Engineering Notes

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Improved Automatic Carrier Landing using Deck Motion Prediction

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Introduction

THE primary purpose of the Navy's All-Weather Carrier Landing System (AWCLS) Mode I is to provide fully automatic control of an aircraft from AWCLS entry point to touchdown on the carrier deck. Reference 1 states the performance criteria which must be met. These include landings in zero visibility with a touchdown longitudinal dispersion of ±40 ft from the point midway between the #2 and #3 wires on the carrier deck, in sea conditions resulting in deck motion of 1.25 deg root-mean-square (RMS) pitch, 4 ft RMS heave and with maximum vertical translation of the ramp of ±20 ft.

The main hardware components of the longitudinal channel of the AWCLS include the aircraft and the SPN-42, a shipboard navigation system. The SPN-42 uses radar to determine the aircraft position and a real-time digital computer to generate pitch commands for the aircraft automatic Flight Control Systems (AFCS). These pitch commands are generated in part by a digital compensation network which receives an error signal proportional to aircraft deviation from the desired flight path, and in part by a change in the desired flight path which occurs when Deck Motion Compensation (DMC) is utilized. DMC initiates a change in aircraft altitude because of the motion of the desired touchdown point due to carrier heave. These DMC commands are summed with the flight-path altitude errors to generate pitch command signals, beginning at 12 sec from touchdown and continuing until frozen at 1.5 sec from touchdown. AWCLS operation requires that the aircraft possess an Approach Power Compensator System (APCS) for maintaining constant angle-of-attack on glideslope, and an AFCS for processing the SPN-42 pitch commands. The lateral AWCLS channel, not considered here, is similar to the longitudinal channel but processes bank angle commands that result from measured lateral excursions from the carrier runway centerline.

Of primary interest, is the ability of the existing AWCLS to perform acceptably under the sea/deck conditions indicated in military specifications. Ref. 2 states that six separate parameters are needed to describe total landing performance: the means and standard deviations of a) ramp clearance, b) impact velocity, and c) touchdown distance.

This Note describes a brief simulation study aimed at improving the performance of the current AWCLS concept for a particular aircraft. Specifically, the effect of utilizing deck heave prediction to generate sufficient lead to meet the altitude response limitation of an A-7E aircraft is evaluated in terms of the six parameters mentioned previously.

Deck Motion Prediction

The SPN-42 AWCLS deck motion compensation mode is designed to increase the probability of an arrested landing in the presence of deck motion by commanding the aircraft to chase the touchdown point during approach. Because of inevitable time lags between command and aircraft response, it is necessary for the command to lead the deck position. The amount of lead depends upon the response of the airplane/AFCS system. Presently the SPN-42 uses a second-order filter for lead generation and achieves a lead of 1.7 sec, a number suitable for F-4 response but not for A-7. Attempting to increase the amount of lead to an amount suitable for an A-7 would significantly increase prediction errors. An attempt to "quicken" the A-7's AFCS would probably incur objectionable pitch overshoot or other symptoms of marginal stability. A preferable solution would be to increase the capability of the lead generation, i.e., employ a deck motion predictor. A relatively simple predictor generating a signal leading the vertical displacement of the touchdown point by up to 4.5 secs has been proposed.[3] The efficacy of such lead generation is examined in the research to be described.

System Model

The fully automatic carrier landing mode (Mode I), utilizing the current operational concept of the A-7E AWCLS longitudinal channel, served as a baseline configuration for this study. Also modeled was a modified baseline configuration, with deck motion predictor information used to provide nearly zero phase lag between deck heave and the A-7E altitude response. The prediction was assumed to be exact. In both configurations, the total closed loop system consisted of the airframe, the engine, the approach power compensator, the longitudinal flight control system (AFCS), the automatic carrier landing system (ACLS), and parameters associated with the deck motion and carrier landing environment.

