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Initial Piloted Simulation Study of Geared Flap Control For Tilt-Wing V/STOL Aircraft

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SUMMARY

A simulation model was developed for piloted evaluations of a representative tilt-wing V/STOL (Vertical/Short Takeoff and Landing) aircraft. Using this model an initial tilt-wing simulation study was conducted in 1990 on the Ames Vertical Motion Simulator

In the past, all tilt-wing aircraft have required a horizontal tail rotor or reaction jets to provide pitch control in hover and low speeds. To alleviate this need, devices such as monocyclic propellers and a geared flap have been proposed for providing control at low speed. The geared flap is the subject of this study and it is compared to the conventional flap used in previous tilt-wing aircraft.

Objectives of the study were to simulate a tilt-wing V/STOL aircraft, to evaluate and compare the control effectiveness and handling qualities of both a conventional (programmed flap) and the geared flap control configurations, and to determine the feasibility of eliminating the horizontal tail rotor or reaction jets of prior designs through the use of the geared flap control configuration.

Pilot evaluations indicated that in general, both flap control configurations had level 2 handling qualities. The handling qualities of both flap control configurations were comparable during conversion from hover to airplane mode and during reconversion from airplane mode to hover The programmed flap configuration had slightly better handling qualities than the geared flap configuration during STOL (fixed wing deflection) landings and hover

Results from this preliminary study show that with the geared flap control configuration the tail thruster requirement for pitch control during hover and low speeds is reduced compared to the programmed flap configuration.

NOMENCLATURE

i_W	wing incidence angle
$\dot{i}_W$	wing incidence angular rate
$\ddot{i}_W$	wing incidence angular acceleration
K	geared flap on the stick gain
K_1	geared flap on the stick gain
K_2	wing rate gain
$K_{\delta f}$	geared flap gain
g	acceleration due to gravity

δ_f	flap deflection
δ_{LN}	longitudinal stick
τ	tilt actuator time constant

INTRODUCTION

A simulation study of a representative tilt-wing V/STOL (Vertical/Short Takeoff and Landing) aircraft was conducted in 1990 on the Ames Vertical Motion Simulator. This simulation was conducted because of renewed interest in tilt-wing aircraft for use in several applications including the U. S. Special Operations Command Special Operations Forces aircraft, the U. S. Air Force Advanced Theater Transport, the NASA high speed rotorcraft studies, and proposed designs for civil applications. A new look at tilt-wing aircraft was further motivated by advances in technologies such as propulsion, materials, and flight control systems which can address shortfalls of previous tilt-wing aircraft.

The tilt-wing concept has been in existence for many years. Through the mid-70's, four notable tilt-wing aircraft were built and flight tested with varying degrees of success: the Boeing-Vertol VZ-2, the Hiller X-18, the Canadair CL-84, and the Vought-Hiller-Ryan XC-142. All of these aircraft required a tail rotor or reaction jet at the tail for pitch control during hover and low-speed flight. Monocyclic propellers or a geared flap have been proposed as alternate methods for providing pitch control at low speed. The geared flap concept has the potential for reducing or eliminating the need for a tail rotor, reaction jets or cyclic propellers and it is the subject of this current study

The objectives of the simulation study were to:

- Simulate a representative tilt-wing V/STOL aircraft.
- Evaluate and compare the control effectiveness and handling qualities of conventional (programmed flap) and geared flap tilt-wing control configurations.
- Determine the feasibility of eliminating the horizontal tail rotor or reaction jets of prior tilt-wing designs using the geared flap control configuration.

This report describes the geared flap concept, the representative tilt-wing aircraft, the simulation math model, and the simulation facility and experiment setup. The pilot evaluations of tasks are discussed, and the results obtained from the simulation experiment are presented. Appendix A documents the pilot evaluations and comments.

GEARED FLAP CONCEPT

The geared flap control concept utilizes the wing flap as an aerodynamic servo tab to control the wing incidence relative to the fuselage. The geared flap results in an integrated pitching and longitudinal control effector that could eliminate the need for auxiliary pitch control during hover and transition.

A schematic of the geared flap control concept is shown in figure 1 The pilot input can come from a beep trim switch located on the throttle, from the longitudinal stick, or from a combination of the beep trim switch and the longitudinal stick. Most of the results from this preliminary study of the geared flap are for a pilot input through the beep trim switch, although some results were also obtained with a combination of the pilot input through the beep trim switch and the longitudinal stick. This will be discussed further in subsequent sections of this report.

In the geared flap configuration (regardless of how the pilot input is implemented) the wing is free to pivot and is driven primarily by the forces generated by the flap within the propeller slipstream. Friction and artificial damping, as well as aerodynamic moments generated by aircraft motion, also affect the pivoted wing response. The pilot input controls the flap which then controls the wing incidence relative to the fuselage. For example, an increase in flap deflection causes a moment about the wing pivot. This moment remains unbalanced until the wing rotates to cancel the moment through mechanical feedback to the flap through the flap pushrod.

In hover the pilot input operates the flap, giving him a second order wing incidence response. In transition the geared flap control system provides tight control of the aircraft linear accelerations, with the fuselage being relatively unaffected by the wing-propeller moment variations.

Further information on the geared flap concept is available in reference 1

TILT WING AIRCRAFT

The tilt-wing aircraft used in the simulation study represented a mid-sized V/STOL transport aircraft. The overall length was 97 ft and the gross weight was 87,000 lbs. It had four engines with 26.4 ft diameter propellers. The thrust-to-weight ratio was 1 15. The wing span was 109 ft with an aspect ratio of 9. The low horizontal tail was fully positional. The aircraft had a 0.46 wing-chord-to-rotor-diameter ratio, 65.86 lbs/ft^2 wing loading, and 39.73 lbs/ft^2 disk loading. A tail thruster provided auxiliary pitch control during hover and low speeds for the programmed flap configuration and for the geared flap configuration as required. A conceptual sketch of this aircraft is shown in figure 2.

SIMULATION MATH MODEL

The complete longitudinal rigid airframe aerodynamic and dynamic characteristics were modeled. The aerodynamic model used a component buildup method to develop total forces and moments. Momentum theory was used to calculate propeller slipstream velocities which were then used with the "power-off" aerodynamics data to obtain "power-on" aerodynamic characteristics. Other elements in the math model included a dynamic model of the power plant, a model of the flight control system which included both programmed and geared flap control configurations, and a generic second-order landing gear model. Ground effects were not included. The simulation cycled real-time at a frame rate of 15 msec.

The longitudinal equations of motion were complicated by the fact that the wing was free to move relative to the fuselage. Thus the total center of gravity was not fixed at any time and the accelerations of the total center of gravity became functions of the total and relative accelerations of the wing and fuselage separately. The equations of motion, therefore, considered two free bodies, the wing and the fuselage, and the interrelationships of their separate equations of motion to describe the over-all aircraft dynamics.

The lateral/directional response and dynamic characteristics were simply modeled using stability derivatives with turn coordination added. The lateral/directional dynamics were not critical to this simulation study since we were primarily interested in the longitudinal handling qualities of the aircraft.

A detailed discussion of the equations of motion and the simulation math model may be found in reference 2 and a forthcoming NASA Technical Memorandum (Churchill, G.. Longitudinal Equations of Motion for Tilt-Wing/Rotor V/STOL Aircraft).

Aircraft Control Modes

The longitudinal control of the tilt-wing aircraft during hover and conversion depended on the flap configuration and is discussed further below.

During hover and low speeds pitch control for the programmed flap configuration was provided by the tail thruster. During conversion the pitch control effectors were the elevator, the horizontal tail, and the tail thruster. The throttle was used for heave control during hover and conversion.

In the case of the geared flap, the wing was free floating and hence aided the tail thruster in providing pitch control during hover and conversion. During hover and low speeds the longitudinal control effectors of the geared flap configuration were the wing incidence and the tail thruster as needed. During conversion the pitch control effectors were the wing incidence, the elevator, the horizontal tail, and the tail thruster as needed. The throttle was used for heave control during hover and conversion.

During airplane mode both flap configurations behaved in the same manner, using the elevator as the pitch control effector

Since the lateral/directional portion of the simulation model was characterized by stability derivatives, roll control and yaw control for both flap configurations were accomplished with a steady state aircraft response to the pilot input.

SIMULATION STUDY

Simulation Facility

This study was conducted on the NASA Ames Vertical Motion Simulator (VMS). The VMS has the capability for ±25 ft of vertical motion and depending on cab orientation ±17.5 ft of longitudinal or lateral motion. This simulation dictated ±17.5 ft of longitudinal motion, since we were interested in the longitudinal handling qualities of the aircraft. In the VMS the pilots could experience up to 3/4 g vertically, and up to 1/2 g longitudinally

Cockpit Layout

The cockpit setup provided the pilots with the essential instruments and controls to effectively "fly" the aircraft. Two wing tilt indicator dials (one digital and one analog) and a beta indicator were provided in addition to the conventional panel instruments. The cockpit controls consisted of a center stick with a trim button, a left-hand throttle with a rotary wing tilt beep switch, rudder pedals, and a flap lever located to the left of the pilot and aft of the throttle. An interior layout of the cockpit is shown in figure 3.

A four-window, computer-generated imaging (CGI) system provided the external view The CGI presented an airfield scene representing Ames' experimental facility at the Crows Landing Naval Auxiliary Landing Field.

Control Configurations

Three distinct control configurations were evaluated. The first configuration was a programmed flap. The other two configurations were variations of the geared flap. These control configurations are described further below

The programmed flap configuration used a spring return rotary beep switch located on the throttle to control the wing tilt. This configuration was called the "programmed" flap because the flap deflection was strictly a function of the wing incidence, as shown in figure 4. The pilot "beeped" the desired wing incidence through a rate command and then the flap responded as shown in the control schematic on figure 5.

Two geared flap configurations were evaluated. One geared flap configuration used the beep switch on the throttle to control the tilting mechanism. This configuration was referred to as geared flap on the beep. The other geared flap configuration split the tilting control between the beep switch on the throttle and the longitudinal stick (this resulted in wing-on-the-stick). This configuration was referred to as geared flap on the stick. With both geared flap configurations the pilot input generated an error command to the flap; the flap in turn controlled the wing incidence relative to the fuselage. Control schematics of both geared flap configurations are shown in figures 6 and 7

Evaluation Tasks

The evaluation tasks during the simulation were conversion, reconversion, hover, STOL landing, and to a very limited extent, STOL takeoff.

The conversion task began in hover at 50 ft AGL (Above Ground Level). While in hover, the pilot smoothly increased power and ascended to 100 ft AGL. He then incrementally lowered the wing, as he tried to maintain constant altitude. After a wing incidence of 40° to 45° and a velocity around 80 knots the wing could be lowered more aggressively to gain speed and altitude. Conversion ended at 180-200 knots and 500 ft AGL as shown in figure 8.

