

# The Army Aviator's HANDBOOK

For  
**MANEUVERING FLIGHT**  
And  
**POWER MANAGEMENT**



**USAFAVNC**

24 Mar 05

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## **PREFACE**

Recent world events have precipitated a change in Tactics, Techniques and Procedures (TTPs) for the successful employment of Army Aviation. In addition to terrain flight, NOE tasks, and hovering engagements, aviators must be well versed in high energy techniques and maneuvering weapons employment.

This Handbook is a companion document to existing Army Aviation flight related Field Manuals (FMs). It represents a step in a path to the future of a more flexible and mission capable aviation Unit of Action (UA). It is provided to give aviators a concise, easy to understand source of critical considerations for performing maneuvering flight and engagement.

Contributors to this document include the Directorate of Evaluation and Standards (DES), the Gunnery Branch in the Directorate of Training and Doctrine (DOTD), the Aviation Technical Test Center (ATTC), and the Aviation Training Brigade (ATB).

Ultimately this product will mature into a Training Circular. In the near term, use the information herein to help ensure you are intimately familiar with the basics of maneuvering flight and keenly aware of the pitfalls that can prevent successful mission accomplishment.

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*//Original Signed//*  
EDWARD J. SINCLAIR  
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Commanding

## **SECTION I. Introduction**

The employment techniques for Army Aviation have seen vast changes since the Vietnam War. The development of integrated air defenses and MANPADS predicated shifts in Tactics, Techniques, and Procedures (TTP) resulting in executing engagements from NOE altitudes as opposed to diving fire. Target arrays changed considerably. Attack aviation transitioned from a close combat role to one of anti-armor in a European environment over open, rolling terrain.

As a result, TTP's changed to adapt to the new tactical environment. Aviators developed the skill of firing rockets from a hover, which presented new dynamics and coordination challenges. The rotary wing aviation industry reacted and provided aircraft with basic fire control computers that provided a Fire Control reticle for rocket engagements. Aviators began to maneuver the aircraft to a computer generated "release point" as opposed to an out the window (via grease mark) aim point.

As aviation matured in the 80's we began to execute more missions at night to enhance advantages that NOE tactics provided and counter increasing enemy anti-helicopter capabilities. Again, new aircraft were provided to the army aviator to meet the challenges of effective acquisition and targeting in the night environment. The AH-64A and OH-58D provided enhanced capabilities for around the clock operations. These tactics and capabilities were validated in 1991, not on the European plains, but in the deserts of Iraq.

Now in the War on Terror, running and diving fire TTP's has reappeared as a critical mission requirement. These TTP's require Army Aviators to be intimately familiar with the aerodynamics and maneuvers that are associated with high energy weapons platform employment. These skills are required to support engagement of a distributed enemy in complex terrain.

**The purpose of this Handbook is to provide a basic guideline for the performance of Combat Maneuvers and Power Management to support successful high energy employment.**

## **SECTION II. Basic Maneuvering Flight Aerodynamics**

**Just as rotor performance is affected by the platform being in or out of ground effect, there are several characteristics that aviators must be aware of to successfully perform combat maneuvers.**

### **Best Rate of Climb/Best Endurance Airspeed**

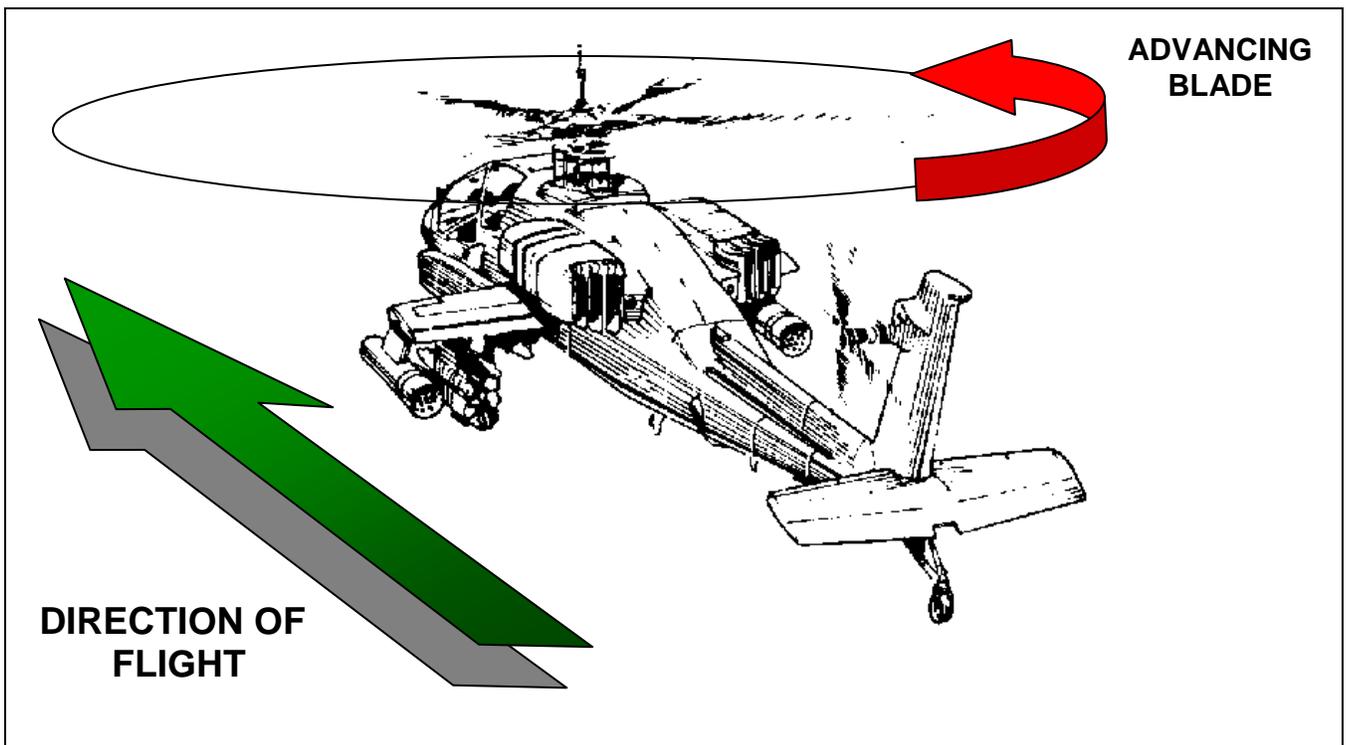
The best rate of climb airspeed is that airspeed at which maximum excess power is available. This provides the largest amount of excess power margin and the lowest fuel flow during powered flight. It is also where the maximum single engine gross weight can be carried (for dual engine aircraft). Aviators should always be aware of their best Rate of Climb airspeed as it is where the aircraft will turn the best, climb the best, maximize available power margin, and get the lowest fuel flow.

### **Bucket Speed Defined**

The bucket speed is typically defined as the speed where the greatest excess or unused power exists. This is easily found in the performance chart as the max rate of climb/max endurance airspeed. This is usually the speed where power required due to total drag is at its lowest. You will also notice that excess power tapers off for airspeeds slower and faster than the bucket speed. To establish the airspeed range that provides the best power margin for maneuvering flight, use the cruise chart for current conditions, enter at 50% of the maximum torque available, go up to the gross weight, over to the lowest and highest airspeed that intersects the aircraft gross weight, and note the speeds between which you will have the greatest power margin for maneuvering flight. Of course the most critical is the lower speed since at higher speeds we can trade airspeed energy to maintain altitude while maneuvering. If we go below our minimum bucket speed we must reduce our bank angle otherwise altitude loss may become unavoidable.

### **Transient Torque**

Transient torque is a phenomenon that occurs in single rotor helicopters when lateral cyclic is applied. For conventional American helicopters where the main rotor turns counterclockwise when viewed from above, a left cyclic input will cause a temporary rise in torque and a right cyclic input will cause a temporary drop in torque.



Transient torque is caused by aerodynamic forces acting on the rotor. At the rear half of the rotor disk, downwash is greater than that seen at the forward half of the rotor disk. This effect is more pronounced for heavier aircraft, which will exhibit greater coning due to their weight, which caused even greater downwash at the rear of the rotor disk. If a left cyclic input is made by the pilot, the following events occur which will lead to a temporary increase in torque:

1. Pilot makes a left cyclic input – the swashplate commands an increased blade angle of attack as each blade passes over the tail.

