The Motion Base Requirement

(As seen through the eyes of a Feedback Control System Engineer)

Written by

E. Bruce Baker

Over the last several years, there has been much discussion about the need for motion bases for aircraft simulators. Several times, an attempt has been made to prove or disprove the need for a motion base, and indeed, the need has been both proved an disproved. From all these studies and from personal experience, a few fundamental truths have emerged:

1. Air combat does not require and motion base
2. Hovercraft simulation (Helicopters VSTUL) requires a motion base
3. Nap of the Earth flight, particularly under IFR conditions, using a system such as the AH-64 PNVS, requires a motion base
4. Manual terrain following (200' altitude, 300 knots) requires a motion base
5. Carrier landings require a motion base
6. Realistic pilot response to wind gusts require a motion base

In general, any pilot task with requires frequent, rapid control inputs requires a motion base.

And analytical approach can be taken to understand exactly what a motion base is doing as far as the pilot is concerned. Figure 1 shows a block diagram of the pilot's roll control loop for a real aircraft. The pilot gets cues from the aircraft which tells him what the aircraft is doing. The roll acceleration and velocity cues are primary through the "seat of the pants," while the roll angle cues are entirely visual. Admittedly, the pilot gets some velocity cue from looking out the window, but under transient conditions, it is difficult for the pilot as he must derive velocity by mentally differentiating position. The pilot cannot get accelerations cues by looking out the window.

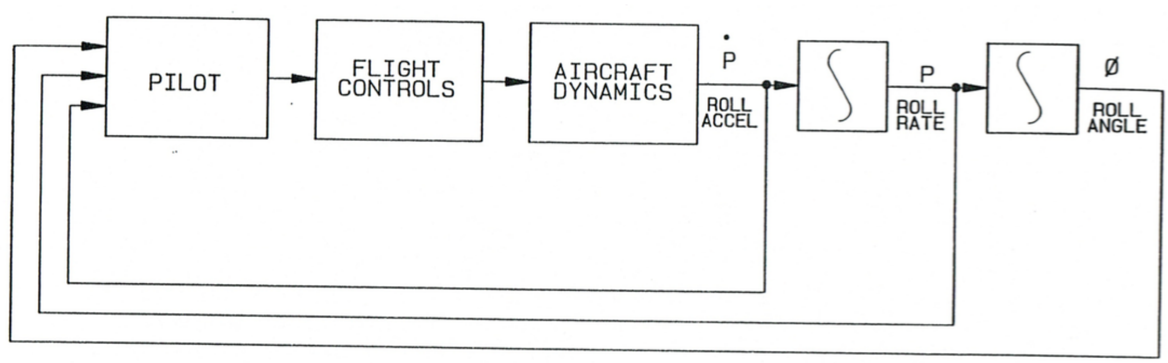

FIGURE NO. 1
PILOT'S ROLL CONTROL LOOP FOR A REAL AIRCRAFT

Figure 2 shows the pilot's roll control loop for a simulator with motion. The roll acceleration and velocity feedback signals are still present although they have been modified by the two filters. It should be relatively obvious that the design of these filters is critical.

