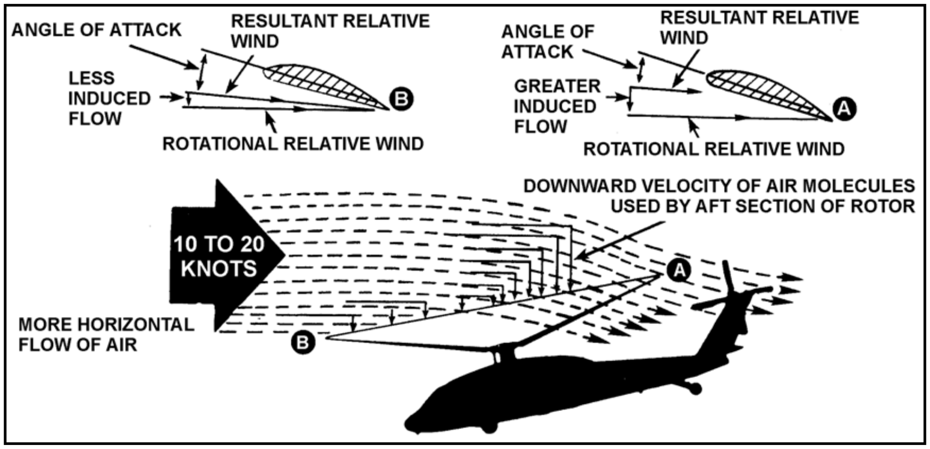

Figure 1-60. Transverse flow effect

EFFECTIVE TRANSLATIONAL LIFT

1-121. Effective translational lift (ETL) (figure 1-61) occurs with the helicopter at about 16 to 24 knots, when the rotor—depending on size, blade area, and RPM of the rotor system—completely outruns the recirculation of old vortexes and begins to work in relatively undisturbed air. The rotor no longer pumps the air in a circular pattern but continually flies into undisturbed air. The flow of air through the rotor system is more horizontal, therefore induced flow and induced drag are reduced. The AOA is subsequently increased, which makes the rotor system operate more efficiently. This increased efficiency continues with increased airspeed until the best climb airspeed is reached, when total drag is at its' lowest point. Greater airspeeds result in lower efficiency due to increased parasite drag.

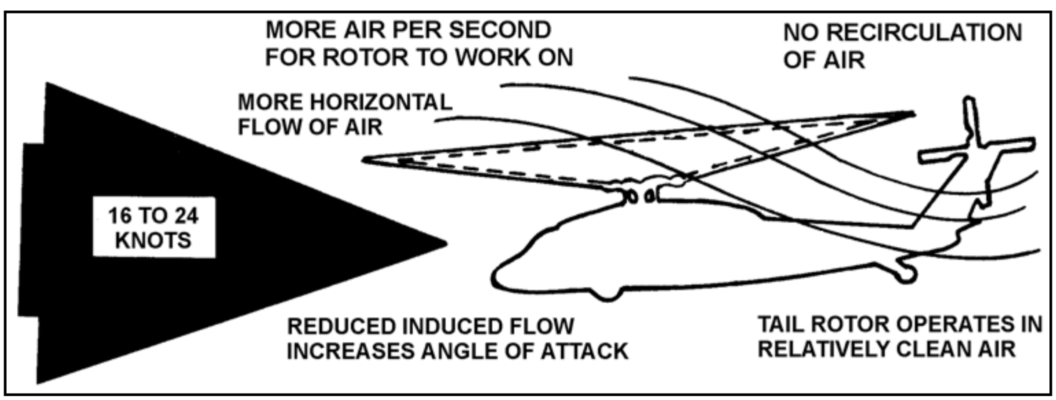

Figure 1-61. Effective translational lift

1-122. As single-rotor aircraft speed increases, translational lift becomes more effective, nose rises or pitches up, and aircraft rolls to the right. The combined effects of dissymmetry of lift, gyroscopic precession, and transverse flow effect cause this tendency. Aviators must correct with additional forward and left lateral cyclic input to maintain a constant rotor-disk attitude.

