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AN ANALYTICAL INVESTIGATION OF THE EFFECTS OF INCREASED INSTALLED HORSEPOWER ON HELICOPTER AGILITY IN THE NAP-OF-THE-EARTH ENVIRONMENT

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This report describes an investigation of the effects of increased horsepower on the agility of a helicopter in nap-of-the-earth (NOE) maneuvers. A computer program, the Maneuver Criteria Evaluation Program, was used to simulate the flight of a representative scout-type helicopter, the OH-58. Calculations were made for both the standard OH-58 and an OH-58 with increased installed power. The increased installed power had significant effects on the agility of the helicopter in evasive-acceleration type maneuvers.

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INTRODUCTION

Agility is the capability of an aircraft to quickly perform commanded maneuvers. The agility of helicopters is becoming increasingly important with the recent emphasis on nap-of-the-earth (NOE) tactics in hostile environments. The problem of delivering close support and observation in a mid-intensity conflict is made more difficult by new, sophisticated fire control systems. The vulnerability of the helicopter has been increased by these new weapon systems, which have high rates of fire, are able to penetrate foliage, and are augmented by greatly increased detection abilities that allow sophisticated radar range firing, and automatic range corrections and radar directing. High-speed flight is no longer sufficient alone; it is also necessary to have good agility, through greater acceleration capabilities, to evade the new weapon systems.

The object of the investigation described in this report was to determine the effect of increased available power on helicopter agility while performing evasive-acceleration type maneuvers. Increased power should allow faster accelerations, thus making a helicopter more agile.

There are four sources of power for a helicopter: the engine (installed power), rotor inertia (rotational kinetic energy), altitude loss (potential energy), and airspeed loss (kinetic energy). Gains of potential and kinetic energy are impractical in the NOE environment, where the helicopter cannot afford to lose altitude or airspeed. Installed engine power and rotational kinetic energy are the remaining sources. The approach taken in our investigation was limited to increasing the horsepower of the engine. The use of increased rotational kinetic energy was not investigated because we lacked the ability to model rotor inertia effects.

A standard OH-58 was chosen as a representative scout-type helicopter to be used as a baseline vehicle. Helicopter flight performance was calculated for selected maneuvers with the aid of the Maneuver Criteria Evaluation Program (MCEP). Then the performance of an OH-58 with increased horsepower was calculated for the same maneuvers to identify the potential improvements in agility.

VEHICLE CHARACTERIZATION

The characterization of the standard OH-58 helicopter, used in this investigation, is as follows:

STANDARD OH-58

Number of blades	2
Rotor radius	17.650 ft
Rotor chord	1.080 ft
Tip speed	654.0 ft/sec
Blade section lift curve slope	6.28/rad
Blade section drag	$C_D = 0.008\alpha + 0.59\alpha^2$
Drag divergent Mach number	0.75
Equivalent flat plate drag ($\beta = 0^o$)	9.7 ft^2
Equivalent flat plate drag ($\beta = 90^o$)	102 ft^2
Gross weight	2767 lb
Allison T63-A-733 Engine	317 shp

The modified OH-58 with increased power had the same characterization as the standard OH-58 except that the engine produced 420 shp (representing an Allison 250-C-20B).

We assumed that the modified version would have an uprated transmission, that the rotor would have the aerodynamic and dynamic qualities to allow the increased thrust, and that the modification would not change the gross weight of the vehicle. Standard sea level conditions were used in the calculations (US Standard Atmosphere, 1962).

DESCRIPTION OF THE MANEUVER CRITERIA EVALUATION PROGRAM (MCEP)

The MCEP is a digital computer program that solves helicopter flight path equations.[1] The program uses basic work, energy, and power relationships to calculate a helicopter's ability to change its speed and direction. The program predicts how much power is required by the helicopter as a function of the flight condition, the load factor, and certain physical parameters of the helicopter, from a set of closed-form equations. Any excess in engine power over the power required at the specific flight condition may be used by the helicopter to increase altitude, airspeed, or rotor speed, or to change direction. The concept of changing energy levels to control the direction and speed of flight is explained in Reference 2.

The power requirements of an OH-58 as calculated by the MCEP correlate well with data obtained from actual flight tests (Figure 1). Examples of program outputs are given in Appendix A.

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[1] T. L. Wood, D. G. Ford, and G. H. Brigman, *Maneuver Criteria Evaluation Program*, Bell Helicopter Company, USAAMRDL Technical Report 74-32, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, May 1974, AD 782209.

[2] C. D. Wells and T. L. Wood, "Maneuverability–Theory and Application," *Journal of the American Helicopter Society*, Volume 8, Number 1, January 1973.

DESCRIPTION OF THE MANEUVERS

The maneuvers chosen for the investigation were representative of maneuvers flown in NOE. The selected evasive-acceleration type maneuvers were:

Bob-Up

In this maneuver the helicopter changes altitude while maintaining a constant attitude by climbing vertically from a hover.

Pop-Up

This maneuver is similar to the bob-up except that it is initiated at low airspeeds. The helicopter gains altitude while maintaining a constant attitude and ground speed.

Lateral Acceleration and Deceleration

In this maneuver the helicopter accelerates to the right or left from a hover while maintaining a constant altitude and tracking a target. The helicopter accelerates until the desired sideward velocity is reached; then it decelerates to a hover while still tracking the target. This maneuver is controlled by the bank angle that the helicopter maintains in the acceleration phase of the maneuver.

Lateral Acceleration With Recovery

In this maneuver the helicopter accelerates to the right or left from a hover while maintaining a constant altitude and tracking a target. The helicopter accelerates until a command velocity is reached; then the helicopter stops tracking the target and swings its nose into the wind.

Longitudinal Acceleration

In this maneuver the helicopter accelerates to a specified velocity while maintaining a constant altitude and attitude. The thrust vector of the main rotor is tilted so that the horizontal component is increased until the power required matches the power supplied by the engine.

Longitudinal Deceleration

In this maneuver the helicopter decelerates to a specified velocity while maintaining a constant altitude and attitude, through a power relationship in which the available power is determined by the specified minimum power allowable.

All of the above maneuvers are limited by the power available and are controlled by the rate at which the power is applied with the exception of the longitudinal deceleration maneuver. In each case, the power was applied at the fastest possible rate, simulating maneuvers of maximum urgency.

RESULTS AND DISCUSSION

The MCEP simulations showed that horsepower has a significant influence on the agility of the OH-58. Selected time histories from the series of simulated maneuvers are presented in Figures 2 through 7.

Bob-Up

Time histories for the bob-up maneuver are shown in Figure 2. In this manevuer, the helicopter was initially hovering and was commanded to rise 50 feet in the minimum time. The simulated maneuver was performed with the maximum power available. Both helicopters had the same vertical jerk limit, which is the rate of change of load factor. This is usually a limit imposed by the pilot and was set at 0.5g/sec for this investigation. This limit can be seen in the time histories of the normal load factors, where the initial slope is the same for both helicopters. The difference between the performance of the helicopters is the ability of the helicopter with 420 shp to attain a maximum load factor of 1.5, resulting in a maximum vertical velocity 11.6 ft/sec; while the helicopter with 317 shp can only reach a 1.27 load factor, resulting in a maximum vertical velocity of 3 ft/sec. This difference in maximum vertical velocity affected a significant parameter in this maneuver: the time it took each helicopter to reach 50 feet. This difference in ability is important in NOE, where a helicopter might bob up from behind ground cover, such as trees, for surveillance or a rapid gun burst. The helicopter with 420 shp was able to stabilize at 50 feet in 6.3 seconds; the helicopter with the standard, 317 shp engine took 17.4 seconds.

Pop-Up

The pop-up maneuver is controlled in exactly the same manner as the bob-up; however, the helicopter has forward speed in the pop-up maneuver. For the pop-up shown in Figure 3, the forward velocity was set at 15 knots. Because less rotor-induced power is required and because the system has more kinetic energy, more of the engine's total energy is available for the maneuver. The helicopter with 317 shp was able to climb to 50 feet in 7.85 seconds, at a maximum vertical velocity of 8 ft/sec; while the helicopter with 420 shp climbed to 50 feet in 3.45 seconds, attaining a maximum load factor of 1.69 and a maximum vertical velocity of 25.4 ft/sec. In fact, the modified OH-58 overshot and did not arrest its vertical velocity until 5 seconds at an altitude of 57 feet. The differences in performance indicate the value of increased available horsepower. The results of this maneuver also allow an observation relevant to tactics. A helicopter is much more agile in a pop-up maneuver than in a bob-up maneuver: the time needed to reach 50 feet was halved with only 15 knots of forward speed. The resulting longitudinal ground run may be significant when considering the terrain and foliage, and was 199 feet for the standard OH-58 and 127 feet for the increased horsepower model.

