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A Prediction Model for Night Recovery of Embarked Aircrafts Based on System Dynamics

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ABSTRACT: In order to make a sensible prediction on the air traffic flow management with conditions of wave-off and bolter, a system dynamic model for the night recovery operations of embarked aircrafts is built to ensure the adaption of air traffic flow with the capacity of air control at each phase of the recovery operations. The model aims at the characteristics of multiple feedbacks, delays and complex time varying, builds a stock flow diagram and operation model with impact factors of the night recovery system, and is simulated in Vensim® Personal Learning Edition 5.9. The simulation shows a reasonable prediction result for the night recovery of embarked aircrafts with conditions of bolter and wave-off and can provide a theoretical basis for scheduling the air traffic flow management of embarked aircrafts formation recovery.

KEYWORDS: Air traffic flow management, Recovery, Embarked aircrafts formation, System dynamics, Complex system modeling.

INTRODUCTION

Aircraft Carrier Attack (CVA), with the ability of fast oversea power projection, becomes the main combat force of modern navies. For a large number of aircrafts in the process of formation recovery, secure, efficient and sequential air traffic flow managements are necessary to make full use of the capacity of airspace and flight deck, improve the utilization of time and space, and provide the latest information for the carrier-aircrafts system.

The issue on civil air traffic flow management has been well studied by researchers both at home and abroad. Taking the complexity of the air traffic management system (Zhang *et al.* 2009) into consideration, researchers presented 3 approaches to solve the air traffic flow management problem: air traffic capacity management (Yang and Hu 2010), ground holding management (Ye and Hu 2010) and flight schedule optimization (Zhang and Hu 2010). Meng *et al.* (2012) studied the problem of air traffic flow management in uncertain severe convective weather and established a dynamic reroute planning model based on genetic algorithms. In Liu and Hu (2011), an auction-based market method was proposed to solve the congestion problem of airspace in the stage of pre-tactic and tactic air traffic flow management, and a decision-making model for airline company was analyzed based on game theory. Bertsimas *et al.* (2008) used an integer optimization method to research the air traffic flow management while DeArmo *et al.* (2010) studied the preliminary benefits of the analysis of air traffic flow management. Weigang *et al.* (2008) studied a decision-support system of the tactical air traffic flow management.

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A dynamic model for air traffic flow management and a research about the flight deck scheduling based on distributed network were presented in Mukherjee and Hansen (2009) and Dastidar and Frazzoli (2011), respectively. Ryan *et al.* (2011) designed an interactively local and global decision-support system for aircraft carrier deck scheduling. In Yue *et al.* (2013a), the stock flowchart and the mathematical model of the complex time-varying system for dynamic handling of embarked aircrafts were built based on system dynamics (SD) after discussion of the process of aircraft turnaround and transferring of embarked aircrafts among the flight deck, hangar and elevators. In Yue *et al.* (2013b), to make a reasonable schedule of recovery considering wave-off and bolter of aircrafts, an operation model on embarked aircraft recovery in good weather was built. Wesonga (2015) presented a practical stochastic optimization model for air traffic flow management (ATFM) of airports, considering the airport delay based on multivariate statistics. The uncertainty of effective measures in ATFM was estimated with multivariate probabilistic collocation method (PCM) in Zhou *et al.* (2014). The issue of determining the stochastic capacity of airspace in ATFM was discussed in Clarke *et al.* (2013). The heating effect of jet blast from 4 embarked aircrafts on take-off zone of the flight deck was studied in Yue *et al.* (2015a) based on CFD technique and, similarly, the impact of the jet blast on the jet blast deflector (JBD) was discussed based on CFD theory in Yue *et al.* (2015b).

Nevertheless, researches on the system modeling problems of ATFM model, like multiple feedback factors, time delay and complex time-varying, are not sufficient. In addition, the study on the differences of ATFM between the aircraft carrier and civil airport brought by different environments and platforms is also inadequate. For example, due to the high risk of night recovery of embarked aircrafts, an accurate recovery schedule is necessary to ensure the security. However, if bolter or wave-off happens due to landing misses, the time schedule of recovery will be disrupted, recovery will be delayed, reduction of efficiency will be consequent, and the recovery security will be even harmed.

In order to solve the existing problems in the previous models, a system dynamic method is applied in this study to build an ATFM model of embarked aircraft night recovery. It is expected that it provides a viable solution to solve such ATFM problems.