The reconversion task began downwind at 500 ft AGL, 200 knots, and the initial aircraft position was 12,000 ft to the left of the runway and 4,000 ft forward of the start of the runway, as shown in figure 8. The pilot slowed the aircraft to about 180 knots and lowered the landing gear on the downwind leg. On the base leg he descended to 300 ft AGL, slowed to about 100 knots and raised the wing incidence to 10° On the turn to final he extended full flaps, slowed down to about 70 knots, and raised the wing to 20° On final approach he incrementally raised the wing, adjusting power accordingly, and slowing down to about 35 knots. As he approached the hover position above the touchdown point, he descended to 50 ft AGL and continued to raise the wing as appropriate. Reconversion ended when the pilot brought the aircraft to a hover and landed.

The hover task began at 50 ft AGL over a checkerboard pattern to the right of the runway The pilot performed a visual hover over a precise spot for 3 minutes (see fig. 8).

The STOL landing task consisted of four approach speeds (60, 50, 40, and 35 knots) starting at 500 ft AGL and the initial aircraft position was 5,000 ft to the left of the runway and 2,000 ft forward of the start of the runway with the landing gear down (see fig. 8). For each initial velocity there was a corresponding wing incidence depending on the flap configuration The wing incidence remained constant during the approach. The task ended when the aircraft landed at the target point.

The STOL takeoff task consisted of four wing incidence positions (20°, 30°, 35°, and 40°). The task ended when the aircraft cleared a 50 ft obstacle 500 ft away

All tasks were performed visually without the aid of a flight director or a heads-up display and under calm conditions.

DISCUSSION OF RESULTS

Thirteen pilots participated in this study The pilot comments and Cooper-Harper pilot ratings were recorded during 119 runs. Pilot task evaluations for the programmed flap and geared flap on the beep configurations are summarized in figure 9. The results are presented in terms of the mean pilot ratings and the standard deviation of the pilot ratings for each task and flap configuration. The individual task results are covered more thoroughly in the following subsections. The handling qualities levels referred to in the following subsections refer to the Cooper-Harper pilot rating scale as noted below:

Handling Qualities Level	Cooper-Harper Pilot Rating Scale	
1	1.0 - 3.5	(satisfactory)
2	3.5 - 6.5	(adequate)
3	6.5 - 10.0	(inadequate)

The majority of the geared flap pilot evaluations were for the geared flap on the beep. A limited number of pilot evaluations exist for the geared flap on the stick, and many of these evaluations were done during pilot familiarization runs (which were not officially recorded). The geared flap on the stick results are covered separately at the end of this section.

The following qualifications should be noted before reading the results:

(1) No ground effects were modeled.

(2) The lateral/directional characteristics were modeled simply using stability derivatives with turn coordination added.

(3) There was no attempt at control law refinement and only pitch rate feedback was used.

These qualifications were not considered restrictive for our purposes, since the evaluation of the flap control configurations was comparative and limited only to the longitudinal handling qualities.

Conversion

During this task (as well as during reconversion) the wing conversion could be executed either by incrementally beeping the rotary knob as desired or by continuously holding the rotary knob depressed. The maximum wing rate during conversion and reconversion was 10 deg/sec.

Programmed Flap. The initial portion of the conversion (i.e., the climb to 100 ft) was straightforward. Initial rotation of the wing resulted in a pitch down moment of the aircraft. This was due to the increase in the moment arm from the thrust line to the total aircraft center of gravity as the wing rotates down. Also, at approximately 50° wing incidence the aircraft tended to balloon. This was because less horsepower was required with increasing forward speed, and the aircraft ballooned before the pilots had a chance to correct the situation by reducing the power. One pilot, who was a former XC-142 project pilot, noted that both the nose down moment and the ballooning effect were similar to the XC-142 aircraft behavior. In addition, all pilots noticed the longitudinal acceleration when they beeped the wing.

The pilots were busy trying to control altitude and minimize large nose down attitudes during mid-conversion. Unfortunately, some pilots experienced a significant nose down attitude (as much as –20°) during climb. Pitch oscillations were sometimes encountered while trying to correct this problem. Also, throttle sensitivity and heave damping were low, causing overcontrol while monitoring altitude.

The two most common pilot comments were with regard to the large negative pitch attitudes and the altitude control problems. Handling qualities were generally in the level 2 range.

Geared Flap on the Beep. The initial portion of the task (the climb to 100 ft) was straightforward. The first major difference from the programmed flap noted by the pilots was the rearward acceleration pulses caused when beeping the geared flap, as seen in figure 10. The time histories in figure 10 show the relationship between the flap deflection and the resulting rearward acceleration pulses and wing incidence changes. The acceleration pulses were nonminimum-phase-shift like in character and will be the subject of a future control study.

Some pitch down moment and accompanying ballooning were also noted; however, the majority of the pilots felt that the nose down attitude during mid-conversion was not as severe as experienced with the programmed flap configuration. The pilots had trouble with the coupling of negative pitch attitudes with altitude control. Some pilots indicated that pitch control and aircraft acceleration were better for this configuration than for the programmed flap configuration. Again the handling qualities were generally in the level 2 range.

Figures 11 and 12 show two typical conversion time histories for the programmed flap configuration and the geared flap on the beep configuration, respectively. The time histories shown are for the first 60 seconds of the conversion for the same pilot and similar conversion techniques. Comparison of both figures shows that the tail jet pitching moment of the geared flap configuration is much lower (about 50,000 ft-lbs less) than that of the programmed flap during hover. A reduced tail jet pitching moment means less tail thrust was required for pitch control. The figures also show that for a wing incidence of 50°, the geared flap configuration negative pitch attitude is lower (–2°) than the programmed flap configuration pitch attitude (–7°). This confirms the pilot comments that the nose down attitudes during mid-conversion were smaller with the geared flap configuration.

Reconversion

The pilots first encountered the stick shaker during the reconversion task. The stick shaker represented the buffet onset, or the beginning of wing stall. It was modeled as a function of equivalent angle of attack and flap deflection.

Programmed Flap. The pilots had difficulty controlling pitch attitude, altitude, and flight path. Ballooning and lack of heave damping added to the pilot workload. The stick shaker was often encountered at around 40°-50° of wing incidence, although the addition of power alleviated this problem. Glide path control also added to the pilot workload. Many pilots were constantly working the throttle to control the glide path.

Wing incidence changes required high pilot compensation on the vertical descent rate during reconversion. A NASA pilot noted that it was unlike flying the Harrier or the Tiltrotor because of the "barn door" (increased drag) effect caused by the large wing deflections. Handling qualities were generally in the level 2 range.

Geared Flap on the Beep. The pilots had difficulty controlling pitch attitude, altitude, and flight path. The approach could not be rushed, or the flight path was hard to control. The altitude changes seemed more exaggerated than for the programmed flap. When reducing power to hold attitude, the stick shaker was often encountered. Some pilots got into lag situations and overcontrolled power. Handling qualities were generally in the level 2 range.

Hover

Programmed Flap. Height control was precise and hence the pilot workload was low. Pitch, roll, and yaw controls were predictable. The pilots had difficulty visually holding a point over the checkerboard pad (this accounts for some of the tracking divergence encountered). However, the hover handling qualities of the programmed flap configuration were in the level 1 range.

Geared Flap on the Beep. Some pilots could not detect a difference between this configuration and the programmed flap configuration. Other pilots felt height control was not as precise in this configuration as it was in the programmed flap configuration. The hover handling qualities of the geared flap configuration were in the level 1 and 2 range.

STOL Landings

The speed and wing incidence angle combinations shown in this subsection were based on trimmed flight values achieved with pitch attitudes in the range of ±6°

Programmed Flap. 60 knots, 20° wing incidence—Pilot workload was low. Some initial maneuvering was required for altitude and airspeed, but the overall approach was smooth. Pilots could control flight path and airspeed well by a combination of minor throttle adjustments and pitch attitude. Handling qualities were in the level 1 range.

50 knots, 30° wing incidence—Pilot workload increased. The aircraft was less responsive because of lower dynamic pressure. Pilots were distracted by closeness to the buffet boundary. The heave damping problem encountered before was present again. The technique for flying was the same as above: pitch attitude for airspeed control, and power for glide path control. Some pilots were tending to overcontrol power. Handling qualities were in the level 1 and level 2 range.

40 knots, 35° wing incidence—More degradation was noticed between this case and the last. There were more tasks for the pilots. They now had to monitor angle of attack and sideslip angle (aircraft was departing directionally during turns). The stick shaker was encountered on the base leg and approach. Precision on landing and touchdown was still level 1, but because of the pilot workload on the initial approach and onset of the stick shaker, overall handling qualities were generally in the level 2 range.

35 knots, 40° wing incidence—A large nose down attitude was required to avoid the stick shaker on base leg and on turn to final. Pilots were busy monitoring angle of attack and sideslip. One pilot noted that he would probably lose the aircraft without the sideslip indicator. The control technique was the same: apply power for flight path control, and trade off pitch attitude with airspeed. There was a low sink rate, and a level 1 final approach was still possible. However, because of pilot workload during base leg and turn to final, and because of the stick shaker, the overall handling qualities were generally in the level 2 range.

Geared Flap on the Beep. 60 knots, 44° wing incidence—The technique for control was the same as the programmed flap: power for flight path control, and pitch attitude for speed control. Stick shaker was encountered on base leg and final. Precision on landing and touchdown was level 1, but because of the stick shaker the overall handling qualities were in the level 2 range.

50 knots, 47° wing incidence—Pilot workload was about the same as the previous case. Technique for control was the same. The heave damping problem was creeping up again. Some pilot-induced-oscillations in flight path were noted. The stick shaker was encountered again. The handling qualities were generally in the level 2 range.

40 knots, 52° wing incidence—Pilot workload increased from the previous case. Pilots encountered difficulty holding angle of attack and sideslip. The control technique was a little different: pilots led with pitch attitude and followed with power. The configuration was fine for level flight, but once power was reduced to come down, pilots got the stick shaker. To avoid the stick shaker, the pilots were flying faster than they wanted. Handling qualities were in the level 2 range.

35 knots, 54° wing incidence—Pilot workload was about the same as the previous case. Pilots again traded velocity for the stick shaker. It was difficult to hold angle of attack and sideslip at zero. Handling qualities were generally in the level 2 range.

STOL Takeoffs

Only four programmed flap configuration STOL takeoffs were rated. No geared flap configuration STOL takeoffs were flown.

With the programmed flap configuration excess thrust was available during the 60 knot and 20° wing incidence takeoff. The 50 knot and 30° wing incidence takeoff was less responsive because of the lower dynamic pressure. The 40 knot and 35° wing incidence takeoff was close to a buffet boundary and the pilot was worried about commanding more power than he wanted. The handling qualities of the three cases above were level 1 The 35 knot and 40° wing incidence takeoff handling qualities deteriorated further and were level 2.