Aircraft Model

The aircraft chosen for study was the A-7E, a single-place light attack, carrier and land based aircraft of approximately 20,000 lbs empty gross weight. The A-7E was chosen because of the availability of information on its existing AWCLS components and Model I operational capability,[4] information on its aerodynamic characteristics,[5] and the availability of verbal inputs from experienced A-7 pilots at the Naval Postgraduate School. In addition, the A-7E possesses something found in a majority of modern carrier based aircraft: a turbofan engine whose throttle response is characterized by a relatively large time constant which is a nonlinear function of thrust in the approach thrust range.

Carrier, Deck Motion, and Landing Environment Models

To provide a realistic simulation, carrier geometry corresponding to the USS ENTERPRISE (CVA (N)-65) was obtained. Representative power spectral densities of carrier pitch and heave are shown in Fig. 1. The figure is intended only to give a generic indication of deck motion dominant frequencies and is not specific to the ENTERPRISE. From the figure it can be seen that both heave and pitch motions are essentially band limited in the range from 0.45 to 0.75 rad/sec. In this region, pitch leads heave by 45 to 90 deg.[6] For simplicity, the heave and pitch motions were taken as sinusoids in this analysis, with pitch leading heave by 90 deg and both possessing frequencies of 0.6 rad/sec. The amplitudes of the sinusoids yielded maximum pitch and heave motions of ±1.414 deg and ±8 ft, respectively.

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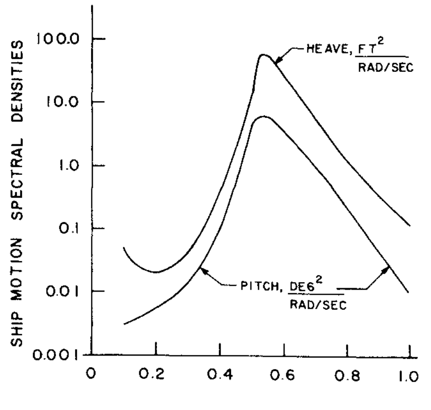

Fig. 1 Ship motion power spectral densities.

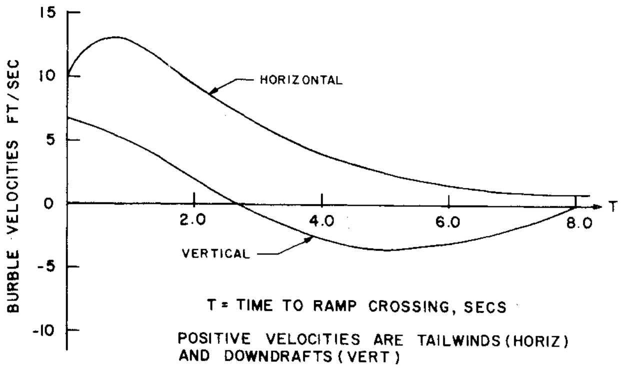

Fig. 2 Steady-state burble model.

A realistic carrier landing will normally be accomplished only after contending with the effects of the air-wake behind the carrier ramp. Ref. 2 surveys work done in identifying and qualitatively describing three carrier air-wake components: steady-state "burble", pitch-induced wake, and random turbulence. Only the first of these components was used in this study. Figure 2 shows the steady-state horizontal and vertical burble air velocities used in this study. This burble model represents maximum burble effects, and once again is not specific to the ENTERPRISE. No other ship motion/environmental effects such as wind-over-deck were included.

Digital Simulation

The entire nonlinear, closed loop system was simulated on the Naval Postgraduate School's IBM 360 digital computer utilizing the IBM Continuous System Modeling Program (CSMP). For details regarding the mathematical models etc., the reader is referred to Ref. 7.

From baseline configuration digital output, the time lag between actual deck heave and the resultant aircraft altitude response was determined to be approximately 1.1 sec (this means the actual lag is approximately 2.8 sec since the SPN-42 itself provides 1.7 sec heave prediction). For the modified baseline configuration, therefore, the heave input to the DMC transfer function was advanced 1.1 sec. The entire 2.8 sec lead time is well within the capabilities of the predictor discussed in the proposal of Ref. 3.

