SYSTEMIC ANALYSIS OF A C-130H HERCULES AIRCRAFT ACCIDENT: AN MBSE-BASED APPROACH INTEGRATED WITH SMS

Ester dos Santos Quintino[1], Christopher Cerqueira[2], Moacyr Cardoso[1], Guilherme Moreira[1], Willer Gomes[1]

[1]Instituto Tecnológico de Aeronáutica (ITA), São José dos Campos/SP – Brazil

[2] Embry-Riddle Aeronautical University, Daytona Beach/FL – United States of America

Resume — Military aviation operates in a highly complex sociotechnical environment in which human, operational, technological, and organizational factors interact dynamically. This study applies Model-Based Systems Engineering (MBSE) to the systemic analysis of an accident involving a C-130H Hercules aircraft during landing. The methodology combined documentary research with functional modeling of the main functions involved in the approach, touchdown, weight transfer to the wheels, braking, and aircraft stopping. Contributing factors identified in the investigation report were then related to Safety Management System (SMS) processes. The results showed that excessive approach speed triggered successive functional failures, compromising touchdown conditions, weight transfer to the wheels, and braking effectiveness. The integration between MBSE and SMS provided a structured representation of the accident's functional interdependencies and enabled operational deviations to be interpreted within a safety risk management perspective. The proposed approach supports the structured integration of accident investigation findings with SMS processes.

I. INTRODUCTION

Safety in military aviation results from the dynamic interaction among aircraft, crews, operational procedures, infrastructure, environmental conditions, and organizational structures. Therefore, accidents should not be analyzed solely as the result of isolated failures, but as events emerging from interactions among technical, human, operational, and organizational factors. Although accident investigation reports provide valuable sources of organizational learning, their predominantly descriptive nature may limit their direct integration with formal engineering and risk management processes. MBSE supports the structured representation of system functions, interfaces, and interdependencies, while SMS provides a systematic framework for hazard identification, risk assessment, and the implementation of mitigation measures.

Objective: To apply MBSE concepts to the systemic analysis of a C-130H Hercules accident, reinterpret the contributing factors from an SMS perspective, and explore the integration of system modeling, accident investigation, and safety management.

II. METHODOLOGY

The study adopted a qualitative, applied, exploratory, and descriptive approach based on a single case study. The selected case was the accident involving a C-130H Hercules aircraft at Camp Taji, Iraq, in 2020, during the landing phase.

Analysis Steps:

1. Documentary analysis of the official accident investigation report and literature on aviation safety and systems engineering.
2. Identification of the event sequence, operational parameters, crew actions, and contributing factors documented in the investigation.
3. Functional representation of the landing sequence, organizing the accident information into the functions of energy management, approach profile control, touchdown, load transfer to the wheels, braking, and aircraft stopping.
4. Analysis of functional relationships and failure propagation, based on the sequence of events and technical dependencies described in the investigation report.
5. Integration with SMS processes, relating the identified elements to hazards, degraded conditions, mitigation barriers, and undesired events.

The methodology integrated documentary analysis, systemic modeling, and the interpretation of the results from an operational safety perspective.

Manage Aircraft Energy
Control aircraft speed, attitude, and configuration during approach.
Failure: Excessive Speed
Approach speed above the recommended value.
↓
Control Approach Profile
Maintain a stable descent path in accordance with procedures.
Failure: Deviation from the Approach Profile
Descent angle steeper than recommended.
↓
Perform Touchdown
Establish initial contact with the runway under proper conditions.
Failure: High-Energy Touchdown
Hard touchdown with excessive vertical and horizontal energy.
↓
Transfer Load to Wheels
Transfer aircraft weight to the wheels after touchdown.
Failure: Insufficient Load on Wheels
Residual lift and porpoising reduce wheel loading.
↓
Apply Braking
Apply brakes to reduce speed and stop within the available runway length.
Failure: Ineffective or Delayed Braking
Reduced braking effectiveness due to insufficient wheel loading.
↓
Stop Aircraft
Reduce speed to zero within the available runway length.
FINAL FAILURE: RUNWAY OVERRUN
The aircraft exceeds the runway end and collides with obstacles.

Figure 1. Functional representation of deviation propagation during the landing sequence.

