出國報告(出國類別：其他）

波音公司「航空器維護可靠度研討會」出國報告

服務機關：民用航空局
姓名職稱：檢查員廖啟超
派赴國家：美國洛杉磯
出國期間：105 年 9 月 17 日至 9 月 25 日
報告日期：105 年 11 月 4 日

壹、目的

航空器使用人須依據本局核准之維護計畫執行航空器維護作業，以確保航空器符合持續適航之條件。而為提升維護計畫有效性，航空器使用人得輔以可靠度計畫做為調整維護計畫之依據。為使檢查員了解製造廠對於可靠度計畫之建議，並透過研討過程了解他國可靠度計畫執行情形，進而提昇檢查員監理之能力，以確保航空器使用人可靠度計畫之有效性，故派員參加本次於美國洛杉磯舉行之航空器維護可靠度研討會 (Maintenance reliability and cost analysis seminar)

貳、過程

一、 本次出國行程 (共計9日) 摘要如下

日期	行程
9 月 17 日	起程
9 月 18 日 至 9 月 23 日	參加航空器維護可靠度研討會
9 月 24 日 9 月 25 日	回程

二、 本次研討會之議程摘要如下

1. Evolution of maintenance and reliability programs
2. Reliability regulatory requirement
3. Extended operation (ETOPS) maintenance program
4. Organization and performance standards
5. Data collection system
6. Data display and reporting
7. Data analysis and corrective action
8. Schedule reliability
9. Developing a component reliability program
10. Reliability metrics

11. Rogue components
12. Structure reliability
13. Digital transformation for improved engine availability
14. Maintenance program interval adjustment
15. Tableau data visualization and airplane reliability index
16. Airline maintenance costs
17. Maintenance costs and value of reliability
18. The value of sharing reliability data

參、心得:

本次研討會除介紹現有可靠度計畫之歷史沿革、法規與特殊作業 (ETOPS) 需求、組織與手冊架構及性能標準...等外，亦提出更準確、有效及快速的執行方式供航空器使用人參考，以下就 (1) 組件可靠度指標、(2) Rogue Component 及 (3) 統計分析工具 (Tableau) 等 3 項加以說明：

1. 組件可靠度指標

傳統上零組件可靠度指標包含 (1) MTBR, Mean Time Between Removals, (2) MTBUR, Mean Time Between Unscheduled Removals, (3) MTBF, Mean Time Between Failure, (4) URR, Unscheduled Removal Rate 等，其計算方式分別為：

MTBR = Fleet flying hours x (QPA, Quantity per aircraft) / Total number of removal
MTBUR = Fleet flying hours x QPA / Unscheduled removal
MTBF = Fleet flying hours x QPA / Failures
URR = (1000 x unscheduled removals) / (Fleet flying hours x QPA)

然而前述可靠度指標受限於其計算方式，有時不易反映真實的情況，以 MTBUR 為例，假設
Fleet flying hours = (Fleet size) x (hours/year utilization per aircraft) = 100000
QPA = 2
Unscheduled removal = 5
其 MTBUR = 100000 x 2 / 5 = 40000 hours

對於 5 具不同的組件各更換 1 次，與同 1 組件更換 5 次所得的 MTBUR 皆為 40000 hours。然而，其所代表的意義卻截然不同。 另，MTBUR 容易受機隊規模影響，對於機隊小的公司，MTBUR 值容易因為單一組件的更換率而劇烈變化，無法呈現真實的情況。

而 MTBF 除有類似 MTBUR 的情況外，另 failure confirmed or not 係由組件維修廠負責判定，然維修廠員工並不一定了解組件裝置於飛機上的運作情形，因而產生誤判的可能性。

綜上所述，波音公司認為，傳統組件可靠度指標無法呈現真實的情況，甚至可能產生反效果。

波音公司提供下列更有效率的方法:

- Pilot report alerting program: Analysis of high maintenance activity
- Premature removals: Flag component serial numbers with low time in service
- Material Services interface: (1) Spares provisioning problems – high usage / low levels (2) Warranty activity – high number of warranty denials
- Maintenance Control interface: Chronic problems, back out of stock installations, etc.
- OEM / Shop interface: High NFF (no fault found), unusual trend of shop findings, etc.

2. Rogue Component

航空業多年來一直嘗試著就各方面降低成本，與飛機維修相關成本包含: 派遣率、飛機維護、零件庫存量、改裝與升級、組件修理等。其中又以 rogue component 為最大單一成本。

Rogue component 的定義為

- 每次裝用後，都於短時間之內因相同的故障情形而遭更換，而故障情形於安裝另一組件後隨即消失。
- 無法經由標準的修理/翻修程序，找到並解決故障 ”屢修不好” 的情形。

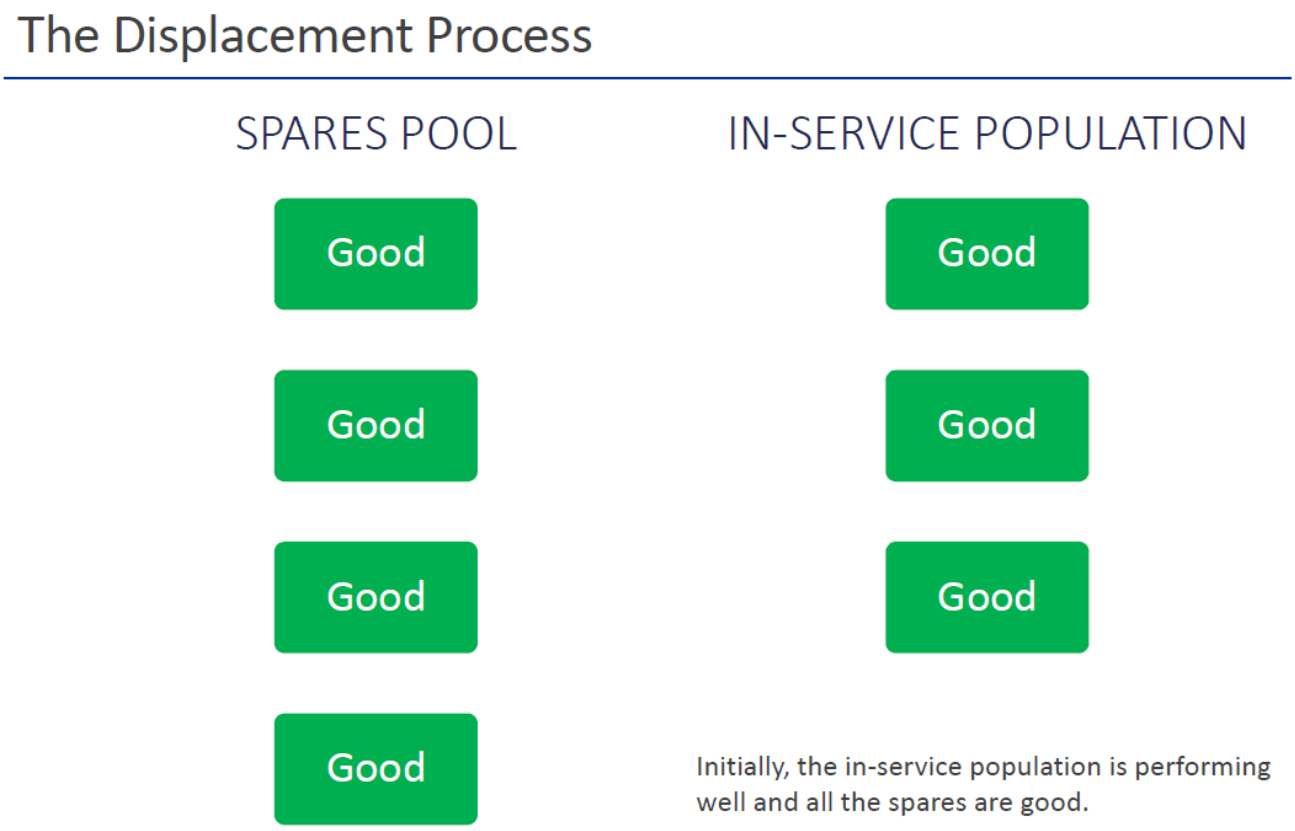
以下原因促使波音公司認為 Rogue component 現象是不可避免的:

