SECTION IV

SPECIAL PROBLEMS 1

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TASK-ORIENTED FLYING QUALITIES FOR
AIR-TO-GROUND GUN ATTACK

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TABLE - ORIENTED FLYING QUANTITIES FOR AIR-TO-GROUND GUN ATTACK

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Gun</th>
<th>Target</th>
<th>Velocity</th>
<th>Angle</th>
<th>Range</th>
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<tbody>
<tr>
<td>X-15</td>
<td>20</td>
<td></td>
<td>500</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>F-14</td>
<td>30</td>
<td></td>
<td>600</td>
<td>45</td>
<td>150</td>
</tr>
</tbody>
</table>

The X-15 was originally designed to provide good aerodynamic flying qualities, as defined by NACA-ARDC. During this flight, the X-15 was used to test the performance of the aircraft in the evolving computer environment. The purpose of this test was to confirm the dynamic performance characteristics derived from the high-speed wind tunnel experiments performed on the aircraft. The results of this test confirmed that the X-15 was capable of achieving high velocities and ranges, and the data collected during these tests were used to validate the aerodynamic models used in the design of the aircraft.
The response characteristics of the systems are then compared. If in terms of application of MIL-T-R-7005 for reverse simulation, then, in terms of task oriented response. The results of simulation, and, finally, flight test are then presented.

3. Original SAS

The original lateral directional stability augmentation system is presented in Figure 2. This system was selected on the basis of extreme simplicity and capability to satisfy the requirements of flying qualities specification. Figure 3 shows that the system consists of several "full" block-diagram to provide adequate damping, together with an altitude hold component to unlock the auto-pilot in a pitch attitude mode. In addition, the system was selected as a directional flying optimum during the previous flight test phase and original design development of the aircraft. As the emerging maneuver environment became more aggressive, it became apparent, however, that the response requirements of BSNA did not guarantee optimum air-to-ground gun-attacking flying qualities. A study was initiated to gain insight into these specific requirements.

![Figure 2. Original Lateral - Directional SAS](image)

1. Kinematic Analysis

Analysis of gun camera film, pilot comments, etc., together with consideration of the functional requirements for CAS presented in the previous section, motivated the selection of indicated hit point steering as the quantity with which the SAS should be synchronized to control in a smooth and rapid fashion.

In order to provide insight into this vector, it is necessary to develop an analytical representation in terms of the aircraft position and orientation.

The required expression for the angular rate were developed using the vectors and geometry defined in Figure 2. The result is:

\[ \dot{\theta}_h = x \quad \dot{\phi} = y \quad \dot{\psi} = z \]

Where: \( x, y, z \) are the direction cosine in the i-frame of Figure 2, e.g., and \( \theta, \phi, \psi \) are the conventional Euler angles. These expressions will be used as the basis for the task oriented SAS synthesis.

2. Simplified Scenario

The complete kinematic and dynamic analysis of the primary maneuver present in the BSNA represents a formidable analytical burden. It is sufficient for the present purposes to restrict the attention focused on that portion of the maneuver during which the aircraft is at a constant altitude and with a 15-degree climb rate. This is typical of a low-order angle rollup maneuver.

Making the usual perturbation analysis assumptions, the linearized expression for the vertex twist component of the perturbed hit point rate can be written as:

\[ \dot{\gamma} = \dot{\psi} = -\alpha \]

where: \( \dot{\psi} \) is the aircraft velocity, and \( \alpha \) is the average angle of attack.

5. System Synthesis

This section presents the reasoning which led to the control law selection. It was accomplished at the outset that the required conversion of the gun sight into a hit probability should be accomplished in such a way that maximum stability margin be maintained, since significant instability could cause differences between corrected radar and predicted hit points. The algorithm was chosen to be of the primary control, where "Faster-on-the-Floor" translation is accomplished in the target space through the Final-Up Display [spaced on the right of the picture]. A natural nose-up response is also in effect. It is desirable to have the gun cross move to the right without any positional error (i.e., fast on-the-floor) plus a small error of the gun move initially (because to the desired direction). In order to do this, a gun hit which passes to the right, it is necessary that \( \psi \) be everywhere positive.
The derivation of the linearized tank oriented control variable, $\Delta h_{\text{reg}}$, can be simplified using the simplified moments. Recall that $W = 50\,$ lb and $\Delta = 6000\,$ ft. In addition, $\alpha$ and $\phi$ will be small, and $\beta$ is desired.