Geared Flap on the Stick

A limited number of pilot evaluations exist for the geared flap on the stick because trimming the aircraft in this configuration was a challenging task. Three pilots flew this configuration. The following statements are based solely on pilot comments during practice runs. The geared flap on the stick was better than the geared flap on the beep during hover because the pitch response to longitudinal stick inputs was smoother The two geared flap configurations did not seem very different during conversion and reconversion.

CONCLUSIONS AND RECOMMENDATIONS

(1) The tilt-wing simulation model is valid for research purposes. Two former tilt-wing pilots (one flew the XC-142, the other flew the CL-84) commented that the programmed flap tilt-wing model responded similarly to their tilt-wing aircraft behavior

(2) Generally, both control configurations showed level 2 handling qualities. The geared flap on the beep configuration mean pilot ratings were level 2 in all cases. The programmed flap configuration mean pilot ratings were level 2 except for hover and one STOL landing configuration (60 knots and 20° wing incidence) which had level 1 mean pilot ratings.

The handling qualities for the geared flap on the beep configuration and the programmed flap configuration were comparable during conversion from hover to airplane mode and during reconversion from airplane mode to hover and landing. The programmed flap configuration had slightly better handling qualities than the geared flap on the beep configuration during STOL (fixed wing deflection) landings and hover.

(3) Results from this preliminary look at the geared flap on the beep configuration show that the tail thruster requirement for pitch control during hover and low speeds was reduced compared to the programmed flap configuration.

(4) By comparing the handling qualities of both configurations this preliminary study showed that the geared flap concept is feasible for tilt-wing aircraft.

However, more testing is necessary for the geared flap configurations. The geared flap on the beep configuration needs control law refinement, not only to exploit further reduction of the tail thruster requirements, but to reduce the negative effects of the longitudinal acceleration pulses on the handling qualities, and to relieve overall pilot workloads. Also, control law tailoring for the geared flap on the stick configuration has the potential for providing short period low speed pitch control thru the geared flap mechanism.

Based on pilot comments recommended changes for a follow-on simulation include a rate or attitude command control system, a higher definition visual display, a digital speed indicator, a glide slope indicator, and a radar altimeter that measures height above the ground (not sea level) for terrain following tasks.

REFERENCES

1 Churchill, G. Evaluation of Geared Flap Control System for Tiltwing V/STOL Aircraft, AD 712 645, January 1969.

2. Totah, J.. Description of a Tilt Wing Mathematical Model for Piloted Simulation, Presented at the 47th Annual Forum of the American Helicopter Society, Phoenix, Arizona, May 1991.

APPENDIX A

PILOT EVALUATIONS

PILOT EVALUATIONS

RUN NO.	Date	Pilot	Task	Flap Configuration	Winds/Turb	Pilot Rating	Comments
	9/4/90	A	conversion	programmed flap	0	3	Motion cues are outstanding; tried a power wave-off at 100 ft, aircraft
							pitched down & ballooned (around iw=50°)- very similar to XC-142.
1	9/6/90	A	conversion	programmed flap	0	practice	
2	9/6/90	A	conversion	programmed flap	0	3.25	Minor pitch oscillation out of hover: more a physical phenomenon
							than visual. Some sinking at the end of run.
3	9/6/90	A	reconversion	programmed flap	0	practice	
4	9/6/90	A	reconversion	programmed flap	0	2.5	At wing incidence of 35° got the stick shaker; addition of power fixed it.
							Generally a good approach.
5a	9/6/90	A	60 kt STOL landing	programmed flap	0	practice	
5b	9/6/90	A	60 kt STOL takeoff	programmed flap	0	practice	
6a	9/6/90	A	60 kt STOL landing	programmed flap	0	2	Very easy task to do.
6b	9/6/90	A	60 kt STOL takeoff	programmed flap	0	2	Excess thrust available at takeoff.
7a	9/6/90	A	50 kt STOL landing	programmed flap	0	2.5	A little less responsive because of less q (dynamic pressure).
7b	9/6/90	A	50 kt STOL takeoff	programmed flap	0	2.5	Same.
8a	9/6/90	A	40 kt STOL landing	programmed flap	0	3	Stick shaking quite a bit on approach.
8b	9/6/90	A	40 kt STOL takeoff	programmed flap	0	3	Because of lower q and proximity to buffet, constantly worried about
							having more power than you really want. All these tasks easy to do.
9a	9/6/90	A	35 kt STOL landing	programmed flap	0	practice	
9b	9/6/90	A	35 kt STOL takeoff	programmed flap	0	practice	
10a	9/6/90	A	35 kt STOL landing	programmed flap	0	4	Having to push nose down (15°) a long way to avoid stick buffet.
							Got stick shaker on approach.
10b	9/6/90	A	35 kt STOL takeoff	programmed flap	0	4	(pilot forgot to set flaps at 60%) This wouldn't correlate with XC-142.
11a	9/6/90	A	50 kt STOL landing	programmed flap	0	4	Nominal wt + 13000 lbs; Stick buffet at 60 kts. Right on the nervous

RUN NO.	Date	Pilot	Task	Flap Configuration	Winds/Turb	Pilot Rating	Comments
							edge of buffet all the way.
11b	9/6/90	A	50 kt STOL takeoff	programmed flap	0	4	Nominal wt + 13000 lbs; Similar to the iw=40° task at lighter weight.
12a	9/6/90	A	50 kt STOL landing	programmed flap	0	4.5	Nominal wt + 18000 lbs; Pattern getting larger as you increase weight.
12b	9/6/90	A	50 kt STOL takeoff	programmed flap	0	4.5	Nominal wt + 18000 lbs.
13	9/6/90	A	hover	programmed flap	0	2.5	3 minute hover; (weight was still nominal wt + 18000 lbs by mistake).
14	9/6/90	A	hover	programmed flap	10 kts,4.5fps	scratch	10 kt crosswind from right of a/c; back to regular weight.
15	9/6/90	A	hover	programmed flap	10 kts,4.5fps	2.75	Workload goes up, but still controllable.
16	9/6/90	A	conversion	geared flap	0	practice	Got a pitch trim change right when I first moved the wing.
17	9/6/90	A	conversion	geared flap	0	practice	Couple of step trim changes with flap going on & off stops. May
							have hurried that a little bit.
18	9/6/90	A	conversion	geared flap	0	3	Smoother. Did not hit flap stops.
19	9/6/90	A	reconversion	geared flap	0	3	(Maximum wing rate dropped to 10 deg/sec max). At wing incidences
							of 45°-50° got a little buffet. Wing incidence <25° have to wait for the
							flap to come out. Definitely shows promise.
	9/10/90	B	conversion	programmed flap	0	4	Pitch down and ballooning noted.
	9/10/90	B	reconversion	programmed flap	0	5	Hard time settling on final tilt; pretty high workload.
	9/10/90	B	reconversion	geared flap	0		Helpless feeling when beeping and flap stays on the stop.
20	9/12/90	C	conversion	programmed flap	0	4.5	Rate hover a 1. Ht control is very precise; pitch, roll, yaw are like a rock.
							High climb rate out. Not doing a good job controlling alt. Pretty busy
							trying to keep up with alt and pitch attitude. The biggest factor for the
							"4.5" rating was trying to hold 500 ft. Could not do it smoothly. I was
							distracted holding altitude.
21	9/12/90	C	conversion	programmed flap	0	4.5	Still sorting out alt, speed, attitude. Ending up nose low, climbing

PILOT EVALUATIONS

RUN NO.	Date	Pilot	Task	Flap Configuration	Winds/Turb	Pilot Rating	Comments
							when I don't want to.
22	9/12/90	C	reconversion	programmed flap	0	5	Ballooned a lot. I was way high, not a good landing, but right on.
							For smoothness, the longer you wait on deflecting the wing, the better
							but not at 200 ft, you start decending too fast. I was pretty busy.
23	9/12/90	C	60 kt STOL landing	programmed flap	0	3	Approach very stable. Sink rate 300 ft/min. Initially jocking altitude,
							speed, but overall very smooth approach.
24	9/12/90	C	50 kt STOL landing	programmed flap	0	4	A little bit distracting to be so close to a buffet boundary. Want more
							margin. Approach went ok, "floated" quite a lot before landing.
25	9/12/90	C	40 kt STOL landing	programmed flap	0	5	Didn't like the nibbling on the stick shaker - base leg & approach are
							on the ragged edge. Precision on landing & touchdown is good, a "3".
26	9/12/90	C	35 kt STOL landing	programmed flap	0	4	Low sink rate at touchdown. Very smooth final approach rates "2.5".
							Overall "4", because base leg & turn to final got the stick shaker.
27	9/12/90	D	conversion/recon	programmed flap	0	2, 2	Both tasks rate a "2". Nice 8° glideslope; very nice.
28	9/12/90	D	60 kt STOL landing	programmed flap	0	practice	
29	9/12/90	D	60 kt STOL landing	programmed flap	0	1	Like a normal fixed wing approach. That was pretty easy.
30	9/12/90	D	50 kt STOL landing	programmed flap	0	3	Picking up some wing buffet on base leg, had to add power.
31	9/12/90	D	40 kt STOL landing	programmed flap	0	3	Wing buffet on final approach.
32	9/12/90	D	35 kt STOL landing	programmed flap	0	2	Some wing buffet again.
33	9/12/90	D	hover	programmed flap	0	1	Hover at runway crossroads for 3 min. Could use more depth cues.
							Drifted >100ft in X.
34	9/12/90	D	hover	programmed flap	0	1	Hover over checkerboard. Lot better visual cues over here.
35	9/13/90	E	conversion	programmed flap	0	5	These comments are based on this run and the practice runs. Initial
							portion: climbing to 100ft is straightforward, heave damping and

RUN NO.	Date	Pilot	Task	Flap Configuration	Winds/Turb	Pilot Rating	Comments
							throttle sensitivity are low, just have to get used to it with practice.
							Beeping out: must do it incrementally. You can feel the long. accel
							pulses as you beep the wing. Must monitor alt; control with power.
							It's easy to overcontrol. A/C responds well. Nothing is long dyna.
							was detrimental. There is a nose down pitching moment - would like
							this taken care of. An attitude hold system would improve handling
							qualities. Problems are: height control and coping with trying to keep
							a contant attitude.
36	9/13/90	E	reconversion	programmed flap	0	practice	Would like to repeat.
37	9/13/90	E	reconversion	programmed flap	0	practice	Immediate reaction is that I wouldn't do the task the way requested.
							The pattern seems too wide and flat for my experience.
38	9/13/90	E	reconversion	programmed flap	0	5.25	Certainly controllable. Pilot workload on the same two areas: height
							and pitch attitude on long. axis. Need to keep looking outside, or
							there's a tendency to over correct. The digital wing incidence indicator
							is a great help. Considerable pilot compensation required.
39	9/13/90	E	conversion	geared flap	0	5	First big difference: you can feel the accel pulses of the flap. You can
							feel the pulses rearward instead of forward. Have to be patient with
							it, once you get moving, the accel pulses disappear. Big pitching
							moment change and nose up. Rate command or attitude command
							system would releave the pilot workload due to the compensation
							required to hold the aircraft level.
40	9/13/90	E	reconversion	geared flap	0	5	There's a learning curve going on. I rushed things around, but still
							put the aircraft where I wanted it. Says something for the handling

