SPIN PREDICTION AND HIGH ANGLE OF ATTACK FLIGHT TEST

CONFERENCE HELD BY Dott. Ing. ERNESTO VALTORTA

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INDEX

0. SUMMARY

This Memo contains the written text of the conference held by Dott. Ing. Ernesto Valtorta at CFTE in December 1996.

1. INTRODUCTION

In the years 60’s when I was a student, the simulator was a very big machine with a big and complex computer.
The computer was analog-digital and it was possible to evaluate the flying characteristics in linear range only.
The simulation of stall and spin behaviour was considered impossible mainly because a wind tunnel test methodology was not available, nor were known the criteria required to determine the aerodynamic coefficients necessary to represent the high angle of attack characteristics and to build a mathematical model.
A standard mathematical model was not considered representative of phenomena like wing rock, stall, spin and autorotation.
The investigation of spin characteristics was then performed with some empirical criteria and with a dynamically scaled free flight model in a vertical wind tunnel. From this test it was practically impossible to investigate the spin entry characteristics; only the developed spin mode and the recovery characteristics from developed spin were obtained.
The estimated characteristics of the developed spin and recovery on several occasions were not fully representative of the airplane behaviour and it was usual to modify the model with some asymmetry in order to obtain the airplane characteristics.
When I started my career in Aviation (1970), the high angle of attack characteristics were not considered very important. In several cases it was necessary to perform additional flight tests with trainers and fighters after several spin flight accidents. Due to lack of confidence many a prototypes were lost during flight tests at high angle of attack.
The criteria connected with the development and sizing of the emergency recovery systems was not adequate in helping with the recovery from fully developed spin.
Some companies did not consider it essential to investigate wind tunnel stall angle of attack with transport airplanes because a stick pusher was installed.
When my university professor showed me the flying simulator, I was very interested and I tried to understand how it was possible to prepare the mathematical model and to perform the simulation at six degrees of freedom .
I started thinking that performing the evaluation, only in the low angle of attack region with such a big machine, was a relatively poor task.
From 1970 to 1971 I was in charge as a teacher at the Italian Air Force Academy in Pozzuoli (Naples).
During my stay with the Air Force I had to do with several pilots and it was possible for me to know more about flying characteristics at low and high angle of attack of the airplanes used by the Italian Air Force.

I was surprised that the airplanes used by the Academy students for basic training could not perform a spin because this was considered a dangerous maneuver.
Soon after I started to be trained as private pilot and I realized that quite a few general aviation airplanes were only seldom spin tested and some of them could not offer a safe recovery.
In one flying school I was unable to be trained in the spin rotation because the instructor did not agree to perform this maneuver.
The experience with the Air Force was very interesting because my relationship with a number of pilots is still open and during my career it was possible to exchange ideas and acquire practice.
In 1971 I started my collaboration with Aermacchi and I found a totally different situation. Every project created in this company was evaluated at high angle of attack too. In addition, in the company wind tunnel a particular device was installed which could simulate the stable spin characteristics and measure the aerodynamic coefficients during spin rotation. This device is now called a rotary balance.
I gained confidence with analyzing rotary balance data. In the meantime it was possible to write a FORTRAN program capable of performing a six degrees freedom simulation, thanks to a new generation of computers.
Aermacchi was in charge with the performance of the rotary balance tests on several airplanes and configurations, including transport airplanes, like the G-222 and a new-generation supersonic fighter, the MRCA Panavia PA 200 Tornado. We thus started to be familiar with aerodynamic data at high angle of attack in very different airplane configurations.
It was possible for me to evaluate not only wind tunnel tests, but also flight test results and in 1975 I was able to prepare an aerodynamic data set and to carry out a simulation of spin entry, developed spin and recovery of an Aermacchi jet trainer.
The simulation results were very close to flight test results and we started to be more and more confident in the preparation of a mathematical model and in performing wind tunnel tests.
Since 1975 the wind tunnel test result analyses in Aermacchi have been based on the estimation of spin equilibrium conditions and on the evaluation of control effectiveness for the recovery from spin equilibrium conditions.
Always in 1975 we started to evaluate the motion of the airplane during the complete maneuver.
In my opinion it was easy to be successful in performing six DOF simulations at high angle of attack, mainly on account of the good accuracy of wind tunnel data. The accuracy of aerodynamic coefficients was above all possible in consideration of the suspension of the wind tunnel model which does not entail significant interference problems.
The wide experience acquired in performing wind tunnel tests with a static and rotary balance enabled us to evaluate the reliability of the results with a remarkable degree of familiarity and to complete wind tunnel test programs in a

position to identify the most important coefficients and to prepare the data base for the complete simulations.
Moreover, we started to perform flow visualizations at high angle of attack and to correlate the flow characteristics with the value of the aerodynamic coefficients.
It was very interesting to discover that it was possible to simulate wing rock and wing drop phenomena, spin entry, developed spin and recovery without particular problems.
In 1978 we started to collaborate with SAAB. Marcel Dassault specialists analyzed the possibility to test with rotary balance and in 1979 General Dynamics asked me to test F-16 models at high alpha.
In 1979 I visited the United States for the first time and I started to exchange data on high angle of attack with U S A specialists.
In 1980 I visited Prof. Barlow and Mark Tishler at the University of Maryland and we discussed the criteria connected with the use of rotary balance data.
I was confident that we were very well prepared in carrying out high angle of attack evaluations and we were able to offer complete static and rotary balance wind tunnel tests and the simulation of a spin behaviour.
Always in 1980 I collaborated with SAAB (B3LA and Viggen programs), PIAGGIO (P 180), CATIC (K-8), and CAE HARI (general aviation models).
I was involved in the AM-X program, a ground-attack fighter developed by Alenia and Aermacchi (Italy) and Embraer (Brasil) together.
In this program it was possible to perform a complete work, and thanks to the Italian Air Force that allowed me to be trained on the MRCA simulator, I was able to install the mathematical high angle of attack model in a simulator. Besides, for the first time in Italy, it was possible to offer a flying simulator able to simulate the airplane in the complete flight envelope without limitations to a flight test pilot.
The simulations were carried out with an Alenia flying simulator.
The work was not easy because it was necessary to perform the validation of the system at high angle of attack.
The standard simulator was not designed for high alpha simulations. The solution of an equation of motion in a simulator is equally obtained with a very simple algorithm which is not the best in case of high alpha motion. It is easy to find problems through high alpha or 90 degrees attitude.
The most common problem is that the visual system is not working properly and in a number of cases it is possible to find some divergent phenomena due to lack of aerodynamic data at alpha greater than 90 degrees. In some cases it is not easy even to identify these divergent phenomena and it is possible to be mistaken and consider this like a loss of control situation.
The performance of such a job involves several specialists and pilots. The flying simulator too is quite expensive to run and it is possible to carry out this job only if you have a remarkable budget and if a simulator is already available.