AUTOROTATION

AERODYNAMICS OF VERTICAL AUTOROTATION

1-123. During powered flight, rotor drag is overcome with engine power. When the engine fails or is deliberately disengaged from the rotor system, some other force must sustain rotor RPM so controlled flight can be continued to the ground. Adjusting the collective pitch to allow a controlled descent generates this force. Airflow during helicopter descent provides energy to overcome blade drag and turn the rotor. When the helicopter descends in this manner, it is in a state of autorotation. In effect, the aviator exchanges altitude at a controlled rate in return for energy to turn the rotor at a RPM that provides aircraft control and a safe landing. Helicopters have potential energy based on their altitude above the ground. As this altitude decreases, potential energy is converted into kinetic energy used in turning the rotor. Aviators use this kinetic energy to slow the rate of descent to a controlled rate and affect a smooth touchdown.

1-124. Most autorotations are performed with forward airspeed. For simplicity, the following aerodynamic explanation is based on a vertical autorotative descent (no forward airspeed) in still air. Under these conditions, forces that cause the blades to turn are similar for all blades, regardless of their position in the plane of rotation. Therefore, dissymmetry of lift resulting from helicopter airspeed is not a factor. During autorotation, the rotor disk is divided into three regions—driven, driving, and stall (figure 1-62).

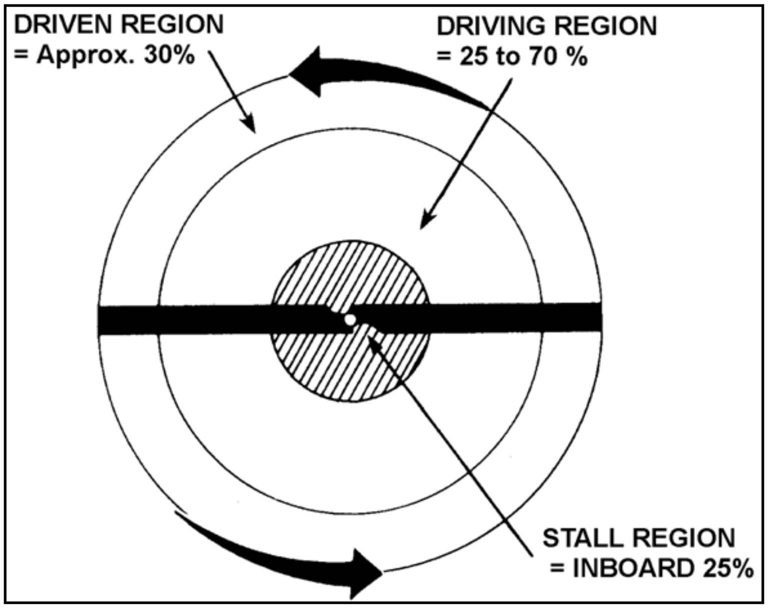

Figure 1-62. Blade regions in vertical autorotation descent

Driven Region

1-125. This region is also called the propeller region and nearest the blade tip. It normally consists of about 30 percent of the disk radius. In the driven region, the TAF acts above the blade and behind the axis of rotation. This region creates lift, which slows the rate of descent and drag, which slows rotation of the blade. Region size varies with the blade pitch setting, rate of descent, and rotor RPM. Any change of these factors also changes the size of the regions along the blade span.

Driving Region

1-126. This region extends from about the 25 to 70 percent radius of the blade. It lies between the driven and stall regions. It can also be identified as the area of autorotative force because it is the region of the blade that produces the force necessary to turn the blades during autorotation. TAF in the driving region is inclined slightly forward of the axis of rotation and produces a continual acceleration force. This direction of force supplies thrust, which tends to accelerate the rotation of the blade. The size of the region varies with the blade pitch setting, rate of descent, and rotor RPM. Any change of these factors also changes the size of the regions along the blade span.

Stall Region

1-127. This region includes the inboard 25 percent of the blade radius. It operates above the stall AOA and causes drag, which tends to slow the rotation of the blade.

Blade Region Relationships

1-128. Figure 1-63, page 1-45, illustrates the three regions. Additional information in the figure pertains to force vectors on those regions and two additional equilibrium points. This figure serves to locate those regions/points on the blade span and depict the interplay of force vectors. Force vectors are different in each region because rotational relative wind is slower near the blade root and increases continually toward the blade tip. In addition, blade twist gives a more positive AOA in the driving region than in the driven region. The combination of inflow up through the rotor with rotational relative wind produces different combinations of aerodynamic force at every point along the blade.

