Early Flights Achievement with the Aermacchi M-346 Advanced Trainer

Paolo Chimetto & Rodolfo Carabelli
Aermacchi M-346 Flight Test
Aermacchi S.p.A. Via Paolo Foresio 1
21040 Venegono Superiore
(Varese) Italy
Telephone 0039 331 813 965
FAX 0039 331 813 042

chimetto.paolo@aermacchi.it

SUMMARY

The M-346 advanced trainer, designed and built by Aermacchi, has made its first flight on mid July 2004 and completed a first set of 54 flights in March 2005. The aircraft, on the leading edge of its class of flying vehicles in terms of performance, technology applied and mission capability, has confirmed the soundness of its design. As expected, the initial envelope explored has been found trouble-free, confirming the satisfactory level of reliability of the modelling used for predictions. Next stage of development tests will take the aircraft off the feathers bed of the initial envelope to identify the margins existing against the flutter domain while developing the Flight Control System control laws to be implemented aiming at the carefree handling as final target to achieve.

INTRODUCTION

The first leap of a demanding 800 flight, flight test program was taken on July 15th, 2004 when X615, the first M-346 prototype, took off from the Venegono runway for its maiden flight with O. Cecconello,

Chimetto, P.; Carabelli, R. (2005) Early Flights Achievement with the Aermacchi M-346 Advanced Trainer. In *Flight Test – Sharing Knowledge and Experience* (pp. 13-1 – 13-12). Meeting Proceedings RTO-MP-SCI-162, Paper 13. Neuilly-sur-Seine, France: RTO. Available from: http://www.rto.nato.int/abstracts.asp.

Aermacchi chief test pilot, at the controls. First flight testing consisted of a package of handling assessment maneuvers up to an altitude of 20,000 feet were carried out. The maximum Angle of Attack flown was 15 degrees, and landing occurred at a speed of 120 knots at touch down some 55 minutes later. The aircraft has shown a sound design since its first flight. The absence of any problem allowed four flights to be conducted in short sequence with three different pilots sitting alternatively in the front seat of the aircraft. The experience gained and lessons learned since initial ground testing till late December 2004 when the first lay up for engines configuration upgrade has started is the result of thirty-three flights and 125 tests in total carried out during that period.

The M-346 is on top of a family of products designed and manufactured by Aermacchi S.p.A. Venegono Superiore (Varese) Italy, and capable to satisfy the training needs of any modern Air Force. Other products are:

- the SF-260EA primary trainer. The SF-260 is a fully aerobatic aircraft suitable for **Screening and Primary Training phases**. Certified to *FAA FAR-23*, it is available with piston or turboprop engines. Its excellent flight characteristics and low operating costs are testified by the presence around the world of over 850 SF-260 of various models which have accumulated 1.5 million flying hours.
- the M-311 basic trainer, offers to the student pilot a true jet environment and handling in a very simple and economic aircraft. Derived from the S-211, already in service with a number of air forces, meets the mission requirements of **Basic Training**. The M-311 new digital avionics has been developed to meet more demanding operator requirements, thanks to the adoption of a HUD, Hotas controls and MFDs based MMI. Furthermore, the M-311 has higher performance, enlarged manoeuvre envelope and enhanced operational capabilities.