In the same period I spent some time in developing relatively inexpensive simulation tools, however in a position to give the same results as with a big simulator.
In 1974, when I started to carry out spin simulations with a FORTRAN program, quite a few hours of calculations were required to simulate 30 sec. maneuver. Now, a similar program running in Windows 95 ambient and written in C++ language can perform a simulation in quasi real time. With this program it is possible to analyze the low and high angle of attack behaviour in a complete manner and the cost is much lower.
The method of performing the wind tunnel tests, implementing the data base and the mathematical model in the simulator and carrying out the simulations seems adequate and able to offer valuable means in order to predict spin behaviour.
I spent some time too in developing radio-controlled models in order to have some tools, to be equivalent or better than vertical wind tunnel.
In the vertical wind tunnel the dimension of the model is limited due to the tunnel dimensions, the section available being generally 4 m. (diameter of the section) and it is not possible to test a model with a wing span exceeding 1 m.
With radio-controlled models we do not have limitations. The cost of radio controlled models can be similar to the cost of standard vertical wind tunnel models and the cost of a test campaign can be much lower.
This approach is very helpful mainly for propeller-driven general aviation airplanes because it is relatively easy to build a dynamically scaled model and to fly it like a radio controlled model.
The experience gained with this approach shows that the criteria are very powerful and they enable good data at low cost. This is very important for general aviation and it allows an approach to flight tests with safety.

2. THE PREDICTION OF TEST TECHNIQUES OF HIGH AOA, STALL AND SPIN CHARACTERISTICS.

The criteria which are generally used for the study of high AOA behaviour are the following:

- Analysis of Parameters

It consists of the geometric evaluation of some values which are considered of fundamental importance to determine high AOA damping characteristics and flight control effectiveness.
The most common are the TDPF (Tail Damping Power Factor) and the URVC (Unshielded Rudder Volume Coefficient).
These criteria were normally applied during the plan initial phase, when no wind tunnel data were available. They served the purpose of giving dimensions only in principle and in some cases they were absolutely unreliable as for the anticipation of the actual aircraft behaviour. These criteria were generally used as reference for stability and control surface dimensions, especially for checking general aviation aircraft.

Each designer follows his own criteria for surface dimensions in principle. These same criteria are often based on the above parameters or similar criteria as jointly developed by a project team.
Years ago these methods were often the only ones followed for preliminary tests of spin behaviour and unfortunately vertical wind tunnel tests were carried out only after a number of airplanes (and pilots) were lost during a spin maneuver.

• Vertical Wind Tunnel Tests

The vertical wind tunnel tests were the only standard criterion for the study of spin behaviour until a few years ago.
The model is to be built on a geometric and dynamic scale. It is thrown into the wind flow according to different attitudes and a pre-set control deflection. The behaviour characteristics are qualitatively analyzed.
Once the model evolution was photographed in sequence, thus enabling the evaluation of the typical spin attitudes, the time per turn and, considering the vertical wind speed, the falling speed.
The spin recovery performances were evaluated throwing a model into a spin attitude with the flight controls selected for spin attitude recovery and taking into account the number of turns which are required for recovery.
The behaviour evaluation at high altitude was carried out by increasing the model weight and inertial moments, on the basis of air density. In order to simulate a high altitude behaviour, it is necessary to increase the model weight. In some cases two models would be required in order to perform a complete behaviour evaluation at different altitudes.
The model behaviour can be filmed and rather accurate time histories can be obtained by analyzing these films.
The model can be equipped with radio controls: in this way flight check maneuvers can be carried out during the tests.
During these tests an anti-spin parachute can be dimensioned as for cable length and drag area.
The tests to be made in the vertical wind tunnel are essentially quality tests since the model is manually thrown on the right and on the left, according to different attitudes and rotation speeds.
It is rather important to be present during the tests and be able to personally evaluate the behaviour characteristics or, at any rate, analyze the results if in possession of the tests film, thus becoming aware of what can happen.
This analysis is important since it will be possible through it to better evaluate the flight test results as and when required and to become familiar with the procedure.
During these tests the Reynolds numbers cannot be changed since the wind speed is to be the same as the airplane descent speed, and the aircraft scale depends on the wind tunnel dimensions.
Generally speaking, the Reynolds numbers are rather low.

The test results in a vertical wind tunnel are rather reliable for high wing load configurations, as is the case with fighters,

while they can be scarcely reliable with light aircraft. This occurs due to the fact that AOA behaviour is characterized by mass effects and aerodynamic effects.
In the case of aerodynamic effects an inaccurate simulation can be negligible for mass effect configurations, while substantial differences can be found for those configurations where mass effects are low.

- Wind Tunnel Tests with Static Balance

Stability and control characteristics are obtained from wind tunnel static balance tests. These tests can be carried out being the model both in the angle of attack and yaw ranges. Usually an alpha range is as wide as ±90° as regards an evaluation for an AOA behaviour.
Some experimenters claim they perform their tests within an AOA range of zero to 360 degrees. Beta values are often limited to a ±30° range.
During these tests the model must be supported so as to be fastened to the wind tunnel. The support dimensions and positions for the model are to be such as not to alter remarkably the aerodynamic field.

It is necessary to use several types of support to cover the complete AOA range.
Within high AOA ranges the support entails interferences which must be corrected. It is advisable to arrange the test so that these interferences are reduced to the minimum.
$C_{n\ \beta\ dyn}$ and LCDP values can be obtained from these tests. These two parameters were normally used to obtain high AOA behaviour evaluations, when more accurate tests could not be carried out.
There are documents illustrating how the values of these two parameters are connected with AOA behaviour. During static balance tests, any wind speed can be selected and it is possible to evaluate Reynolds effects.
Should a big wind tunnel be available, it would be possible to use big models, thus performing tests at high Reynolds number which would give very similar results to the aircraft values.

- Wind Tunnel Tests with Rotary Balance

Systems with the purpose of obtaining rotary balance measurements were developed many years ago; however they have become rather widespread only in the last few years as test methods. This delay is due to the fact that it was previously rather difficult to obtain reliable and accurate results with a rotary balance model. The problem has been overcome only recently with the adoption of accurate measurements systems, as well as data analysis computers.
Additional difficulties were due to the lack of a methodology enabling the adoption of these tests and their high cost.
Besides stability and control characteristics (to be checked with the static balance tests), also omega rotation speed damping values can be obtained through the tests in question. With these tests it is possible to work with an extra dimension,

besides the alpha and beta common variables, a adimensional rotation speed (wb/2V) can be taken into consideration.
With a rotary balance there are the same problems as with a static balance as regards model supports: here too it is necessary to avoid interferences as much as possible, at the same time attaining the purpose of supporting the model in the whole AOA range without a remarkable alteration of aerodynamic flows.
Tests can be performed with sufficiently high Reynolds numbers by increasing wind speed and by means of big wind tunnels and big models.
It is important to choose the proper ?b/2V field and keep the tests to the strict necessary in order to maintain both time and costs to a minimum and, at the same time, obtain the required data on behaviour simulation.
The potential of these tests for the study of AOA behaviour is very high. It is possible to obtain also remarkably accurate damping derivatives due to accelerations by performing the tests with a model rotating around an axis which is not in line with the wind drift.

• Wind Tunnel Tests with Oscillating Balance

Stability and control characteristics, as well as model damping characteristics can be obtained from oscillating balance tests.
For behaviour evaluation purposes, static and rotary balance results can be compared.
Usually, I did not use the results of these tests since I did not have high AOA data available and I could not become so familiar with the oscillating balance as I would have wished.
Only recently (about 1985) I have had the opportunity of having at hand rather reliable data and I could thus make significant comparisons.
Hysteresis areas can be well traced and stability and control data are rather reliable. The same cannot be said about damping characteristics which in some cases gave very different results as compared with rotary balance data and less similar as compared with the aircraft behaviour.