2. The increase in blade angle of attack causes the rotor disk to tilt left, which is felt as a left roll on the aircraft.
3. With increased lift on the rotor blades passing over the tail, comes increased drag (induced drag).
4. The increased rotor drag due to the left turn will initially try to slow the rotor, but is sensed by the ECU/DECU/FADEC. The engine will respond by delivering more torque to the rotor system in order to maintain rotor speed.

The opposite holds true for right cyclic turns, but is less pronounced. Unlike the left hand turn, in right turns blade pitch is being changed at the front of the rotor disk where induced downwash is lower, so the drag penalty is lower. Transient torque will not be as prevalent at slower airspeeds because the induced downwash distribution is nearly uniform across the rotor disk.

Five factors affect how much torque change occurs during transient torque.

1. Torque transients are proportional with the amount of power applied. The higher the torque setting when lateral cyclic inputs are made, the higher or lower the transient.
2. Rate of movement of the cyclic. The faster the rate of movement the higher the resultant torque spike.
3. Third, magnitude of cyclic displacement directly affects the torque transient. An example of worst-case scenario occurs when a pilot initiates a rapid right roll, then due to an unexpected event such as taking fire, he must break left. The transition from right cyclic applied to left cyclic applied results in a large amount of pitch change in the advancing blade, resulting in large torque transients.
4. Drag is increased or decreased proportionally with a change in velocity squared ( $V^2$ ). Thus, the higher the forward airspeed, the higher the torque transient that results.
5. High aircraft weight increases coning, which will make transient torque more pronounced.

Extreme caution must be used when maneuvering at near maximum torque available especially at high airspeeds. It is not uncommon to experience as much as 50% torque changes in uncompensated maneuvers with high power settings at high forward airspeeds. In these situations, the pilot must ensure that collective is reduced as left lateral cyclic is applied and increased for right cyclic inputs. Conversely, when recovering from these inputs, opposite collective inputs must be made so aircraft limitations are not exceeded.

As a good basic technique, imagine a piece of string tied between the cyclic and collective (e.g., right cyclic-collective increase/left cyclic-collective decrease). Also, inputs must be made to keep the aircraft from descending due to torque reductions, (e.g. when recovering from left cyclic inputs with collective reduced).

Note: 701C equipped AH64 helicopters employ Maximum Torque Rate Attenuator (MTRA) which attempts to prevent transient torque related over-torques but may produce a rotor droop and a loss of roll rate. Once the pilot has gained confidence in the ability of the MTRA to prevent over-torques resulting from transient torque overshoots, the pilot can aggressively maneuver the aircraft without closely monitoring engine torque. While it would be desirable to be able to aggressively maneuver the aircraft without a decrease in roll rate when the MTRA becomes active, the transient torque response of the 701C equipped AH-64 is satisfactory.

### **Mushing**

Mushing is a temporary stall condition that occurs in helicopters when rapid aft cyclic is applied at high forward airspeeds. Normally associated with dive recoveries, which result in a significant loss of altitude, this phenomenon can also occur in a steep turn that will result in an increased turn radius. Mushing results during high g maneuvers when at high forward airspeeds aft cyclic is abruptly applied. This results in a change in the airflow pattern on the rotor exacerbated by total lift area reduction as a result of rotor disc coning. Instead of an induced flow down through the rotor system, an up flow is introduced which results in a stall condition on portions of the entire rotor system. While this is a temporary condition (because in due time the up flow will dissipate and the stall will abate), the situation may become critical during low altitude recoveries or when maneuvering engagements require precise, tight turning radii. High aircraft gross weight and high density altitude are conditions that are conducive to, and can aggravate mushing.

Mushing can be recognized by the fact that the aircraft fails to respond immediately, but continues on the same flight path as before the application of aft cyclic. Slight feedback and mushiness may be felt in the controls. When mushing occurs, the tendency is to pull more aft cyclic which will prolong the stall and increase recovery times. The cyclic must be moved forward from the position that caused the mushing condition in order to recover once mushing occurs. This reduces the induced flow, improves the resultant angle of attack, and reduces rotor disc coning which increases the total lift area of the disc. The pilot will immediately feel a change in direction of the aircraft and increased forward momentum as the cyclic is moved forward.

To avoid mushing in future situations, the pilot must avoid abrupt inputs but instead smoothly and progressively apply aft cyclic during high g maneuvers such as dive recoveries and tight turns.

### **Conservation of Angular Momentum**

The law of Conservation of Angular Momentum states that the value of angular momentum of a rotating body will not change unless external torques are applied. In other words, a rotating body will continue to rotate with the same rotational velocity until some external force is applied to change the speed of rotation. Angular momentum can be expressed as:

$$\text{Mass} \times \text{Angular Velocity} \times \text{Radius squared}$$

Changes in angular velocity, known as angular acceleration or deceleration, will take place if the mass of a rotating body is moved closer to or further from the axis of rotation. The speed of the rotating mass will increase or decrease in proportion to the square of the radius.

Most of us have seen an excellent example for this principle when watching a figure skater on ice skates. The skater begins a rotation on one foot, with the other leg and both arms extended. The rotation of the skater's body is relatively slow. When the skater draws both arms and one leg inward, his/her body is suddenly rotating almost faster than the eye can follow. When the skater pulls his/her arms and leg in, the moment of inertia (Mass times Radius Squared) became much smaller. Because the angular momentum must, by law of nature, remain the same (no external force applied), the angular velocity must increase.

The mathematician, Coriolis, was concerned with the forces generated by such radial movements of mass on a rotating disc or plane. These forces, which cause acceleration and deceleration, bear his name. It may be stated that:

*A mass moving radially outward on a rotating disk will exert a force on its surroundings opposite to rotation!*

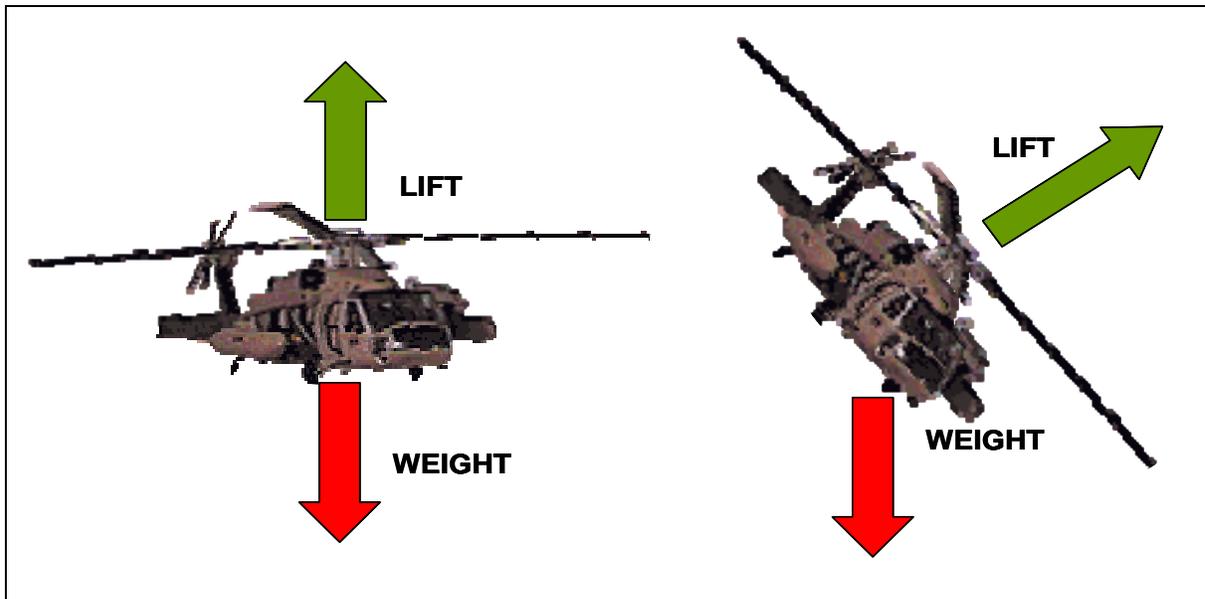
*A mass moving radially inward on a rotating disk will exert a force on its surroundings in the direction of rotation.*

How does this affect the rotational characteristics of a rotor system? First of all, what is there in a rotor system that has mass? Obviously the major rotating elements in the system are the rotor blades. As the rotor begins to cone due to g-loading maneuvers the diameter of the disc shrinks. Due to the Conservation of Angular Momentum the blades will continue to travel the same speed even though the blade tips have a shorter distance to travel due to the reduced disc diameter. This results in an increase in rotor RPM. Most pilots arrest this increase with an increase in collective pitch.