Lateral Acceleration and Deceleration

Lateral acceleration and decleration maneuvers are important in NOE tactics. For example, a helicopter could be flown sideways from behind a group of trees to allow the observation of or to fire at the enemy. Also, the maneuver can be used as an evasive tactic that allows the target to be tracked at the same time.

The simulated maneuver we performed involved a lateral acceleration from hover to 30 knots and, immediately, a deceleration back to hover. In this maneuver the thrust vector accelerates and decelerates the helicopter, and is controlled by the bank angle. The bank angles for acceleration and deceleration were opposite but of equal magnitudes. The bank angle was reversed when the desired sideward velocity was approached.

Increased horsepower did not improve sideward acceleration and deceleration as much as it improved pop-up and bob-up (see Figure 4). The helicopter with the increased horsepower reached 30 knots about 1/2 second sooner than the standard OH-58.

Lateral Acceleration With Recovery

Additional power improved the performance of the lateral acceleration with recovery maneuver more than it improved the performance of the lateral acceleration and deceleration maneuver. In this maneuver (see Figure 5), when the helicopter approaches the desired 35-knot lateral velocity, it rolls to a bank angle at which the thrust vector balances the drag (i.e., no acceleration). Then the helicopter stops tracking the target, swings its nose into the wind, and maintains the commanded recovery velocity. The helicopter with the increased horsepower was 1 second ahead of the standard OH-58 and reached a maximum lateral acceleration of 31 ft/sec^2, at a bank angle of 45 degrees, while the standard OH-58 was able to reach a maximum lateral acceleration of only 20 ft/sec^2, at a bank angle of 32.5 degrees. In both lateral acceleration maneuvers, the acceleration of the high power helicopter could have been even better had the helicopter been allowed to bank more than 45 degrees. The bank angle is limited by the pilot; many pilots might exceed 45 degrees bank. The standard OH-58 was limited by its power in each case, having been able to reach bank angles of only 38.4 and 32.5 degrees.

Longitudinal Acceleration

The longitudinal acceleration of the helicopter was significantly affected by the additional horsepower. Time histories for a typical longitudinal acceleration run are presented in Figure 6. As can be seen in the figure, the high horsepower helicopter was run at 378 shp, although the actual installed horsepower was still 420 shp. The maneuver was run with 90 percent of the available engine power since the application of full power caused the high powered helicopter to assume an angle of attack exceeding -90 degrees in an effort to use all of the power available. This is unrealistic, of course, and the maximum power setting was consequently reduced. The results of the standard helicopter reflect the maximum performance of that helicopter since the power setting was 100 percent. With 378 shp, the modified helicopter attained the desired speed of 60 knots 1.5 seconds before the 317 shp helicopter.

Longitudinal Decelerations

The effect of increased horsepower on the results of the longitudinal decelerations is inconclusive (Figure 7). This is a result of the manner in which the longitudinal deceleration is modeled in the MCEP. In this program, longitudinal deceleration is controlled by the minimum power allowed from the engine during the maneuver, while the maximum deceleration is restricted to a negative 0.5g. The deceleration is not a function of the flare attitude and maximum power available. The minimum power allowed is specified by the user; whereas the restriction on the maximum deceleration is specified within the MCEP. For the maneuvers presented in Figure 7, it was specified that both helicopters be allowed 10 percent of their maximum installed horsepower. Thus the standard OH-58 had a minimum power limit of 31.7 shp, and the modified OH-58, a minimum power limit of 42 shp. This resulted in the standard OH-58's decelerating to a hover sooner than the modified one. In practice, the pilot determines what his lower limit should be; if he had a maximum installed power equal to 420 shp and limited his power to 7.4 percent, the results would be identical to those obtained with 10 percent of 317 shp. Furthermore, in practice, the pilot is more likely to decelerate the helicopter by flaring to a pitch-up attitude and increasing the thrust vector, providing a force in opposition to its motion. If this were allowed, the agility would improve with increased horsepower.

CONCLUSIONS AND RECOMMENDATIONS

Increased installed power has significant effects upon the agility of the OH-58. This is shown in the results from the bob-up, pop-up, and lateral and longitudinal accelerations, where increased installed power produced improved agility. This is particularly important in NOE missions where, in general, agility cannot be gained through other sources of energy. The gaining of energy through airspeed and altitude losses is impractical in the NOE environment.

While the longitudinal deceleration results did not indicate improved agility, due to the manner in which longitudinal deceleration was modeled, in actual NOE flight the pilot would probably use a technique that would result in improved agility if a minimum deceleration time was essential.

Pilots' techniques and limitations play an important role in the performance of a helicopter. This can be seen from several of the maneuvers in this investigation. The pilot possesses certain limits with respect to rates and reaction times. The helicopter possesses another set of limits. If the helicopter's abilities are improved so that its limits are beyond those of the pilot's, the pilot's limits will obviously prevail, and the improvements to the helicopter will go unnoticed.

To establish helicopter design criteria that reflect the limitations of the pilot, the following investigations should be made with the use of a ground-based simulator:

1. An investigation of the pilot's tolerance to angular rates and accelerations experienced in lateral and longitudinal maneuvers.

2. An investigation of the effects of angular rates and accelerations on the pilot's ability to maintain control of the aircraft.

Another source of power, increased rotor inertia, should also have a beneficial effect on maneuverability and agility. It has been estimated that an OH-58 with approximately 50 pounds of weight added to each blade tip would have 30 to 50 percent more power available for quick maneuvers than a standard OH-58.

To facilitate research into the effects of rotor inertia on agility, the MCEP should be modified to handle variable main rotor inertia and rate of rotor revolution. This would also allow an investigation of a potential "reserve" maneuverability in the event of a power failure during NOE and improved autorotation landings.

