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HELICOPTER AEROBATIC FLIGHT - THE TACTICAL SIGNIFICANCE

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by

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Definitions

θ	- Pitch attitude
ϕ	- Roll attitude
n_z	- Normal acceleration
$(n_z)_{max}$	- Maximum allowable normal acceleration
h_d	- Density altitude
h_p	- Pressure altitude
p_{max}	- Maximum roll rate
p_{min}	- Minimum roll rate
P_s	- Specific excess power
AACT-IV	- Air-to-Air Combat Test, Phase IV
AATD	- Army Applied Technology Directorate
ACM	- Air Combat Maneuvering
AGL	- Above Ground Level
AVSCOM	- Aviation Systems Command
FAA	- Federal Aviation Administration
GW	- Gross Weight
KCAS	- Knots Calibrated AirSpeed
MBB	- Messerschmitt-Blkow-Blohm GmbH
USAAEFA	- U.S. Army Aviation Engineering Flight Activity

1.0 Background

For the purposes of this paper, an old FAA definition of aerobatic flight will be utilized since it is the only attempt to define aerobatic flight; aerobatic flight is any flight condition where $\theta > 30^o$, $\phi > 60^o$, or $n_z > 2.0$ g. The term "aerobatic flight" is somewhat controversial when applied to helicopter operations. As such, synonymous terms, like transient, all-attitude maneuvering or high angle maneuvering, will be used. The subject matter also requires a disclaimer; the author is not advocating routine, general or everyday use of aerobatic flight. Proper technical evaluation should determine the capabilities and limitations involved in helicopter aerobatic flight. Once the capabilities have been documented and an operational requirement has been established, proper flight procedures must be specified to train the appropriate aircrews and to retain their currency. Unless a bonafide operational requirement can be established, demonstrated and documented, aerobatic flight with helicopters should not be accepted for operational use.

Aerobatic flight for helicopters has been performed for some years by a few intrepid aviators walking on the edge. However, several changes have taken place recently which are making aerobatic maneuvering more commonplace. Modern tactical helicopters, such as the UH-60A and AH-64A, have been built to stringent specifications which make these aircraft considerably more capable and tolerant of over-stress events than aircraft of previous generations. Additionally, aerial combat practice has demonstrated the unique challenges facing today's operational aviators. The analogous effort in the fighter community is the current work to expand the agility of the aircraft, not necessarily the ultimate performance. Agility enables the pilot to be more unpredictable, and to an extent, less vulnerable.

Helicopter air-to-air combat has for some time been characterized as "Very Quick and Very Lethal". This description for the most part applies to that portion of the aerial fight known as the contact fight; also known as "the fur ball" or "the cat fight". A contact fight will be defined as that portion of an aerial engagement where both opponents are aggressively maneuvering against each other at ranges less than 500 meters. As such, there are often few options available to the pilot. The author's ACM experience has shown that there are specific conditions where high angle maneuvering may be beneficial.

This paper will present some of the recent results of aerobatic flight with helicopters, some of the experience in helicopter aerial combat, and some potential tactical situations where high angle maneuvering may make the difference between life and death.

2.0 Helicopter Aerobatic Flight

Several helicopters over the years have demonstrated aerobatic flight capability. Lockheed conducted a series of aerobatic tests with their rigid rotor, Model 286 (XH-51) in the late 60's. These tests were documented in Reference 1. In addition, Lockheed demonstrated some unique maneuvering capability with the AH-56A Cheyenne before its demise. Sikorsky Aircraft conducted a demonstration program in Japan in the 70's with a production CH-53D which included rolls, and Split S in an impressive maneuvering flight program. MBB has conducted aerobatic demonstrations for many years with the BO-105. The unfortunate part of the aerobatic flying referred to above is that it is, for the most part, undocumented except for some film coverage. There is no structural data and minimal performance data which can be referenced. Recent testing conducted by USAAEFA using the MBB BK-117 was reported in References 2 and 3, and was useful in developing the AH-64A aerobatic flight demonstration program. The need as well as the difficulty of defining and presenting the maneuvering envelope to the pilot was presented in

Reference 4, as well as the implications of testing to a specification vice the ultimate aircraft performance.

During the preparation for the McDonnell Douglas Helicopter Company participation in the AACT-IV program, it was recognized that the potential existed for the aircraft to be exposed to attitudes in excess of those defined above as "aerobatic". Furthermore, the AH-64A Operator's Manual, Reference 5, states: "Aerobatic maneuvers are prohibited"; however, there is no definition of what aerobatic maneuvers are considered to be. In order to eliminate this ambiguity, McDonnell Douglas Helicopter Company conducted a preliminary investigation of aerobatic flight with the AH-64A Apache in preparation for the AATD sponsored AACT-IV program. The aerobatic flight portion of the AACT-IV preparation was actually a brief, limited evaluation to determine high angle maneuvering potential for possible utilization during the AACT-IV flight tests. The demonstrated maneuvers included: roll, Split S, hammerhead, skewed loop and vertical loop. The aircraft used in the evaluation was a structurally instrumented, production AH-64A. Structural data was observed real-time during the events, and was analyzed in detail after the flight. All of the maneuvers were performed successfully; no abnormal Apache flight loads were encountered.

As a result, the flight release from AVSCOM for the AACT-IV tests authorized the test helicopter to use $\pm 360^{\circ}\,\phi$ and $\pm 360^{\circ}\,\theta$ except for a notch of $\pm 30^{\circ}$ from the vertical from $+90^{\circ} \rightarrow +180^{\circ}$. Although the authorized Apache envelope was essentially unrestricted by attitude, there was a concern about the overall safety of the AACT-IV program since all of the project pilots had not been exposed to the use of high angle maneuvering. Therefore, the Apache's AACT-IV envelope was restricted to: $\pm 90^{\circ}\,\theta$ or $\pm 120^{\circ}\,\phi$.

3.0 Flight Results

The results of the aerobatic flight evaluation will be discussed with respect to the individual maneuvers performed. The maneuvers were flown at two gross weights: 14,700 pounds (structural design GW), and 16,300 pounds (AACT-IV Mission GW). Two external (drag) configurations were flown: clean wing, and eight HELLFIRE missiles plus two 19-shot 70mm rocket pods. The nominal altitude was: 5,000 feet h_p (approximately 7,000 feet h_d) at 2,500 feet AGL. No attempt was made to determine limit conditions or limit performance, but simply to demonstrate a reasonable capability during this stage of testing. In other words, minimum as well as maximum performance maneuvering was not established.

