2
5,000	1.4
< 1,000	1.5

$1.0 \leq V \leq 1.5$

Fatigue Life Prediction Algorithm

Galvanic Activity

Galvanic activity is a function of rank difference*:

$$\Delta = \left| G_{Mat-A} - G_{Mat-B} \right|$$

*Based on the inorganic surface treatment between two interface materials

Material	Surface Treatment	Galvanic Rank G: Bare	Galvanic Rank G: With Surface Treatment
Aluminum	Clean/none	4	4
	Chromic acid anodize		4
	Cadmium plate		3
	Nickel plate		16
	Silver plate		18
Stainless Steel	Clean/none	11	11
	Cadmium plate		3
	Electroless nickel		16
	Chrome plate		10
	Silver plate		18
Alloy Steel	Clean/none	6	6
	Cadmium plate		3
	Nickel plate		16
	Chrome plate		10
	Silver plate		18
Titanium	Clean/none	17	17
	Anodize		17
	Nickel plate		16
	Chrome plate		10

Δ = Rank Difference

Galvanic Action

Rank Impact

Rank Δ	P
0	1.00
6	1.22
12	1.56
18	2.00

$1.0 \leq P \leq 2.0$

Small Anode Effect

Rank Δ	S
0	1.00
4	1.00
8	1.12
14	1.24
18	1.36

$1.0 \leq S \leq 1.36$

Organic Surface Finish Thickness Effect

Thickness	Q
0	1.00
≥ 6	0.25

$0.25 \leq Q \leq 1.0$

Interface corrosion potential:

$$G = P \cdot S \cdot Q \qquad 0.25 \leq G \leq 2.72$$

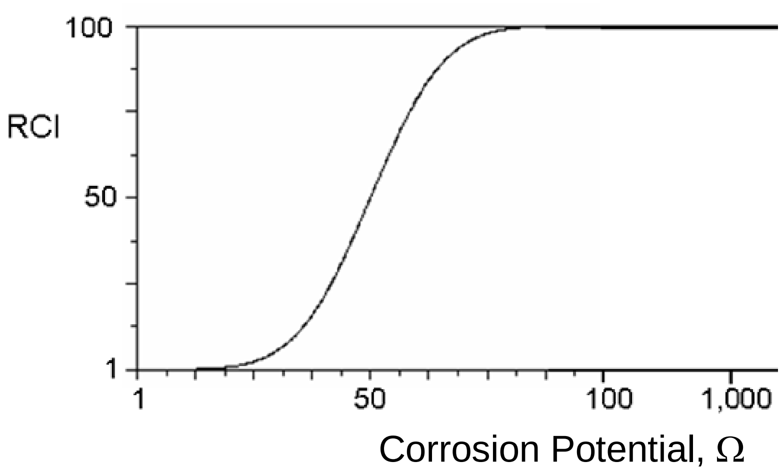
- Interface corrosion potential (risk) depends on:
  - Material potential for individual components
  - Galvanic interaction between the two materials

cWorks RCI Calculation

- Material resistance, R, is modified based on factors for surface treatment, damage potential, moisture (location, drainage, fastener fit), galvanic action, and the environment

$$\Omega_{Mat} = R \cdot N \cdot f(F, V, M, G) \quad 1 \le \Omega_{Mat} \le 407$$

- Cumulative probability density function is used to convert the material's corrosion potential score, Ω, to a relative corrosion index, RCI $1 \le RCI \le 100$



What can we do with cWorks?