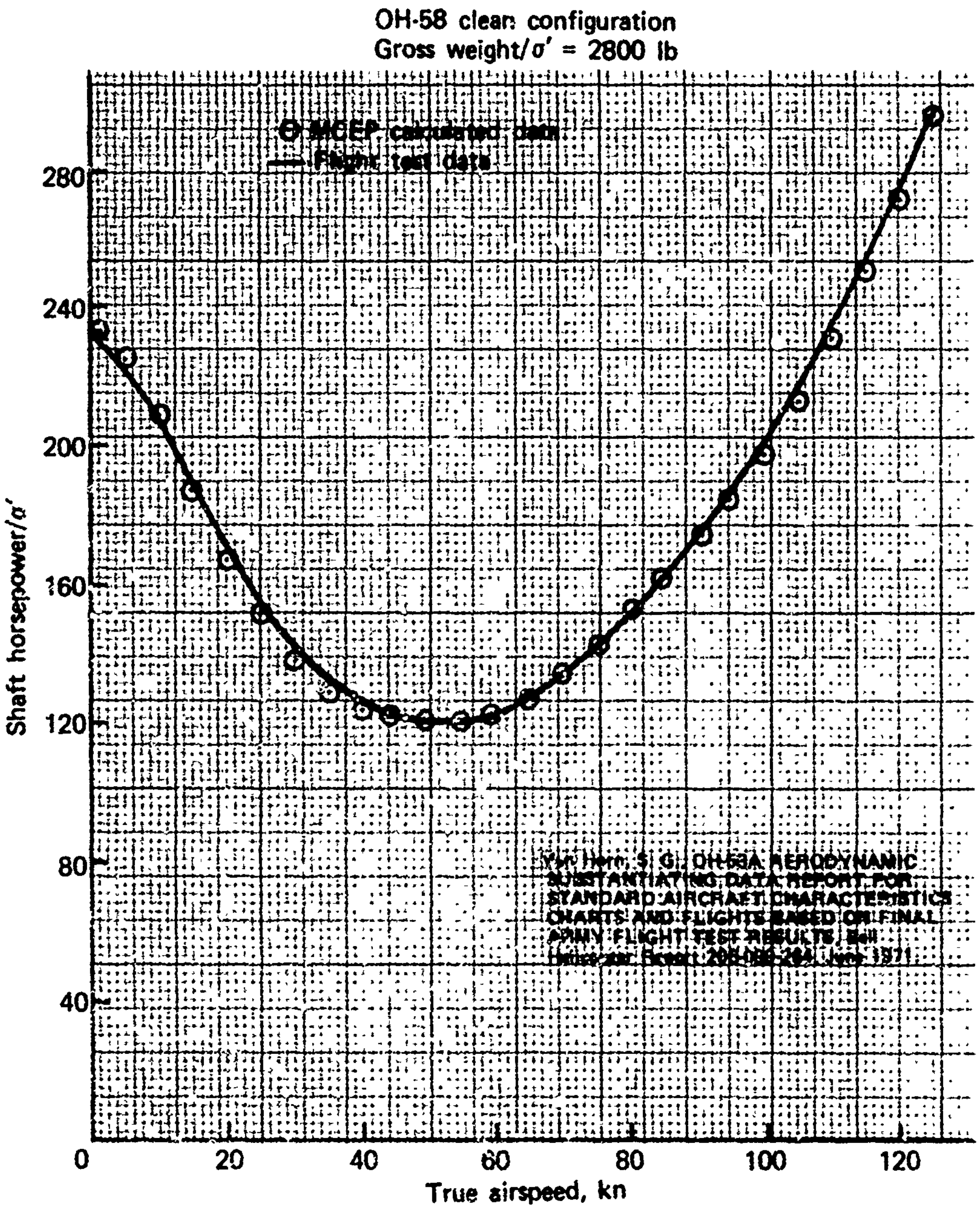


Figure 1. Power required for the level flight of an OH-58.

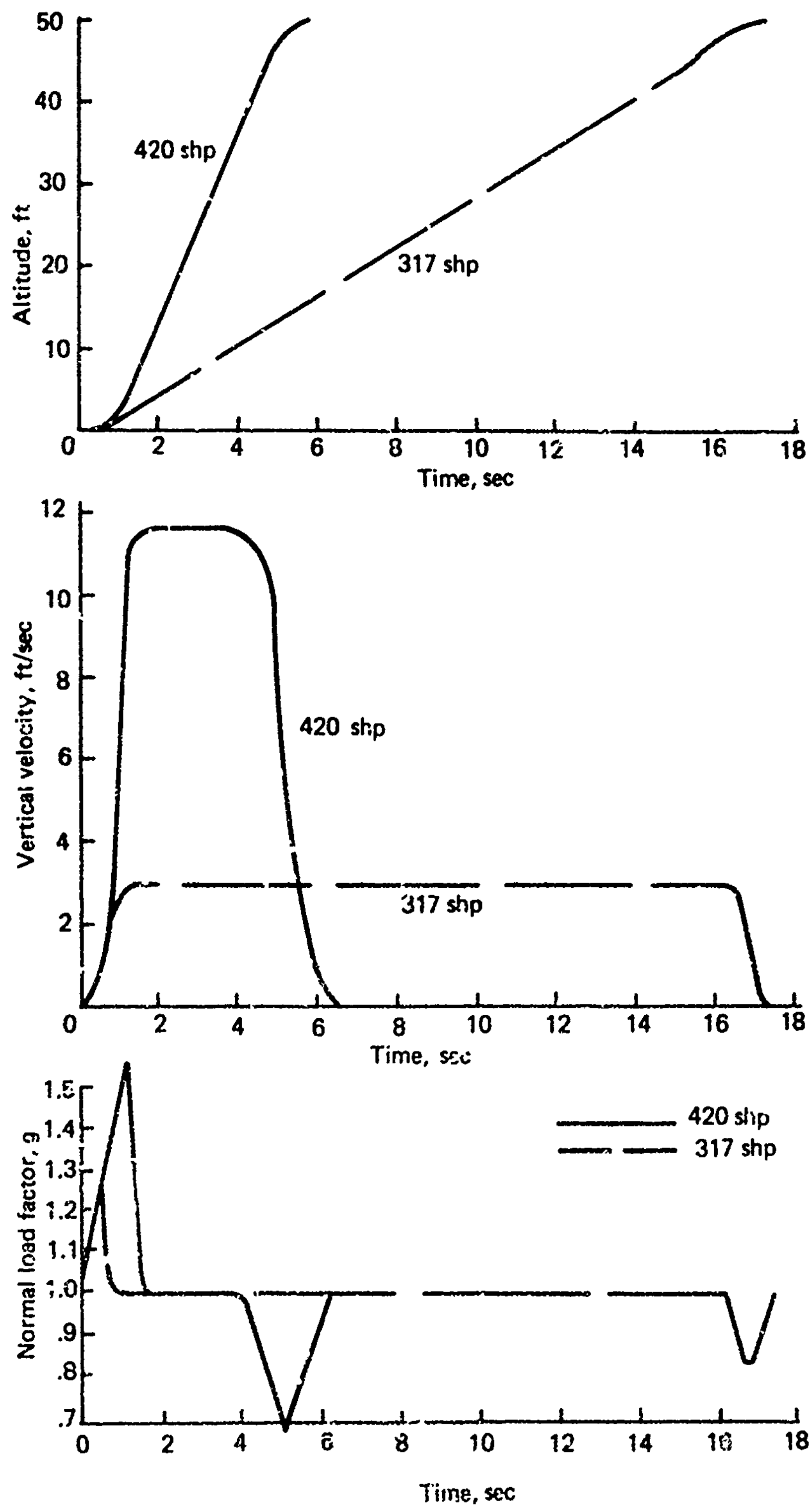
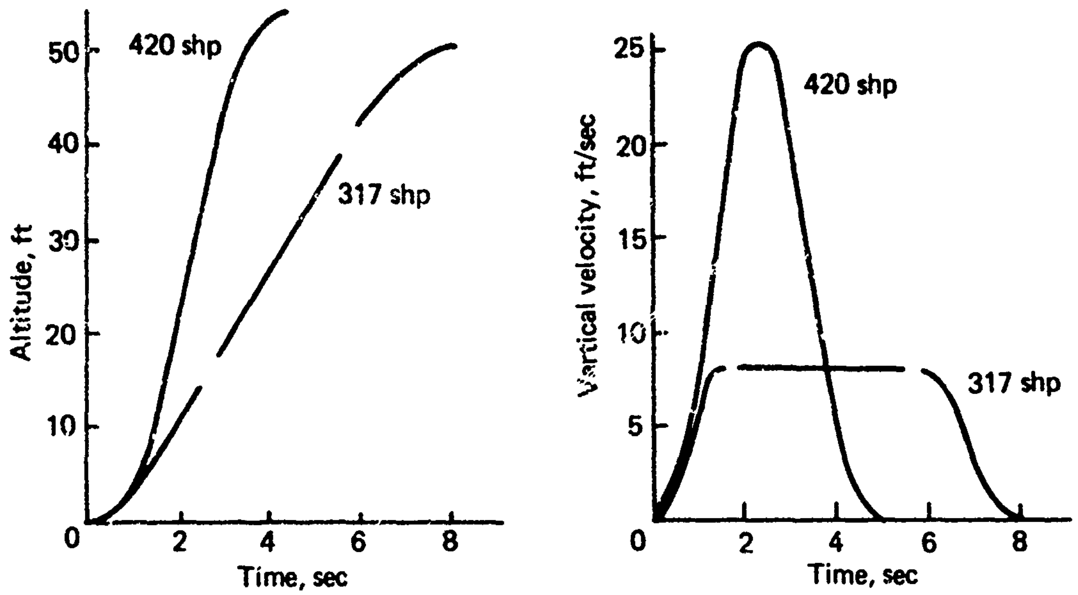
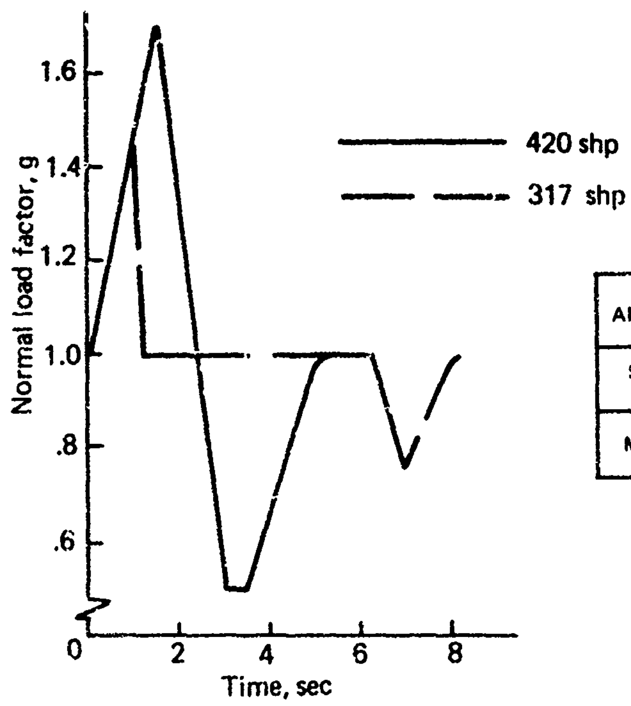