RUN NO.	Date	Pilot	Task	Flap Configuration	Winds/Turb	Pilot Rating	Comments
							qualities. When I let go of the beeper (and flap came off the stop),
							there was a big pulse in the system. Controllable & adequate, but still
							feel improvements can be made. Deficiencies are more than minor
							and annoying. Again a level 2 aircraft.
41	9/13/90	E	60 kt STOL landing	programmed flap	0	3	Fairly low pilot workload (no wing to move). Can just concentrate
							on flight path. Could hold airspeed well using a combination of
							pitch hold and with minor throttle adjustments. Certainly satisfactory
							without improvement. Not real rock solid on glide slope (minor
							deficiency).
42	9/13/90	E	50 kt STOL landing	programmed flap	0	4.25	As I slowed down, started to see the heave damping problem coming
							in. I was overcontrolling with power. Used pitch attitude for speed
							control and power for glide path control. Didn't like the workload.
43	9/13/90	E	40 kt STOL landing	programmed flap	0	practice	
44	9/13/90	E	40 kt STOL landing	programmed flap	0	6	Had to monitor angle of attack and sideslip. Got some sideslip.
							Used power to hold rate of descent. Required more effort & more
							workload because aircraft departs directionally, and I had to work
							to maintain angle of attack and zero sideslip.
45	9/13/90	E	35 kt STOL landing	programmed flap	0	6.25	More of the same. Directional stability really goes to pieces. Without
							that sideslip gage would probably lose this aircraft. Can start large
							excursions on angle of attack. Like a blimp, very slow. Monitored
							angle of attack and beta. Used power for flight path control, then
							followed with pitch attitude, then powered again for flight path control.
							From wing incidence of 30° to 35° there was a more pronounced

PILOT EVALUATIONS

RUN NO.	Date	Pilot	Task	Flap Configuration	Winds/Turb	Pilot Rating	Comments
							degradation than from 35° to 40°.
46	9/13/90	E	hover	programmed flap	0	3	Aircraft fairly steady. If we had targets we could do a better job.
							Handling qualities are fine; fairly easy to handle. Divergence because
							it is hard to track fore/aft over this checkerboard pad. Certainly
							level 1 for hover.
47	9/13/90	E	60 kt STOL landing	geared flap	0	3.5	Looked pretty good. No sideslip departure in the turn. Did notice the
							stick shaker. This configuration requires a zero angle of attack.
							Technique was the same, looked like the 20° approach of the
							programmed flap.
48	9/13/90	E	50 kt STOL landing	geared flap	0	4.25	Looked about the same as the previous run. Got stick shaker again.
							Technique the same. Got into a gamma P.I.O. The heave damping
							problem creeping up again.
49	9/13/90	E	40 kt STOL landing	geared flap	0	5	There was quite a change there. Difficulty holding angle of attack and
							beta. Starting to really have to concentrate. Technique is a little bit
							different: lead with pitch attitude, follow with power. Pilot workload
							goes up, but it is controllable.
50	9/13/90	E	35 kt STOL landing	geared flap	0	6.5	Speed control problem while trying to hold alpha; speed went from 35
							to 50 kts. On final airspeed dropped. Not trying to hold velocity. It is
							more important in this envelope to hold alpha and beta. Heave
							damping is increased and associated pilot workload goes up.
51	9/13/90	E	hover	geared flap	0	3.25	Hit some pilot fatigue. Couldn't really see a difference from the
							programmed flap hover task. Maybe subtle differences. Trying to
							rule out fatigue.

RUN NO.	Date	Pilot	Task	Flap Configuration	Winds/Turb	Pilot Rating	Comments
52	9/14/90	C	reconversion	programmed flap	0	6	Have a nose low attitude (8°). Got some stick shaker when I started
							beeping the wing. Once you get stabilized, workload is pretty low
							on final approach, rate it a "4". The set-up on base leg was a higher
							workload (pretty busy), rate it a "6".
53	9/14/90	C	conversion	geared flap	0	practice	Can still control it. Vertical landings, height control similar. Can
							stop where you want to and ease it on to the run way.
54	9/14/90	C	conversion	geared flap	0	6	Got to 19° nose down. Got stick shaker when I tried to raise the nose.
							Same problems as with the programmed flap. This one seemed to
							give me higher nose down. Didn't see any great improvement. The
							nose down was more distracting. Need to modulate power better. On
							first crack, I didn't like it.
55	9/14/90	C	conversion	geared flap	0	practice	The nose low is the big problem.
56	9/14/90	C	reconversion	geared flap	0	practice	First impression: final approach deteriorated.
57	9/14/90	C	reconversion	geared flap	0	6	The alt gain seems more exagerated in this configuration. To hold
							altitude, need to reduce power, but then you get stick shaker. Should
							not be that way. It is not a smooth operation.
58	9/14/90	C	60 kt STOL landing	geared flap	0	practice	Nice and slow, have a little more time on base leg now. Screwed up
							by moving flap. Repeat.
59	9/14/90	C	60 kt STOL landing	geared flap	0	6	That landing was as good as I've done. The problem on base and final
							was stick shacker. Either we need to be faster or need a different wing
							incidence and flap setting. Touchdown was a "2", but because of
							shaker, give it a "6".
60	9/14/90	C	50 kt STOL landing	geared flap	0	6.5	This one gives you better pitch att. (3.5°). Stick shaker is the problem.

PILOT EVALUATIONS

RUN NO.	Date	Pilot	Task	Flap Configuration	Winds/Turb	Pilot Rating	Comments
61	9/14/90	C	40 kt STOL landing	geared flap	0	6	Had to fly faster than desired to avoid stick shaker.
62	9/14/90	C	35 kt STOL landing	geared flap	0	3	Traded speed for stick shaker; flew 38-40 knts (5+ knots more than
							specified). Much more comfortable approach. Low workload.
63	9/14/90	C	hover	geared flap	0	4	Some altitude changes due to pitch oscillations.
64	9/14/90	C	hover	programmed flap	0	2.5	Marked improvement; altitude control better.
65	9/14/90	F	reconversion	programmed flap	0	4	Initial 5° of wing incidence ballooned the a/c. At around 20° wing inc.
							you really have to come in quick with power. Flying aircraft like a
							helicopter (on the back side), but more difficult to fly than a helicopter.
66	9/14/90	F	conversion	programmed flap	0	practice	Large pitch down.
67	9/14/90	F	conversion	programmed flap	0	practice	
68	9/14/90	F	conversion	programmed flap	0	5	Uncomfortable; required a lot of compensation to avoid wild attitudes.
69	9/14/90	F	conversion	geared flap	0	practice	
70	9/14/90	F	conversion	geared flap	0	practice	Less ballooning than programmed flap. Around 2° wing incidence,
							got a complete unloading - kick in the pants.
71	9/14/90	F	conversion	geared flap	0	4	When the wing gets to 2°-4°, aircraft drops a lot of lift.
72	9/14/90	F	reconversion	geared flap	0	5	Don't like power response lags. Had to lead it a lot more.
73	9/14/90	F	50 kt STOL landing	geared flap	0	practice	
74	9/14/90	F	50 kt STOL landing	geared flap	0	3	Bothered by throttle response but minor pilot compensation required.
							*** Tail incidence limited to 19° for remainder of runs***
75	9/18/90	G	conversion	programmed flap	0	practice	
76	9/18/90	G	conversion	programmed flap	0	practice	Altitude control best done out the window.
77	9/18/90	G	conversion	programmed flap	0	8	Large nose down, ballooned to 300 ft. Couldn't stay between 100-300 ft.
78	9/18/90	G	conversion	programmed flap	0	9	Difficult pitch and altitude control.

RUN NO.	Date	Pilot	Task	Flap Configuration	Winds/Turb	Pilot Rating	Comments
79	9/18/90	G	reconversion	programmed flap	0	6	Easier than conversion. About -3° GS; hover was the most difficult.
							Rate altitude control a "5", glide path control and speed control a "6".
80	9/18/90	G	50 kt STOL landing	programmed flap	0	practice	Got stick shaker on power changes, to get out of it you add power
							which increases velocity. Don't have a good feel for alpha.
81	9/18/90	G	50 kt STOL landing	programmed flap	0	5	Made wide steep turn. Controllable: within 5 knts for airspeed, and
							within 50 ft for altitude. Rate of descend about 200 ft/min. Adequate.
82	9/18/90	D	conver/reconver	programmed flap	0	4, 4	Pitched down during conversion. Constantly working the throttle to
							stay on glide path.
83	9/18/90	D	conversion	geared flap	0	3	Less pitch down.
84	9/18/90	H	conversion	programmed flap	0	5	Would not be good for night flying with visual goggles because
							the nose down pitch attitude is really distracting.
85	9/18/90	H	reconversion	programmed flap	0	2.5	Better than conversion; My smoothest run, yet. Maybe I'm learning.
	9/18/90	H	conversion	geared flap	0	3	A world of difference converting out. Pitch control was better. When
							wing incidence first comes down, you almost go backwards. Not as
							much nose down as with other configuration.
86	9/18/90	H	reconversion	geared flap	0	practice	
87	9/18/90	H	reconversion	geared flap	0	practice	
88	9/18/90	H	reconversion	geared flap	0	2	More responsive to wing changes, a little more sensitive in power.
							Definitely like this geared flap instead of programmed flap.
89	9/18/90	H	reconversion	geared flap	0	repeat	More controllable; more responsive. Seems to work better.
90	9/18/90	H	60 kt STOL landing	programmed flap	0	practice	
91	9/18/90	H	60 kt STOL landing	programmed flap	0	4.5	Touchy in pitch.
92	9/18/90	H	50 kt STOL landing	programmed flap	0	5	Big changes in power; overcontrolled power.