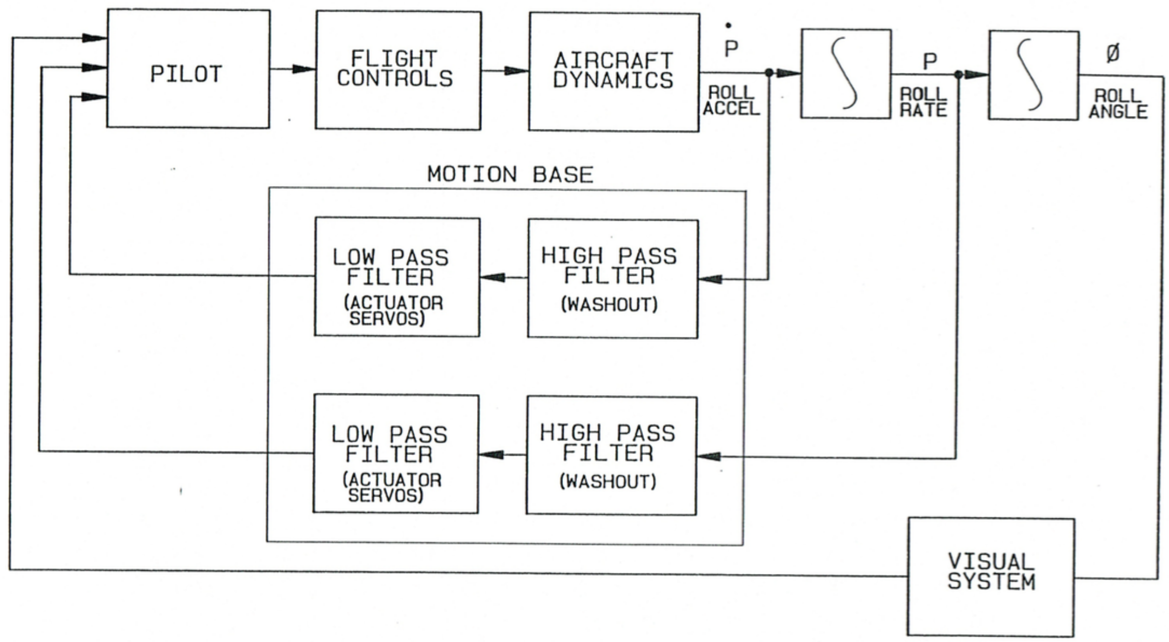

FIGURE NO.2
PILOT'S ROLL CONTROL LOOP FOR
A SIMULATOR WITH MOTION

It has been determined experimentally that pilots normally close the roll control loop in the 1.0-1.5Hz region when they are doing a high work load control task. This means that the pilots are responding to inputs which are below 1.0-1.5Hz and are ignoring inputs above 1.5Hz. Id can be shown analytically that the roll control loop transient response will not change significantly provided the motion base filters do not appreciably change the phase of the acceleration and velocity signals in the vicinity of the cross over frequency (1.0-1.5Hz).

Figure 3 shows the phase shift for two different combinations of the motion base wash-out filters and actuator servo bandwidths. Both of these combinations were designed to provide zero hase shift at 1.0Hz. The objective is to provide a phase curve that is flat (0 degrees) in the vicinity of 1.0Hz. The objective is to provide a phase curve that is flat (0 degrees) in the vicinity of 1.0Hz. Increasing the actuator servo bandwidth and decreasing the wash-out filter frequency improves the flatness of the phase curve. The actuator servo bandwidth is normally limited by the motion base and cockpit structure. The wash-out frequency is limited by the actuator stroke since decreasing the wash-out frequency by a factor of 2 requires increasing the stroke by a factor of 4.