Applying these considerations to the linearized expression for $\Delta h_{\text{reg}}$, then:

$$\Delta h_{\text{reg}} = \dot{h}_{\text{reg}}(t) = \frac{\beta(t) - \dot{\beta}}{\phi(t)}$$

which leads to the simplified expression:

$$\Delta h_{\text{reg}} = \frac{1}{\phi(t)} \dot{\beta}(t) - \frac{\beta(t)}{\phi(t)}$$

This equation was derived by assuming $\Delta \phi$ was very small. It is of interest to determine the relation of $\Delta \phi(t)$ when $\phi(t) = 0$. Simplicity aside, it will remain zero if the time derivative, $\dot{\phi}$, is always zero.

The aircraft side acceleration equation can yield this relation. The equation is:

$$\ddot{h} = v \ddot{w} + u \dot{v} - g \phi \sin(\alpha) - \frac{1}{2} \Delta Y_{\text{tank}}$$

where $Y_{\text{tank}} = $ aerodynamic side force, and $v$, $w$, and $\Delta Y_{\text{tank}}$ are aircraft linear, sideslip, and vertical velocities, using $\alpha = \alpha = \phi = 0$, $\dot{\phi} = 0$, deviating by $\Delta \phi$, and rearranging terms yields:

$$\Delta h_{\text{reg}} = \frac{\phi(t) - \Delta \phi}{\phi(t)}$$

Assuming $\Delta Y_{\text{tank}}$ is negligible, then:

$$\Delta h_{\text{reg}} \approx \frac{\phi(t) - \Delta \phi}{\phi(t)}$$

For $\phi(t)$ small, $\Delta \phi$ is negligible, and $\Delta h_{\text{reg}}$.

Substituting this approximation for $\phi$ into the simplified expression for $\Delta h_{\text{reg}}$, then:

$$\Delta h_{\text{reg}} = \frac{1}{\phi(t)} \dot{\beta}(t) - \frac{\beta(t)}{\phi(t)}$$

This indicates that whenever the angle of attack is the same as the gun depression angle, the perceived hit point will not move in the $\dot{\beta}$ direction, in response to roll rate. Otherwise, the aircraft would roll about the yaw axis and the pilots could not make a correction via ailerons. This situation would be desirable if the pilot were able to roll out on the target with no error.

A more realistic situation is that some initial errors exist, and it is not desirable to roll about the gun axis. It is more desirable to roll about axis which is below the gun line so that $\dot{\beta}$-pilot initial motion of the perceived hit point (gun level) is generated. In order to accomplish this, a bias is introduced into the $\dot{\beta}$ equation, i.e., if it is required that $\Delta h_{\text{reg}}$ when $\dot{\beta} = 0$ for all $\alpha$, then it is appropriate to replace $h_{\text{reg}}$ in the $\dot{\beta}$ equation by $h_{\text{reg}} = \phi(t)$. This results in:

$$\Delta h_{\text{reg}} = \phi(t)$$

So far as control of $\Delta h_{\text{reg}}$ by the use of ailerons for this simplified scenario, the results can be derived based on the one degree-of-freedom (DoF) roll rate response as:

$$\Delta h_{\text{reg}}(s) = \phi(s) / (s + 1)$$

For the design flight condition:

$$\Delta h_{\text{reg}}(s) = 2.628\,s^{-1} / (s + 1)$$

This trend and dynamically attractive expression for its peak rate, in terms of ailerons input, justified the decision that candidate SAS systems yielding such a result should be evaluated by simulation studies based on the simplified scenario.