3.1 Build-up and abort maneuvers. The flight test build-up procedures were established to provide the crew with a good feel for the aircraft, to increase the confidence of the test team in aerobatic flight, and to identify abort maneuvers or procedures in the event that the target maneuvers did not occur as planned. The build-up sequence did establish one or more abort maneuvers for every aerobatic, end-point, maneuver. The large maneuvering envelope of the

AH-64A provided the crew with good confidence that any maneuver could be aborted. Furthermore, the inherent characteristics of a helicopter allow a generally greater maneuvering margin than most fixed wing aircraft. For example, a moderate offset main rotor helicopter, such as the AH-64A (3.9 percent), possesses reasonably good rolling and pitching performance at zero airspeed and normal acceleration.

3.2 Roll. During the build-up events, it was apparent that pitch-roll coupling would be present and that adequate compensation would be required. A +10° pitch up was established as the initial target pitch attitude to compensate for the pitch-roll coupling during the roll. Rolls were performed to the left and right using roll rates of 50°/s → 90°/s as illustrated in Fig. 1. The slower rate rolls, having greater exposure to the pitch-roll coupling, resulted in more of a nose down recovery attitude. The higher rate rolls seemed to be more precise with less pitch coupling.

A bunt entry technique was utilized on one of the roll events. Slight negative pitch rate was applied prior to the roll initiation. The result was a very tight roll finishing with the nose above the horizon. It should be noted that all of the rolls were performed at a fixed collective setting and power for level flight. It is hypothesized that the use of collective could substantially alter the roll characteristics. Based on the magnitude of the lateral input, it was estimated that p_{max} should be about 120-150°/s; a tolerable p_{min} could not be predicted. The rolls were smooth and predictable.

Rolls were performed from airspeeds of 100 → 130 KCAS. The altitude loss during all the rolls was directly dependent on the amount of pitch-roll coupling commanded. The maximum altitude loss was 200 feet during the slow roll. Reducing the amount of pitch-roll coupling reduced the amount of altitude loss during the roll.

3.3 Split S. The Split S (Fig. 2) is a maneuver combining the first half of a roll and the last half of a loop. A fixed collective setting was utilized with power for level flight. These maneuvers were performed with initial entry airspeeds of 70 → 130 KCAS. Moderate entry roll rates were used. Altitude loss and airspeed gain

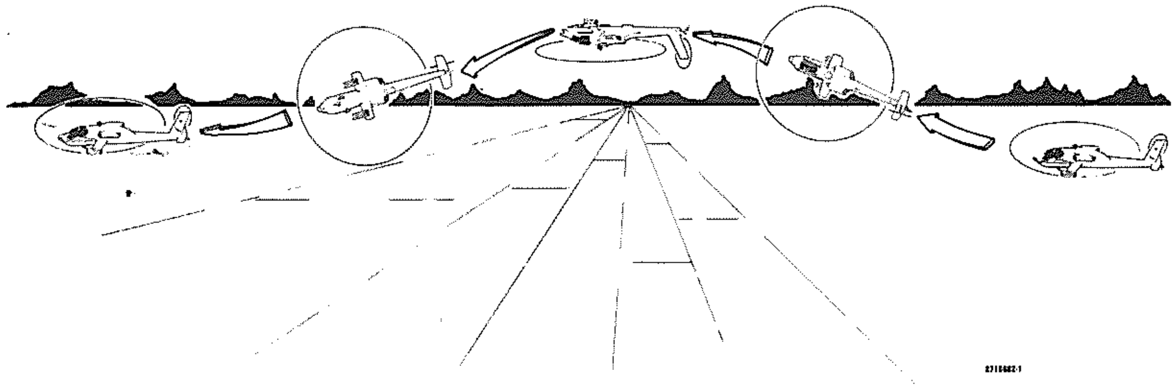


Fig. 1. Roll

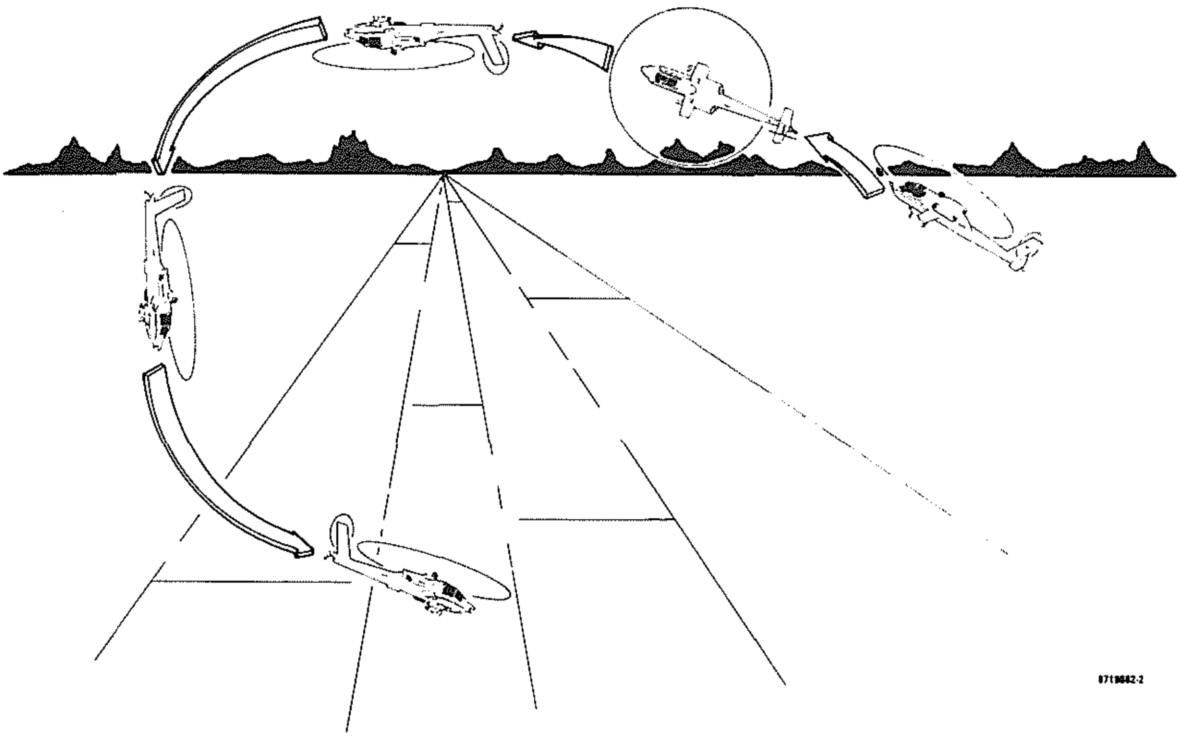


Fig. 2. Split "S"

were controlled by the amount of pitch rate and normal acceleration utilized from the inverted position. For all the maneuvers performed, the minimum altitude loss was 200 feet with a maximum altitude loss of 1,800 feet. The maximum normal acceleration utilized was: n_z = 2.0 g; $(n_z)_{max}$ = 2.9 g at the test conditions. The minimum airspeed gain was zero with a maximum airspeed gain of 40 KCAS. All of the maneuvers were smooth with a good linear response and essentially no change in vibration level. No structural limits were reached or approached during any of these maneuvers.

