“A Model for Manual Decelerating Approaches to Hover”

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A MODEL FOR MANUAL DECELERATING APPROACHES TO HOVER

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ABSTRACT

A mathematical model is presented which describes the manual deceleration of a helicopter or VTOL aircraft from high speed flight to hover. The model combines the rules of visual perception with the crossover model of the human operator. The result is a two parameter, time varying description of closure speed versus range for which time and deceleration can be solved directly. The model compares well with flight test measurements of helicopter deceleration maneuvers. One potential use of the model is as a simulator validation tool by comparing simulator-measured model parameters with in-flight measurements. Extension of the model to vertical and lateral axes is briefly discussed.

LIST OF SYMBOLS

A	Effective size of viewed object
c	Constant (eq. 6)
h	Altitude
$\dot{h}$	Altitude rate
k	Constant of proportionality for range
k_h	Constant of proportionality for height
k_y	Constant of proportionality for lateral offset
n	Exponential constant (Eq. 6)
R	Range from hover point
$\dot{R}$	Range rate
$\ddot{R}$	Deceleration
R_p	Perceived range
$\ddot{R}_{pk}$	Peak deceleration
y	Lateral offset
$\dot{y}$	Lateral velocity
t	Time

(Numerical subscripts are used to denote corresponding range-time combinations.)

INTRODUCTION

The manually controlled decelerating approach to hover in a helicopter or VTOL aircraft is normally viewed as a time varying maneuver for which conventional analysis techniques do not apply. A mathematical model has been formulated, however, which combines the crossover model with the effects of visual perception and yields a simple guidance law which agrees well with in-flight measurements of pilot actions.* Although the model is time varying, it permits closed form solutions for speed, acceleration, and time as functions of range. In addition, the same ideas applied to the deceleration model can also be extended to vertical and lateral flight path guidance.

In the following pages we describe the basis of the model, its practical formulation, agreement with flight data, and potential applications.

THEORETICAL BASIS

The hypothesis used to formulate the decelerating approach model is that range rate is varied in direct proportion to perceived range, i.e.,

$$\dot{R} = -k\,R_p \qquad (1)$$

where $\dot{R}$ is actual range rate

R_p is perceived range

k is the constant of proportionality

This carries the implication of rate-command-like behavior implicit in the crossover model of the human operator as described in Ref. 1 with allowance for visual perspective effects.

The key to describing the visual aspect is provided in Ref. 2 where the psychological measurements of apparent size and distance are related to various analytically derived relationships. It is shown that perceived range, R_p, is related to true range, R, by:

$$R_p = \frac{R}{1 + R/A} \qquad (2)$$

where the length A is a measure of the effective size of the object being viewed.

Thus the psychological perception of range combined with the crossover model for human operator behavior leads to the following block diagram description for control of range-to-go:

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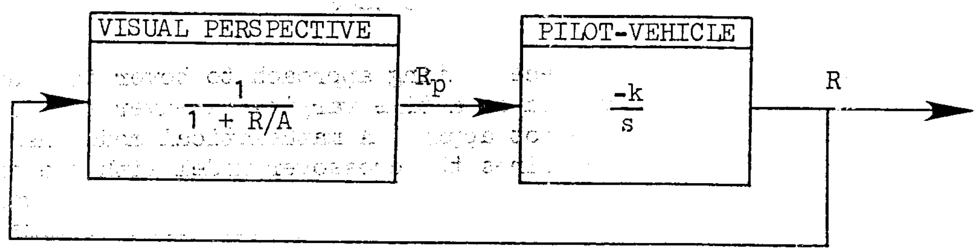
* The model was developed in direct support of Naval Air Engineering Center Contract N68335-78-C-2019 and Naval Air Development Contract N62269-77-C-0509.