Conversely, as the g-loading subsides and the rotor disc flattens out from the loss of g-load induced coning, the blade tips now have a longer distance to travel at the same tip speed. This will result in the reduction of rotor RPM. However, if this droop in rotor continues to the point that it attempts to decrease below normal operating RPM, the engine control system will add more fuel/power to maintain the specified engine RPM. If the pilot does not reduce collective pitch as the disc unloads, the combination of the engines compensating for the RPM slow down and the additional pitch added as g-loading increased may result in exceeding the torque limitations or the power that the engines can produce. This problem is exacerbated by the effects of the total aerodynamic force encountered during maneuvering flight.

### **High Bank Angle Turns**

As the angle of bank increases, the amount of lift opposite to the vertical weight decreases. If adequate excess engine power is available, increasing collective pitch will enable continued flight while maintaining airspeed and altitude. If sufficient power is not available to compensate for the lift offset, airspeed must be traded to maintain altitude, or altitude must be traded for airspeed.



As mentioned before, at some point (i.e., airspeed / angle of bank) sufficient excess power will not be available and the aviator must apply aft cyclic to maintain altitude. The excess power required to continue flight at constant airspeed and altitude is shown below. The percentages shown are not a direct torque percentage, but the percentage of torque increase required based on aircraft torque to maintain straight and level flight. That is, if indicated cruise torque is 48% and a turn to 60 degrees is initiated, a torque increase of 48% (96% torque indicated) is required to maintain airspeed and altitude.

<b>Bank Angle (o)</b>	<b>Increase in <math>T_R</math> (%)</b>
<b>0</b>	<b>---</b>
<b>15</b>	<b>3.6</b>
<b>30</b>	<b>15.4</b>
<b>45</b>	<b>41.4</b>
<b>60</b>	<b>100.0</b>

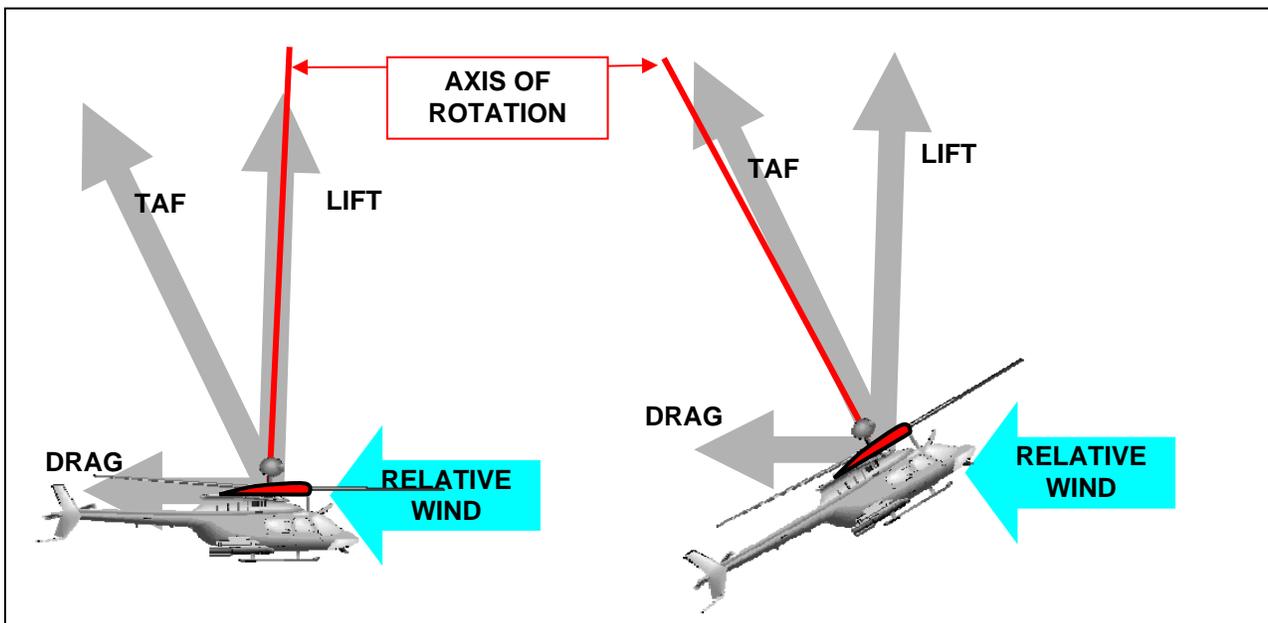
Additionally, rotor system capability may limit the maneuver as opposed to insufficient excess power (engine) on advanced aircraft like the AH-64 or UH-60 (the OH-58 D may be limited by the rotor as well). It must be remembered that in high energy maneuvering, the rotor is normally a limiting factor. It is not unusual in these types of aircraft for a reduction in collective to be required to achieve maximum performance when maneuvering at increased g, altitudes or high weights.

Aviators must be intimately familiar with this characteristic, anticipate cyclic input results, and apply the appropriate control inputs to successfully conduct combat maneuvers. Aviators unfamiliar with this characteristic may be surprised at the rapid build of sink rates when turning the aircraft to bank angles approaching 60 degrees. When flying heavy aircraft in a high hot environment, sufficient time and altitude may not be available to arrest the resultant descent.

### **Maneuvering Flight and Total Aerodynamic Force (TAF)**

The cyclic inputs and associated rotor disc pitch changes required to accomplish successful combat maneuvers have a substantial effect on TAF. Large aft cyclic inputs increase the inflow through the rotor system. Since lift is perpendicular to the relative wind, the TAF of each rotor blade may move to a point aligned with or forward of the axis of rotation (much like the driving and driven region of a blade is affected during autorotational flight). While the engine control system will reduce fuel flow to reduced load, the rotor system may still climb to transient ranges or attempt to overspeed.

Conversely, when the cyclic is rapidly repositioned to a more forward position the inflow through rotor is rapidly reduced. This results in the blade TAF moving aft of the axis of rotation and a resultant slowing of rotor RPM. The engine control systems will sense this and increase fuel flow to the engines to maintain rotor RPM causing torque to increase. As a general rule, when traveling at airspeeds above bucket speed, aft cyclic will result in a reduction in torque and an increase in rotor RPM. Recovery from an aft cyclic input, (i.e., pushover or high-g turn recovery) will result in a torque increase as the engines compensate for the rotor system slow down. In aggressive maneuver this may result in an overtorque or overspeed if appropriate collective input is not made to keep torque and rotor consistent.



This phenomenon is exacerbated by high gross weight and also affected by ambient temp and DA. Typically, cold dry air will result in more rapid rotor rpm increase during aft cyclic input and a corresponding higher torque increase with a forward cyclic input. Hot temps and higher DAs will result in more collective input required to arrest a climbing rotor.

### **Angular Momentum and TAF Combined Effects**

Angular Momentum and TAF combine during cyclic pitch changes. During aft cyclic or g-loading, the rotor will increase and the torque will go down. During g-load recovery the torque will increase as the engine control systems work to maintain a rotor RPM that is attempting to decrease. Aviators must be aware of these characteristics and apply appropriate and timely collective inputs to maintain consistent torque and keep rotor RPM within limits.

### **Dig In**

While making large aft cyclic movements, the pilot should be aware of the helicopter's tendency to rapidly and unpredictably build g-forces. As the cyclic is moved aft, the rotor disk responds by tilting aft, which tilts the thrust vector aft and ultimately causes the aircraft to pitch nose-up. This rapid pitch-up also increases the length of the aircraft thrust vector, which will in-turn increase the pitch-up rate. The rapid onset of the pitch-up motion due to the tilting and then lengthening of the thrust vector is considered destabilizing and is countered by the helicopter's horizontal tail or stabilizer, which will try to drive the nose back down. For large pitch-up rates, the tendency of the main rotor to continue pitching-up will overpower the horizontal tail/stabilizer and the aircraft will "dig-in" and slow down rapidly. Dig-in will usually be accompanied by airframe vibration and sometimes control feedback.

Aft cyclic movements will give predictable increases in g-load up to the dig-in point; however, the dig-in occurs at different g-levels for each model of helicopter. The point at which dig-in occurs depends on a number of factors, but most important is the size of the horizontal tail/stabilizer and the amount of rotor offset. For most helicopters, this point is between 1.5 and 2.0 g. Pilots should be prepared for dig-in during aggressive aft cyclic inputs, especially during break turns.