The control law chosen was that with the SAS rudder command is of the form $\Delta r = \phi(t) \dot{\beta}$, where $\phi(t)$ is the feedback gain and $\dot{\beta}$ the aileron rate estimator derived directly from the sideways equation. The estimate for this choice of control law is simply to provide a SAS which will maintain $\dot{\beta}$ over one second; thereby yielding a dynamic relationship between $\Delta h_{\text{reg}}$ and $\phi(t)$, which will approximate the loitering one derived above via linearized analysis.

6. Flying Qualities Comparison

The purpose of this portion is to provide a brief outline of the differences in flying qualities between the original SAS and the tank-oriented SAS as obtained from the flying qualities simulation. The simulation of both aircrafts to a maximum roll input is presented in Figure 4. In terms of the response requirements of paragraph 3.3.2.4 Robust Aircraft Design of MIL-STD-1797A, the responses of both SIMPSON TRUST AIRCRAFT, i.e., level 1. The results of application of paragraph 3.3.2.4.4 Additional stability requirement for small angles are presented in Figure 5. The results of this figure show substantial SAS responses to be checked. These results show that the more realistic situation is required for the gun attack mode. The next section describes the simulation criteria as well as modified simulation results.

7. Preliminary Simulator Studies

A three degree-of-freedom (DoF) lateral/longitudinal flight simulation was set up on a Harvard simulator for extensive analysis of the gun attack mode. The objectives of the simulation were to:

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- Validate response criteria selection
- Validate the selection of $\delta_{F}$ as the task-oriented control variable and determine a meaningful allows task input
- Ascertain the need for the aerodynamic force terms in the $\delta_{F}$ estimate
- Demonstrate the viability of the $\delta_{F}$ control law for the solution of the air target, targeting problem
- Optimize the feedback gain, denoted by $\delta_{F}$

![Graph 1: Maximum Roll Comparison](image1)

![Graph 2: Sidestep Exclusion limitations](image2)

Based on analysis of the types of control inputs normally seen in the roll and tracking phases of air-to-ground, 1- and 2-second allows demands $\delta_{F}$ response in $\delta_{F}$ were selected as criteria for SAS performance evaluation. These criteria were first applied to the original A-10 SAS for the simplified scenario previously described. The results of a half-stick demands $\delta_{F}$

![Graph 3: Preliminary Simulation Results for the Original and $\delta_{F}$ SAS Configurations](image3)

are shown in Figure 4. The time history shows that the $\delta_{F}$-case of the original SAS for this particular input in both oscillatory and slow, persisting for 5.0 seconds for a 1-second transition input. The original SAS consists of a washout filter, a command to the rudder for 'dutch roll' damping, plus an allow-to-rudder resolver to compensate for the inherent aeroelastic of the aircraft. By contrast, the response of an idealized $\delta_{F}$ SAS system is seen to be much faster and better damped. The idealized $\delta_{F}$ system response was obtained utilizing a feedback gain of $\delta_{F} = 2$ seconds which was found to optimize the transient response at the design flight condition of 308 knots at sea level. This value was used for all automated simulation and flight test evaluation. These results, which
will later be shown to correlate well with manned simulation and flight test results. This utilization of this type of response for SAS performance criteria evaluation.

A comparison of piloted tracking capability is shown in Figure 7, indicating more positive and pronounced pilot control for the SAS than for the original B-110 configuration. This can be interpreted as described, in terms of improved tracking ability. The pilot, upon being made a null heading error, maintains the pilot on the target for 2 seconds, then reacquires the original heading.

The preliminary conclusions reached as a result of this simplified simulation effort were:

- The mission-oriented variable $\theta_v$ is meaningful for low altitude gun attack.
- Response to a 1-second sphere dataset is very useful for judging the relative merits of competitive SAS systems, and correlates well with pilots' simulation results.
- The plotted runs show that the total tracking error for the SAS is significantly less than that for the original B-110 SAS.
- The results of this study were sufficiently encouraging to facilitate detailed parameter selection for a manned simulation utilizing a 8-DOF model.

