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ANALYSIS OF APPROACHES TO ASSESSING FLIGHT DELAYS DUE TO TECHNICAL ISSUES AT AIRLINE NETWORK AIRPORTS WITHIN THE OPERATIONAL MANAGEMENT FRAMEWORK

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ABSTRACT

This paper analyzes approaches to developing models for the technical exploitation (TE) of aircraft within operational management framework. The operational management contour of the TE of the airline's AC fleet is considered as a TE process consisting of a sequence of flight routes, which, in turn, comprise a sequence of flights between airports in the airline network during the calendar interval when the aircraft are in this contour. We present a model that evaluates the capacity for aircraft recovery at the network airports of a hypothetical airline (dubbed "RAF") if the need so arises, utilizing the probabilistic and temporal characteristics of the airports used for aircraft recovery.

Keywords

aircraft; technical exploitation; operational management.

1. INTRODUCTION

The technical exploitation of aircraft is carried out through a process of sequential changes in organizational and technical states. Technical states correspond to changes in the technical quality of the aircraft as an operational object [1,2,3]. Organizational states are associated with the processes of organizing and utilizing aircraft at various stages of their technical exploitation, including the phases where the aircraft is:

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– at its home (base) airport;
– in flight;
– at a transit airport;
– at an airport of the transit base type;
– outside the operational management contour of its technical exploitation.

The sequence of transitions and stays of the aircraft through these stages of its technical exploitation is determined by a number of factors [1,2]:

- the demands for aircraft utilization generated by the flight phase, characterized by the parameters of the flight schedule within the airline network;
- the necessity for aircraft recovery outside the operational management contour of the aircraft fleet's technical exploitation (including periodic technical exploitation and/or maintenance, etc.);
- the need for aircraft recovery at the airports of the airline network, prompted by changes in the aircraft's state during flight operations;
- the opportunities for aircraft recovery at the airports of the airline network;
- the list of permissible failures reflecting the structural and operational properties of the aircraft.

The technical exploitation of aircraft includes [2]:

- ground maintenance of the aircraft;
- airborne technical exploitation during flight (in the air).

For each of these, there is a characteristic set of states that may be represented in the form of graphs containing a specific set of nodes and transitions [4]. The nodes (vertices) of the graph correspond to tasks, while the edges represent relationships between tasks. Such graphic models facilitate the identification of quantitative relationships between nodes to improve the processes of aircraft technical exploitation through statistical research methods [5].

Operational management of technical exploitation processes involves the continuous monitoring of parameters of the aircraft technical exploitation process and adherence to the dispatch schedule for aircraft utilization [6]. The operational control loop is based on the model of aircraft technical exploitation processes, presented in the form of technological chains consisting, in turn, of technological elements related to the aircraft utilization process at various stages. Therefore, a crucial aspect of describing the aircraft technical exploitation process, in addition to describing its structure, is describing the mechanism that determines the sequence of transitions and stays of the aircraft in different states at various stages of technical exploitation [1,2].

2. CHARACTERISTICS OF THE AIRLINE NETWORK OF THE INVESTIGATED AIRLINE

Each route within the airline's network, taking into account intermediate landings between the base (initial) and final destination airports, consists of N individual (discrete) elements, representing individual flights [7]. The parameter n represents the flight number within a particular route, taking values within the sequence of integers $n \in \{1, ..., N\}$. Individual flights are separated by layover time intervals, Ts. If technical failures arise during any flight requiring resolution at any airport, potentially leading to flight delays, these recovery periods should be considered to assess the probability and duration of delay. Flights along the route proceed between airports of different types [2]. For the purposes of this study, the airports along a route are classified into three categories, based on their capabilities for aircraft recovery, if necessary:

- B – Base Airport (serves as the initial and final airport on any route),
- T – Transit Airport (facilitates intermediate stops but not necessarily equipped for extensive recovery operations),
- TB – Transit Base (facilitates intermediate stops, is equipped for extensive recover operations).

The airline's information base contains the necessary probabilistic and other data required to reduce the risks of departure delays at these airports due to the need for aircraft recovery [8], as shown in Table 1 [9].