### **SECTION III. Maneuvering Flight Rules of Thumb.**

1. Never move the cyclic faster than you can maintain trim, torque and rotor. If you enter a maneuver and the trim, rotor or torque reacts quicker than you anticipated, then you have exceeded your own limitations. If you continue on this path, you will most likely exceed an aircraft limitation. Slow down and perform the maneuver with less intensity until you can control all aspects of the machine.
2. Anticipate changes in aircraft performance due to loading or environmental condition. The normal collective increase to check rotor speed at Sea Level Standard (SLS) will not be sufficient at 4000 ft PA and 95 degrees Fahrenheit (4K95).
3. Anticipate the following characteristics during maneuvering flight and adjust or lead with collective as necessary to maintain trim and torque:
  - a. During aggressive left turns, torque increases.
  - b. During aggressive right turns, torque decreases.
  - c. During aggressive application of aft cyclic, torque decreases and rotor climbs.
  - d. During aggressive application of forward cyclic (especially when immediately following aft cyclic application), torque increases and rotor speed decreases.

4. Always leave yourself a way out. Regardless of the threat, the ground will always win a meeting engagement.
5. Know where the winds are.
6. Most engine malfunctions occur during power changes.
7. If you haven't performed Combat Maneuvers in a while, start slowly. Much like NVD flying, your cross check slows and it will take sometime to develop proficiency at tasks that have not been performed for extended periods of time.
8. Crew coordination is critical. Everyone needs to be fully aware of what is going on and each crewmember has a specific duty.
9. In steep turns the nose will drop. In most cases you must trade energy (airspeed) to maintain altitude as you may not have the required excess engine power (i.e., to maintain airspeed in a 2G/60degree turn you will have to increase rotor thrust/engine power by 100%). Failure to anticipate this at low altitude will endanger yourself, your crew and your passengers. The rate of pitch change will be proportional to gross weight and DA.
10. Many maneuvering flight over-torques occur as the aircraft unloads G's. This is due insufficient collective reduction following the increase to maintain consistent torque and rotor as g-loading increased (i.e., dive recovery, recovery from high-g turn to the right)

#### **SECTION IV. High, Heavy, Hot.**

**Rotor and engine performance decrease as ambient temperature and pressure altitude increase. The affects of ambient condition related performance degradation and high gross weight considerations must be intimately understood by aircrews. Additionally, rotor performance/capability must be carefully considered before attempting maneuvers that require the platform to hover out of ground effect. There are several characteristics that aviators must be aware of to successfully perform combat maneuvers.**

#### **Air Density**

Air density is inversely proportional to temperature. As air gets hotter, it expands occupying more volume with fewer molecules per foot. As air becomes "thinner", engine capability is reduced and rotor lift production is degraded. Conversely, cold air results in increasing available engine power and enhancing rotor performance.

#### **Density Altitude (DA)**

Density Altitude is the theoretical air density that exists under standard pressure conditions at a given altitude. At sea level, air is denser than at high altitudes. However, cold ambient air at higher altitudes may not degrade performance as much as hot air at sea level. Thorough performance planning must be performed to ensure mission accomplishment. For example, an aircraft at 1000 feet MSL and a temperature of 30°C is experiencing a DA of 3000 feet. Factors affecting density altitude are:

1. Altitude

2. Atmospheric Pressure
3. Temperature
4. Moisture

### **Altitude**

The greater the elevation, the lower the atmospheric pressure. Low atmospheric pressure results in less dense air and higher density altitude.

### **Pressure**

Atmospheric pressure changes from day to day. Changes may be substantial and when coupled with other factors, can result in significant changes in helicopter performance. Higher pressure equates to higher air density and lower density altitude. Lower pressure equates to lower air density and higher density altitudes. Higher density altitudes result in degraded helicopter performance.

### **Temperature**

Great changes in air density will be caused by temperature changes. The same amount of air that occupies at one cubic inch at low temperature may expand to occupy up to 4 cubic inches as temperature increases. Again, as temperature increases, air becomes less dense and density altitude increases.

### **Moisture**

Given constant temperature and pressure, changes in moisture content will act to change air density. Water vapor is lighter than dry air so as the moisture content increases, air loses density. Additionally, as air temperature increases, its ability to hold water increases. Relative humidity is the ratio of moisture present to total moisture holding potential at a constant temperature.

A relative humidity of 90% at 10° C reflects much lower moisture content than 90% relative humidity at 35° C. It should be remembered that actual density altitude can be much higher than indicated on charts if high moisture content is present.

### **Retreating Blade Stall**

While nearly all Army aviators have been through academics on retreating blade stall and frequently describe it during annual evaluations, most rarely experience it. During missions with a heavy aircraft in a high, hot environment the onset of retreating blade stall occurs sooner (a good hint is when you notice a reduced VNE during PPC computation). conducive conditions for retreating blade stall are as follows:

1. High gross weight.
2. High temperature.
3. High DA.
4. Low Rotor RPM.
5. High g Maneuver.
6. High speed flight.

The onset of retreating blade stall is noted by increased vibration (1/blade/rev) as each blade passes through the affected portion of the rotor disc. If the severity of the maneuver or speed is

increased, the aircraft may pitch up and roll left due to the stalled portion of the disc producing insufficient lift. This may be insignificant in aircraft with semi-rigid rotor systems (i.e., UH-1, OH-58 A/C).

The best path to recover from retreating blade stall is to change what you can change from the cockpit. This pretty well rules out 1 through 4 above. So, in order of priority, accomplish the following:

1. Reduce power (using caution not to over-reduce to the point of rotor overspeed).
2. Reduce airspeed.
3. Reduce g-loading (maneuver severity).
4. Check and correct pedal trim.

Applying forward cyclic prior to reducing power may worsen the condition. Also, while some manuals also recommend increasing rotor RPM, this is not easily accomplished in most Army helicopters and it is not a path that is intuitive to most during the onset of retreating blade stall.

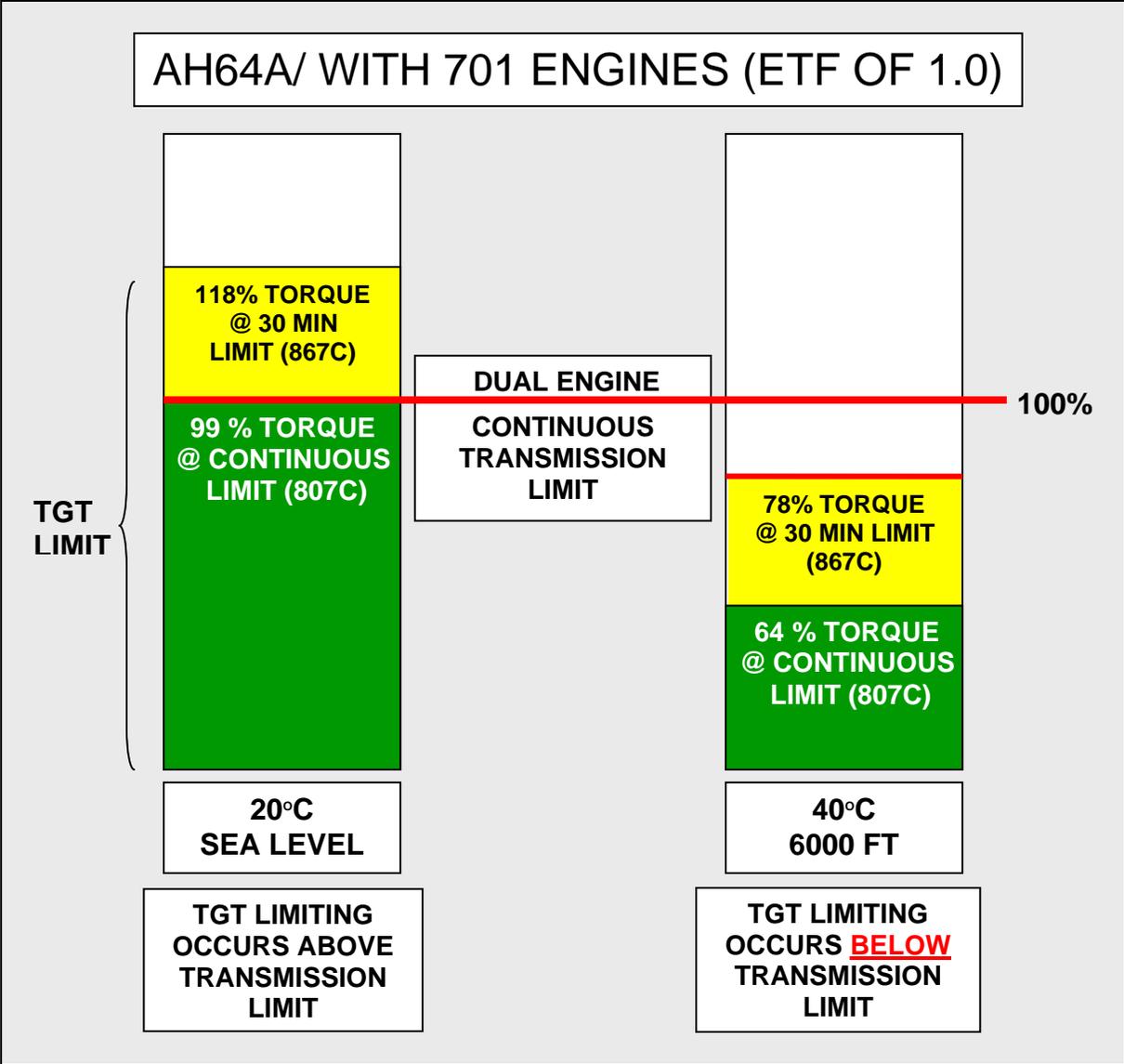
Finally, ensure a mental note is made of the condition which caused the onset. In subsequent maneuvers/missions self-limit maneuver severity and speed to prevent reoccurrence. The bottom line for this whole discussion is that the rotor thrust limit of the aircraft being flown is the critical factor. Once you are in a situation or environment where the rotor is the limiting factor, application of more torque is bad and will exacerbate the situation.