3.4 Hammerhead. The hammerhead (Fig. 3) is a pitch up to $+90^\circ$ θ (the first quarter of a loop) followed by a 180° yaw and recovery. The yaw portion, or kick out, was initiated as the airspeed passed 60 KCAS so as not to exceed the Operator's Manual sideward flight limit of 45 knots. Airspeeds of 100 → 130 KCAS were used in order to evaluate the loop entry procedures as well as potential unusual attitude recovery procedures.

3.5 Skewed Loop. The skewed loop (Fig. 4) is, as the title suggests, a loop in a plane skewed off of inertial vertical. The skewed loop was utilized as a build-up maneuver for the vertical loop to further evaluate entry and performance checkpoints and procedures. Skewed loops were performed using 45°, 30° and 15° off of vertical. These maneuvers correlated quite well with the analysis and previous build-up points. It should be noted that the skewed loop was the only aerobatic maneuver utilized during AACT-IV due to the more restrictive flight envelope allowed by AATD.

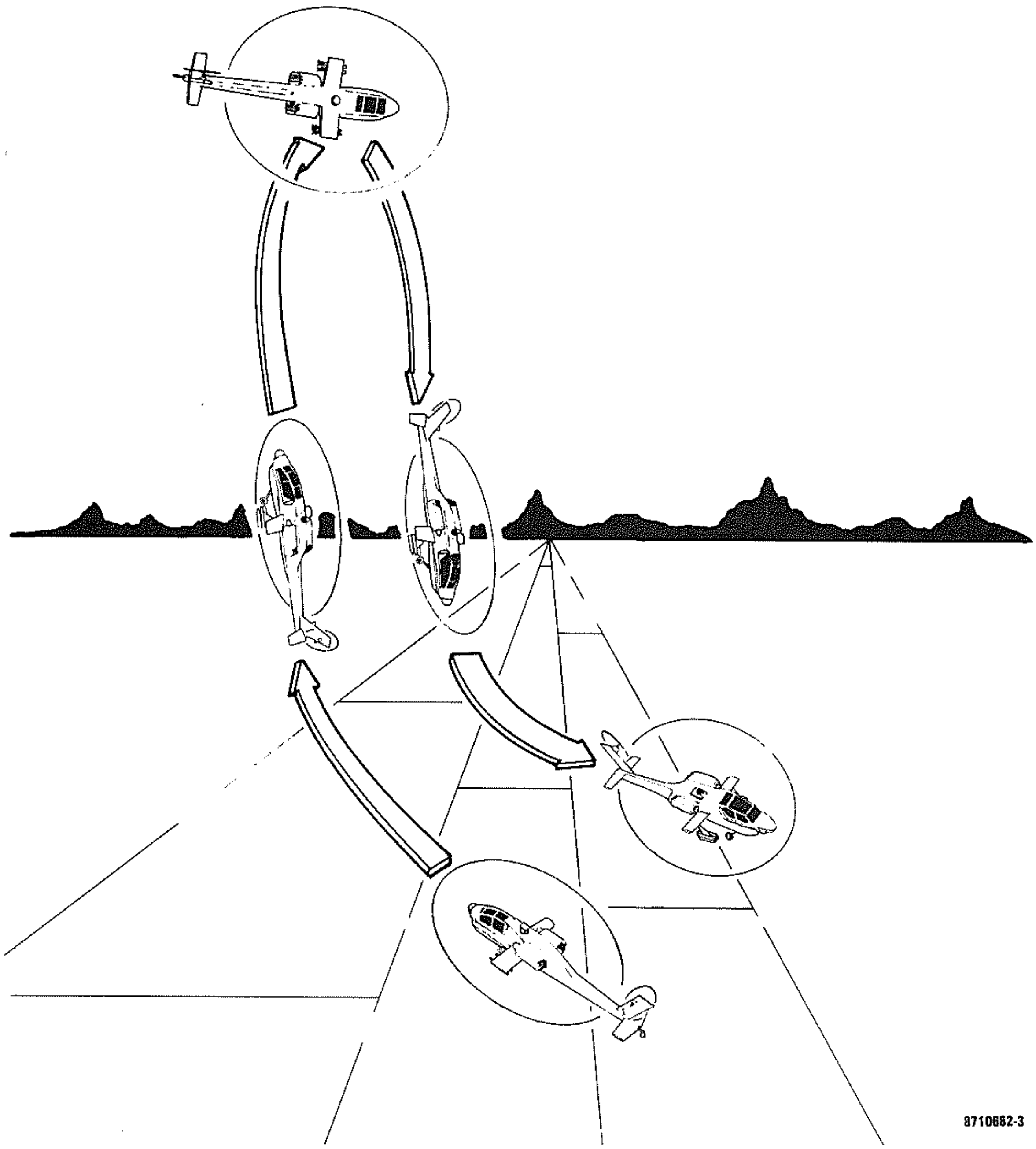
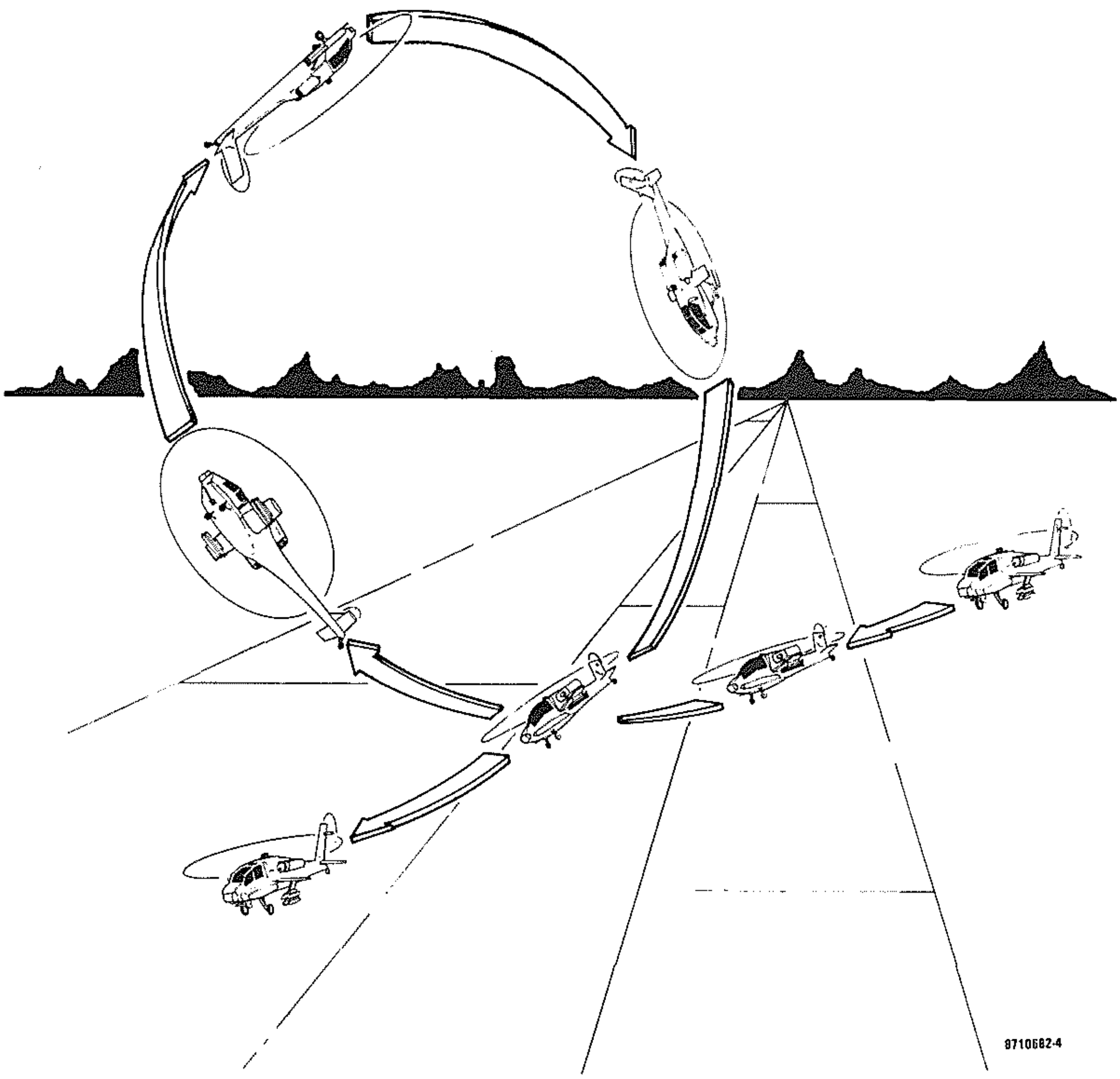


