MSG-3: A reliability centered approach to identify maintenance measures

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Agenda

- Motivation
- Maintenance in the aviation industry
- Exemplary application to a space system
- Future Considerations

Motivation

More than 65 years of expertise from aviation

procedures and processes continuously improved

Increasing demand and utilization of space vehicles

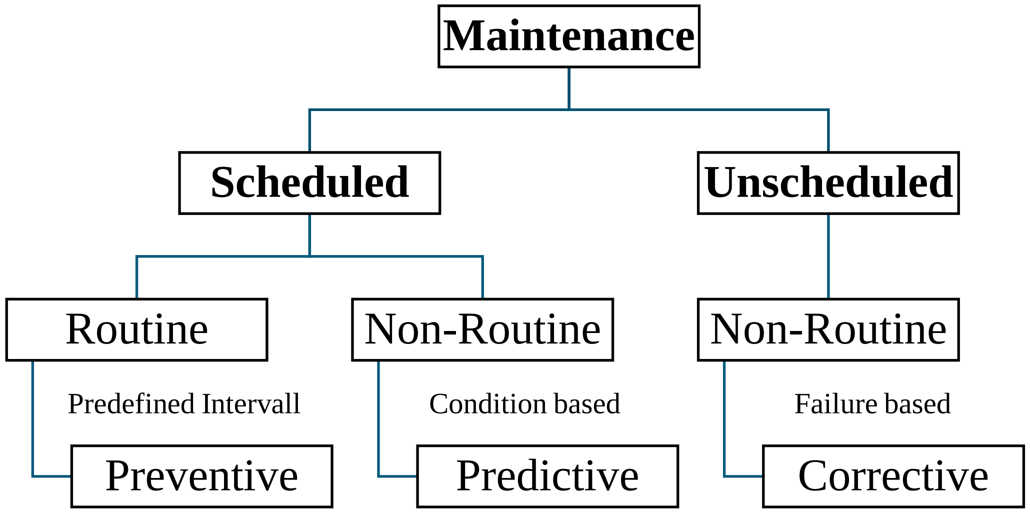
comparable operational scenarios

Competitiveness of spacecraft operation

Sustainability, Economy, Ecology

Maintenance in the aviation industry

Definition and understanding of maintenance (in the context of aviation)



Definition of …

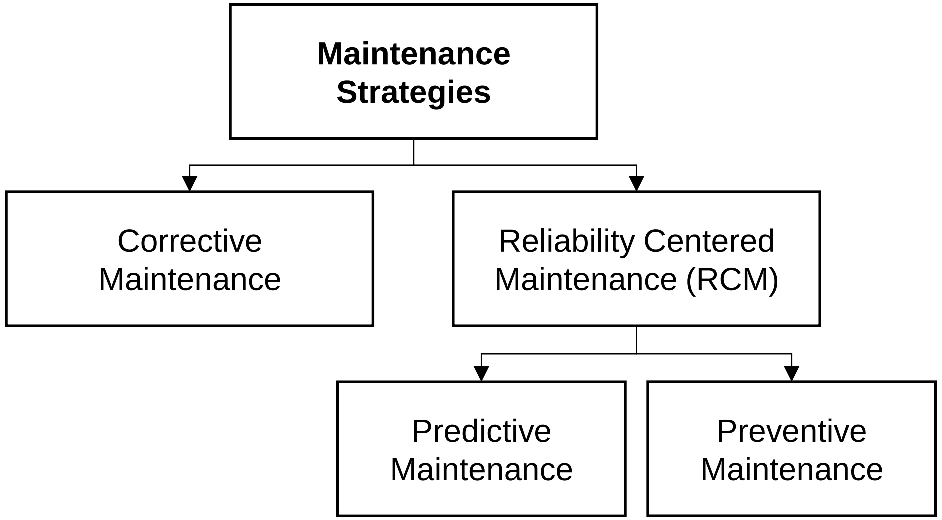
… Maintenance

*"Maintenance are measures taken to **maintain the designed condition** of a product (service), to **determine and evaluate the actual condition** (inspection) of a product, and to **restore** (repair) the product to its **designed condition**."* [6]

It can be grouped into four different aspects:
Servicing, Inspection, Modification, Restoration [7]

… Reliability Centered Maintenance

It is a systematic, **risk based method**, whereby components – or more specifically, their **failure modes** – are investigated and prioritized according to the **severity of their consequences to safety and reliability**, which enables the development of an cost-effective maintenance plan [8,9,10]



Maintenance in the aviation industry

MSG-3 – An established logic to derive maintenace implications

Maintenance Estimation

Failure Modes and Effects Analysis (FMEA)
- Functions
- Failure Cases
- Failure Effect
- Failure Cause

→

Failure Criticality Assessment
- Failure Evidence
- Operational impact
- Failure Effect Category (FEC)