### **Limit of the Day**

A discussion of high/hot considerations would not be complete without the factors that limit available power. Some environments require rapid flight technique change due to elevated temps and altitudes. The use of torque as the primary measure of power available and aircraft capability is instilled in army aviators from the very onset of their training. Additionally, there is a trend to focus on torque as a result of the environment that aviators fly in most frequently. The predominance of flight training occurs at relatively moderate temperatures and low PAs.

From a design perspective, an engine is developed to provide the required horsepower in a high/hot environment (mil spec based on 95°F and 4000ft PA). Making more horsepower means generating more internal engine heat. Since a turbine engine uses approximately 70% of its air for cooling, much more horsepower is available at lower altitudes/temperatures due to the enhanced cooling capability of colder, thicker air. As a result, the engine horsepower available at low altitudes/temperatures is typically limited by drivetrain components (i.e., transmission, nose gearbox). However at some point, as temperature and altitude increase, the engine's maximum Turbine Gas Temperature (TGT) is reached at a power output level that is lower than the power that the drivetrain can handle. At this point, TGT becomes the limiting factor, not torque. Army aviators face this limitation as they perform missions in a high hot environment.

In the figure below, note that at sea level and 20°C, the engines are capable of producing much more power than the continuous power limit of the transmission. In this instance, torque is the limiting factor. Conversely, at 6000 FT PA and 40°C, the engines reach their TGT limit well before reaching the limit of the transmission. If the aviator attempts to increase power above this level, the engine control system will limit the fuel and as a result, **rotor speed will droop**.



Additionally, in the previous chart, the stated 30-minute TGT limit is 867°C. In an AH64A equipped with 701 engines, the onset of TGT limiting occurs at 859 +/- 9°C. **This means the onset of TGT limiting may occur before the 867°C limit!** This type of variance is present in many Army aircraft. Aviators must be aware of these functions and associated logic for their particular aircraft.

It is also very important to remember, that this chart was computed for an aircraft that has perfect engines. As engines wear, their efficiency decreases. This means that the TGT limit will be reached sooner for a given ambient condition. Pilot's must be aware of the conditions of their engines and correctly compute this capability loss with the charts provided in their respective Operator's Manuals.

Many times in the high/hot environment, torque is a consideration, but the primary limiting factor, is the TGT at which the rotor speed droops. As temperature/PA climbs, it becomes

difficult or impossible to over-torque the aircraft as TGT limiting will occur first and rotor speed will decrease as a function of TGT limiting. Be aware of the torque at which critical TGT's are reached. It is a good habit to correlate TGT and torque indications during the conduct of the flight. Crosscheck TGT as applied torque comes within 5 to 10% of the computed limits (continuous and timed) for the day.

Finally, be aware of the environment and the aircraft limit that is more crucial for a given mission profile. Have an intimate knowledge of the relationship between torque and TGT and correlate this knowledge to ensure safe and effective operation of in demanding mission environments.

NOTE: The FADEC in the OH58R Kiowa Warrior will temporarily disable the normal TGT limiting function upon a rapid collective application. A rapid power application is interpreted as a critical need for power in order to save the aircraft in a combat or emergency situation.

### **Heavy Helicopters**

When high gross weights are added to the equation, crews must be extremely thorough in mission/performance planning and cover contingencies during crew briefs. Reduced power margins that result from heavy aircraft and high DAs give crews considerably less flexibility to handle contingencies. Aerodynamic factors such as transient torque, mushing, and rotor speed increase occur more rapidly. The onset of retreating blade stall occurs sooner and VNE's are reduced. Additionally, sink rates build faster and are much harder to arrest. Crews must be aware of the dangerous combination of heavy aircraft and high DAs. Flying heavy aircraft requires the crew to be well ahead of the sequence of events and fly the aircraft differently. Sink rates must not be allowed to develop or build during aggressive turns and approaches to OGE hover. Just as a vehicle driver is more careful, looks further down the road, and brakes sooner when towing a heavy trailer/load, so must aviators when flying heavy aircraft.

### **SECTION V. High, Heavy, Hot Rules of Thumb.**

1. If at all possible, always land or take off INTO THE WIND. It sounds incredibly basic, but we don't always do it.
2. If at all possible, maintain ETL until within ground effect.
3. When OGE power is close to max power available there is very limited ability to arrest descent when hovering or flying at speeds well below ETL. As an example, in an AH64A Apache, if your OGE hover power is 92% and your Max Torque available is 98% you have roughly enough power margin to establish a 300ft/minute vertical climb while at a hover. That means if you allow a sink rate of more than 300ft/minute to develop, you will not be able to recover without building airspeed to above ETL and trading energy. This will take a lot of altitude to accomplish.
4. If you must approach to an OGE hover, be keenly aware not to allow a sink rate to develop (see rule 3). Execute the deceleration slowly. A large flare is conducive to a sink rate that you may not be able to arrest.

5. When margins are close, avoid left turns until above ETL. Substantial left pedal inputs may very well over-torque or droop the rotor when operating near the limits.
6. When operating near the margins do not forget the option to jettison the stores/load. This should be an integral part of the brief.
7. High DAs, hot ambient temperatures, or a heavy helicopter, will require more altitude to recover from dive pull outs/breaking turns and less engine/rotor capability to recover with.
8. Know your aircraft's limits and power margin before you leave the ground. Performance planning is not conducted to check a block. When computed correctly, it provides the aviator with critical information to enable mission accomplishment and sound cockpit decision making.
9. When conducting a multiple aircraft operations, do not conduct takeoff in trail. The downwash created by the aircraft to your front may exceed your power margin during takeoff. When possible, takeoff individually and conduct an in flight link up.
10. While nearly all Army aviators have been through academics on retreating blade stall and frequently describe it during annual evaluations, most rarely experience it. During missions with a heavy aircraft in a high, hot environment the onset of retreating blade stall occurs sooner (a good hint is when you notice a reduced VNE during PPC computation). Review and know the causes, the onset characteristics for your aircraft, and recovery methods before any deployment to a high, hot environment. Good information can be found in FM 1-203 (dated October 1988) on pages 6-39 through 6-43

## **SECTION VI. Combat Maneuver Do's and Don'ts.**

Employ Combat Maneuver as a function of mission requirement, not recreation. Every aviator that employs these techniques at the wrong place and time endangers our ability to continue this critical training.

Only train maneuvers that have a combat application. These platforms are made to engage/destroy the enemy and are not purchased to enable you to impress friends, relatives, or passengers. Again, one incident will endanger your fellow aviators by denying them training.

Taking unnecessary risks when carrying a load of combat equipped infantry soldiers can be equated to a Commercial Airline pilot showing off when carrying athletes to the Olympics. There is no excuse. **Do what the mission requires.**

## **ANNEX A: Definitions, Terminology, and Performance.**

**1. Definitions.** The aviator should be familiar with certain definitions to facilitate the use of common terminology.

a. **Maneuver:** Any planned motion of the aircraft in the air or on the ground.

b. **Maneuverability:**

(1) A measure of the ability of the helicopter to change the flight path, speed or altitude, i.e., the ability to perform maneuvers. Maneuverability also implies the degree and magnitude to which a specific maneuver can be performed.