Figure 2. Bob-up from hover to 50 feet.





AIRCRAFT	SHAFT HORSEPOWER	LONGITUDINAL GROUND RUN
Standard	317 shp	199 ft
Modified	420 shp	127 ft

Figure 3. Pop-up to 50 feet at 15 knots.

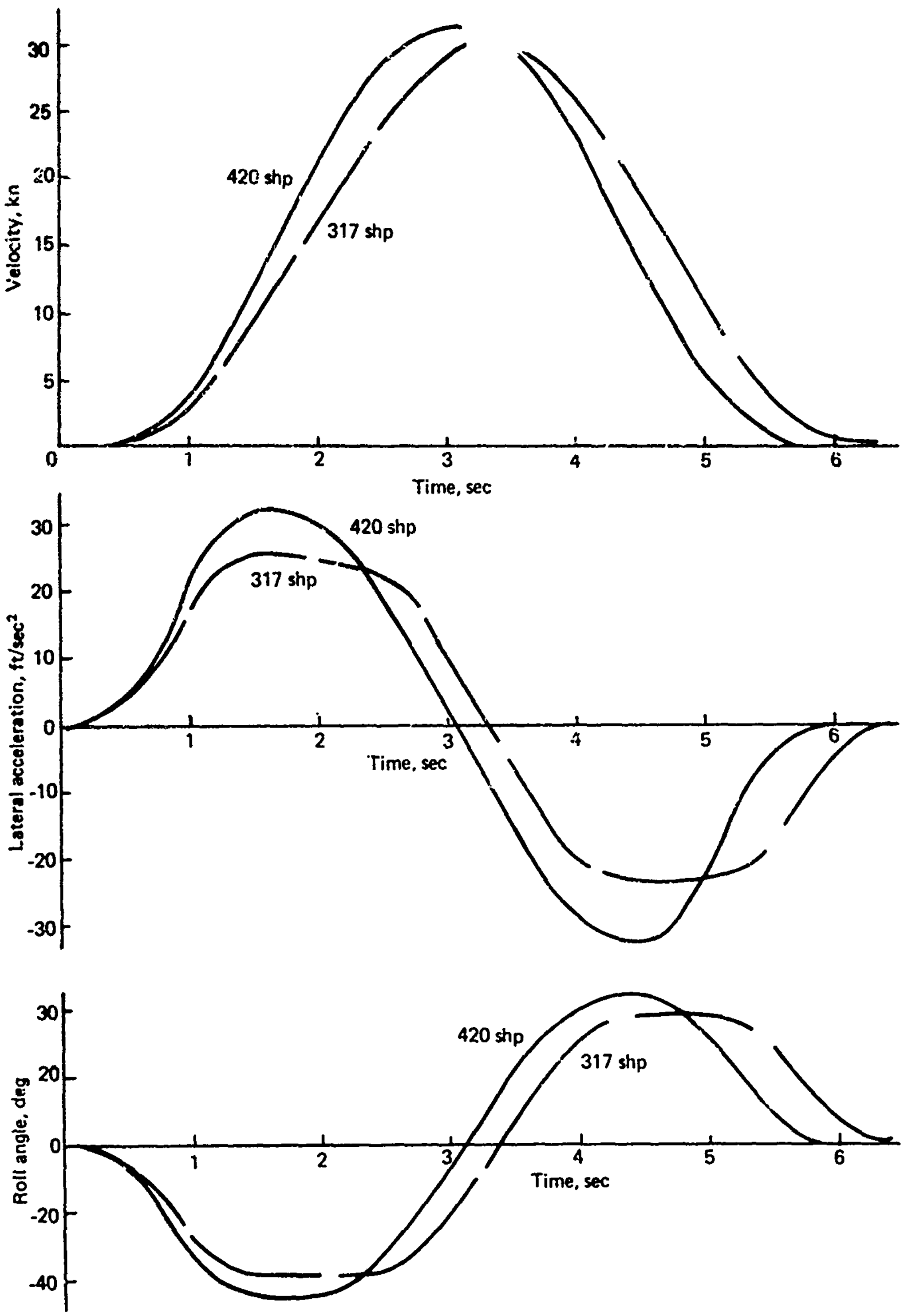


Figure 4. Left lateral acceleration to 30 knots and deceleration to hover.

