



1st Annual Symposium on Tackling '*No Fault Found*' in Maintenance Engineering

18th March 2013



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IET Manufacturing TPN and AAD KTN

Contents

4 About the Symposium

6 Keynote Presentations

15 Open Forum

16 Key Research Themes

18 Outlook

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*“It has become harder and harder
to find the problem in the depth
domain over the years...”*
Wg Cdr Fergus Hawkins

About the No Fault Found Symposium

The symposium aims to become the first port of call for discussing NFF and grow to become a knowledge hub for NFF solutions. It brings together practitioners from across various industrial domains to share their experiences, best practices and ideas for future solutions in order to address the problem of NFF.

The Benefits of Participating:

- An in-depth view of common NFF issues including introduction, management and technical solutions
- Presentations and discussions around the cost and impact on resources
- Analysis of false removals through knowledge sharing
- The importance of establishing cross disciplinary approaches
- Technological advancements in maintenance activities

‘A Problem of Scale and Scope’

Understanding system reliability from technical and non-technical perspectives has become the focal point in research when considering faults which cannot be correctly diagnosed or even detected under standard maintenance testing. This is commonly termed ‘No Fault Found’ (NFF) amongst a multitude of other similar terms (such as Fault Not Found (FNF) Retest Okay (RTOK) or Cannot Duplicate (CND) to name a few.

The issue exists across several industries, organisations and even individual maintenance lines, which often struggle to address the root causes that range from simple faults in electronics, to the way in which the organisational structure is setup or the way equipment is designed. Even though there may be good individual practices for mitigating the consequence of NFF, such practices are rarely being shared. One universal solution is unlikely, but what has not worked in one industry may be just what another industry needs.

The EPSRC TES Centre's NFF Research Group



145 Delegates attended
the Symposium



Organisations
represented **60**



“There is a **too much** focus on testing – this has its place but we need to get back to basics and go straight back to the equipment design”

Angus Murray
BAE Systems

Keynote presentations

The first keynote speaker of the day was Angus Murray, a reliability specialist in the Military Air & Information business at BAE Systems. He set the scene for the day by highlighting the extent and potential cost of the problem from a platform integrators point of view.

Mr Murray began by explaining how the NFF phenomena effects the customer through increased maintenance burdens, pressure on the supply chain and the reductions in aircraft fleet availability. He went on to then expand this to the impact on design and manufacturing. There was a strong focus on the need to engage with the equipment suppliers and address necessary design changes.

The second part of the keynote looked at some of the perceived causes of NFF within avionics focusing on environmental factors (humidity, temperature, vibration), intermittence within EWIS, protection of equipment during storage as well as the less recognised factors of tin whiskers arising from lead free solder and atmospheric neutron radiation.

Angus summarized his ideas by commenting that:

- This is not a new problem but is still largely unsolved!
- Annual costs are still in the millions of pounds
- Causes are a mix of environmental, cultural & technical

Solutions will always reside in maintenance data, design, manufacturing, testing, organisational imperatives & operator policies.



Keynote presentations

Wg Cdr Hawkins brought his experience as an RAF officer to provide a view of NFF from the MOD Air Community. The keynote provided conclusions on the extent of the NFF problem across multiple air frames derived from recent analysis of LITS and GOLDesp data.

One of the interesting facts pointed out was that despite the phenomena being widely recognised for decades, the NFF rate at the front line environment, tends to be consistent across all platforms through the years. This was in contrast to the rotary fleets situation in the depth maintenance, where the situation has begun deteriorating rapidly over the past 5 years.

Some of the key observations from the data sets include:

- The problem affects all aircraft types, to roughly the same order of magnitude
- 25% of fixed wing NFFs were generated in the 'depth' environment
- Combined total of 17016 NFF arising in 2012
- 3-fold increase in rotary wing depth NFFs over 5 years
- Limited data set indicates a 2:1 ratio for electrical vs mechanical NFFs

After some 'fun with numbers', Wg Cdr Hawkins remarked that other than focusing on the maintenance aspects of NFF, it is just as important to get down to the business unit level, a view echoed across many of the delegates present. The question was posed on *"What is the situation for each platform in its usage context and support environment and what intervention strategies might be appropriate?"*



"Apache seems to indicate a 55:45 electrical/mechanical NFF split... so we cannot discount the mechanical environment in the NFF domain"

Wing Commander Fergus Hawkins Log Network-Enabled Capability Programme, de&s

For example within the defence community we need to consider:

- Supply lines & levels
- Fleet sizes
- OSDs (e.g. Tornado , Sentinel)
- On site capability (e.g. Ships)
- Value of availability

The keynote concluded with a look at this business environment again emphasising the need to identify the different 'aggravators' for differing fleets, in order to address commercial contractual boundaries, establishing a full cost appreciation and establishing realized benefits through ROI planning horizons for NFF solutions.

