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COMPUTER-AIDED FAILURE ANALYSIS DURING PRODUCT DESIGN

KOMPUTEROWE WSPOMAGANIE ANALIZY WAD NA ETAPIE PROJEKTOWANIA WYROBU

A b s t r a c t

The paper describes computer support of failure analysis by failure detection method on the basis of product function (FFDM). The application of this method in the process of design allows the prediction of prospective product failures and elaboration of precautionary actions.
Failure analysis was carried out for the Bell 206 helicopter and supported by "FMEA Analysis" software available at the Institute of Applied Informatics, Cracow University of Technology. The obtained results were presented in a form of diagrams which allowed an easy way of a given function failure probability description. The results obtained were compared with the results described in literature [1].

Keywords: *failure analysis, Function–Failure Design Method (FFDM), computer-aided, EC matrix, CF matrix, EF matrix*

S t r e s z c z e n i e

W niniejszym artykule przedstawiono komputerowe wspomaganie analizy wad metodą wykrywania defektów na podstawie funkcji wyrobu (FFDM). Zastosowanie tej metody na etapie projektowania pozwala przewidzieć potencjalne wady wyrobu, dzięki czemu można podjąć odpowiednie środki zaradcze.
Analiza wad została przeprowadzona dla śmigłowca Bell 206 z zastosowaniem programu komputerowego „Analiza FMEA” dostępnego w Instytucie Informatyki Stosowanej Politechniki Krakowskiej. Otrzymane wyniki przedstawiono za pomocą wykresów. Pozwoliło to w łatwy sposób określić prawdopodobieństwo wystąpienia wady dla danej funkcji. Uzyskane z analizy wyniki porównano z przedstawionymi w pracy [1].

Słowa kluczowe: analiza wad, metoda FFDM, wsparcie komputerowe, macierz EC, macierz CF, macierz EF

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1. Introduction

Modern designing and product development is computer-aided. In the process of product design it is necessary to test its properties, usability and to evaluate its aesthetic value. For this purpose, apart from CAD programs, various analytic methods are applied and supported by proper software. One of such methods, which nowadays arouse much interest, is the product/process failure mode and effect analysis. To carry out the analysis, in the process of design another method called "Function–Failure Design Method" (FFDM) can be applied. Applying it, a designer can carry out other analyses of a product, describe its prospective defects and elaborate preventive measures. Failure mode and effect analysis should be supported by proper information technology tools, however, due to its being a novelty on the market, no such professional software is available. Research on this method supported by proper software is being done at the Institute of Applied Informatics, Cracow University of Technology. The present paper shows the application of function–failure design method in Bell 206 helicopter actuators. The results of the analysis by FFDM method supported by FMEA Analysis programme available in the Institute of Applied Informatics were compared with the results obtained by Roberts [1]. The results have been shown in a graphic form.

2. Failure analysis methodology with the use of FFDM method

The use of FFDM requires the creation of a component list (Fig. 1) on the basis of information in the data base of a similar system. Such data may be available in the form of pictures, schemes, diagrams, etc.

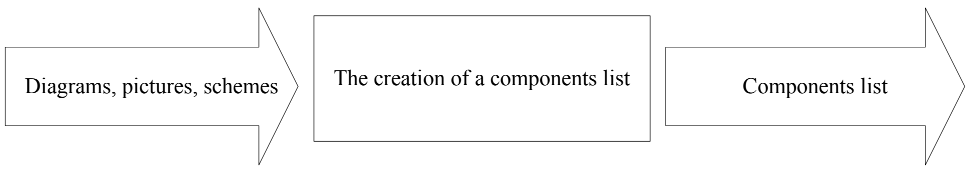

Fig. 1. Creation of a components list

Rys. 1. Tworzenie listy komponentów

In creation of a component list, another step in failure mode and effect analysis with the use of FFDM is the creation of a functional system model (Fig. 2). The model will contain sets of functions which determine specific order of the process.