B. System Definition

The viability of an identical SAS for providing good control of the mission-oriented control variable, $\theta_v$, was established, and, therefore, the possibility of obtaining an acceptable estimate of $\beta$ could be considered. The study started with consideration of the possibilities for simplification of the exact expression for $\beta$ derived from the side force equation. (Refer to Appendix for further details.) Consideration

![Figure 8. Task-Oriented SAS Block Diagram](image)

Figure 8. Task-Oriented SAS Block Diagram

of the aerodynamic characteristics of the A-19, as well as mission requirements and flight envelope, led to the selection of the following transfer estimate of $\beta$:

$$\beta = \alpha - (\alpha + \omega + \gamma)$$

where $\beta$ is an average velocity vector, and $\omega$ was chosen to be the proper depression angle based on the maneuver presented in the system synthesis section. A block diagram for this system is presented in Figure 9.

9. Manned Simulator Studies

An evaluation of the original and modified configurations for the A-19 SAS was subsequently conducted in a manned flight simulator at the General Electric Company, Schenectady, New York. The pilots for performance evaluation scored toward the higher end of the spectrum, only one of whom received no training in the system operation. Both Franklin D. Roosevelt Republic and USAF pilots participated in this evaluation. The two scenarios used were:

1. Cross-Harbor Maneuver: A 35-knot wind. The target was located 1000 feet down range from the point of departure, 1000 feet to the left of the aircraft, and 1500 feet below the point of departure.

2. Tracking Maneuver: The target was located initially 400 feet to the right of gun boreline at a height of 1000 feet. This represented an error of 100 feet, to be corrected by a turning maneuver in minimum time, followed by a period of gunfire.

Ten runs were made for each scenario studied, and key measurements were taken and averaged for each set of runs. The measurements made were as follows:

a. Shot Range at Baseline: An indication of the accuracy of the pilot's guidance. The range value indicates superior piloting control and enhanced survivability. At the longer range however, better tracking accuracy is required to achieve the same miss distances at the target.

b. Trigger Depression Time: The length of time the pilot was committed to a gun firing solution.

c. Average Miss Distance: A measure of the projective average miss distance during the gunfire period.

d. Minimum Miss Distance: The smallest miss obtained during the gunfire period.

Run Data and Pilot Evaluations

Average measurements for Pilots 1 and 2' are represented in Figure 10, and for Pilot 3 in Table 2. It is seen that the SAS is clearly superior. This conclusion is validated by the much larger range at gun boreline, horizontal run, and vertical run of the data presented in Figure 10. The error data presented in Table 2 are summarized with the following. Note that Pilot 3 obtained an average miss distance of less than 15 feet at the tracking test with the B-110 SAS. Figure 9 and 10 are summaries of the two scenarios, flown by Pilot 2, and were employed in the time of the computer. The improving lateral tracking error characteristic of the SAS system is clearly indicated, as well as the much larger range at shot.
Table 1. Original Versus SAS Comparisons

<table>
<thead>
<tr>
<th>SAS Type</th>
<th>Tracking</th>
<th>38° = 90 Degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Original</td>
<td>Original</td>
</tr>
<tr>
<td>Rotor at Confine (Ps)</td>
<td>2.90</td>
<td>3.40</td>
</tr>
<tr>
<td>Trigger Time (Sec)</td>
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<td>1.3</td>
</tr>
<tr>
<td>Minimum Size (Ps)</td>
<td>2.5</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Table 2. Tracking Task Averages for Pilot 3

<table>
<thead>
<tr>
<th>SAS Type</th>
<th>Original</th>
<th>Original</th>
<th>Original</th>
<th>Original</th>
<th>Original</th>
<th>Original</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotor at Confine (Ps)</td>
<td>3.00</td>
<td>3.20</td>
<td>3.00</td>
<td>3.20</td>
<td>3.10</td>
<td>2.90</td>
</tr>
<tr>
<td>Trigger Time (Sec)</td>
<td>1.7</td>
<td>1.7</td>
<td>1.7</td>
<td>1.7</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Average Size (Ps)</td>
<td>24.5</td>
<td>3.5</td>
<td>24.5</td>
<td>3.5</td>
<td>24.5</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Additionally, the simulator was flown by Pilot 3 in a variety of maneuvers at all flight speeds in order to test the SAS configuration. The maneuvers included weight, pitch, yaw, roll, pitch, and roll, and were tested in the presence of random noise and air gusts. The characteristics of the SAS were described, in fact, flying appeared to be easier, and the pilot's work load less than with the original system. Throughout the test, there was consistently representative, non-reaction control of the aircraft with the SAS.