Fig. 3. Hammerhead

3.6 Loop. The vertical loop (Fig. 5) was performed in the clean configuration only from an entry speed of 130 KCAS in level flight. The analysis had indicated a slow airspeed at the 180° position. There was some concern about the interaction of the stabilator at moderate deceleration values and low airspeed. The decision was made to fly the loop with manual stabilator set at 0°, DASE ON, and control any adverse pitch rate with cyclic. The initial



NOTE: X^{o} roll, then loop in-plane.

Fig. 4. Skewed loop

pull to enter the loop was slightly higher than desired (n_Z = 2.9 g vice 2.5 g). At about the 135^{o} position (45^{o} past vertical), pitch rate began to increase rapidly from the nominal 20-30^{o}/s to 49^{o}/s most probably due the manual stabilator setting at low airspeed. A correction was made to reduce the pitch rate in order to prevent the nose from snapping through, and about 0.5 second later, the DASE responded, as programmed, and added about 30 percent forward cyclic to the pilot's input. The result was a 100 percent flapping excursion just prior to the inverted position; there were no in-flight or post-flight indications of droop stop contact. The loop was smooth, low vibration level, and comfortable. Hindsight would indicate that the

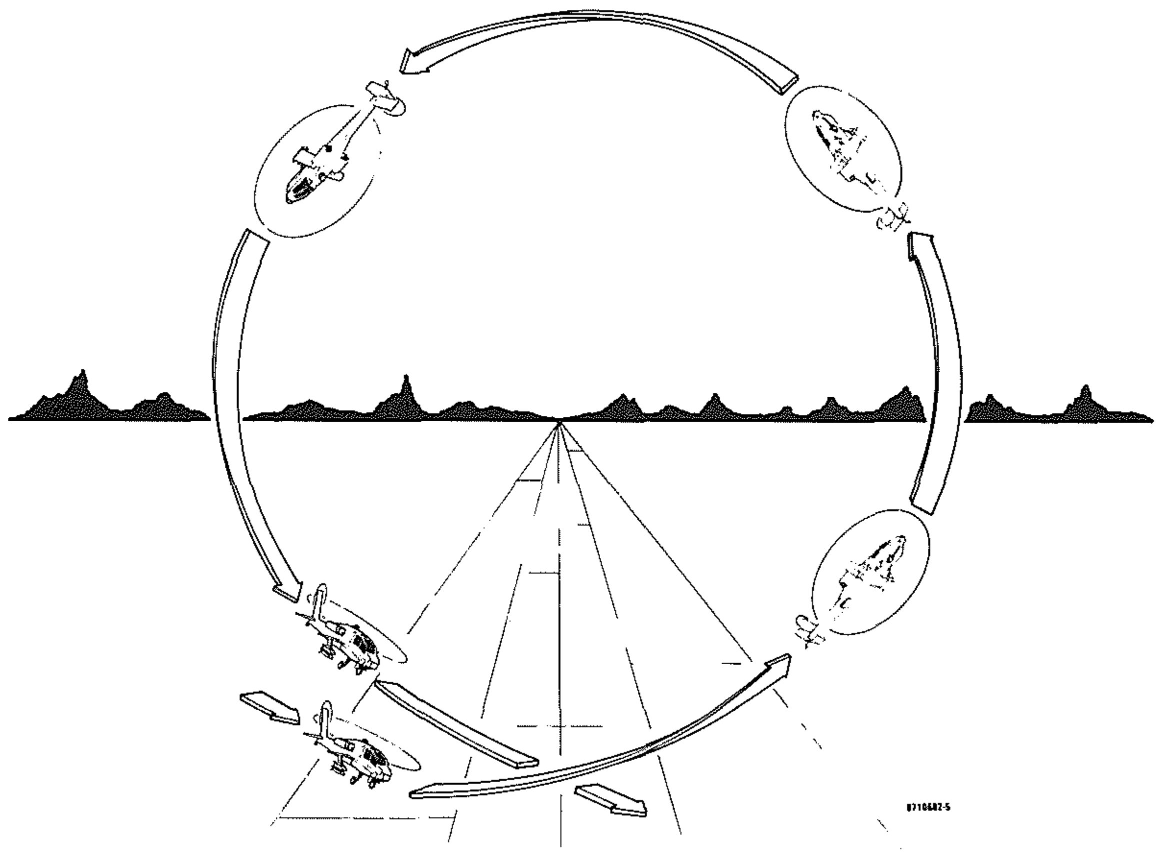


Fig. 5. Loop

higher than desired entry g coupled with the manual stabilator contributed to the high flapping event.