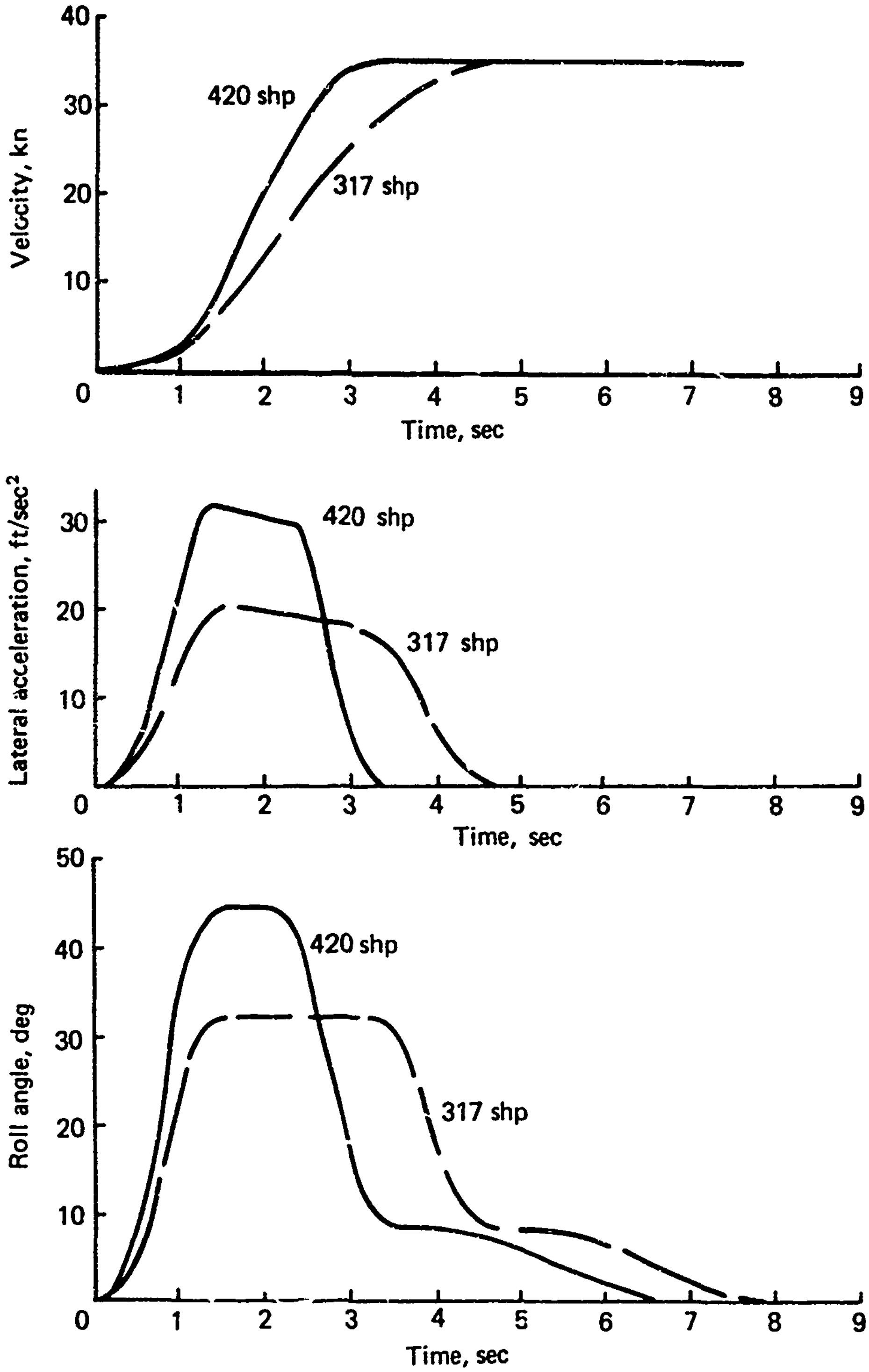
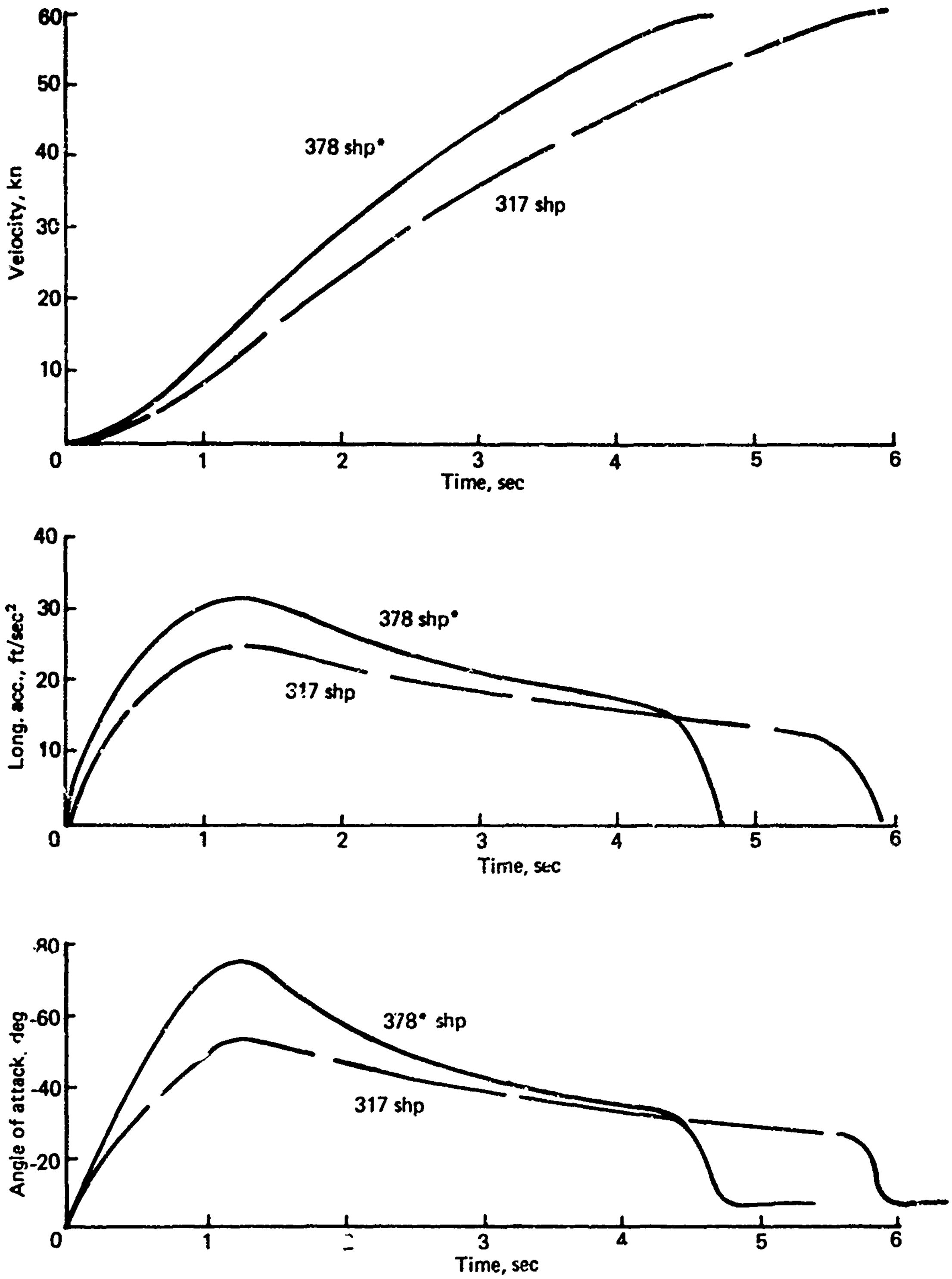


Figure 5. Lateral acceleration with recovery at 35 knots.



*378 shp reflects the 90 percent limit placed on the 420 shp available.

Figure 6. Longitudinal acceleration to 60 knots.

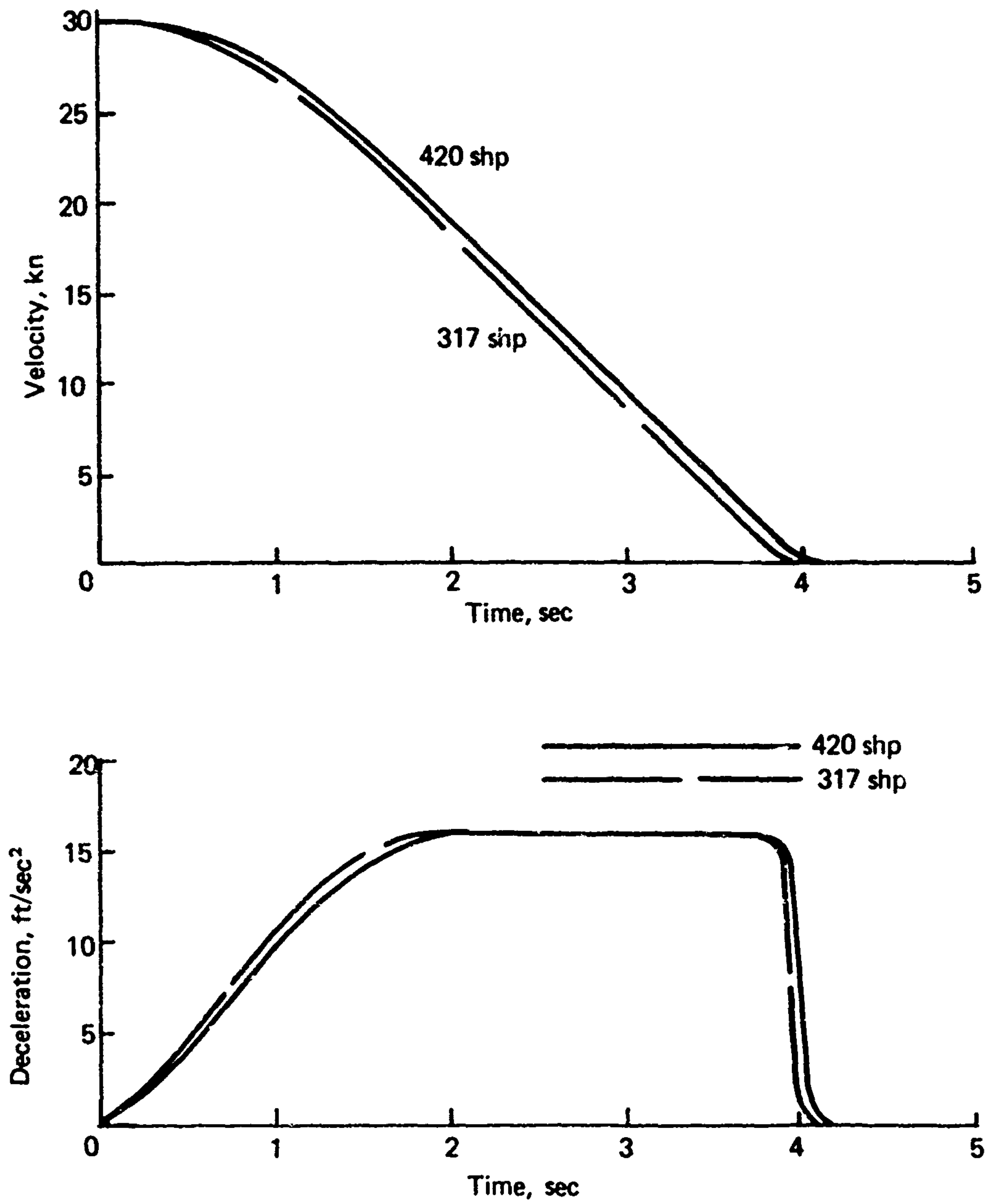


Figure 7. Longitudinal deceleration from 30 knots.