**EXAMPLE:** 500 FPM climb versus (vs) 2,000 FPM climb or 60° angle of bank versus a 45° angle of bank.

(2) Maneuverability is a function of engine power, stored energy, and ultimately the rotor systems maximum thrust capability.

c. **Agility:**

(1) The ability of the helicopter to move quickly and easily between maneuvers; i.e., a measure of the time required to change maneuvers.

**EXAMPLE:** The time requires to move from a steep left turn to a steep right turn. An F-15 is very fast (very agile), a Boeing 747 is very slow (not agile).

(2) Agility is a function of the flight control power which is designed into the machine. Helicopters by nature are relatively agile.

d. **Comparison of maneuverability and agility.**

(1) Agility remains constant for most conditions. Maneuverability varies with power available and stored energy up to the maximum thrust capability of the rotor system.

(2) **Maneuvering sustainability.**

(a.) **Continuous:** This is the maneuvering capability due to engine power available exceeding the power required for the immediate flight condition.

**EXAMPLE:** The ability to obtain a climb rate at some constant airspeed, gross weight and altitude. If all available engine power is required to maintain level flight, a climb cannot be established at that gross weight, altitude, and airspeed.

(b.) **Transient:** The maneuvering capability as a result of speed and altitude.

**EXAMPLE:** The ability to establish a climb rate by trading airspeed for altitude (i.e., a cyclic climb).

## **ANNEX A: Definitions, Terminology, and Performance.**

### **2. Maneuverability factors:**

a. Some of the factors which influence the maneuverability of the helicopter include thrust, energy, load factor, acceleration capabilities, climb performance, descent performance, and turning performance.

b. As defined earlier, maneuverability refers to the ability of the helicopter to change speed, altitude, or direction of flight.

(1) To maneuver the helicopter the pilot changes rotor thrust from that required to maintain unaccelerated flight.

(2) The degree to which the pilot can change the direction and amount of rotor thrust determines the maneuverability of the helicopter.

(3) Very maneuverable helicopters have the potential to significantly change rotor thrust.

### **3. Thrust.** The total force generated by the rotor. It acts perpendicular to the tip path plane.

a. At a hover, thrust is equal to and opposite helicopter weight.

b. In forward flight the tip path plane is tilted in reference to the horizon. Thrust remains perpendicular to this tilted tip path plane, but a portion of it is used to support the weight of the helicopter while a portion of it is used to develop the forward airspeed. In unaccelerated directional flight the vertical component of thrust ( $T_v$ ) is equal to the weight and the horizontal component of thrust ( $T_h$ ) is equal to parasite drag.

c. At normal cruise speeds the angle between the tip path plane and the horizon is generally between 3 and 8 degrees with 5 degrees being a good average. Consider a 10,000 lb helicopter flying a normal cruise speed and a constant altitude. The angle between the tip path plane and the horizon is 5 degrees. The vertical component of thrust is 10,000 pounds (lb), the horizontal component of thrust is 875 lb, and total thrust is 10,038 lb. Increasing the rotor angle of tilt to 10° require 10,154 lb of thrust to maintain altitude and yields 1,763 lb of horizontal thrust.

d. As the angle between the tip path plane and the horizon increases, rotor thrust must be increased. This increase in thrust requires an increase in engine power.

e. Changes in the direction and magnitude of the thrust vector cause the helicopter to accelerate. This acceleration may result in a change in airspeed, altitude, heading, or any combination of the three. In other words, a maneuver.

4. Energy. Energy is a measure of a body's capacity to do work. Work is the product of a force times a distance. Power is the rate at which work is accomplished. Changes in rotor thrust require changes in power supplied to the rotor. This power comes from three energy sources – kinetic, potential, and the engine.

## **ANNEX A: Definitions, Terminology, and Performance.**

a. Kinetic energy is the result of airspeed. It can be converted to rotor thrust by decelerating the helicopter. Kinetic energy increases with the square of the velocity. Since airspeed has to be traded for kinetic energy, the potential thrust available from airspeed is limited and can be consumed very rapidly during maneuvering flight.

b. Potential energy results from altitude. Rapid descents can provide a significant amount of energy to the rotor system. Potential energy, like kinetic energy, can be rapidly consumed during maneuvering.

c. Engine power is the most important source of energy for rotor thrust. It will provide a sustainable amount of energy and will determine the continuous maneuvering capabilities of the helicopter. It is the initial source of both kinetic and potential energy.

d. It is useful to think of kinetic and potential energy as sources of stored energy. Energy can be traded between kinetic and potential stores and both can be increased by converting engine power to airspeed or altitude. The sum of all three energy sources determines the total energy available to the rotor.

e. Engine power, kinetic energy (airspeed), and potential energy (altitude) can be traded between sources. For example, 240 feet (ft) of altitude or 80 knots (kts) airspeed has the same energy value as 5 seconds of maximum excess engine power. This energy could be converted to altitude or used to supplement engine power for increased maneuvering performance.

**5. Load factors.** Load factors refer to the acceleration forces affecting an aircraft in flight. If no acceleration is taking place, the load factor is equal to the force of gravity, 1 gravity (G).

a. When the rotor is producing more thrust than required for unaccelerated flight, the load factor will be greater than 1 G.

b. In hovering flight, load factor can be determined simply by dividing rotor thrust by weight. Therefore, 20,000 lb of thrust applied to a 10,000 lb helicopter will result in a load factor of 2 Gs.

**6. Acceleration / Deceleration.** Helicopters can accelerate faster than most other types of aircraft since the rotor produces a large amount of force that can be used for acceleration. Surprisingly, it takes very little additional thrust from the rotor to make large amounts of thrust available for acceleration. Deceleration capabilities cannot be computed as easily. The initial speed of the helicopter, gross weight, rotor dynamics, power available, and other factors will all affect how rapidly the helicopter can be decelerated before encountering an increase in rotor RPM due to autorotational forces or a decrease in rotor RPM because of insufficient engine power.

## **7. Climbs and Descents.**

a. Climb performance is primarily a result of the excess engine power that can be used to increase rotor thrust.

## **ANNEX A: Definitions, Terminology, and Performance.**

(1). At a hover and very low airspeeds, the induced drag of the rotor system will require high power settings to maintain rotor thrust. Very little power is required to overcome parasite drag.

(2). Initially, as airspeed increases, induced drag decreases more rapidly than parasite drag increases. This decreases the power requirements until at some airspeed, drag and power required, is at a minimum.

(3). At airspeeds above the airspeed for minimum power requirements, parasite drag increases very rapidly. This causes the power required to increase very rapidly.

NOTE: Profile drag increases slightly with airspeed until the blades begin to stall, then increases rapidly.

(4) Therefore, maximum sustained climb rates will occur at airspeeds where the power required to maintain flight is lowest. For most modern helicopters this speed is between 50 and 75 knots. This airspeed is generally referred to as “bucket speed”.

(a). Steady rate climb performance can be predicted by referring to the climb / descent chart available in the aircraft operators manual, -10. Notice that climb performance is predicted on changes in torque or engine power.

(b). Cyclic climb, which is a function of airspeed, is transitory since airspeed dissipates very rapidly in a nose high attitude. Still, very high inertial climb rates are possible at high forward airspeeds by applying aft cyclic and power simultaneously.

b. Descent performance at a constant airspeed is limited by the autorotative characteristics of the individual helicopter type.

### **8. Specific Excess Power, $P_s$**

a. Specific Excess Power refers to a technique developed by USAF Colonel John Boyd in the 1960's to stop air-to-air losses in the Vietnam War. This technique relies on a basic understanding of physics and energy management, and if used correctly can predict the capabilities of your aircraft during extreme maneuvering.

b. The energy contained in any object can be categorized as either kinetic or potential. Kinetic energy is that energy due to motion. For the helicopter, we can say that there is kinetic energy associated with the aircraft's flight velocity and rotor RPM. Potential energy is primarily due to the aircraft's height above the ground. Energy can be traded between kinetic and potential freely. For example, if you were at a stable 500 foot hover and wished to assume forward flight you could trade your altitude (potential energy) for airspeed (kinetic energy) by simply nosing over into a shallow dive. If you did not adjust the collective, we could say that this maneuver was done with approximately constant aircraft energy.

c. Let's say that now you could not spare the altitude to accelerate, and instead wanted to accelerate to 100 knots. In this case, you would need to hold your potential energy (altitude)

## ANNEX A: Definitions, Terminology, and Performance.

constant and increase your kinetic energy (airspeed), which means that total aircraft energy would have to be increased by applying more power.

d. Knowing how much power remains for your use can explain how your aircraft will respond in maneuvering flight. Time for some math – let’s look at the basic energy theory discussed above:

$$\text{Total Energy} = \text{Potential Energy (altitude)} + \text{Kinetic Energy (speed)}$$

e. In order to change the amount of energy that we have at any one moment, we need to add power. If we add power to our aircraft, this will be felt as a change in altitude (climb) or an increase in speed (acceleration), or some combination of the two. Let’s re-write the above equation now in terms of changing our energy state:

$$\text{Change in Energy (power)} = \text{Change in Potential Energy (climb)} + \text{Change in Kinetic Energy (Acceleration)}$$

f. So, in the OGE hover case we looked at above, if your hover torque was 80% and you had 100% torque available for that day, you have 20% torque left with which to either climb, accelerate, or both.