The M-311 & the SF260EA

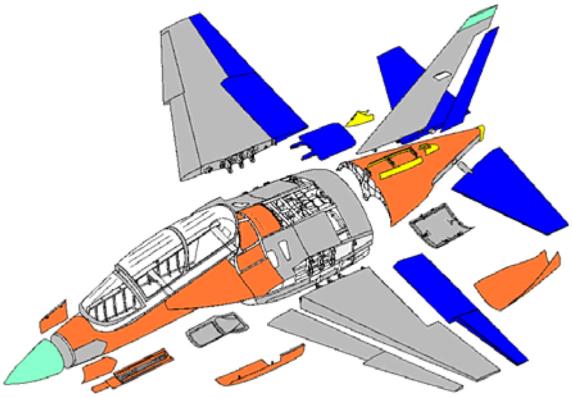
The M-346 is a Lead In Fighter Trainer (LIFT) that allows student pilots to develop knowledge, skills, and habits needed for effective familiarization with high performance advanced configuration combat aircraft. It is a twin engine, tandem seat, and transonic aircraft with supersonic capability in slight dive. Two 2850 kg thrust Honeywell F124-GA-200 turbofan engines power the aircraft, giving it high thrust to weight ratio as well as potential for effective secondary role (air to air and air to ground combat missions). The F124-GA-200 cold section configuration has a three-stage fan and a five-stage axial-centrifugal high-pressure compressor. Engine control system is a redundant, fault tolerant automated system that provides complete and stable automatic control at all power setting and during transients. Resistance to surge is enhanced by a bleed valve by passing high-pressure compressor air to fan duct.

An advanced man-machine interface (HOTAS control, three colour LCD MFD), in-flight refuelling capability, nine hard points to hang a variety of external stores will make the aircraft configuration even more attractive when fitted with mission-tailored sensors.

The external configuration of the M-346 gives it transonic performance while a quadruple-redundant, self-reconfiguring, and full-digital Flight Control System augments the aircraft stability and control to the level requested for achievement of satisfactory manoeuvring and target aiming characteristics while protecting against loss of control through the carefree handling implemented functions. On first prototype, for the first flight test phase, a simplified control laws mode is implemented that allows safe flying in the low subsonic flight envelope.

Air data are measured by four Integrated Multifunction Probes, and digitally interfaced to the FCS. Their output is processed to generate consolidated inputs to cockpit displays and FCS Control Laws. Probes location and functionality do require Air Data System optimization before it can be finally integrated. Meanwhile, an Interim Air Data System, based on a Nose Pitot Boom is used on first prototype for deriving parameters for Pilot Indications.

The figure beside shows some detail on how the M-346 structure is built. In grey are those components where metal is used while coloured are composite-made parts on prototype X615.