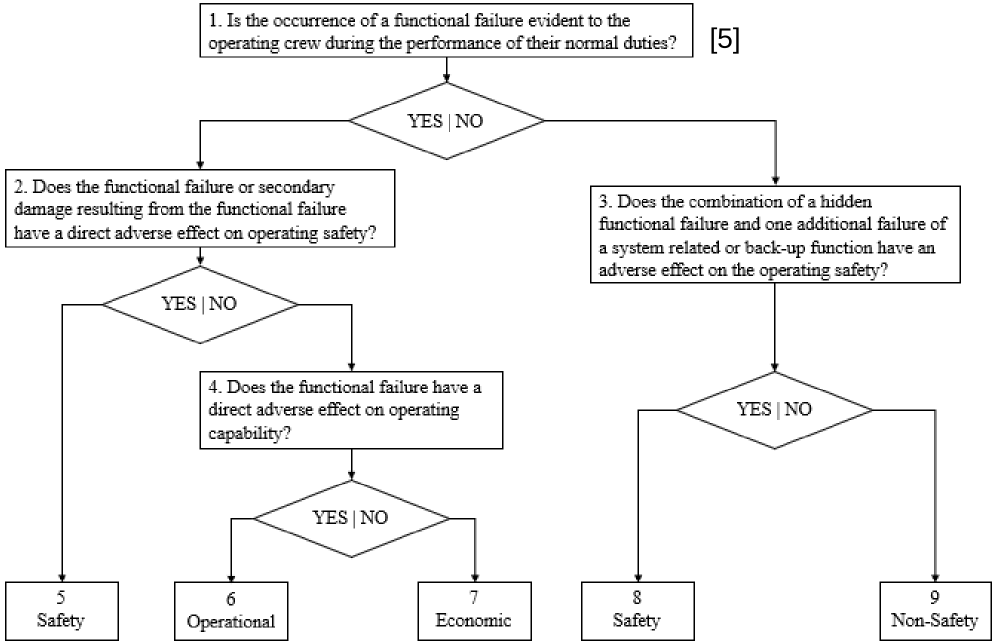
→

Maintenance Task Allocation
- Effective/ Applicable Tasks
- Failure identification
- Failure prevention
- Failure correction

→

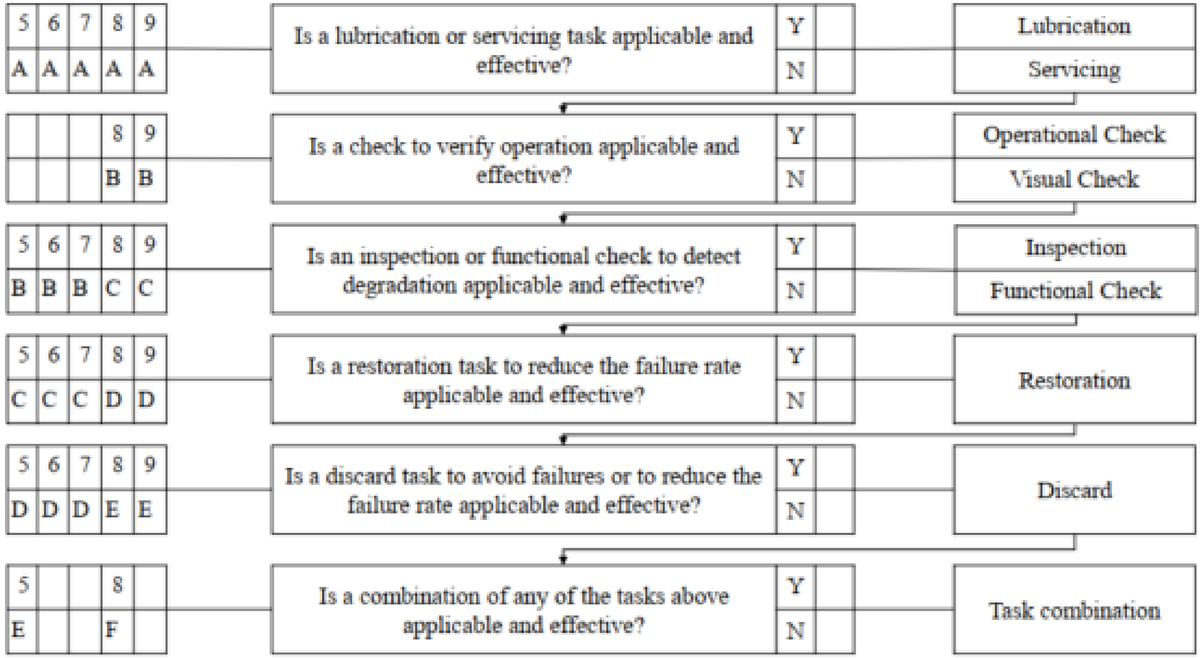
Task Detailing
- Interval
- MMH

Failure Criticality Assessment



[5]

