

Criteria to Predict High Alpha Behaviour And Approach to Flight Test



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Criteria to Predict High Alpha Behavior And Approach to Flight Test

SUMMARY

In this report, the most common criteria actually used to predict high alpha characteristics are presented.

The cost-effectiveness of the various methodologies is evaluated, and some suggestions are presented, based on our experience, in order to save time and reduce cost.

A typical approach adopted in our company and a simulation program developed by ourselves are presented.



**Criteria to Predict High Alpha Behavior
And Approach to Flight Test**

INDEX

Summary

List of Specific Symbols

Introduction

High Alpha Prediction Methodologies

Evolution of Methodologies, Present Approach Through Simulation

Simulation

General Considerations

E.V. Company Capabilities

Conclusions

References

Tables



**Criteria to Predict High Alpha Behavior
And Approach to Flight Test**

LIST OF SPECIFIC SYMBOLS

AOA **Angle of attack**

HAOA **High angle of attack**

β **Angle of sideslip**

Cn **Yawing moment coefficient**

ω **Rotation rate about wind vector**

b **Wing span**

V **True airspeed (TAS)**



Criteria to Predict High Alpha Behavior And Approach to Flight Test

INTRODUCTION

High alpha prediction capabilities are essential for a team dealing with aircraft design. With modern technology available, it is possible to predict high alpha behaviour and approach flight test activity with good confidence.

It is needed to avoid marginal characteristics as much as possible, and to be confident in the effects produced by the various elements of the aircraft.

The estimation methodology to be used is a function of the aircraft configuration and, in many occasions, it is needed to consider budget problems as well. In the following chapters we intend to summarize our experience and give some suggestions in order to approach safe flight test activities and, in the same time, avoid spending a lot of time and money.



**Criteria to Predict High Alpha Behavior
And Approach to Flight Test**

HIGH ALPHA PREDICTION METHODOLOGIES

The criteria that are generally used for the study of high angle of attack (HAA) behaviour are the following:

- **Analysis of Parameters**

It consists on the geometric evaluation of some surfaces that are considered of fundamental importance to determine high AOA damping characteristics and flight control effectiveness.

The most common criteria are the TDPF (Tail Damping Power Factor) and the URVC (Unshielded Rudder Volume Coefficient).

In general, every designer uses particular criteria during the preliminary design phase. Only few highly skilled designers can successfully approach flight test without additional evaluations.

Criteria to Predict High Alpha Behavior And Approach to Flight Test

- **Vertical Wind Tunnel Tests**

Vertical wind tunnel tests were the only standard criteria for the study of spin behaviour that one could mostly rely on until a few years ago.

The test model is to be built in geometric and dynamic scales. It is dropped into the upward wind flow in the test section according to different attitudes and rates of rotation. Its behaviour characteristics can be analyzed only qualitatively.

This methodology is still in use, but now it is not considered really important, and it is not conclusive.

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- **Wind Tunnel Tests with Static Balance**

Stability and control characteristics are obtained from wind tunnel static balance tests. Usually the alpha range is as wide as $\pm 90^\circ$, and the beta range approaches $\pm 50^\circ$ for the evaluation of erect and inverted stall/spin behaviour.

The methodology is commonly used, and the two parameters $C_{n\beta Dyn}$ and LCDP can be estimated.

$C_{n\beta Dyn}$ values can give some indications about spin characteristics, and LCDP (Lateral Control Departure Parameter) helps in predicting aileron effectiveness at high alpha.

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- **Wind Tunnel Tests with Rotary Balance**

Systems for the purpose of obtaining rotary balance measurements were developed many years ago. However they have become rather widespread as common test methods only in the latest few years. This delay is due to the fact that it was previously rather difficult to obtain reliable and accurate results with this particular rig.

Additional difficulties were due to the lack of a well defined methodology for the adoption of these results, and their higher cost.

Besides stability and control characteristics (to be checked with the static balance tests), also damping values or derivatives due to rotation speed ω can be obtained by means of these tests.

Criteria to Predict High Alpha Behavior And Approach to Flight Test

With these tests it is possible to work with an extra dimension. Besides the alpha and beta common variables, a dimensionless rotation speed ($\omega b/2V$) can be taken into consideration.

The potential of these tests for the study of high AOA behaviour is very high because they allow to identify the possible spin equilibrium conditions and to evaluate if these conditions are stable or not.