This can be written as:

$$\dot{R} = -k \frac{R}{1 + R/A} \tag{3}$$

SOLUTION OF THE GUIDANCE LAW

The above guidance law yields a direct closed-form solution if the cross-over gain, k, and the effective size parameter, A, are assumed constant. Starting with Eq. 3,

$$\frac{dR}{dt} = \frac{-k\ R}{1 + R/A}$$

and integrating

$$\int_{t_1}^{t_2} dt = -\frac{1}{k}\int_{R_1}^{R_2}\left(\frac{1}{R} + \frac{1}{A}\right) dR$$

we obtain the result

$$t_2 - t_1 = \frac{1}{k}\left(\ell n \frac{R_1}{R_2} + \frac{R_1 - R_2}{A}\right) \tag{4}$$

where R_1 is range at time t_1
and R_2 is range at time t_2

Inertial deceleration with range, $\ddot{R}$, can be computed by differentiating Eq. 3, i.e.,

$$\ddot{R} = \frac{k^2\ R}{(1 + R/A)^3} \tag{5}$$

A maximum deceleration can thus be found to occur at a range equal to A/2 with a magnitude of $4k^2A/27$. Plots of range rate and deceleration therefore have the characteristic shapes shown in Fig. 1.

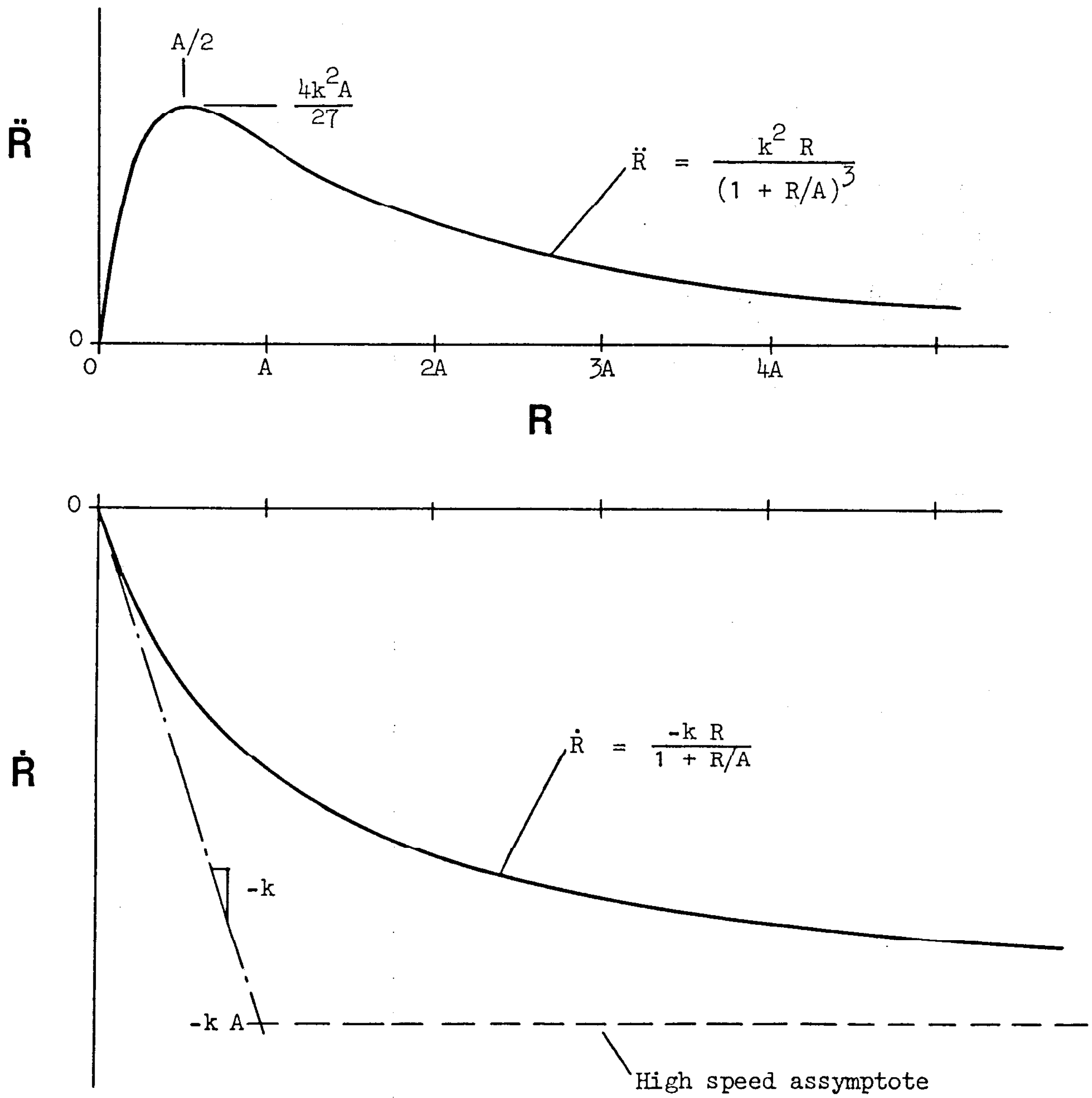


Figure 1. Deceleration and Closure Speed Versus Range

AGREEMENT WITH FLIGHT DATA

The analytical model thus described reflects the essential features of deceleration profiles obtained from flight test measurements. Reference 3 contains data based on two hundred approaches by various pilots using four types of helicopters. The approaches were started at combinations of three airspeeds and three altitudes. Representative initial conditions for the approach were considered to be 80 kt airspeed and 1,000 ft altitude. A typical deceleration profile taken directly from Ref. 3 is shown in Fig. 2 with two analytical