M-346 TEST AND EVALUATION APPROACH

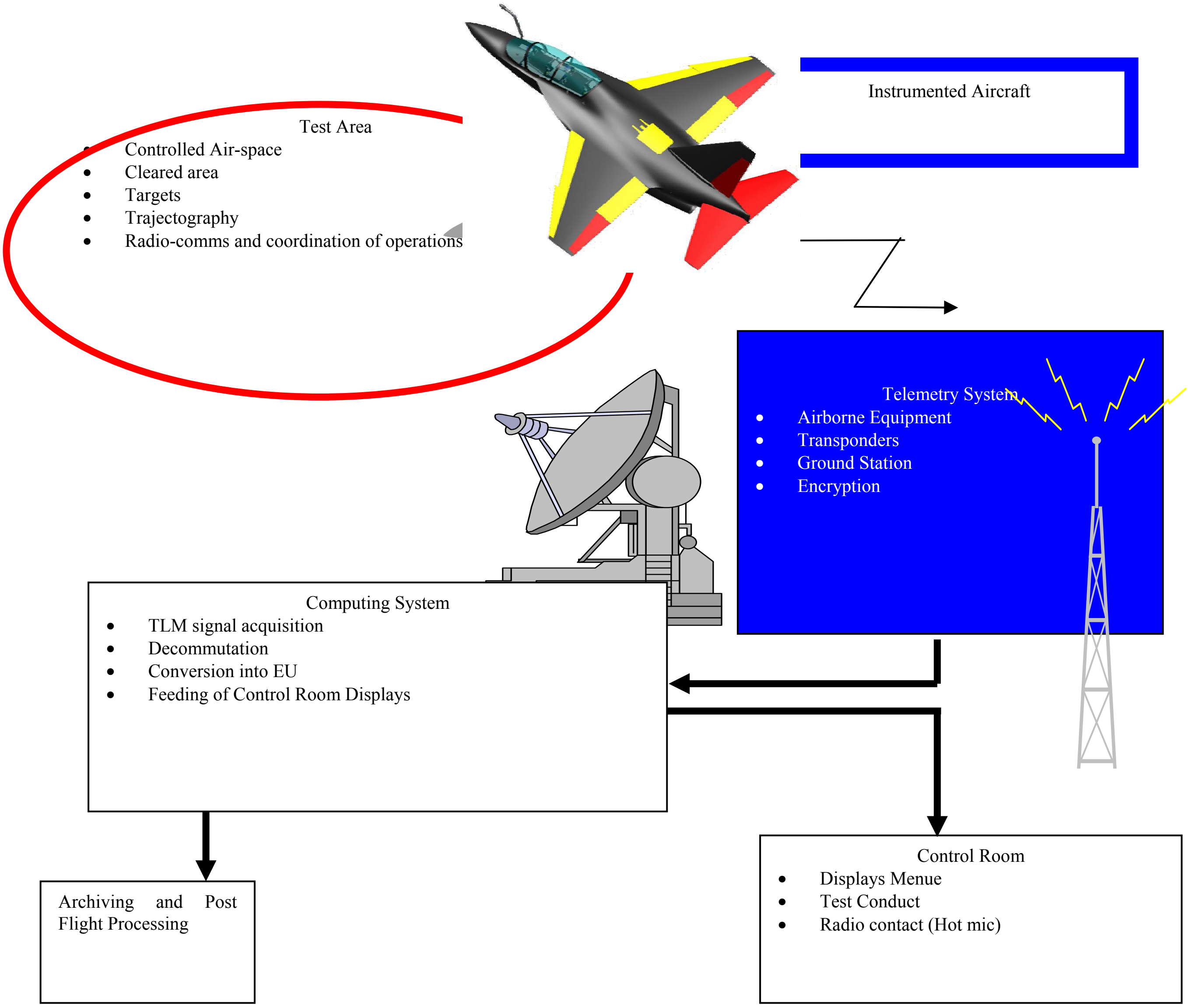
It is common practice today to develop advanced air vehicle starting with a great deal of ground test activities conducted on facilities specifically designed for equipment, subsystem and system performance verification and functional integration.

The last step of integration (hardware and software) also starts on ground facilities to be continued and completed on the aircraft as soon as the major components start feeding the final assembly line.

Additional information on the tests schedule met is given in the following figure. The best performance was achieved in November while in October the visit made by the Italian government represented a big success and a significant achievement of the program.

The Flight Test organization got truly involved in the test activities when the flight test instrumentation (FTI) was switched on and ran for the first time. From then on, the Flight Test Engineers (FTE) assigned to the program made practise, in view of first flight.

Training of FTE is the result of prolonged practise in two areas: data processing specification and analysis, real time data interpretation. Next figure shows in schematic form the data acquisition and processing in use at Aermacchi



Since the beginning of the M-346 program, flight test management put emphasis on test conduction and planning with support of automated information distribution tools in order to save time and take advantage of their integration for optimising test schedules.

A working group was appointed to specify the requirements and address software designers in the development of a set of connected Data Bases, encompassing the following applications: configuration change documentation, aircraft software configuration update and integration results, test requirement documentation, test documentation, flight test cards and flight test analysis documentation.

All users of EXPEDATA get access to a summary of inputs stored, can easily navigate among the information set by hypertext links, make sorting, export, and search of data, get access to reporting. Test card as well as fix data for post flight processing, and pilot flight test report have their modules automatically generated. Archiving of documentation like test cards completed, pilot report, quick look output (time histories), and flight test summary report is finally carried out.

A final concept to highlight in the introduction to the M-346 Program is the policy of risk mitigation extensively applied in the design phase wherever possible.

Its application was made easier by the number of simulation models set up in advance of flying the airplane. The most critical systems were backed up by simplified configurations operated within a reduced but safer flight envelope. That applies in particular to the Flight Control System, the Interim Air Data System and the Engine Control System.

The step-by-step approach was a winning choice. It was implemented as a sequence of complementary activities that could be carried out as a single block.