Possible Next Steps...

- Acquire more data in promising areas:
 - Look for the low-hanging fruit
 - Look for the rogue LRUs that can be removed from the population
 - Could consider increasing fidelity of data capture, to board level?
- Is the maintenance construct still right ?
 - Greater test & diagnosis capability at MOB's ?
 - Better test sets in the right place with trained technicians
- Developing the 'capability' in people & process & technology



Keynote presentations

The Industry norm for aircraft avionics repair success is less than **60%**

Giles Huby
Copernicus Technology Ltd

Mr Giles Huby, the managing director of Copernicus Technology Ltd, which delivers through-life services to defeat NFF, focused his presentation on demonstrating the proven benefits of data exploitation solutions to NFF across the entire repair chain; and of testing solutions for one of the major root causes of NFF – intermittency. One of the main focus points was the need to begin looking past functional testing only and begin implementing testing for system integrity.

System Integrity degrades in vulnerable points of a system: interconnects in wiring, components and PCBs. These problems also occur during assembly of new-build equipment or equipment undergoing maintenance/upgrades and causes intermittency

It was demonstrated how conventional testing fails to adequately detect and localise intermittent faults, resulting in speculative removals and hence unnecessary maintenance – the solution is to apply full testing to all test points simultaneously and continuously.

Mr Huby provided case studies to illustrate his recommendations for data-driven and targeted use of Intermittent Fault Detection Equipment (IFD) as being fundamental to rapidly finding fault root causes.

How much does NFF cost?

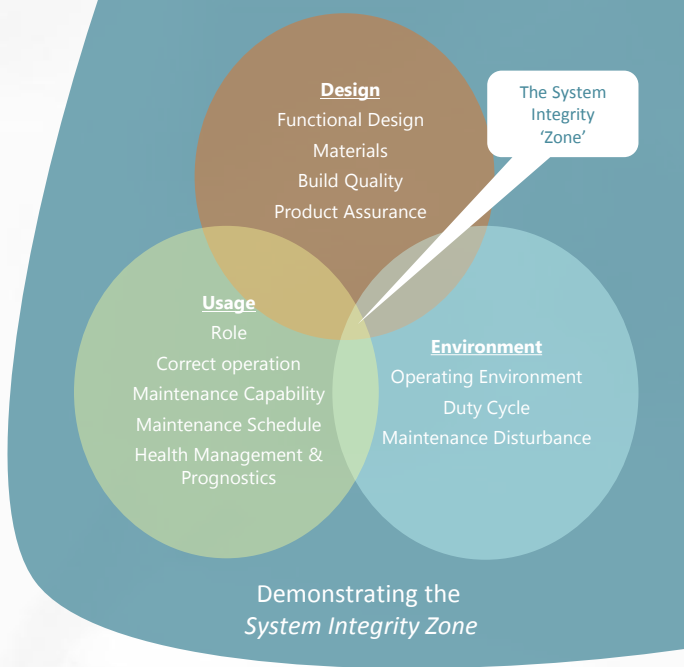
In 1997, IATA estimated NFF costs for commercial aircraft at \$100k per aircraft per year (equivalent to \$185k in 2013). However, using the same \$100k estimate still equates to a global bill of \$1.5 Bn per

year, growing to \$2.8Bn per year by 2025. In the US DOD the NFF cost is over \$2Bn per Year. In the UK MOD – NFF cost figures are not formally collated, but are predicted to be at least tens if not hundreds of million per year.

Recommended NFF Solutions Strategy

- Use Data Exploitation and Symptom Diagnostics to:
 - Identify where to prioritise effort
 - Inform Fault Diagnosis decision-making and training
 - Stop speculative changes of prioritised LRUs
- Apply targeted use of IFD testing to rapidly find fault root causes in wiring, EWIS, components and LRUs.