The amount of energy that you can add to your aircraft is referred to as Specific Excess Power,  $P_s$ . It can be determined by looking at the cruise charts in chapter 7, and using the following equation:

$$P_s = \frac{(\text{Engine Power Applied} - \text{Engine Power Required})}{\text{Aircraft Gross Weight}} \times 33,000$$

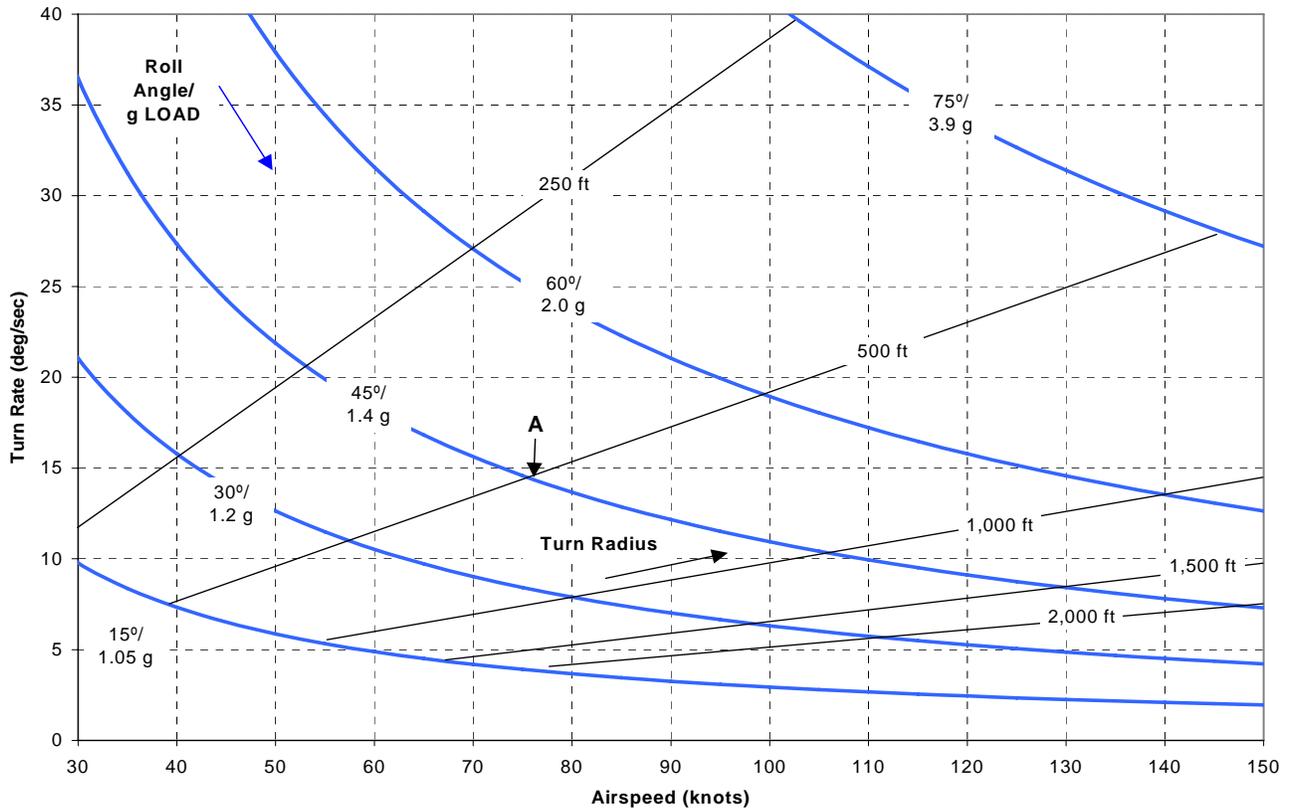
The answer that you would get would be in units of feet per minute (fpm), in other words what your climb rate would be. It is important to remember that if you have applied a g load to the aircraft to the aircraft in maneuvering flight, the aircraft gross weight value changes and hence the  $P_s$  value. For instance if you are flying a 16,000 pound aircraft with 200 horsepower applied above your entry power, your  $P_s$  value is 412.5 fpm. If you execute a level, constant airspeed 1.5 g turn your new effective gross weight would be 24,000 pounds, which drops your  $P_s$  value to 250 fpm.

g. Specific Excess Power is best displayed as a chart, with positive values of  $P_s$  indicating excess power available as a function of airspeed. If  $P_s$  is 0, your aircraft has no excess power remaining and increases in altitude or airspeed are only possible by trading one for the other. For negative values of  $P_s$ , your aircraft will lose airspeed and/or altitude unless the pilot can reduce aircraft gross weight either through reducing the g load or jettisoning stores.

h. On the topic of g-loading, it is helpful to look at this factor and its effect of aircraft turn rate and turn radius. The turn rate tells you how fast an aircraft can change heading, and we would like this number to be as high as possible so that weapons can be brought to bear quickly. The turn radius describes how tight a turn can be made. We may want turn radius to be very small if we are maneuvering in a confined area, or possibly large if we are looking to displace across the ground and break contact with an enemy. The g-load ( $N_z$ ) that we place on the aircraft directly

## ANNEX A: Definitions, Terminology, and Performance.

influences these two factors. The following chart shows the relationship between airspeed, turn rate, turn radius, and g-load for any aircraft:

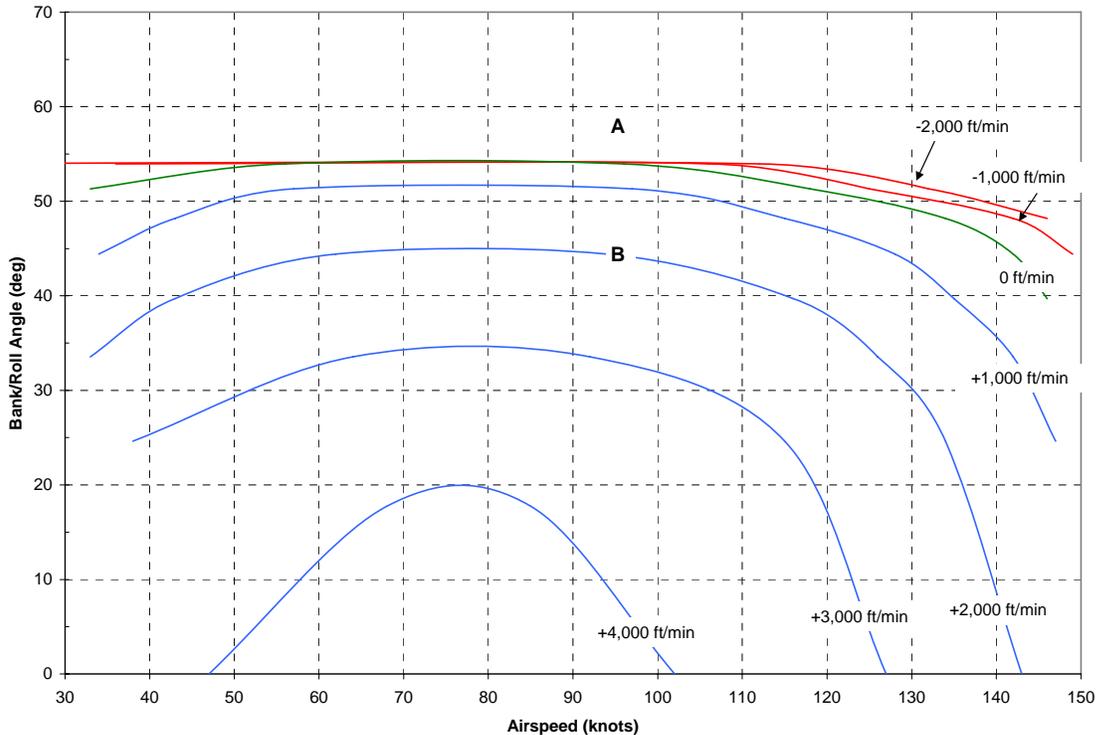


For instance, if we were to enter a level turn at 75 knots and roll to an angle of 45° (point A), we would have a turn radius of 500 feet and a turn rate of just under 15 degrees per second. We can see that for a fixed airspeed, as the g-load is increased in a turn the turn radius decreases and turn rate increases. Because g-load in a steady-level turn is directly tied to roll angle, we can also say that for a fixed airspeed, as bank angle is increased the turn radius decreases and turn rate increases.