Last but not least an integrated team of design and test engineers was created to climb all the steps.

GROUND TESTING

A considerable effort was produced to make the aircraft flying at the planned date despite of the number of tests to conduct on ground.

These consisted of functional tests on aircraft as soon as each system and/or subsystem was assembled and integrated on the aircraft (Stage B tests). A significant milestone met was of course the first engine run which paved the way to the Stage C tests i.e. final systems integration, and to the engineering tests for issuing the first flight clearance. About 80 ground tests were carried out including E.M.C./H.I.R.F. Structural Coupling and Ground Vibration tests.

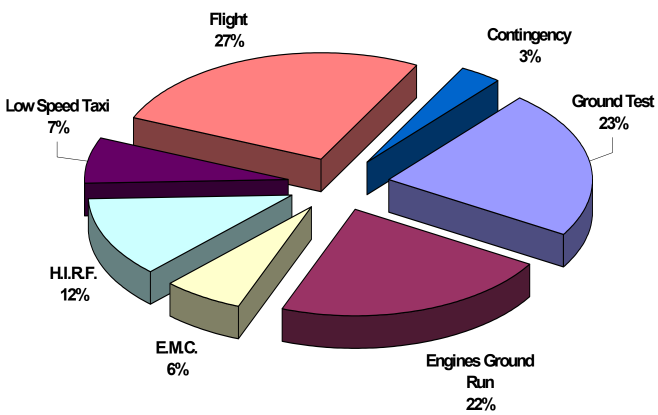
The percentage of tests conducted on ground is larger than ever, the 66% in the above figure being relevant to those on aircraft only.

Rigs and Flight Simulator tests are not here considered, though representing a large portion of expenditure for they help the integration process heavily.

In summary ground tests do represent the meaningful portion of the effort produced in the experimental area. Their complexity required a heavy toll to pay to build and set up facilities but they contributed to save flight hours and mitigate risk as reward.

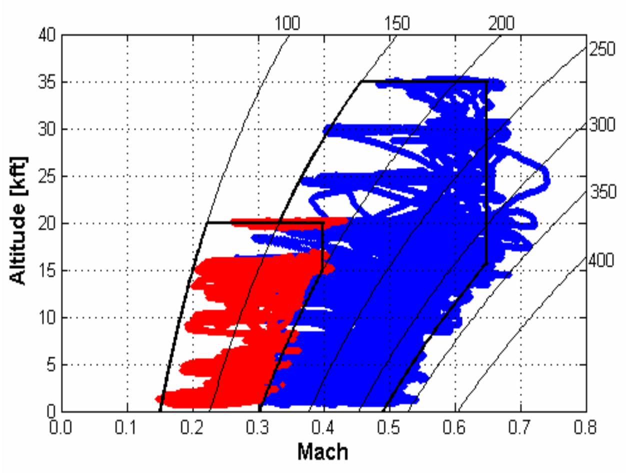
The last step done before first flight were taxi runs to assess brake and steering systems and more in general the ground handling of the aircraft.

The following picture presents the 2004 test activity performed on first prototype, divided according type of testing.