NFF on-aircraft



A fault occurs in the electronics or wiring



The pilot observes a symptom



Technicians can't reproduce the symptom or find the fault

Repair?
Speculative LRU change? NFF?



- Successful Repairs
- Functional Test Only, but fault returns
- Speculative Replacement, but fault returns



“As always... airlines want more for less!”



Andy Johnson
Flybe

Keynote presentations

Over the last 9 years Flybe have been driven to continually improve performance. The Airline Industry have pushed and continue to push for the delivery of more reliable aircraft whilst offering less time for maintenance – this brings into the frame the impact of operational pressure on NFF rates.

Flybe already have excellent aircraft reliability, with a figure of 97.99% in November 2012 for their Turbo Prop Q400 fleet. If the NFF problem could be removed, for very little time, effort or cost, this figure could be increased by 0.21% having a strong positive financial impact on the airline. Mr Johnson emphasised that in his opinion the main NFF issues can all be traced back to poor component or aircraft system design coupled with weak functional tests.

A key example is the De-ice system used on many Turbo Prop aircraft. These systems are designed to operate in wet and icy conditions yet often fail to do so. Once the aircraft is on the ground there is no test available to replicate the environmental conditions, the result – a delayed aircraft and yet another NFF.



From the perspective Mr Johnson the main areas which should be focused on to reduce NFF are:

- Improving system/component design
- Improving repeatable defect reporting
- Working with spares providers to identify “rogue” parts
- Work with overhaul/test providers to provide feedback and improve quality of tests

Key NFF points

- Total number of scheduled and unscheduled removals between July 2012 & September 2012 is 761
- 143 of these removals classed as NFF
- Total number of NFF represents 19% of all removals

Keynote presentations



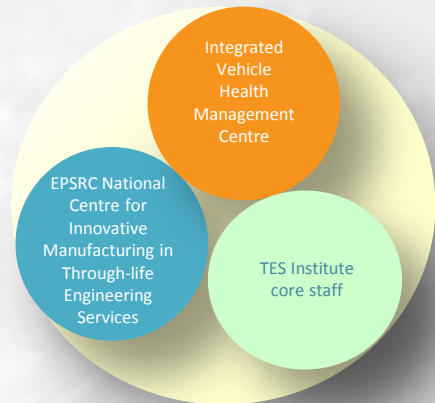
Prof Andrew Starr
Cranfield University

Professor Andrew Starr is the head of the Through-life Engineering Services Institute at Cranfield University. He Presented some of the future challenges in Integrated Through-life Support for high-value systems and set out the work plans for the latest maintenance related research project being run at Cranfield – AUTONOM.

As part of the Autonomous and Intelligent Systems Programme the aim of this research is to integrate:

- Data fusion and mobile platforms
- Planning and scheduling
- Cost analysis

The wider context of the research has direct relevance to NFF solutions with the research identifying requirements for interchange of maintenance data between fixed and mobile actors, automation of monitoring on mobile platforms, and interface with other actors, new cost modelling tools for complex distributed health monitoring, and value to the business.



Keynote presentations



“The ‘real world’ experience must be blended with the other diagnostic and prognostic tools and techniques”

Phil D'Eon
CaseBank Technologies

Phil D'Eon is the co-founder and Chief Technology Officer of CaseBank Technologies. His keynote presentation looked at the role and value of field experience in reducing NFFs, and described a practical means to both deploy field experience, and to capture it for feedback to design engineering.

Technicians around the world are discovering novel causes of failures on a daily basis. That “field experience” needs to be shared by inserting it directly into the troubleshooting workflow so that others will identify the cause of that problem on their first attempt, whenever or wherever it next occurs. Furthermore, that field experience can assist design engineers in improving the reliability of the equipment. At the core of the challenge to better troubleshooting is the difference between ‘anticipated failures’ and the ‘real failures’ that appear in service.

When complex equipment or systems are designed, engineers typically identify the potential failure modes and their effects on the system using a “Failure Modes and Effects Analysis” or “FMEA”. When the equipment enters service, as the “real world” imposes itself - some faults that were anticipated actually happen, and some will never happen.