As a result of the high flapping event and the short available time window, no additional vertical loops were flown. Operationally, the intent is to fly the vertical loop in the normal flight configuration (auto-stab and DASE ON). It was recommended and accepted that a $\pm 30^{\circ}$ from vertical maneuvering notch from $+90^{\circ}$ (nose up) to 180° (inverted) should be excluded; all other pitch attitudes were acceptable.

There is no definitive data which can be presented which categorically establishes the requirement for aerobatic flight in the tactical environment. There is, however, a sufficient question about the practical utility of aerobatic flight, or lack thereof, to warrant at least a limited investigation into the tactical employment of high angle maneuvering.

4.0 Aerial Combat

A detailed discussion of aerial combat with helicopters is important and relevant to the application of high angle maneuvering. Air-to-air engagements between helicopters are a total environment and total system problem. As such, it is extremely difficult to separate any one element or portion of the aerial combat task. Reference 6 presented a good discussion of the significance of agility and maneuverability in air-to-air combat. A discussion of the application will help to understand the aerobatic flight hypothesis.

The attack helicopter's flight environment is definitely low altitude or near earth. Current tactics are designed to take the fullest advantage possible of the terrain in accomplishing the mission and minimizing the aircraft's vulnerability. As such, the ideal aerial engagement, assuming that it is required or unavoidable, is carried out at maximum range without exposure to the adversary. While this is a logical and ideal objective, chance encounters will ultimately occur. A chance encounter will be defined as an engagement where an unanticipated detection of adversary(ies) occurs at a relatively close range (<1000 meters). Chance encounters will generally lead to a contact fight because of the relative short ranges unless the adversary is eliminated quickly or unaware of the encounter. Further, one of the major contributors to the typical degeneration of chance encounters down to a contact flight is the inability of helicopters to disengage. Modern weapon's capabilities are sufficient to preclude a turn-and-run maneuver in most cases. As such, the closer the detection range, the less options available to the crew especially if first detection is by the opponent. There are assumptions and variations with this premise. Previous experience in mock battle and training conditions has indicated that these assumptions are generally true. It is the chance encounter which leads to a contact fight that is the worst case from a tactical point of view as well as aircraft structures and systems.

Since chance encounters occur at relatively close ranges, there is generally very little time to react. A split second of indecision could provide the adversary with an advantage position. Furthermore, the close ranges virtually eliminate the ability of either combatant to avoid the fight; neither aircraft can disengage. Weapons envelopes and lethality are such that unless one is well in excess of 450 knots, one can't reach the adversary's outer kinematic boundary quickly enough. This general hypothesis could be somewhat mitigated by the possible use of terrain and/or weather to break line of sight. Again, ACM experience has shown that this type of defensive maneuvering especially in the face of an offensively maneuvering adversary is risky and may not be successful.

First, detection presents the pilot with several immediate decisions:

1) Target type?
2) Potential weapons complement of the adversary?
3) Number and position of the adversary's wingmen?
4) Position of one's own wingman? Does he have a better shot?
5) Is the target an immediate threat to the flight, the mission or other friendly units?
6) How does this encounter fit into the current rules of engagement?
7) What is the current aircraft state? Ordnance type and quantity, airspeed, altitude and fuel endurance available?
8) Available terrain and weather?

There is no intent to address all of the variables on the battlefield. Therefore, only unavoidable chance encounters will be discussed.

Experience from AACT-IV and previous programs has shown that the level of aggressiveness warranted is directly dependent on the range of the adversary. For example, if simultaneous detection occurs at 200 meters, the highest level of aggressive maneuvering may be required; if simultaneous detection occurs at 1,000 meters, initial maneuvering could be predicated on the initial reaction of the target or other specific factors.

A contact fight as defined earlier is that portion of an aerial fight where aircraft maneuvering is the primary activity of the pilot. Once the contact fight is joined, the pilot must use all the maneuvering potential of the aircraft to first prevent the adversary's shot, then maneuver from the advantage position for the shot. Experience during AACT-IV dramatically illustrated that if the pilot maneuvered to get the first shot then it was generally the last shot opportunity. However, once the advantage position was attained, multiple shots could be taken without exposure to the adversary's weapons. Today's battlefield does not guarantee a pilot maneuvering superiority; plus, the situation may eliminate the initial reaction advantage. It is absolutely essential that the pilot have the largest latitude available in maneuvering. From the contact fight point of view, the first choice is to have the superior aircraft. The second choice is to have the largest "bag of tricks". The bag of tricks provides the pilot the capability to be unpredictable. In an environment where split second decisions are crucial, unpredictability is the edge the pilot must have. If a pilot fails to take the vertical and his adversary does, the pilot has zero options.

The use of the vertical dimension in aerial combat is a bit controversial in today's air-to-air discussions. There are those that espouse that the battlefield will be controlled to the extent that chance encounters and contact fights will not occur. Further, this control will come from timely intelligence (choosing the engagement), mutual support (my wingman will get the shot), and air defense (the vertical will be denied by ADA). This paper is not intended to debate the veracity of these arguments. However, the fundamental premise of this paper is that chance encounters are going to happen no matter how detailed or purposeful the planning and execution, and, as a result, the contact fight can not be avoided. Once an aerial engagement has degenerated to a contact fight, the fight is very personal; a wingman or other outside influence can not effect the outcome of the fight due to the extremely close ranges and high turn rates. A good analogy is the classic gunfighter's dilemma of when to shoot with his buddy in a rolling, tumbling, hand-to-hand fight. The pilot must be prepared for the worst case - a contact fight. Furthermore, once a contact fight is joined, it is virtually a one-versus-one (1v1) fight until one or both combatants are eliminated.