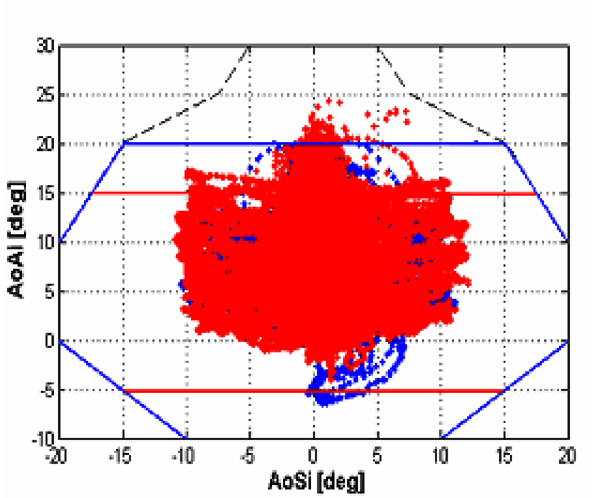
FLIGHT TESTING

In line with the risk mitigation policy constantly adhered in the M-346 program, the first flight was done with a single pilot aboard and landing gear extended throughout. Manoeuvres consisted of blocks of clinical control inputs to assess handling qualities. Wing configurations selected were with high lift devices extended. A three-ship formation was flown, the M-346 being chased by two MB-339 on duty as safety and photographic chase respectively. From 5th flight on, there was no chasing the interim air data system being so reliable and accurate to satisfy the safety criteria of the Program. Furthermore, the flight envelope was extended from 0.4 Mn/250 kts CAS to 0.65 Mn/325 kts CAS. The extended envelope was large enough to make performance, handling qualities and engine-air intake integration tests sensible. Two further steps are foreseen in the clean aircraft envelope expansion process, to 0.95 Mn/572 kts CAS the former, to 1.2 Mn/500 kts CAS approximately the latter.



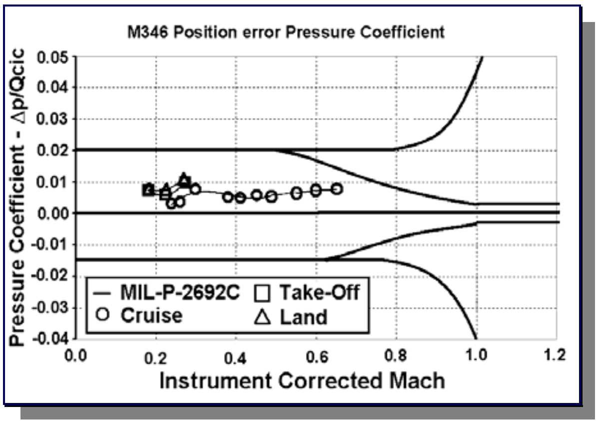
The manoeuvre characteristics have been investigated from –1 to 5 g without problems. A general loads survey did not show any exceeding of limits while matching the model.

Dynamic loads on the horizontal tail were found within the scatter margin and tolerances used for flutter margins calculation. No excitation system was installed with the consequence that evidence of peaks of response was insufficient for a complete assessment. The horizontal tail response to buffet is according the calculations. Its effectiveness is as predicted as shown by the pitch trim curves.

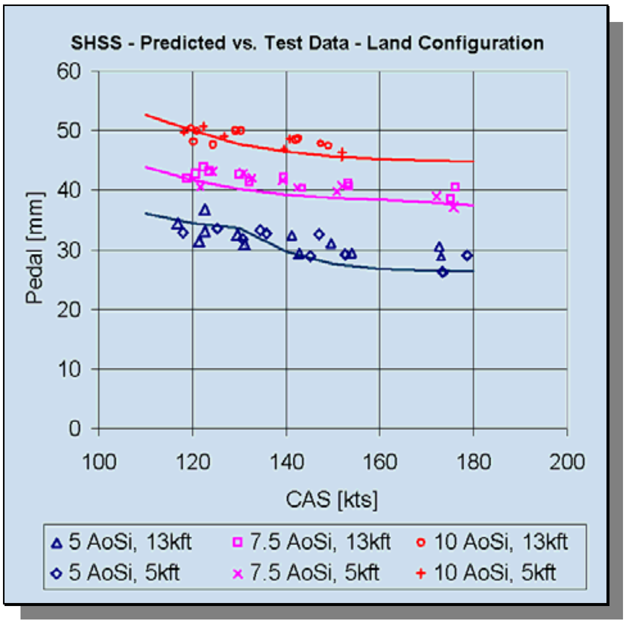


An interim air data system is installed with boom-mounted probes to back up the IMFP- based production system while tested for development and qualification. The interim system has been calibrated carrying out a number of tower fly bys. The onboard FTI GPS output was used as reference to complete the job on a ride along base. Position errors have been found compliant with military standard and system specification.