Table 1. Probabilistic and Other Data for Airports in the Airline Network [9]

	Characteristic	**Airport Type**		
		T	**TB**	**B**
1	Probability of Availability of Spare Parts Required for Aircraft Recovery	$P_{\square}^{T}$	$P_{\square}^{TB}$	$P_{\square}^{B}$
2	Probabilistic Characteristics of Aircraft Recovery Time (T_R)	$F^{T}(t)$	$F^{TB}(t)$	$F^{B}(t)$
3	Probabilistic Characteristics of Operational Delivery of Required Spare Parts in Case of Their Absence at the Airport (T_D)	$G^{T}(t)$	$G^{TB}(t)$	$G^{B}(t)$
4	Availability of Specialists for Aircraft Recovery Work	No	Yes	Yes
5	Average Aircraft Ground Time at the Airport	T_{CT}^{T}	T_{CT}^{TB}	T_{CT}^{B}

3. THE STRUCTURE OF AIRLINE NETWORK FLIGHTS

The structure of network flights for an airline with the provisional name "RAF" is presented in Table 2. Each flight route within the network consists of a sequence of flights with layovers at airports of different types.

Table 2. Structure of the airline network routes for RAF

	Flight Route Structure (Graphical Representation)	Flight Parameters
1	B – T – B	1/2
2	B – T – T – B	1/3
3	B – T – T B – B	1/3
4	B – T – T – T – B	1/4
5	B – T – T – TB – B	1/4
6	B – T – TB – T – B	1/4
7	B – TB – TB – T – TB – B	1/5
8	B – TB – B – TB – TB – B	1/5
9	B – TB – T – TB – T – TB – B	1/6
10	B – T – T – T – TB – T – TB – B	1/7
11	B – TB – T – TB – T – T – TB – B	1/7
12	B – TB – T – T – TB – T – TB – B	1/7

Let X_l represent a flight route of type l in the general set $X = \{X_1, X_2, \ldots, X_L\}$, where L is the total number of flight route types in the airline network (for Table 2, $L = 12$). Each flight route X_l within a given calendar time interval can be described by the following quantitative parameters:

- The proportion P_l of flights of type X_l in the total number of flights X performed by the airline within the airline network;
- The ratio $K_l = V_l^B / V_l$ of the number of departures (landings) that occur at the base airport for each route type l.

3. THE 'STATES' OF THE AIRCRAFT IN THE IN-FLIGHT TECHNICAL EXPLOITATION PROCESS

Definition: By "state of the aircraft in-flight," we mean situations that arise when an aircraft is in a normal flight mode, but affected by one or more adverse factors, leading to diminished level of flight safety l. In this context, adverse factors are exclusively considered as failures of aviation equipment [10,11].

In general, the "state of the aircraft in-flight" encompasses a combination of aircraft properties and psychophysiological indicators of pilots, which are subject to change due to the impact of adverse factors affecting the aircraft, leading the flight mode to deviate from the "normal" state. Regulatory documents categorize these deviations as "special situations" [10,11]. According to these documents, there can be four potential special situations in flight: complicating flight conditions (CFC), a complex situation (CS), an emergency situation (ES), or a catastrophic situation (CatS), see Fig. 1.

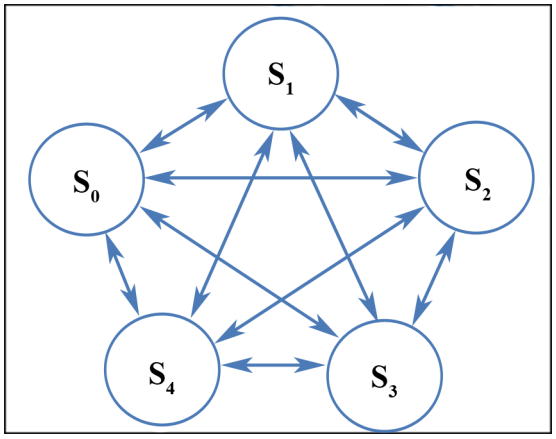


Fig. 1. Graph of the "states" and transitions within the in-flight technical exploitation process of the aircraft

Transitions from the normal state (S_0) to any of the other four states, and from intermediate states to any other, depend on the magnitude of changes in aircraft properties and psychophysiological status of pilots. These transitions are determined by the characteristics of special situations [12].

The identification of specific failures during flight and their impact on flight operations is guided by a list of permissible failures, which classifies the aircraft's states into several categories for managing aircraft recovery within the airline network [8,10]:

S_0 – The aircraft is free from detected failures.

S_1 – The aircraft has at least one detected failure, for which the aircraft is allowed to continue operations until the next periodic maintenance.

S_2 – The aircraft has at least one detected failure, for which the aircraft is allowed to continue operations until the base airport.

S_3 – The aircraft has at least one detected failure, for which flight of the aircraft is not permitted.

Note that in the absence of a list of permissible failures, only to two states, S_0 and S_3 will be recognized.

Figure 2 presents a diagram of possible transitions of the aircraft through states S_0 within the operational management contour of the technical exploitation process.

