Synthesis of a Separate Surface Wing Leveler

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Theme

THE purpose of this synoptic is to present a method for sizing and for synthesizing a separate surface wing leveler for general aviation aircraft. The method can be readily extended to more general separate surface automatic flight control systems. Unlike large airplanes which use electromechanical or hydraulic devices to drive the control surfaces, light plane control surfaces are driven mechanically by the pilot alone. Thus any attempt to drive these surfaces automatically results in feedback directly to the pilot's controls. To overcome this problem a separate surface stability augmentation (SSSA) concept has been evolved: see Fig. 1 for a general arrangement. A small control surface is devoted to automatic controls while the pilot controls a larger, similar surface. When properly designed, such a system would not feed back to the pilot and, if the system failed, the pilot could still fly the airplane. No redundancy being needed, the system is also a low cost system. The feasibility of such systems was first discussed in detail in Ref. 1.

Contents

The synthesis problem of such separate surface systems must deal with the following questions: 1) Is the separate surface feedback system dynamically acceptable and how can this be predicted? 2) What sizing criteria should be used to obtain satisfactory system operation yet retain safe flight following a hardover failure? 3) For a given size separate surface which does not jeopardize the airplane in the case of a hardover system failure, what are the aerodynamic saturation characteristics of the system when flying through turbulence?

These questions are partially answered in the remaining part of the paper. To illustrate, a Cessna 172 separate surface wing leveler system is analyzed. For the analysis of separate surface control systems two types of models are needed: a transfer function model and a saturation prediction model.

Transfer Function Model: The dynamic response of aircraft is determined by linearizing the equations of motion after assuming small motion perturbations from a steady flight condition.[2] From the resulting linear differential equations, a transfer function model for separate control surfaces can be derived as shown in Refs. 2 and 3. From the transfer function model, the augmented airplane matrix can be found. To analyze the dynamic behavior of separate surface augmented airplanes with conventional root-locus techniques, it is necessary to invert the augmented airplane matrix algebraically or numerically. Methods and computer programs to accomplish this have been developed in Ref. 3 and are summarized in Ref. 4.

Saturation Prediction Model: To determine the saturation characteristics of the separate surface augmented airplane, it is necessary to use the tools of statistical analysis. The probability of a separate control surface saturating has also been derived in Ref. 3. Having stated the mathematical models for analyzing the separate surface systems, some sizing criteria are now discussed.

Sizing Criteria: Two types of criteria must be considered in sizing separate surfaces for use in automatic control systems: sizing for static control and sizing for avoiding saturation.

Sizing for Static Control: One advantage claimed for separate surface control systems is low cost. That implies also that electrical components of the system will have no redundancy. This, in turn, means that after a hardover failure, the pilot must still be able to retain sufficient control as well as a sufficient "level" of handling qualities so that safe landings can be accomplished. The problem, then, is to determine what constitutes an acceptable post-failure configuration. Because the civil regulations are not explicit enough, the military handling quality specifications of Ref. 5 were used as a guide. One example of how these handling qualities specifications can be used as separate surface aileron sizing criteria is now discussed.

Figure 2 shows how much percentage of basic roll control power is needed at a given failure level. Notice that according to Ref. 5, the Cessna 172 has too much roll control power! Even after trimming a hardover failure of the separate surface aileron (this costs the pilot 2 × 15% = 30% of his roll control power), the airplane still meets the Ref. 5 criteria for zero failure. Control forces needed to trim a 15% hardover failure were calculated. The wheel force was found to be always less than 2 lb in the case of the example airplane. This is within the friction bandwidth.

Sizing for Avoiding Saturation: Three types of saturation are to be considered in separate surface control systems: 1) Deflection saturation caused by the actuator or the surface hitting geometric stops. 2) Rate saturation which occurs when the actuator reaches its highest rate. 3) Hinge moment saturation which occurs when the hinge moment reaches a magnitude that cannot be overcome by the actuator.

It was assumed that saturation of types 2 and 3 would be avoided by proper actuator design. The first type of saturation is probably most serious in turbulent flight conditions. For that reason, the power spectral density (PSD) approach mentioned before was used in studying this problem. To determine the probability of saturation of an automatic flight control system, first the control deflection-per-gust-input transfer function is calculated by multiplying the feedback variable-per-gust-input transfer function by the control system forward path transfer function. Second, given the gust-input power spectral density, the control surface deflection power spectral density is determined and integrated numerically to obtain the standard deviation. The probability distribution function then gives the likelihood of reaching or exceeding a given deflection. The latter

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Index categories: Aircraft Handling, Stability, and Control; General Aviation Systems; Navigation, Control, and Guidance Theory.