Also Angle of Attack and Sideslip as well as pressure lag were checked and proved satisfactory. Data in the above figure provide evidence of significant achievements in terms of maximum AoA (24°) and AoS (10°)..



The directional stability was found good and the rudder control proved adequate to sustain crosswind as required. Up to now a 20 kts component has been demonstrated at landing. A target of 30 kts is the aim to be achieved on opportunity base.



The dynamic stability in landing configuration is generally well damped (Dutch roll) while the Spiral mode is convergent or neutral. Lateral control is good the performance being in the order of 120 deg/sec.

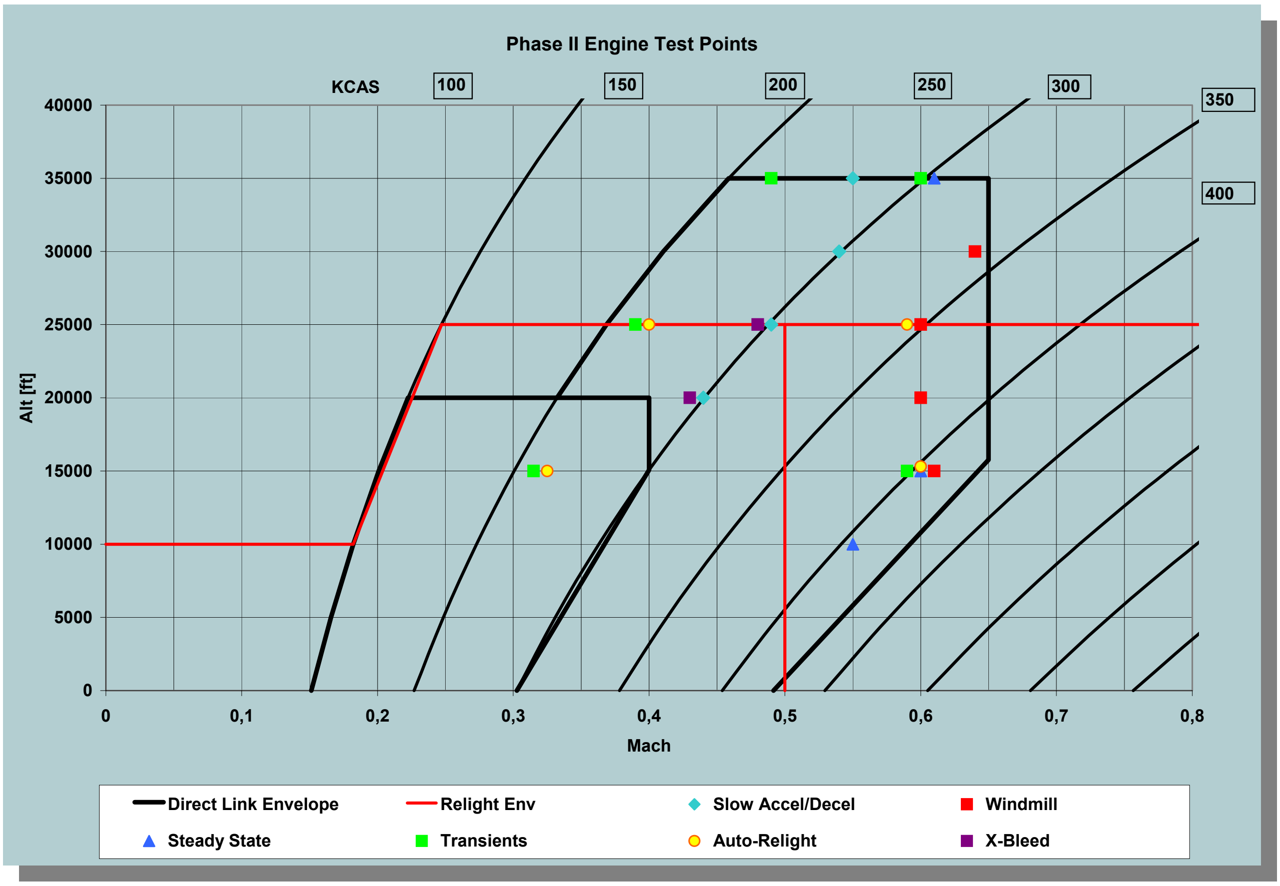
Engines were subject to intensive assessment while configured with interim digital control system (ECU BEC RIU, Electronic Control Unit Back-up Engine Control Remote Interface Unit, already tested on other aircraft), and with newly developed FADEC. Handling and performance were investigated to identify surge margins and windmill characteristics. In this way a relight envelope has been cleared for initial testing use (green area).