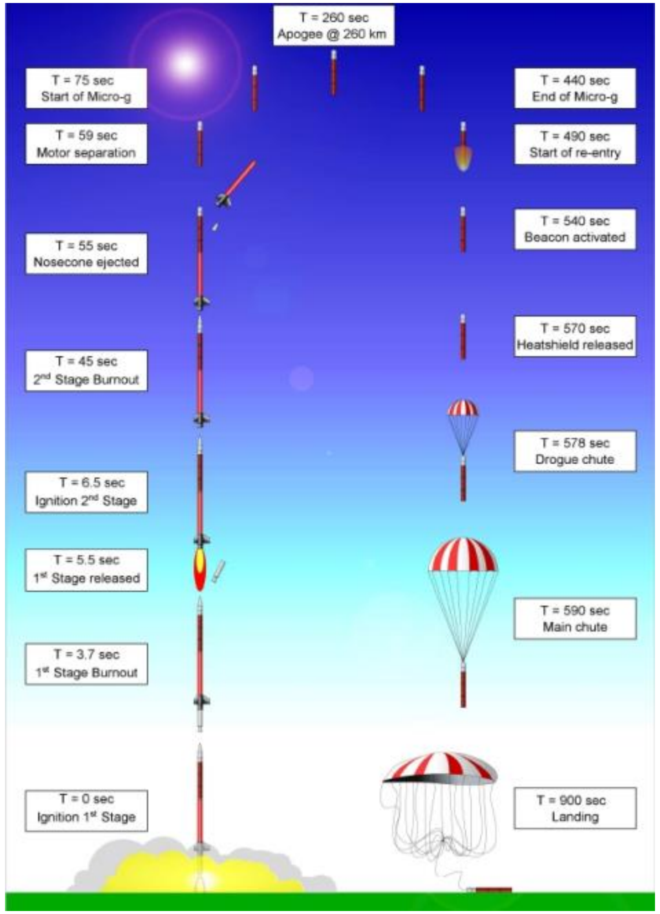
Maintenance Task Allocation



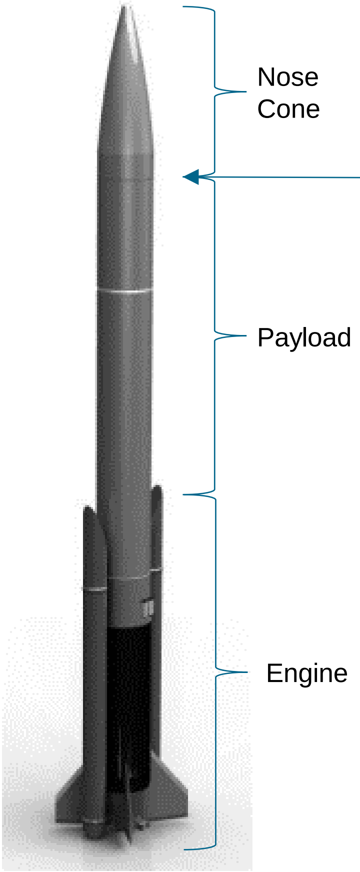
[5]

Exemplary application to a space system

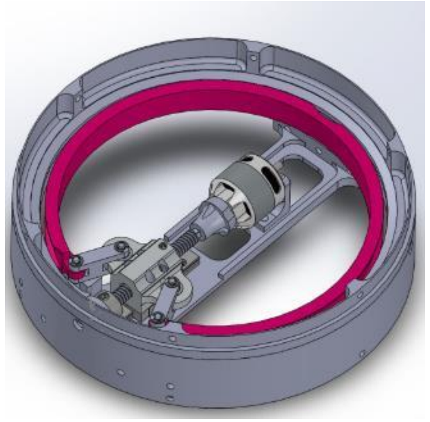
Use case: Forward Recovery System (FRS) of a sounding rocket



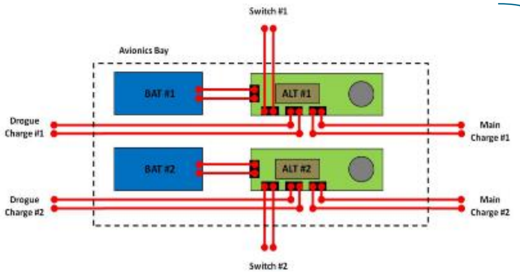
Typical Trajectory of a sounding rocket [2]