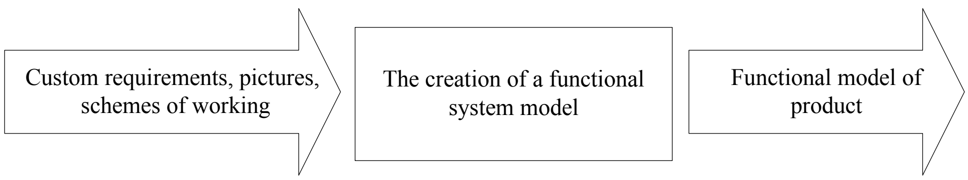

Fig. 2. Creation of a functional system model

Rys. 2. Tworzenie modelu funkcjonalnego

After the second step of the analysis with the use of FFDM is completed, a failure list (Fig. 3) has to be created with the application of knowledge of actual or potential defects which may appear in the system under analysis. The actual defects may be obtained from the reports on defects, and potential defects in the FMEA (failure mode and effect analysis).

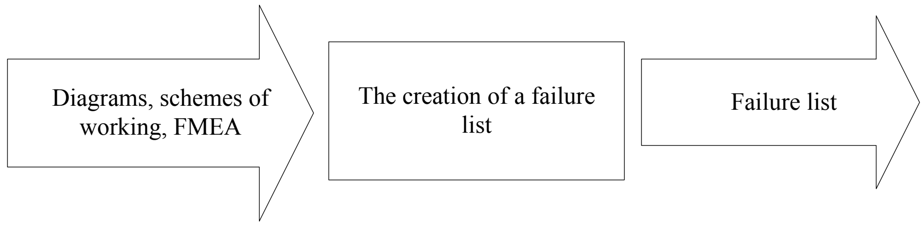

Fig. 3. Creation of a failure list

Rys. 3. Tworzenie listy defektów

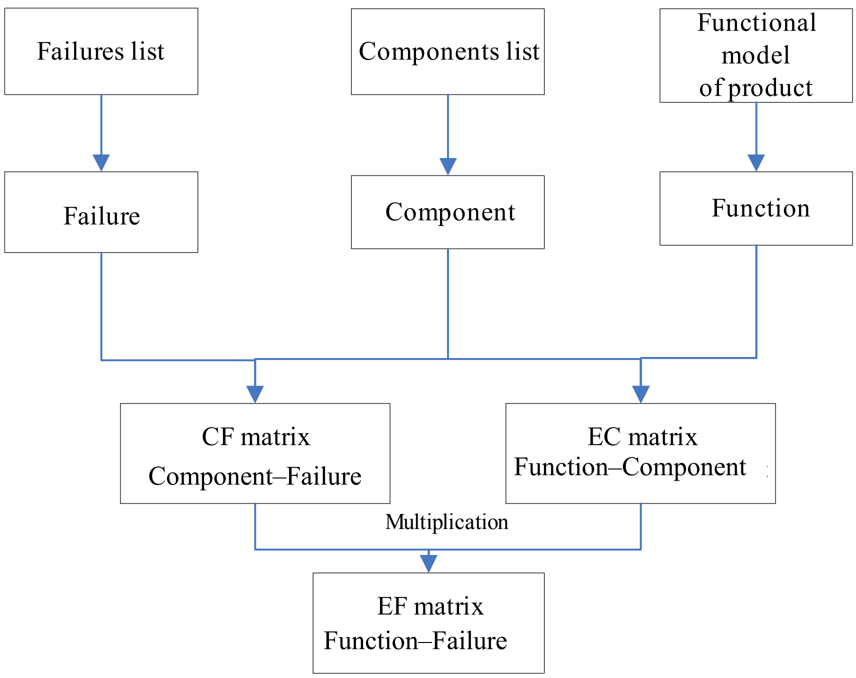

Fig. 4. Procedure of Function–Failure Design Method

Rys. 4. Schemat postępowania w metodzie FFDM

The component list, functional model and failure list create two matrices: EC and CF. The EC matrix is formed as follows: the first row of the matrix contains functions and the first column contains components. In the intersection point of *i* row with *i* column a number is put depending on situation:

– 0 when a component does not have a given function,
– 1 when a component has a given function,
– a real number, when the value is determined on the basis of weight.

The CF matrix is formed in such a way that the first column contains failures, and the first row contains components. Similarly to EC matrix, this one contains 0 and 1 numbers, and real numbers in the case of weight. This matrix shows how many times a failure caused damage to a constituent.

Once CF and EC matrices are formed and their multiplication is completed, EF – Function–Failure matrix is formed, which defines:
– how many times a component responsible for a given function was damaged as a result of a given failure;
– the probability of a component being damaged in the future.

