Table 1 Properties of Concorde on-track sonic boom signal after reflection by the thermosphere compared to the primary boom

	$2\Delta p_G$,N/m^2	T_G,s	$(E/A)_G$,j/m^2	$2I_G$,NS/m^2
Conservative estimate	0.048	6.97	3.24×10^{-6}	1.68×10^{-1}
Low estimate	0.036	7.08	1.86×10^{-6}	1.28×10^{-1}
Linearized caustic, graphical advance and shock	front 0.020	4.5	—	—
	rear 0.036	6.6	—	—
Primary boom below Concorde (approximate)	75	0.12	1.35×10^{-1}	7.5

of order 2 N/m^2 and half-periods (T) of 0.5-3.5 s are intermediate between the primary on-track results and the present calculations. The present approach could be modified to deal with intermediate rays, with the major complications being in the ray tube area analysis and in accounting for a stratified wind structure in the atmosphere.

To put the present order-of-magnitude calculations into perspective, comparison with the primary boom of the Concorde shows that all signature measures are negligible, except perhaps for the impulse which is as great as 2.2×10^{-2} of the Concorde value due to the increased T. This impulse is still very small, but perhaps could lead to some structural vibration of buildings with very low resonant frequencies. However, even if fully coupled, with vibration amplitude squared taken to be proportional to energy, the vibration energy squared ratio would be proportional to the E/A ratio or about 46 dB below the Concorde's primary boom value. Of course, individual occurrences will vary statistically around these values due to atmospheric inhomogeneities and nonuniform flight conditions. These might result in amplifications of order 5 at most,[12,13] but even with such amplifications, it appears extremely unlikely that the on-track secondary sonic boom can be involved in any reported audible events.

Similar general conclusions have been recently reached independently in Ref. 14.

Acknowledgment

This work was supported by the Federal Aviation Administration, U.S. Department of Transportation.

References

[1] Balachandran, N.K., Donn, W.L., and Rind, D.H., "Concorde Sonic Booms as an Atmospheric Probe," *Science,* Vol. 197, July 1977, pp. 47-49.

[2] Federation of American Scientists, "Federation of American Scientists Relates Concorde to Mysterious High Altitude Explosions," press release, Washington, D.C., March 15, 1978.

[3] Garwin, R.L., "Speculation on Long-Range Effects of Supersonic Flight," Paper released by R. L. Garwin at Federation of American Scientists Press Conference, Washington, D.C., March 15, 1978.

[4] George, A.R. and Plotkin, K.J., "Sonic Boom Waveforms and Amplitudes in a Real Atmosphere," *AIAA Journal,* Vol. 7, Oct. 1969, pp. 1978-1981.

[5] Hayes, W.D., "Long-Range Acoustic Propagation in the Atmosphere," Institute for Defense Analyses, Jason Res. Paper P-50, 1953.

[6] Guiraud, J.P., "Acoustique Geometrique, Bruit Ballistique dis Avions Supersonique et Focalisation," *Journal de Mecanique,* Vol. 4, 1965, pp. 215-267.

[7] Hayes, W.D., "Similarity Rules for Nonlinear Propagation Through a Caustic," Second Conference on Sonic Boom Research, NASA SP-180, 1968, pp. 165-171.

[8] Gill, P.M. and Seebass, A.R., "Nonlinear Acoustic Behavior at a Caustic: An Approximate Analytical Solution," *Progress in Aeronautics and Astronautics,* Vol. 38, AIAA, N.Y., 1975, pp. 353-386.

[9] Plotkin, K.J. and Cantril, J.M., "Prediction of Sonic Boom at a Focus," presented as Paper 76-2, at the AIAA 14th Aerospace Sciences Meeting, Washington, D.C., Jan. 1976.

[10] Carlson, H.W., "Simplified Sonic-Boom Predictions," NASA Tech. Paper 1122, 1978.

[11] Carlson, H.W., private communication, 1978.

[12] George, A.R., "The Effects of Atmospheric Inhomogeneities on Sonic Boom," Third Conference on Sonic Boom Research, NASA SP-255, 1971, pp. 33-57.