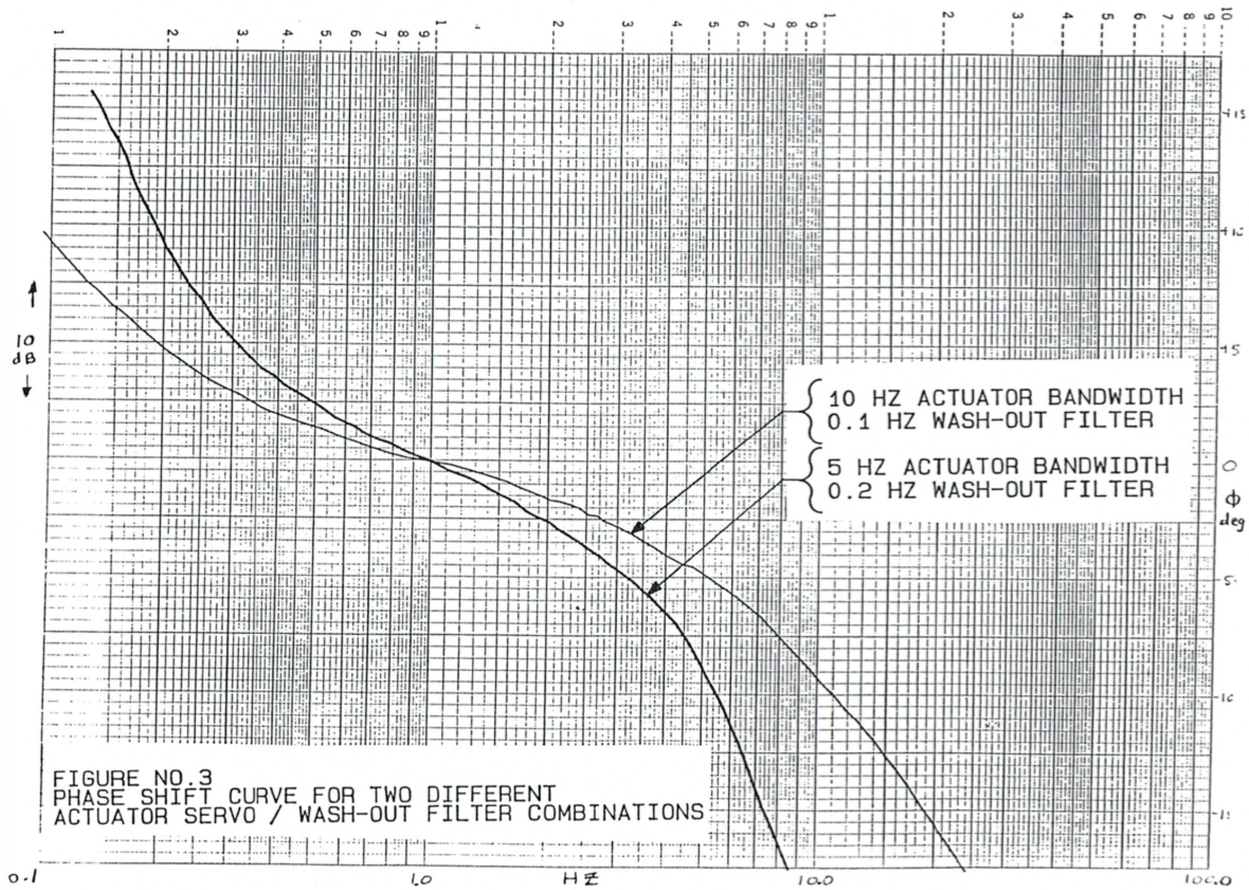

FIGURE NO.3
PHASE SHIFT CURVE FOR TWO DIFFERENT ACTUATOR SERVO / WASH-OUT FILTER COMBINATIONS

Figure 4 shows the pilot's roll control loop for a simulator without motion. Note that the acceleration feedback is completely missing and any rate information must be derived

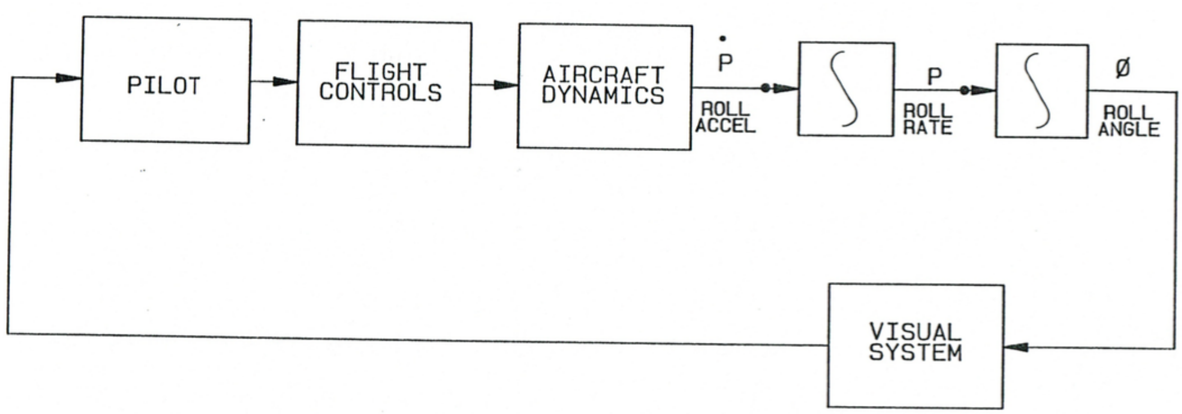

FIGURE NO.4
PILOT'S ROLL CONTROL LOOP FOR A SIMULATOR WITHOUT MOTION

by differentiating the roll position from the visual display. It can be shown analytically that unless the pilot drastically changes his compensation - i.e. the way he uses cues to control the aircraft - the roll control loop becomes unstable. Furthermore, the pilot's gust response is completely different without motion than it is with motion.

This argument can be extended to include the other axes of the aircraft.

The following documents are actual documents from the simulation industry. The comments in the documents are from actual pilots after being in the simulator. Their comments are from before and after simulation tuning occurred.

MARTIN MARIETTA

INTRACOMPANY MEMORANDUM

DATE 10 April 1978

TO: Messrs. M. Schwartz, R. A. Jackson, P. C. Gregory, M. Coenson, R. Chubboy, R. Monroe, W. Trippe, R. B. Blanning, R. J. Milelli

CC: All STL Engineering Staff

FROM: E. Bruce Baker DEPT. 5660 MP-~~75~~ 216 EXT. 2970

SUBJECT: STL Cockpit Motion Base

We recently finished a group of runs for the RAE which simulated the low-level attack of several types of ground targets (primarily vehicles). These missions required the pilots to fly at low altitudes (200') and maintain that altitude during weapon delivery and evasive maneuvers. The video tapes and the analog recordings of the pilot's stick inputs showed very definitely that the task was very nearly impossible without the motion base.

Attached is a transcript of a conversation between Squadron Leader (Major) Stu Penny (RAF) and the author concerning the motion base. These comments were endorsed by the other pilots involved in the task. The pilots were all in agreement that the motion base was absolutely essential for a task like this. The pilots were questioned about the presence of false cues from the washout, and all of them indicated that they were not aware of any. Also, none of the pilots indicated any lack of coordination between the visual and motion.