PREDICTION MODEL

System dynamics is an integrated science of systems theory and computer simulation focusing on the system feedbacks and actions (Yue *et al.* 2011). It is introduced into various fields, such as economic, military, and ecological to solve the problems of complex non-linear giant systems with feedback structures (Wolstenholme 2003; Thompson and Tebbens 2007).

The prediction model based on system dynamics theory has 4 parts: the analysis of night recovery process of embarked aircraft formation, the system boundaries determination and basic assumptions, stock flow diagram analysis and equation setups.

NIGHT RECOVERY PROCESS OF EMBARKED AIRCRAFT FORMATION ANALYSIS

Night recovery of embarked aircraft is quite different from that in the daytime, because this operates under the Case I weather condition while night recovery is conducted under the Case III one.

The process of night recovery of embarked aircraft formation includes the arrival, approach, final approach, deck landing, bolter or wave-off phases (Figs. 1 and 2).

Wave-off means the maneuver of nose-up for climbing of the embarked aircraft before touching the deck. It happens generally in adverse meteorological conditions of landing, inappropriate manipulating of the pilot, excessive deck motion etc. Bolter happens if the tail hook of the aircraft bouncing above the arrestor cable when touching the deck or the aircraft misses all the cables on the arresting area when landing. In this case, the aircraft must be powered up immediately to climb for safety.

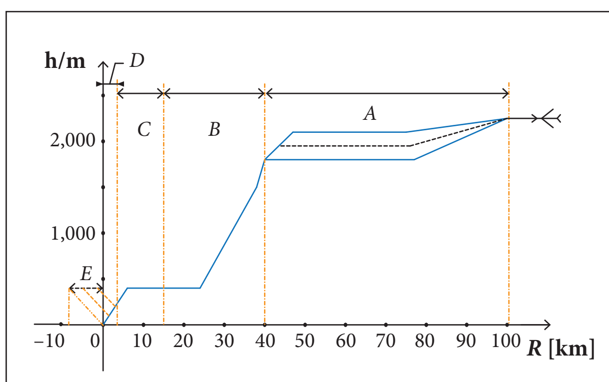

Figure 1. Flight cross-sectional view of the night recovery of embarked aircraft formation.

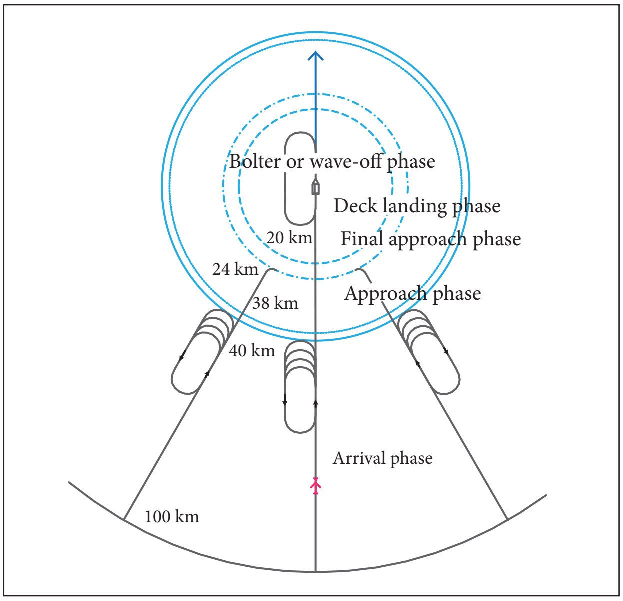

Figure 2. Vertical view of night recovery patterns for embarked aircrafts.

THE DETERMINATION OF SYSTEM BOUNDARIES AND BASIC ASSUMPTIONS

The system boundaries of the prediction model depend primarily on the scope and span of the variables and time, being determined according to the state variables. The subject of this paper is the number of embarked aircrafts at each phase of the night recovery. Only the related entities are concerned, including the number of embarked aircrafts at the mentioned phases (*A* — arrival; *B* — approach; *C* — final approach; *D* — deck landing; *E* — bolter or wave-off; Fig. 1), deck arrestor gear area, flight deck landing area and temporary spots. The connections of the entities form the entire system discussed here.

Various uncertainties exist in the night recovery process during over-sea operations. The primary concerns of this research include key factors such as spinning of the embarked aircrafts, target acquisition with landing director radar and optical landing aid system, wave-off, bolter, touching the deck, arresting, and taxiing.