Results and Recommendations

The results and recommendations of the second simulator performance evaluation were:

1. The three pilots rated the SAS system superior to the original SAS.

Figure 1. Tracking Scenario Compared

Figure 2. Cross-Image Scenario (38° = 90 Deg) Comparison

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Table 3. Summary of Aircraft Data from Gun Camera Films

|-----------|----------------|---------------|------------|--------------|----------------|---------------|------------|--------------|-------------|-------------|---------------|

Average: 346 1436 -17 5310 335 860 -14.6 2010

Original S.A. 305 1215 -15 3750 315 780 -13 2090

Subsequent abrupt heading change maneuvers may be required to keep a target on target unless it is blurred. The ability of the aircraft to make these changes quickly, as shown by the time required prior to firing, is the true measure of S.A. characteristics and performance.

Abrupt Heading Change Data

The abrupt heading change maneuver consisted of accelerating on the target with a 10-degree dive angle, a 30-degree bank angle, at 1000 feet per second, and a angle of attack of 10 degrees. The maneuver from 1000 feet to 500 feet altitude was made. The most significant performance in evaluating system performance is the maneuver time. This should be considered when accounting for the varying range of the heading change.

Average data over five pilots and three maneuvers for each pilot. The normalized maneuver time is 0.87 seconds per degree of heading change range for the average of between 5.5 and 9.8 degrees. While no quantitative flight test data is available for the original S.A. performance in this maneuver environment, qualitative examination of gun camera film, as well as pilot comments, reveals a large improvement in aggressiveness of aircraft response in these aggressive maneuvers. Therefore, examination of the data required to achieve heading changes should be done in the system.

Climb Descent Data

The average values for maximum lead factor and roll rate during the rollout, maximum bank angle during the turn, and banking time were:

\[
\begin{align*}
\text{Max. Lead Factor} & = 0.5
\end{align*}
\]

\[
\begin{align*}
\text{Max. Roll Rate} & = 35 \text{ deg/sec}
\end{align*}
\]

\[
\begin{align*}
\text{Tracking Time} & = 2.33 \text{ sec}
\end{align*}
\]

during very aggressive maneuvering. The most important parameter in this time, but load factor, bank angle, and roll rate are all indicative of the pilot's ability to control the system.

Again, no quantitative flight test data for the original S.A. is available for current maneuver at the degree of aggressiveness. However, the average tracking time of 2.33 seconds, which was achieved with a S.A. angle of more than 30 degrees for the original S.A., is significantly less aggressive maneuvers. This improvement is, perhaps, the most significant operational feature derived from utilization of the test-oriented S.A.

Gun Camera Film Analysis of Climber Strains

It was decided to analyze in detail all climber maneuvers performed by one pilot for a complete flight with the P.F.D. and one typical maneuver by the pilot with the original S.A.

The gun camera film material is presented in tabular and the film results. Each maneuver is plotted by displaying the target plane on the camera axis and marking key features to indicate climb or descent. The lateral and vertical offset of the camera plane from the center of the target. Positive offset indicates the target is up to and to the right.

Table 4 presents approximate climb, altitude, pitch angle, and climb rate at two points in time for each maneuver. The first time is when the pilot has been reduced to 30 degrees during the rollout between time of ascent, and at times when pulling off the target. The first time is approximately 10 degrees above the altitude and pitch angle are also indicated from the gun camera film. Slight in altitude increase by 20 feet, the geometry range altitude, therefore. This table presents height above the ground level (AGL).

The estimated per cent range in an average of two calculations. The first is based on aircraft altitude above ground level, altitude angle with respect to horizontal. The second estimates range from the film, while the last is based on calculated range from the film. The data is based on the minimum altitude and horizontal distance. These parameters are important for giving a feel for the range of maneuvers which were being used.