EF matrix may be used in the future to detect and analyze prospective new product failures or to introduce changes to existing ones.

Therefore, creation of Function–Failure matrix should be made according to the scheme in Fig. 4.

3. Analysis by FFDM with software support

A helicopter (Fig. 5), details of which are referred to in literature [1], has been the subject of analysis. The analysis hase been focused on the drive system.

Fig. 5. The Bell 206 helicopter

Rys. 5. Śmigłowiec Bell 206

The Bell 206 helicopter is equipped with two drive turbines with two blade rotors: the main rotor and tail rotor. It is hydraulically controlled and has the function of autorotation. Therefore, despite an engine failure, an accelerated main rotor allows firm landing. The helicopter was the subject of FMEA by FFDM [1] carried by Roberts. On the basis of the information, analysis was carried out with the use of software available at the Institute of Applied Informatics.

3.1. The course of analysis

In his work for the analyzed object, Roberts distinguished 7 subsystems: a compressor, an engine, a gear drive system, a turbine, fuselage, a fuel unit and a rotor unit. The analysis concerned 29 components (Table 1), 25 functions (Table 2) and 10 failures (Table 3).

Table 1

Components of the Bell 206 helicopter in Roberts' analysis

Components		
1. Air discharge tubes 2. Bearing 3. Bleed valve 4. Bolt 5. Compressor case 6. Compressor mount 7. Compressor wheel 8. Coupling 9. Diffuser scroll 10. Exhaust collector	11. Fire wall 12. Front diffuser 13. Front support 14. Governor 15. Housing 16. Impeller 17. Mount 18. Nozzle 19. Nozzle shield 20. 'O' ring	21. P3 line 22. Plastic lining 23. Pressure control line 24. Pylon isolater mount 25. Rear diffuser 26. Rotor 27. Shaft 28. Spur adapter gearshaft 29. Turbine wheel

Table 2

Functions in Roberts' analysis

Functions				
1. Change gas 2. Change th 3. Convert me to pn 4. Convert th to pn 5. Couple me	6. Couple solid 7. Distribute gas 8. Export gas 9. Guide gas 10. Guide solid	11. Import gas 12. Regulate gas 13. Regulate liquid 14. Regulate me 15. Secure solid	16. Stop liquid 17. Stop me 18. Stop mixture 19. Stop solid 20. Stop th	21. Store gas 22. Store solid 23. Transfer gas 24. Transfer me 25. Transfer pn

Table 3

Helicopter's failure in Roberts' analysis

Failure	
1. Bond failure 2. Corrosion 3. Fatigue 4. Fracture 5. Fretting	6. Galling and seizure 7. Human 8. Stress rupture 9. Thermal shock 10. Wear

Contrary to Robert's analysis, the paper shows a more detailed functional model of the drive system. Failure taxonomy showed 25 components (Table 4), 51 functions (Table 5) and 15 failures (Table 6).

Table 4

Components of the Bell 206 helicopter in analysis contrary to Roberts' analysis

Components		
1. Compressor wheel	11. Plastic lining	21. Spur adapter gearshaft
2. Compressor bearing	12. Bolt	22. Turbine coupling
3. Compressor body	13. Exhaust manifold	23. Turbine shaft
4. Compressor gasket	14. Nozzle sheild	24. Turbine wheel
5. Engine bearing	15. Pressure control line	25. Fin stabilizer
6. Governor	16. Pylon isolater mount	
7. Nozzle	17. Diffuser scroll	
8. Nut	18. Blade of control rotor	
9. O - ring	19. Fuselage tail boom	
10. P3 line	20. Bleed valve	

Table 5

Functions in analysis contrary to Roberts' analysis

Functions		
1. Change gas	18. Export The	35. Location solid
2. Change liquid	19. Export solid	36. Regulate HyE
3. Change PnE	20. Guide gas	37. Regulate liquid
4. Change RotE	21. Guide HyE	38. Regulate ME
5. Conversion HE to RotE	22. Guide liquid	39. Secure solid
6. Conversion PnE to ME	23. Guide PnE	40. Stabilization solid
7. Conversion RotE to PnE	24. Guide RotE	41. Stop gas
8. Couple solid	25. Guide solid	42. Stop HyE
9. Distribute solid	26. Import gas	43. Stop liquid
10. Distribute ME	27. Import HE	44. Stop PnE
11. Distribute ThE	28. Import HyE	45. Stop solid
12. Export gas	29. Import liquid	46. Store ME
13. Export HyE	30. Import ME	47. Supply ME
14. Export liquid	31. Import PnE	48. Transfer ME
15. Export ME	32. Import RotE	49. Transfer PnE
16. Export PnE	33. Import solid	50. Transfer RotE
17. Export RotE	34. Import ThE	51. Transfer ThE

