Spins Unspun

By Bob Moreau

Introduction

During the period of 2000 to 2001 a test program was conducted at the University of Tennessee Space Institute in support of a thesis project aimed at qualitatively evaluating the spin and recovery characteristics of the Yak-52. Good fortune in timing allowed for the use of an inertial data acquisition system, which added greatly to the information gathered. The purpose of this article is to provide a summary of the results obtained during the evaluation and to present it in a "plain language" form to the membership of the Yak Pilots Association. The material presented here is not meant as a "how to" on spinning the Yak-52. It is meant to elevate the knowledge and safety base for the membership and to bring home the fact that without properly qualified training in the Yak-52's spin and recovery characteristics, the membership list will inevitably be pruned from time to time. With the proper training, the Yak-52 is a thoroughly delightful airplane that can be enjoyed by many pilots.

Theory

Even before getting the airplane into the air for a flight test, a slow visual inspection on the ground will reveal much about the probable spin and recovery characteristics of many airplanes. The Yak-52 is no different and so a short description of some of the traditional spin theories is in order.

Of prime importance are the mass distribution and mass density of the airplane. Mass distribution looks at whether the mass is mainly concentrated along the wings, fuselage or is evenly balanced between the two. Historical data suggest the ranges for each category. The importance of this is in determining which is the primary control for effective recovery. For the Yak-52 the mass distribution is borderline neutral when flown solo and slightly fuselage dominant when both seats are occupied. For the pilot, this translates into the rudder being the primary recovery control when neutral and the aileron being the primary recovery control when fuselage dominant. Of course, these statements are general, and as we will see when we get to the data plots, the individual spin mode governs the recovery technique.

The mass density of the airplane is another important factor to consider. The greater the density, the greater the inertia that builds up during the spin requiring that much more of the flight controls to generate the aerodynamic forces that are necessary to effect a recovery. For the Yak-52 the mass density is relatively high and is more akin to a 1940's era advanced trainer or fighter than to the light trainers available for spin training on this side of the Atlantic.

Fuselage shape is another important factor in predicting how an airplane might recover from a spin. For the Yak-52, the aft fuselage is more or less oval in shape and provides good anti-spin moments during the spin, which helps to recover. The forward fuselage is circular, which is neutral, thus providing neither pro-spin nor anti-spin moments for recovery.

A review of the literature concerning spins will reveal a lot of references to such things as the "tail damping power factor, tail damping ratio, unshielded rudder volume coefficient and the inertia yawing moment parameter," all resulting in something called the "tail design requirement." This material dates back to work done in the 1930s by NACA, the purpose of which was to give engineers parameters to use in designing an airplane for good spin recovery characteristics. Although the Yak-52 is predicted to exhibit good behavior based on these parameters, it is worth noting that this method has fallen out of favor based on problems with some of the original assumptions and how the available data was interpreted at the time to produce the parameter requirements. Unfortunately, even in recent publications concerning spins, this methodology is still quoted as being gospel, when in fact it provides only a general "feel" at best.

A more recently developed methodology looks at the ratio of the length between the center of gravity and the rudderpost and the center of gravity and the propeller plane to determine the relative control power available for recovery. The Yak-52 falls in the good category on this scale.

Having said all of this, it is worth pointing out that two identical types of airplanes, loaded identically, and spun on at the same time may, or may not, exhibit the exact same spin and recovery characteristics. Small variations allowed for during manufacture, slight differences in rigging, minor hanger rash or twists and turns from age, can all result in huge variations in how the airplane responds.

Spin Nomenclature

Briefly, so everyone is talking about the same thing, some definitions, since not every author uses the same meaning or words to describe the same thing. The incipient spin is that portion during which the flight path vector of the airplane is in transition from the horizontal to the vertical. The fully-developed spin is that portion after the incipient phase during which the aerodynamic and inertia forces and moments are more or less in equilibrium. An accelerated spin is one where the rotation rate is measurably increased through the use of either forward elevator or out-spin aileron control input. A flat spin is one where the wing maintains an angle of attack exceeding 60 degrees, either by natural aerodynamic or inertial means, or by the use of increased propeller thrust over the tail surfaces. In-spin aileron means deflecting the control stick in the direction of the spin. Out-spin aileron means deflecting the control stick opposite the rotation of the spin. The axes of the airplane as viewed from the cockpit are the x-axis (roll about the line running from nose to tail, positive when the rotation is clockwise when looking at the nose), the y-axis (pitching about the line running from wingtip to wingtip, positive when the rotation is clockwise when looking at the right wingtip), and the z-axis (yaw about the line running vertically and perpendicular to the other two axes, positive when the rotation is clockwise when looking down along the z-axis).