In any case I deem that having these data too is a positive fact. In this way, it is possible to have a thorough cognizance of the behaviour.
In general we can assert that the high alpha spin attitude includes a rotary motion and an oscillatory motion. The rotary portion is represented by rotary balance tests and the oscillatory portion can be obtained with oscillating balance tests.
The main motion is the rotary one and a possible mistake with oscillatory motion data does not entail big behaviour discrepancies.

- Flying Models

The tests with flying models, both propelled and not propelled, are often performed for high AOA behaviour studies.
Theoretically these tests are most effective because through the model it is possible to carry out all the aircraft maneuvers, evaluating possible danger conditions.
Jet microengines have been available since a number of years and it is possible to simulate very well the actual airplane through the model.
Several years ago the tests in question were performed dropping the model from an airplane or a helicopter. Some companies have used even captive pilot balloons.

As I read in Chinese documents, even missiles are used to take the model to high altitude. This technique is quite satisfactory with general aviation aircraft or with low wing load airplanes since it is easy to make a model capable of taking off on its own and carry out a complete and inexpensive test campaign.

I often followed this analysis criterion and in some cases we accepted to fly dynamically out of proportion fighter models in order to maintain a low wing load and easily fly the propelled model.
In case of instrumented models it is possible to obtain all dynamic derivatives through parameter identification programs, as well as to obtain a mathematical model for a flight simulator.

The reliability of these tests gave excellent results, even better results than those obtained in vertical wind tunnels since it is possible to work with bigger scale models and all entry maneuvers, which in a vertical wind tunnel are neglected, can be simulated.
Modern technology makes it possible to proceed with a miniaturized instrumentation and a model can be equipped with instruments at rather low costs.
Should we get a good shot of the tests, we would have a qualified result as to the behaviour and in many cases this is more than sufficient for our scope. A good film gives indications on the spin typical attitude, rotation speed, entry control effects, during the spin maneuver and on recovery. Mostly, this is more than enough to face flight tests with the utmost safety.

- Flow visualization

Flow visualization around high alpha aircraft is very useful in order to become aware of what occurs and to find the best solution when correcting possible incorrect behaviours.
An evaluation of the flow characteristics can be given with static, rotary or oscillating balance tests through the installation of mini-tuft in the interested area or through particular solutions with oil paintings.

Also interesting are the visualizations which can be obtained in a water tunnel. With these tests the simulation is excellent and the areas connected with separated flows on high AOA aircraft can be accurately evaluated. The model in a water tunnel can be static or can be rotated. Both methods can be visualized.

2.1. FLYING QUALITIES FOR HIGH AOA

With new generation fighter aircraft it is possible to fly at relatively high AOA, however it is not easy to guarantee a good maneuverability at high AOA. In particular the turn performance becomes very low and the airplane becomes practically motionless, as well as slow while maneuvering, even longitudinally, due to dynamic low pressures associated with high AOA. Under these conditions it is possible to have good maneuver capabilities only when using a thrust vector.
If we have to establish high AOA flight requirements, we could start with the normal flying qualities MIL requirements and derive them for high AOA regions.
In particular, it is necessary to guarantee a good stability and a control possibility to be adequate to the mission to be performed, avoiding to create undesired autorotation conditions. Considering the fact that these are aerodynamic data, in the preliminary project phase, we should try to eliminate such configurations which entail: strong longitudinal stability changes on AOA changes (C_m essentially linear with alpha in the whole operating field), substantial changes to directional stability (C_n vs beta and C_l vs beta essentially correct) and a positive effectiveness of flying controls.
In addition, it will be necessary to ascertain that the configuration is not inclined to autorotate in such a way as to provoke control loss. Control effectiveness, for the whole alpha field, is to reach such a level as to counteract asymmetries due to autorotation phenomena and the autorotation phenomena should be limited to a minimum and be such as not to cause stable spin conditions of the aircraft when controls are neutral.
This last condition should bring about safety conditions in case of failure of the flight control system.
Among the problems which are to be faced during the designing phase there are those covering the flight controls which are to be dimensioned to operate through the whole speed range and as for the maximum required high AOA .
The standard method to meet these requirements is to obtain variable gains. The controls deflection range attainable in flight depends on flight speed. Up to a certain speed the pilot is in a position to select full controls deflections. In case of higher speeds, deflections are reduced in consideration of a dynamic pressure law.
It is necessary to finalize a rather firm criterion in order to be able to recognize these conditions without making mistakes since in case of speed sensor malfunctioning - and this may easily occur with high AOA maneuvers - the gain system could

fail and the results would mean non perfectly operating flight controls.
This could be a reason for requiring a configuration capable of recovery from control loss conditions with neutral controls.

2.2. DEMONSTRATION REQUIREMENTS OF STALL AND SPIN FLIGHT TEST

Stall requirements generally cover a warning which must have a certain margin as compared to stall speeds themselves or the speed entailing a control loss and the maximum wing drop allowed by stall.
Only seldom do stall warnings occur naturally. Therefore, usually it is necessary to adopt artificial systems, like the “shaker” controlled by alpha or dynamic pressure sensors.
With general aviation aircraft less sophisticated and inexpensive systems are adopted, like acoustic indications given by depressure on the leading edge.
The stall wing drop can be easily contained within certain limits through stall strips at wing root, with nose drop towards the wing tip before the ailerons.
More difficult to be corrected by means of small changes are the pitch up phenomena or in general loss of control at stall due to non controlled autorotation or lack of control effectiveness.
In case the stall appears dangerous, a system is to be introduced which pushes the stick forward, should the pilot insist with the stall (Stick Pusher).
As far as the spin is concerned, the requirement is determined since the design phase for a military airplane, while well settled tests are required for a civil airplane.
I personally believe that civil rules are to be considered as an essential minimum, while the behaviour is to be more thoroughly investigated during flight tests.
Unfortunately it is enough to meet the rules in order to obtain a certification and often the pilots who purchase the airplane fly as test pilots without knowing it.
Two years ago I certified an airplane (SD 27) according to the JAR-VLA new rules. Spin tests are not required, but I preferred to carry them out experimenting up to 4 turns since I know that several pilots consider it normal to perform spin maneuvers.
In order to certify an airplane according to FAR 23 rules, three turns are required. In some cases only three spin turns are performed during a test flight.
In most cases a spin is considered wholly developed after two turns and the airplane can be considered safe. There are configurations however where the spin is not completely developed and recovery is possible when the maneuver is performed after three turns. Should the spin maneuver be longer, the results would be doubtful or negative.
The same consideration applies to aerobatic airplanes requiring six turns. I deem it essential not to limit tests to the bare necessary, thoroughly evaluating the aircraft behaviour and ascertainny what can occur after a longer spin maneuver. In this