5.0 Tactical High Angle Maneuvering

There are several specific engagement conditions where high angle maneuvering would be beneficial, if not the deciding factor. The most obvious is a chance encounter where the adversary appears behind the aircraft, has detected and is turning to engage. The specific maneuver depends on the range and speed of both combatants. The immediate objective is to counter the opponent's advantage position. In other words, turn and face the attacker. At low speed, the maneuver of choice would probably be a maximum rate turn (with roll and/or yaw). Even with moderate speed, 60 - 80 knots, the aircraft can be pulled up into a modified (not necessarily a classical pure maneuver) Half Cuban Eight as illustrated in Fig. 6. This type of maneuver accomplishes a number of immediate objectives. It gains the maximum conversion rate of available P_S in an effort to deny the opponent's shot, as well as get the nose turned around for a shot. A variation of this maneuver might be a modified hammerhead (Fig. 7) for close tail engagements where a Half Cuban Eight maneuver might cause an overshoot. This maneuver would again be a maximum P_S conversion accompanied by a high rate turn. The modified hammerhead with a yaw turn has also been used effectively in other engagement situations.

The immediate objective, as indicated above, is to deny the opponent's shot, and then position for one's own shot. Once the immediate fight is won, the next problem is situation awareness; where

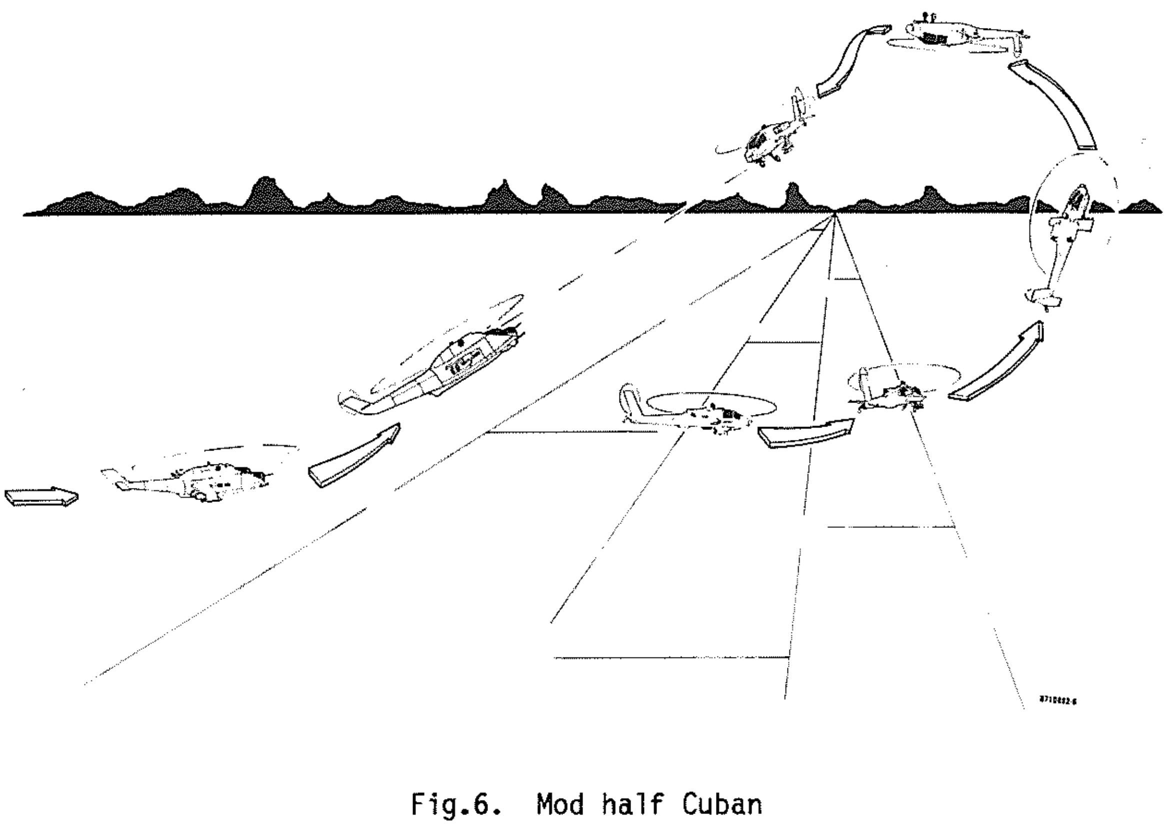


Fig.6. Mod half Cuban

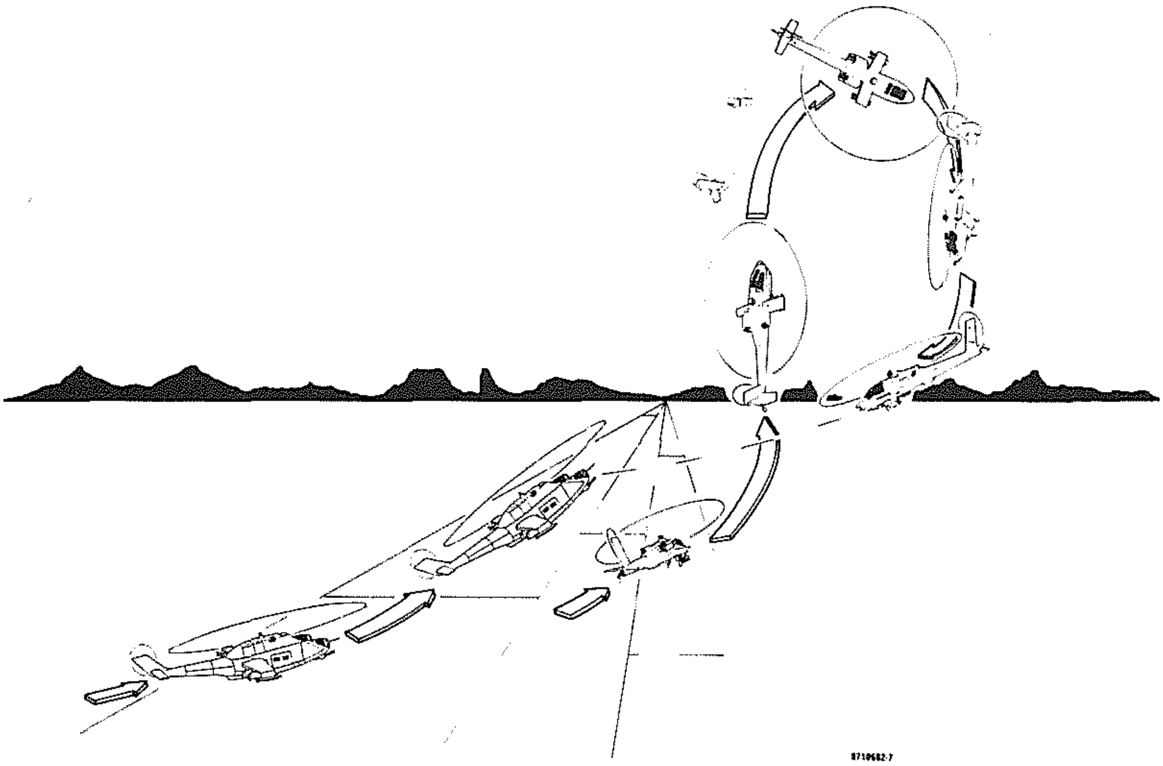


Fig. 7. Mod hammerhead

am I, where are the other threat aircraft, where is the best terrain? In this process, the pilot's immediate flying task is to deal with any other immediate airborne threats from an advantage position. The next action is to return to the protection of the terrain as quickly as possible. The classic maneuver in this situation is a Split S type of maneuver. Fig. 8 depicts two variations on this type of quick altitude loss maneuver. Fig. 8A illustrates a same direction maneuver, while Fig. 8B shows a direction reversal type of maneuver. The demonstrated maneuvering potential of the AH-64A provides the pilot exceptional latitude and control. In short, the pilot has numerous alternatives or variations of any of the above maneuvers depending on the specific situation. The AH-64A pilot has a large envelope with considerable margin to maneuver within. For example, the AH-64A has a very useful transient over-torque capability to values as high as 125 percent with no post-flight maintenance action required. There is also substantial evidence that the rearward/sideward flight limit is well in excess of the current specification (and operator's manual) limit of 45 knots.

Another potential maneuver is a pitch coupled, roll. A maneuver of this type would generally be appropriate for close, contact fights where unpredictability is important. It could be an initial counter from a disadvantage position, or a means to create an overshoot by an opponent as illustrated in Fig. 9. The intent of a 270° pitch-coupled roll would be to create an initial move in one direction and use the