- 組件維修手冊 (CMM) 所要求的測試程序無法完全模擬組件裝置於飛機上所遭遇的環境(溫度、壓力、應力及震動)。
- 組件測試項目係製造廠依預期發生的故障而設計，對於非預期的故障，則無法有效偵測。

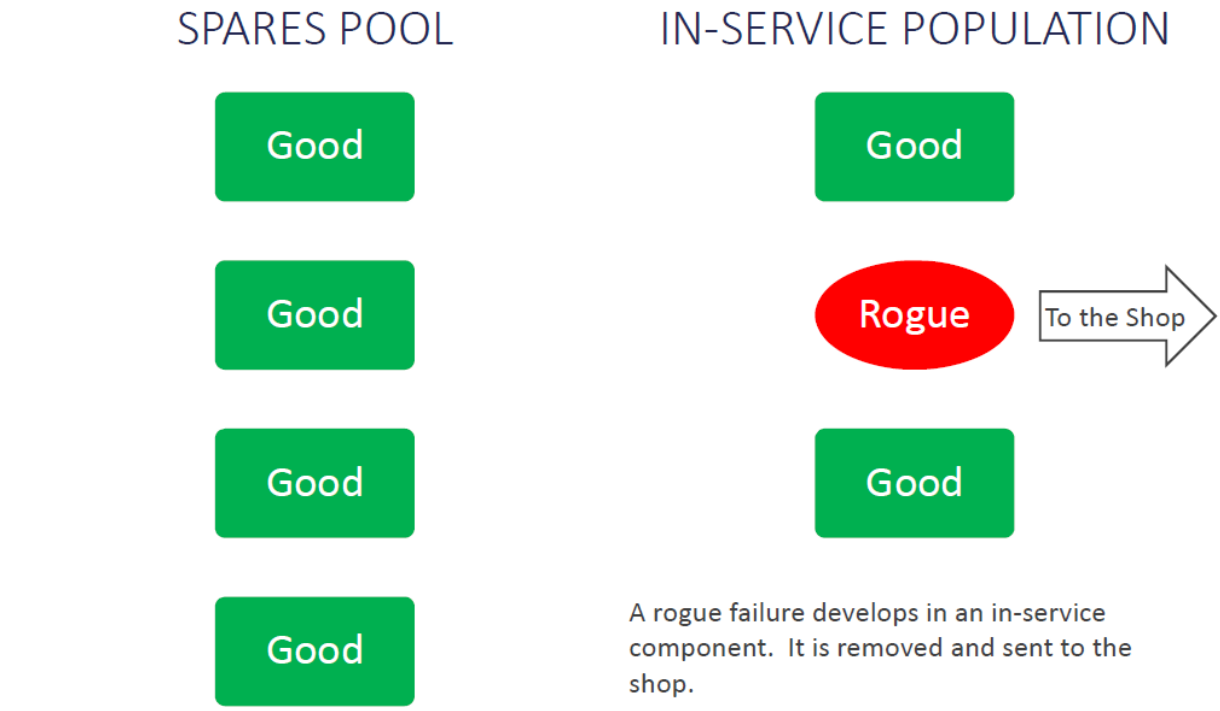
除此之外，與人為因素相關的原因包括:

- 組件維修廠執行組件修理/翻修之工作範圍 (work scope) 係由航空器使用人於修理訂單 (repair order) 內明訂，而 repair order 僅要求對故障情形執行修理，未要求全面翻修，造成組件出廠後因另一故障情形而遭更換。
- 組件維修廠品質不佳。

Rogue component 會造成劣幣驅逐良幣的現象，其過程圖示如下:

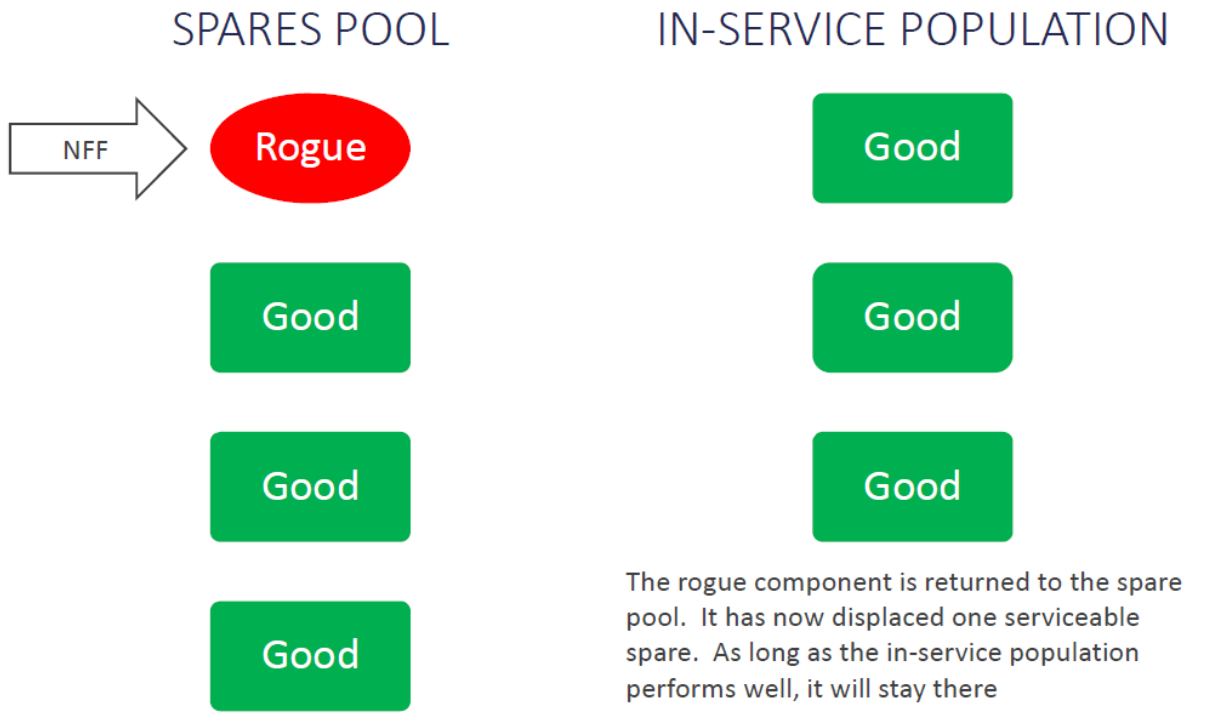


The Displacement Process



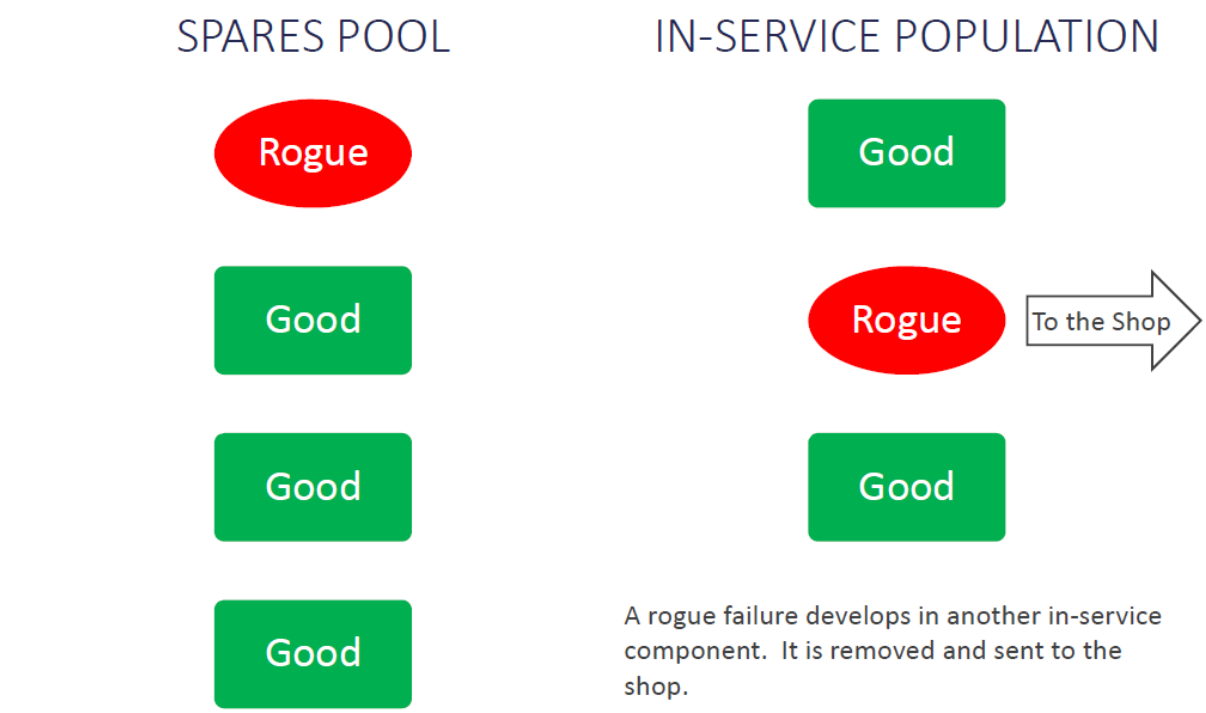
A rogue failure develops in an in-service component. It is removed and sent to the shop.

The Displacement Process



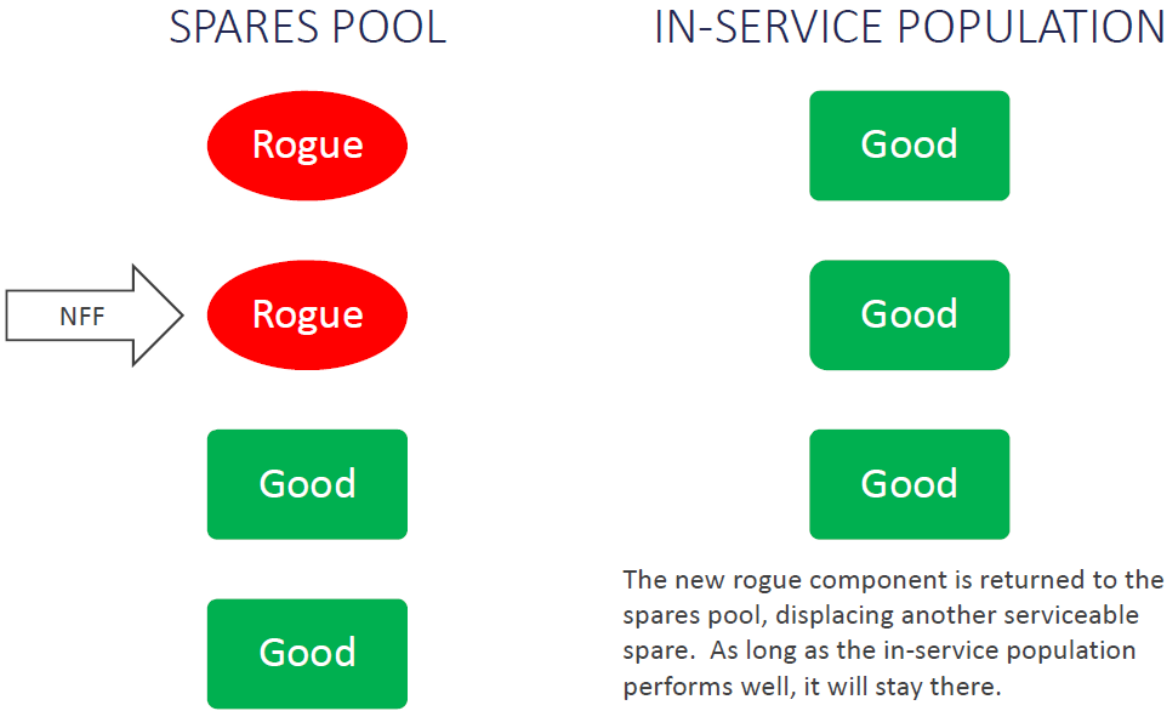
The rogue component is returned to the spare pool. It has now displaced one serviceable spare. As long as the in-service population performs well, it will stay there

The Displacement Process



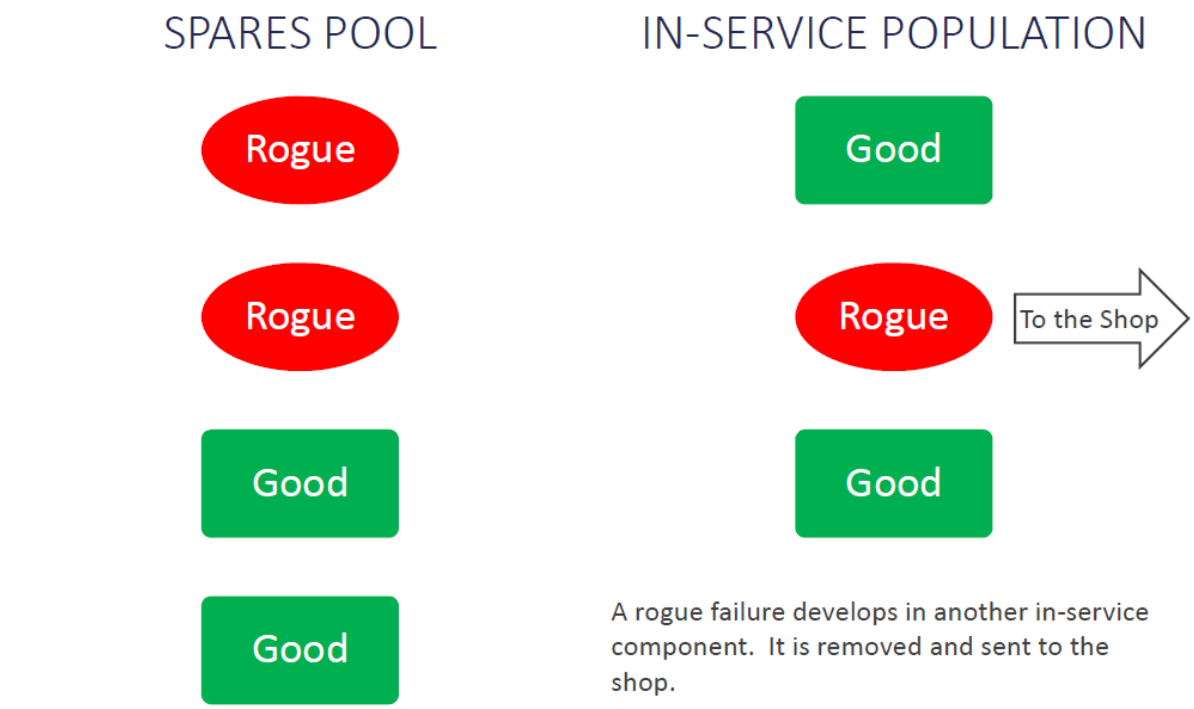
A rogue failure develops in another in-service component. It is removed and sent to the shop.