The following assumptions are presented to simplify the prediction system:

- The night recovery system of embarked aircrafts is continuous over time.
- The remaining fuel of aircrafts is sufficient for landing, waving-off and bolter.
- Flight accidents are excluded from the model.

STOCK FLOW DIAGRAM ANALYSIS

The stock flow diagram is built to distinguish the variables, clarify the logical relationships among the various elements, feedback forms and control laws of the system. It is a representation method with intuitive symbols for further research on the system.

The stock flow diagram of the prediction system is a structural description of the arrival holding pattern, approach and final approach, landing route, wave-off, bolter, arresting gear area, deck landing area and temporary spots. It holds much more information than written statements can do and is clearer and more accurate in logic. The diagram consists of 9 state variables, 11 rate variables and 23 auxiliary variables (Fig. 3).

EQUATION ESTABLISHMENT

The operation of the prediction system has the characteristics of complex time-varying. Figure 3 presents the explanations of the system, which can improve the understanding of Eqs. 1 to 24.

$$\frac{dL_{jc}(t)}{dt} = \xi_{jc}(t) - \xi_{tcdd}(t) \tag{1}$$

$$\frac{dL_{jj}(t)}{dt} = \xi_{tcdd}(t) - \xi_{ld}(t) \tag{2}$$

$$\frac{dL_{zhjj}(t)}{dt} = \xi_{ld}(t) + \xi_{ffqr}(t) + \xi_{tyqr}(t) - \xi_{gx}(t) \tag{3}$$

$$\frac{dL_{zjhx}(t)}{dt} = \xi_{gx}(t) - \xi_{ff}(t) - \xi_{cj}(t) \tag{4}$$

$$\frac{dL_{ff}(t)}{dt} = \xi_{ff}(t) - \xi_{ffqr}(t) \tag{5}$$

$$\frac{dL_{zlq}(t)}{dt} = \xi_{cj}(t) - \xi_{zl}(t) - \xi_{ty}(t) \tag{6}$$

$$\frac{dL_{ty}(t)}{dt} = \xi_{ty}(t) - \xi_{tyqr}(t) \tag{7}$$

$$\frac{dL_{lt}(t)}{dt} = \xi_{zl}(t) - \xi_{hx}(t) \tag{8}$$

$$\frac{dL_{lstj}(t)}{dt} = \xi_{hx}(t) \tag{9}$$

where: $L_{jc}(t)$ is the number of embarked aircrafts in arrival holding pattern; t represents time, in min; $\xi_{jc}(t)$ is the flow rate of arriving embarked aircrafts; $\xi_{tcdd}(t)$ is the flow of embarked aircrafts departing from the spin holding pattern; $L_{jj}(t)$ is the number of aircrafts in approach phase; $\xi_{ld}(t)$ is the flow rate of embarked aircrafts captured by landing director radar; $L_{zhjj}(t)$ is the number of embarked aircrafts in final approach; $\xi_{ffqr}(t)$ is the flow rate of embarked aircrafts from wave-off to final approach; $\xi_{tyqr}(t)$ is the flow rate of aircrafts from bolter to final approach; $\xi_{gx}(t)$ is the flow rate of embarked aircrafts captured by optical landing aid system; $L_{zjhx}(t)$ is the number of embarked aircrafts deck in landing pattern; $\xi_{ff}(t)$ is the flow rate of embarked aircrafts waving off; $\xi_{cj}(t)$ is the flow rate of embarked aircrafts touching the flight deck; $L_{ff}(t)$ is the number of embarked aircrafts waving off; $L_{zlq}(t)$ is the number of embarked aircrafts in the arresting gear area;