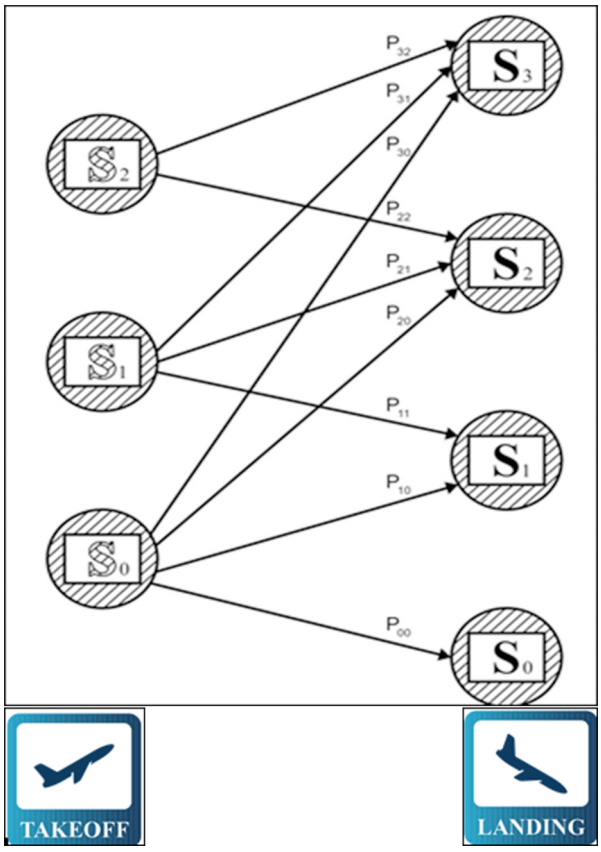


Fig. 2. State graph and transitions of the aircraft during the flight

To describe the dynamics of an aircraft's state within a given airline network structure, it is necessary to account for the processes of changes in state during each flight on a specific route, and the sequence of flights within the timeframe of the aircraft's presence in the operational control loop of the technical exploitation process, under certain assumptions.

- In-flight, the aircraft's state does not improve.
- Departure for a flight (i.e., from an airport of type B) is allowed only in states S_0 or S_1.
- Departure for a flight from airports of types T and TB is allowed in states S_0, S_1 or S_2.

According to Figure 2 and Table 1, the possibilities for aircraft recovery at airports are as follows [11]:

– At airports of type B, states S_2 and S_3, depending on the production situation and characteristics $P^B, F^B(t), G^B(t), P_Z, P_{RES}, T^B_{CT}$ may be restored to the level of S_0 or S_1.
– At airports of types T and TB, state S_3, depending on the production situation and characteristics $P^B, P^{TB}, F^T(t), F^{TB}(t)$, G^T($t$), $G^T(t), G^{TB}(t), T^T_{CT}, T^{TB}_{CT}$ may be restored to the level of S_0, S_1 or S_2. State S_2 at these airports may be restored to the level of S_1 or S_0, or may not be restored at all, depending on the circumstances.

Thus, the differences between airports of types T and TB essentially boil down to variations in the characteristics $P, F(t), G(t)$ and T_{CT}. In the absence of specific dependencies for the given aircraft operated by the airline on the parameter of failure flow based on usage, and without information on the distribution of aircraft and their components by usage, it is reasonable to assume that the parameters of the aircraft failure flow remain constant – both within the time frame of the aircraft's presence in the operational control loop of the technical exploitation process, and within the sequence of transitions of the aircraft within this loop.

4. THE PROCESS OF AIRCRAFT RECOVERY AND THE OCCURRENCE OF DEPARTURE DELAYS AT AIRPORTS WITHIN THE AIRLINE NETWORK

The recovery of the aircraft state at airports within the airline network and the occurrence of departure delays, driven by the need for aircraft state recovery, are influenced by several factors:

- The emergence of recovery demand, generated by changes in aircraft state during flight.
- The conditions and organization of aircraft recovery at the airports within the airline network, which can be described using the characteristics provided in Table 1.
- The permissible failure list, i.e., the presence of states S_1 and S_2.