1-129. There are two points of equilibrium on the blade (figure 1-63, page 1-45)—point B, between the driven and driving regions, and point D, between the driving and stall regions. At this point, TAF is aligned with the axis of rotation. Lift and drag are produced, but overall, there is neither acceleration nor deceleration force developed.

1-130. The aviator manipulates these regions to control all aspects of the autorotative descent. For example, if the collective pitch is increased, the pitch angle increases in all regions. This causes point of equilibrium B to move inboard and point of equilibrium D to move outboard along the blade span, thus increasing the size of the driven and stall regions while reducing the driving region. The stall region also becomes larger while the driving region is reduced in size. Reducing the size of the driving region decreases acceleration force and rotor RPM. An aviator can achieve a constant rotor RPM by adjusting the collective pitch so blade acceleration forces from the driving region are balanced with deceleration forces from the driven and stall regions.

AERODYNAMICS OF AUTOROTATION IN FORWARD FLIGHT

1-131. Aerodynamic forces in forward flight (figure 1-64, page 1-46) are produced in exactly the same manner as in vertical autorotation. However, because forward speed changes the inflow of air up through the rotor disk, this changes the location and size of the regions on the retreating and advancing sides of the rotor disk. Because the retreating side experiences an increased AOA, all three regions move outboard along the blade span with the stall region growing larger and an area nearest the hub experiencing a reversed flow. Because the advancing side experiences a decreased AOA, the driven region takes up more of that blade span.