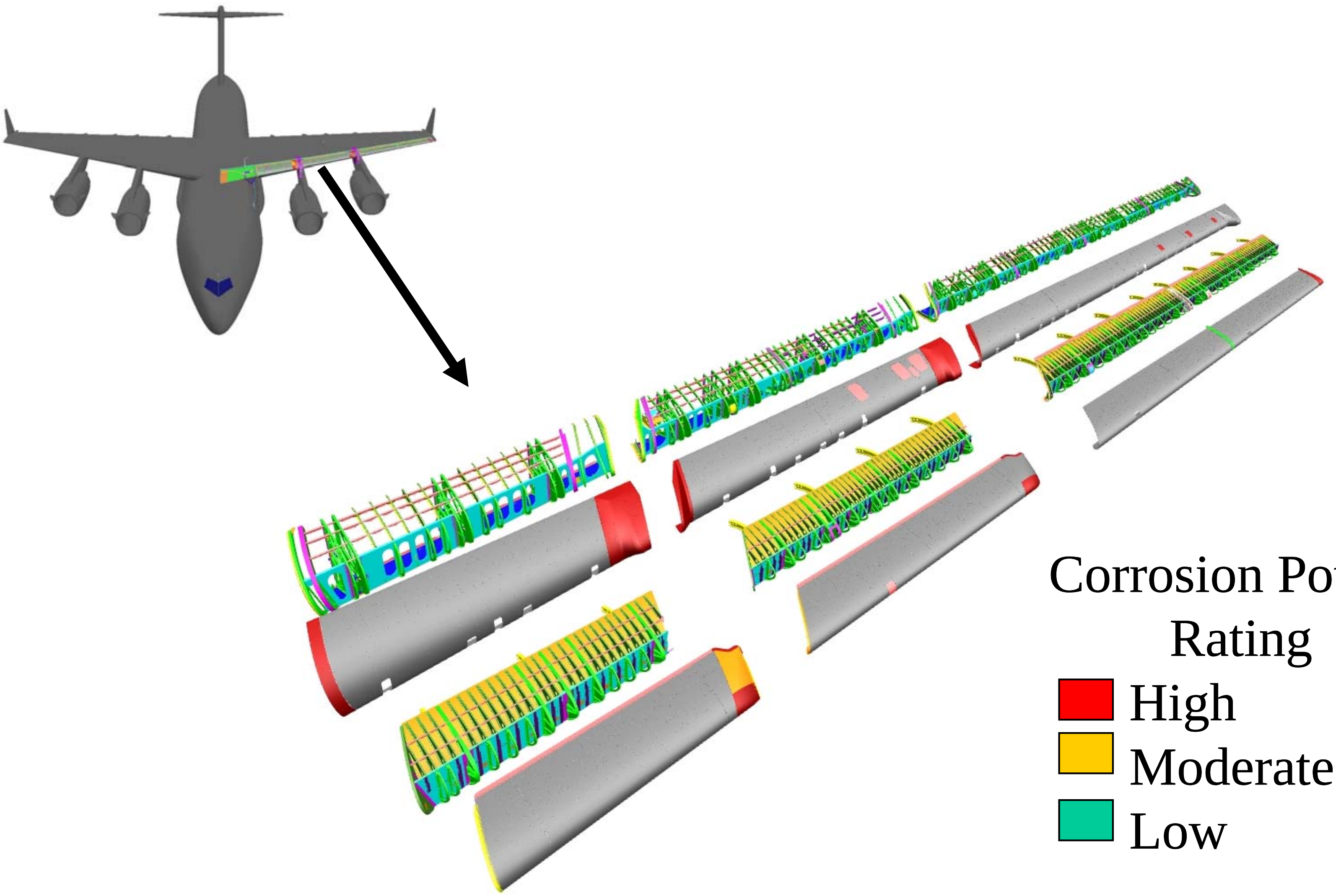
- On existing aircraft: corrosion-based inspection intervals can be determined and inserted into existing maintenance plan
- In the design phase: mitigate corrosion risk items before they occur

cWorks Used for Inspection Intervals

- **RCI is a relative indicator of corrosion *potential* only**
- **Implement subjective relationship between RCI and inspection interval**

RCI	Flag	Design	In-Service Relative Inspection Interval	Inspection Interval
75 – 100		Must fix it		240 days
50 – 74		Suggest fix it		720 days
30 – 49		Marginally okay		Five years
15 - 29		Okay		Half-lifetime
0 - 14		Very good		No inspection

cWorks Used for Design



Corrosion Potential Rating

- High
- Moderate
- Low

Current Status

Engineering, Operations & Technology | **Boeing Research & Technology** **Chemical Technology**

- **Current Status**
  - Stand-alone PC-based software program developed
  - Patent Issued –

United States Patent
Meyer et al.

(10) **Patent No.: US 7,704,371 B2**
(45) **Date of Patent: Apr. 27, 2010**

CORROSION IDENTIFICATION AND MANAGEMENT SYSTEM

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Assignee: **The Boeing Company**, Chicago, IL (US)

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Filed: **Dec. 11, 2006**

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Int. Cl.
C23F 13/04 (2006.01)
C23F 13/22 (2006.01)

(52) **U.S. Cl.** **205/725**; 205/775.5; 324/71.2; 324/71.1; 324/700; 702/31; 702/32; 702/34; 702/189; 703/2

(58) **Field of Classification Search** 324/71.1, 324/71.2, 700; 205/725, 775.5; 702/31, 702/32, 34, 189; 703/2
See application file for complete search history.