Table 4 lists the data obtained from the gun camera film records of the terminal portion of the maneuverable system. The measurements in the table are the values for evaluating the S.A. normal condition, comprising the weapon delivery system as follows:

1. The time from 30 degrees to 10 degrees of climb; 5.5 degrees to the 30-degree null, and null is indicated in the target is pulled on the 30.35 degrees at the edge, then extending the time to the 5.5-degree null; and then extending the line to the null. Within 1 second from the 30-degree climb, the maximum pitch angle from the target was held to less than 15 degrees, or the average, with the gun system. The same tan was accomplished with the original S.A., i.e.,
the piper was offset more than 4.5 miles from the target throughout most of the maneuver.

2. The time within 2.5 miles laterally indicates the total time the piper was within less than 2.5 miles of the target in a straight line, and indicates sensor control in the lateral/vertical plane. The time is in the most desirable, with 3.2 seconds for the SAS, and 0.4 second for the original SAS.

3. The time from $\Phi$ = 20 degrees to $\Phi$ = 0 indicates the time the maneuver was made, including any loss in position beyond the target, and indicates sensor control. The maneuver time is in the most desirable, with 3.2 seconds for the SAS, and 0.4 second for the original SAS. Indicating that the piper was continuously maneuvering.

4. The total time measures the time from the reference 10 degrees to pull back from the target. This only indicates the maneuver direction.

5. The percentage of time within 12.5 miles laterally indicates the ratio of time within 12.5 miles to the total time of the maneuver, percent of maneuver. The SAS averaged 62 percent of the total time of the maneuver, as compared with only 15 percent for the original SAS. Note that every maneuver with the SAS was within 12.5 miles for over two-thirds of the total time of the maneuver.

6. The percentage at $\Phi$ = 20 degrees average is 6.4 miles with the SAS, as compared with 0.1 mile with the original SAS. However, the maximum lateral offset occurring during the maneuver averages 12 miles with the SAS, and is 15 miles with the original, the time to the maximum offset occurring to the $\Phi$ = 20 degrees reference point is less than 1 second, indicating sensor control for the remainder of the maneuver with the SAS. Minimum lateral offset with the original SAS occurred from 2.4 to 1.4 seconds, and at 3.2 seconds, indicating sensor control for the remainder of the maneuver with the SAS.

Figure 11. Gun Camera Tracking Data: $\Phi$ SAS

11. Conclusions

The concept of a task-oriented SAS seems fundamentally straightforward, having been derived from the design and implementation of the A-20 SAS. However, SAS is a significant departure from the current primary sensor requirements of the aircraft, and rather than being an integral part of the aircraft, it is an auxiliary sensor requiring a special mount. The concept of the task-oriented A-20 SAS design seems to be an extension of the SAS in all subsequent production A-20 aircraft. Importantly, the sensor was achieved while adhering to the ground role
that any improved SAS must not involve costly modifications, i.e., it must be cost-effective.

15. Acknowledgments

The development of the SASS carried out in this paper was due to the hard work and contributions of many individuals, particularly Mr. Byers, Mr. Reilly, and Cope Miss Dino of the 4-18 STF, Enders, Boss, and Fuqua, and Mr. Weidler, a member of the General Electric Company, the members of the Flight Dynamics Division, and the members of the AIAA Testing Systems and Technology Committee in August, 1979.

16. Appendix

This appendix presents a brief outline of the various methods used in the SASS design. The most complete text matrix statement for $\hat{g}$ is:

$$\hat{g} = \hat{\alpha} (v) \hat{g}_p + (v) \hat{\alpha}_{\text{ang}}$$

where:

- $\hat{\alpha}$ is a function of $v$
- $\hat{\alpha}_{\text{ang}}$ is a function of $\alpha$
- $\hat{g}_p$ is a constant

Cost-effectiveness was a primary goal in the design of the SASS, and thus various criteria of estimating $\hat{g}$ were evaluated. The criteria selected for the final model is $\hat{g} = \hat{\alpha} (v) \hat{g}_p + (v) \hat{\alpha}_{\text{ang}}$. All of the options considered were examined thoroughly via manual and simulation, concluding both weapon delivery maneuver and resolution.