case too it becomes important to seriously carry out the tests, thus avoiding difficulties for the operator.
In case of military aircraft, it is necessary to consider training aircraft and fighter aircraft separately.
For training aircraft the trend envisages civil requirements and, besides meeting the various MILs, also FAR and JAR rules are to be met, at least as regards flight qualities.
To summarize: tests anticipate up to six turns for basic configurations, up to three to four turns for configurations with external loads, one turn for take-off and landing configurations.
In the case of fighters the requirement is mostly to prove a recovery possibility from a developed spin and if it is so the manufacturer has two alternatives:
a) to manufacture an airplane which cannot perform a spin and test all possible maneuvers in the high AOA taken as limit (carefree handling);
b) to manufacture an airplane capable of performing the spin and then proceed with recovery without particular difficulties.
The first solution is the one adopted - it seems - for the F-16, EF2000, Dassault Rafale, SAAB Gripen aircraft.
The second solution seems to have been adopted, at least in principle, for aircraft such as the F-4 Phantom, Mirage F1, SAAB Viggen, F-15, F-18, PA200 Tornado, AM-X, MiG 29, Sukhoi 27 and derivatives.
Unfortunately, due to mass and inertia characteristics, as well as high wing load of a fighter, the time required for spin recovery and the consequent altitude losses may be remarkable and almost always even airplanes submitted to spin tests are equipped with systems limiting the possibility of entry in a developed spin.
In these last few years the concept of supermaneuverability has been developed and a certain amount of work has been accomplished in order to obtain aerodynamic configurations capable of guaranteeing a maneuverability up to high AOA.
NASA activities on new configurations and on an F-18 aircraft are well known and other examples are given by the new Russian fighters from Mikoyan and Sukhoi design bureaux.
If we analyze the above configuration, it seems very positive to have a good directional stability. In addition, the configurations with two vertical tails on fuselage sides are the most suitable to guarantee this requirement.
We also saw manufacture of STEALTH aircraft which seem to have very little to do with agility and can fly thanks to an artificial stability system.
I am not in possession of sure data, however I think that these aircraft encounter some difficulties in recovering from spin conditions and they belong to the first group of aircraft.

2.3. PRE-FLIGHT PREPARATION

During a project preliminary phase, the aerodynamic configuration is evaluated on the base of previous experiences,

calculation criteria, parameter analysis, in order to offer good characteristics both at low and high AOA.
During a project development phase, wind tunnel tests and tests with flying models are usually performed. On the bases of the results thus obtained the aircraft characteristics can be improved so as to carry out flying tests with a sufficient knowledge about the envisaged behaviour.

In my opinion this phase is very important since it enables technicians and pilots to safely face flight tests and thoroughly evaluate test results.
Unfortunately, due to difficulties regarding budget, time, specific know-how, it is not always possible to be completely familiar with the aircraft being tested and with new configurations there are always some problems for whose solution tests flights are to be performed and this entails some risks.
Studies and flight tests are different in case of civil or military aircraft, above all in connection with budget problems.

Not many years ago I had to follow flight tests almost contemporarily both on AM-X and Piaggio P 180 aircraft. Even though the fighter configuration was very traditional, wind tunnel tests on it were quite complete, while excellent tests on static and rotary balances and tests with propeller simulation had been enough for the P 180 aircraft. These tests were by far more accurate as compared to those performed for aircraft of the above class, since it was a three-surface aircraft with T tail configuration which could have given pitch-up problems.

Early in my career I had the opportunity to know the costs of high AOA tests performed on two rather similar fighters.
One fighter had been developed in the United States and the other in Europe and I was surprised at the paramount cost difference: about one third less in the case of the American program.
Let us analyze hereunder the methodologies usually followed in connection with behaviour predictions.

2.3.1. THEORETICAL PREDICTION

It is rather difficult to make theoretical predictions about high AOA behaviour. In some instances it can be very risky to try to solve everything through calculation methodologies. These are always very sophisticated and probably it will be possible to find a criterion accurately simulating flows. At the moment, however, it seems that no substantial steps have been taken and what can be obtained theoretically is suitable only for the preliminary project phase.
In order to develop accurate calculation systems, it should be necessary to be in a position to carry out quite precise tests and be able to turn test results into calculations.
Leonardo da Vinci used to say that if you want to understand the flow motion, take your experience first and then reason into consideration.

At present it does not seem to me they have yet finalized a methodology capable of translating in a complete way such a complex phenomenon as high AOA flows around an airplane.
Theoretical predictions are often based on the experience of similar configurations as previously developed, on geometrical analyses of control and stability surfaces (URVC, TDPF), and they are reliable only as rough approximation and on condition that configurations are actually similar.
This approach was formerly used above all for general aviation aircraft design, where, mainly for lack of funds, wind tunnel tests were seldom performed.

2.3.2. TEST TECHNIQUES AND CRITERIA TO ANALYZE THE TEST RESULTS

As we said under Para 2, the test techniques usually followed for high alpha behaviour study are:
- vertical wind tunnel tests
- static balance wind tunnel tests
- rotary balance wind tunnel tests
- oscillating balance wind tunnel tests
- tests with flying models
- flow visualization

According to my experience, the tests with flying models are the most effective because they enable a complete simulation of the aircraft behaviour, and an evaluation of spin resistance and stall behaviour, beside stabilized spin conditions, as well as recovery characteristics.

Vertical wind tunnel tests are useful but they enable only an evaluation of recovery and stabilized spin conditions.

Static, rotary or oscillating balance wind tunnel tests supply aerodynamic coefficients and give the possibility to build the aircraft mathematical model for the performance of simulations. By means of rotary balance tests it is possible to obtain spin equilibrium conditions, where applicable, with few calculations.
These tests are the most important for high AOA study since through them it is also possible to simulate the stabilized spin behaviour and to have aerodynamic data on the basis of the adimensional rotation speed.
The flow visualizations serve above all the purpose of investigating and better understanding possible behaviours and finding out their origin.

Wind tunnel tests are to be conducted in such a way as to obtain essential data without incurring high costs, nor spending too much time. However, it is important to find the right measure so as not to neglect aircraft safety.
When test results have been obtained through different methods, results are always to be compared and evaluated. It is rather easy to make mistakes and with high AOA it becomes difficult to see them.
In particular:
- the damping characteristics evaluated on a rotary balance must be at least similar to those evaluated on an oscillating balance;
- control and stability characteristics evaluated by means of the various methods are to be similar;
- the spin equilibrium conditions evaluated on the rotary balance are to be similar to those obtained in a vertical wind tunnel or with flying models.

It is important to be sure of wind tunnel data. A further check can be made by performing behaviour simulations and verifying cross-reference with vertical wind tunnel tests or flying model data, where available.
The AOA range to be evaluated in a wind tunnel can be limited to ±90 deg for cruise configurations and -15 deg/+45 deg for take-off and landing configurations. Beta values can be limited to ±10 deg, ±20 deg, depending on the aircraft characteristics.
The wb/2V values for rotary balance tests are to be evaluated on the basis of the maximum values envisaged for the aircraft and evidenced by vertical wind tunnel tests or flying models.

The mathematical model I usually adopt for simulation at high AOA does not generally entail particular difficulties. It is rather similar to models usually operated for low AOA. The only substantial difference is a ?b/2V variable which is here encountered besides the usual alpha, beta, Mach variables.
It is necessary to be familiar with high alpha aerodynamic data and be aware of the various coefficients impact on the aircraft behaviour. This knowledge facilitates remarkably the job and enables to avoid useless difficulties for the mathematical models.