PILOT EVALUATIONS

RUN NO.	Date	Pilot	Task	Flap Configuration	Winds/Turb	Pilot Rating	Comments
93	9/18/90	H	40 kt STOL landing	programmed flap	0	5	Slower closer to hover. I don't think it's a problem.
94	9/18/90	H	60 kt STOL landing	geared flap	0	3.5	More controllable than the programmed flap.
95	9/18/90	H	50 kt STOL landing	geared flap	0	3.5	Definitely better than programmed flap.
96	9/18/90	H	40 kt STOL landing	geared flap	0	3.5	Similar to the last run; more sensitive to power inputs.
97	9/18/90	H	40 kt STOL landing	programmed flap	0	5	Power lags noted, tend to overcontrol. That's the biggest difference.
							It takes a little more getting used to it.
98	9/18/90	D	reconversion	geared flap	0	4	Small pitch down noted at start.
99	9/18/90	D	60 kt STOL landing	programmed flap	0	2	Fairly easy.
100	9/18/90	D	60 kt STOL landing	geared flap	0	4	Hit stick shaker a few times.
101	9/18/90	D	50 kt STOL landing	programmed flap	0	2	Straightforward.
102	9/18/90	D	50 kt STOL landing	geared flap	0	4	Stick shaker again because of how close it is to stall.
103	9/18/90	D	conversion	geared flap on stick	0	practice	
104	9/18/90	D	conver/reconver	geared flap on stick	0	2,4	Not much different; less aft. cyclic.
							stick shaker off for remainder of runs
105	9/19/90	I	conversion	programmed flap	0	2.5	Continuous wing beeping is much smoother. Power is required to
							compensate for nose down.
106	9/19/90	I	conversion	geared flap	0	3.5	Left power alone and kept attitude +/- 7°.
107	9/19/90	I	reconversion	programmed flap	0	2	Incremental conversion used; approached sideways.
108	9/19/90	I	reconversion	geared flap	0	2.5	Similar.
109	9/19/90	I	hover	programmed flap	0	1.5	Stabilized at 75 ft.
110	9/19/90	I	hover	geared flap	0	1.5	A little better than last run.
111	9/19/90	G	conversion	programmed flap	0	5	Steady beep easier; climb out difficult; hard to hold rate of climb.
							Compensation needed for flight path stability.

PILOT EVALUATIONS

RUN NO.	Date	Pilot	Task	Flap Configuration	Winds/Turb	Pilot Rating	Comments
112	9/19/90	G	conversion	geared flap	0	8	Large pitch changes at the end of conversion to control 15° of flap in
							logic. 3-4 cycles noted.
113	9/19/90	G	reconversion	programmed flap	0	8	Too much time spent on pitch attitude, and too difficult to arrest
							rate of climb (-500 to +1000 ft/min).
114	9/19/90	G	reconversion	geared flap	0	practice	
115	9/19/90	G	reconversion	geared flap	0	abort	
116	9/19/90	G	reconversion	geared flap	0	8.5	Power/altitude control a problem; harder than programmed flap.
117	9/19/90	G	reconversion	geared flap	0	practice	
118	9/19/90	G	hover	programmed flap	0	5	Experienced altitude control problems but still OK.
119	9/19/90	G	hover	geared flap	0	6	Less than OK.

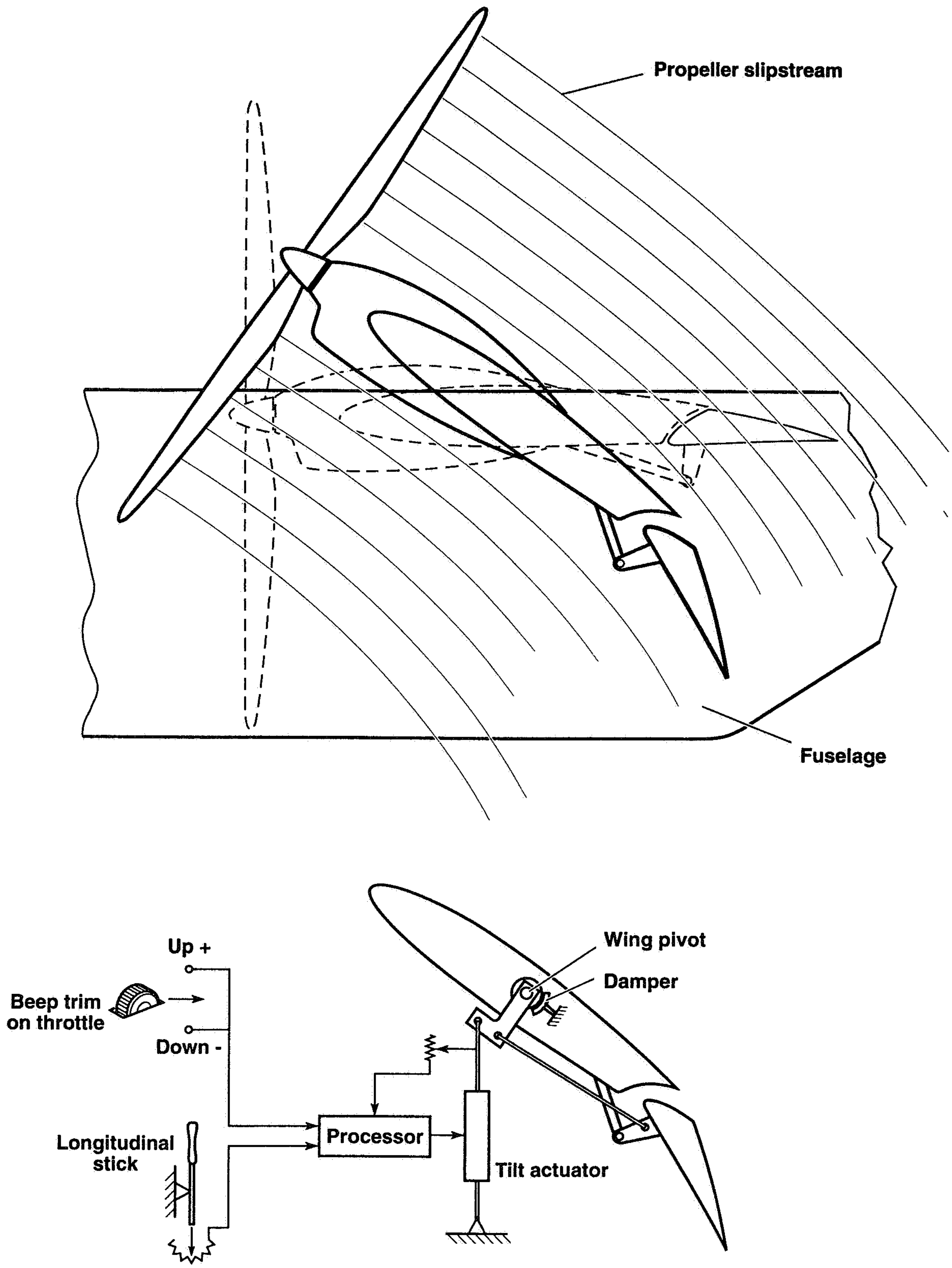

Figure 1 Geared flap control concept.

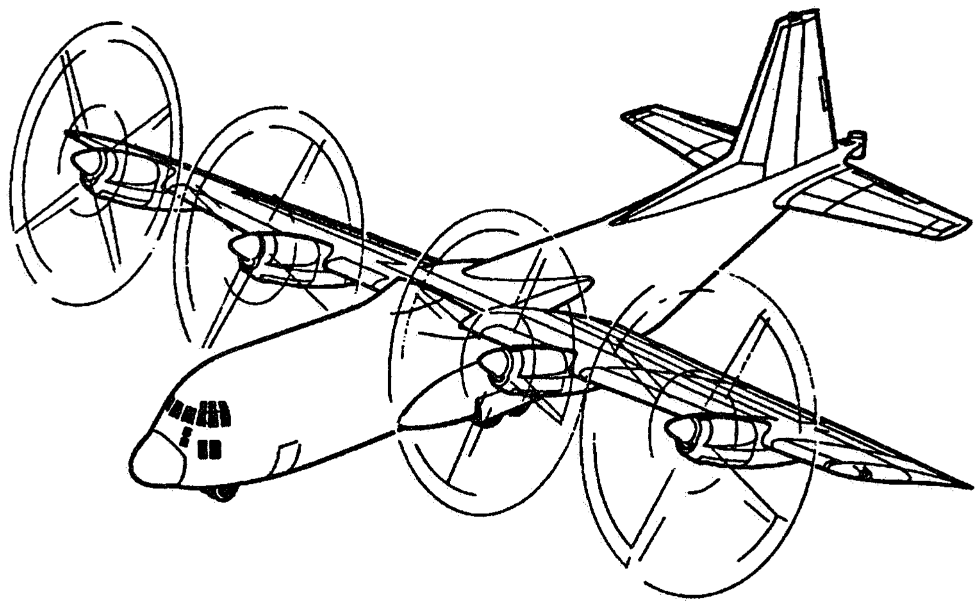

Figure 2. Simulation V/STOL tilt-wing transport aircraft.

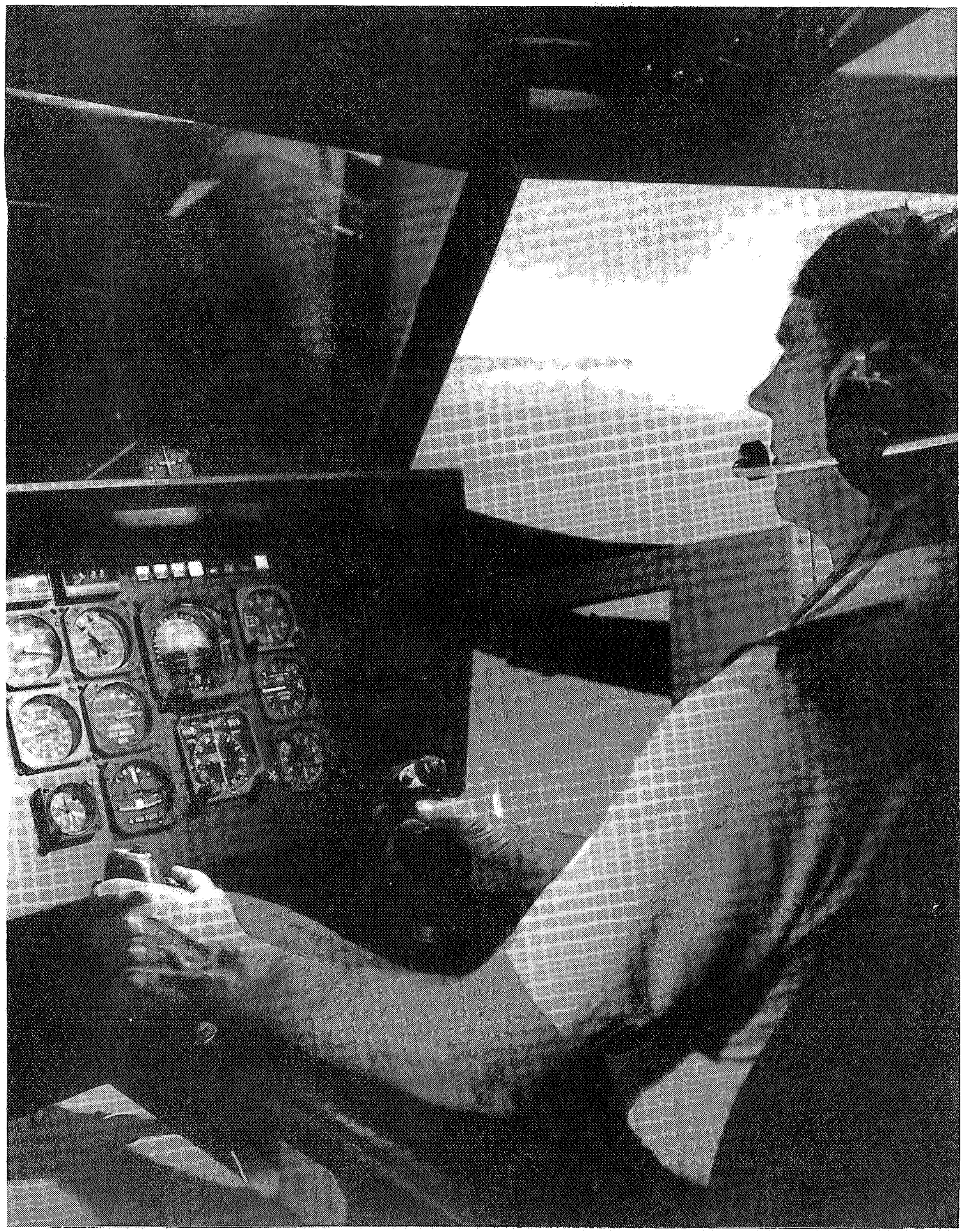

Figure 3. Simulator cockpit arrangement.