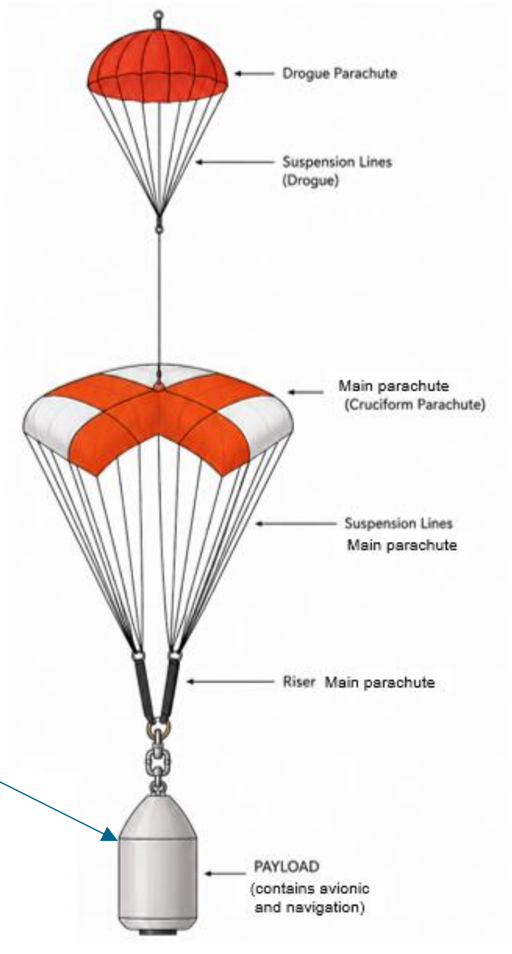
Typical Layout of a sounding rocket [1]



CAD model of (inverted Marmon clamp) separation system [3]



Exemplary FRS control system [4]



Exemplary layout of a FWR [AI-generated] [11]

Exemplary application to a space system

Use case: Forward Recovery System (FRS) of a sounding rocket

FRS separation in different Subsystems

Component allocation of each subsystem

Function allocation of each component

Forward Recovery System (FRS)

- Separation System
- Drogue Parachute Deployment System
- Main Parachute Deployment System
- Main Parachute System
- Additional Equipment

Separation System

- (Brushed) DC motor
- V-Band
- Mechanical Clamp mechanism components
- Upper and Lower Ring

V-Band

- keep upper and lower ring in position during flight trajectory
- providing clamp force on upper and lower ring
- reduce clamp force to release ring connection and start separation

Maintenance Estimation

Failure Modes and Effects Anaysis (FMEA)
- Functions
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Failure Criticality Assessment
- Failure Evidence
- Operational impact
- Failure Effect Category (FEC)

Maintenance Task Allocation
- Effective/ Applicable Tasks
- Failure identification
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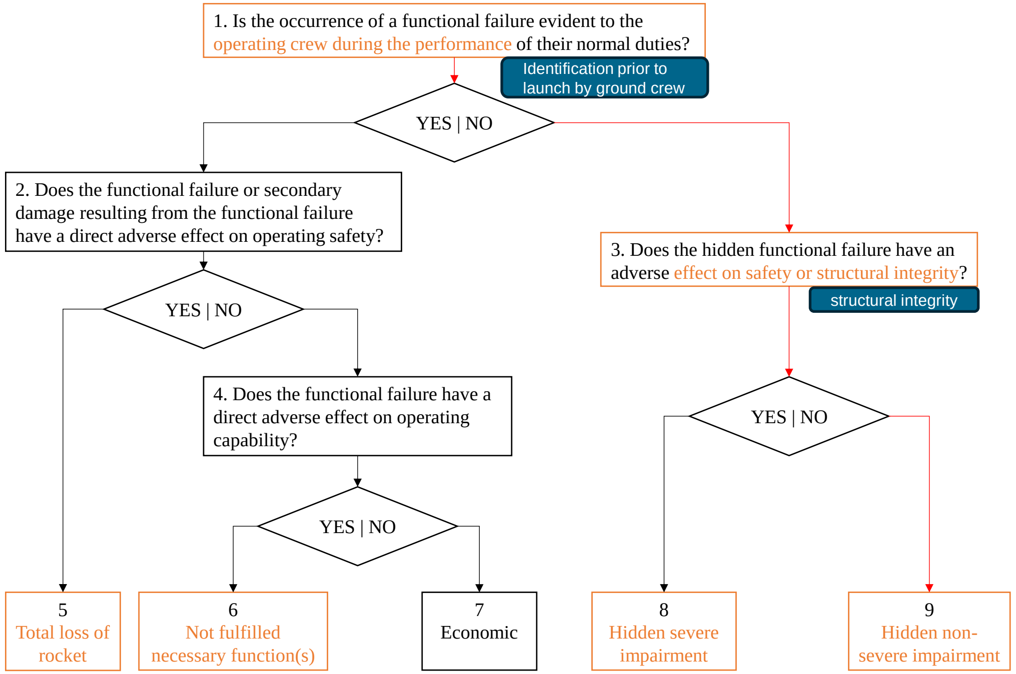
Exemplary application to a space system