Due to the low dynamic pressures associated with high alpha evolution and due to the high inertia with new generation fighter configurations, it occurs that 50 percent changes on damping and stability coefficients do not alter the behaviour effectively and therefore it is not necessary to make the mathematical model unnecessarily complex to reflect the changes of some coefficients.

2.3.3. GROUND BASE SIMULATOR.

When we try to analyze a motion like a stall or a spin by simplified calculation criteria the results cannot be very accurate and they can lead to gross mistakes.
According to our experience, the best way of evaluating a behaviour is to perform behaviour simulations by means of calculation programs which solve six DOF equations of motion. Such programs are now available on small PCs and they enable a quite complete behaviour evaluation.
Predictions reliability is undoubtedly tied to the accuracy of wind tunnel tests and to the results given by the various coefficients covering the aircraft flight characteristics. Our experience leads us to rely on simulation systems which proved suitable to reflect even phenomena connected with high AOA in a more than satisfactory way.
Most work can be carried out at rather low costs by following simulation programs operating on small PCs. In this way costs can be limited to a minimum and we can obtain a complete work. Simulations can be performed starting from trimmed flight conditions and evaluating spin resistance characteristics and the most suitable maneuvers for spin entry. Alternatively we can start from prerotated spin initial conditions, as done with vertical wind tunnel tests, and evaluating recovery and stabilized spin characteristics.
It is possible to adopt emergency system mathematical models (anti-spin parachute), to check drag surface dimensions and also to evaluate the behaviour, in case of recovery with a deployed parachute. Effect of external stores, asymmetrical loads, all possible failure conditions can be evaluated without particular difficulties since in general they can easily be translated on a simulator.

Once the calculation models have been verified, common flight simulators can be used, where available, thus offering the pilot the possibility of performing the behaviour evaluation in real time. During the AM-X development I could carry out this job in a complete way and the test pilot could perform evaluations with a flying simulator, even at high AOA, before the flight tests.
The following work schedule has been adopted:
- the maneuvers envisaged for each flight test were tested on the simulator by a pilot assisted by flight mechanics technicians and simulator specialists;
- on the basis of simulation results, the system reliability could be checked. It was then possible to proceed with the flight tests with better familiarity and a good safety standard.

Flight test results confirmed the representativeness of the simulation evaluations and the correctness of the predictions made.

I pointed out on purpose that simulator flight tests were carried out by the pilot assisted by flight mechanics technicians and simulator specialists. Actually, the flight

simulator is only a big videogame with many limitations. It is important not to leave the range where the simulator can operate correctly during the tests. It is also important to accurately check the data banks and the mathematical models, as well as evaluate the system within the high AOA and yaw ranges which are considered significant.
Should these limits be overcome during a simulation, the results would no longer be effective and they often would lead to strange aircraft behaviours which could be misinterpreted.

The system evaluation for the high AOA work is not easy and sometimes even gross mistakes with data banks are difficult to be detected. The risk is that the test pilot may evaluate an aircraft model which is not very representative and draw wrong conclusions. It is therefore important to ensure the presence of the technicians who have to do with the data banks and the simulator specialists in order to be able to tell the behaviours which are representative of the aircraft from those due to the data misinterpretation or limitations typical of the simulator.
For this reason it is worth keeping the simplest possible aerodynamic data base, in order to be able to check data. It is also advisable not to use complex mathematical models that can lead to mistakes which are difficult to be found, as well as have a sound experience on high AOA behaviour, so as to be able to detect incorrect behaviours which are the consequence of mistakes as regards inertia and aerodynamic data.
We must bear in mind that the pilot, when using a simulator, is led to perform emphasized maneuvers, and to keep spin conditions for a very long time, which is not compatible with actual maneuvers during flight tests: that is why it is difficult to remain within the limits of the machine.

2.3.4. COMPILING METHOD OF TEST PLAN AND STALL AND SPIN TEST PROGRAM

High AOA test schedules and time predictions required for test performances are mostly inaccurate since during tests we can be faced with unexpected behaviours which require additional wind tunnel studies or tests in order to safely complete flight tests.
With fighters in some cases it is preferable to carry out a test campaign in two phases. The first phase would require clean configuration tests, while the second phase would envisage armed and asymmetrical configurations.
The required times can be very different according the aircraft complexity. However, much depends also on the preparation before simulation tests and above all on the preparation of the staff responsible of the tests.

High AOA tests can usually be performed on a regular basis only in a flight test center. With aircraft companies, tests of this type are carried out every ten years or even more seldom and every time it is necessary to find experienced

personnel, where still available, give instructions to this personnel, become familiar again with the different safety systems, test them on the ground or in flight, equip the ground station. Reliable staff may no longer be available and even among managerial staff there may be none who followed tests of this type in due time. In this case it is necessary to start practically from the beginning and even flight tests require quite a lot of time.
Also very important is the pilot preparation. It may occur, that there are no aircraft available at the company suitable for spin training and flight tests are faced on a new fighter with a poor standard of training.
It is important for a pilot to feel confident about the job he is doing and to participate to the test preliminary stage.
It is paradoxical, but in most cases the personnel attain a sufficient preparation degree only after flight test completion.

It is quite desirable to have a wind tunnel and a flying model available during flight tests so as to be able to perform the tests which would appear necessary to clarify possible results for not envisaged tests.
In general when predictions are correct, flight tests can be completed within a very short time.

In many cases during flight tests, it is not possible to detect all spin maneuvers and the operational pilots may succeed in discovering behaviours which had not been detected before. This happens for different reasons: in the first instance when the tests are performed by means of a prototype airplane which is not completely representative of the operating airplane; on other occasions the test program does not envisage certain maneuvers which are often carried out by operational pilots. It is therefore desirable to arrange tests with a joint pilot team, so as to avoid partial evaluations. Of course the fact of having more pilots testing an aircraft extends the time required for the tests, but it guarantees more reliable and complete results.

For a military trainer all tests required to complete flight tests can be performed within a year. For a fighter two years are required: in general one year is necessary for wind tunnel and simulator tests and another year for flight tests.
In the past I have carried out tests on a trainer in less than four months. Wind tunnel tests were limited only to static and rotary balance tests and flight tests were performed within a little more than two weeks with two flights per day. The time required for tests can increase considerably when the aircraft is equipped with a new-generation engine and therefore also the engine behaviour is to be evaluated.
For general aviation aircraft (SD 27) the tests were limited to a radio-controlled model and all the tests were performed within less than two months, e.g. one month for model manufacture, two weeks for model tests and one week for airplane flight tests.

2.3.5. EMERGENCY RECOVERY DEVICES PRESENTATION

An aircraft high AOA behaviour was considered difficult to be predicted with certainty. Therefore, systems capable of guaranteeing a return to normal flight conditions, in case of emergency, were developed. The most common is the antispin parachute installed in the aircraft tail, which can be opened by the pilot and which is released after recovery from spin. Also rockets placed on wing tips or aircraft tail were used.