The FMEA will never be truly accurate. But it can determine how best to :

- Employ On-Board Diagnostic (Built-In Test) technologies to detect failures.
- Implement Prognostics and Health Monitoring (PHM) strategies, including Trend Monitoring, to detect potential failures (impending functional failures).
- Prepare troubleshooting procedures, in advance, for analysing the functionality of the system. This can help differentiate among the many possible root causes of anticipated failures.

Collective Experience

- One technician – random experience
- ALL technicians – TOTAL BODY of experience
- Must become part of the troubleshooting process

A fraction of the theoretically possible failure modes will make an appearance – and it is those that we are most interested in. The weaknesses in a piece of equipment will become known during the operation of the equipment in service. Things that fail on one aircraft are more likely to fail on another aircraft of the same design, operated in similar conditions.

But most importantly, many real-world faults were not anticipated by the design engineers, and therefore the traditional diagnostic systems do not resolve them. In those cases, human ingenuity resolves the problem – but where does that knowledge reside after its creation?

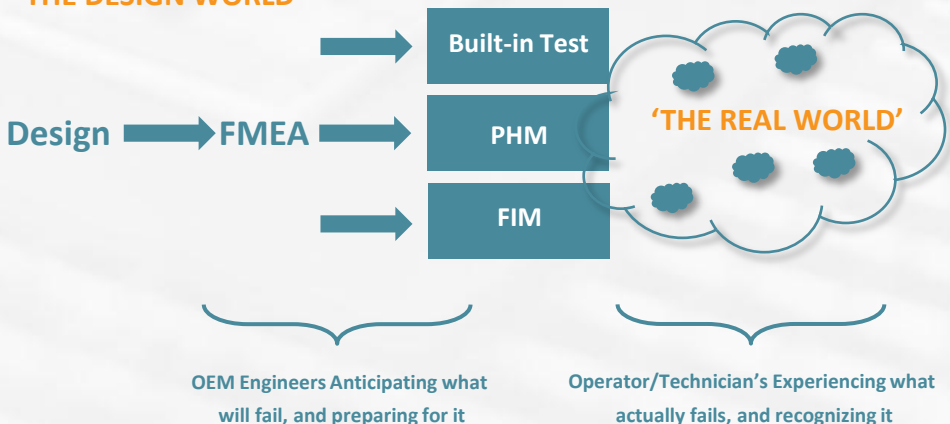
This “real world” experience must be blended with the other diagnostic and prognostic tools and techniques.

What are the Challenges?

- To store experience-based knowledge, and deliver it at the time and place when problem symptoms occur, so that these can be re-used to help resolve the problem on the first attempt
- To deliver knowledge in a form that is useful to experts and less-experienced technicians alike
- To share knowledge so that everyone benefits from the experience of others
- To integrate the knowledge access with the existing troubleshooting tools so that it becomes part of the usual troubleshooting workflow

Demonstrating Troubleshooting: Anticipated vs Actual Faults

‘THE DESIGN WORLD’





Joanne Lewis
Bombardier Transportation

53%

of existing failures have diagnostic or prognostic potential”

Keynote presentations

Dr Lewis, representing Bombardier Transportation brought her 15 years of experience in Product Safety and Reliability Management, and presented a new perspective to the day by looking at dealing with NFF in reliability growth for modern rolling stock. Historically when trains first enter passenger service they are not considered to be highly reliable. New technology & novel designs which when coupled with an aggressive operating environment will lead to a variety of unpredicted failure modes, not captured in the original FMECA.

She focused her keynote on the need to implement the tools and techniques required to predict these failures increasing the rate of reliability growth and hence reducing NFF. The keynote was concluded with a short video demonstrating how Bombardier Transportation implemented a proactive approach in order to achieve success in delivering a quality, reliable service during the London 2012 Olympic Games. The challenge is for other industries to bring similar success stories to next year's symposium.

How Bombardier Investigate NFF

- Challenge NFF reports with more depot detail relating to the failure
- Get the supplier to the depot to experience the fault first hand
- Visit the supplier to check how they test the vehicle - is it representative?
- Quarantine the part if the depot has doubts and try on another vehicle/unit before returning to supplier
- Introduce additional testing of the part before sending to the supplier e.g. test rig at depot
- Agree a 'joint investigation' after 3 NFF failures

Open forum

At the end of the Keynote presentations an open discussion forum was held across the delegates.

