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Executive Summary of the Thesis

Structural damage and repair assessment for Neos Air commercial aircraft: engineering data management, trend analysis, and economic impact.

Laurea Magistrale in Aeronautical Engineering - Ingegneria Aeronautica

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1. Introduction

Structural damage management represents one of the most critical aspects of commercial aircraft maintenance, as it simultaneously involves safety requirements, operational continuity, and economic sustainability. In an aeronautical context characterized by increasingly complex fleets, extended service lives, and a continuously evolving regulatory framework, the ability to collect, organize, and systematically analyze data related to damage and repairs plays a central role in supporting both technical and managerial decision-making within an airline operator.

This thesis addresses the evaluation of structural damage within the Neos Air fleet through an integrated approach that combines three main elements: the management and migration of technical data (see *Section 4*), the statistical analysis of damage trends, and the assessment of the associated economic impact. The objective is to develop an innovative structured, data-driven methodology capable of improving information traceability, supporting the prediction of future damage, and providing a reliable estimate of maintenance costs, with particular focus on the most recurrent types of structural damage: lightning strike, Foreign Object Debris (FOD) and ground impact.

2. State of Art

From a technical perspective, this work is grounded in the fundamental principles of aircraft structural design and maintenance, with particular emphasis on the concepts of fatigue and damage tolerance, which form the regulatory basis for the definition of maintenance programs and the management of structural fatigue life. These concepts ensure that aircraft structures can safely withstand the initiation and growth of damage throughout their operational life, provided that appropriate inspection and repair actions are implemented.

Within this framework, the Structural Repair Manual (SRM) [2] represents the primary reference document for the classification and management of structural damage and repairs. The SRM defines criteria to distinguish between allowable and non-allowable damage, as well as between minor and major repairs, depending on their impact on structural strength, damage tolerance, and the aerodynamic performance of the aircraft. In addition, the SRM provides a detailed classification of damage types, including abrasion, corrosion, cracks, creases, delamination, dents, disbonds, fretting, gouges, heat damage, holes, nicks, punctures, and scratches. Repairs applied to non-allowable damage are classified as major or minor repairs [1], based on the effect that the repair—when properly installed—has on the aircraft. The responsibility for the proper installation and compliance of the repair lies with the operator.

Inspection methods are also defined and derived within the SRM framework, as they represent a direct consequence of damage tolerance requirements and allowable damage limits. The SRM specifies the appropriate inspection levels and techniques needed to detect damage before it reaches critical size. Routine inspection activities typically include General Visual Inspections (GVI) and Detailed Inspections (DET), complemented, when required, by Non-Destructive Testing (NDT) procedures. The use of NDT techniques allows for earlier detection of hidden or subsurface damage and can significantly extend the damage detection interval. The most commonly employed NDT methods in aircraft structural maintenance include ultrasonic testing, eddy current inspection, dye penetrant inspection, resonance frequency methods, and X-ray inspection.

Finally, according to the SRM, aircraft structures are classified into primary and secondary structures based on their structural function. Primary structures are those that carry flight, ground, or pressurization loads and are further subdivided into Principal Structural Elements (PSEs). These elements contribute significantly to carrying critical loads, and their failure could result in catastrophic consequences for the aircraft. Secondary structures, while still essential for overall structural integrity and functionality, carry only aerodynamic or inertial loads and play a significant role in the aerodynamic performance of the aircraft.

3. Neos Air

The application context of this work is Neos Air, an Italian airline founded in 2001 and part of the Alpitour World Group. Neos Air operates a mixed fleet consisting of four Boeing 737-800 (NG), eight Boeing 737-8 (MAX), and six Boeing 787-9 Dreamliner aircraft. The diversity of the fleet, together with network expansion and the progressive phase-out of some aircraft, makes the need for a coherent and centralized management of structural data throughout the entire aircraft life cycle particularly relevant.
Within this framework, the aircraft I-NEOZ (Boeing 737 NG) was selected as a representative case study, as it is characterized by a long operational history and a large dataset of structural damages and repairs accumulated over time.