guidance model solutions superimposed, assuming k and A to be constants. The model parameters k and A are taken to be 0.23/sec and 600 ft in one case and 0.30/sec and 400 ft in the other. Note that the characteristic shape of the deceleration profile is followed using either pair of values for k and A although one pair matches the longer ranges better and the other pair, the shorter ranges. This may reflect a shift in the effective field of interest by the pilot between long range and short range. At longer ranges the field of interest may encompass the overall landing area, hence a larger value of A; and at shorter ranges the pilot may focus only on the precise landing spot with a correspondingly smaller A. Nevertheless, a reasonably accurate deceleration profile is given by a single set of (constant) model parameters.

The method used to pick a value for A can be based on an empirical relationship noted in Ref. 3, that is,

$$\frac{\dot{R}^2}{\ddot{R}} = c\,R^n \tag{6}$$

where c and n are constants

The analytical guidance model, at the same time, can be represented in the following form:

$$\frac{\dot{R}^2}{\ddot{R}} = R(1 + R/A) \tag{7}$$

Therefore, to solve for A we can match $\dot{R}^2/\ddot{R}$ over the range of the deceleration maneuver. The results of this match for A = 600 ft are shown in Fig. 3.

The second parameter, k, can be chosen by matching peak deceleration. Thus with the A obtained using Eq. 7 we can solve for k using the theoretical peak $\ddot{R}$:

$$k = \sqrt{\frac{27\,\ddot{R}_{pk}}{4A}}$$

Therefore, if $\ddot{R}_{pk}$ is 0.15 g, then k is 0.25/sec.