The representation organizes the sequence of events described in the accident investigation report. Excessive approach speed affected touchdown conditions, while residual lift reduced load transfer to the wheels and compromised braking effectiveness, ultimately leading to the runway overrun. The contribution of the representation is the structured visualization of the relationships among system functions and deviations.

III. RESULTS AND DISCUSSION

The functional representation showed that the accident did not result from a single isolated failure, but from the propagation of deviations across interdependent system functions. Aircraft energy management played a central role in the event, since excessive approach speed affected touchdown conditions, load transfer to the wheels, and braking effectiveness.

The accident sequence was already documented in the official investigation report. The contribution of the proposed representation was to organize these findings into a structured view of functional relationships and support their interpretation within an SMS perspective. The analysis highlighted how operational deviations, degraded conditions, and reduced barrier effectiveness contributed to the runway overrun.

Key Contributions:

- Structured organization of investigation findings.
- Explicit representation of functional relationships.
- Integration of accident investigation findings with SMS concepts.
- Improved visibility of accident interdependencies.
- Support for traceability between operational evidence and safety interpretations.

Table 1. Relationship between Identified Element and SMS interpretation

Identified Element	SMS Interpretation
Excessive approach speed	Operational hazard
Approach profile deviation	Operational failure
High-energy touchdown	Degraded condition
Residual lift	Barrier failure
Ineffective braking	Mitigation failure
Runway overrun	Undesired event

The integration between MBSE and SMS provided an interpretative framework relating accident investigation findings to SMS concepts. The representation highlighted how operational deviations progressed through degraded conditions and reduced barrier effectiveness until the runway overrun occurred.

III. CONCLUSION

The study demonstrated how accident investigation findings can be organized into a structured functional representation and related to SMS concepts. The proposed approach improved the visibility of relationships among operational evidence, system functions, deviations, and safety barriers, supporting a more systematic interpretation of accident data in military aviation.

REFERENCES

[1] International Civil Aviation Organization, *Annex 19: Safety Management*. [Online]. Available: ICAO Annex 19. Accessed: Jun. 28, 2026.

[2] J. Reason, *Managing the Risks of Organizational Accidents*. Ashgate Publishing, 1997.

[3] International Civil Aviation Organization, "Safety Management System (SMS) framework." [Online]. Available: ICAO SMS Framework. Accessed: Jun. 28, 2026.

[4] International Civil Aviation Organization, *Safety Management Manual*, Doc 9859. [Online]. Available: ICAO Safety Management Manual. Accessed: Jun. 28, 2026.

[5] International Civil Aviation Organization, *Annex 13: Aircraft Accident and Incident Investigation*, 13th ed., Jul. 2024. [Online]. Available: ICAO Annex 13. Accessed: Jun. 28, 2026.

[6] International Civil Aviation Organization, *Manual of Aircraft Accident and Incident Investigation*, Doc 9756. [Online]. Available: ICAO Accident Investigation Documents. Accessed: Jun. 28, 2026.

[7] INCOSE and Object Management Group, "Model-Based Systems Engineering (MBSE) definition." [Online]. Available: INCOSE/OMG MBSE Wiki. Accessed: Jun. 28, 2026.

[8] Object Management Group, *Model-Based Systems Engineering*. [Online]. Available: OMG MBSE Document. Accessed: Jun. 28, 2026.

[9] Systems Engineering Body of Knowledge, "Model-Based Systems Engineering." [Online]. Available: SEBoK MBSE. Accessed: Jun. 28, 2026.

[10] S. Mbaye, G. Jones, S. Infeld, and M. Davies, "A model-based systems engineering evaluation of the evolution to an in-time aviation safety management system," in *Proc. AIAA AVIATION 2022 Forum*, Chicago, IL, USA, 2022. [Online]. Available: NASA Technical Reports Server. Accessed: Jun. 28, 2026.

[11] Aircraft Accident Investigation Board, *Aircraft Accident Investigation Board Report: C-130H, T/N 94-6706, Camp Taji, Iraq*, 2020. [Online]. Available: C-130H Accident Investigation Report. Accessed: Jun. 28, 2026.

[12] Air Mobility Command, "C-130H mishap investigation results released." [Online]. Available: Air Mobility Command Investigation Release. Accessed: Jun. 28, 2026.