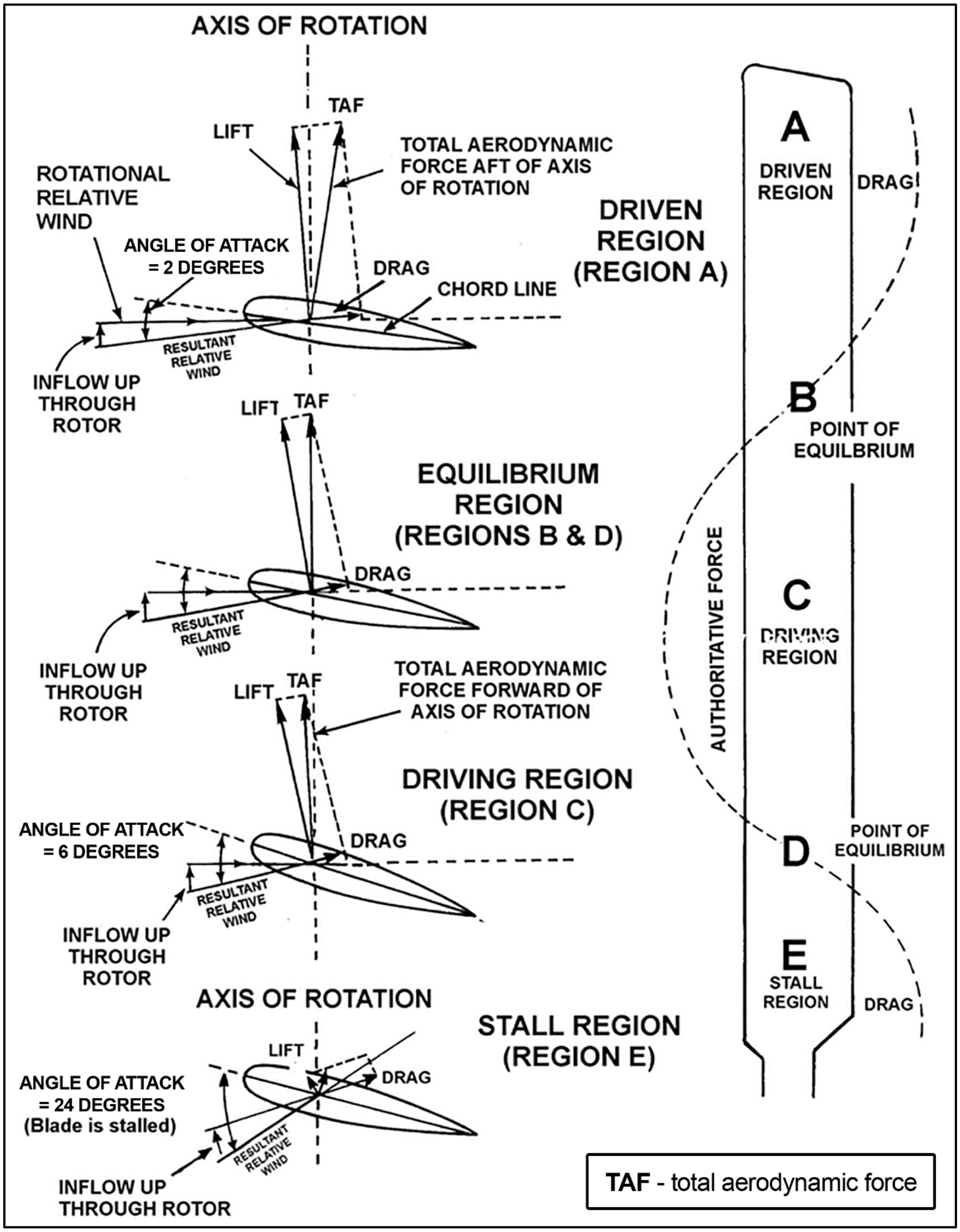

Figure 1-63. Force vectors in vertical autorotative descent

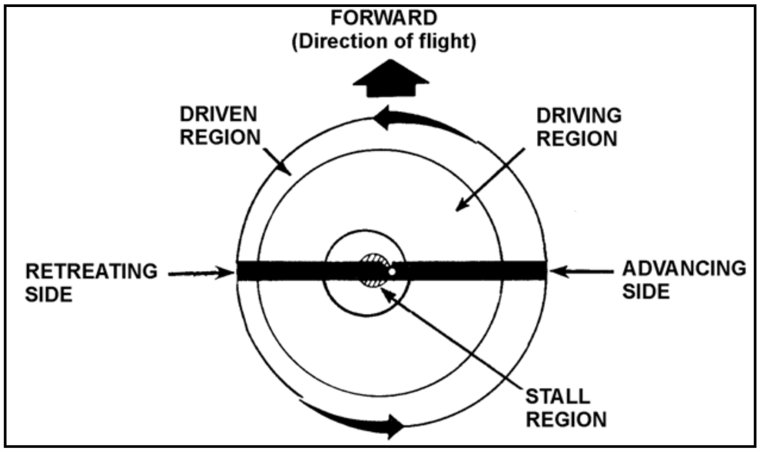

Figure 1-64. Autorotative regions in forward flight

AUTOROTATIVE PHASES

1-132. Autorotations may be divided into three distinct phases—entry, steady-state descent, and deceleration and touchdown. Each phase is aerodynamically different from the others.

Entry

1-133. This phase is entered after loss of engine power. The loss of engine power and rotor RPM is more pronounced when the helicopter is at high gross weight, high forward speed, or in high-density altitude conditions. Any of these conditions demand increased power (high collective position) and a more abrupt reaction to loss of that power. In most helicopters, it takes only seconds for RPM decay to fall into a minimum safe range requiring a quick collective response from the aviator. Entry is a combination of figures 1-65 and 1-66.

Level-Powered Flight at High Speed

1-134. Figure 1-65 shows the airflow and force vectors for a blade in this configuration. Lift and drag vectors are large, and the TAF is inclined well to the rear of the axis of rotation. An engine failure in this mode will cause rapid rotor RPM decay. To prevent this, an aviator must lower the collective quickly, reducing drag and inclining the TAF vector forward, nearer the axis of rotation.