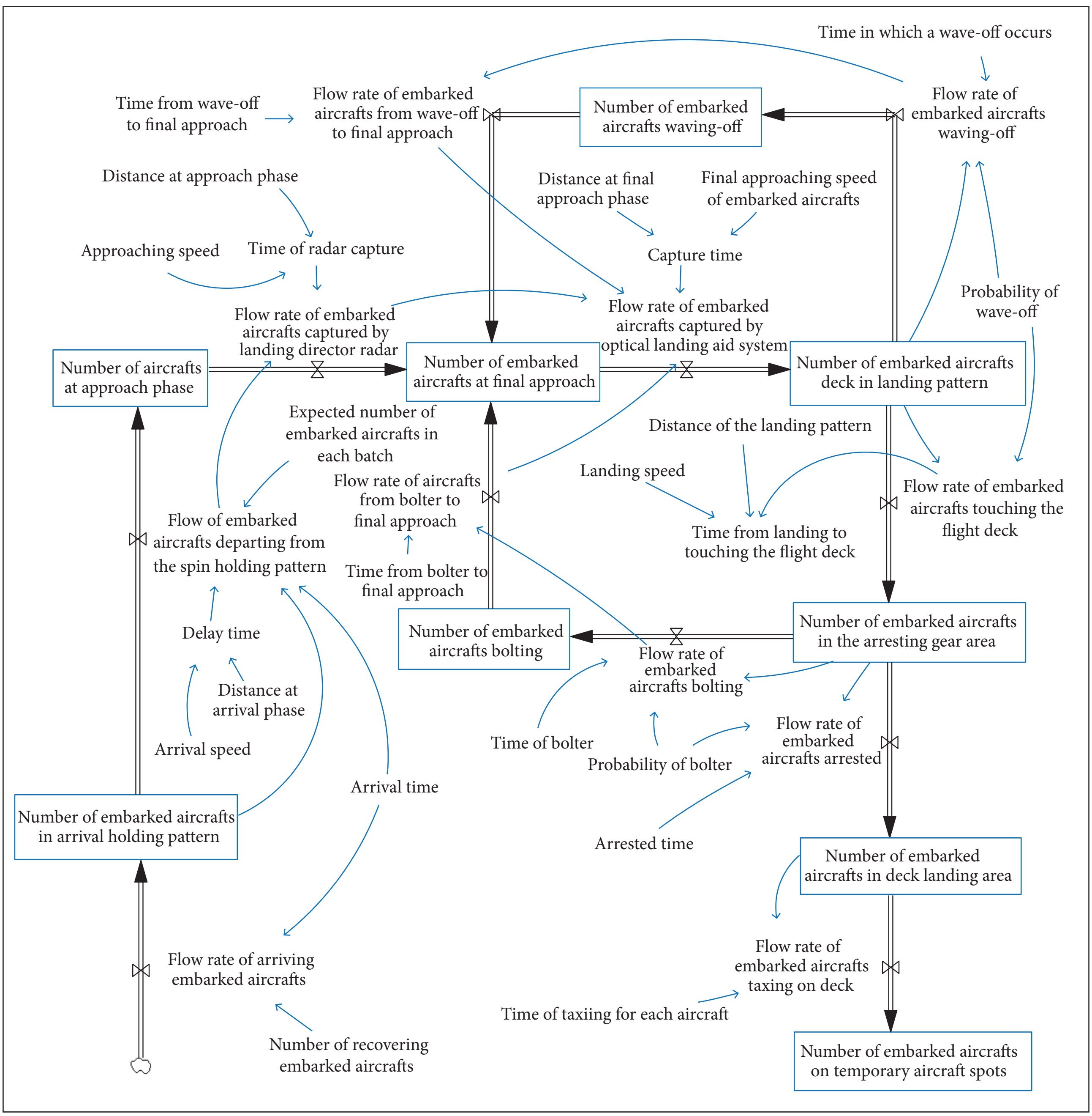

Figure 3. Stock flow diagram of the prediction system for the night recovery of embarked aircrafts.

$\xi_{zl}(t)$ is the flow rate of embarked aircrafts arrested; $\xi_{ty}(t)$ is the flow rate of embarked aircrafts bolting; $L_{ty}(t)$ is the number of embarked aircrafts bolting; $L_{lt}(t)$ is the number of embarked aircrafts in deck landing area; $\xi_{hx}(t)$ is the flow rate of embarked aircrafts taxing on deck; $L_{lstj}(t)$ is the number of embarked aircrafts on temporary aircraft spots.