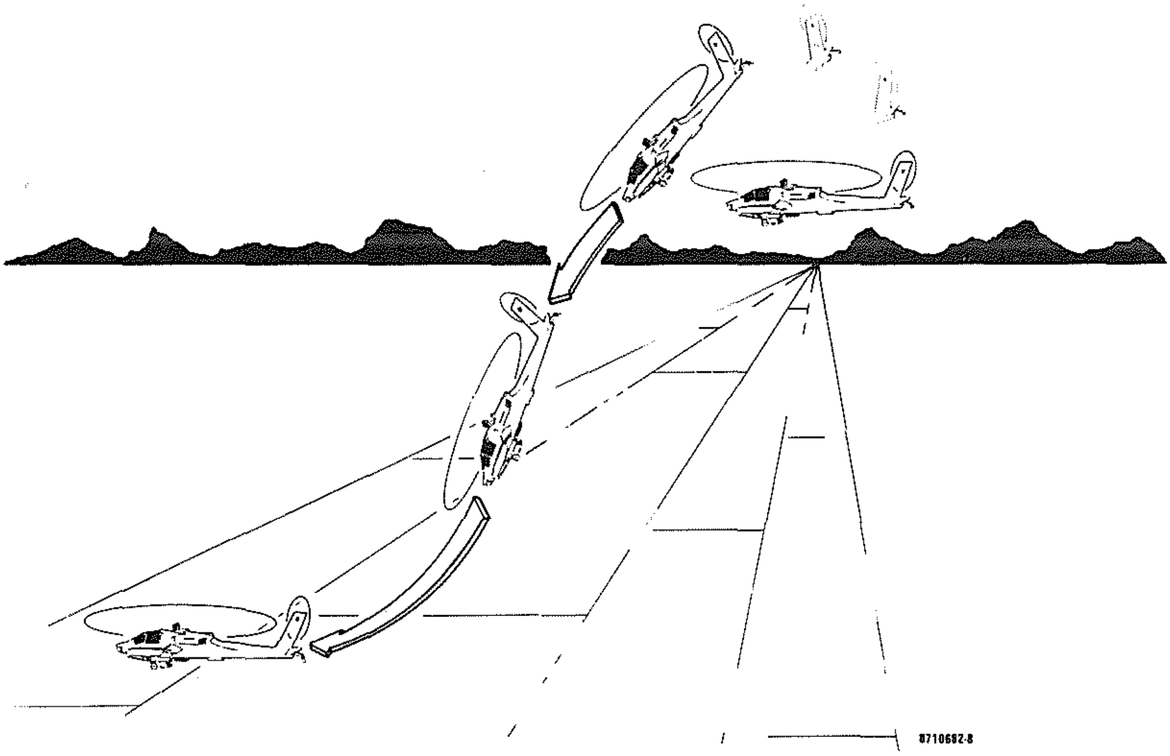


Fig. 8A. Same direction

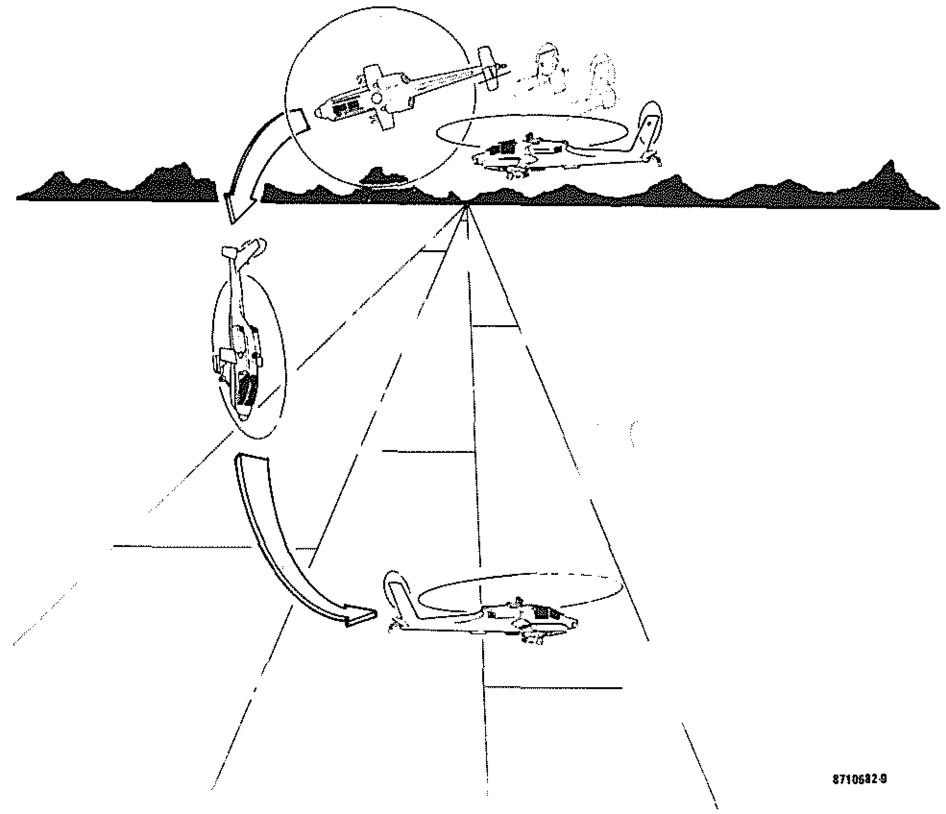


Fig. 8B. Reverse direction

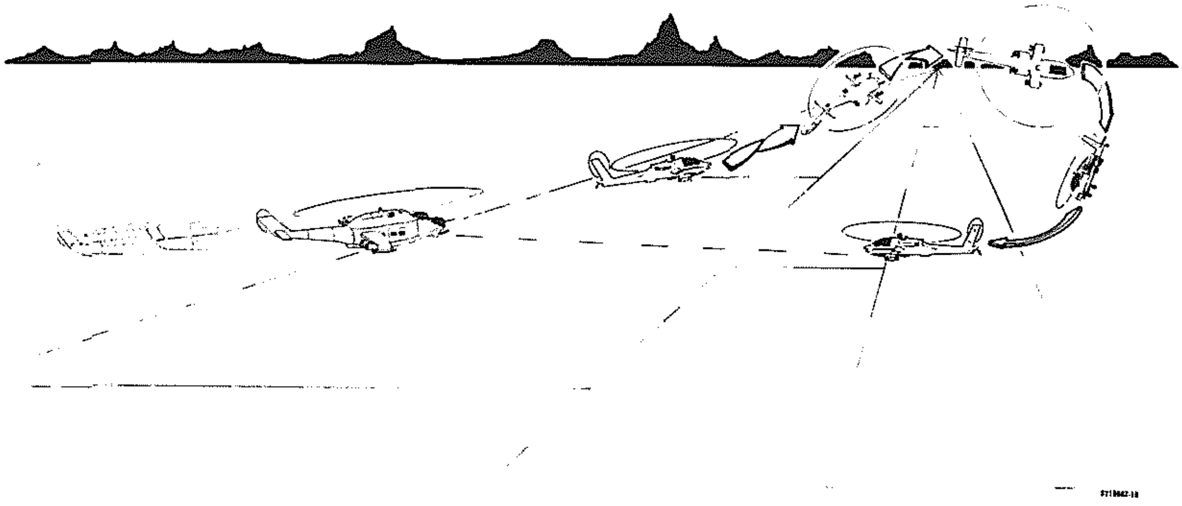


Fig. 9. Pitch coupled roll

rolling momentum to carry through, and a high rate turn to convert to advantage. The initial maneuver direction would force the adversary to counter with a similar roll and then draw him into an unplanned maneuver or a maneuver his aircraft is not capable of. The benefit of a maneuver of this type can only be realized when the time compression of a close, contact fight prohibits planned or anticipated counter-maneuvering. Another application of this type of maneuver is a situation where the pilot needs to create an out-of-phase condition in order to convert from an initial disadvantage position.

The bottom line to this discussion is that we just don't know how far modern helicopters can go in high angle maneuvering, nor, in practical terms, what advantage high angle maneuvering might provide. The maneuvers presented above have not been performed operationally; the hypothesis is based purely on conjecture related to real-world situations and experience in a wide variety of aerial engagements against both rotary wing and fixed wing opponents. The truth is, we will never know what can be done until we investigate this unknown flight regime and any potential advantage there may be operationally.

6.0 Training

The question of training operational aviators presents a rather thorny problem to the command organization. There is a definite fear that once the aerobatic flight Genie is released from the bottle, the accident rate will increase dramatically. No evidence can be presented based on current data which might reduce or eliminate that fear. An argument often heard is, the training risk far exceeds any possible operational value. The difficulty in answering these concerns is the fact that there is a large amount of resistance to even acquiring the requisite data. It is important to note that the build-up process used in this evaluation represents not only a considerable maneuvering margin, but also a significant flexibility which can help pilots improve unusual attitude recovery techniques, and master abort techniques for aerobatic maneuvering. The aerobatic training dilemma is quite similar to stall/spin training for fixed wing pilots. If a fighter pilot is going to learn how hard he can maneuver the aircraft, he must be able to recover if he goes too far (which is in fact part of the learning process). It is the opinion of the author that, if an operational requirement for aerobatic flight can be demonstrated, a safe, acceptable training program can be developed and administered which will provide and retain proper aviator proficiency.