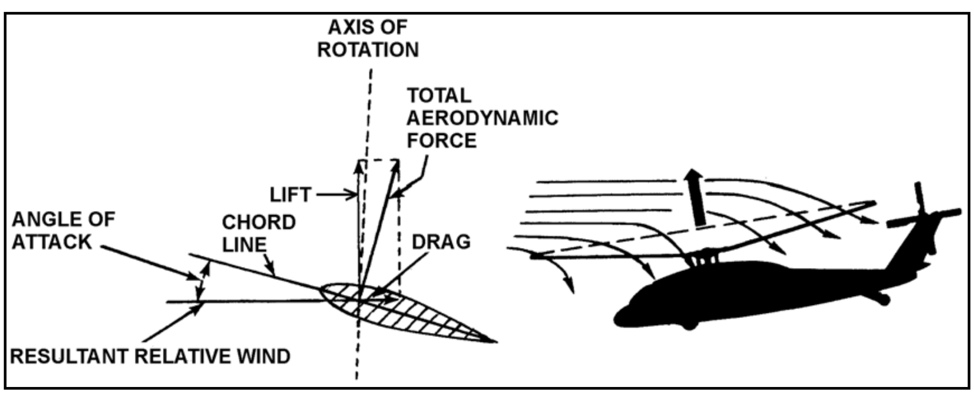

Figure 1-65. Force vectors in level-powered flight at high speed

Collective Pitch Reduction

1-135. Figure 1-66, page 1-47, shows airflow and force vectors for a blade immediately after power loss and subsequent collective reduction, yet before the aircraft has begun to descend. Lift and drag are reduced, with the TAF vector inclined further forward than it is in powered flight. As the helicopter begins to descend, the airflow begins to flow upward and under the rotor system. This causes the TAF to incline further forward until it reaches an equilibrium that maintains a safe operating RPM.

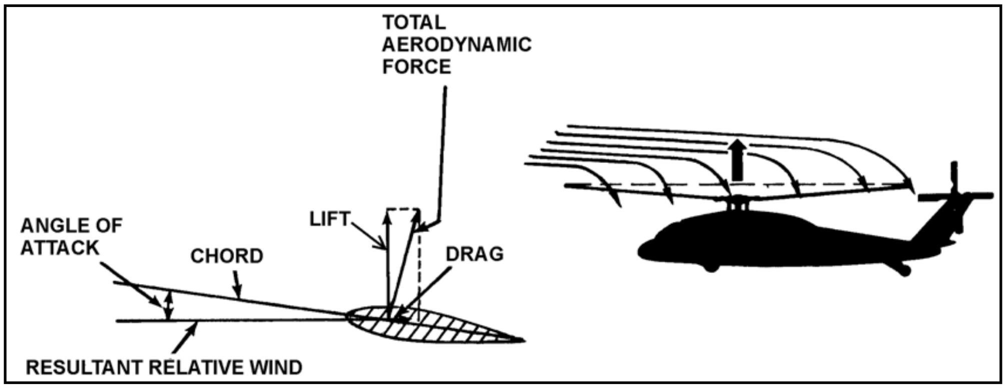

Figure 1-66. Force vectors after power loss–reduced collective

Steady-State Descent

1-136. Figure 1-67 shows airflow and force vectors for a blade in steady-state autorotative descent. Airflow is now upward through the rotor disk because of the descent. This inflow of air creates a larger AOA although blade pitch angle has not changed since the descent began. TAF on the blade is increased and inclined further forward until equilibrium is established, rate of descent and rotor RPM are stabilized, and the helicopter is descending at a constant angle. Angle of descent is normally 17 to 20 degrees, depending on airspeed, density altitude, wind, and type of helicopter.