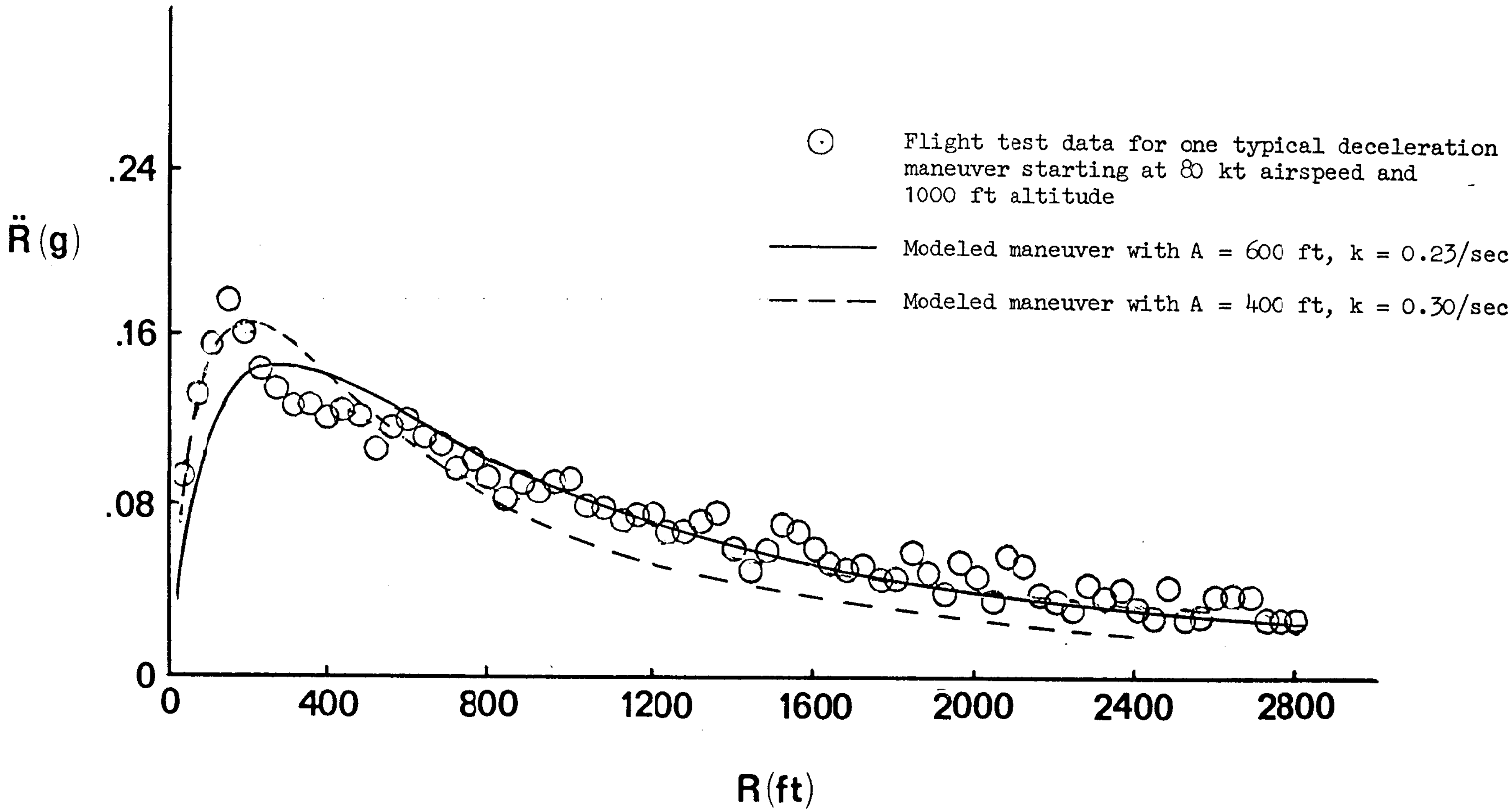


Figure 2. Comparison of Deceleration Profiles Between Analytical Model and Flight Test Data