It is possible to obtain also remarkably accurate damping derivatives due to accelerations by performing the tests with a model rotating around an axis that is not parallel to the wind drift.

Rotary balance tests are now used in many research centers.



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- **Wind Tunnel Tests with Oscillating Balance**

Stability and control characteristics, as well as model damping characteristics can be obtained from oscillating balance tests.

This methodology is generally used to provide dynamic derivatives, and it is also used to study high alpha unsteady aerodynamic behaviour.

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Sivel SD-27



- **Flying Models**

Tests with flying models are often performed for high AOA behaviour studies. Theoretically, these tests are most effective because a controlled flying model can perform all the aircraft manoeuvres, and this allows to evaluate all possible dangerous conditions. With instrumented models it is possible to obtain all dynamic derivatives through parameter identification programs, as well as to obtain a mathematical model for flight simulation.



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Should we get a good shot of the tests, we would have a qualified result as to the HAOA 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, control effectiveness during spin, the spin entry and recovery manoeuvres. In general, these data are more than enough to face flight tests with the utmost safety.

Flying models approach was chosen in the past in order to have high Reynolds numbers compared to vertical wind tunnel. It is still used in many research centers and we are considering flying models as the most cost-effective approach for high alpha study in the case of light aircraft.

Criteria to Predict High Alpha Behavior And Approach to Flight Test

- **Flow visualization**

Flow visualization around an aircraft at high alpha is very useful in order to become aware of what occurs and to find the best solution to some flow separation problems.

An evaluation of the flow characteristics can be obtained by means of static, rotary or oscillating balance tests through the installation of fluorescent mini-tufts in the interested area or through particular solutions with oil flow pattern topology analysis.

Also interesting are the visualizations that can be obtained in a water tunnel. With these tests the simulation process is enhanced and the areas correlated to separated flows on aircraft at high AOA can be accurately evaluated.

The model tested in a water tunnel can be static or can be rotated. With both methods the detailed flow can be visualized with colour dye supply system or PIV system.

Water tunnel tests are very effective and have low cost. It is a commonly used methodology.





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And Approach to Flight Test**

**EVOLUTION OF METHODOLOGIES
AND PRESENT APPROACH
THROUGH SIMULATION**

In the Sixties, the high alpha behaviour was estimated only using vertical wind tunnel tests. 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 produce a mathematical model.

Criteria to Predict High Alpha Behavior And Approach to Flight Test

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, or even by dropping the model from a balloon.

In the Seventies, high angle of attack characteristics were not predicted accurately. In several cases it was necessary to perform additional flight tests of trainer and fighter aircraft after several flying accidents, caused by unrecoverable spin, had occurred.

The criteria connected with the development and sizing of the emergency recovery systems were not adequate to help recovering from a fully developed spin.

Criteria to Predict High Alpha Behavior And Approach to Flight Test


Some companies did not consider it essential to investigate the stall angle of attack of transport aircraft in a wind tunnel because a stick pusher was installed.

In 1971, when I started my collaboration with Aermacchi and Dr. Bazzocchi, I got acquainted with a particular device that was installed in the company's wind tunnel. By means of it one could simulate the stable spin characteristics of an aircraft and measure the aerodynamic coefficients during spin rotation. That device is called a rotary balance.

In 1975, thanks to the static and rotary balance wind tunnel data, 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.

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The wide experience acquired in performing wind tunnel tests with static and rotary balances enabled us to evaluate the reliability of the results with a remarkable degree of confidence and to complete our wind tunnel test programs with the capability to identify the most important coefficients and to prepare the aerodynamic data base for complete simulations.

All the research centers in the world dealing with HAOA are now using mainly static and rotary balance wind tunnel tests for high alpha aerodynamic data base preparation, and high alpha behaviour is today estimated through simulation. Vertical wind tunnel tests with dynamically scaled models are no more considered very representative due also to the low Reynolds number obtainable during this kind of tests.

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SIMULATION

Simulation is the innovative criterion to approach HAOA behaviour estimation. Aerodynamic database can be relatively similar to classic low AOA, as we need to consider only an additional dimension ($\omega b/2V$, the non-dimensional rate of rotation) and not only the Alfa and Beta variables.

With simulation it is possible to evaluate the effects of the different coefficients on high alpha behaviour and consider all the conditions of mass and inertia of the aircraft. With new-generation personal computers it is possible to perform real time simulation as well, and a PC can be a low-cost substitute of a classic simulator for the evaluation of the HAOA behaviour.