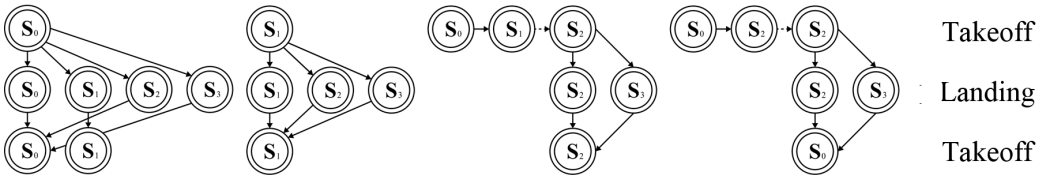
According to the definition of aircraft states, the following regeneration cycles are associated with aircraft state recovery [8,14]:

- For state S_1 – recovery of the aircraft by transitioning from S_1 to S_0, is realized through periodic maintenance and/or repair, within the time between consecutive transitions into the operational control loop of the technical exploitation process for the aircraft.
- For state S_2 – recovery of the aircraft by transitioning from S_2 to S_0 or S_2 to S_1, is only implemented at airports of type "B," within the time between consecutive

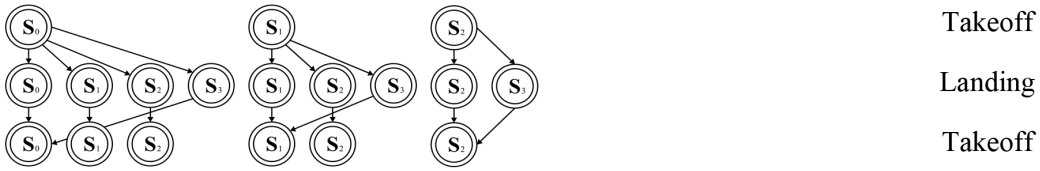
flight routes. If the preceding flights involved a transition from S_0 to S_2, then the recovery is accomplished by transitioning from S_2 to S_0. If the previous flights involved a transition from S_1 to S_2, then the recovery is accomplished by transitioning from S_2 to S_1 (corresponding to the regeneration cycle of state S_1 mentioned earlier).

- For state S_3 – recovery of the aircraft by transitioning from S_3 to S_0 or S_3 to S_1 or S_3 to S_2, is implemented within the time the aircraft spends at any of the considered types of airports, i.e., within the time between consecutive departures. The state to which the aircraft transitions is determined by the state in which it departed for its preceding flight and the type of airport where the recovery is carried out.

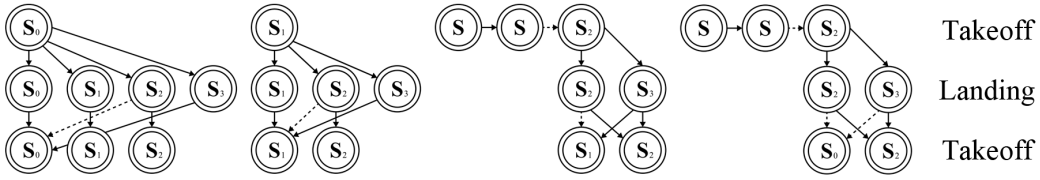
The regeneration cycles of aircraft states in the process of their technical exploitation is presented in Figure 3 as graphs of aircraft recovery [5], for airports of type "B," "T," and "TB," respectively.



Graphs of aircraft states and transitions at a "B" type airport and the preceding flight



Graphs of aircraft states and transitions at a "T" type airport and the preceding flight



Graphs of aircraft states and transitions at a "TB" type airport and the preceding flight

Variant regeneration cycles at different airports for aircraft states during their technical operation in the event of aviation equipment failures

Fig. 3. The regeneration cycles of aircraft states in the process of their Technical Exploitation

5. CONCLUSION

The need to restore aircraft states at airports within the airline network is prompted by in-flight situations related to technical failures, leading to possible departure delays.

Two main mechanisms can be identified for the formation of such delays:

1. The first mechanism is characteristic for airports of type "T" and "TB" and involves the following:
   - When a need for aircraft recovery arises, it is contingent upon the availability of the necessary spare parts at the airport. The overall duration of aircraft recovery in this case is described by the recovery time distribution function $F(t)$ for the corresponding airport type.
   - If the required spare parts are not available, the parts must be delivered through available channels, and the duration is determined by the distribution function $G(t)$ for the corresponding airport type. The total duration of aircraft recovery is the sum of durations according to the distributions $F(t)$ and $G(t)$ for the corresponding airport type.
2. The second mechanism, in turn, is characteristic for airports of type "B" and is related to the probability of including the aircraft in the next flight route.
   - If the aircraft is indeed slated for the next flight route, unlike the first mechanism, the probability P_{pe3} of having a reserve aircraft available is established. If no reserve aircraft is available, the recovery default to the first mechanism.
   - If the aircraft is not included in the next flight route, it is assumed that situations leading to departure delays do not occur.

If the total duration of aircraft recovery (under both the first and second mechanisms) does not exceed the aircraft's parking time (T_{CT}) at the corresponding airport type, then departure delays do not occur. Otherwise, the duration of the delay is determined as the difference between the total duration of aircraft recovery and T_{CT}.

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