Test Airplane and Instrumentation

The airplane used for the tests was a 1985 Yak-52, which differed from the production standard in the following ways: the shutters at the front of the cowling were removed and a large diameter spinner was installed, the centering springs in the flight control system were removed, aileron spades were installed, the flight data recorder and ADF system were removed, the flight control fabric was replaced with Stits, the wheels and tires were replaced with western equipment and the brakes were converted to hydraulic toe brakes for the front cockpit.

For the tests conducted at forward CG (18%) the rear seat was removed and a MEMS-based (Micro Electro Mechanical System) inertial data acquisition system (AVS-18H, on loan from the U.S. Army) was installed on a specially built platform. Rotary potentiometers, known as string pots, were installed to provide the AVS-18H with control position inputs for elevator, aileron and rudder. A laptop computer was installed to capture the data for later analysis. Although the AVS-18H was capable of capturing 14 different parameters, for the purposes of this test the parameters of interest were the body axis rates, control positions and the y-axis magnetic vector (explained later when we get to the data plots) all plotted against time.

The right wing was tufted and a video camera was installed in the rear cockpit to capture airflow visualization data at forward CG (18%) to supplement the data from the AVS-18H.

Tests were also performed at aft CG (25%). The AVS-18H was not available for these tests as it was returned to the U.S. Army for the helicopter dynamic flight testing for which it was designed. It was necessary to have the rear seat installed and obtain a volunteer to act as spin ballast (no easy task) to get the CG aft. Although manually gathered, and hence not as accurate, the data at aft CG was in keeping with the known characteristics of the airplane.

A hand-held force gauge was utilized to get stick force data during the stall evaluation but was not used during the spin tests due to safety considerations. Control force measurement during the spin evaluation was done subjectively after performing pilot force calibrations utilizing measurable weight lifting machines — more on this later.

Test Methods

All spins were conducted from coordinated, 1-G, level flight. The recovery techniques used were those as specified in the translated airplane manual. As a qualitative evaluation it is important to keep in mind that this was not a full-up certification flight test program, which typically would entail well over a thousand individual spins for an airplane certified under FAR Part 23 in the aerobatic category. The intent was to evaluate the published techniques and to examine and document the dynamics behind them.

The techniques for entry were as follows:

- Normal Upright – Full aft stick, neutral aileron, full rudder (right or left) at the stall to initiate the spin.
- Accelerated Upright – Full aft stick, neutral aileron, full rudder (right or left) at the stall to initiate the spin followed immediately by full out-spin aileron.
- Flat Upright – Same as accelerated except that the power was increased to full throttle simultaneously with out-spin aileron.
- Inverted – Full forward stick, neutral aileron, full rudder (right or left) at the stall to initiate the spin.

The entry controls were held in place until initiation of recovery. The techniques for the recoveries were as follows:

- Normal Upright – Full opposite rudder, neutral aileron and neutral elevator. Controls were immediately neutralized when the spin stopped.
- Accelerated Upright – Full opposite rudder, full forward stick and full in-spin aileron. Controls were immediately neutralized when the spin stopped.
- Flat Upright – Same as for accelerated except for power being reduced to idle.
- Inverted – Full opposite rudder, full aft stick and neutral aileron. Controls were immediately neutralized when the spin stopped.

Test Results

Before getting to the data plots I would like to start with the airflow visualization video data obtained from the tufted-wing flights. Normally when you see pictures of tufted wings during stalls or spins the tufts everywhere on the wing, including the ones on the ailerons, go from smooth airflow to reversing direction at the moment of stall to flying about in all directions in very chaotic airflow. When the wing stalls on the Yak-52 the airflow on the wing itself is seen to separate, starting at the aft wing root area and progressing outward along the wing. In a bit of a surprise the airflow on the ailerons themselves does not separate at all. This non-stalled condition continued throughout the spin, regardless of spin mode and position, up or down, if the aileron was deflected, as during the accelerated and flat spins. This is a result of the large aileron to wing gap brought about by the Frise-type aileron design. The open slot allows for high-energy airflow from the underside of the wing to flow over the aileron upper surface keeping the airflow attached all the while the airflow on the wing itself is completely separated.

The importance of this is two-fold. First, the ailerons are powerfully effective on the Yak-52 regardless of flight condition. Second, traditional spin theory states that aileron input against a spin will create strong differential drag forces which will act to increase the yaw rate thus hindering recovery attempts, although before spin dynamics were better understood this was precisely what was taught as a spin recovery technique for many World War II-era fighters. With the ailerons of the Yak-52 retaining airflow throughout any spinning maneuver, out-spin aileron input adds an additional force-moment couple to the equation. Using a right upright spin as an example, with out-spin aileron applied there is now a lift vector, which is deflected rearward, coming off the right aileron and a lift vector, which is deflected forward, coming off the left aileron. The net result is that not only is there an increase in differential drag adding to the yawing inertia, but there are now lift vectors from the ailerons acting in the direction of the spin to further increase the yawing inertia. As you can see from the data presented in Table 1 there is a marked increase in the rotation rates for the accelerated and flat spin modes.