We can see here that the airspeed and g-load/roll angle combination will tell us a lot about our capabilities at any given point. The key issue now is, can I achieve that airspeed and g-load/roll

## ANNEX A: Definitions, Terminology, and Performance.

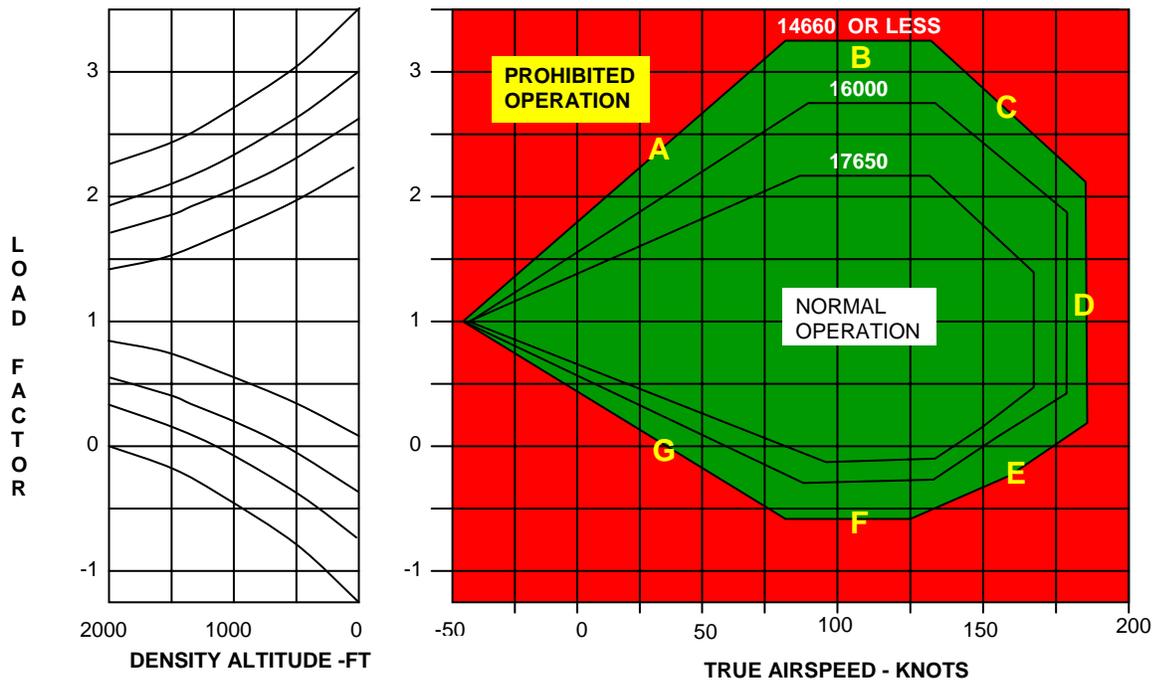
angle combination with the power that I have available? For this, we need to look at the specific excess power chart for our weight and conditions. A sample  $P_s$  chart is shown below.



Notice the green  $P_s = 0$  line. It tells you that if I apply maximum power to maneuver (say 100% dual-engine torque) I can complete turns without losing energy for all combinations of airspeed and g-load (bank angle) on that line or below it (where  $P_s$  is greater than 0). For points above the line, the aircraft will lose energy in the maneuver, which means it will lose speed (kinetic energy) and/or altitude (potential energy). If you were to attempt a turn at 95 knots with a roll angle in excess of approximately 55 degrees (point A), you would decelerate and/or descend. However, if you were to reduce your roll angle by 10 degrees (point B), the turn may be completed with energy to spare.

This brings us to an important question – is there a single “best” speed for maneuvering flight in a helicopter? Most experts say “No.” From the two charts above we notice that slow speeds generally give us the most excess power and the highest turn rates; however, if you need to mask quickly and evade enemy fire a slow airspeed is obviously not the answer. High speeds, while giving you the most kinetic energy with which to enter a maneuver will also limit the amount of excess power available and will probably lead to energy loss in high bank, high-g turns. Mid range speeds seem to give a good mix of both extremes – a good turn rate and turn radius, with good rates of climb available, and enough airspeed to get you out of harm’s way quickly.

## ANNEX B. The Flight Envelope Chart Explained



### Preface

This annex is provided as a general explanation of a typical Flight Envelope Chart and a summarization of typical results as the aviator pushes the platform to the designated limits of maneuver (A-G above). It is not designed to give specific rationale or technical data for a specific, individual airframe or configuration.

### Velocity vs. Load factor chart (or V-n diagram)

Velocity vs. Load factor chart (or V-n diagram) defines the safe maneuvering envelope of the aircraft. The shape of the curve is based on various considerations, which will be pointed out below. The primary purpose of the chart is to protect the aircraft components from excessive, repetitive loads, which can lead to fatigue damage. Consider a specific component (e.g. a pitch link), which undergoes cycles of compression and tension with each rotor revolution. As long as the loads are reasonable (below its endurance limit), it will never fail due to fatigue. However, if it is exposed to loads outside of what the designers intended, it will accrue some amount of damage; the larger the excursion from the design load, the more the damage. Imagine a paper clip which is just barely flexed; it will never fail under these small loads. However, if you apply enough force to significantly bend it one way and then alternate the load and bend it the other way, it will accrue damage. If enough of these excursions are applied, it will eventually fail.

## **ANNEX B. The Flight Envelope Chart Explained (cont.)**

### **Origin (lowest airspeed/highest rearward airspeed ).**

The origin is generally just based on the operational requirement (why do you need to fly backwards at high speed where your visibility is poor and your weapons/sensors are facing forward?), but may also be due to poor flying qualities or control limits.

### **Areas A and G.**

Low forward airspeed and insufficient excess power in these regions prevent the aircraft from reaching higher loads. The slope starts moving back around the bucket speed until it intercepts the 1 G line at the maximum rearward airspeed (back side of power curve). Several things influence this:

1. The manufacturer doesn't want anyone flying at the max rearward airspeed to be maneuvering (they've limited it at that point for valid reasons).
2. Flight control inputs through the Automatic Flight Control System (AFCS, if equipped) to the tail rotor may be excessive in rearward flight.
3. Impressed pitch or flapping angles whether the a/c is augmented or not.

### **Area B.**

The primary factors are structural and aerodynamic (static strength and blade stall). Blade stall onset begins to transition in this region and severity increases to become the primary factor for area C. This is typically where the rotor system can just not produce more lift regardless of the additional engine power applied. Note that as DA increases, the total G capability/limit decreases.

### **Area C.**

The limit in this area is blade stall, as stated above.

### **Area D.**

This area is very dependent on rotor design and the operating weight. Primary limiters are blade stall and compressibility effects. What limits one aircraft may not limit another with an airfoil designed for high speeds. Also, the amount that the maximum airspeed will decrease as weight increases is directly related to how well the airfoil handles retreating blade stall. Airfoil design also drives the aggravation of compressibility effects (i.e., increasing operating weight) as angle of attack is increased.

## **ANNEX B. The Flight Envelope Chart Explained (cont.)**

### **Area E.**

Flapping angles are the primary culprit. In tandem seat aircraft, incursion into this area may result in the rotor blades coming dangerously close to the canopy or physically striking components on the nose of the aircraft.

### **Area F.**

This is very rotor dependent. A teetering rotor loses cyclic control at zero G (i.e., mast bump), but designers of articulated, hingeless, rigid types tweak this area by the amount of flapping offset. In advanced rotors, negative G capability is achieved this way, but offset comes with penalties in other areas as well (phase lag angle, for example creates rigging problems throughout the envelope). The tradeoff usually places the negative G capability between -0.2 and -1.0 G for modern combat helicopters. The other major concern in this area applies to a/c systems that are not designed for negative G's. Fuel, oil, and hydraulic pumps may cavitate due to the shift of fluids in the reservoir/tanks. The engineering and modifications to enable all of these systems to withstand significant negative G's are in most cases, cost prohibitive given the limited time where envelope capability extension would provide significant benefit.

## ANNEX C. References

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