Recently, quite a number of studies about the possibility to use rockets or alternatives to the parachute were conducted since in order to guarantee spin recovery it is necessary to install parachutes of remarkable dimensions which entail heavy tail loads. Moreover their installation often requires a rugged reinforcement in the tail area.
Actually, a safety system, in order to be considered as such, is to ensure recovery from the worst spin conditions and with all flight controls deflected pro-spin. Should the pilot use controls to obtain recovery, the system cannot be considered an emergency system but only a flying control aid.
The criteria of dimensioning anti-spin parachutes used in the past were very simple and did not give good guarantees of recovery above all in the case of aircraft with heavy wing load, apart from the airplane characteristics, and they were based only on features like wing span, fuselage length, and wing load.
The parachute dimensioning can be easily carried out in a vertical wind tunnel, as well as with calculation systems. The vertical wind tunnel dimensioning seems more reliable since it enables the evaluation of the aircraft wake effect and a good compromise with the purpose of determining the length of the connecting cable to the airplane.

The parachute is still the most used system since, once it has been opened, it is capable of aligning along the wake and supplying the necessary yaw effect which serves the purpose of recovering from spin without further interventions on the part of the pilot.
The connecting cable length is to be such as to take the parachute away from the aircraft wake and at the same time it should not be too long so as to enable the parachute to supply a good yaw effect which is essential for spin recovery.
The parachute pitching moment serves only the purpose of recovery from deep stall conditions; for recovery from spin conditions it is not strictly necessary.
The problems to be solved for the parachute installation are aerodynamic. The installation should not alter significantly the aircraft shape: big parachutes encumber considerable volumes and it is not easy to find an area in the airplane tail for their installation.

These problems cover:

- structures, since the loads given by the parachute are remarkable and often stronger than the tail structure. It is mostly necessary to reinforce structure and to limit the flight speed;
- systems, since it is necessary to guarantee the emergency system reliability by separated controls and ensure the possibility, once the parachute is open and the airplane is recovered from spin, to release the parachute as the landing becomes dangerous, should the parachute remain linked to the airplane.

Personally, I have never used rockets as emergency systems. They are not much used since they are much more expensive than parachutes. In addition they require an automatism or the pilot intervention who is to evaluate the spin direction and operate the right rocket for spin recovery.
In case of control loss and during some maneuvers, it is a problem for the pilot to recognize the spin trend and probably even an automatism in case of a very oscillatory spin may not correctly operate.

Under other respects, rockets are more desirable than parachutes since they do not bring about strong loads on the structure (for spin recovery only the yaw moment is required) and they are less encumbrant than parachutes.
Some aircraft companies prefer not to install the anti-spin parachute since during some maneuvers the cable could damage the flight controls.
The present trend, in case of new configurations, is to always install a parachute, even if many improvements have been achieved about the flight quality behaviour predictions.
Only at the end of the tests, it is necessary to remove the emergency system and verify the aircraft behaviour in the operational configuration.

2.3.6. MODIFICATIONS TO BE INTRODUCED IN THE AIRCRAFT

The changes to be introduced on an airplane which is to face high alpha tests are different according to the aircraft class.
Mostly, for a general aviation aircraft, it can be enough to envisage a canopy rapid release system to enable the pilot to escape in case of an emergency.
For certification purposes according to FAR 23 it is not necessary to have instrumentations on board. In most cases it is sufficient to install one or more cameras enabling aerial shots.
Flight tests are followed via radio by the pilot or ground technicians and possibly filmed from the ground or from a chase airplane.
When sufficient wind tunnel or flying model tests have been performed and the operator is confident about the estimated

behaviour, the installation of an anti-spin parachute can be avoided.

On occasion of the SD-27 airplane certification, the following procedure was adopted.
The behaviour predictions have been made only on the basis of a 1:6 scale radio-controlled flying model and the canopy was ready for rapid release, the maneuvers were filmed from the ground since it was a very clear day and it was not deemed necessary to fly a chase airplane.
Sometimes additional instruments used on purpose for spin tests are added on the panel (spin panel). They include: a precision altimeter, a turn-and-bank indicator, as well as two lights indicating the rotation trend which are switched on when the yaw rate exceeds a preselected limit (15 deg/sec).
To film the instrument panel can be useful to reexamine the maneuvers and give comments in the test report. A voice recorder can also be installed.
When the proper instruments are installed on the airplane, the test results can be better evaluated and should it be possible to have the results in real time on the ground station, the technicians can follow the maneuvers and supply the pilot with useful information where necessary.
As regards general aviation airplanes, changes to the fuel system and the engine are not required; it is only necessary to know what are the possible limits, in order not to exceed them.
In general aviation aircraft limits can be due to stresses on the propeller (gyroscopic moment), prolonged reverse flight attitude originated by engine lubrication and fuel problems, as well as speed and load factor limits.
At times it is easy to exceed these limits above all when performing tests in the take-off and landing configurations.
Since in these configurations it is not required to evaluate a developed spin, it is usually allowed to retract flaps and landing gear, should the structural limits be exceeded during the maneuvers.
I have heard of propeller and crankshaft failures during stall tests on big twin-engine airplanes or during spin maneuvers on acrobatic airplanes with engine at maximum rpm.
Should it be necessary to carry out tests on fighters, the changes to be introduced on the airplane to attain a certain degree of safety are more demanding, above all when flight controls depend on engine hydraulic or electrical supplies. In this case it is a must to envisage additional engine starters and emergency systems in order to obtain the required hydraulic and electrical supplies.
Systems such as the ram-air turbine are here scarcely suitable since, due to high attitudes and the low dynamic pressure associated with these maneuvers, they are not always capable of guaranteeing a good operation.
Usually the problem is solved with emergency and auxiliary batteries or with an APU (Auxiliary Power Unit) which starts operating immediately in case of an engine failure;

alternatively, a hydraulic accumulator can be installed on each flight control channel.
It is advisable, in any case, to select a test area so as to be able at least to come back to the airfield with a dead stick since the engine may have been damaged and the relight may be impossible.

In twin-engine fighters the tests can be performed with one engine running, while the other engine is prearranged for relight in case of failure of the first one.
As for variable gains flight controls, it is possible to install a system controlled by the pilot on the airplane or by a safety pilot from the ground who bypasses air data. This allows a maximum gain in case of control failure.
It is advisable not to install automatic systems which can in turn be the subject of failure.
The same considerations apply to the emergency system (anti-spin parachute or similar). It is better to have a simple and very reliable system rather than using complex systems which may undergo failures and require accurate controls in order to guarantee a sufficient degree of safety.

We must know the high AOA engine characteristics. In some cases throttle shifting to "idle", during high AOA maneuvers, prevents engine shut-off, while in other instances, throttle position is not to be changed since changed rpms certainly lead to engine shut-off.
Some engines are limited by negative load factors and this limitation may be such as not to enable the evaluation of an inverted spin behaviour in a complete way with the engine running.
It could also be necessary to change the air data system to have more accurate data at least with maximum positive AOAs.

Usually, high AOA and sideslip sensors are installed on fighters. To enable the pilot to perform a good check of the situation, it is advisable to have these indications on the instrument panel.
Besides installing easily readable altimeters, almost always it is necessary to arrange for installation of warning lights pointing out the requirement of ejection in case of a too low altitude.

Another necessary change is the one for data recording and telemetry systems which is to be equipped with an emergency battery in case of electrical failures.
Obviously also the instrument panel of such an airplane may be quite different from an operational aircraft panel, due to the different changes which have been introduced on the airplane.

The spin maneuver on some fighters may turn out to be violent and therefore it is advisable to arrange additional straps on the pilot seat and helmet to avoid that accelerations may originate control loss or physical damages to the pilot.