The engine handling characteristics proved quite satisfactory even at low speed/high AOA i.e. 92 kts/22° when throttling forward to recover from incipient stall conditions

Fuel consumption during cruise at 25,000 feet and 30,000 feet was found as predicted or lower. During climb little scatter between test and predictions have been found.

Airfield performance resulted as expected. Average TO run is less than 500 meters with a weight in the order of 7000 kg.

At landing the ground run can be kept within 500 meters the touch down speed possible being as lower as 105 kts.



An extensive test activity dedicated to the identification of aero derivatives is begun. The first step has been dedicated to verify the consistency of flight test recorded signals.

TEST ACTIVITIES STATUS AND WAY-AHEAD

To date about 60 test flights have been carried out with prototype n.1, after the first flight of 15th July 2004.

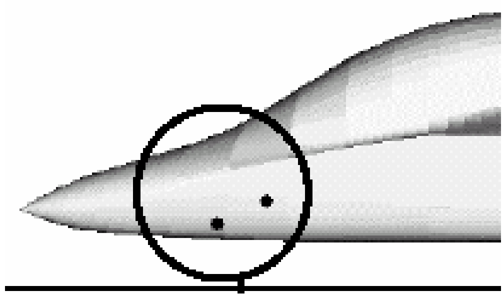
Envelope expansion was completed by the end of 2004, with the completion of more than 30 flights. Engines dual FADEC control configuration was cleared at the end of February 2005, at flight n.45.

Next step is the first flight of prototype n.2, scheduled within May.

Two M-346 prototypes are planned thus to participate at Paris Air Show, in July this year, and to expand the envelope with FCS phase II Control Laws.

Areas of investigation are now considered separately to pinpoint the approach followed while investigating the relevant characteristics and how to continue in the near future.

- *Aerodynamics* investigation took advantage from the definition of a set of manoeuvres suitable to identify stability and control characteristics before moving to the parameter identification (PID). This approach helps selection of those areas of the envelope where simulation model does require accuracy enhancement. Tests consisted of trim shots, slowdowns, wind up turns, and steady heading sideslips, partial rolls for static and manoeuvre stability investigation. Dynamic stability made use of stick jerks and yaw doublets.
- PID was first limited to practice of manoeuvring and to sensors output check of consistency. Initial PID activities was beneficial to assess aerodynamic derivatives behaviour. Extensive investigation by PID will be carried out for expanding the flight envelope beyond 0.65 M and in the high AOA/AOS domain.
- *Air Data System* initial standard consists of a Pitot-boom and AOA, and AOS boom-mounted probes. The production standard ADS is run in parallel but its outputs are not feeding any function in the first test phase.

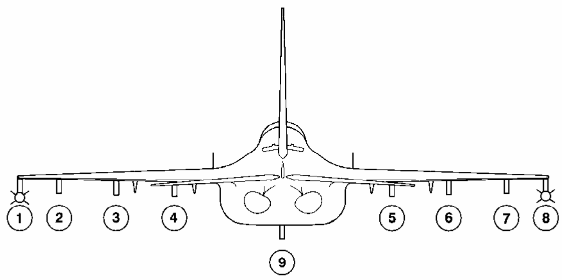


  The complete functionality and the effects of relative position of the four integrated probes, two on each side and skewed have also to be investigated in the enlarged flight envelope.