Maintenance Estimation

FMEA

Component	Function	Ref	Failure Case	Failure effect	Failure Cause
v-band	keep upper and lower ring in position during flight trajectory	A03	unintended opening of v-band clamp connection, separation in-flight	unintended parachute deployment entanglement, interrupted experiments, total loss	faulty signal transmission
	providing clamp force on upper and lower ring	A04	structural impairing/ damage on the back side of the v-band	connection becomes loose during operation, unintended separation	local force concentration
	reduce clamp force to release ring connection and start separation	A05	failure to proper release of the v-band	clamping connection does not open, nose does not get separated from body, no ejection of recovery system, loss of rocket/ potential fatalities	band deflections (bending moments)
		A06	v-band fails to separate rings		cold welding of clamp band and ring(s)

Failure Criticality Assessment



1. Evidence of the failure
   NO Bigger damages might be easily detectable but not minor or inner structural impairings.
2. Consequences of failure on operating safety and structural integrity
   N/A Not applicable
3. Consequences of failures on operation or safety
   NO Failure leads to interruption of experiments and early return of the payload
4. Consequences of the failure on operating capability
   N/A Not applicable

FEC 9 (Hidden non-severe impairment)

- Failure doesn‘t cause a complete loss of the rocket
- Recovery of payload and experimental results still possible
- Impact only on continuation of experients

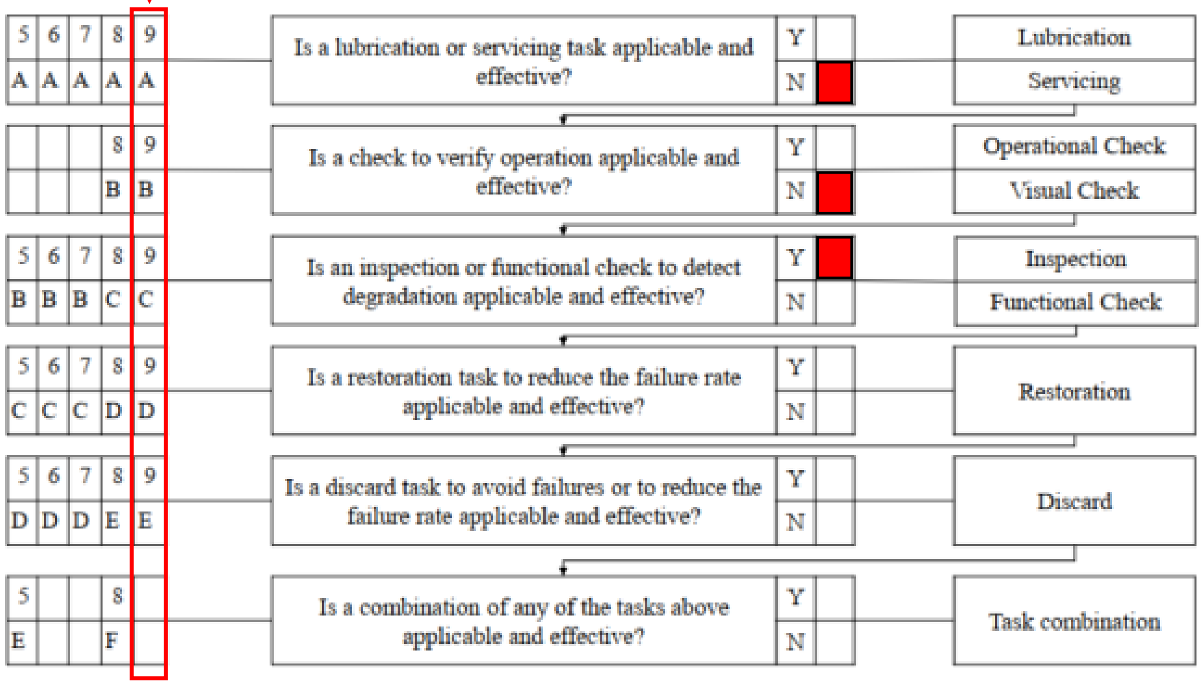
[5]

Exemplary application to a space system

Maintenance Estimation

Maintenance Task Allocation

structural impairing/ damage on the back side of the v-band



1. Failure servicing
   NO Component can‘t be serviced for the related failure case
2. Failure identification by OPC or VCK
   NO Not effective, inner damages would not be identified
3. Identification of structural changes of the v-band
   YES Special Detailed Inspection (SDI) in form of non-destructive testing (NDT) of the v-band

Following questions are not relevant after task identification
N/A Not applicable

This leads to a **Special Detailed Inspection** (SDI), performed as a **Non-destructive test**, as an **effective, applicable and least effording task** to address the corresponding failure.