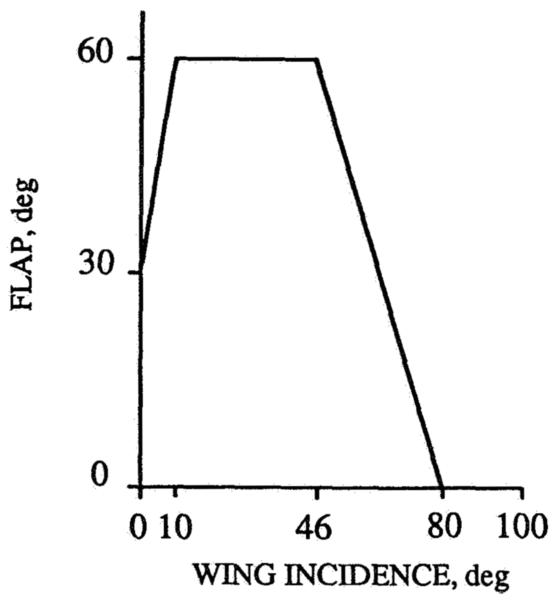

Figure 4. Flap schedule for programmed flap configuration.

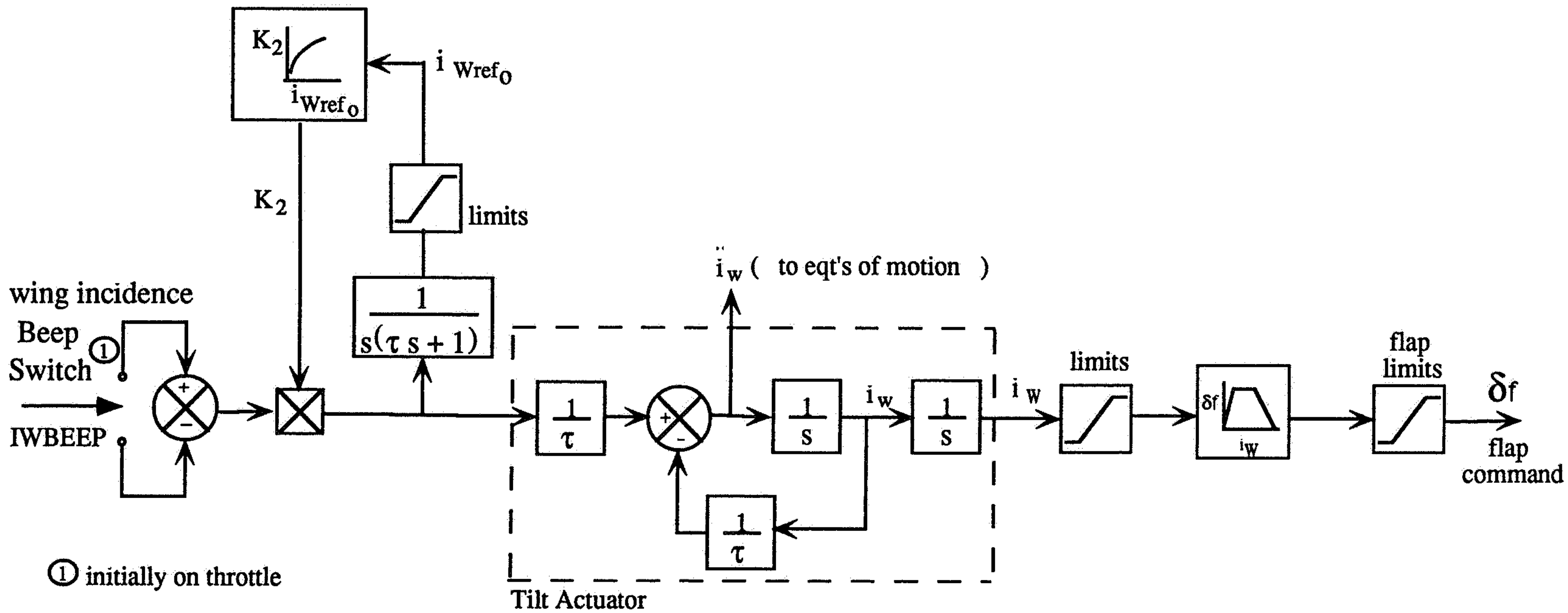

Figure 5. Control schematic of the programmed flap configuration.

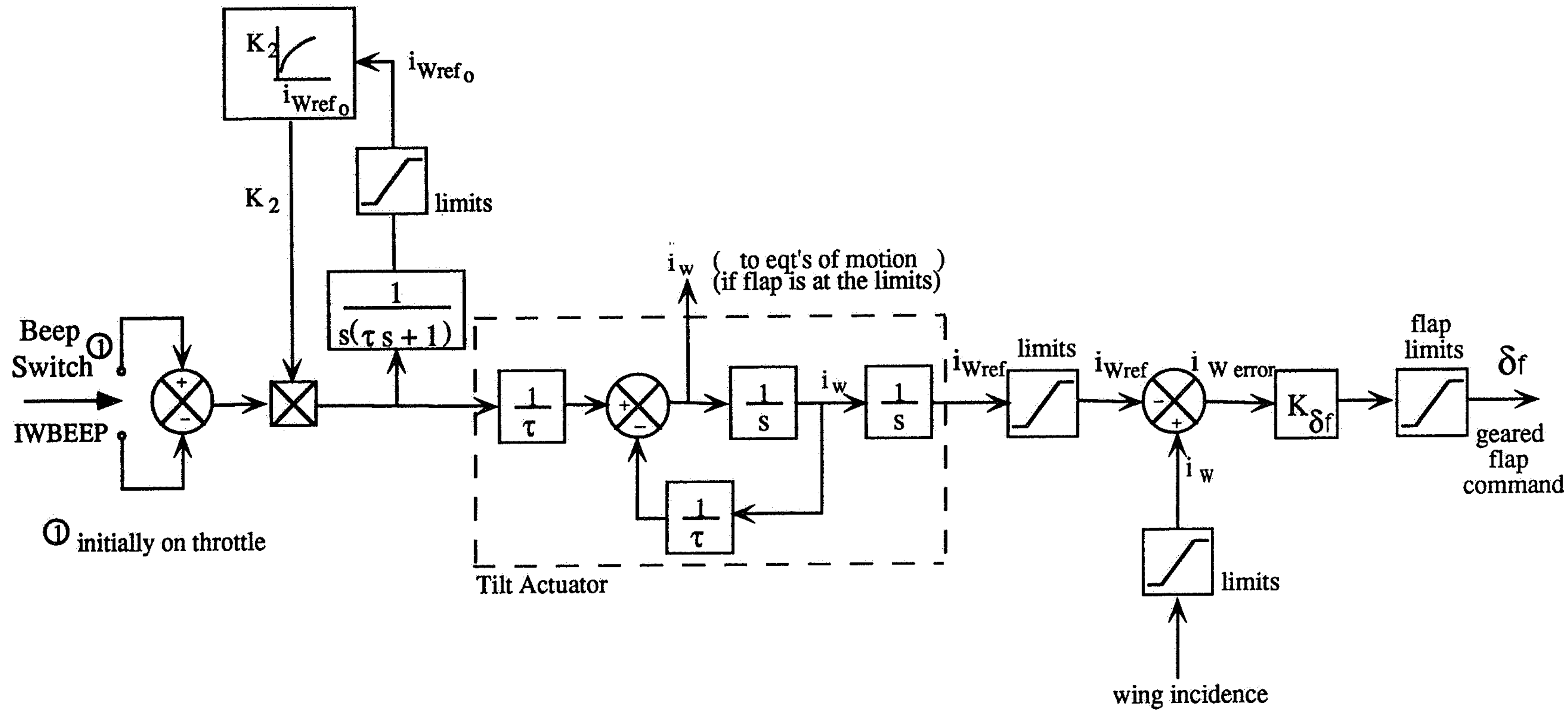

Figure 6. Control schematic of the geared flap on the beep configuration.