- *Flight Control System* development is approached with a step by step design and test process. The first flight standard was important for risk mitigation during the initial flight envelope expansion, but is not intended to be a production reversionary FCS standard. Next step of Control Laws, i.e. Reversionary, will embody dynamic pressure-variable gains, three-axes stability and control augmentation system. The ADS at production standard will be used to feed the FCS control laws.

  Reversionary FCS has also basic carefree capability, that will be fully demonstrated with final FCS Control Laws.
- *Handling Qualities* are generally good but control harmony needs deeper investigation and confirmation when crosswinds in excess of twenty knots are met. Comment applies to both flight and ground handling.

- *Aircraft with external stores*. A significant change in aircraft characteristics will occur when the M-346 will take off with stores externally hung to its strong points. Nine points are available to give the aircraft a range of training and combat capabilities. Their position is:



1	2	3	4	9	5	6	7	8
Missile AA	*Light Ordnance*	*Std Ordnance*	*Heavy Ordnance*	*Fuel Tank*	*Heavy Ordnance*	*Std Ordnance*	*Light Ordnance*	*Missile AA*

LESSONS LEARNED

The experience of the one of the authors extends over a period of forty years, and six development programs; nevertheless, the M-346 does represent something new and unexpected.

- **Involve flight test teams early in the test process.**

  Flight M-346 Test managers were responsible to coordinate the ground testing phase, and the test team was involved in the activity. Attending the B tests execution as well as participation to planning activities of first and second level is highly beneficial. In that way a lot of information is gained and good feeling established between design and test teams. The starting point for training could be even earlier on Rigs. The concept behind is the integrated team moving from one phase to the other as soon as the program progresses.

- **Mitigation of risks is a rewarding policy.**

  Three examples may be derived from the M-346:

  a) FCS Phase 1 Control Laws Mode as a solution that guarantees the aircraft is safely flyable though in a smaller than final envelope. The advantage is obvious: the aircraft can be flown earlier and freely to set up systems.

  b) An Interim Air Data System to back up the production system quite complex to develop. This helps in the no-risk assessment of new integrated IMFP during initial flight phase, validate models and allowing design team to refine the SW releases, with flight test outcome.

  c) An interim engine control system, already tested and flight proven, assured test activity while developing the final FADEC.

- **Flight test activity is a process.**

  M-346 program is a professinonally driven “flat” organization that embodies a tightly integrated test team aiming at data collection and analysis to transfer test results and not only valid data to designers, since rigs and aircraft ground testing start up.

  The Flight Test Manager, the process owner responding to the Program Management, is oriented to project development success, and is working to assure that all functions in the organization act in a coordinated and planned way.

- **Implement a collaborative approach inside and outside the company.**

  The collaborative approach has been adopted within the company and for the partners.

  For aircraft type certification an independent, third-party certifiyng agency is established within Italian MOD for the M-346 program.

  A working group composed both by M-346 specialists and Italian MOD personnel has been charged for the certification process, with the same collaborative approach. In particular, the certifying Agency has full visibility on the program and relevant test results. Participation to flight test activity for IAF test engineers and test pilots is also planned.

- **Use state of the art technology**

  Large use of COTS SW is made in Flight Test Department, especially for data reduction and post flight analysis. This is based on existing code used by design teams, in particular for model development and predictions.

  FTEs can share experience and applications with colleagues without expensive in-house SW development.

  For the future a new real time analysis capability will be implemented, in order to shorten the analysis time, by performing it directly in ground station during the test flight.

  Another important achievement is using the Expedata connectivity of Data Bases. In this case the information are managed only one time directly by their owner, while visibility and traceability are guaranteed over the process.

  Also from this side continuous improvement, by adding capability to the SW tools, are under way.

CONCLUSIONS

The m-346 aircraft successful test program, before and after the first flight, is due mainly to an integrated approach, in terms of test team and test methods / facilities.

This resulted in:

- a complete experimental process, aimed to the flight clearance of the first prototype, in a short time.
- an efficient utilization of the IPT concept and process management approach.
- full compliance of all the safety and airworthiness requirements.