[5]

Exemplary application to a space system

Preliminary maintenance implications based on first changes on MSG-3 methodology

27 identified maintenance tasks for the Forward Recovery System (FRS) of a sounding rocket

Most of the tasks are categorized as FEC 5 and 8	No FEC 7	Around 50% of the tasks are quantitative inspections

- Approx. 70% of identified tasks are safety critical
- No economic related tasks
- Labour intense and time-consuming tasks

Highly dependend on aviation industry requirements

Future consideration

- Adaptation of the method
- Maintenance interval and effort estimation
- Maintenance investigation of further systems and vehicles
- Incorporation of the maintenance perspective during design
- Maintenance estimation method improvement

KEY TAKEAWAYS

1. The aviation domain provides an established method to elaborate efficient and applicable maintenance measures, the MSG-3 method.

2. Based on engineering judgement and failure scenarios, maintenance actions to mitigate them, can be elaborated.

3. The applicability of the MSG-3 method highly depends on the operating conditions of the considered space system.

THANK YOU FOR YOUR ATTENTION

R. Dauer

DLR - MO

References

/1/ Marciniak, 2015, Development of Parachute Recovery System for sounding rockets
/2/ Kirchhartz, 2018, Sounding Rockets as Experimental Platform
/3/ Roland, 2016, Electronic-nose-cone-separation-ring-(ensr)-for-deployment-of-rocket-recovery-parachute
/4/ NASA, 2024, Student Launch ARW Recovery System (exemplary)
/5/ Airlines for America, 2018, *MSG-3: Operator/Manufacturer Scheduled Maintenance Volume 1 - Fixed Wing Aircraft*. Washington, D.C.
/6/ VDI., 2001, Konstruieren instandhaltungsgerechter technischer Erzeugnisse: Grundlagen
/7/ Deutsches Institut für Normung e.V., 2012, Grundlagen der Instandhaltung.
/8/ A. R. S. Queiroz et al., 2017, Maintenance Strategy for Electrical Equipment Based on Integrated Operations.
/9/ A. Ahmadi et al., 2010, On aircraft scheduled maintenance program development.
/10/ G. P. Sullivan et al., 2002, Operations & Maintenance: A Guide to Achieving Operational Efficiency
/11/ OpenAI.(2026, May 18). Schematic layout of a FWR [AI-generated]. GPT-5.5 Image. URL: 2-stufiges Fallschirmrettungssystem

Exemplary application to a space system

Preliminary maintenance implications based on first changes on MSG-3 methodology

Task_no	consolidated tasks	Task Code	Final FEC
1	FNC of electric DC motor power supply	FNC	5
2	Cleaning of electric DC motor area	SVC	5
3	FNC of DC motor control signal transmission	FNC	5
4	SDI (NDT) of the v-band and rings for change in material properties	SDI	9
5	DET (measurement) of v-band for deflections	DET	9
6	RST of material properties of v-band and rings	RST	8
7	Cleaning (and possibly lubrication) of clamp mechanism	SVC	5
8	Visual Check of clamp mechanism for any signs of wear and tear or corrosion	VCK	8
9	GVI of fulfillment of packing and installation requirements	GVI	5
10	GVI of drogue parachute bag connection	GVI	5
11	DET of the drogue parachute	DET	5
12	GVI of suspension lines and connections	GVI	5
13	DIS of drogue and main parachute suspension lines	DIS	5
14	DIS of drogue and main parachute riser	DIS	5
15	VCK of satisfactory packing and installation	VCK	8
16	FNC of wire cutter	FNC	5
17	FNC of wire cutter initiation	FNC	5
18	Cleaning of wire cutter and surrounding area/ components	SVC	5
19	DET of the main parachute	DET	5
20	DET of swivel	DET	5
21	OPC of avionincs battery's power supply function	OPC	9
22	OPC of altimeter signal transmission	OPC	9
23	OPC of pressure sensor signal transmission	OPC	9
24	Calibration/ Cleaning of pressure sensor port	SVC	9
25	FNC of sensor to altimeter signal transmission	FNC	5
26	VCK for any sings of damage or degradation of GPS Antenna	VCK	9
27	OPC of correct GPS Antenna signal transmission	OPC	9

Exemplary application to a space system

Preliminary maintenance implications based on first changes on MSG-3 methodology

27 identified tasks

FEC Analysis			
Category	**FEC**	**#**	**Adjusted category**
Evident safety	5	22	Total loss of rocket
Operational	6	7	Not fulfilled necessary functions
Economic	7	0	Only economic loss
Hidden Safety	8	6	Hidden severe impairment
Non-Safety	9	9	Hidden non-severe impairment

Most of the tasks are safety critical (FEC 5 and 8)
No economic related tasks (FEC 7)

Task Code Distribution									
LUB	SVC	VCK	OPC	FNC	GVI	SDI	DET	RST	DIS
0	4	3	4	5	3	1	4	1	2