7.0 Conclusions

Modern helicopters have demonstrated significant aerobatic flight capability. Current evidence indicates that there is more untapped maneuvering potential in modern helicopters which can be exploited. Aerobatic or high angle maneuvering flight is essentially a new region for helicopter pilots and designers. The full extent of a helicopter's maneuvering potential is not well defined nor understood; and, it can not be better defined or understood until more detailed flight evaluations can be conducted. Based on the information presented in this paper, it would appear that there is sufficient justification to continue the controlled investigation into the helicopter's aerobatic flight capability.

8.0 Recommendation

A program, or series of phased programs, should be conducted under strict control for maximum safety to investigate the utility of aerobatic flight. The objectives of such a program should be to expand the limited database of aerobatic structural/performance data, develop specific maneuvers which may be of potential value, and conduct a limited flight evaluation to determine the applicability of the proposed maneuvers to specific tactical conditions. The program could be structured as follows:

Phase I. Maneuvering flight envelope expansion (Contractor)

a. Simulation - analytic and flight

b. Flight - limited envelope expansion to include a range of rates, airspeeds, recovery techniques, and variations. This phase should include those areas of known capability such as, rearward/sideward flight, as well as aerobatic flight.

Phase II. Preliminary aerobatic maneuvering application evaluation (Joint Contractor/DOD)

a. Simulation - development of potential tactical maneuvers

b. Flight - initial unopposed manevuer development to be followed by 1v1 application evaluation

Phase III. Aerobatic flight and tactical maneuvering exploitation (Joint DOD/Contractor)

a. Simulation - initial training

b. Flight - training, demonstration and evaluation of developed capability and potential tactical maneuvers

Phase IV. Service implementation (DOD)
Further operational evaluation

Initial government involvement would be limited to a small group of selected aviators and engineers. As indicated above, the data could be presented to the military technical and operational communities after each phase for evaluation and consideration for further development.

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