For this purpose a dedicated simulation program AIRSIM was developed in our company. The program runs on a PC with Windows XP operating system. Thanks to the good accuracy of the algorithm used to obtain the solution of the equations of motion, AIRSIM is able to perform a simulation in all the situations, including spin entry, developed spin and spin recovery.

Criteria to Predict High Alpha Behavior And Approach to Flight Test

The main features of the AIRSIM program are:

PC-based high accuracy simulation software;

Implement reliable and precise aircraft simulation with six degrees of freedom;

Ability to simulate critical situations such as stall, spin and autorotation, and high angle of attack flight conditions in general;

User friendly interface to prepare, manage and use different aircrafts databases;

Graphical and tabulated Time History display and print (see tables 2 through 5).

AIRSIM is an effective tool for:

New aircraft design;

Analysis of aircraft behaviour in all conditions, and particularly in HAOA situations;

Reconstruction and study of aircraft accidents.

Criteria to Predict High Alpha Behavior And Approach to Flight Test

GENERAL CONSIDERATIONS

In an aircraft manufacturing company HAOA tests are performed every some 10 years, or more, in the occasion of the development of a new project. Therefore it is not easy, even for a big company, to have skilled specialists in HAOA at hand when it is needed to perform tests of a new aircraft. Because of such a long period of time, it is difficult to maintain the “historic memory”. For other aspects, technologies associated to the tests are changing very rapidly, and sometimes ten-year-old solutions are no more effective.

We must consider the cost of HAOA tests necessary to approach flight tests in relation with safety. For example, wind tunnel test with static and rotary balance cannot be affordable in the case of general aviation aircraft. In this case, the approach with radio-controlled models is recommended: the cost is very low and the model can be used also for exhibitions. In case of general aviation aircraft or light trainers, due to the low weight of the model and in order to have the dynamic scale, it is possible to fly it as a normal radio-controlled model and it is not necessary to drop it from a helicopter or a balloon to complete the tests.

Criteria to Predict High Alpha Behavior And Approach to Flight Test

E.V. COMPANY CAPABILITIES

Our company has been operating in collaboration with different organizations such as:

NASA (USA), DLR (Germany), DRA (UK), ONERA (France), CFTE (China), ADD (Korea), TsAGI (Russia).

We have participated in different HAOA test programs, and our purpose is to offer consultancy and technical support to manufacturers and organizations in order to approach the flight test maximizing safety and minimizing costs.

The activities performed by our company in several national and international programs are listed in the attached tables 1a and 1b.

Criteria to Predict High Alpha Behavior And Approach to Flight Test

E.V. COMPANY IS PREPARED FOR SUPPORT IN::

- **Preliminary configuration design**
- **Wind tunnel model construction for static and rotary balance tests**
- **Wind tunnel test program preparation**
- **Wind tunnel test conduction**
- **Wind tunnel test results analysis and database preparation**
- **Simulation of aircraft behaviour including HAOA**
- **Radio-controlled model design and construction**
- **Assistance to the flight test with radio-controlled models**
- **Preparation of the test aircraft for HAOA flight tests**
- **Project of a recovery system, if required**
- **Installation of recovery system and verification tests**
- **HAOA flight test activity and assistance to flight tests**
- **Reports editing and assistance to the certification activities.**



Criteria to Predict High Alpha Behavior And Approach to Flight Test

CONCLUSIONS

Wind tunnel tests with static and rotary balances are up to now the best approach methodologies to study the HAOA characteristics of a new aircraft.

The wind tunnel test results can produce enough reliable data to prepare the aerodynamic data base and to simulate all possible conditions.

The simulation activity can be performed by means of a PC with a dedicated simulation program.

Radio-controlled flying models can be considered the most cost-effective approach to the high alpha study of light aircraft.