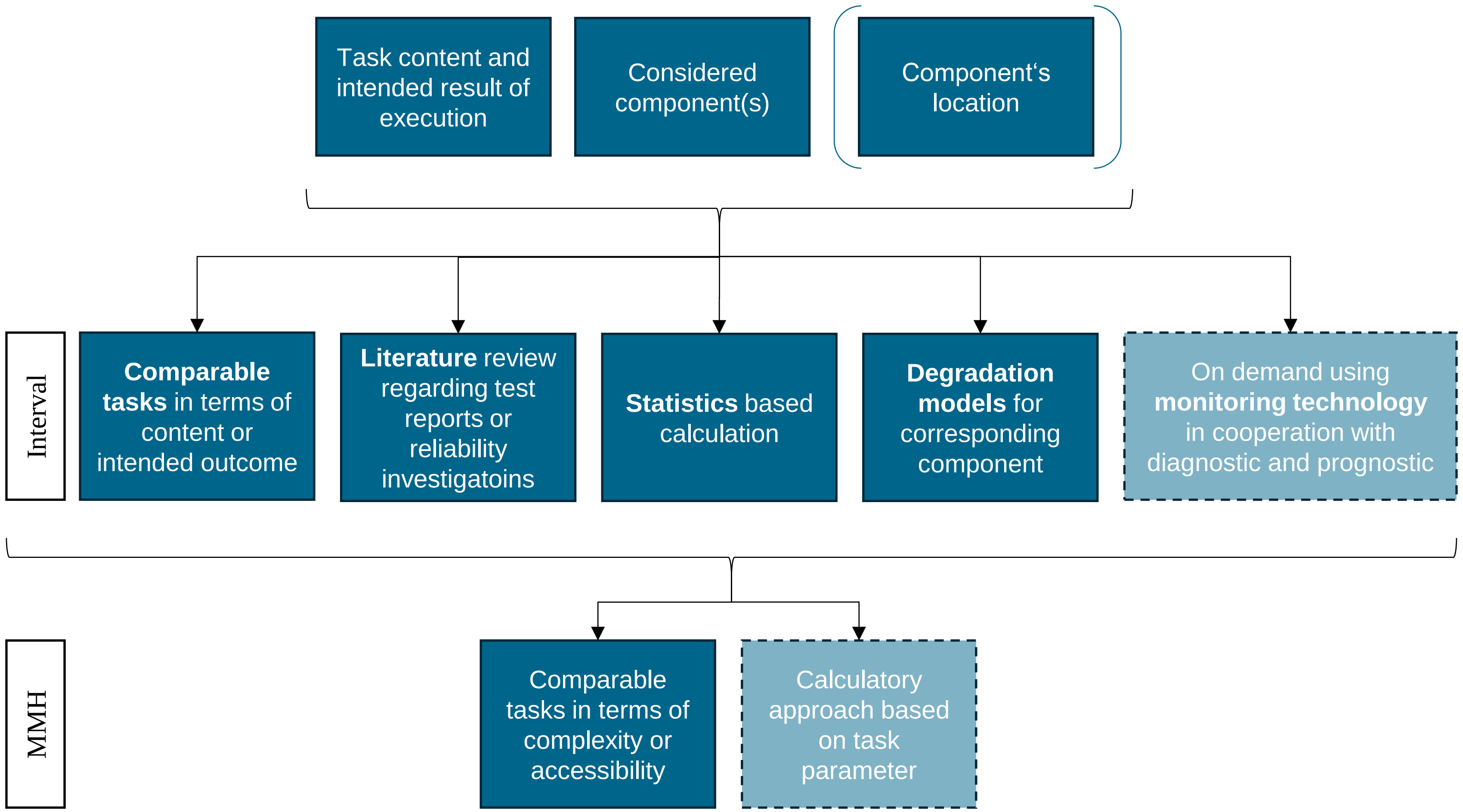
Nearly equal task code distribution, many tasks for a „simple“ subsystem

Maintenance categories	#	%
Failure prevention	4	14,8
Failure Finding Task	7	25,9
Quantitative inspection	13	48,1
Failure avoidance	3	11,1

Quantitative inspections are dominant, which means labour intense and time-consuming tasks

Maintenance in the aviation industry

Approaches for a detailed definition of the tasks



Approaches for a detailed definition of the tasks

Approaches for a detailed definition of the tasks

TASK NUMBER	ZONE	DESCRIPTION	SAMPLE THRESHOLD (ST) SAMPLE INTERVAL (SI) THRESHOLD (T) INTERVAL (I)	SOURCE	REFERENCE	MEN	M/H	APPLICABILITY
	210	AILERON HYDRAULIC ACTUATION EL OPC OPERATIONAL CHECK OF DAMPING MEASUREMENT BY BITE	I: 36 MO OR 5000 FH	CMR** LUR MRB 8		1	0.10	ALL