Throughout the day the key themes which were identified as being the most influential contributors to the NFF problem and were posed to the audience for comment.

These included:

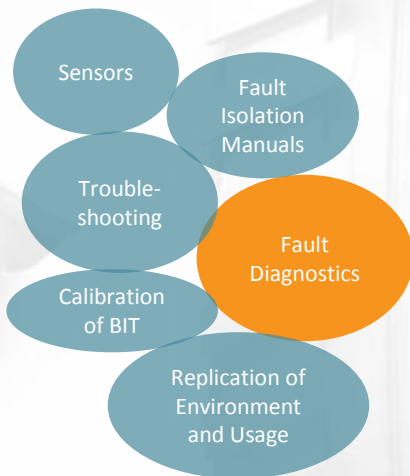
- Fault Diagnostics
- Human Factors
- Data Management
- System Design



Key messages for reduction of NFF:

- NFF is not a new problem, but all industries appear to still be roughly in the same place in their ability and willingness to tackle the problem
- The financial impact of NFF still needs to be pinned down. If savings in the millions of pounds per year can be made once the problem is solved, then why is this amount not invested up front in order to achieve these savings?
- To understand NFF we need to capture information on how close is the design to its true operating environment in order to improve the design of tests and diagnostics
- Engineers must strive to understand how the burden of NFF changes throughout the lifecycle of the product
- The 'blame culture' surrounding NFF hinders real progress towards a solution. The downstream effect throughout the supply chain needs investigating
- More work is required to understand the link between equipment design, faults, Diagnostics and NFF
- There is a need to improve data capture and knowledge transfer which extends past merely information on the failure mode, but also includes operating environment and usage
- Mechanisms for in-service feedback to designers and suppliers need to become more robust and better utilised

Key research themes

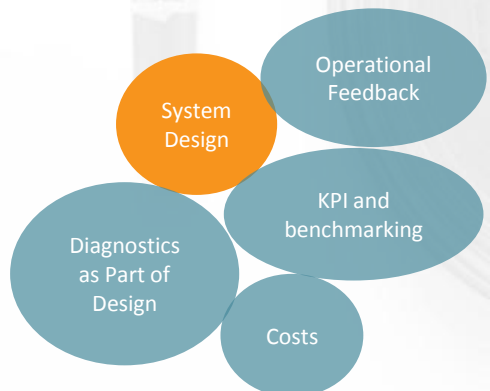


A major concern is the failure to successfully diagnose the problem that has led to the maintenance action resulting in NFF. Focused effort is required around understanding test coverage represented by BIT/BITE/ATE deficiencies, development of new maintenance troubleshooting tools, techniques and concepts as well as changes to management processes.

Accurate fault models, fault/event trees and system understanding, are paramount to recognising false BIT alarms caused by such things as a sensor – system synchronisation problems, or operation conditions, allowing the root causes of BIT deficiencies to be addressed. There is also a call for a shift towards an increased proactive approach to fault diagnostics and improving the communication mechanisms to share information and knowledge designers, manufacturers, service providers and equipment operators

During the day it was alluded that there must be a relationship connection between NFF levels and the type of equipment, complexity and equipment usage. There is however no current established relationship for this. It was proposed that by understanding equipment design and by tracking NFF occurrences, this may lead to electronic designs which are increasingly immune to NFF occurrences. It is also important to understand the dependency that NFF events have on repairable items, and how they may change throughout the operational lifecycle. Such questions which can be asked include:

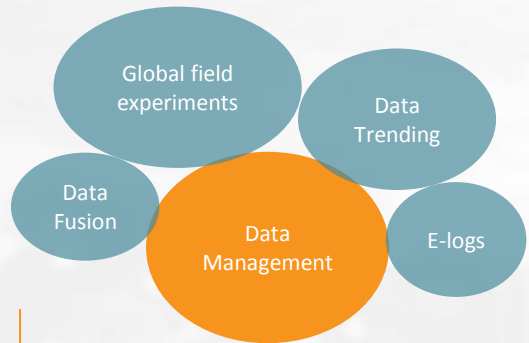
- Do NFF problems become more common after initial repair than after the original delivery?
- Does the number of repairs have any influence?
- Is there any impact of component modification?