A check of the fixings of the various board installations is also required to ascertain that they are capable of withstanding the envisaged accelerations.
Also as regards changes to be introduced on the airplane, an accurate check before test flights enables an evaluation of the actual requirement of safety systems, as well as the choice of the strictly necessary changes, so as to avoid to have an unnecessarily complex airplane.

Some aircraft companies have proceeded with test flights of new configurations without introducing substantial changes and without installing emergency systems.
This can easily be obtained when a team including technicians and pilots is well prepared and confident about their job, in case of new configurations and at least with engines of well known reliability.

2.3.7. PILOTS AND FLIGHT TEST ENGINEERS TRAINING

Pilots and technicians training is essential to carry out the tests safely. Only with qualified personnel it is possible to eliminate inconveniences in a short time. Problems must be mostly solved in real time to escape an emergency situation.

It is unpleasant to be at a ground station while the flying airplane is having some problems. It is difficult to remain cold and collaborate, above all if without an adequate experience.

Several years ago, when telemetry systems did not exist, the pilot was to be in a position of recognizing the various spin conditions and evaluate the best recovery maneuver. An engineer could only talk by radio and supply information on the basis of the envisaged estimations and possibly remind the pilot about the emergency procedures agreed before the flights.

A substantial assistance to the pilot could be given by another pilot in a chase airplane. Still nowadays the tests of general aviation aircraft are mostly carried out without a telemetric system.

It is required that both pilots are test pilots with a good experience on high AOA tests. In particular, for the test pilot, a good knowledge of the airplane being tested is required (flight qualities and emergency procedures).
Should the spin behaviour predictions be such as to entail strong accelerations, it is advisable for the pilot to get trained in a centrifuge.

Before flight tests it is necessary to perform several spin maneuvers by means of trainers qualified for carrying out spins.

This training will put the pilot in a condition to be able to better analyze the airplane behaviour and easily bear the loads during the maneuvers.
The spin effects on the pilot in some cases are upsetting and it is easy not to recognize the rotation trend, above all in case of inverted spins. A good training reduces the possibility of making mistakes to a minimum.

With a telemetric system it is possible to monitor the aircraft maneuvers. The ground personnel, engineers and safety pilot, may have a complete control of the situation and sometimes make decisions also for the test pilot who certainly encounters bigger difficulties in recognizing the spin direction when submitted to violent swings.
Some aeronautical companies have arranged small flight simulators supplying the ground station with flight data.
The staff is trained to recognize the maneuvers on the basis of the data received at the ground station.
It is of course necessary that all the personnel associated with the tests is familiar with the results of the predictions.
The pilot should follow vertical wind tunnel or flying model tests personally.
In fact, in general it is not enough to read the test report.
Also engineers should be well acquainted with the test results and the performed simulations and have a good familiarity with high AOA maneuvers and the aircraft limitations.

2.4. TEST PROCEDURES

The test procedures depend on the aircraft configuration and class.
As a basic criteria, I deem it necessary to proceed by degrees starting from the simplest configurations. For example: try first clean configurations and then the armed ones and the asymmetric ones; the normal spin first and then the inverted one.

This approach enables the operator to become self-confident and face the most dangerous conditions with better reliability.
As previously mentioned, it is difficult to have well trained personnel available, while it is rather easy to lose control of the situation and make mistakes during the tests.
A data interpretation mistake in the initial phase may bring about loss of reliability towards the team to the job detriment.

2.4.1. HOW TO ARRANGE THE FOUR TEST PHASES A,B,C.D ACCORDING TO MIL-F-83691.

In these last few years, a remarkable importance is being given to the behaviour of stall/departure phases of out-of-control flight.
Personally I believe this type of approach correct, since the pilot is above all to be in a position to recognize the spin/departure phenomenon in the initial phase and possibly recover the aircraft and limit the control loss.

The complete performance of these tests require a certain length of time since also in a general aviation aircraft or a trainer the implied variables are different, such as: deceleration plus or minus slow (1,3,5 Kt/sec), engine setting, controls sequence and speed, configuration.
The results are quite significant and enable a complete evaluation of spin characteristics, as well as the best entry and recovery maneuvers from incipient spin.
On certain fighters which are not qualified for a safe recovery from spin, the above are the only maneuvers which can be performed and, should there be good guarantees of spin recovery, only Phase "C" is carried out.

In order to obtain a good scheduling of the test in question, it is always important to compare results with predictions, as well as update mathematical models before the tests, where necessary, so as to be able to envisage the aircraft behaviour during the tests with a good approximation.

With a simulation program it is possible to easily reproduce the different maneuvers and immediately obtain an indication as regards the predictions reliability.

In particular, the possible aerodynamic asymmetries on a fighter can be evaluated finding out the roll and yaw accelerations which had not been commanded by the pilot, the autorotation characteristics on the basis of the remaining rotation speed during the recovery, the longitudinal moment determined by the control stick to maintain the AOA.

The AOA (alpha) value can be verified on the basis of the ratio: rolling rate/yaw rate, while the control effectiveness is ascertained by the accelerations due to deflected controls. Practically by performing stall tests it is possible to obtain useful indications on prediction reliability and easily face the subsequent tests by deflected laterodirectional controls.

These tests may also serve the purpose of evaluating the actual control power requirements, as well as optimize its range in order to guarantee a better spin resistance and facilitate its recovery from departure conditions.
It is relatively easy to evaluate stall and departure conditions through a control partial deflection, in case of excessive effectiveness, while, within certain limits, ranges can be increased in case of scanty effectiveness.
It is always necessary to introduce changes which do not disturb low AOA behaviour and do not alter control effort values excessively.

An accurate evaluation of the different control effect allows sufficient data for the preparation of a flight control system limiting spin entry and departure possibilities, where necessary and evaluate the effective requirements of possible control interconnection (aileron-rudder interconnected).
Sometimes this interconnections allow the resolution of some low AOA behaviour problems, however, they are not very suitable to guarantee a good spin resistance.

In some cases a longitudinal trim may be used to change the longitudinal control power during the tests (control configuration with stabilator trim) and proceed by degrees in the behaviour evaluation on AOA basis.

The lateral control effect for fighter configurations generally changes with alpha (LCDP changes sign) and during these tests rather accurate data are obtained.
It is necessary to carry out evaluations also at relatively high speeds and to detect alpha limits and load factors which may lead to violent autorotations and control losses.

2.4.2. TYPICAL DEMONSTRATION ACTIONS AND PILOT TECHNIQUES

It is rather complex to determine typical demonstration actions since the pilot should be able to perform any maneuver within the limits of the flight envelope and in some cases beyond these and be able to control the situation.
In case the airplane escapes the pilot control beyond a certain attitude, it is necessary to demonstrate that there are recovery possibilities or behave in such a way as to avoid reaching these conditions with automatic limitations of flight controls.

In general aviation airplanes the requirements (FAR 23, JAR 23) usually claim recovery from a spin after one turn or three seconds, whichever takes longer, in no more than one additional turn for cruise, take-off and landing configurations.

Should the airplane be of aerobatic type, six spin turns are required and the airplane must recover from any point in a spin in no more than one and a half additional turns after initiation of the first control action for recovery.