Table 6

Helicopter's failure in analysis contrary to Roberts' analysis

Failure	
1. Abrasive wear	9. Fretting
2. Human factor	10. HCF
3. Buckling	11. Stress corrosion
4. Corrosion	12. Thermal fatigue
5. Deformation	13. Thermal shock
6. Chemical activity	14. Material creep
7. Fracture	15. Surface wear
8. Bond failure	

Taking into consideration the above mentioned information, EC and CF matrices were formed and completed with input data (0, 1), which were entered into the FMEA software. Then, EC and CF matrices were formed and analysis carried out in which the EF matrices for Roberts' analysis (Table 7) and contrary to Roberts' analysis (Table 8). Function–Failure matrices showing the probability of failure occurrence for function was generated (grey colour designates critical function–failure pairs).

Table 7

EF matrix for Roberts' analysis (fragment of table with highest values)

		Failure							
		fatigue	fracture	fretting	galling and seizure	human	stress rupture	therma l shock	wear
Function	couple me	3	0	0	0	0	1	2	0
	couple solid	3	0	1	0	0	1	1	1
	distribut e gas	0	0	0	0	0	0	0	0
	export gas	0	0	0	0	0	0	0	0
	guide gas	2	0	0	0	0	2	2	0
	guide solid	1	0	0	1	0	0	1	1
	import gas	0	0	0	0	0	0	0	0
	regulate gas	0	0	0	0	0	0	0	0
	regulate liquid	1	1	0	1	0	0	0	1
	regulate me	0	0	0	0	0	0	0	1
	secure solid	4	0	1	1	0	0	2	4

Table 8

EF matrix for contrary to Roberts' analysis (fragment of table with highest values)

		Failure					
		HCF	Stress corrosion	Thermal fatigue	Thermal shock	Material creep	Wear surface
Function	distribute solid	14	1	2	6	6	13
	distribute ME	3	0	0	0	3	0
	distribute ThE	7	1	0	0	1	4
	export gas	6	0	2	6	2	3
	export HyE	0	0	0	1	2	0
	export liquid	1	0	0	0	0	1
	export ME	6	0	0	0	4	4
	export PnE	2	0	0	0	0	5
	export RotE	6	1	0	4	2	4
	export The	3	0	2	2	1	0
	export solid	14	1	2	6	6	13

3.2. Analysis results

With the use of computer software the results obtained were presented in the form of charts. On the X axis there are functions of the component and on the Y axis the helicopter failure factors. In Fig. 6 (Roberts' analysis) and Fig. 7 (contrary to Roberts' analysis) the functions with greatest failure rate were illustrated.

According to Fig. 6, in Roberts' analysis the greatest value was reached by secure solid function, for which wear and fatigue failures probability equals 4.

The secure solid Function consists in fixing, assembly, blocking and support of components of the subassembly. Wear and fatigue functions are considered to be critical for this function. The fatigue failure occurs when a unit is working with a considerable load for many thousands of cycles. Such failure may lead to helicopter crashes, as mechanical components in the drive system tend to be overloaded. The wear failure corresponds to wearing of the fricative pair, which causes destructive changes of the nature of surface.

In this analysis, illustrated in Fig. 7, the HCF failure creates a critical danger, which is a high number of rotation cycles and material creep. HCF is a kind of fatigue of jet engines when the resonance is caused by external factors activity. Fig. 8a (Roberts' analysis) and Fig. 8b (analysis contrary to Roberts' analysis) show accumulative failure values for all functions in the object under analysis.