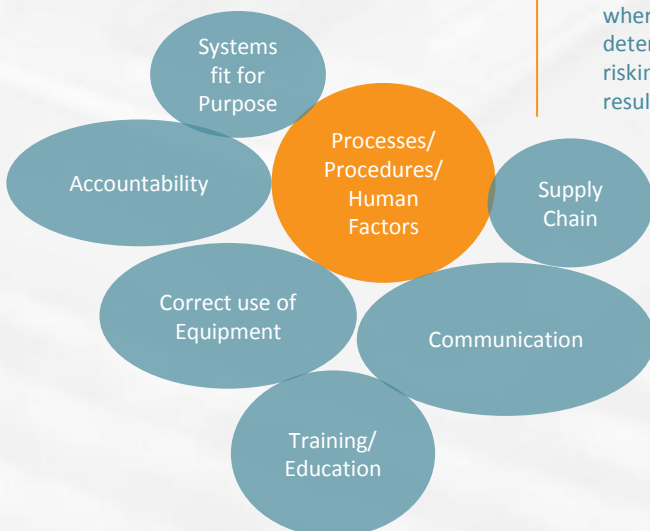
Key research themes

Throughout the day it began to become increasingly evident that there was a strong feeling that many of the quick wins in solving NFF could be gained not from directly technical means, but looking at the way the organisation itself operates.

These are defined as organisational factors that are business orientated and commercially driven. They have a strong influence over human and system interactions through predefined procedures.



In many cases the desired sources of information may not be readily available, incorrectly configured to support rapid diagnostics, or they are simply lacking in sufficient depth of information or practicality. The factors which can contribute to these include the failure to complete maintenance documentation, failure to store documentation in a user friendly manner and the lack of robust diagnostic fault trees connecting events-symptoms-faults. This results in the case where a unit is replaced without determining the nature of the fault – risking its reoccurrence - and hence resulting in a NFF event.





“Engineers can understand and explain the problem but commercial contracts need to be aligned to these”

Outlook

During the day all the keynote presentations and delegate inputs at the NFF Symposium clearly identify that establishing the scale of the NFF problem is widely recognised. Solution requirements across multiple industries including aerospace, automotive, rail and the energy sectors the root causes of the issues are almost identical. While there are solutions and best practice out there what became evident is that in some ways there is a reluctance to invest the necessary resources into the problem. Many of the barriers to this investment are identified as complex commercial contracts and a lack of a business case due to no standardised method or metric of costing the impact of NFF.


There is clearly two dimensions to be problem – improvement of NFF mitigation processes that are currently in place, and designing future systems with better maintainability. It was also pointed out that organisations can often be overly bureaucratic and cumbersome in their response to change, and may not even recognise that it has a problem.

There is a need for adequate data and evidence on the cost of NFF in order to justify significant investment. The costs, however, may not be so easy to establish, and there is the need to begin addressing commercial contracts and the downstream effects of NFF throughout the supply chain.

Within an industry and given the variety of NFF sources each key player – OEM’s maintenance suppliers and operators – all approach NFF differently. This could arise due to the nature of their self-interests and differing viewpoints, for example, do they take a company or a strategic view.

Each of these key players therefore tend not to be transparent in the approaches which they adopt and the transfer of knowledge and expertise in dealing with NFF; hence not adopted within the industry culture. Organisational culture may dictate that, taking a machine offline, or grounding an aircraft for a period of time, should take place at an appropriate time and for a period no longer than absolute necessary. As a result, the situation arises where internal pressure is placed upon the maintenance personnel to reduce their maintenance turnaround times. This leads to a culture where units are replaced rather than the ‘root cause’ of a failure being identified and fixed.

An industrial strategy which is currently being driven by the ADS MRO & Logistics NFF Working Group working with the EPSRC TES Centre to address the commercial barriers to NFF solutions. The challenge is for next years debate is for some of these burning issues to be answered so that the community can move forward in tackling NFF in maintenance engineering.



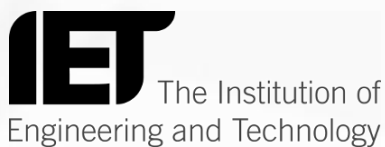
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