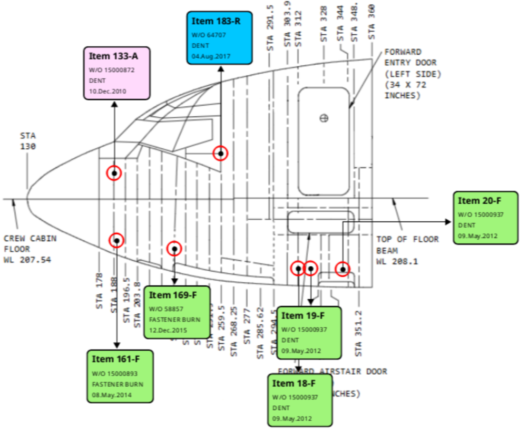
4. Data Processing and Migration Workflow

The principal contribution of this thesis concerns the migration of historical structural damage and repair data from the two systems currently in use—`Microsoft Access` and `Dent & Buckle`—to a single integrated platform, `Amos`.
`Dent & Buckle` is a specialized digital tool developed for the documentation, assessment, and tracking of aircraft structural damage, supporting standardized damage evaluation and repair decision-making.
`Amos`, on the other hand, is a widely adopted integrated maintenance and engineering software solution in commercial aviation, used for the planning, execution, and control of maintenance activities while ensuring regulatory compliance through a modular and highly integrated architecture.
The initial situation was characterized by fragmented information, with structural data distributed across two independent systems that were not directly interconnected. This fragmentation required partially manual workflows involving both technicians and the engineering department to ensure data consistency and traceability, resulting in duplicated efforts and reduced efficiency.

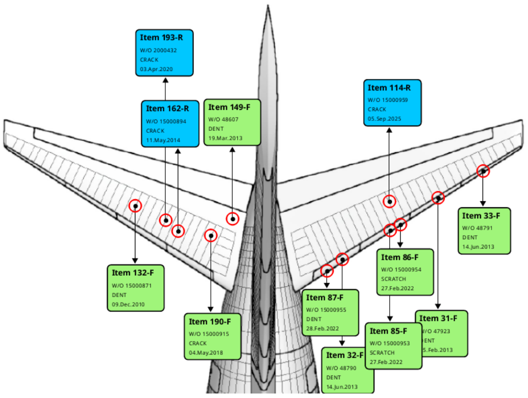
The migration process was developed through a detailed mapping of all relevant fields across the three systems and the implementation of automated procedures based on scripts developed in the MATLAB environment. The final objective was the creation of a comprehensive struc-

tural damage chart for the aircraft, ensuring the correct association of each damage with its corresponding information, including location, dimensions, damage type, inspection methods, repair classification, and the related work order.
To support this phase, an AI-based system was employed for the preliminary extraction of textual information from historical repair files. This approach significantly reduced manual workload and improved the overall efficiency and reliability of the data migration process.

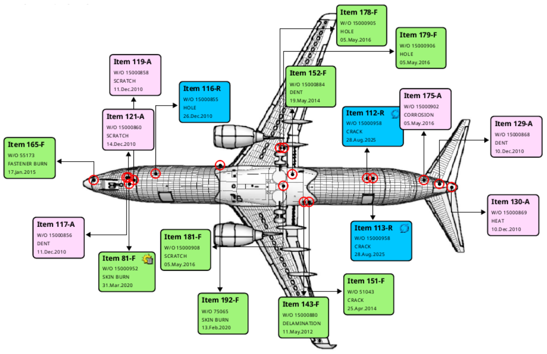
The final outcome of the migration process is the creation of a fully integrated Structural Damage Chart within `Amos`, enabling an immediate and coherent visualization of all structural damages and repairs accumulated over time. Some examples of the new SDC are shown in the figures below. It can be immediately observed that different colors are used for each box: pink indicates allowable damage, green represents a Category A repair (permanent), blue a Category B repair (interim), and light blue a Category C repair (temporary).



(a) Section 41 – LH.



(b) Top view of horizontal stabilizers.



(c) Bottom view.

Figure 1: I-NEOZ `Amos` SDC.

The adoption of a single, unified platform significantly improves data traceability, reduces the risk of information loss between maintenance and engineering functions, and provides a solid foundation for future analytical activities, aircraft phase-out processes, and potential fleet transfers to other operators.
From an operational perspective, the analysis highlights a potential reduction in the workload of the structural engineering department, estimated at approximately 50%, achieved through information centralization and by allowing technicians to directly enter data into the system.