Moving on to the data plots, Table 2 presents the legend for the rate and control deflection plots as well as the y-axis magnetic vector plots. Keeping in mind the earlier definitions of the x, y, and z-axes as viewed from the cockpit, the axis rate plots are pretty self-evident. The control deflection plots assume that the neutral position is at the 50 percent of full travel position for each given control. The y-axis magnetic vector is a parameter derived from the fact that each axis of the AVS-18H had a small magnetic flux valve installed to measure the magnetic field strength along that axis. This proved of great value in that it allowed a means to accurately determine the rotation rate of the whole aircraft within the earth-based fixed magnetic field, regardless of aircraft attitude. The resulting plot is a wave where one full turn of rotation can be measured by simply noting the distance from peak to peak, trough to trough, or any similar points in the wave and deriving the rotation rate by measuring this distance in terms of time. This was also highly useful in determining the exact number of turns from the point of initial rudder input for recovery to actual termination of the spin as marked by the rapid reversal and return to neutral of the rudder.

Now for the actual data plots. For brevity, I am presenting only the plots for the right normal, accelerated and flat spin modes . The information to be learned illustrates the characteristics of the Yak-52 very well and is no different from the left spin modes with the exception that the left spins exhibited greater pitch oscillations than did the spins to the right.

The right normal spin was initiated with full right rudder and full aft longitudinal stick being applied 1.1 seconds (Figure 1). The yaw rate increased smoothly with variations in pitch and roll rates. The spin was fully developed at 4.5 seconds, which corresponded to 1.25 turns. The peak roll rate was 170 deg/sec and the peak yaw rate was 75 deg/sec. Recovery was initiated at 9.0 seconds by a rapid reversal of rudder a reversal of longitudinal stick toward neutral. Aileron was not applied as a method of recovery. An immediate decrease in yaw rate was observed. The difference between yaw rate and roll rate at the point of yaw rate decrease was 90 deg/sec. A movement toward neutral rudder occurred at 10.2 seconds, indicating the end of the spin. This corresponded to 0.75 turns to recovery. The rotation rate determined from the y-axis magnetic vector was 126 deg/sec for the fully developed portion of the spin. The recovery was too rapid to determine an average rotation rate for the recovery portion of the spin.

The right accelerated spin was initiated by reaching full right rudder and full aft longitudinal stick at 2.3 seconds (Figure 2). Left lateral stick, aileron against the spin, was applied beginning at 2.3 seconds. The yaw rate increased smoothly with variations in pitch and roll rates until the spin was fully developed at 4.5 seconds, which corresponded to 0.75 turns. The variations in pitch and roll rates between 4.5 to 10.5 seconds again appear to indicate strong coupling due to gyroscopic precession. At 7.5 seconds the yaw rate exceeded the roll rate. Recovery was initiated at 10.5 seconds by a rapid reversal of rudder deflection followed by a rapid reversal of lateral stick to aileron with the spin and longitudinal stick to well forward of neutral. The yaw rate showed a modest decrease from the maximum value achieved of 135 deg/sec to 120 deg/sec.

There was a rapid increase in roll rate to a peak value of 230 deg/sec. A marked decrease in yaw rate did not occur until the roll reached a value of 190 deg/sec, a difference of 70 deg/sec from the yaw rate. A movement toward neutral controls occurred at 12.8 seconds, indicating the end of the spin. This corresponded to 1.25 turns for recovery. The rotation rate determined from the y-axis magnetic vector was 160 deg/sec for the fully developed portion of the spin and 218 deg/sec for the recovery portion of the spin.