The Displacement Process

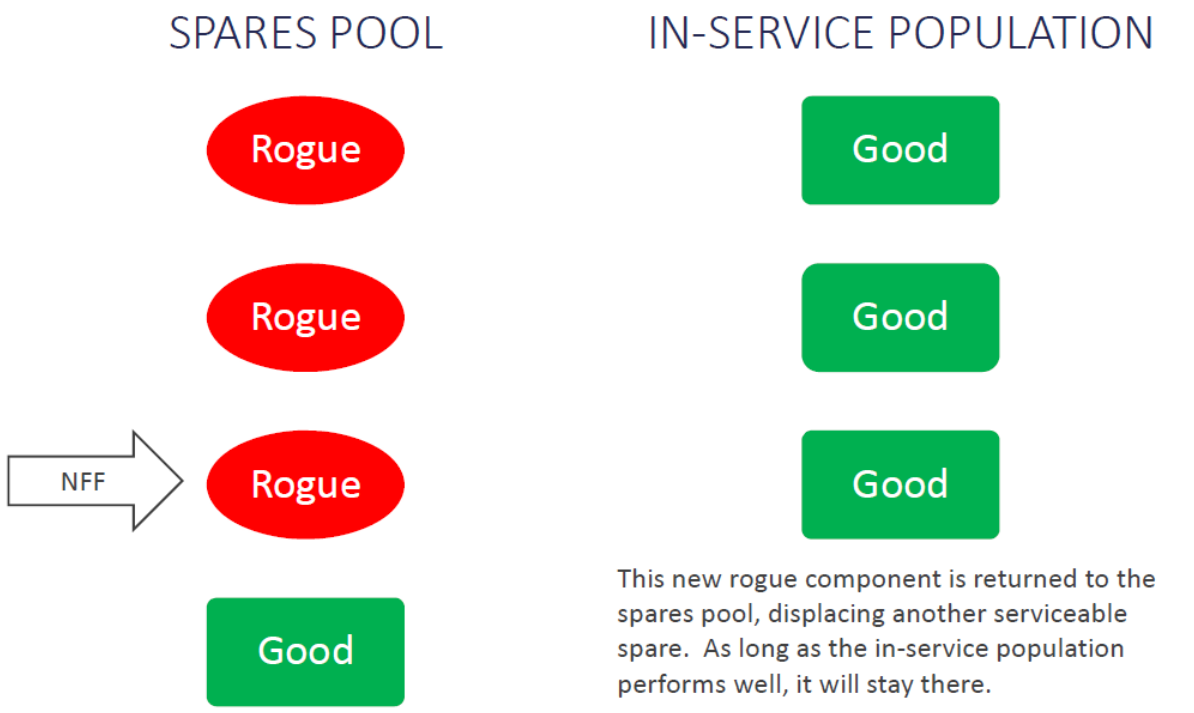


The new rogue component is returned to the spares pool, displacing another serviceable spare. As long as the in-service population performs well, it will stay there.

The Displacement Process



The Displacement Process



Rogue component 會造成全面性的影響，包括：

- 營運可靠度 (Operational Reliability)
  - 營運限制 (Increased operational restrictions, ex. MEL)
  - 延誤及取消航班 (Increased delays and cancellations)
  - 飛渡 (Increased maintenance ferry flights)
  - 監管審查 (Regulatory scrutiny)

- 維修 (Maintenance)
  - 屢修不好情形 (Persistent chronic system faults)

Typical Chronic System Fault

Date	System Fault	Maintenance Action
May 5	"Cabin Alt Auto 2" Message.	BITE check shows no faults. Replaced #2 Cabin Pressure Controller
May 6	"Cabin Alt Auto 2" Message.	BITE check shows no faults on #2 controller. Replaced #2 Cabin Pressure Controller
May 9	"Cabin Alt Auto 2" Message.	Operational check normal per FIM.
May 9	"Cabin Alt Auto 2" Message. Pressurization normal after message displayed	Found controller fault. Replaced #2 Cabin Pressure Controller.
May 17		Swapped #1 & #2 Cabin Pressure Controllers for evaluation per Tech Services request.
May 17	"Cabin Alt Auto 1" Message. Pressurization normal after message displayed	BITE checks normally.
May 22		Replaced #1 Cabin Pressure Controller per Tech Services request.
NO FURTHER COMPLAINTS AS OF JULY 2		

  - 低信心度 (Low confidence in replaced components)
  - 故障排除困難 (Inability to progress in troubleshooting)
  - 故障訊息增加 (Additional fault indication)
  - 監管審查 (Regulatory scrutiny)

- 維護支援 (Maintenance Support)
  - 維護工時成本 (Excessive man-hour expenditures)
  - 維護空間 (Hangar space requirements)
  - 運送成本 (Additional spare shipments)
  - 組件庫存量 (Low spare availability)

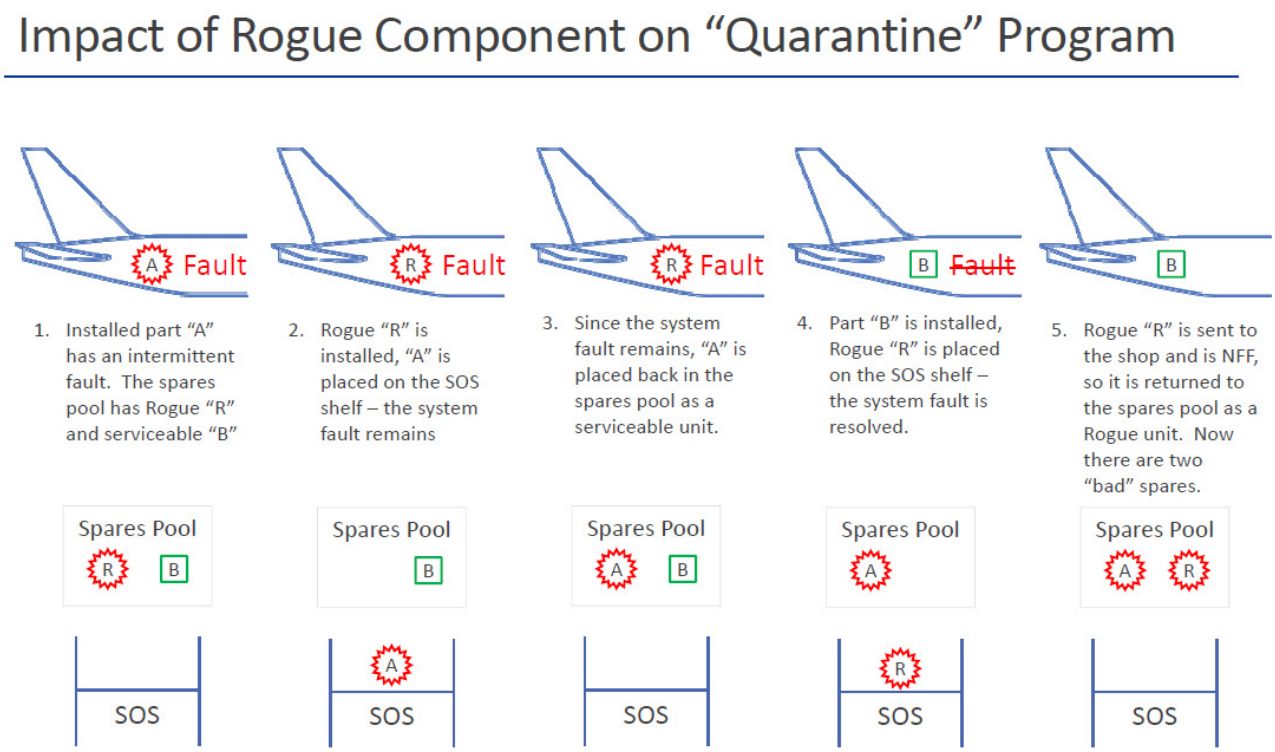
- 維修設施 (Repair Facility)
  - 低使用率 (Low MTBUR)
  - 找不到故障原因 (High NFF, No fault found, Incidence)
  - 召回 (High Volume of Returns)
  - 維護空間及人員 (More Work Stations / Personnel Required)
  - 交運時間 (Long Lead Times)
  - 庫存需求量增加 (Greater Demand for Spares)