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Primary Examiner—Bruce F Bell
(74) *Attorney, Agent, or Firm*—McNees Wallace & Nurick, LLC

(57) **ABSTRACT**

The present invention is directed to a system for identifying and managing corrosion and methods related thereto. In particular, the invention provides a system for identifying and managing the structural corrosion potential for an assembly by measuring a "Relative Corrosion Index" ("RCI").

28 Claims, 8 Drawing Sheets

cWorks Enhancements

- **CWorks v2.0 Enhancements:**
  - **Corrosion Ranking for Air Force Bases Added**
    - **Dover, Charleston, McChord, Travis, Altus, McGuire, Elmendorf, Jackson, March, Edwards, Hickam, and Foreign Bases**
  - **Composite materials added**
  - **Fastener joint designs added (cWorks Fastened Joint Wizard)**
  - **User Friendly Software**

cWorks Fastened Joint Examples

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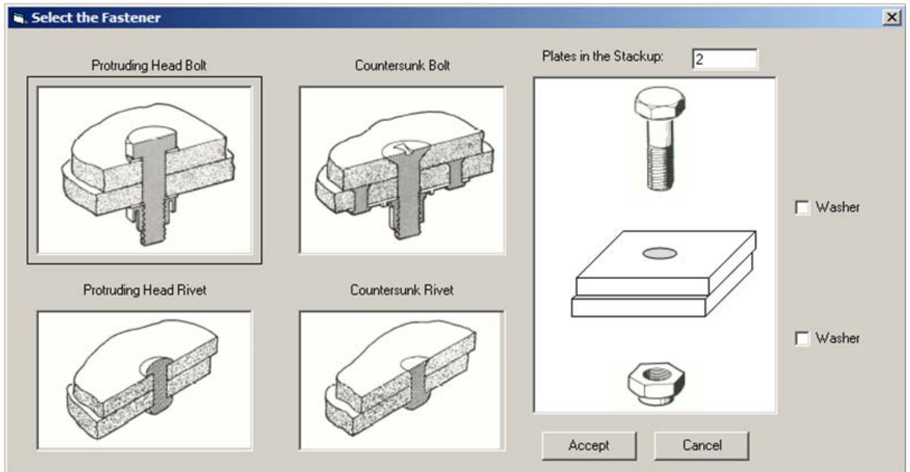
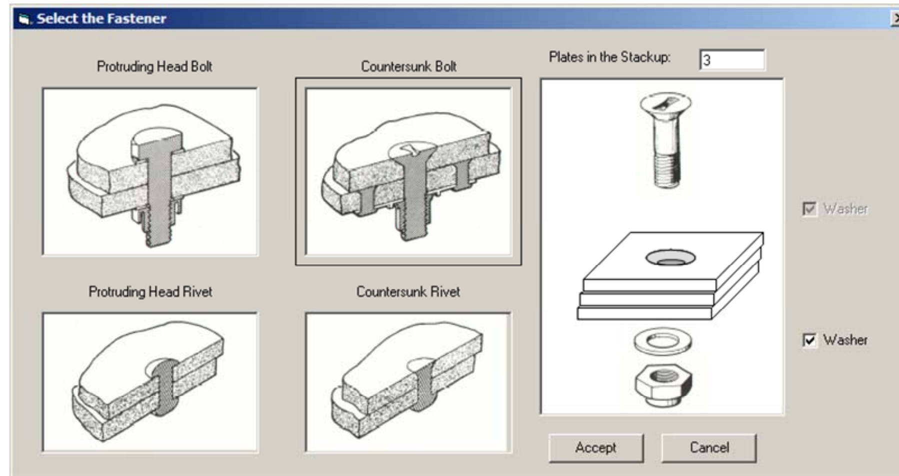
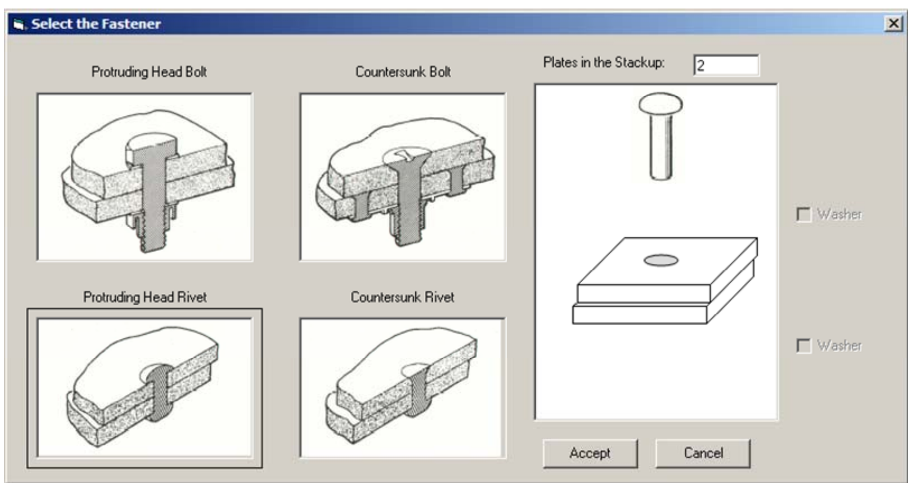
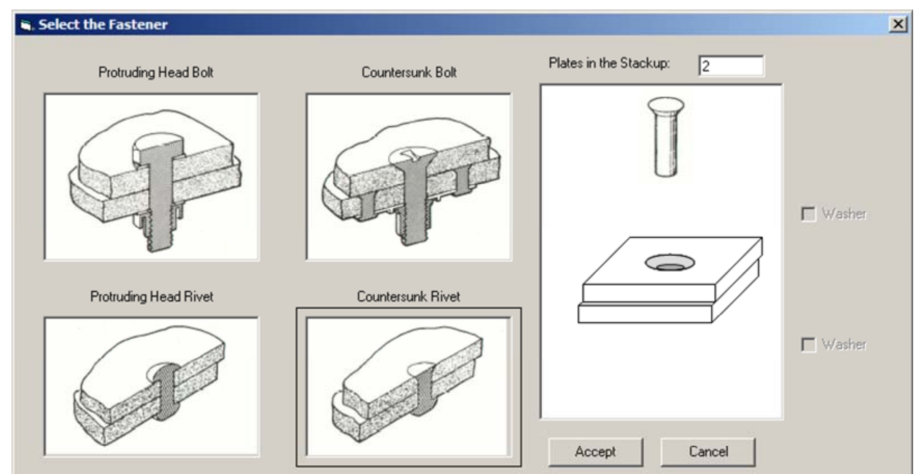