$$\xi_{jc}(t) = m_{hs} \times PULSE(t_{jc}, 1) \tag{10}$$

$$\xi_{tcdd}(t) = \begin{cases} PULSE(t_{jc} + t_{yc}, n_{db}) & L_{jc}(t) \geq 0 \\ 0 & L_{jc}(t) < 0 \end{cases} \tag{11}$$

$$t_{yc} = \frac{l_{jc}}{v_{jc}} \tag{12}$$

$$\xi_{ld}(t) = \eta_{gd}\left\langle \xi_{tcdd}(t), t_{ld}, 0 \right\rangle \tag{13}$$

$$t_{ld} = \frac{l_{jj}}{v_{jj}} \tag{14}$$

$$\xi_{gx}(t) = \eta_{gd}\left\langle \xi_{ld}(t) + \xi_{ffqr}(t) + \xi_{tyqr}(t), t_{bh}, 0 \right\rangle \tag{15}$$

$$t_{bh} = \frac{l_{zhjj}}{v_{zhjj}} \tag{16}$$

$$\xi_{ffqr}(t) = \eta_{gd}\left\langle \xi_{ff}(t), t_{ffqr}, 0 \right\rangle \tag{17}$$

$$\xi_{tyqr}(t) = \eta_{gd}\left\langle \xi_{ty}(t), t_{tyqr}, 0 \right\rangle \tag{18}$$

$$\xi_{ff}(t) = \begin{cases} L_{zjhx}(t) \times \lambda_{ff} / t_{xhff} & L_{zjhx}(t) \geq 0 \\ 0 & L_{zjhx}(t) < 0 \end{cases} \tag{19}$$

$$\xi_{cj}(t) = \begin{cases} L_{zjhx}(t) \times (1 - \lambda_{ff}) / t_{xhcj} & L_{zjhx}(t) \geq 0 \\ 0 & L_{zjhx}(t) < 0 \end{cases} \tag{20}$$

$$t_{xhcj} = \frac{l_{zjhx}}{v_{zjhx}} \tag{21}$$

$$\xi_{ty}(t) = \begin{cases} L_{zlq}(t) \times \lambda_{ty} / t_{ty} & L_{zlq}(t) \geq 0 \\ 0 & L_{zlq}(t) < 0 \end{cases} \tag{22}$$

$$\xi_{zl}(t) = \begin{cases} L_{zlq}(t) \times (1 - \lambda_{ty}) / t_{zl} & L_{zlq}(t) \geq 0 \\ 0 & L_{zlq}(t) < 0 \end{cases} \tag{23}$$

$$\xi_{hx}(t) = L_{lt}(t) / t_{hx} \tag{24}$$

where: m_{hs} is the number of recovering embarked aircrafts; t_{jc} is the arrival time, in min; $PULSE(t_{jc},1)$ is the single impulse function with a start point t_{jc} and a length of 1; t_{yc} is the delay time, in min; n_{db} is the expected number of embarked aircrafts in each batch; l_{jc} is the distance in arrival phase, in m; v_{jc} is the arrival speed, in m/min; $\eta_{gd}(\cdot,\cdot,\cdot)$ is the pipeline delay function; t_{ld} is the time of radar capture, in min; l_{jj} is the distance in approach phase, in m; v_{jj} is the approaching speed, in m/min; t_{bh} is the capture time, in min; l_{zhjj} is the distance in final approach phase, in m; v_{zhjj} is the final approaching speed of embarked aircrafts, in m/min; t_{ffqr} is the time from wave-off to final approach, in min; t_{tyqr} is the time from bolter to final approach, in min; ξ_{ff} is the probability of wave-off; t_{xhff} is the time when a wave-off occurs, in min; t_{xhcj} is the time from landing to touching the flight deck, in min; l_{zjhx} is the distance of the landing pattern, in m; v_{zjhx} is the landing speed, in m/min; λ_{ty} is the probability of bolter; t_{ty} is the time of bolter, in min; t_{zl} is the arrested time, in min; t_{hx} is the time of taxiing for each aircraft, in min.

SIMULATION CASES AND ANALYSIS

The model according to Eqs. 1 – 24 were simulated in Vensim® Personal Learning Edition 5.9. In this section, the model of night recovery is simulated based on the Russian aircraft carrier Kuznetsov. The initial values of the factors of the prediction system are: $L_{jc}(t_0) = 0$, $L_{jj}(t_0) = 0$, $L_{zhjj}(t_0) = 0$, $L_{zjhx}(t_0) = 0$, $L_{ff}(t_0) = 0$, $L_{zlq}(t_0) = 0$, $L_{lt}(t_0) = 0$, $L_{lstj}(t_0) = 0$, $m_{hs} = 8$, $t_{jc} = 10$ min, $n_{db} = 8$, $l_{jc} = 60$ km, $v_{jc} = 800$ km/h, $l_{jj} = 25$ km, $v_{jj} = 380$ km/h, $l_{zhjj} = 9$ km, $v_{zhjj} = 280$ km/h, $t_{ffqr} = 6$ min, $t_{tyqr} = 6$ min, $\lambda_{ff} = 0.2$, $t_{xhff} = 10$ s, $l_{zjhx} = 1$ km, $v_{zjhx} = 240$ km/h, $\lambda_{ty} = 0.3$, $t_{ty} = 3$ s, $t_{zl} = 3$ s and $t_{hx} = 30$ s. The control parameter $t = 0 \sim 90$ min.