- 飛機系統 (Aircraft Systems)
  - 高更換率 (High replacement activity)
  - 額外應力 (Hardware stressed beyond normal)

- 工程師工作負擔 (Operator, component and aircraft OEM Engineering)
  - 改裝計畫無效 (Ineffective modification programs)
  - 升級更換無效 (Needless upgrade replacements)
  - 改裝計畫造成可靠度反效果之錯覺 (Perception that modification program had adverse effect on reliability)

- 組件庫存 (Component Spares)
  - 高更換率 (Sporadically high usage)
  - 定期庫存量增加 (Periodic level increases)
  - 高峰庫存量異常 (Abnormally high levels)
  - 庫存汙染 (Spares pool pollution)

- 隔離計畫 (Quarantine Program)
  - 運送或上架 (Ship Or Shelve)
  - 節省庫存 (Save Our Stock)



- 維護計畫 (Maintenance Programs)
  - 縮短維護時距 (Shortened interval checks / replacements)
  - 額外維護/更換需求 (Additional interval checks / replacements)

- 訓練計畫 (Training Programs)
  - 複訓 (Recurrent training requirements)
  - 額外訓練 (Additional training programs)

- 組件 (Components Themselves)
  - 遺失 (Loss)
  - 運送損傷 (Shipping Damage)
  - 移除及安裝損傷 (Installation and Removal Damage)

- 民航主管機關 (Regulatory Agency)
  - 監管難度 (Accurate assessment of Operational and Maintenance Difficulties)
  - 適航指令 (Airworthiness Directives)

因 Rogue component 而增加的財務成本包括:

- 航空器使用人 (Operator)
  - 組件更換成本 (Installation and Removal of Rogue and Associated System Components)
  - 運送及處理成本 (Shipping and Handling of Components)
  - 估價成本 (NFF Charges)
  - 維修工時程本 (Excessive Man Hour Expenditures)
  - 營運衝擊 (Operation Impacts)

- 修理廠 (Repair Facility)
  - 交貨期 (Lead Time Excursions)
  - 及時供貨計畫失敗 "Just In Time" Parts Programs Failures
  - 損失維修合約 (Loss of Contract)
  - 聲譽 (Reputation)

- 組件/飛機製造廠 (Component / Airframe OEM)
  - 改裝及升級工程師 (Modification and Upgrade Engineering)
  - 改裝及升級驗證 (Modification and Upgrade Certification)
  - 及時到貨計畫失敗 "Just In Time" Parts Program Failure
  - 共用零件 (Spares Pooling)
  - 聲譽 (Reputation)

對航空器使用人而言，1995 年的研究顯示，單一 rogue component 平均單次更換成本為 2,400 美金 (Average Component Removal/Installation Cost, 1995 Study for Tracked Rotables including)

- Mechanics
- Stock Clerk
- Engine Run
- APU Run
- Stock Transportation
- Aircraft System Wear
- GSE Support
- Component/Aircraft Paperwork Processing
- Mainframe Processing (ordering, issuing, shipping, tracking)

Average Total Costs = $2,400 each removal/installation

而 1995 年的研究亦顯示，單一 rogue component 產生的額外總成本為 50,000 美金
(Typical Financial Impact of each Rogue Unit Life Cycle **Note1**, 1995 Study)

- 6 Rogue Unit Removals/Installations (6 x $2,400 per occurrence) $14,400
- 6 No Fault Found Charges (6 x $1,000 industry average) $6,000
- 4 Extended Troubleshooting Periods (4 x $50 x 6 hours x 2 men) $2,400
- 8 Associated Components Replaced (8 x $2,400 per occurrence) $19,200
- 8 No Fault Found Charges (8 x $1,000 industry average) $8,000

Total Typical Financial Impact $50,000

Note1 Does not include operational delays, cancellations, or flight restriction costs

因 rogue component 造成的影響及財務成本，航空器使用人、維修廠及組件/飛機製造廠需共同合作解決此一議題。

3. 統計分析工具 (Tableau)

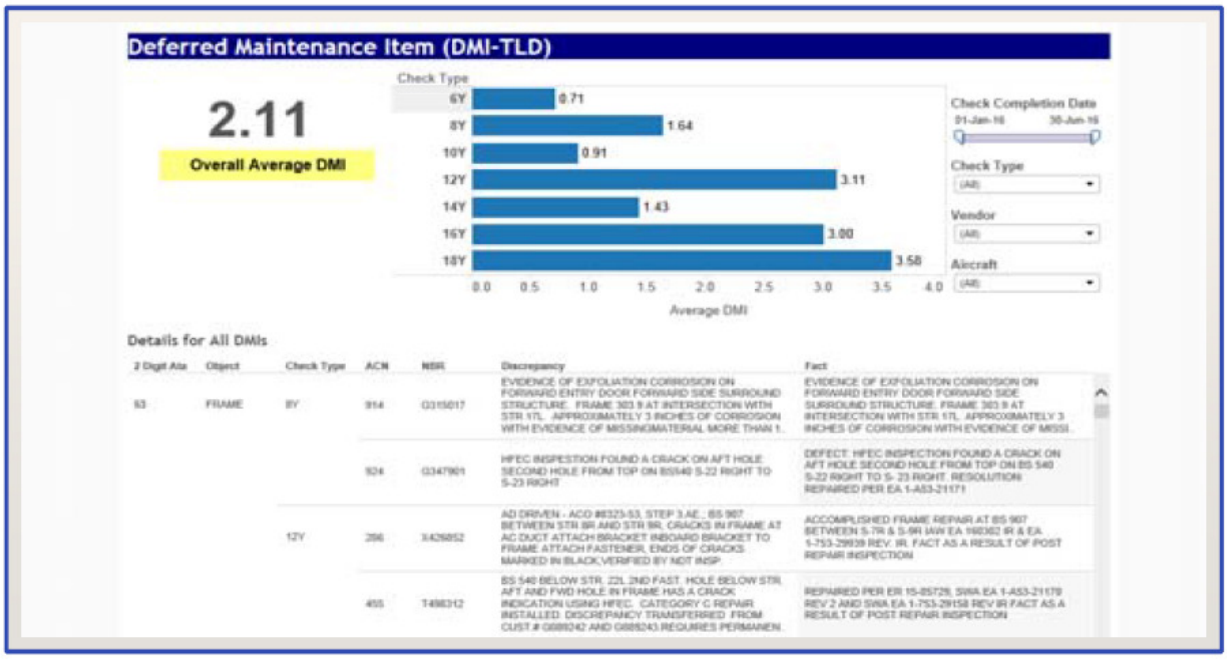
研討會中，波音公司認為新一代的統計分析軟體 (Tableau) 有助於航空公司分析所收集之維修資料，以即時及視覺化方式呈現維修相關趨勢，並幫助管理層迅速作出決策。