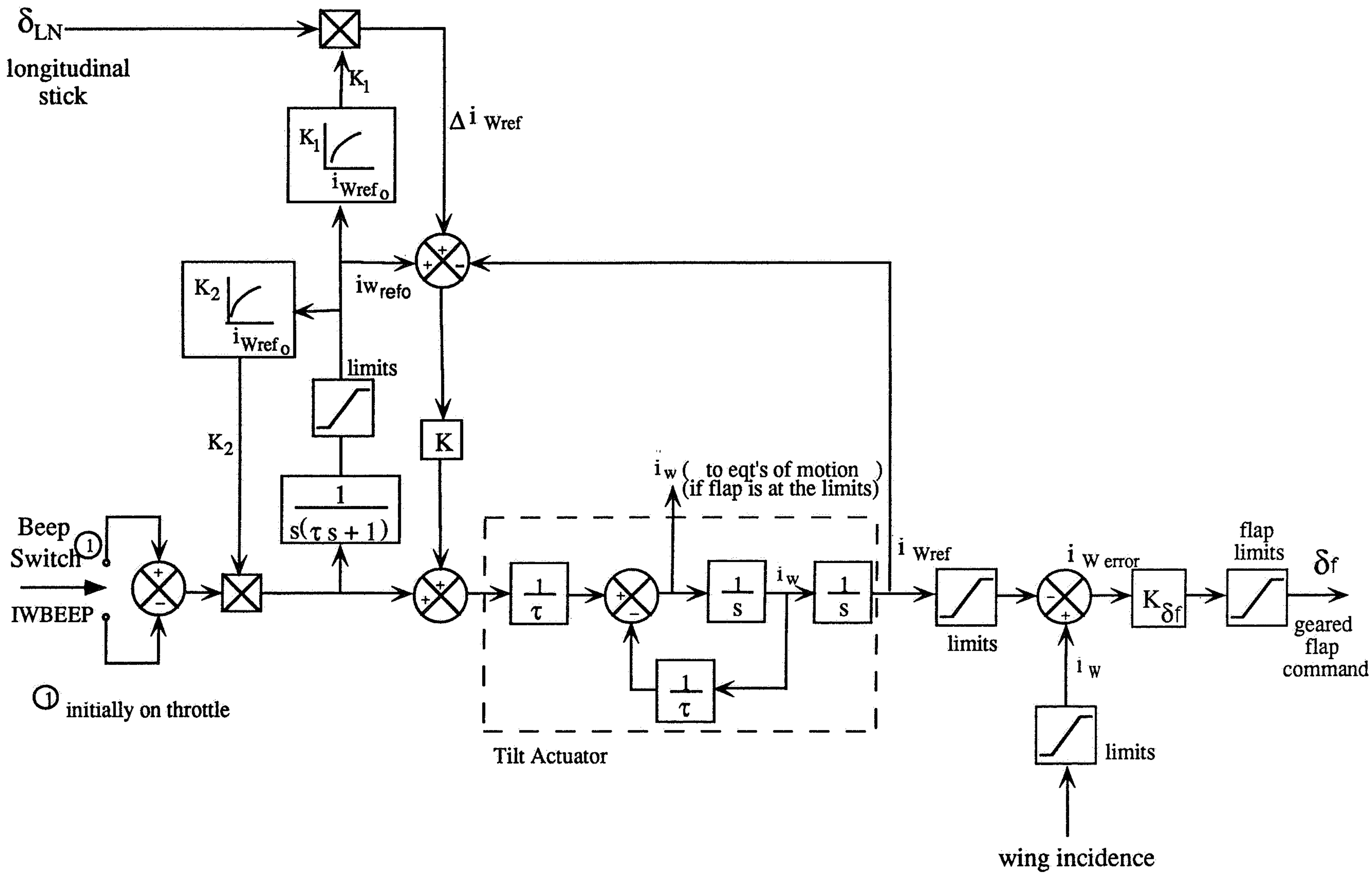

Figure 7 Control schematic of the geared flap on the stick configuration.

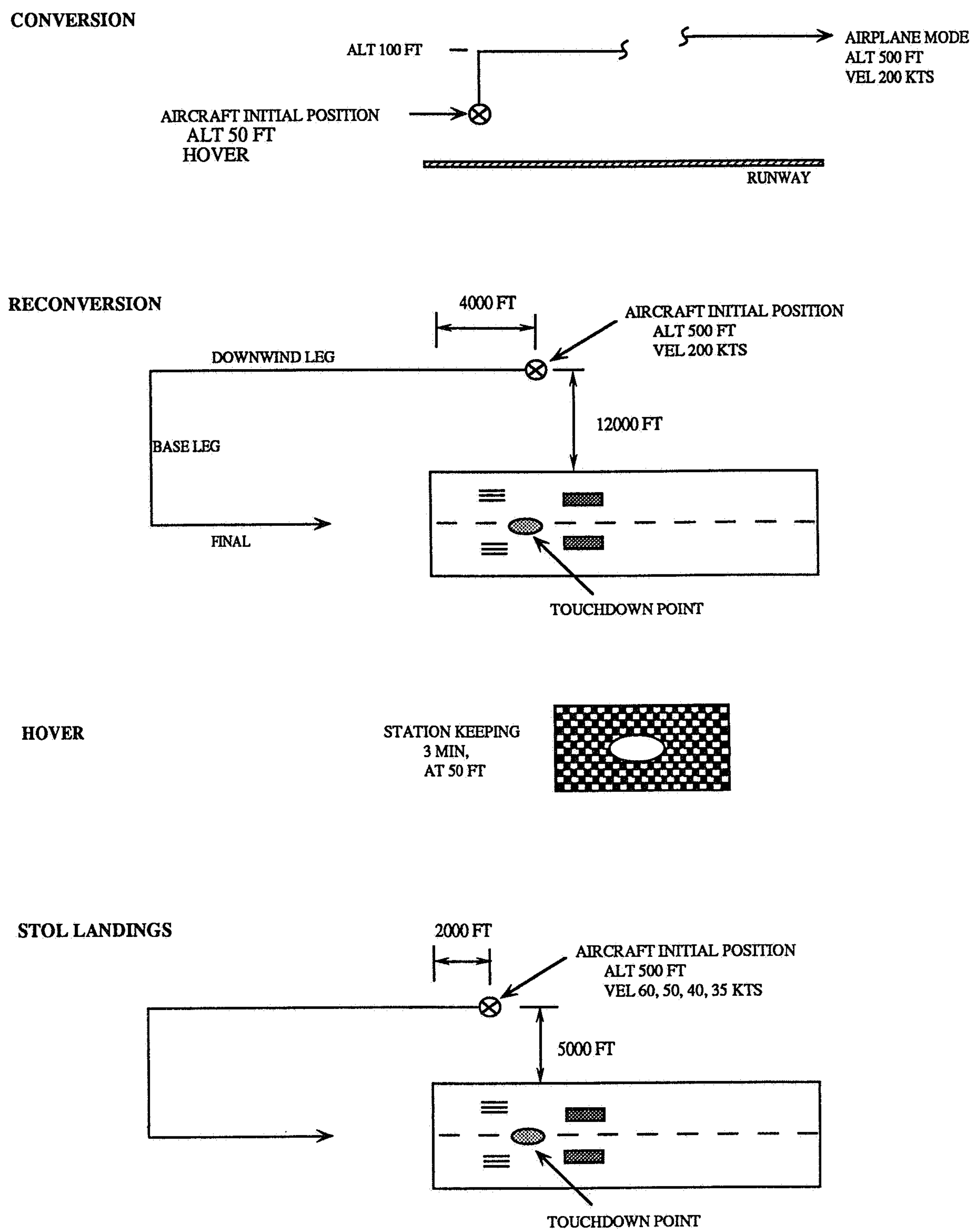

Figure 8. Pilot tasks.

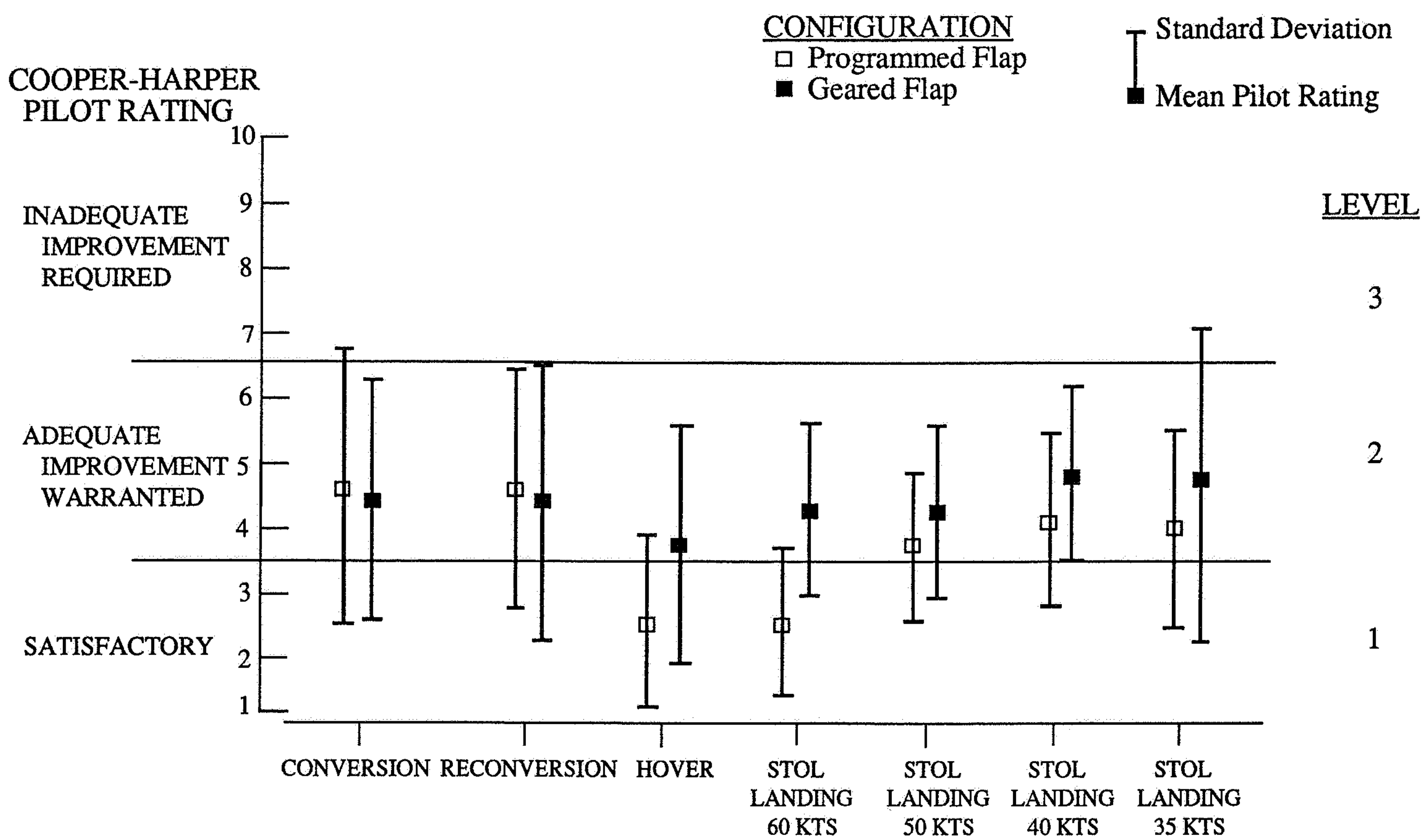

Figure 9. Pilot evaluations of tasks.