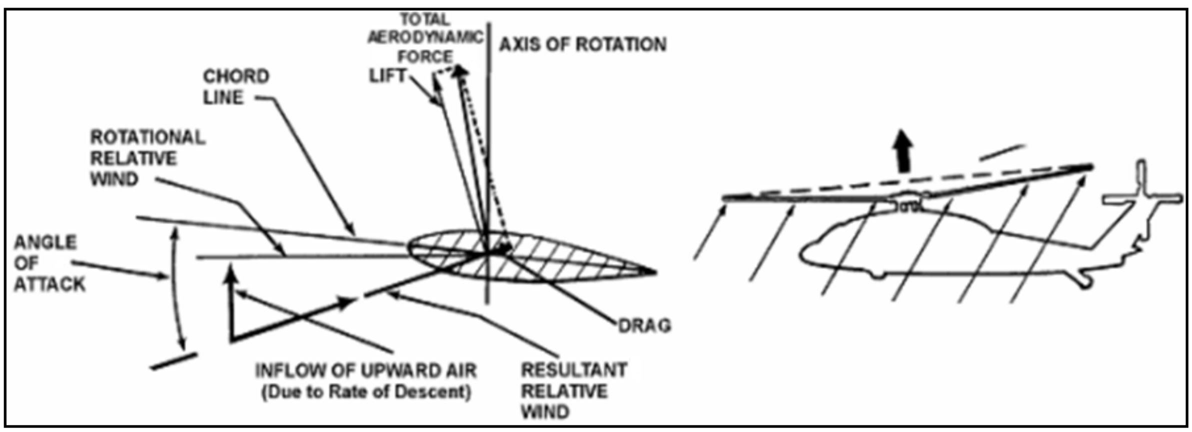

Figure 1-67. Force vectors in autorotative steady-state descent

Deceleration and Touchdown

1-137. Figure 1-68, page 1-48, shows airflow and force vectors for a blade in autorotative deceleration. To make an autorotative landing, aviators reduce airspeed and rate of descent just before touchdown. They can partially accomplish both actions by applying aft cyclic, which changes the attitude of the rotor disk in relation to the relative wind. This attitude change inclines the resultant lift of the rotor system to the rear, slowing forward speed. It also increases AOA on all blades by changing direction of airflow through the rotor system, thereby increasing rotor RPM. The lifting force of the rotor system is increased and rate of descent is reduced. After an aviator reduces forward speed to a safe landing speed, the helicopter is placed in a landing attitude while applying collective pitch to cushion the touchdown.

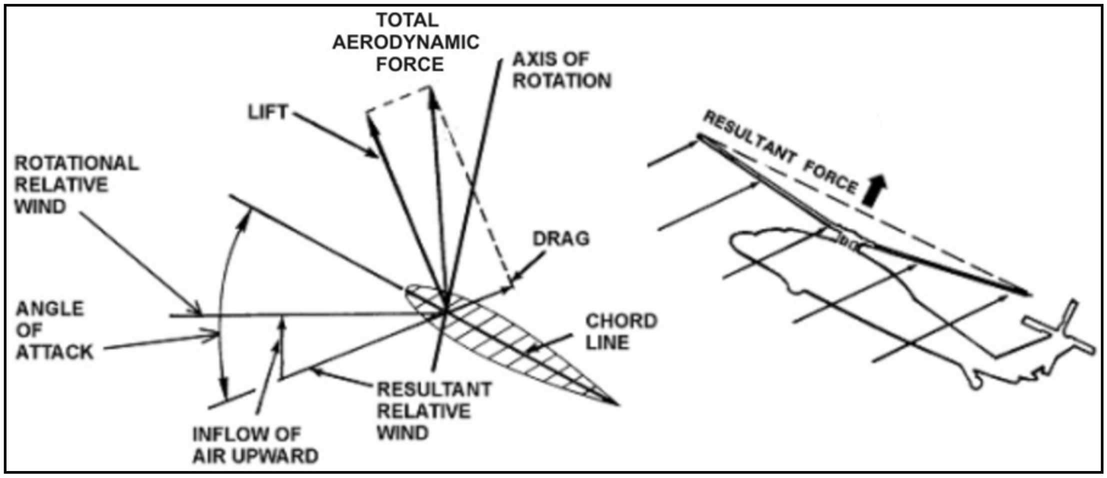

Figure 1-68. Autorotative deceleration

GLIDE AND RATE OF DESCENT IN AUTOROTATION

1-138. Helicopter airspeed and drag are significant factors affecting rate of descent in autorotation. The rate of descent is high at very low airspeeds, decreases to a minimum at some intermediate speed and increases again at faster speeds. Airspeeds for minimum rate of descent and maximum glide distance vary by helicopter type and can be found in individual operator manuals (figure 1-69, page 1-49).

Circle of Action

1-139. The circle of action is a point on the ground that has no apparent movement in the pilot's field of view (FOV) during a steady-state autorotation. The circle of action would be the point of impact if the pilot applied no deceleration, initial pitch, or cushioning pitch during the last 100 feet of autorotation. Depending on the amount of wind present and the rate and amount of deceleration and collective application, the circle of action is usually two or three helicopter lengths short of the touchdown point.

Last 50 to 100 Feet

1-140. It can be assumed autorotation ends at 50 to 100 feet and landing procedures then begin. To execute a power-off landing for rotary-wing aircraft, an aviator exchanges airspeed for lift by decelerating the aircraft during the last 100 feet. When executed correctly, deceleration is applied and timed so rate of descent and forward airspeed are minimized just before touchdown. At about 10 to 15 feet, this energy exchange is essentially complete. Initial pitch application occurs at 10 to 15 feet. This is used to trade some of the rotor energy to slow the rate of descent prior to cushioning. The primary remaining control input is application of collective pitch to cushion touchdown. Because all helicopter types are slightly different, aviator experience in that particular aircraft is the most useful tool for predicting useful energy exchange available at 100 feet and the appropriate amount of deceleration and collective pitch needed to execute the exchange safely and land successfully.