1. Interval definition according comparable component or task (MPD)

2. FFI = 2 * Unavailability (0,0001) * MTBF (with different techniques to estimate MTBF*)

*MTBF =(1/λ) [="Mean Time Between Failure"]

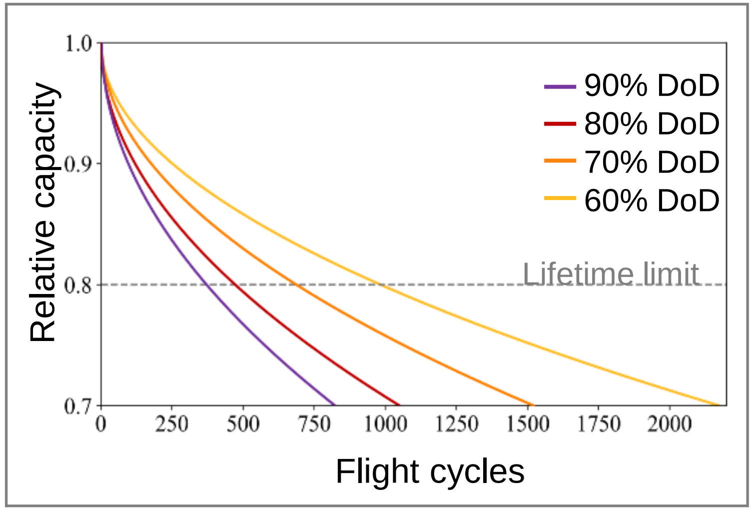
$$\lambda_{CM} = \lambda_{Part} \cdot (1 - POD_{95/95})$$

$$\frac{\lambda}{\lambda_N} = \frac{(-1/t_{MTBF}) \cdot ln(1-0,632)}{(-1/t_{MTBF}) \cdot ln(1-0,2)} \Rightarrow \lambda_N = 0,2238 \cdot \lambda$$

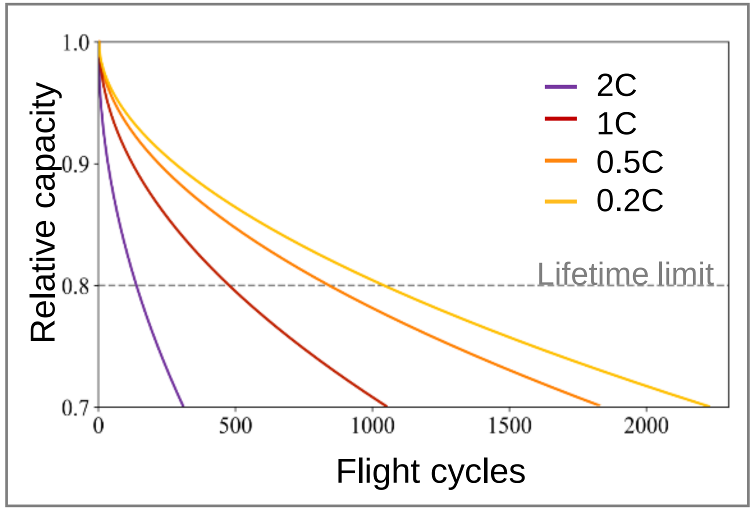
Approaches for a detailed definition of the tasks

Approaches for a detailed definition of the tasks

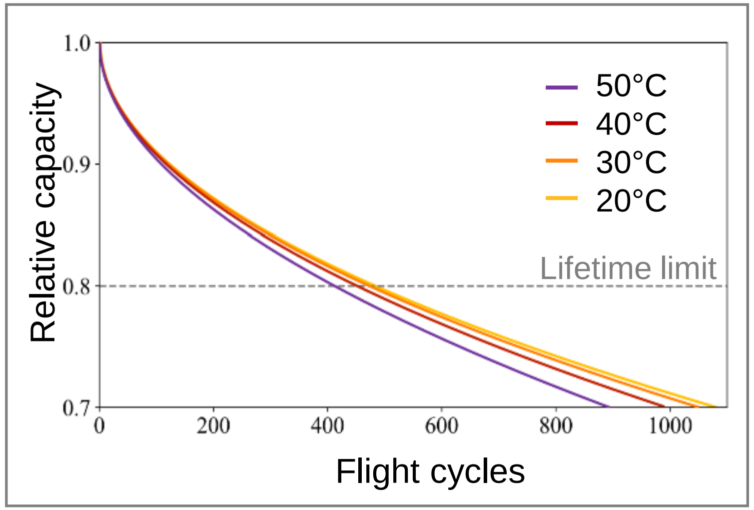
3. Degradation models based on utilization scenarios (exemplary for Battery based propulsion system)



Battery aging based on Depth of Discharge (DoD)



Battery aging based on charging rate



Battery aging operating temperature