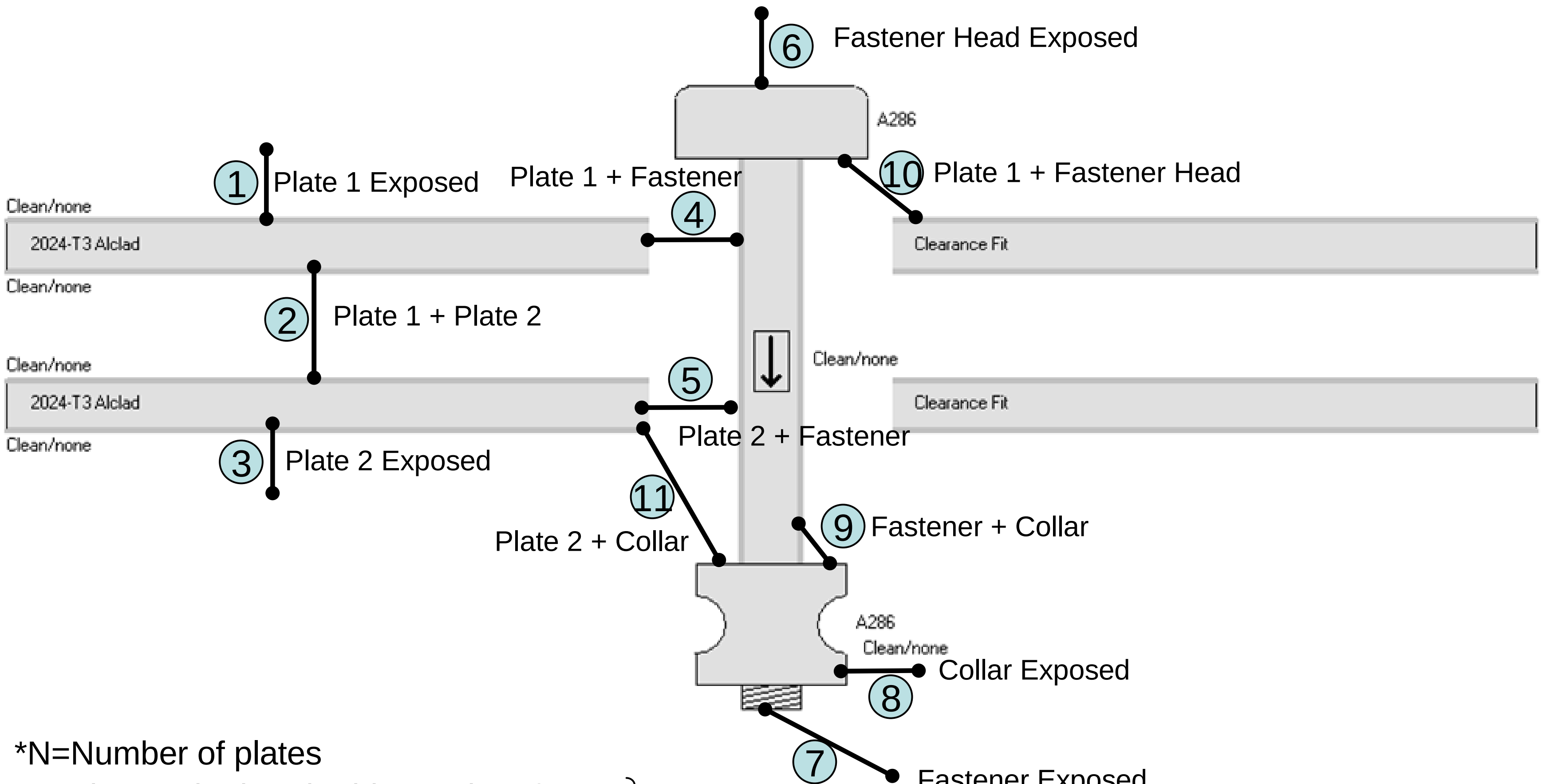






cWorks Fastened Joint Wizard

Wizard creates (7+2N)* interfaces



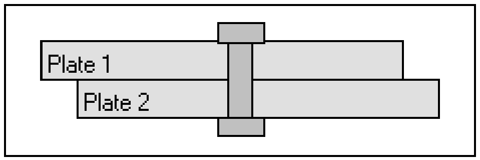
*N=Number of plates

Washer under head adds one interface

Washer under collar adds two interfaces