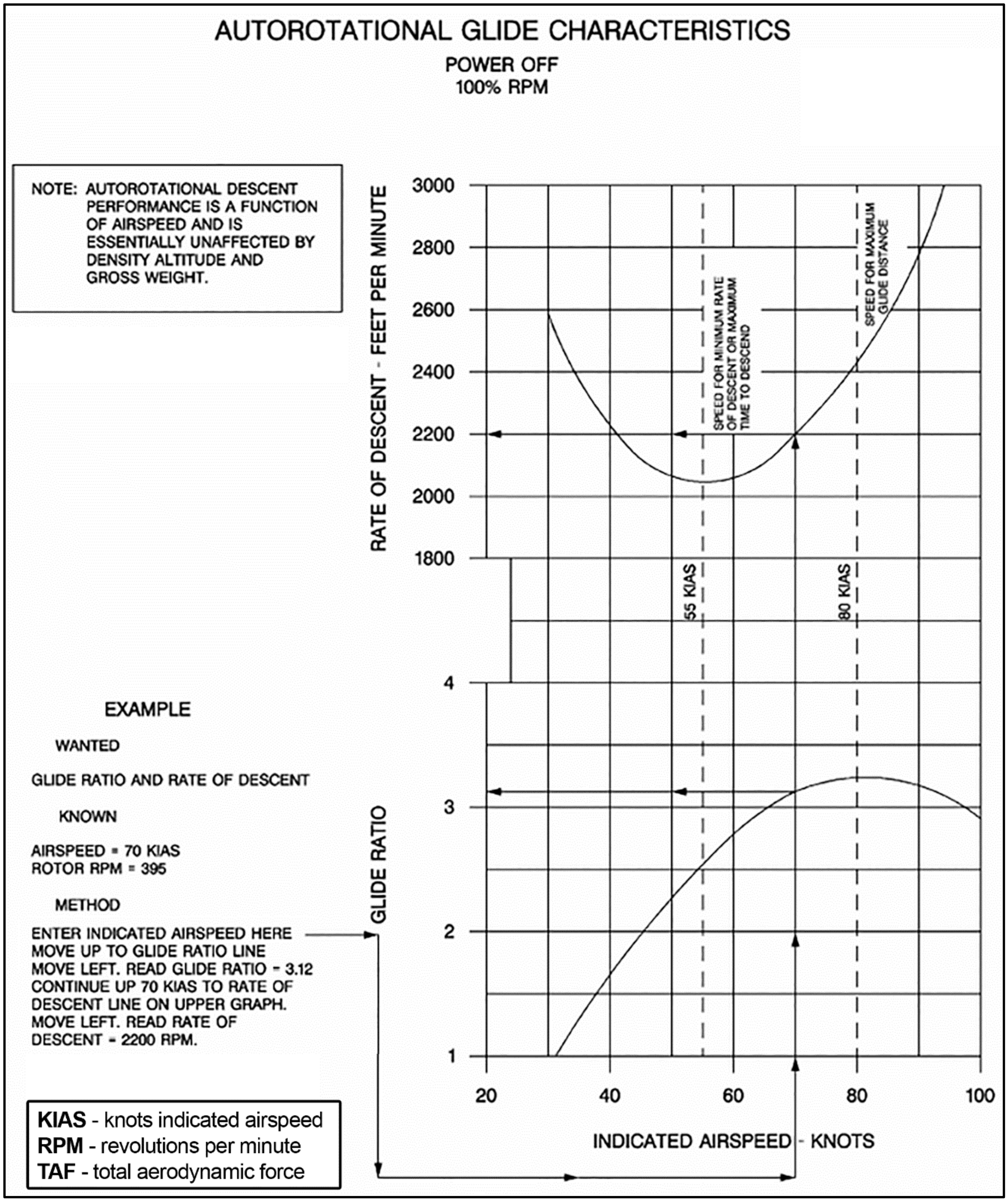

Figure 1-69. Drag and airspeed relationship