The right flat spin was initiated with full aft longitudinal stick and right rudder being applied at 2.3 seconds (Figure 3). Although not indicated on the plot the engine power was increased to approximately 90 percent at 2.6 seconds. Left lateral stick, aileron against the spin, was applied beginning at 3.4 seconds. The yaw rate increased smoothly with variations in roll and pitch rates until the spin was fully developed between 4.5 and 5.3 seconds. The yaw rate continued to increase until it reached a maximum value of approximately 135 deg/sec at 9.0 seconds, where it also exceeded the roll rate. Again, the pitch and roll rate variations appear to be strongly coupled due to gyroscopic precession. Recovery was initiated by a rapid reversal of rudder deflection and idle power at 9.8 seconds, with no corresponding decrease in yaw rate. The lateral stick was also reversed, aileron with the spin, at 9.8 seconds. The longitudinal stick was reversed to a point well forward of neutral beginning at 10.5 seconds. There was a rapid increase in roll rate beginning at 9.8 seconds, which continued to a maximum value of 230 deg/sec at 12.0 seconds. There was no decrease in yaw rate observed until 11.7 seconds, which corresponded to the roll rate value exceeding the yaw rate value by 70 deg/sec. A movement toward neutral controls occurred at 12.8 seconds, indicating the end of the spin. This corresponded to 1.75 turns to recovery. The rotation rates determined from the y-axis magnetic vector was 143 deg/sec for the fully developed portion of the spin and 228 deg/sec for the recovery portion of the spin.

Table 3 presents the control force data obtained. Of particular note is the increase when going from a normal spin to an accelerated or flat spin and the sharp increase when the CG is in the aft position. Remember, these values were obtained subjectively without accurate measuring devices so are general in nature, but they are in keeping with those values found in the translated material that accompanies the airplane.

Data Analysis

All three data plots show that the incipient phase takes about one full turn. Not reflected in the plots is the fact that regardless of entry, if the recovery was initiated during this incipient phase an immediate recovery was possible. This is vitally important to understand for several reasons. For most pilots trained in the west (discounting military trained and CFIs), if they have spin training at all, it rarely goes beyond one full turn. This means that the spin and recovery characteristics experienced are quite docile indeed. Even for aerobatic pilots, most spins are one turn spins (I haven't seen the Yak-52 compete in anything higher than the Sportsman category), although for this year the Sportsman category calls for a 1 ¼ turn spin, which means that the recovery is applied at precisely the moment the spin is changing from the incipient phase to the fully developed phase. Perhaps someone with far more talented feet and hands than mine can discern a difference here.

Figure 1 shows that there was an immediate response to the initiation of recovery controls. For an upright normal (and all inverted spins for that matter) the meaning is that the controls surfaces are capable of generating the aerodynamic forces necessary to counter the inertia forces to terminate a spin precisely as commanded by the pilot. This is true whether the spin is in the incipient or fully developed phase.

For the fully developed accelerated spin shown in Figure 2 and flat spin shown in Figure 3 the situation is something quite different. With the yaw rate exceeding the roll rate, initiation of recovery controls shows that the control surfaces are not capable of generating the necessary aerodynamic forces to immediately terminate the spin. With in-spin aileron applied as part of the recovery technique it clearly takes time for the roll rate to accelerate to the point where it exceeds the yaw rate by a margin great enough for the aerodynamic forces to overcome the inertia forces and terminate the spin. This aspect is even more so at aft CG. The Yak-52 will recover, but it takes time. At forward CG it is 1.5 to 1.75 turns. At aft CG it can take up to 3.5 or so turns before this condition necessary for recovery is reached. These characteristics are directly attributable to the mass distribution and mass density of the Yak-52, especially when compared to western light aircraft available for spin training. Notice from Table 1 that the rotation rates are increasing all the while you are waiting for the roll rate to exceed the yaw rate enough for recovery. This translates directly into a very disorienting ride for the untrained and when coupled with the high control forces encountered at aft CG certainly argues against the self-taught method.

Conclusions

There is no question that for the untrained pilot the Yak-52 can provide a truly exciting ride, regardless of a pilot's level of experience or background, civilian or military. It is also true that the Yak-52 lives by the same rules of physics as the rest of the universe. It is very important that the pilot is properly educated. The key is to obtain the proper training. Being experienced in spinning other types of airplanes, such as western training types or even military types does not necessarily translate into the requisite skills to handle the Yak-52 in all of its modes, nor does it translate into being qualified to teach spins in the Yak-52. Good training is out there and I can't recommend enough seeking it out.

Editor's Note 1: There are two very important things to think about as you consider this in-depth analysis of the Yak-52 spin characteristics. First, the aircraft used in this flight-test program was modified significantly as Bob points out in his description of the test airplane. Second, Bob also points out that "two identical types of airplanes, loaded identically, and spun on at the same time may, or may not, exhibit the exact same spin and recovery characteristics." This is similar to the observation made by Richard Goode and Gennady Elfimov in the ***Warbird Flyer****, 2nd Quarter 2001 (Page 7, The Mail Run) where they point out that "We know of at least two Yak-52 aircraft that after a fully developed flat spin (i.e. four or so turns) will NOT recover with the conventional spin recovery…" You should not have the expectation that your aircraft will behave the way this test aircraft did in a spin recovery. You should also make every effort to get proper spin training from a qualified instructor in your specific aircraft.*