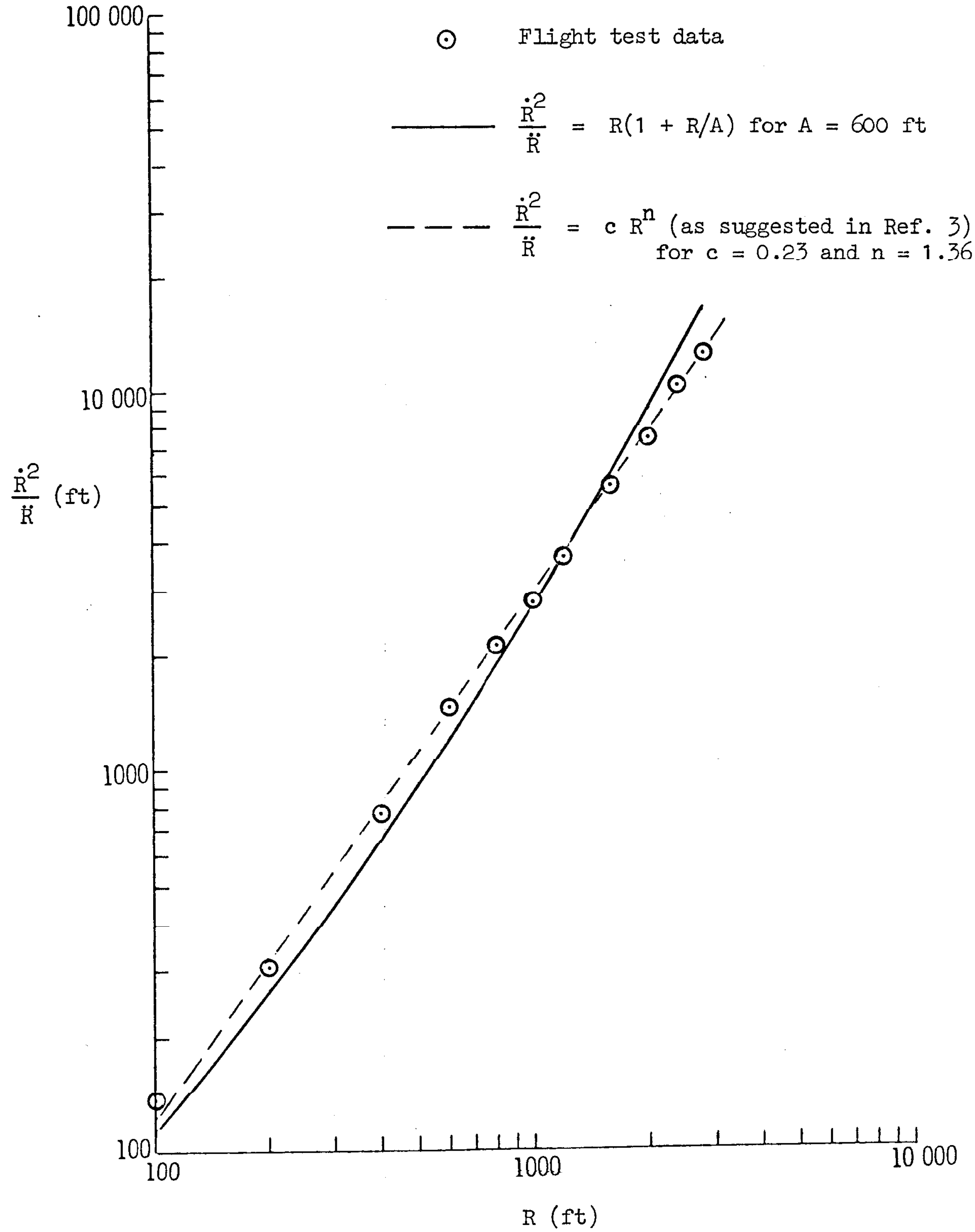


Figure 3. Logarithmic Plot of Parameter $\dot{R}^2/\ddot{R}$ Against Range

USEFULNESS OF THE MODEL

The deceleration model described here is useful because it represents pilot behavior over a wide range of speeds with a minimal number of parameters. At long range, the model yields a constant closure speed; at zero range it provides suitable hover position regulation.