When deck motion compensation is introduced 12 sec prior to touchdown in the actual AWCLS, it is done so gradually, over a two sec period, increasing from zero to full compensation. The same technique was utilized in the simulation. In this study, the deck motion compensation was introduced while the deck was in 36 different positions in its sinusoidal motion. The positions corresponded to 10 deg increments in the arguments of the sinusoids.

Table 1 Landing performance table

Configuration	Height above ramp (ft)		Landing position (ft)		Impact velocity (fps)	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Baseline	16.5	8.3	22.8	75.8	20.9	6.0
Modified baseline	10.5	6.5	77.1	53.9	18.9	5.0
Modified baseline with error ramp	14.5	7.0	13.0	58.1	16.4	6.1

Results

Table 1 compares the landing performance of the baseline and modified baseline AWCLS configurations. The landing position is measured from the ideal touchdown point midway between #2 and #3 wires, positive values aft, negative values forward of the ideal point. For the baseline configuration, the 36 "landings" involved 12 ramp strikes, 15 hard landings (aircraft exceeding structural limits set as 23 fps) and 2 bolters (aircraft missing last arresting wire). Only 9 landings reflected meeting the military specifications of ±40 ft around the ideal touchdown point. It should be noted that the current AWCLS lessens the chances of the aircraft being low at the ramp by introducing "error ramp" and "command ramp" commands to the AFCS. The error ramp raises the vertical reference of the aircraft to counteract the settling effect of the burble. The command ramp provides a slight increase in aircraft power as it nears touchdown. Both command and error ramps are functions of the ship and aircraft type. Since currently used values were not available they were neglected in modeling the baseline configuration. While inclusion of these commands would undoubtably reduce the ramp strikes, no improvement in hard landings or touchdown dispersions would be expected, and the number of bolters would probably increase.

The modified baseline data demonstrates a dramatic reduction in the standard deviations of the three measures. The 36 landings involved 4 ramp strikes, 9 hard landings and no bolters. The extreme effects of the burble are seen to compromise the effectiveness of the heave prediction as reflected in the mean landing position. Now, however, an error ramp can be implemented with few detrimental effects. The addition of 6 ft to the aircraft vertical reference resulted in the performance statistics in the last row of the table. This configuration exhibited no ramp strikes, 7 hard landings and 5 bolters with 14 landings meeting military specifications.

Conclusions

Considering the reduction of accidents to be the main purpose for improving the current AWCLS, it is possible that substantial improvement can be realized using deck heave prediction. Better glide-path control results in near elimination of ramp strikes, as well as in overall reduction in landing impact velocities. Due to the dominating effect of the severe burble, bolter rate improvement was not noted with the prediction configuration. However, the decreased standard deviation of landing position indicates the benefits of the modified configuration.

This Note is the result of the first in a series of studies dealing with the AWCLS in general and the efficacy of deck motion prediction in particular. Additional studies are planned which will increase the complexity of the system model according to the following hierarchy: 1) inclusion of wind-over-the-deck and actual band-limited ship motion; 2) inclusion of predictor dynamics; and 3) inclusion of random atmospheric turbulence in the approach and a more realistic carrier air wake.

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Representation of the Drag Polar of a Fighter Aircraft

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Introduction

THE possibility of an analytical approximation of the drag polar of a fighter aircraft which would be applicable to the large values of angles of attack encountered in maneuvers is considered. Evidently, a simple representation can be conveniently used for making rather accurate estimates of turn performance in aircraft design and evaluation, and in the optimization of flight paths.

The classical representation, which approximates the drag coefficient, C_D, by $C_{D0}+kC_L^2$, is compared in Fig. 1 with the drag polars of YF-16.[1] In order to ensure the accuracy of the classical representation near zero C_L, the drag coefficient at zero C_L, C_{D0}, and the induced drag coefficient k are chosen so that the classical curve is tangent to the curve of the square of the lift coefficient, C_L, vs C_D. The need for an improved representation is evident. It is also clear that strakes and automatically controlled flaps do not change the qualitative nature of the curve. Available data on other fighter configurations further suggests that the nonlinearity indicated in Fig. 1 is quite typical.