5. Data Analysis

Based on `Dent & Buckle` data and the reorganization process previously described, this thesis proceeds with a statistical analysis of the principal types of damage affecting Neos Air fleet, with particular focus on the three most relevant categories in terms of frequency and operational impact: lightning strike, Foreign Object Debris, and ground impact. The analysis was normalized with respect to flight hours to make operational periods with different usage levels comparable. The study was conducted separately for Boeing 737 NG and Boeing 787, while for Boeing 737 MAX, the results for 737 NG were extended using an appropriate scaling based on flight cycles, due to insufficient data to establish an independent trend.

To identify trends and forecast the number of damages for 2026, five different analytical approaches were applied and compared: polynomial regression, Gaussian Process with lograte, Monte Carlo simulation, Poisson regression, and negative binomial regression. Each method highlights advantages and limitations linked to the observed data, which are characterized by high variability, the presence of many zeros, and the inherently stochastic nature of these phenomena.

Model performance was evaluated using walk-forward validation. According to this technique, for each validation month, the model is trained exclusively on previous data, thereby simulating a true out-of-sample forecast. Specifically, the model is trained on the first $k-1$ months and then used to predict the k-th month. The prediction error is calculated by comparing the estimated value with the actual observed value. This approach allows for a reliable assessment of model performance on unseen data.
Furthermore, three quantitative metrics were calculated to evaluate prediction accuracy: Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and Mean Absolute Percentage Error (MAPE). The validation results show that no single method is optimal for all damage categories.

A completed example is provided for lightning strike damages on the Boeing 737 NG (Figure 2), illustrating the inherent difficulty of forecasting such events. Among the tested approaches, the Gaussian Process (GP) and Monte Carlo (MC) models capture the overall low-intensity trend and short-term fluctuations, but both tend to smooth the data and underestimate extreme peaks. Polynomial regression produces smoother, more persistent predictions but less accurately reflects variability.

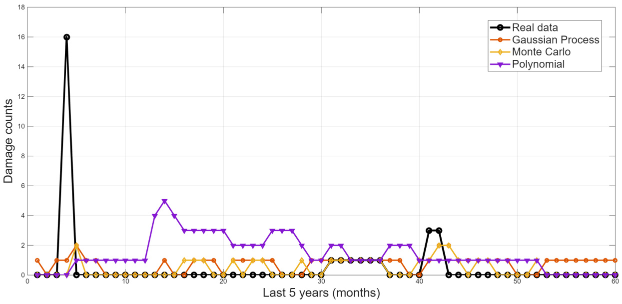


Figure 2: B737 NG – Lightning strike damage validation process.

The table below reports the final MAE, RMSE, and MAPE values. Overall, the Monte Carlo method achieved the best predictive performance, estimating a total of 17 lightning-induced damage events for 2026.

Method	**MAE**	**RMSE**	**MAPE [%]**
GP	0.88	2.11	61
MC	0.53	2.15	24
Polynomial	1.60	2.73	128

Table 1: MAE, RMSE, and MAPE metrics for lightning strike damage on Boeing 737 NG.

For lightning strike damages on the Boeing 787, the polynomial regression provided the best results. The analysis highlights pronounced monthly variability in damage rates. These fluctuations reflect seasonal and meteorological effects, rather than purely random behavior. The smoothed regression curve reveals a clear annual seasonality, with peaks roughly every 12 months, indicating higher damage rates in winter and late autumn, and lower rates in spring and early summer. The estimated second-degree polynomial is nearly flat, with both linear and quadratic terms close to zero. Accordingly, the forecast for 2026 aligns with this baseline behavior.