The results of the analysis by FFDM supported by software available at the Institute of Applied Informatics were compared with results obtained by Roberts [1]. Both analyses proved the same type of failure to be dangerous. Roberts' analysis designated fatigue to be the most dangerous, and in the paper the most dangerous seems to be HCF failure, which is a specific type of fatigue. When comparing both analyses an observation has been made that there is a huge discrepancy between the two defects. Roberts calls the failure wear while this analysis designates material creep. It is a superficial difference, as Roberts did not use names for particular defects in his paper. Using the word wear he meant plastic deformation, which may also be creep. In taxomy there is a clear division into repetitive plastic deformations (in a group called wear) and plastic deformations, one of which may be creep. Table 9 illustrates verification of both analyses.

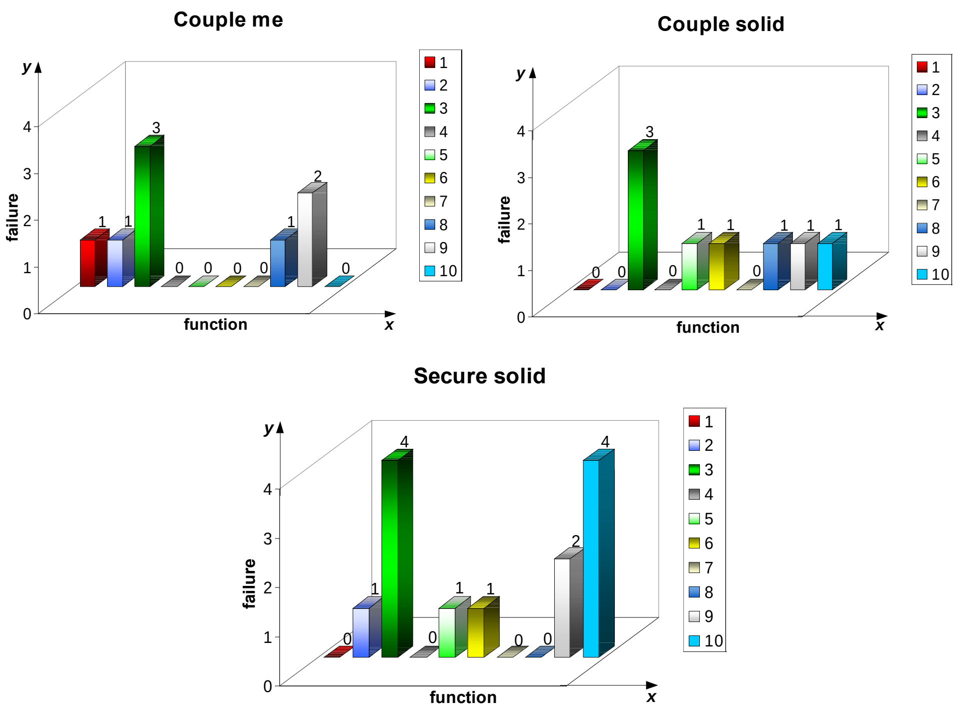

Fig. 6. The results in a graphic form of Roberts' analysis: 1 – bond failure, 2 – corrosion, 3 – fatigue, 4 – fracture, 5 – fretting, 6 – galling and siezure, 7 – human, 8 – stress rupture, 9 – thermal shock, 10 – wear

Rys. 6. Wyniki analizy Robertsa: 1 – wady połączeń, 2 – korozja, 3 – zmęczenie, 4 – pęknięcie, 5 – zużycie cierno-korozyjne, 6 – zatarcie, 7 – czynnik ludzki, 8 – zerwanie, 9 – wstrząs cieplny, 10 – zużycie