The pilots involved in the task were:

Squadron Leader (Maj.) Stu Penny
Squadron Leader (Maj.) Richard Rhodes
Squadron Leader (Maj.) Terry Adcock
Col. Neal Hayward
2nd Lt. Brian Collins

Several of the pilots have had experience in several R&D and training simulators, and they indicated that the motion cues we provided were the best they had encountered. They also indicated that the visual system was the best they had seen when it was working properly (which wasn't all the time).

All this indicates to me that the conclusion many experimenters have reached about motion - i.e., that motion cues are not necessary and sometimes detract from the task - is incorrect. Somebody should probably inform GD that they need to put their cockpit on the motion base.

E. Bruce Baker

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Attachment

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Conversation with Stu Penny re the motion base & motion cues, Mon, 3-27-78.

1. Motion allows much better short term controllability of A/C when pilot must divert attention away from flying task.

   A. Pilot puts POI on target and in doing so, noses over the A/C. The acceleration he receives is a stronger cue to him that he will have to be concerned about subsequently pulling up than he would receive from visual alone.

   B. When the pilot leaves the flying task for an ancillary function (i.e., control of the ATLIS on the head-down display) he sets a timer in his mind as to when he must recheck the flight path of the aircraft even though he may not have completed the ancillary task.

      With motion cues, he is more able to realize what is happening to the aircraft while his attention is away from the flying task and more realistically to assess the period for which he can concentrate on the ancillary task. With visual only, he must recheck the flight path at more frequent intervals to assess what has happened and, in addition, each assessment takes longer.

2. Low-level flight (2-300 scale feet above terrain model) is a demanding task in a simulator. Without motion cues, it is, at best, a poor approximation to actual flight. While flying under these conditions can be learned, the task demands a high degree of concentration, which is reduced with the motion base on. The reduction in concentration on the pure flying task is highly beneficial when demands for ancillary tasks are placed on the pilot.

3. Coming back off an ancillary task, the pilot is in much better condition to pick up the flying task with motion. Without motion, when the pilot returns from an ancillary task, he must interrogate the visual display and recompute the A/C attitude, altitude, rate of climb, etc. Roll attitude is relatively easy to pick off the visual display. Pitch attitude is somewhat more difficult still, since the cues are not terribly good. Rates are much more difficult to determine, as they must be computed by an approximate differentiation, and this requires several seconds. With the motion on, these variables are continuously computed within the pilots brain, and a glance out the window is sufficient to verify the correctness of these mental computations.

4. This short term controllability of the A/C is significantly better with the motion on. The pilot's ability to steer the POI and place it on a target is much better with motion than without. The pilot's inputs are much smoother when he can feel the A/C acceleration.

March 27, 1992

Mr. Edward M. Boothe
Manager
National Simulator Evaluation Program
Flight Standards Division, ASO-205
P.O. Box 20636
Atlanta, Georgia 30320

Dear Ed:

In February of this year, we at Servos and Simulation together with Eyring Corporation from Salt Lake City completed a major upgrade to the CH-46 simulator at MCAS Tustin. This upgrade consisted primarily of the addition of a blade element rotor model and improvements in the motion base. Now that the Marine pilots have been flying the simulator for six weeks, I called one of the instructor pilots (Jim Shirk 714-726-7557) at Tustin to discuss the reaction of the pilots. Following are his comments:

1. There is a tendency to over control the aircraft in roll with the motion base turned off. This tendency disappears with the motion turned on.

2. The simulator is much easier to fly at hover with the motion on than with the motion off. At forward speed the improvement is not as noticeable, primarily since the aircraft is easier to fly.

3. The simulator sickness problem may have been solved. The overcontrolling of the aircraft in roll may have been a primary contributor to simulator sickness. Sherry Jones at NTSC is doing a study on sickness and one of the simulators she is studying is the CH-46.

The frequency response of the motion base was measured including the washout equations. The aircraft acceleration input was driven, and the acceleration of the motion base was measured. The motion base coordinate system was centered at the cg of the aircraft, which on the CH-53 is 15 feet behind the pilot. The frequency response plots show a 5-9 Hz response (90 deg phase) in all axes, with the highest response being in roll, pitch, and heave. The phase response goes through zero between 1 and 2 Hz, and so the phase margin of the pilots control loop has not been significantly changed in the vicinity of his crossover frequency. I have enclosed copies of the motion base measured response.

It appears from this that a competent human factors study would put to bed the question of motion vs no motion, and that the worth of the motion bases would be firmly established.

Glory to God. Jesus is alive.

Sincerely,

E. Bruce Baker,
President