**Criteria to Predict High Alpha Behavior
And Approach to Flight Test**

REFERENCES

- *AGARD – AR-265 Rotary-Balance Testing for Aircraft Dynamics*
- *AGARD – AR-305 Cooperative Programme on Dynamic Wind Tunnel Experiments for Manoeuvring Aircraft*
- *AIDAA XIV Congresso Nazionale, Napoli 20-24 October 1997
Wind Tunnel Tests at High Alpha and Criteria to Predict High Alpha Behaviour -- Lou Haiye, Ernesto Valtorta*
- *Lecture in CFTE of Xian, China, December 1996
Spin Prediction And High Angle-of-Attack Flight Test –Ernesto Valtorta*


Criteria to Predict High Alpha Behavior And Approach to Flight Test

Aircraft type	Radio-controlled Model Tests	Vertical Wind Tunnel Tests	Static Balance Wind Tunnel Tests	Rotary Balance Wind Tunnel Tests	Oscillatory Balance Wind Tunnel Tests	Erect Spin Performed
MB-326 (Aermacchi) Italy	NO	YES	YES	YES	NO	YES
MB-339 (Aermacchi) Italy	NO	YES	YES	YES	NO	YES
S-211 (SIAI Marchetti) Italy	NO	YES	YES	NO	NO	YES
Jet Squalus (Promavia) Italy, Belgium	NO	NO	NO	NO	NO	YES
SF-260 (SIAI Marchetti / General Avia) Italy	NO	NO	NO	NO	NO	YES
F-22 Pinguino (General Avia) Italy	NO	NO	NO	NO	NO	YES
SD-27 (SIVEL) Italy	YES	NO	NO	NO	NO	YES
Aeriks 200 Switzerland	YES	NO	YES	NO	NO	YES**

Table 1a - Activities Performed

** departure only

Criteria to Predict High Alpha Behavior And Approach to Flight Test



Aircraft type	Radio-controlled Model Tests	Vertical Wind Tunnel Tests	Static Balance Wind Tunnel Tests	Rotary Balance Wind Tunnel Tests	Oscillatory Balance Wind Tunnel Tests	Erect Spin Performed
MRCA Tornado (Panavia) International	YES	YES	YES	YES	YES	YES
AMX (Alenia/Aermacchi/ Embraer)	NO	YES	YES	YES	YES	YES
K-8 (NAMC) China	YES	YES	YES	YES	YES	YES
KT-1 (ADD) Korea	YES	YES	YES	YES	YES	YES
P-180 (Piaggio) Italy	NO	NO	YES	YES	NO	YES**
T-50 (KAI) Korea	YES	YES	YES	YES	YES	YES
AM-3 (Aermacchi) Italy	NO	NO	YES	YES	NO	YES

Table 1b - Activities Performed

**** departure only**

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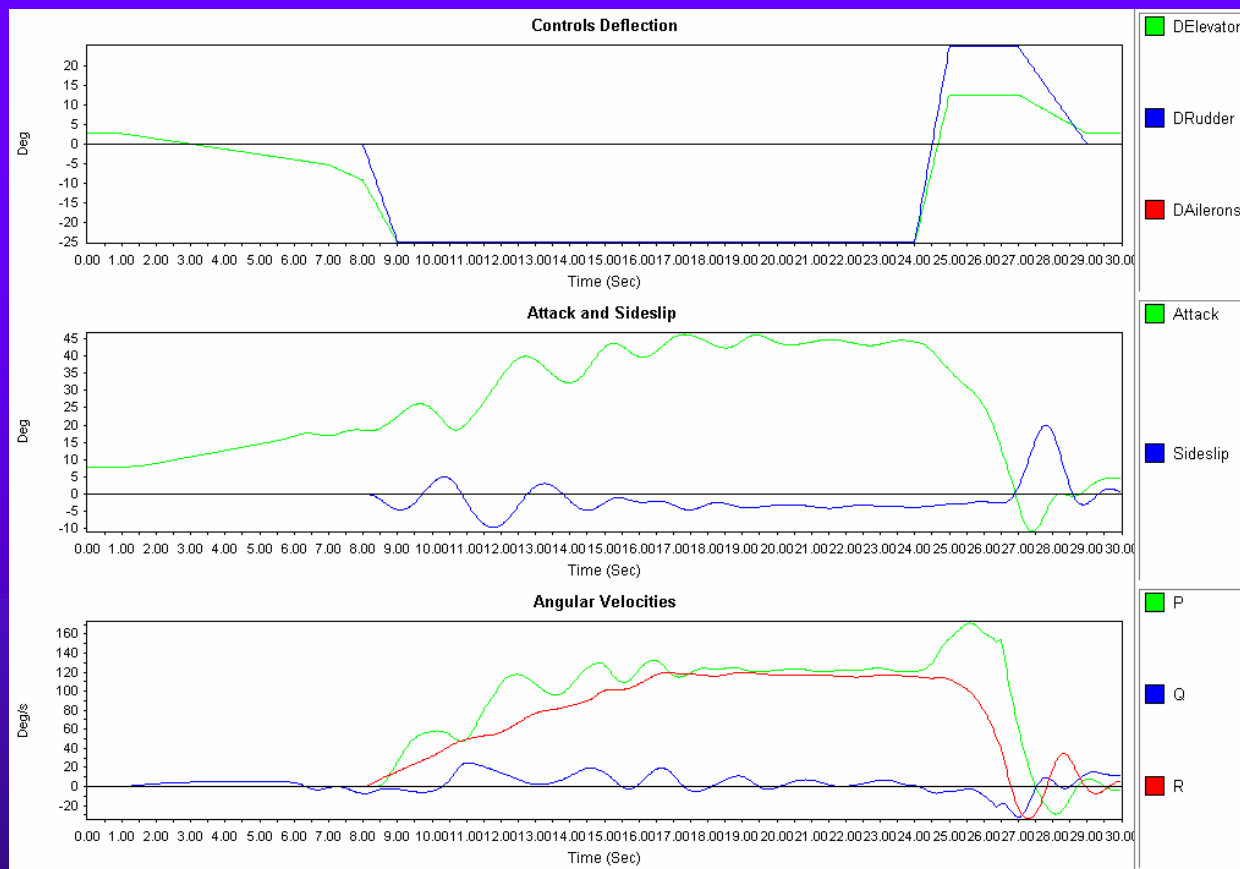