[13] Maglieri, D.J., Huckel, V., Henderson, H.R., and McLeod, N.J., "Variability in Sonic Boom Signatures Measured Along an 8000-foot Linear Array," NASA TN D-5040, 1969.

[14] Gardner, J.H. and Rogers, P.H., "Thermospheric Propagation of Sonic Booms from the Concorde Supersonic Transport," Naval Research Laboratory Memorandum Rept. 3904, Feb. 14, 1979.

Technical Comments

Comment on "Flight Test of Stick Force Stability in Attitude-Stabilized Aircraft"

W. O. Breuhaus*

Institute for Defense Analyses, Arlington, Va.

A PAPER by Mooij and van Gool[1] reported results of flight tests which investigated the effects of positive stick force stability (PSFS) on the handling qualities of an airplane equipped with a pitch-rate-command/attitude-hold (PRC/AH) longitudinal control system. It was found that glide path control deteriorated at the highest value of PSFS gradient investigated.

The increase in PSFS gradient during the investigation reported in Ref. 1 was accompanied by reduction in the damping of the long period (phugoid) longitudinal oscillation. In fact, at the higher value of this gradient the phugoid motion (or its equivalent with the "nonaerodynamic" control system used on the airplane) was an unstable oscillation. This was attributed to the value of the stability derivative M_u which was introduced by the mechanization of the PSFS control system used in this investigation.

It is this writer's opinion that the observed deterioration of glide path control may well have been caused by the destabilization of the phugoid mode rather than by the introduction of positive stick force stability. Flight research performed more than twenty years ago[2] produced results

Received Sept. 27, 1978; revision received Nov. 1, 1978.

Index categories: Handling Qualities, Stability and Control; Flight Operations.

*Research Staff Member, Systems Evaluation Division. Associate Fellow AIAA.

which were generally similar to those reported in Ref. 1. In this earlier work the damping of the phugoid oscillation was varied systematically from substantial positive to substantial negative values, with the values of all other characteristics (including positive stick force stability) held essentially constant. It was concluded that negative damping of the phugoid has a very definite and deleterious effect on the instrument flight characteristics of the airplane.

Most of the work of Ref. 2 was performed in cruising flight, with only a small amount of the investigation devoted to flight along the landing glide path. A later report[3] investigated glide slope performance of standard operational aircraft under GCA control. While evidence of phugoid content was found in the landing flight path during this latter investigation, lack of airborne instrumentation prevented the determination of firm conclusions. Also, none of the operational aircraft observed during that investigation exhibited negative phugoid damping.

Those who remember when a downspring in the elevator control system was viewed (with some suspicion) as the ultimate in control system sophistication and complexity may also remember that this device could produce PSFS at the expense of reduced (or negative) phugoid damping. It produced a change in M_u similar to that reported in Ref. 1. Numerous anecdotal reports of such control systems, backed by some measurements, are on record[4] describing the deterioration of handling qualities that occurs when the damping of the phugoid becomes very low or negative.

Thus the undesirable results reported by Mooij and van Gool quite probably were due to low or negative phugoid damping rather than positive stick force stability. It would be interesting to see results from tests similar to those reported in Ref. 1, but with appropriate phugoid stabilization. Such stabilization can be obtained, without significant modification of the PSFS gradient, by the introduction of another stability derivative $M\dot{u}$ (where the $\dot{u}$ is suitably filtered to prevent response to turbulence).

References

[1] Mooij, H.A. and van Gool, M.F.C., "Flight Test of Stick Force Stability in Attitude-Stabilized Aircraft," *Journal of Aircraft*, Vol. 15, Sept. 1978, pp. 562-566.

[2] Newell, F.D. and Rhoads, D.W., "Flight Evaluations of the Effect of Variable Phugoid Damping in a JTB-26B Airplane," WADC TR 56-223 (also Cornell Aeronautical Laboratory Rept. TB 969-F-1), Oct. 1956.

[3] Newell, F.D., "Investigation of Phugoid Effects on GCA Landings," WADC TR 57-560 (also Cornell Aeronautical Laboratory Rept. TB-1142-F-1), Dec. 1957.