WAVE-OFF OR BOLTER

The mathematical model of night recovery is a non-linear time-varying complex giant system with delays and feedback loops. The probability of wave-off and bolter is relatively high in night recovery. The simulation results of the number of aircrafts at each stage of the night recovery for an 8-aircraft formation with $\lambda_{ff} = 0.2$ and $\lambda_{ty} = 0.3$ are shown in Fig. 4.

In Figs. 4 and 5, the abscissa represents the time points of the embarked aircrafts in the recovery process and the vertical axis represents the quantity of embarked aircrafts.

Figure 4a shows the quantity of embarked aircrafts during night recovery at the arrival, approach, final approach and landing pattern phases. At the arrival phase, embarked aircrafts are assumed to enter when t = 10 min and it is completed when t = 11 min; when t = 14.5 min, embarked aircrafts in the 8-aircraft formation begin to withdraw from spin holding pattern in turn, and the phase is finished when t = 22.5 min. The arrival phase has a range of 60 km for the spin holding pattern, and the withdrawing rate of aircrafts can be controlled at 1 aircraft per min. When t = 14.5 min, the formation of embarked aircrafts enters the approach phase in turn. For the relatively small range about 25 km for the approach stage, a maximum of 4 aircrafts can be held in this phase. When t = 18.4 min, aircrafts will be captured by landing director radar and then enter the final approach phase. The whole approach phase will be finished at t = 26.4 min. The status at this phase becomes complex — the maximum number of aircrafts can reach 2, but for the aircrafts re-entering from wave-off or bolter, the quantity can be divided into 7 levels. The number reduces below 0.1 from t = 59.4 min. The quantity of embarked aircrafts at the landing pattern phase is also complex — the phase begins at t = 20.4 min and, for the distance of landing pattern, it is about 1 km; the aircrafts only spend 0.25 min at a speed of 240 km/h in the pattern. Then the maximum number of aircrafts is 0.25 per min. The quantity of aircrafts of this phase also has 7 levels for the same reason of wave-off and bolter. The number of aircrafts reduces below 0.01 per min from t = 61.1 min.

Figure 4b shows the quantity of embarked aircrafts at each phase of the night recovery operations. The case of wave-off and bolter makes the status complex and divides the quantity of embarked aircrafts into 7 levels.

Embarked aircrafts enter the temporary spots when t = 21 min; when t = 45.1 min, the quantity of embarked aircrafts entering into the deck temporary spots is 7 and, when t = 64 min, that number reaches 7.8, which means that 97.5% of embarked aircrafts are recovered in probability.

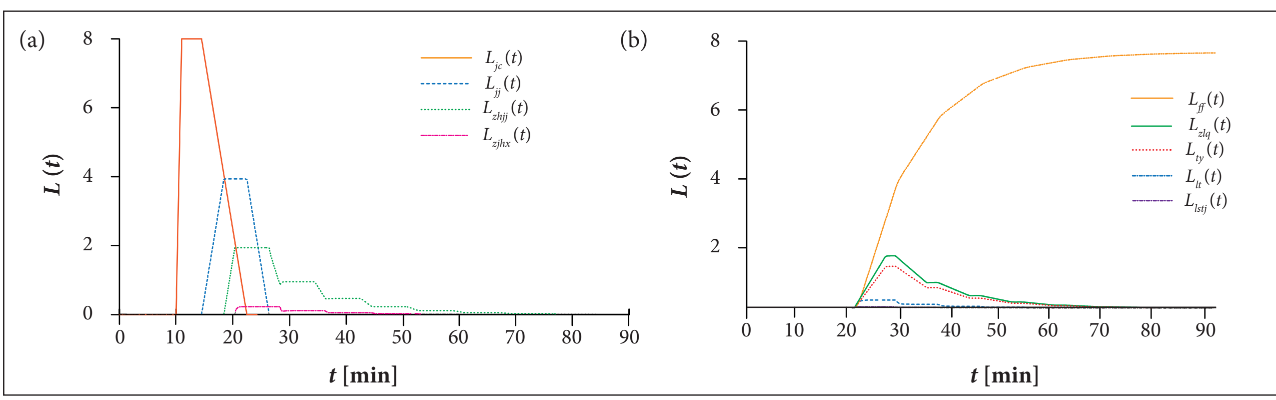

Figure 4. The quantity of embarked aircrafts at each phase in the case of wave-off or bolter. (a) Embarked aircrafts in touch before the flight deck; (b) Embarked aircrafts after touching the flight deck.