The first approximation considered was the elimination of the aerodynamic side force term, $\hat{g}_p$. This did not affect significantly dynamic performance, and further elimination of a requirement for an aerodynamic term was done by simple analysis that the result might be anticipated.

The Laplace transformation of the side force equation can be written as:

$$\hat{\ell}(s) = u(s) + \hat{\ell}_a(s)$$

Where:

- $\hat{\ell}_a(s) = (s + \omega_1) (\hat{\alpha} (v) \hat{\alpha}_{\text{ang}}) (\hat{u}(s) + (v) \hat{\alpha}_{\text{ang}}) (\hat{u}(s) + (v) \hat{\alpha}_{\text{ang}})$

It was then shown, on a linear basis, that the effect of adding the side force term is to decrease the time to:

$$r(s) = u(s) + (s + \omega_1) \hat{u}(s)$$

by unity. However, $\hat{\ell}_p$ is seen to be a long time constant mode unresponsive to the duration of lift-time maneuver elements and will not significantly affect dynamic response during these maneuvers. Thus, the solution for $\hat{g}$ becomes:

$$\hat{\ell}(s) = \hat{\ell}_a(s) \hat{\alpha}_{\text{ang}}$$

Next, it was recognized that, in a low-altitude, tactical maneuver, the pitch angle is very large, so that the approximation $\hat{\alpha}_{\text{ang}} \hat{\alpha} = 1$ should be evaluated. This approximation will produce a further reduction in error by $\hat{\alpha}_{\text{ang}}$, where:

$$\hat{\alpha}_{\text{ang}} = \hat{\alpha} \hat{\alpha} / \hat{\alpha} = \hat{\alpha} / \hat{\alpha}$$

It can be seen that the error will not be significantly reduced since both $\hat{\alpha}_{\text{ang}}$ and $\hat{\alpha}$ are concurrently large. The approximation has been shown to have a negligible effect on the tactical maneuvering simulation results, and did not produce unacceptable dynamic response even for null maneuver as approximately 30-amp pitch attitude. Based on these results, the equation for $\hat{g}$ was taken to be:

$$\hat{\ell}(s) = \hat{\ell}_a(s) \hat{\alpha}_{\text{ang}}$$

The replacement of the $\hat{\alpha}_{\text{ang}}$ term with the pitch, constant is described in the text. This approximation leads to the final form for the $\hat{g}$ estimate of:

$$\hat{\ell}(s) = \hat{\ell}_a(s) \hat{\alpha}_{\text{ang}}$$

with which excellent flight test results were obtained. Other, still simpler, estimate schemes, resulting the replacement of the term $\hat{\alpha}_{\text{ang}}$ with $\hat{\alpha}$, were also considered. But both preference and simplicity of use were paramount concern. Thus, it is obvious that $\hat{\alpha}_{\text{ang}}$ is a constant that can be considered to be the final cost-effective.
QUESTIONS AND ANSWERS

1. Dwight Schaefer - Boeing:

Question: Which of the flight characteristics were the most noticeable to you in your first few days of flying the KC-135? Did you notice any differences between the KC-135 and the KC-10, or were they similar?

Answer: I didn't notice any significant differences between the KC-135 and the KC-10. Both aircraft are very similar in terms of handling and performance.

2. Chuck Chalk, Chippewa:

Question: Are you experiencing any problems with the KC-135's stability during high-speed climbs?

Answer: No, the KC-135 is very stable during high-speed climbs. I haven't noticed any issues.

3. Wayne Thor, ASD:

Question: How do you rate the KC-135's performance in terms of climb rate and altitude?

Answer: The KC-135 performs very well in terms of climb rate and altitude. It's a very capable aircraft.

4. Bill Lemer, AFWAL:

Question: Have you considered any modifications to the KC-135's systems to improve its performance?

Answer: We're always looking for ways to improve the KC-135's systems. So far, we haven't found any significant areas for improvement.

5. Tom Peddle, APF:

Question: What are the most challenging aspects of flying the KC-135?

Answer: The most challenging aspect of flying the KC-135 is handling the high-speed climbs and descents. It takes a lot of skill and precision to maintain control.

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