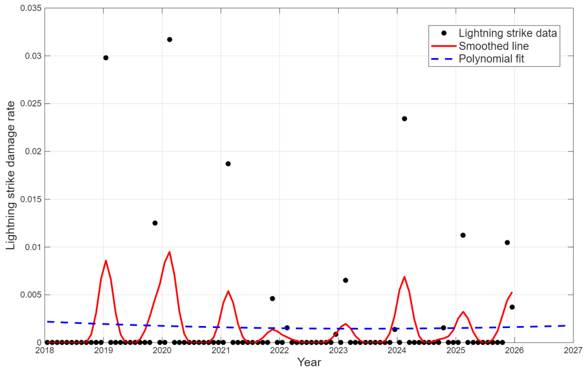


Figure 3: Polynomial regression - Lightning strike damage rate for B787.

For FOD damages, the Gaussian Process provides the best results for Boeing 737 NG, predicting a total of 24 events, while polynomial regression is most effective for the Boeing 787, with a predicted total of 11 events (Figure 5). Figure 4 shows a stable FOD damage rate for the Boeing 737 NG, highlighting a recurring seasonal pattern, where occurrences are influenced by operational periods and environmental conditions.

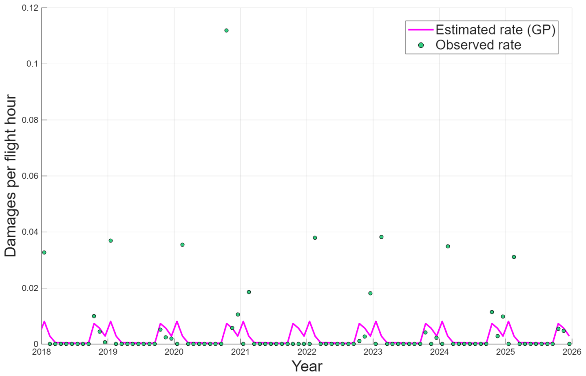


Figure 4: Gaussian Process - FOD damage rate for B737 NG.

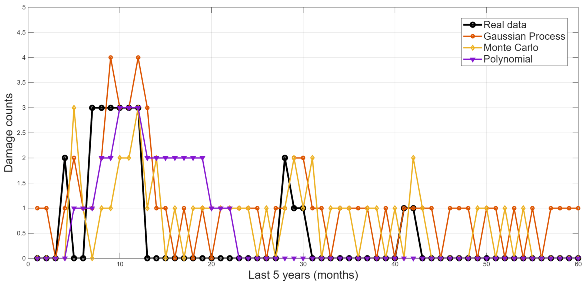
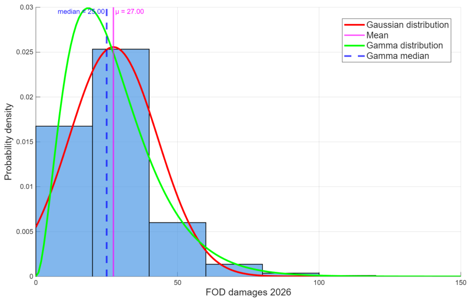


Figure 5: B787 – FOD damage validation process.

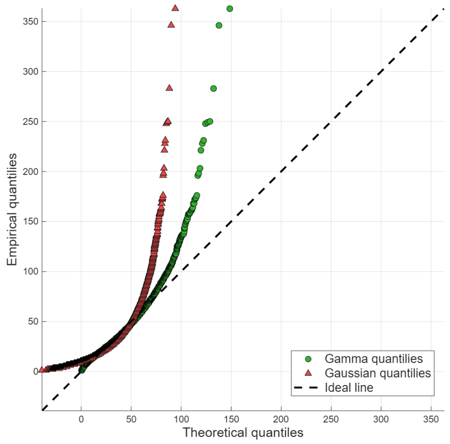
For ground impact damages on both Boeing 737 NG and Boeing 787, the Monte Carlo simulation provided the best estimates, predicting 24 and 11 damage events, respectively.

Figure 6 shows the results of Monte Carlo method for ground impact damage analysis. The mean (27) is slightly higher than the median (25), indicating moderate skewness (Figure 6a). The Gamma distribution fits both the peak and the tail more accurately, while the Gaussian tends to underestimate higher values.

The QQ-plot for the 737 NG (Figure 6b) reveals a much stronger asymmetry: in the right tail, empirical quantiles increase more rapidly than theoretical ones. The Gaussian struggles to capture the tail expansion, whereas the Gamma provides a better fit, although deviations grow at the highest quantiles.