可靠度分析及提升作業，係透過對飛機及組件維修資料的收集、加工和管理，形成多面向的資料庫，經由查詢、分析處理和資料採擷工具，把複雜的維修資料轉化成容易理解的資訊，並將正確的資訊以有效的方式分配給使用者，目的是使航空公司的各級決策者獲得正確的資訊，促使他們更快做出對可靠度有利的決策，幫助提升飛機派遣率，並降低營運成本。然而，傳統的工具受限於不盡友善的介面、資料庫須事先加工、無法及時反應、可用圖表種類不足..等因素，致使可靠度改善空間及效率亦隨之受限。

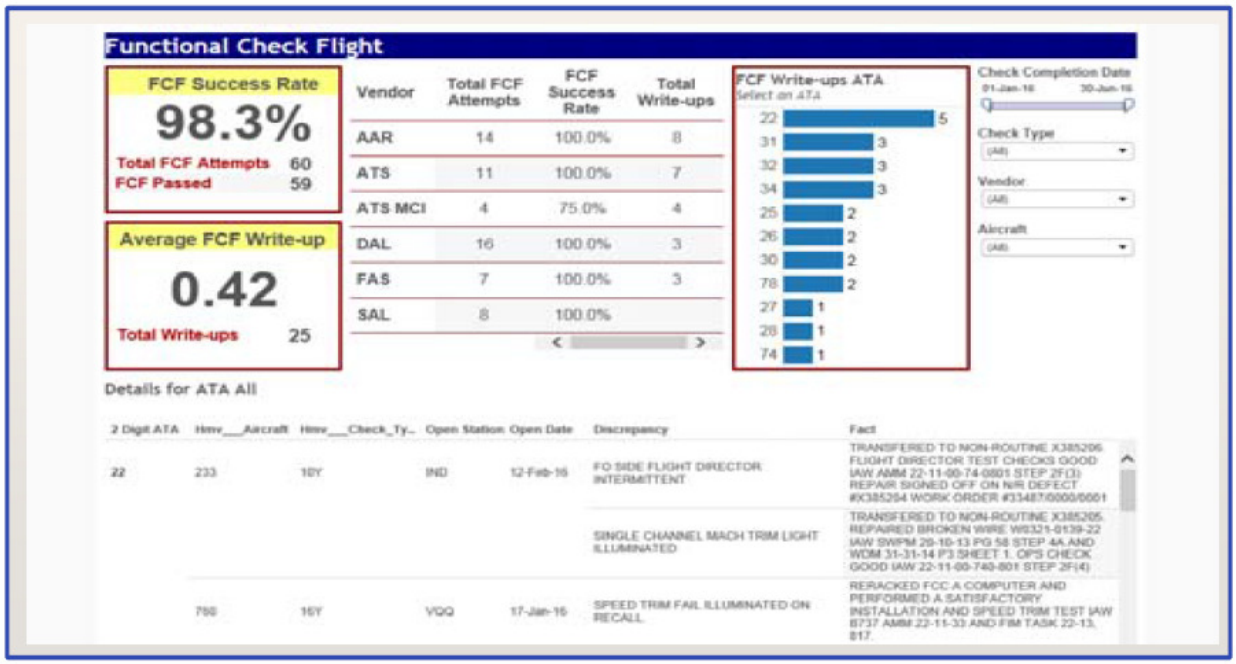
Tableau 的特色包含視覺化分析 (豐富易懂的圖表)、易學易用 (直觀拖拉、互動式動態資料)、彈性快速，相容於行動裝置等。有別於傳統商業資料庫系統之大型繁複、耗時且需專業 IT 才能建置，Tableau 以簡單有效及視覺化互動操作方式、直接讓航空公司內擁有資料的使用者或分析團隊使用，快速以不同角度分析、用內建圖型 (best practice) 製作專業圖報表，快速完成各種可靠度變化所需之分析，轉化數據為資訊，使管理階級得以迅速掌握關鍵數據、降低風險，並發揮最大效益。

於研討會中，外籍航空業分享其使用 Tableau 視覺化圖表範例如下:

DMI-TLD Report



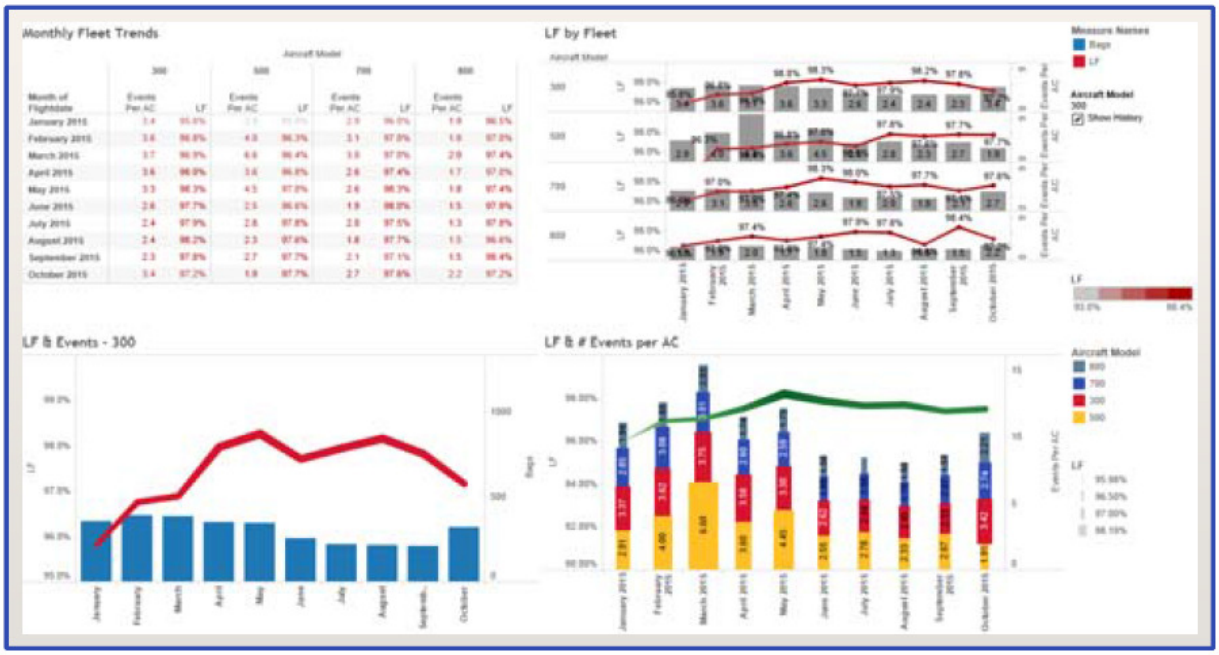
Functional Check Flight Results



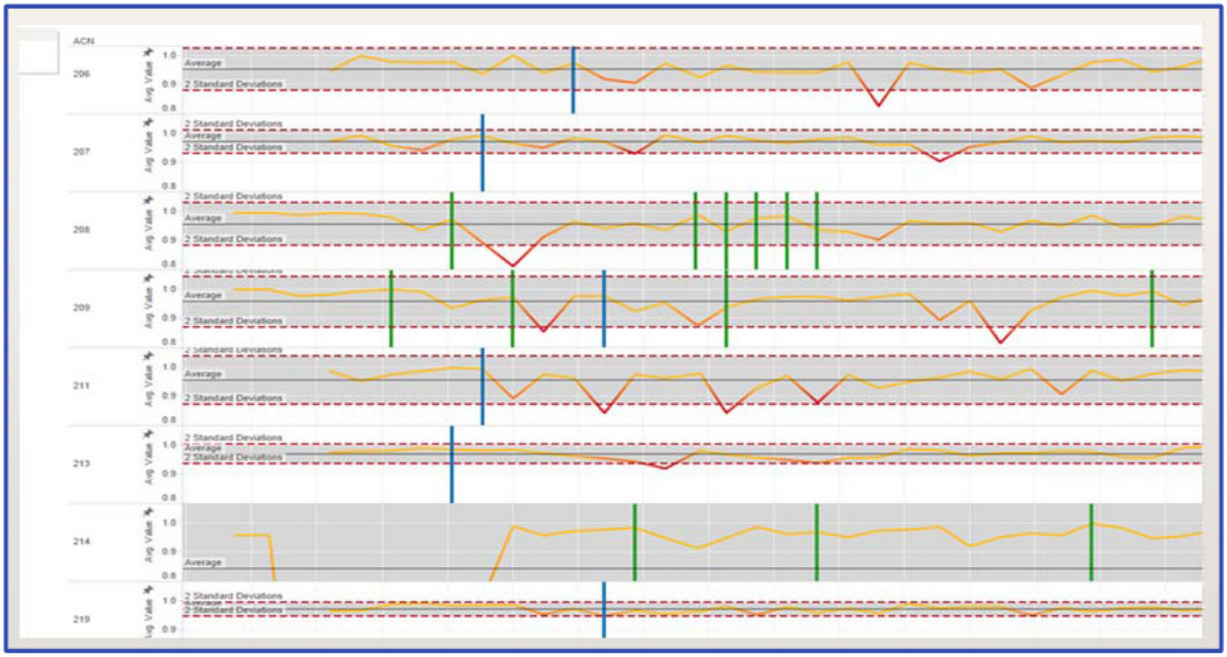
Coastal Routing vs. Aircraft Corrosion

Tracking Level 1 Repair Orders

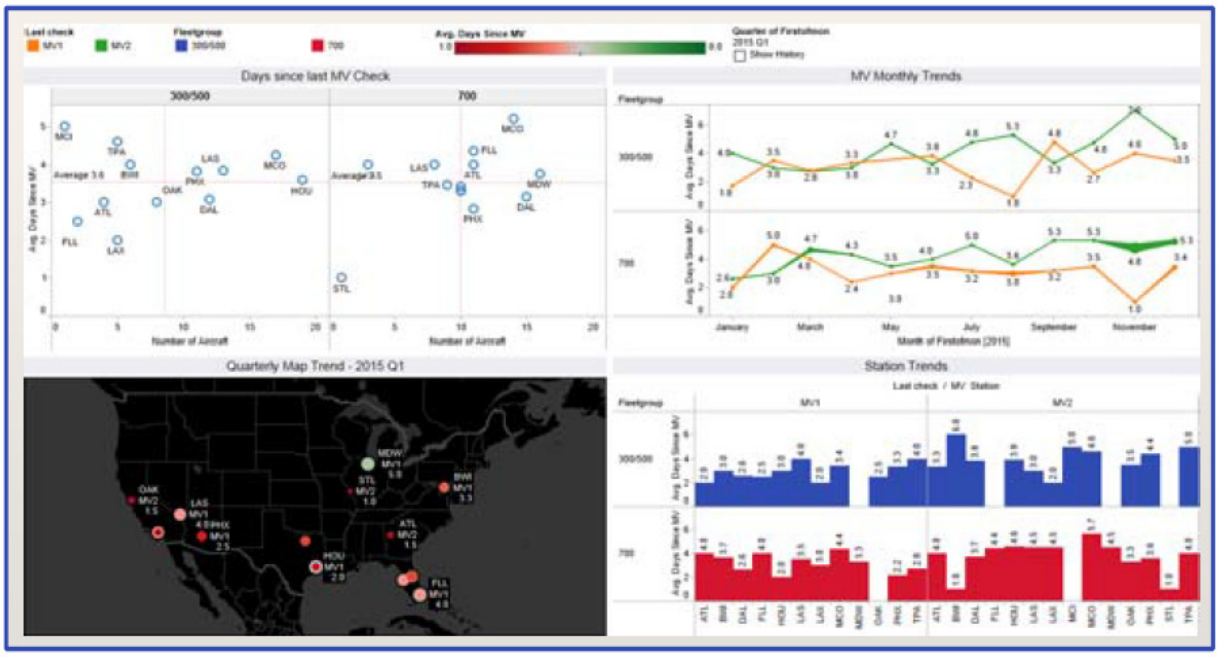
LF by Fleet Type vs. Baggage



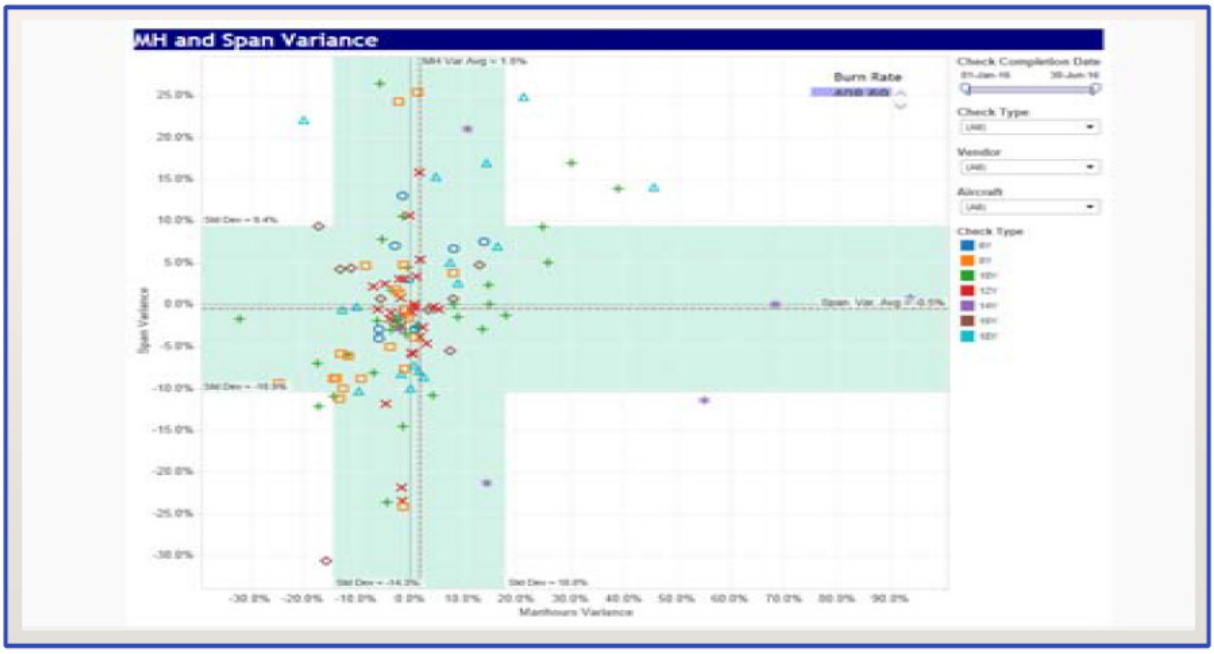
ACARS Performance

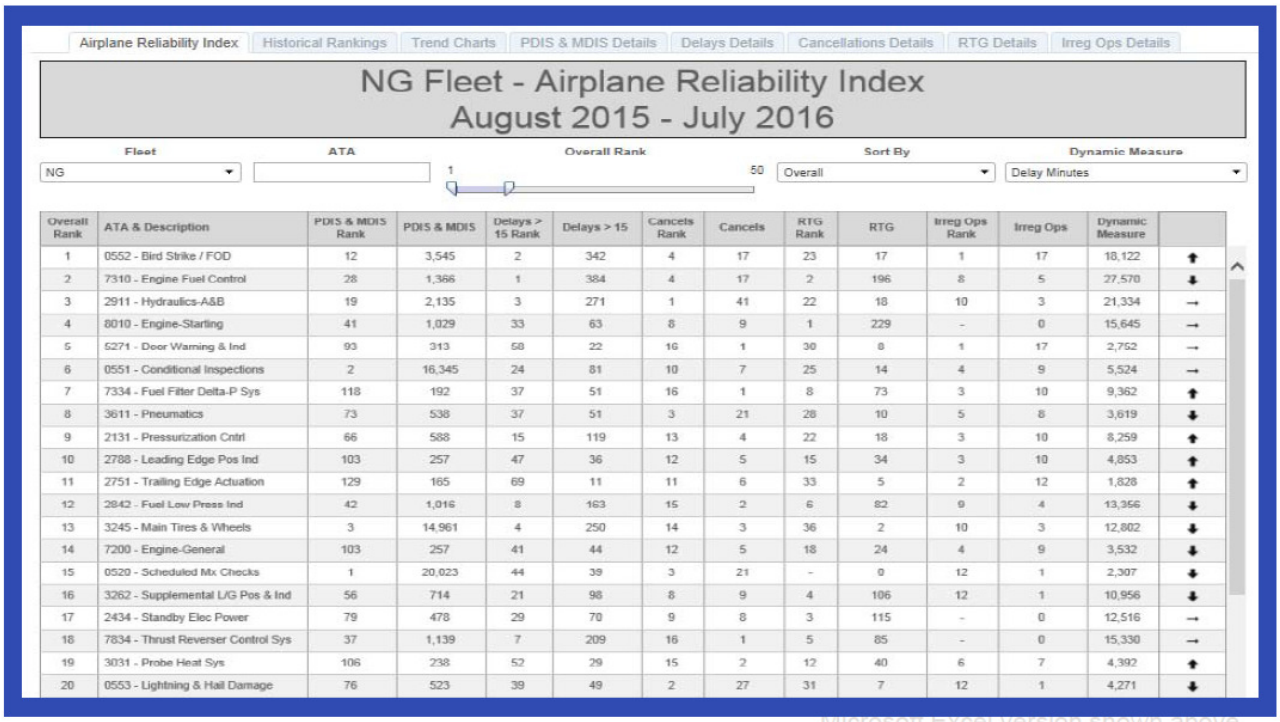


Aircraft Brake Wear Analysis



Heavy Check MH and Span Variance





Airplane Reliability Index | Historical Rankings | Trend Charts | PDIS & MDIS Details | Delays Details | Cancellations Details | RTG Details | Irreg Ops Details

NG Fleet - Airplane Reliability Index
August 2015 - July 2016

Fleet: NG | ATA | Overall Rank: 1 – 50 | Sort By: Overall | Dynamic Measure: Delay Minutes

Overall Rank	ATA & Description	PDIS & MDIS Rank	PDIS & MDIS	Delays > 15 Rank	Delays > 15	Cancels Rank	Cancels	RTG Rank	RTG	Irreg Ops Rank	Irreg Ops	Dynamic Measure	
1	0552 - Bird Strike / FOD	12	3,545	2	342	4	17	23	17	1	17	18,122	↑
2	7310 - Engine Fuel Control	28	1,366	1	384	4	17	2	196	8	5	27,570	↓
3	2911 - Hydraulics-A&B	19	2,135	3	271	1	41	22	18	10	3	21,334	→
4	8010 - Engine-Starting	41	1,029	33	63	8	9	1	229	-	0	15,645	→
5	5271 - Door Warning & Ind	93	313	58	22	16	1	30	8	1	17	2,752	→
