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Multi-body dynamic system simulation of carrier-based aircraft ski-jump takeoff

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Abstract The flight safety is threatened by the special flight conditions and the low speed of carrier-based aircraft ski-jump takeoff. The aircraft carrier motion, aircraft dynamics, landing gears and wind field of sea state are comprehensively considered to dispose this multidiscipline intersection problem. According to the particular naval operating environment of the carrier-based aircraft ski-jump takeoff, the integrated dynamic simulation models of multi-body system are developed, which involves the movement entities of the carrier, the aircraft and the landing gears, and involves takeoff instruction, control system and the deck wind disturbance. Based on Matlab/Simulink environment, the multi-body system simulation is realized. The validity of the model and the rationality of the result are verified by an example simulation of carrier-based aircraft ski-jump takeoff. The simulation model and the software are suitable for the study of the multidiscipline intersection problems which are involved in the performance, flight quality and safety of carrier-based aircraft takeoff, the effects of landing gear loads, parameters of carrier deck, etc.

1. Introduction

Ski-jump takeoff is one of the main takeoff modes for a carrier-based aircraft. Compared with catapult launch, it takes longer time on deck-running, acquires lower speed at ramp exit and greater effects by the aircraft carrier motion, wind field disturbance and launching time. Consequently it is important to take account of those factors comprehensively. From the viewpoint of system engineering, it is necessary to build an integrated system simulation model considering all the kinds of important influencing factors. This model brings about theoretical and practical significance not only to the research of flight dynamic problem referring to carrier-based aircraft, but also to the analysis of multidiscipline intersection problems including the suitability of carrier and aircraft, the motion coupling of deck, aircraft body and landing gears, as well as the safety of carrier-based aircraft takeoff or landing, etc.

Many studies on the simulation of ski-jump takeoff process have been developed recently, including modeling of carrier-based aircraft motion, modeling of aircraft carrier motion and modeling of wind field disturbances, etc.[1–5] Particularity and complexity of the physical system make the research difficult on system modeling and simulating.[6,7] Much work about modeling of the complete system needs to be carried out so far. Based on the latest researches of simulation modeling of ski-jump takeoff, this paper has built an integrated system simula-

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tion model taking account of multi-motion-body coupling between carrier, aircraft and landing gears, as well as the wind field induced by the aircraft carrier, the command decision on deck, and the control policy of pilot.

2. Physical system analysis

The flight path trajectory from a ski-jump takeoff can be divided into two phases: deck run and part-ballistic flight, as shown in Fig. 1. The deck run is from releasing the brakes up to the ramp exit; and the part-ballistic flight is from the moment of leaving board to the fully wing-borne flight. The closed force vector pentagons depict the development of the aircraft acceleration denoted by a hollow arrow during the ski-jump takeoff, where W represents the weight, L the lift, D the drag and T the thrust.

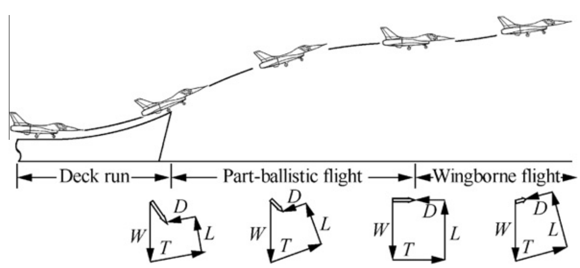

Fig. 1 Schematic of carrier-based aircraft ski-jump takeoff.

2.1. Aircraft carrier motion

Aircraft carrier is a moving platform with pitch, roll and heave motions. This will alter attitude angles and flight-path angles of the carrier-based aircraft at the ramp exit stochastically. At the same time, the moving deck will induce the transport acceleration, which affects the flight state of leaving.

2.2. Bow gust and ground effect

The speed of ski-jump takeoff is much lower than that of catapult launch. When the carrier-based aircraft leaves the board, the ground effect vanishes and the lift is not enough to balance the gravity. The aircraft maintains the early climb away from the aircraft carrier with the help of the upward path angle established by the inclination angle of the deck. Meanwhile, the angle of attack (AOA) increases quickly in short time because of the flow over the carrier bow, especially the sudden upward gust fore of the ramp. It is dangerous for stalling and influences the safety of takeoff. For the vanishing of the ground effect when the aircraft flies away the carrier deck, the part of the lift loses suddenly. Then the flight track will sink. This is another factor influencing the safety of takeoff.

2.3. Dynamics of landing gears

The carrier-based aircraft starts the takeoff roll on the deck when the wheel chock is laid down. At this moment, the front landing gear dumper begins to stretch from the compressed state caused by the full reheating condition of the aircraft. And the main landing gears are further compressed because of bearing more weight. Along with the dumpers of main landing gears compressed excessively, the gas pressure rises to make the compressing stop and then the dumpers stretch. For this repetitive process, the relative pitch angle of the carrier-based aircraft to the aircraft carrier continuously rises and falls in the taxiing stage.

After the carrier-based aircraft rolls on the ramp, the landing gears are shocked respectively for the changed curvature of the deck. The dumpers of landing gears are compressed and stretched again to induce a new wave of the relative pitch angle from its leveling out. This oscillation will change the attitude angle and the angle of attack of carrier-based aircraft at the ramp exit. And the takeoff condition will be affected.

2.4. Multi-kinetic-bodies coupling

The deformation of the tires and dumpers of landing gears will change the forces acting on the bodies connected to it. So the takeoff characteristic is affected by the landing gear system significantly. There are serious couplings between the landing gears and the aircraft body.

2.5. Launching time decision

Carrier-based aircraft launching is a multiplayer and multi-machine system dynamic process. Besides, it is not only affected by the carrier motion and the disturbance of special wind environment, but also involves the collaborative decision control among the launching signal officer (LSO) and the pilot.

The complex environment in takeoff process, the coupling of multi-body motion and the multiplayer collaborative decision control are all the influencing factors of carrier-based aircraft safety.

3. Building method of subsystem models

3.1. Modeling of aircraft carrier motion

In engineering practice, the aircraft carrier motion under the action of sea waves widely described by statistical analysis technique is usually regarded as an ergodic stochastic process. Stationary stochastic process theory is used, supposing the spectrum function of aircraft carrier motion is static continuous, time invariant and zero mean.[8]

3.2. Modeling of aircraft carrier disturbances

According to the physical characteristics and causes of the flow around aircraft carrier, the spatial distribution of steady components, the engineering calculation methods of free turbulent components, random turbulent components and periodic components are given in American standard MIL-1797A.[9] Certain experience about the simulation of the flow around aircraft carrier has been gained at present.[10]

3.3. Ground effect influences

The theoretical formula and modifier formula for calculating the aerodynamic data affected by ground effect have been built in engineering practice. The changes of aerodynamic forces caused by ground effect can be calculated in various flight heights from ground.[11]