APPENDIX A
SAMPLE MCEP OUTPUTS

This appendix contains examples of the outputs provided by the MCEP. The required input data for the OH-58 helicopter and the initial conditions are given in Table A-1. A time history of the bob-up maneuver for the 420-shp helicopter is shown in Table A-2. While calculations were made every .05 second, only every fifth time-history computation was printed. Table A-3 is a summary of the bob-up. For convenience, the format of this output has been standardized. In some cases this means that labels such as "DESIRED", "ACTUAL", and "ERROR" are not meaningful but simply identify end points of the maneuver segment. Power and altitude histograms for the bob-up are shown in Table A-4. The "RELATIVE FREQUENCY" gives the fraction of total flight time spent in each interval of the histogram, while the "RELATIVE CUMULATIVE FREQUENCY" gives the fraction of flight time spent in the current interval and all preceding intervals. The MCEP also prints load factor and velocity histograms.

Tables A-5, A-6, and A-7 provide typical outputs for the lateral acceleration with recovery maneuver for the OH-58 with 317 shp.

TABLE A-1. OH-58 HELICOPTER INPUT DATA

MANEUVER CRITERIA EVALUATION PROGRAM

HELICOPTER INPUT DATA

VARIABLE	DIGITAL NAME	VALUE	UNITS
NUMBER OF BLADES	B	2.000	N.D.
ROTOR CHORD	C	1.080	FT
ROTOR RADIUS	R	17.650	FT
MAIN ROTOR INDUCED VELOCITY FACTOR	K3	2.140	N.D.
TIP SPEED	WR	654.000	FT/SEC
BLADE SECTION LIFT CURVE SLOPE	A2D	6.280	/RAD
BLADE DRAG COEFFICIENT			
	DEL0	0.038	N.D.
	DEL1	0.0	/RAD
	DEL2	0.590	/RAD*RAD
DRAG DIVERGENT MACH NUMBER	MCRO	0.750	N.D.
DIVERGENT THRUST COEFFICIENT CURVE			
	TC1	0.100	[illegible]
	TC2	0.200	[illegible]
MAXIMUM THRUST COEFFICIENT CURVE			
	TCM1	0.360	N.D.
	TCM2	0.0	N.D.
CLIMB/DESCENT EFFICIENCY FACTOR	HPEFF	0.800	N.D.
FUSELAGE ANGLE OF ATTACK COEFFICIENTS			
	KAF1	8.643	
	KAF2	2.478	1/G*G
	KAF3	10.422	1/G
	KAF4	1.600	
	KAF5	17.639	SEC/FT
	KAF6	0.800	N.D.
	KAF7	1.500	DEG
	KAF8	240.000	N.D.
WING AREA	SW	0.0	FT**2
WING INCIDENCE	IW	0.0	DEG
INDUCED VELOCITY FACTOR	KW	0.0	N.D.
WING ASPECT RATIO	ASR	0.0	N.D.
WING COEFFICIENT OF DRAG AT ZERO LIFT	CD0	0.0	N.D.
WING LIFT CURVE SLOPE	AL2D	0.0	/RAD
FLAT PLATE DRAG COEFFICIENT	CDFP	0.0	N.D.
WING EFFICIENCY FACTOR	WEFF	0.0	N.D.
WING INCIDENCE CHANGE WITH LOAD FACTOR	DIWDN	0.0	DEG/G
MAXIMUM POSITIVE LIFT COEFFICIENT	CLMAXP	0.0	N.D.
MAXIMUM NEGATIVE LIFT COEFFICIENT	CLMAXN	0.0	N.D.
LIMIT DIVE VELOCITY	VDL	190.000	KT
MAXIMUM VELOCITY TO THE RIGHT	VMRT	60.000	KT
MAXIMUM VELOCITY TO THE LEFT	VMLT	-60.000	KT

TABLE A-1. CONTINUED

VARIABLE	DIGITAL NAME	VALUE	UNITS
TIME CONSTANT FOR GAMMA	TAUP	1,000	SEC
TIME CONSTANT FOR ROLL	TAUR	0,550	SEC
TIME CONSTANT FOR CHI	TAUY	2,000	SEC
MAXIMUM RATE FOR GAMMA	ARPMX	30,000	DEG/SEC
MAXIMUM RATE FOR ROLL	ARRMX	60,000	DEG/SEC
MAXIMUM RATE FOR CHI	ARYMX	60,000	DEG/SEC
MAXIMUM ANGLE FOR GAMMA	GAMMP	60,000	DEG
MINIMUM ANGLE FOR GAMMA	GAMMN	-60,000	DEG
VERTICAL JERK LIMIT	VJERK	0,500	G/SEC
ERROR IN ANGLE CALCULATION	EPA	0,080	DEG
ERROR IN ANGULAR RATE CALCULATION	EPAV	0,050	DEG/SEC

AIRCRAFT FLIGHT CONDITION

VARIABLE	DIGITAL NAME	VALUE	UNITS
GROSS WEIGHT	GW	2767,000	LB
EQUIVALENT FLAT PLATE DRAG(BETA=0)	F0	9,700	FT**2
EQUIVALENT FLAT PLATE DRAG(BETA=90)	F1	102,000	FT**2
VELOCITY	V	0,0	KT
ALTITUDE	H	0,0	FT
HEADING	CHI	0,0	DEG
AIR DENSITY	RHO	0,002	SLUGS/FT**3
SPEED OF SOUND	VS	1116,000	FT/SEC