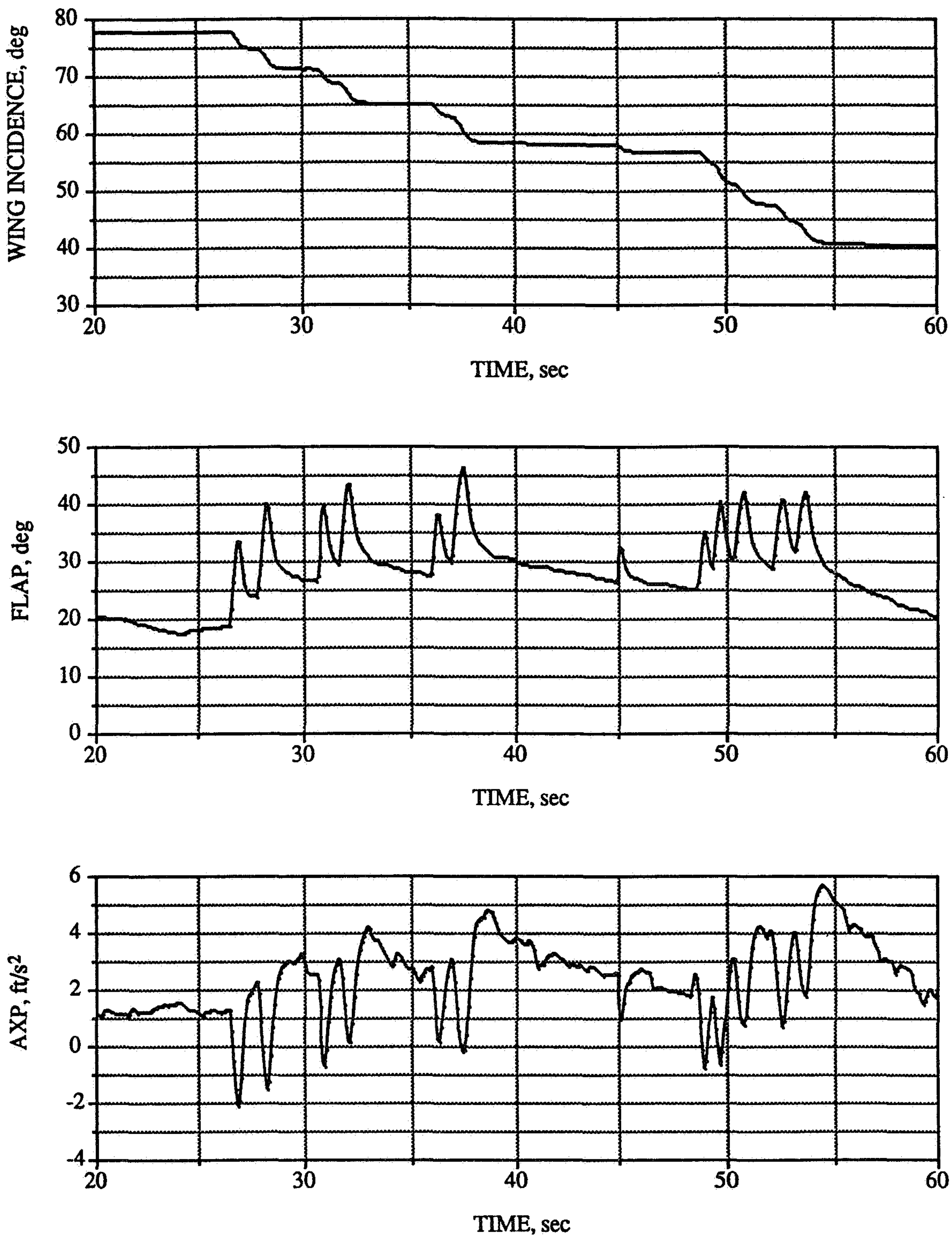

Figure 10. Rearward pilot acceleration pulses caused by the geared flap.

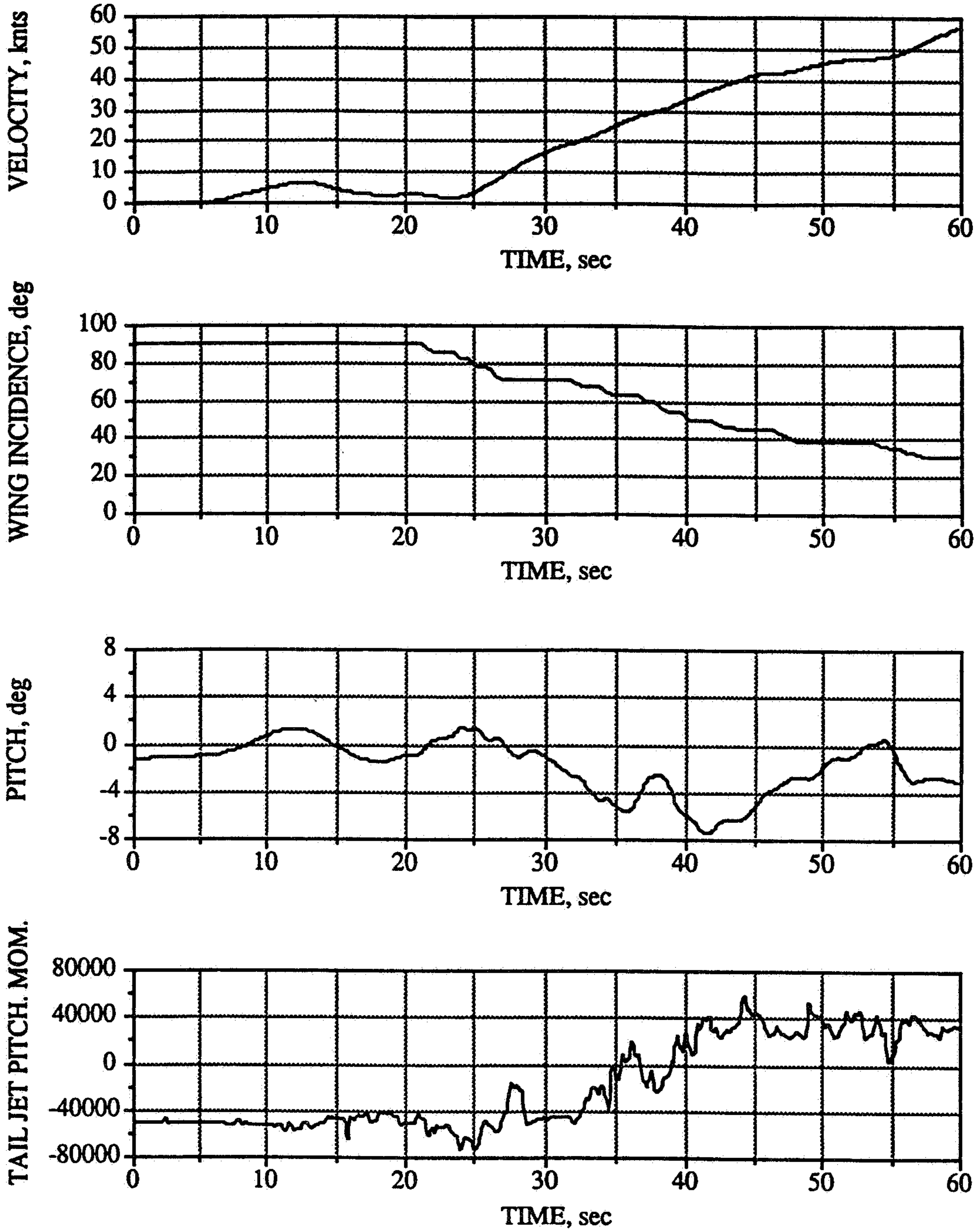

Figure 11. Programmed flap configuration time histories.

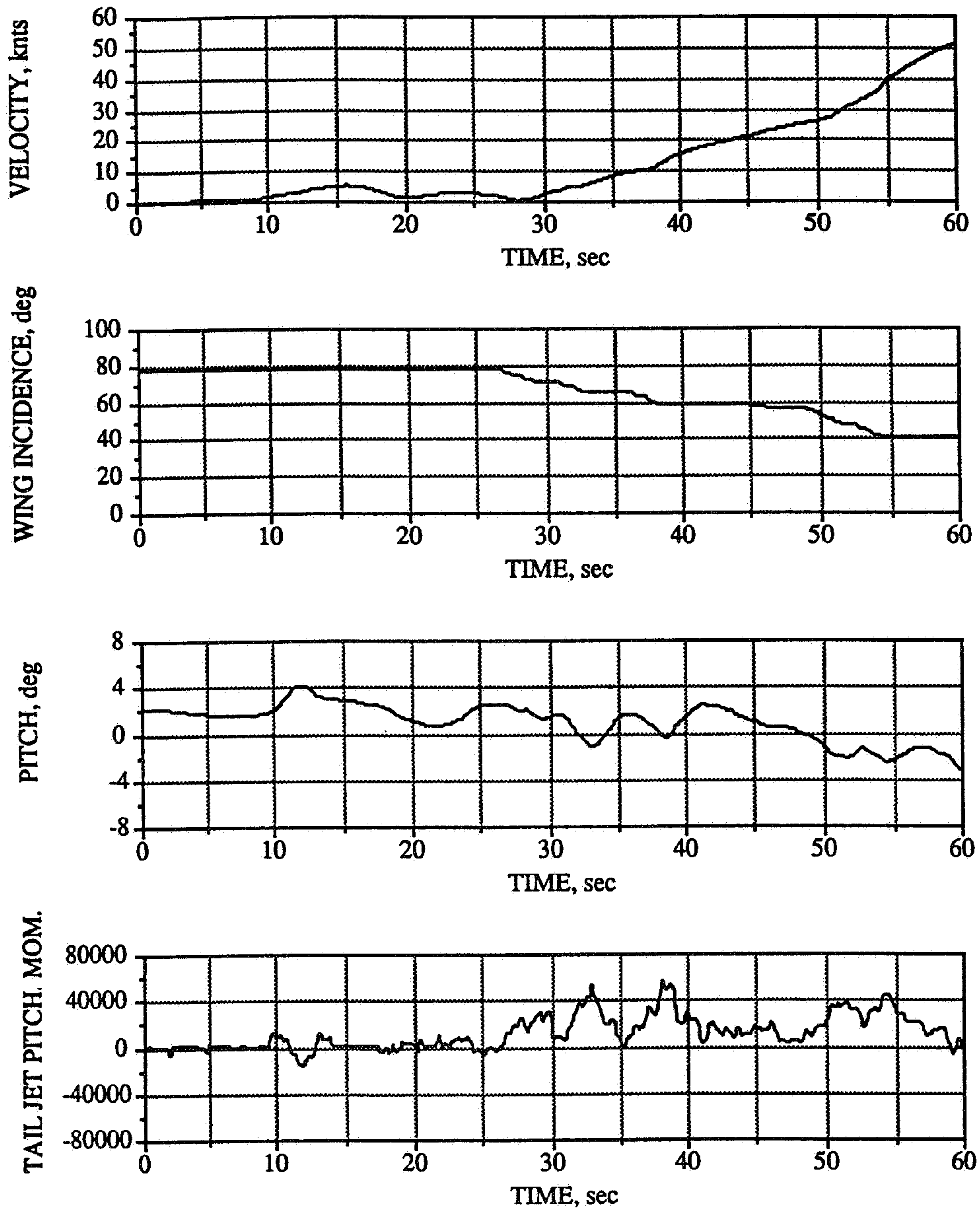

Figure 12. Geared flap configuration time histories.

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13. ABSTRACT *(Maximum 200 words)*

A simulation study of a representative tilt wing transport aircraft was conducted in 1990 on the Ames Vertical Motion Simulator. This simulation is in response to renewed interest in the tilt wing concept for use in future military and civil applications.

For past tilt wing concepts, pitch control in hover and low-speed flight has required a tail rotor or reaction jets at the tail. Use of mono cyclic propellers or a geared flap have also been proposed as alternate methods for providing pitch control at low speed. The geared flap is a subject of this current study.

This report describes the geared flap concept, the tilt wing aircraft, the simulation model, the simulation facility and experiment setup, the pilots' evaluation tasks and procedures, and the results obtained from the simulation experiment. The pilot evaluations and comments are also documented in the report appendix.

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