However, the requirement I believe to be essential is that "it must be impossible to obtain unrecoverable spins with any use of the flight or engine power controls either at the entry into or during the spin and there must be no characteristics during the spin (such as excessive rates of rotation or extreme oscillatory motion) which might prevent a successful recovery due to disorientation or incapacitation of the pilot".

Recently for trainer airplanes (US JPATS program) civil aviation regulations have been adopted as reference and I think that a typical demonstration of AOA behaviour is to envisage all possible maneuvers and check that in no case dangerous situations may be reached.

Personally I deem it necessary for a general aviation airplane to demonstrate a recovery possibility at least from three spin turns for a cruise configuration and from a turn for a take-off and landing configuration. For a trainer and an aerobatic airplane the requirement is to demonstrate the recovery possibility from more than six turns in clean cruise configurations and from at least two to three turns in configurations with external loads and again from a turn in take-off and landing configurations.

For a fighter able to recover from a spin three turns of developed spin in clean configurations and one turn in armed or take-off and landing configurations may be enough.

Pilot techniques must be the most different possible so as to point out all possible behaviours originated by aerodynamic effects and gyroscopic moments.

It may happen that sometimes when the airplanes reach their Operational Air Base, behaviours are discovered which had not been found out during test flights and often these behaviours are not due to differences between the prototype airplane used for flight tests and the operational aircraft.

2.5. TEST INSTRUCTION SHEETS (TIS)

The TIS are documents that collect briefly all the work that must be done for flight test activity.
In the TIS usually the predicted behaviour is presented, and all the emergency systems that can have been installed are described.
In order to organize the activity it is also necessary to define the number of specialists and pilots required, as well as the test area.

Several companies are used to prepare TISs divided into two parts. The first one describes how to prepare the flight test airplane, the ground station and how to perform the tests. The second part collects the results of the flight tests and the eventual changes of the preliminary program.

Due to the high risk of high-angle-of-attack tests the TIS is usually difficult to prepare because it is necessary to satisfy several requirements and it is mandatory to clear the airplane with the lowest cost and lowest risk. On several occasions the tests are divided into different phases due to contractual problems or due to the necessity to open the flight envelope.

For new-generation fighters, usually, it is necessary to discuss the "test philosophy" with the program management and it is not easy to chose a good compromise for reasons of safety, time, cost of the program and clear the configuration in a complete manner.

Here is an example of a list, to be used as a guide, to the chapters of a typical TIS for a new-generation fighter, as follows :

1. Clearance Objectives
2. Introduction
3. Basic Trial Philosophy to Achieve Clearance Objectives
4. Test Equipment

4.1. Aircraft Description

4.1.1. Aircraft Safety Equipment

4.1.2. Anti-spin Parachute

4.1.3. Stability Augmentation, Controls Gain, Cut-out

A typical TIS splitted into two parts can be the following:

1.1. Introduction and Purpose of The Test
1.2. Requirements, MIL
1.3. Preliminary Report or List of Data Necessary to Perform The Tests
1.4. Aircraft Configuration
1.5. Flight Limitations
1.6. Necessary Instrumentation or Flight Test Installations
1.6.1. Modifications to Be Introduced in The Airplane,
1.6.2. Modifications to Be Introduced in The Ground Station
1.6.3. List of Parameters to Be Recorded
1.7. Criteria to Perform The Test and Definition of The Flight Test Area
1.8. Staff Necessary to Perform The Test Activity
1.9. Time Schedule
1.10. Required Output
2.1. Criteria Used to Perform The Test (a description of introduced changes, if any, into the procedure or instrumentation required in part 1)
2.2. Results
2.3. Flight Test Responsible Observations and Comments
2.4. Flight Test Data Analysis
2.5. Conclusion and Recommendations

In my opinion it can be better to prepare the TIS for a completely new configuration in order to perform the test in various steps, and leave open the possibility to modify the procedure as function of the test results.
As an example it can be better to perform the test first in the clean configurations and then in the configurations with external stores.

The preparation of the TIS in two parts is also helpful because the specialists are more prepared to submit the results and it is easier to prepare the final report at the end of the flight test.

2.6. FINAL REPORT

The final report should include the complete panorama of the work.
It is important to collect all the work done and its chronology, the purpose and the methodology of the tests.

Usually only the most significant time histories are included in the basic report but all the test results should be included in an Appendix.
In the final report it is necessary to include a description of the airplane with all the modifications made and the description of the emergency recovery systems. Test performed on the systems must also be documented and all the differences between the test airplane and the production airplane must be included.

It can be useful to include all the pilot reports, the summary of the envisaged work done and the results of the parameter identification work performed.

The typical chapters of the final report should be:

1. Description of The Test Aircraft
2. A Chronology of Tests
3. Loading and Configurations Tested
4. Number of Flights
5. Flight Restrictions Observed
6. List of Parameters Measured
7. Method of Control Applications
8. Discussion of Results
   - 8.1. Spin Resistance Characteristics
   - 8.2. Developed Spin Characteristics
   - 8.3. Recovery Techniques
   - 8.4. Engine Performance
   - 8.5. Time Histories of Typical and Unusual Spins
   - 8.6. Flight Manual Preparation.

2.7. TRAINING FILM

It can be rather difficult to describe some typical behaviours in the high angle-of-attack maneuvers. In some instances even the chase plane pilot is not able to describe thoroughly the maneuver he has seen. Therefore it is possible to obtain a sufficient information for an evaluation of the behaviour of the aircraft by means of a movie shot. Today this is normally performed by means of a TV camera and videotape recording.

A student pilot would find it even more difficult to understand the actual aircraft behaviour and become aware of what actually happens, without the help of a training film.
A training film is required also by regulations and it is my opinion that a good training film is more useful to a student pilot than a flight test report, because it is more directly understandable and in many cases self-explanatory.
Normally, besides the shots on the more relevant maneuvers, the film includes shots on the foreseen behaviour works, such as the vertical wind tunnel tests, flying model tests, flight simulator tests, etc. The aircraft used in the tests, the safety systems installed and the test methodology are described.

The flight tests can be filmed from the ground, from the chase aircraft or by means of cameras installed in the test aircraft itself. Usually, during the editing, by combining and sequencing the shots made from different points of view, it is possible to describe very well even the most complex maneuvers.
It has become a normal procedure, before executing a spin test in an unknown (or not familiar) aircraft, to require to see at least the training film; or, if this is not available, at least the film shots of the relevant maneuvers.

In my experience I have had the chance to participate to the preparation and editing of some training films, and I must admit that it is not a simple and easy job. Good air-to-air shots, in particular, are not easy to be performed and require very experienced chase plane pilots and cameramen. And at the end of the process, an experienced flight test technician and film director is required for a satisfactory editing of the training film.

3. CONCLUSION

I have tried to gather in this document the considerations that I deem most interesting and relevant to the subject and to add my personal experiences.

In the recent years many steps forward have been made in the study and forecast of aircraft behaviour at high angle-of-attack. This allowed to widen the flight envelope of new-generation fighters and to perform flight maneuvers that were considered impossible until a few years ago.
These “impossible” maneuvers are now performed even at low level in front of big crowds during the air shows.

The methodology for studying and predicting aircraft behaviour at high angle-of-attack normally does not require complex and costly facilities. Moreover the simulation systems are becoming cheaper and cheaper, and easier to operate. This means that it is possible to better manage any problem should arise and to face the flight tests more safely.

*** THE END ***