The value of this is that it allows us to study a relatively complex and fairly long term maneuver with some insight into the factors involved. Interestingly enough, the two parameters involved can each be associated with the two aspects of the maneuver — the perception of the visual field and the response of the overall pilot-vehicle combination. For example, it may be *desirable to relate the size of A to a specific landing site, e.g., to a con*ventional helicopter pad, to a shipboard landing pad, or to an open field. As for the pilot vehicle gain, k, we can readily identify its role as the crossover frequency in hovering. The model as formulated, however, implies that the effective crossover frequency is really range-varying according to how the landing site is visually perceived.

As a simulator tool the model described here has a special value in manned simulation. Decelerating approaches made on a simulator could be compared to actual approaches in terms of the two parameters identified. For example, according to Ref. 4 there is some evidence that the pilot's perceived range differs depending upon the means of displaying outside visual information in a simulator (i.e., whether a video display is collimated or not). The idea then would be to use this model as a simulator tool — to see whether the k and A of a simulation agree with those of a flight situation.

The model has a similar value with regard to training or establishing progress along a learning curve. It has been observed that as piloting skill develops for a given task, behavior becomes more consistent and starts to fit into a rather constrained pattern or model. This phenomenon has been observed in such tasks as glide slope tracking and landing flare.

One important application of the model may be with regard to automatic approach guidance systems. Since the model reflects the essential features of a manual decelerating approach, it could provide the basis of an autopilot guidance law which closely mimics manual operation. Thus the resulting automatically performed maneuver might be easier to monitor and more amenable to manual takeover, if required, than for guidance laws based on, say, constant deceleration or on velocity varying in direct proportion to range (exponential deceleration).

Finally, we speculate that the deceleration maneuver performed in an aircraft is akin to a stopping maneuver in an automobile, hence the analytical model presented here should apply. In stopping a car, most of us can probably identify with a gradual application of brakes (i.e., deceleration) up to a point then letting off the brake in the final few feet. Presumably, the effective size of the object being approached in stopping an automobile (i.e., the value of A) would be in line with the dimensions of a roadway or intersection.

EXTENSION OF THE MODEL TO OTHER AXES

The deceleration model as described here applies to range only. We can extend it to vertical and lateral axes, however, by the same application of rules of visual perspective.

According to Ref. 2 perceived size obeys the same relationship as perceived range in Eq. 2. We can follow this line of reasoning and hypothesize that:

$$\frac{\text{Perceived Altitude}}{\text{Actual Altitude}} = \frac{\text{Perceived Lateral Offset}}{\text{Actual Lateral Offset}} = \frac{1}{1 + R/A}$$

Hence,

$$\dot{h} = -k_h h_p = -k_h \frac{h}{1 + R/A}$$

and

$$\dot{y} = -k_y y_p = -k_y \frac{y}{1 + R/A}$$

Closed form solutions for velocities and accelerations can be obtained as functions of range in the same way as for range-related variables $\dot{R}$ and $\ddot{R}$. Although the detailed development and correlation with flight data is the subject of a subsequent paper, the altitude guidance model does appear to reflect the essential characteristics of actual decelerating approaches in helicopters. The usefulness of this extension follows that of the range model.

CONCLUSIONS

The fixed parameter deceleration model presented here is based on a rational hypothesis which combines the basic rules of visual perception with the idea of a constant coefficient crossover model of the human operator. The resulting guidance model formulation permits easy manipulation and solution using range as the independent variable. Most important, the model reflects the essential characteristics seen in actual flight maneuvers.

The usefulness of the visual deceleration model applies to a number of applications. In simulation, the model represents a validation tool as well as a gauge of pilot performance and learning. Since only two parameters are involved, on-line identification can be carried out with minimal computational impact. Also potential flight test applications are similar to those of the simulator. Even an automotive application may exist. But perhaps the most fruitful use of the model is in connection with automatic guidance law formulation where the mimicking of manual operation offers advantages for pilot monitoring. Finally, the same ideas used to create the range model can be applied to vertical and lateral guidance.

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