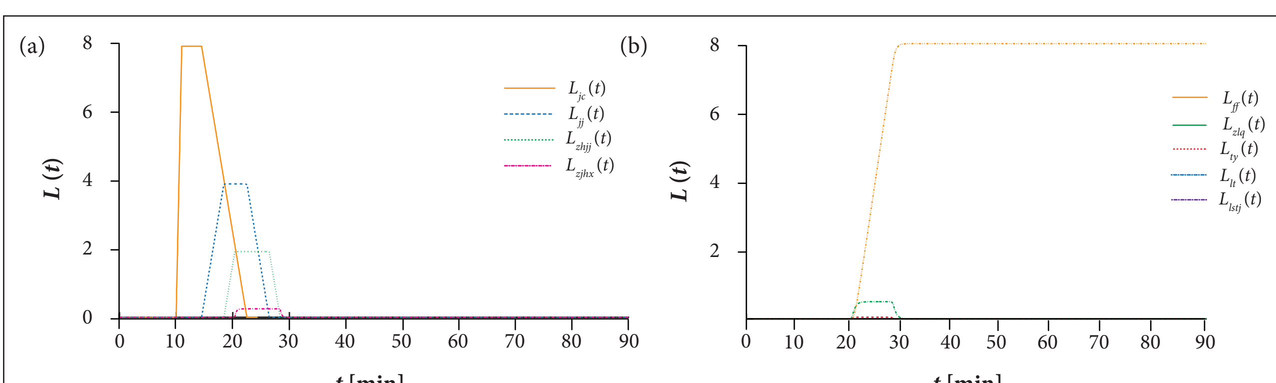

Figure 5. The quantity of embarked aircrafts at each stage without wave-off or bolter. (a) Embarked aircrafts before touching the flight deck; (b) Embarked aircrafts after touching the flight deck.

WITHOUT WAVE-OFF AND BOLTER

The simulation results in the case without wave-off and bolter, which means $\lambda_{ff} = 0$ and $\lambda_{ty} = 0$ are shown in Fig. 5. It can be derived that, for an 8-aircraft formation, 12.5 min are spent at the arrival phase, 12 min at the approach phase, and the time spent at the final approach, landing pattern, arrestor gear area, landing area and temporary spots are 9.875; 8; 8; 8 and 10 min, respectively.

The simulation results in both cases have a high reliability according to the capacity of ATFM of the Kuznetsov carrier during night recovery of embarked aircraft formation.

CONCLUSIONS

The prediction model of night recovery of embarked aircraft formation can provide receivable simulation results for air traffic forecasting in the case of bolter and wave-off to ensure that the flow of aircrafts at each phase of recovery is in accordance with the capacity of ATFM. The implement of air traffic schedule and flight plan can benefit from the simulation results so that delays, holding time and other bottlenecks of the recovery process will be minimized. The results can provide the theoretical and technical basis for the development and implementation of ATFM of embarked aircrafts recovery.

The following results were achieved through the research:

- A sensible prediction model for night recovery of embarked aircraft formation can be established based on the method of system dynamics.
- The characteristics of multiple feedbacks, delays, complex time varying, non-linearity and dynamics of the recovery system are well reflected in the model.
- The simulation results correspond to the case of flight test of embarked aircrafts.

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AUTHOR'S CONTRIBUTION

Conceptualization, Yue K and Cheng L; Methodology, Yue K, Cheng L, and Huang Z; Investigation, Cheng L and Huang Z; Writing – Original Draft, Yue K and Huang Z; Writing – Review & Editing, Cheng L and Yue K; Funding Acquisition, Yue K; Resources, Cheng L and Huang Z; Supervision, Yue K.

REFERENCES

Bertsimas D, Guglielmo L, Odoni A (2008) The air traffic flow management problem: an integer optimization approach. Proceedings of 13th International Conference; Bertinoro, Italy.