[4] Breuhaus, W.O., "Resume of Flight Experience with the Phugoid Characteristics of Aircraft and Possible Methods of Improving these Characteristics of Future Aircraft," Cornell Aeronautical Laboratory Flight Research Memorandum 117, May 4, 1951.

Reply by Authors to W. O. Breuhaus

H. A. Mooij* and M. F. C. van Gool†
National Aerospace Laboratory NLR, Amsterdam, The Netherlands

IN reaction to the comment of Breuhaus on the observed deterioration of glide path control for the highest value of the PSFS gradient, the following remarks are in order:

Received Nov. 28, 1978.

Index categories: Handling Qualities, Stability and Control; Flight Operations.

*Head, Stability and Control Department.

†Research Scientist.

1) A correction should be made to the original paper (Ref. 1): p. 563, right hand column, 4th paragraph, the 2nd and 3rd sentences should be replaced by: "This feedback loop around an airframe with a pitch-rate-command/attitude-hold flight control system introduces an oscillatory long-period mode; for increasing gain the frequency of the oscillation increases while the damping decreases."

2) A comprehensive stability analysis for the medium and high PSFS configurations has been given in Ref. 10 of the original paper. The calculation of the effect of speed feedback cannot be done through introduction of "new" stability derivatives, because the feedback path is upstream of the "model."

3) Breuhaus's opinion that the observed deterioration in glide path control may have been caused by the unstable long-period dynamics is correct for circumstances where the turbulence could not be described by "absent" or "very light." During the flight test discussed in Ref. 1 the stability of the long-period dynamics of the aircraft was a function of the magnitude of the speed deviation: for small speed deviations no oscillatory long-period mode existed (situation identical to no PSFS); for speed deviations in excess of the "speed error threshold," an unstable oscillatory long-period mode existed. The bimodal characteristic of the flight control system was possibly not described accurately enough in Ref. 1. The reason for selecting the particular feedback gain for airspeed deviation has been given (Ref. 1, p. 564).

In conditions of no or very light turbulence, pilots were indeed triggered by pitch attitude rates due to an off-speed condition; however they could easily maintain glide slope while making the necessary power adjustments (Ref. 1, p. 566, B. Results Obtained During Phase 2). This means that the pilots were able to reestablish a situation where the airspeed error was reduced to values smaller than the "speed error threshold."

4) The fifth sentence in the Conclusions section of Ref. 1 can possibly be phrased more clearly as follows: "Therefore great care is needed in selecting an upper value of the feedback gain for the airspeed deviation in order to maintain adequate damping of the long-period dynamics; this limits automatically the maximum value of 'stick-force per knot' for a given sensitivity of pitch rate command per unit stick force."

5) Since Ref. 1 has been written, flight simulator results concerning landing approaches and touchdowns using ILS guidance plus a final visual segment to touchdown of an aircraft with neutral stick force stability have been obtained. (Ref. 2).

Standard deviations of both ILS glide slope error and airspeed error (for configurations operated slightly front-side of the thrust required curve) obtained in the flight simulator program discussed in Ref. 2 are very close to the values of the flight test data presented in Ref. 1 for neutral stick force stability (no PSFS).

During the flight simulator program no adverse pilot commentary was given with regard to airspeed control.

Results of the two programs (Refs. 1 and 2) lead us to the conclusion that a condition of neutral stick force stability is satisfactory for the execution of the approach and landing of attitude-stabilized transport aircraft under manual throttle control; it is remarked that this conclusion is restricted to operation in the bottom or on the frontside of the thrust required curve.

References

[1] Mooij, H.A. and van Gool, M.F.C., "Flight Test of Stick Force Stability in Attitude-Stabilized Aircraft," *Journal of Aircraft*, Vol. 15, Sept. 1978, pp. 562-566.

[2] Mooij, H.A., de Boer, W.P. and van Gool, M.F.C., "A Simulator Investigation of Handling Quality Criteria for CCV Transport Aircraft," *AGARD Conference Proceedings of the Stability and Control Symposium*, Ottawa, Canada, Sept. 25-28, 1978. (Also NLR MP 78035 U).