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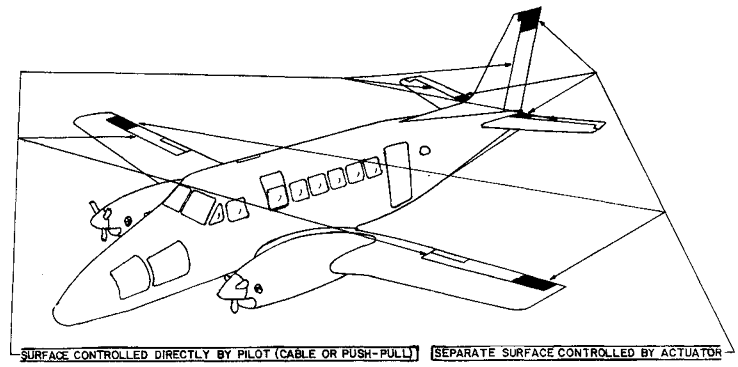

Fig. 1 General arrangement of a separate surface control system.

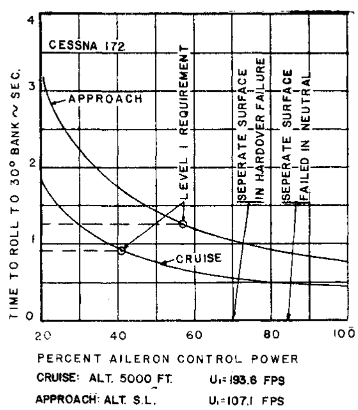

Fig. 2 Aileron control power required to satisfy roll performance requirements of Ref. 5.

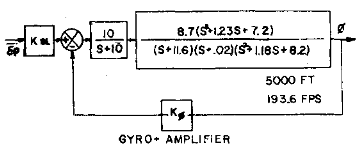

Fig. 3 Block diagram for a Cessna 172 wing leveler system.

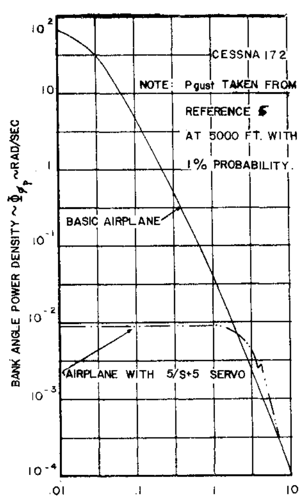

Fig. 4 Effect of a separate surface wing leveler system on bank variance in turbulence.

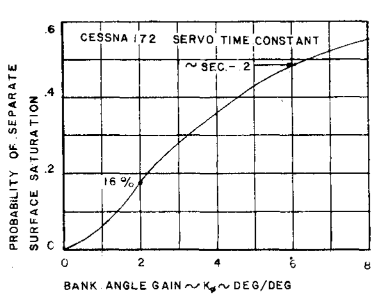

Fig. 5 Effect of bank angle feedback gain on the probability of separate surface saturation.

is taken as the probability of saturation for the given input.[3] These probability levels must then be interpreted against some criterion of usefulness. An example wing leveler utilizing the separate surface approach is now discussed.

Application: Figure 3 shows the block diagram of a Separate Surface Wing Leveler System for a Cessna 172. It is shown in Ref. 4 that the system eliminates the spiral, giving instead a rapid convergence back to the trimmed state. In addition, there is a favorable effect of the wing leveler on dutch roll damping. Fast actuator performance is not needed in such a system.

Quantitative information regarding the performance of this system can be gained from examining the bank angle variance in turbulence. The bank angle PSD due to rolling gust is shown in Fig. 4. The wing leveler greatly decreases the attenuation at the lower end of the frequency spectrum, the first break in the PSD occurring at the first airplane modes.

Unfortunately, the control system has limited authority. When the maximum deflection of the control surface is reached, the automatic control system is no longer effective, and the basic airplane dynamics are back. The probability of this happening can be calculated from the variance of the control surface deflection. The probability of saturation associated with this system is shown in Fig. 5. These probabilities are based on the gust intensities associated with clear air turbulence. It is seen from Fig. 5 that at a roll angle gain of 2, the probability of saturation of this 15% separate surface wing leveler is only 16% in a 1% probability gust-field. At this point in time, however, it is unclear what order of magnitude of saturation probability is acceptable and at what gust intensity. The separate surface wing leveler system has recently been successfully flight tested. Reference 6 gives a detailed hardware description of the system.

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