Table 2 AIRSIM time history

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**TEST Rollio
LGAA**

Aircraft : LGAA Test : TONNEAU

Points : 300,00
Integration Step : 0,02
Printing Step : 15,00

Angular Accelerations and Velocities, Attitude

Time (s)	P. (dg/s ²)	Q. (dg/s ²)	R. (dg/s ²)	P (dg/s)	Q (dg/s)	R (dg/s)	PHI (dg)	THETA (dg)	PSI (dg)
0,00	0,00	30,42	0,00	0,00	0,00	0,00	0,00	5,57	0,00
0,30	0,00	-0,17	0,00	0,00	0,04	0,00	0,00	5,60	0,00
0,60	-76,39	-0,07	-0,37	-4,09	0,01	-0,02	-0,14	5,60	0,00
0,90	-178,23	0,27	-1,94	-45,60	0,02	-0,32	-6,85	5,60	-0,04
1,20	-77,53	2,16	-4,43	-89,47	0,32	-1,24	-28,08	5,57	-0,26
1,50	-17,81	5,37	-5,85	-101,89	1,42	-2,81	-57,28	5,32	-0,85
1,80	-6,00	7,65	-3,22	-104,85	3,37	-4,28	-88,46	4,47	-1,82
2,10	-6,40	5,85	2,34	-106,54	5,50	-4,48	-120,23	2,82	-2,77
2,40	-7,11	0,87	7,20	-108,47	6,54	-3,07	-152,49	0,69	-3,19
2,70	-6,30	-3,80	9,53	-110,39	6,06	-0,55	-185,33	-1,32	-3,03
3,00	-4,24	-6,68	9,17	-111,92	4,44	2,28	-218,70	-2,92	-2,69
3,30	-0,99	-7,47	6,16	-112,71	2,26	4,63	-252,44	-4,39	-2,44
3,60	2,78	-5,74	0,95	-112,51	0,21	5,77	-286,28	-6,00	-2,09
3,90	84,60	4,28	-4,44	-107,12	-0,65	5,26	-319,83	-7,49	-1,28

1 of 1 20 of 20 Total:20 100%

Table 3 AIRSIM tabular report

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AirSim - [Database]