TABLE A-2. TIME HISTORY OF THE BOB-UP MANEUVER – 420 SHP

INPUT DATA: HC = 50.00 MUF = 1.000 NMIN = 0.5000 HPMAX = 420.0

TIME SEC	XE FT	YF FT	ZF FT	CHI DEG	GAM DEG	PHI DEG	ALPHA DEG	THETA DEG	LOAD FACTOR	V KT	VZE FT/SEC	AXW FT/SEC/SEC	CHID DEG/SEC	GAMD DEG/SEC	PHID DEG/SEC	PS	TOTAL POWER HP
0.0	0	0	0	0.0	90.0	0.0	-91.5	-1.5	1.00	0.0	0.0	0.0	0.0	0.0	0.0	0.55	230
0.20	0	0	0	0.0	90.0	0.0	-91.5	-1.5	1.10	0.2	-0.3	0.0	0.0	0.0	0.0	0.60	260
0.45	0	0	0	0.0	90.0	0.0	-91.5	-1.5	1.22	0.9	-1.6	0.0	0.0	0.0	0.0	0.70	305
0.70	0	0	0	0.0	90.0	0.0	-91.5	-1.5	1.34	2.3	-3.9	0.0	0.0	0.0	0.0	0.83	357
0.95	0	0	-2	0.0	90.0	0.0	-91.5	-1.5	[illegible]	4.2	-7.1	0.0	0.0	0.0	0.0	0.96	415
1.20	0	0	-4	0.0	90.0	0.0	-91.5	-1.5	1.43	6.7	-11.3	0.0	0.0	0.0	0.0	1.00	420
1.45	0	0	-7	0.0	90.0	0.0	-91.5	-1.5	1.00	6.9	-11.6	0.0	0.0	0.0	0.0	0.69	288
1.70	0	0	-10	0.0	90.0	0.0	-91.5	-1.5	1.00	6.9	-11.6	0.0	0.0	0.0	0.0	0.69	288
1.95	0	0	-13	0.0	90.0	0.0	-91.5	-1.5	1.00	6.9	-11.6	0.0	0.0	0.0	0.0	0.69	288
2.20	0	0	-16	0.0	90.0	0.0	-91.5	-1.5	1.00	6.9	-11.6	0.0	0.0	0.0	0.0	0.69	288
2.45	0	0	-19	0.0	90.0	0.0	-91.5	-1.5	1.00	6.9	-11.6	0.0	0.0	0.0	0.0	0.69	288
2.70	0	0	-21	0.0	90.0	0.0	-91.5	-1.5	1.00	6.9	-11.6	0.0	0.0	0.0	0.0	0.69	288
2.95	0	0	-24	0.0	90.0	0.0	-91.5	-1.5	1.00	6.9	-11.6	0.0	0.0	0.0	0.0	0.69	288
3.20	0	0	-27	0.0	90.0	0.0	-91.5	-1.5	1.00	6.9	-11.6	0.0	0.0	0.0	0.0	0.69	288
3.45	0	0	-30	0.0	90.0	0.0	-91.5	-1.5	1.00	6.9	-11.6	0.0	0.0	0.0	0.0	0.69	288
3.70	0	0	-33	0.0	90.0	0.0	-91.5	-1.5	1.00	6.9	-11.6	0.0	0.0	0.0	0.0	0.69	288
3.95	0	0	-36	0.0	90.0	0.0	-91.5	-1.5	1.00	6.9	-11.6	0.0	0.0	0.0	0.0	0.69	288
4.20	0	0	-39	0.0	90.0	0.0	-91.5	-1.5	0.95	6.8	-11.4	0.0	0.0	-0.0	0.0	0.66	273
4.45	0	0	-42	0.0	90.0	0.0	-91.5	-1.5	0.88	6.6	-10.7	0.0	0.0	-0.0	0.0	0.61	252
4.70	0	0	-44	0.0	90.0	0.0	-91.5	-1.5	0.81	5.6	-9.5	0.0	0.0	-0.0	0.0	0.56	229
4.95	0	0	-46	0.0	90.0	0.0	-91.5	-1.5	0.74	4.5	-7.7	0.0	0.0	-0.0	0.0	0.50	204
5.20	0	0	-48	0.0	90.0	0.0	-91.5	-1.5	0.70	3.2	-5.3	0.0	0.0	-0.0	0.0	0.44	183
5.45	0	0	-49	0.0	90.0	0.0	-91.5	-1.5	0.77	1.9	-3.2	0.0	0.0	-0.0	0.0	0.44	187
5.70	0	0	-50	0.0	90.0	0.0	-91.5	-1.5	0.84	0.9	-1.6	0.0	0.0	-0.0	0.0	0.46	195
5.95	0	0	-50	0.0	90.0	0.0	-91.5	-1.5	0.90	0.3	-0.5	0.0	0.0	-0.0	0.0	0.49	207
6.20	0	0	-50	0.0	90.0	0.0	-91.5	-1.5	0.97	0.0	-0.0	0.0	0.0	-0.0	0.0	0.52	222

TABLE A-3. SUMMARY THE BOB-UP MANEUVER – 420 SHP

	EXECUTION TIME -SEC	TARGET LOCATION - FT XE	YE	ZE
ROLL IN	0.0	0.	0.	0.
ACHIEVE G	0.0			
HOLD G	0.0			

	TIME SEC.	AIRCRAFT LOCATION - FEET XE	YE	ZE	VELOCITY KNOTS	HEADING DEG
ENTRY	0.0	0.	0.	0.	0.0	0.0
EXIT	6.30	0.	0.	-50.	0.0	0.0

	FLT PATH ANGLE	SLANT RANGE	LOAD FACTOR-G MIN	MAX	VELOCITY-KT MIN	MAX	EXIT HEADING
DESIRED	0.0	0.	0.500	1.566	0.0	0.0	0.0
ACTUAL	90.0	0.	0.686	1.566	0.0	6.9	0.0
ERROR	-90.0	0.	-0.186	0.000	-0.0	-6.9	0.0

	BANK ANGLE MAX	AIM POINT - FEET XE	YE	ZE
DESIRED	0.0	0.	0.	-50.
ACTUAL	0.0	0.	0.	-50.
ERROR	0.0	0.	0.	0.

TABLE A-4. HISTOGRAMS FOR THE BOB-UP MANEUVER – 420 SHP

HORSEPOWER HISTOGRAM

HORSEPOWER INTERVAL-HP	NUMBER OF OCCURRENCES	RELATIVE FREQUENCY	RELATIVE CUMULATIVE FREQUENCY
0.0 - 20.00	0	0.0	0.0
20.00- 40.00	0	0.0	0.0
40.00- 60.00	0	0.0	0.0
60.00- 80.00	0	0.0	0.0
80.00- 100.00	0	0.0	0.0
100.00- 120.00	0	0.0	0.0
120.00- 140.00	0	0.0	0.0
140.00- 160.00	0	0.0	0.0
160.00- 180.00	0	0.0	0.0
180.00- 200.00	17	0.1339	0.1339
200.00- 220.00	10	0.0787	0.2126
220.00- 240.00	9	0.0709	0.2835
240.00- 260.00	6	0.0472	0.3307
260.00- 280.00	8	0.0630	0.3937
280.00- 300.00	60	0.4724	0.8661
300.00- 320.00	2	0.0157	0.8819
320.00- 340.00	2	0.0157	0.8976
340.00- 360.00	2	0.0157	0.9134
360.00- 380.00	1	0.0079	0.9213
380.00- 400.00	2	0.0157	0.9370
400.00- 420.00	8	0.0630	1.0000

ALTITUDE HISTOGRAM

ALTITUDE INTERVAL-FT	NUMBER OF OCCURRENCES	RELATIVE FREQUENCY	RELATIVE CUMULATIVE FREQUENCY
0.0 - 5.00	24	0.1890	0.1890
5.00- 10.00	9	0.0709	0.2598
10.00- 15.00	8	0.0630	0.3228
15.00- 20.00	9	0.0709	0.3937
20.00- 25.00	9	0.0709	0.4646
25.00- 30.00	8	0.0630	0.5276
30.00- 35.00	9	0.0709	0.5984
35.00- 40.00	9	0.0709	0.6693
40.00- 45.00	9	0.0709	0.7402
45.00- 50.00	18	0.1417	0.8819
50.00- 55.00	14	0.1102	0.9921
55.00- 60.00	0	0.0	0.9921
60.00- 65.00	0	0.0	0.9921
65.00- 70.00	0	0.0	0.9921
70.00- 75.00	0	0.0	0.9921

TABLE A-5. TIME HISTORY FOR THE LATERAL ACCELERATION WITH RECOVERY MANEUVER – 317 SHP

SIDEWARD ACCELERATION AND RECOVERY

INPUT DATA = PHIC = 45.00 VC = 35.00 HUF = 1.000 RPMTR = 50.0 RPMAX = 317.0
TARX = 100000.00 TARY = 0.0 TPB = 1.00 BETAD = 30.00 MPRINT = 5 HOVER = F