The slope of the C_L^2 vs C_D curve changes gradually rather than abruptly, which is probably due to the gradual spanwise spread of the separated regions on the wing with increasing angle of attack. It is therefore inappropriate to approximate the curve by two straight lines. What is called for is an additive correction $f(C_L)$ to the classical representation that is insignificant at small values of C_L^2. This Note investigates simple functional forms of f that are capable of describing the available drag polars.

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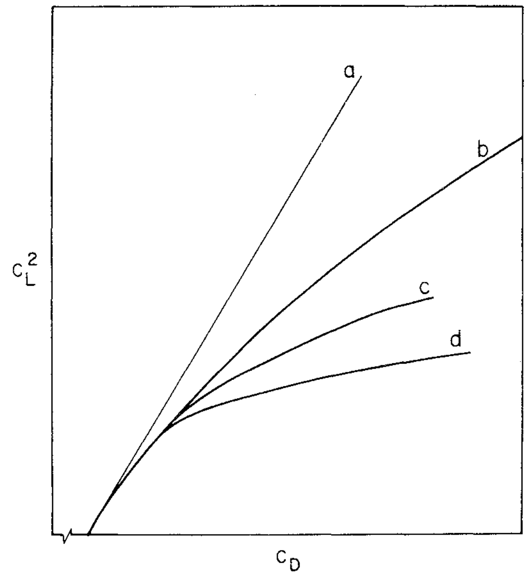

Fig. 1 The classical approximation (a) and the drag polars of YF-16 configurations.[1] (b) with variable LE flap and strake; (c) with flap only; (d) without flap or strake.

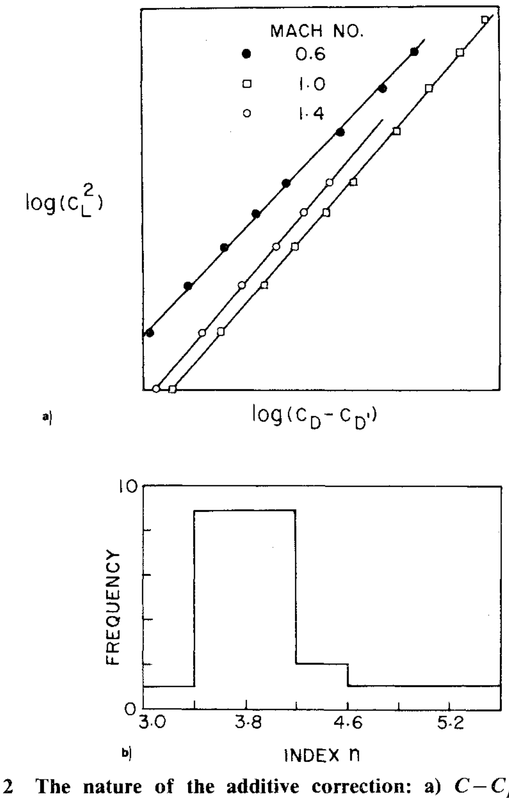

Fig. 2 The nature of the additive correction: a) $C-C_D' \sim aC_L^n$; b) the histogram of n for a sample of 24 drag polars.

Method and Results

A first step in examining the forms of the correction was to determine the appropriate classical approximation for the given drag polar. Since much of the data was available in the graphical form, a graphical method was chosen. A tangent was drawn to the smoothed C_L^2 vs C_D curve at the minimum C_D point, where the value of C_L was usually negligible. Let C_D and C_D' refer to the values on the given drag polar and on the tangent at a given value of C_L. $(C_D - C_D')$ then gives the required correction. It was plotted against C_L^2 on a log-log plot. Figure 2 gives typical cases and shows that a straight line