Windows Reports TimeHistory About

Simulation SPIN ENTRY Aircraft F-5

General Data Simulation Aircraft Database

Database													
AIRCRAFT	Apha	CD	CDDE	CYBETA	CYDE	CYDA	CYDR	CYP	CYR	CL	CLDE	CROLLBETA	CROLLDR
F-5	-11	0,1	0	-0,955	0	-0,005	0,183	0	0,53	-0,735	0,246	-0,066	
F-5	0	0,035	0	-0,993	0	-0,005	0,181	0	0,48	0,099	0,263	-0,064	
F-5	8	0,06	0	-0,99	0	-0,005	0,18	0,3	0,36	0,72	0,268	-0,062	
F-5	11	0,13	0	-0,975	0	-0,005	0,179	0,3	0,2	0,94	0,262	-0,089	
F-5	15	0,23	0	-0,86	0	-0,0075	0,178	0,2	0,1	1,2	0,234	-0,173	
F-5	16	0,26	0	-0,828	0	-0,0085	0,161	0,2	0,1	1,17	0,216	-0,179	
F-5	17	0,298	0	-0,8	0	-0,0095	0,15	-0,2	0	1,1	0,186	-0,205	
F-5	19	0,35	0	-0,76	0	-0,01	0,139	0,2	0	0,87	0,19	-0,17	
F-5	20	0,37	0	-0,74	0	-0,0098	0,13	0,2	0	0,87	0,197	-0,168	
F-5	24	0,44	0	-0,66	0	-0,003	0,099	0,1	0	0,84	0,158	-0,139	
F-5	28	0,53	0	-0,638	0	0,008	0,08	0	0	0,88	0,153	-0,129	
F-5	32	0,64	0	-0,607	0	0,0125	0,06	0	0	0,92	0,133	-0,143	
F-5	36	0,76	0	-0,58	0	0,019	0,042	-0,2	0	0,95	0,125	-0,155	
F-5	40	0,9	0	-0,483	0	0,02	0,039	-0,2	0	0,97	0,125	-0,169	
F-5	44	1	0	-0,373	0	0,042	0,059	-0,3	0	0,978	0,114	-0,189	
F-5	50	1,09	0	-0,34	0	0,029	0,03	-0,6	0	0,94	0,172	-0,16	
F-5	55	1,21	0	0,23	0	0,072	0,02	-1	0	0,88	0,23	-0,16	
F-5	65	1,4	0	0,57	0	0,029	0,01	0	0	0,7	0,19	-0,16	
F-5	75	1,53	0	0,23	0	0	0	0	0	0,45	0,096	0	
F-5	85	1,59	0	0,34	0	0	0	0,05	0	0,16	0	0	
*													

Done Restore Data

Table 4 AIRSIM Aircraft database management sample

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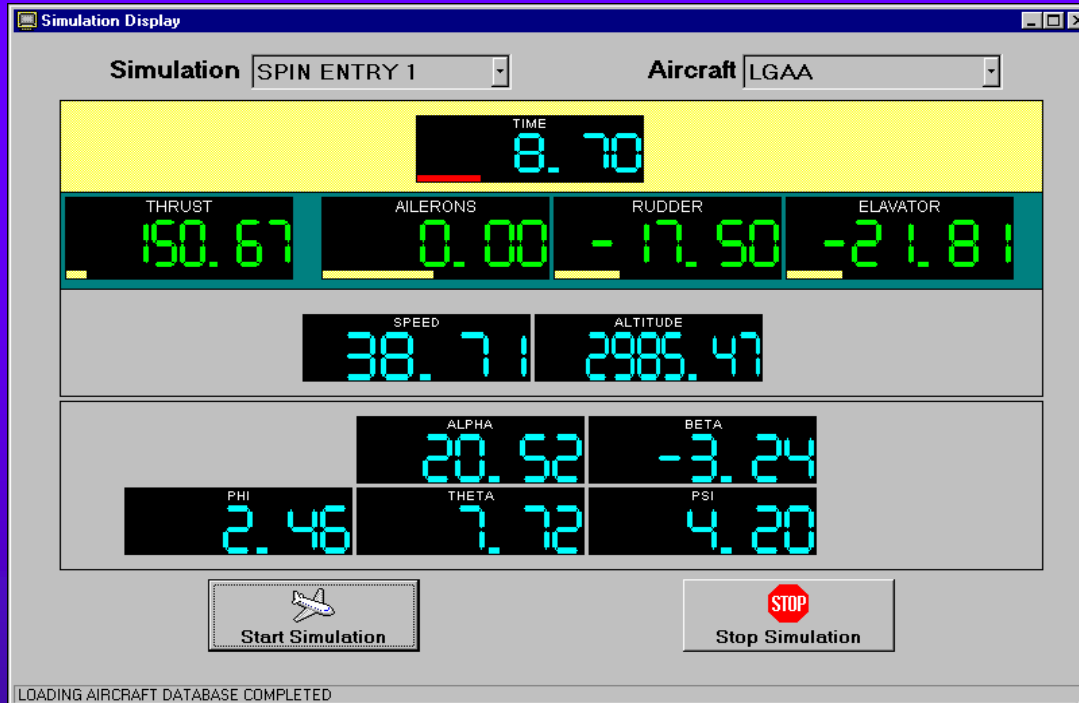