(a) Monte Carlo method - Ground impact damage rate for B737 NG.



(b) Q-Q plot - Ground impact damage for B737 NG.

Figure 6: Monte Carlo method - Ground impact analysis for B737 NG.

The approach for Boeing 787 captures the discrete and intermittent nature of the series, but its inherent randomness leads to a less stable alignment with the timing of observed events (Figure 7). While the overall magnitude of predicted damages remains consistent with the real data, individual occurrences are not always accurately reproduced.

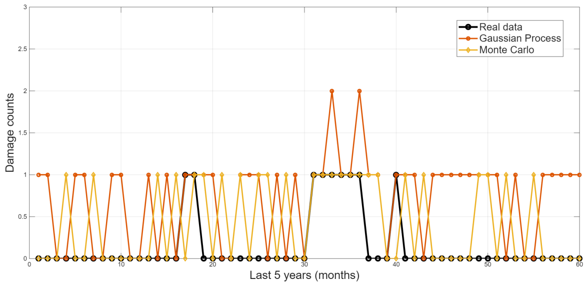


Figure 7: B787 – Ground impact damage validation process.

To summarize and provide a clearer overview, the following table presents the expected structural damages for the Neos fleet in 2026, including those estimated for the Boeing 737 MAX.

Fleet	Damage Type	Count
Boeing 737	Lightning strike	44
	FOD	65
	Ground impact	82
Boeing 787	Lightning strike	37
	FOD	20
	Ground impact	11

Table 2: Total damage counts by fleet and damage type.

6. Cost estimation

The final part of the thesis presents the economic assessment of the predicted structural damages. Damages are classified into three categories—no action, minor repair, and major repair—according to the maintenance activities required. Cost estimation relies on the man-hours necessary for technical, engineering, and NDT activities, combined with an average European labor rate derived from actual data provided by Neos Air and its main maintenance suppliers, and these direct repair costs are largely covered by the company's insurance policies. In the case of major repairs, an Aircraft on Ground (AOG) condition may arise, which in turn triggers indirect operational costs, such as ACMI wet-lease aircraft, aircraft positioning, and EU 261 passenger compensation [3], that are not covered by insurance and frequently represent the most impactful component of the overall financial burden.

For 2026, the economic assessment estimates the following structural damage costs:

- € 314 970 for lightning strike damages;
- € 189 090 for FOD damages;
- € 221 300 for ground impact damages.

The analysis shows that lightning strike events constitute the main cost driver—especially for the Boeing 787 fleet—followed by ground impact and FOD. Integrating indirect costs into the model further highlights that operational disruptions often outweigh repair expenses, emphasizing the need for preventive strategies, improved ground-handling practices, and data-driven planning to mitigate both technical and operational impacts.

7. Further Development

This section summarizes the adopted methodologies and their limitations, outlining key constraints and directions for future work. The thesis demonstrates the feasibility of migrating structural damage data to a single platform-`Amos`-to improve data centralization and support aircraft phase-out and transfer processes. Although validated on a single aircraft due to data complexity, the approach can be extended to the full fleet and largely automated after initial implementation.

A fully integrated database would enhance data accessibility and operational efficiency for both technical and engineering departments, while fleet-wide analyses could reveal additional damage trends, despite persistent limitations in historical data quality. Future improvements include refining damage cause classification, developing more suitable methods for trend analysis of Boeing 737 MAX fleet, and extending the analysis to additional damage categories such as bird strike, fatigue, hail, and corrosion.

8. Conclusions

In conclusion, this thesis proposes an integrated framework for the management of structural damages that combines engineering, analytical, and economic aspects. The adoption of a single data management platform, together with advanced analysis and forecasting methodologies, enables Neos Air to improve cost visibility, strengthen operational control, and address future fleet transitions and the evolving regulatory environment in a more structured and effective manner.

References

[1] Boeing. Service letter 73(6)7-sl-51-041/035: Major/minor repair classification. Technical report, Boeing, 11 2013.

[2] Boeing. *Structural Repair Manual.* Boeing Commercial Airplanes, 2025.

[3] European Parliament and Council of the European Union. Regulation 261/2004 of the european parliament and of the council of 11 february 2004, 2004.