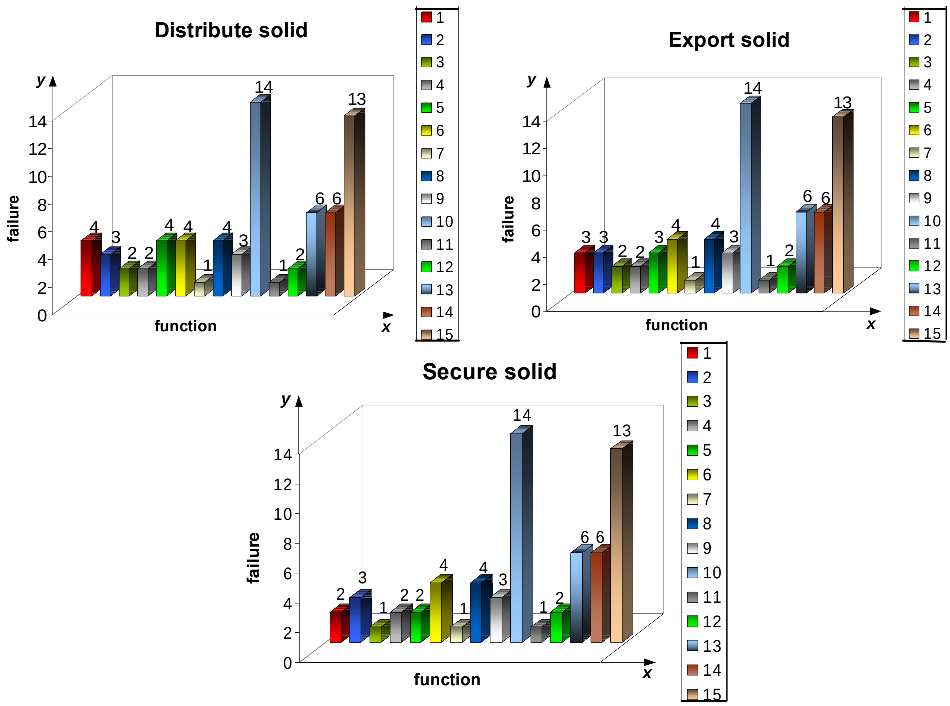

Fig. 7. The results in a graphic form of analysis contrary to Roberts' analysis: 1 – abrasive wear, 2 – human, 3 – buckling, 4 – corrosion, 5 – deformation, 6 – chemical action, 7 – fracture, 8 – bond failure, 9 – fretting, 10 – HCF (a specific type of fatigue), 11 – stress corrosion, 12 – thermal fatigue, 13 – thermal shock, 14 – material creep, 15 – wear surface

Rys. 7. Wyniki obecnej analizy przedstawione w formie graficznej: 1 – zużycie ścierne, 2 – czynnik ludzki, 3 – wyboczenie, 4 – korozja, 5 – odkształcenie, 6 – aktywność chemiczna, 7 – pęknięcie, 8 – wady połączeń, 9 – korozja cierna, 10 – HCF, 11 – korozja naprężeniowa, 12 – zmęczenie cieplne, 13 – wstrząs cieplny, 14 – płynięcie materiału, 15 – zużycie powierzchni

a) b)

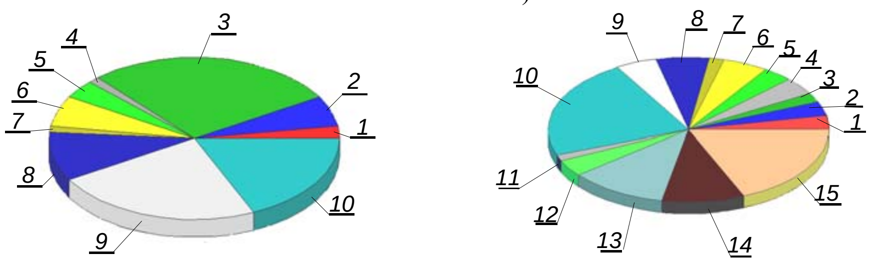

Fig. 8. Accumulative failure values for all functions in the object under analysis: a) Roberts' analysis, b) analysis contrary to Roberts' analysis

Rys. 8. Wykresy skumulowanych wartości defektów: a) analiza Robertsa, b) analiza obecna

T a b l e 9

The verification of both analyses

Roberts' analysis	Analysis contrary to Roberts' analysis
Fatigue	HCF (a specific type of fatigue)
Wear	Material creep

4. Summary

The author of the paper shows the implementation of a failure mode and effect analysis with the use of FFDM. The analysis was supported by software FMEA available at the Institute of Applied Informatics. The software allowed an immediate data entry into the matrix, making necessary calculations and illustrating the results in a graphic form. Due to applied technology the software is easily calibrated, thus there is a possibility of implementation of other methods extending FFDM method. This would allow failure reduction during product designing. A data base integrated with FMEA programme may be easily expanded by any user at his/her option. It is particularly important when the analysis is developed onto other objects. The computer analysis by FFDM for the Bell 206 helicopter described in this paper confirmed the fact FMEA programme may be a tool which efficiently supports product failure analysis and can be used by designers in model construction without the necessity of making prototypes.

R e f e r e n c e s

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