6	0551 - Conditional Inspections	2	16,345	24	81	10	7	25	14	4	9	5,524	→
7	7334 - Fuel Filter Delta-P Sys	118	192	37	51	16	1	8	73	3	10	9,362	↑
8	3611 - Pneumatics	73	538	37	51	3	21	28	10	5	8	3,619	↓
9	2131 - Pressurization Cntrl	66	588	15	119	13	4	22	18	3	10	8,259	↑
10	2788 - Leading Edge Pos Ind	103	257	47	36	12	5	15	34	3	10	4,853	↑
11	2751 - Trailing Edge Actuation	129	165	69	11	11	6	33	5	2	12	1,828	↑
12	2842 - Fuel Low Press Ind	42	1,016	8	163	15	2	6	82	9	4	13,356	↓
13	3245 - Main Tires & Wheels	3	14,961	4	250	14	3	36	2	10	3	12,802	↓
14	7200 - Engine-General	103	257	41	44	12	5	18	24	4	9	3,532	↓
15	0520 - Scheduled Mx Checks	1	20,023	44	39	3	21	-	0	12	1	2,307	↓
16	3262 - Supplemental L/G Pos & Ind	56	714	21	98	8	9	4	106	12	1	10,956	↓
17	2434 - Standby Elec Power	79	478	29	70	9	8	3	115	-	0	12,516	→
18	7834 - Thrust Reverser Control Sys	37	1,139	7	209	16	1	5	85	-	0	15,330	→
19	3031 - Probe Heat Sys	106	238	52	29	15	2	12	40	6	7	4,392	↑
20	0553 - Lightning & Hail Damage	76	523	39	49	2	27	31	7	12	1	4,271	↓

Microsoft Excel version shown above

肆、建議事項:

自 1970’年代起，航空業開始以可靠度方式提升維護計畫有效性及飛機派遣率，並降低維修成本。在執行可靠度計畫的過程中，各家公司對於所面臨的問題，持續不斷地提出解決方案，並改良作業流程。透過研討，與會者得以了解並互相學習最新的執行方式 (例如使用更快速便捷的軟體)，及他國可靠度計畫執行情形，進而提昇可靠度計畫之有效性。

為提昇國籍航空公司可靠度作業有效性，建議持續派員參加此類研討會，以了解國際發展趨勢，並經由與他國航空業與民航主管機關的意見交流，作為本局對國籍航空公司維護計畫監理檢查作業之參考。

伍、附錄: 無