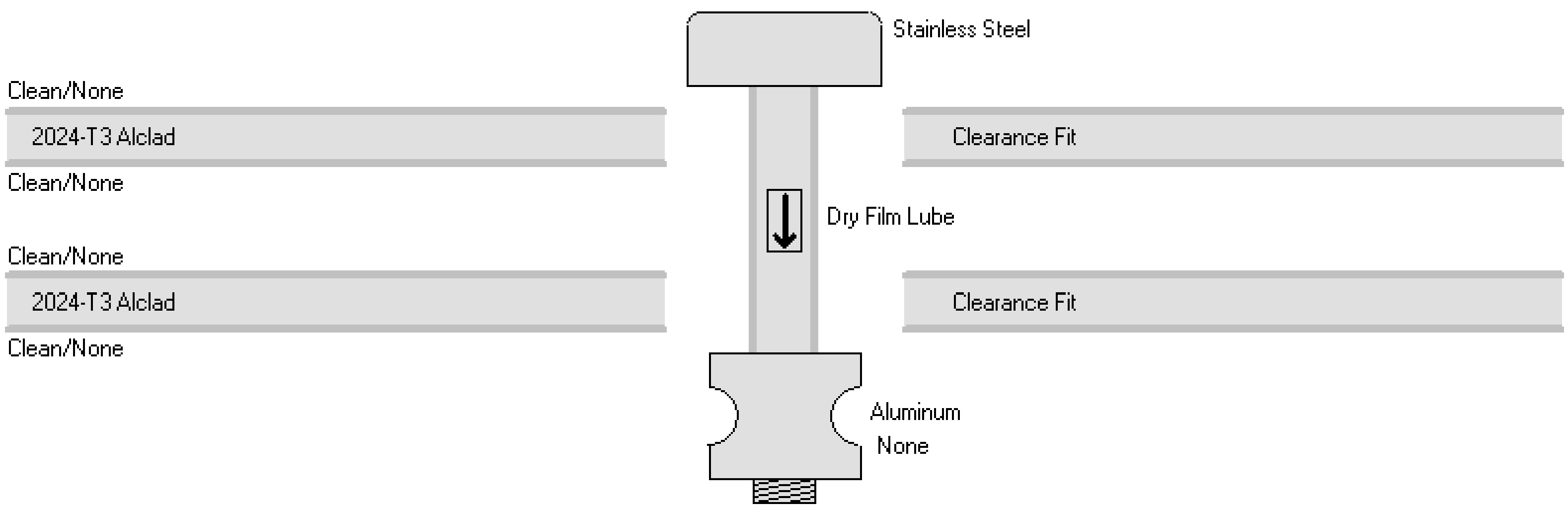
Washers not shown

cWorks Demo



Moisture Intrusion
Dry/Ventilated with Adequate drainage

Environment
External Location



Environment
External Location

Moisture Intrusion
Dry/Ventilated with Adequate drainage

Questions?