Table 5 AIRSIM simulation panel

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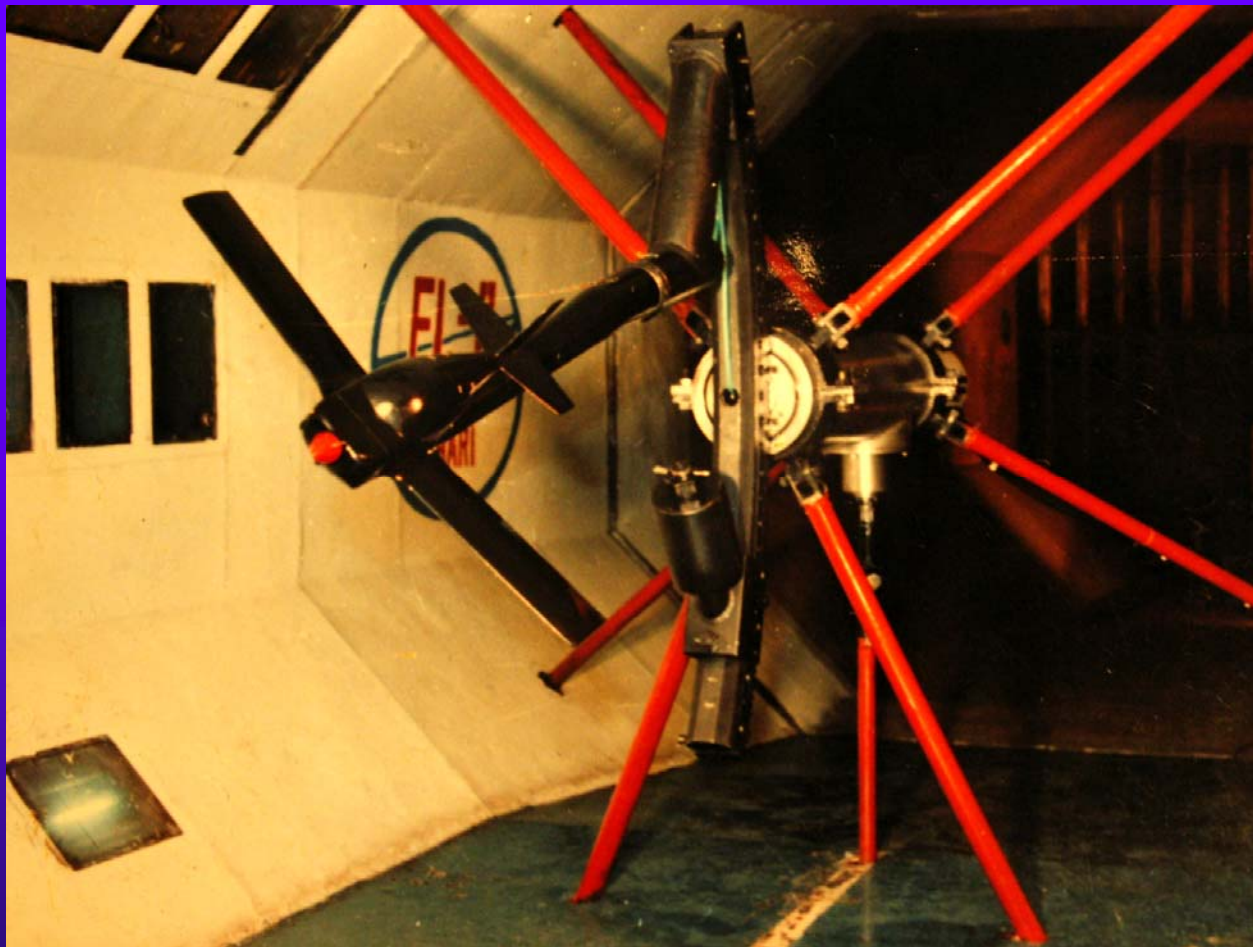


Table 6 Simulation model and rotary balance
cooperation project with HARI (China)