TIME SEC	XE FT	YE FT	ZE FT	CHI DEG	GAM DEG	PHI DEG	THETA DEG	LOAD FACTOR	V KT	VZE FT/SEC	AXW FT/SEC/SEC	CHID DEG/SEC	GAMD DEG/SEC	PHID DEG/SEC	PS	TOTAL POWER HP	HDG DEG
22.70	0	-77	-50	450.04	0.0	0.0	-1.5	1.00	0.0	0.0	0.0	0.0	0.0	0.0	[illegible]	230	0.0
22.90	0	-77	-50	90.04	0.0	0.4	-1.5	1.00	0.0	0.0	0.11	-0.0	0.0	6.4	[illegible]	230	0.0
23.15	0	-77	-50	90.04	0.0	4.5	-1.5	1.00	0.1	0.0	1.82	-0.0	0.0	27.4	[illegible]	230	0.0
23.40	0	-77	-50	90.04	0.0	13.2	-1.5	1.02	0.7	0.0	6.40	-0.0	0.0	39.7	0.82	235	0.0
23.65	0	-76	-50	90.04	0.0	23.1	-1.6	1.07	2.1	0.0	[illegible].49	-0.0	0.0	37.0	0.88	251	0.0
23.90	0	-75	-50	90.04	0.0	30.3	-1.8	1.15	4.4	0.0	1[illegible].96	-0.0	0.0	17.9	0.96	275	0.0
24.15	0	-72	-50	90.04	0.0	32.4	-2.1	1.18	7.2	0.0	20.13	-0.0	0.0	2.1	1.00	286	[illegible]
24.40	0	-69	-50	90.04	0.0	32.5	-2.3	1.18	10.2	0.0	20.14	-0.0	0.0	0.0	1.00	286	[illegible]
24.65	0	-64	-50	90.03	0.0	32.5	-2.6	1.18	13.2	0.0	19.88	-0.0	0.0	0.0	1.00	286	0.0
24.90	0	-58	-50	90.03	0.0	32.5	-2.8	1.17	16.1	0.0	19.55	-0.0	0.0	0.0	1.00	287	0.0
25.15	0	-50	-50	90.03	0.0	32.5	-3.1	1.16	19.0	0.0	19.15	-0.0	0.0	0.0	1.01	289	0.0
25.40	0	-42	-50	90.02	0.0	32.5	-3.3	1.16	21.8	0.0	18.71	-0.0	0.0	0.0	1.02	293	0.0
25.65	0	-32	-50	90.02	0.0	32.5	-3.6	1.15	24.5	0.0	18.21	-0.0	0.0	0.0	1.04	298	0.0
25.90	0	-21	-50	90.01	0.0	32.5	-3.8	1.14	27.2	0.0	17.66	0.0	0.0	-0.3	1.06	305	0.0
26.15	0	-9	-50	90.01	0.0	31.5	-4.0	1.13	29.7	0.0	16.60	0.0	0.0	-9.9	1.07	307	0.0
26.40	0	3	-50	90.01	0.0	27.0	-4.2	1.08	32.0	0.0	13.22	0.0	0.0	-25.2	0.9[illegible]	235	0.0
26.65	0	17	-50	90.01	0.0	19.9	-4.4	1.03	33.6	0.0	8.14	0.0	0.0	-29.6	0.6[illegible]	242	0.0
26.90	0	31	-50	90.01	0.0	13.1	-4.4	1.01	34.4	0.0	3.46	0.0	0.0	-22.7	0.70	199	0.0
27.15	0	46	-50	90.01	0.0	9.4	-4.5	1.00	34.7	0.0	0.72	0.0	0.0	-6.9	0.67	174	0.0
27.40	0	61	-50	90.01	0.0	8.7	-4.5	1.00	34.7	0.0	0.99	0.0	0.0	-0.2	0.59	1[illegible]8	0.0
27.65	0	75	-50	90.01	0.0	8.7	-4.5	1.00	34.7	0.0	0.07	0.0	0.0	-0.2	0.59	168	0.2
27.90	0	90	-50	90.01	0.0	8.6	-4.5	1.00	34.7	0.0	0.03	0.0	0.0	-0.7	0.56	167	2.0
28.15	0	104	-50	90.01	0.0	8.3	-4.5	1.00	34.7	0.0	-0.05	0.0	0.0	-1.6	0.58	166	6.8
28.40	0	119	-50	90.01	0.0	7.8	-4.5	1.00	34.7	0.0	-0.07	0.0	0.0	-2.6	0.57	163	13.8
28.65	0	134	-50	90.01	0.0	7.0	-4.5	1.00	34.7	0.0	-0.03	0.0	0.0	-3.5	0.56	160	21.3
28.90	0	148	-50	90.01	0.0	6.1	-4.5	1.00	34.7	0.0	0.05	0.0	0.0	-4.0	0.5[illegible]	155	28.8
29.15	0	163	-50	90.01	0.0	5.0	-4.5	1.00	34.7	0.0	0.14	0.0	0.0	-4.3	0.52	149	36.3
29.40	0	178	-50	90.01	0.0	3.9	-4.5	1.00	34.8	0.0	0.22	0.0	0.0	-4.3	0.50	144	43.8
29.65	0	192	-50	90.01	0.0	2.9	-4.5	1.00	34.8	0.0	0.25	0.0	0.0	-4.2	0.48	138	51.3
29.90	0	207	-50	90.01	0.0	1.9	-4.5	1.00	34.8	0.0	0.22	0.0	0.0	-3.6	0.46	133	58.8
30.15	0	222	-50	90.01	0.0	1.1	-4.5	1.00	34.9	0.0	0.15	0.0	0.0	-2.8	0.45	128	66.3
30.40	0	237	-50	90.01	0.0	0.5	-4.5	1.00	34.9	0.0	0.08	0.0	0.0	-1.8	0.44	125	73.8
30.65	0	251	-50	90.01	0.0	0.2	-4.5	1.00	34.9	0.0	0.03	0.0	0.0	-0.8	0.43	123	81.1
30.90	0	266	-50	90.01	0.0	0.1	-4.5	1.00	34.9	0.0	0.01	0.0	0.0	-0.3	0.43	123	86.9
31.15	0	281	-50	90.01	0.0	0.0	-4.5	1.00	34.9	0.0	0.00	0.0	0.0	-0.1	0.43	122	89.5
31.40	0	295	-50	90.01	0.0	0.0	-4.5	1.00	34.9	0.0	0.00	0.0	0.0	-0.0	0.43	122	90.0

TABLE A-6. SUMMARY OF THE LATERAL ACCELERATION WITH RECOVERY MANEUVER — 317 SHP

TYPE OF MANEUVER: SIDEWARD ACCEL & TURN INTO WIND

	EXECUTION TIME -SEC	TARGET LOCATION - FT XE	YE	ZE
ROLL IN	0.0	100000.	0.	0.
ACHIEVE G	0.0			
HOLD G	0.0			

	TIME SEC.	AIRCRAFT LOCATION - FEET XE	YE	ZE	VELOCITY KNOTS	HEADING DEG
ENTRY	22.70	0.	-77.	-50.	0.0	360.0
EXIT	31.45	-0.	299.	-50.	34.9	90.0

	FLT PATH ANGLE	SLANT RANGE	LOAD FACTOR-G MIN	MAX	VELOCITY-KT MIN	MAX	EXIT HEADING
DESIRED	0.0	0.	1.000	1.186	0.0	35.0	90.0
ACTUAL	0.0	0.	1.000	1.181	0.0	34.9	90.0
ERROR	0.0	0.	0.0	0.005	-0.0	0.1	0.0

	BANK ANGLE MAX	AIM POINT - FEET XE	YE	ZE
DESIRED	32.5	0.	0.	0.
ACTUAL	32.5	-0.	299.	-50.
ERROR	0.0	0.	-299.	50.

TABLE A-7. HISTOGRAM FOR THE LATERAL ACCELERATION WITH RECOVERY MANEUVER — 317 SHP

HORSEPOWER HISTOGRAM

HORSEPOWER INTERVAL-HP	NUMBER OF OCCURRENCES	RELATIVE FREQUENCY	RELATIVE CUMULATIVE FREQUENCY
0.0 - 20.00	0	0.0	0.0
20.00- 40.00	0	0.0	0.0
40.00- 60.00	0	0.0	0.0
60.00- 80.00	0	0.0	0.0
80.00- 100.00	0	0.0	0.0
100.00- 120.00	0	0.0	0.0
120.00- 140.00	38	0.2159	0.2159
140.00- 160.00	18	0.1023	0.3182
160.00- 180.00	32	0.1818	0.5000
180.00- 200.00	4	0.0227	0.5227
200.00- 220.00	2	0.0114	0.5341
220.00- 240.00	17	0.0966	0.6307
240.00- 260.00	7	0.0398	0.6705
260.00- 280.00	8	0.0455	0.7159
280.00- 300.00	38	0.2159	0.9318
300.00- 320.00	12	0.0682	1.0000
320.00- 340.00	0	0.0	1.0000
340.00- 360.00	0	0.0	1.0000
360.00- 380.00	0	0.0	1.0000
380.00- 400.00	0	0.0	1.0000
400.00- 420.00	0	0.0	1.0000