Clarke JPB, Solak S, Ren L, Vela AE (2013) Determining stochastic airspace capacity for air traffic flow management. Transport Sci 47(4):542-559. doi: 10.1287/trsc.1120.0440.

Dastidar RG, Frazzoli E (2011) A queueing network based approach to distributed aircraft carrier deck scheduling. AIAA 2011-1514. Proceedings of the Infotech@Aerospace; St. Louis; USA.

DeArmo J, Wanke C, Greenbaum D (2010) Probabilistic ATFM: preliminary benefits analysis of an incremental solution approach; [accessed 2017 Jan. 16]. http://www.mitre.org/work/tech-papers/tech-papers-08/07-0168/07-0168

Liu FQ, Hu MH (2011) Auctioning method for airspace congesting resource allocation and game equilibrium analysis. Transactions of Nanjing University of Aeronautics and Astronautics 31(3):282-293.

Meng LH, Xu XH, Li SM (2012) Dynamic reroute planning under uncertain severe convective weather. Journal of Southwest Jiaotong University 47(4):686-691.

Mukherjee A, Hansen M (2009) A dynamic rerouting model for air traffic flow management. Transportation Research Part B: Methodological 43(1):159-171. doi: 10.1016/j.trb.2008.05.011

Ryan JC, Cummings ML, Roy N, Banerjee A (2011) Designing an interactive local and global decision support system for aircraft carrier deck scheduling. AIAA 2011-1516. Proceedings of the Infotech@Aerospace; St. Louis; USA.

Thompson KM, Tebbens RJD (2007) Eradication versus control for poliomyelitis: an economic analysis. Lancet 369(9570):1363-1371. doi: 10.1016/S0140-6736(07)60532-7.

Weigang L, Souza BB, Crespo AMF (2008) Decision support system in tactical air traffic flow management for air traffic flow controllers. J Air Transport Manag 14(6):329-336. doi: 10.1016/j.jairtraman.2008.08.007.

Wesonga R (2015) Airport utility stochastic optimization models for air traffic flow management. Eur J Oper Res 242(3):999-1007. doi: 10.1016/j.ejor.2014.10.042.

Wolstenholme EF (2003) Towards the definition and use of a core set of archetypal structures in system dynamics. Syst Dynam Rev 19(1):7-26. doi: 10.1002/sdr.259.

Yang SW, Hu MH (2010) Robust optimization of aircraft arrival and departure flow allocation based on dynamic capacity. Journal of Southwest Jiaotong University 45(2):261-267. doi: 10.3969/j.issn.0258-2724.2010.02.017.

Ye BJ, Hu MH (2010) Multi-airport ground holding problem based on airline schedule optimization: models and algorithm. Journal of Southwest Jiaotong University 45(3):464-469.

Yue KZ, Sun YC, Liu H (2015a) Analysis of the flow field of carrier-based aircrafts exhaust jets impacting to the flight deck. International Journal of Aeronautical and Space Sciences 16(1):1-7. doi: 10.5139/IJASS.2015.16.1.1.

Yue KZ, Han W, Song Y (2011) System dynamics model on rapid supply of spare parts in carrier formation. Ordnance Industry Automation 30(7):27-32.

Yue KZ, Cheng LL, Liu H (2015b) Analysis of jet blast impact of embarked aircraft on deck takeoff zone. Aero Sci Tech 45(1):60-66. doi: 10.1016/j.ast.2015.04.010.

Yue KZ, Sun C, Luo MQ (2013a) Operation model on dynamic allocation system of embarked aircrafts. Journal of Beijing University of Aeronautics and Astronautics 39(8):1062-1068.

Yue KZ, Sun C, Luo MQ (2013b) Operation model on the carrier warship recovering carrier aircraft. Systems Engineering and Electronics 35(12):2527-2532.

Zhang HH, Hu MH (2010) Collaborative allocation of capacity and slot in CDM ADGDP airport. Systems Engineering — Theory and Practice 30(10):1901-1908.

Zhang J, Hu MH, Zhang C (2009) Complexity research in air traffic management. Acta Aeronautica et Astronautica Sinica 30(11):2132-2142.

Zhou Y, Wan Y, Roy S (2014) Multivariate probabilistic collocation method for effective uncertainty evaluation with application to air traffic flow management. IEEE Trans Syst Man Cybern Syst Hum 44(10):1347-1363. doi: 10.1109/TSMC.2014.2310712.