M-346 FLIGHT TEST PROGRAMME

P.CHIMETTO\textsuperscript{1}, G.PASINETTI\textsuperscript{2}

\textsuperscript{1} Flight Test Manager, Aermacchi S.p.A, Venegono Superiore (VA)
\textsuperscript{2} Flight Test Engineer, Aermacchi S.p.A, Venegono Superiore (VA)

ABSTRACT

The M-346, an advanced fighter lead in trainer designed and built by Aermacchi, performed its first flight on 15th July 2004 and from the beginning proved the goodness of the design showing excellent performance. The M-346 hosts two Honeywell F124-GA-200 engines providing approximately 2850 kg of thrust each thus giving the aircraft a thrust to weight ratio close to one. It is equipped with a fully digital fly-by-wire Flight Control System giving the pilot the ability to fly carefree in the whole flight envelope. This characteristics, along with the complexity of the on-board systems, prompted for a test team with both a deep knowledge of the aircraft systems and a broad understanding of system and aircraft testing and integration. Aermacchi therefore chose to apply a Concurrent Engineering approach within its M-346 Integrated Product Team.

This paper, following a brief description of the aircraft characteristics, presents the approach to ground and flight testing adopted by Aermacchi, the organisation put in place to implement such an approach and the test facilities set up to support the test process.

A summary of the test results along with the lessons learned from the first aircraft test phase is also presented, with particular attention to the benefits of the chosen test and risk reduction aircraft development approach.

1. M-346 A/C OVERVIEW

The M-346 is a new generation advanced trainer designed to be superior to all existing products in its class. It has been designed to provide the best possible balance between high training effectiveness and low life-cycle cost. High Thrust-to-weight ratio, advanced aerodynamics and a re-programmable full authority fly-by-wire control system, allow the M-346 aircraft to be representative of the behaviour of modern fighters in the transonic flight envelope, including high angles of attack (over 40°), at a small fraction of their cost.

In-flight simulation of sensors and tactical scenarios, state-of-the-art man-machine interface, capability of using simulated and/or real weapons provide the trainee pilot with a realistic environment in which to hone his skills, allowing to reduce the training burden in Operational Conversion Units and Fighter Squadrons.
Although being optimized for advanced training, fighter lead-in and operational conversion, the M-346 can perform with significant effectiveness also as a light combat fighter, both in the air-to-air and air-to-ground roles. The M-346 structure is mainly built of light alloys with extensive use of carbon fiber-based composites in areas where they proved to be cost-effective. Damage tolerance concepts are used throughout the airframe design. Four BAeS/Teleavio FCCs provide the aircraft with MIL-STD flying qualities by design, thanks to artificial stability and control which allow carefree handling up to angles of attack (AoA) of 40° and higher. The avionics architecture is based upon a dual-redundant digital data bus MIL-STD-1553B and incorporates a significant growth potential to cater for future development.

Standard Communication / Identification subsystem includes two VHF/UHF transceivers and an IFF transponder. The navigation subsystem allows both autonomous and radio-navigation modes. A latest generation combat aircraft glass cockpit provides each pilot with a Head-Up Display, three raster/stroke type Multi Function Displays, a Helmet-Mounted Display with threat simulation capability, Night Vision Goggle compatible instrumentation and Hands On Throttle And Stick (HOTAS) controls (fig.2). Embedded simulation capabilities are provided in the avionic suite, in order to take full advantage of the airframe / electronic / performance potential of the aircraft.

Simplicity of design and construction, standardization, careful selection of equipment, enhanced reliability and maintainability result in an aircraft with acquisition costs comparable or lower than other advanced / pre-operational trainers, with lower operating and support costs.

2. TEST AND EVALUATION APPROACH / INTEGRATED TEST TEAM

For the M-346 flight test activity and relevant organization breakdown structure, traditional and “collaborative” approaches have been compared:

<table>
<thead>
<tr>
<th>TRADITIONAL</th>
<th>COLLABORATIVE</th>
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<tr>
<td>Hierarchical organization</td>
<td>Flat organization</td>
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<tr>
<td>Ruled by formal procedures</td>
<td>Professionally driven</td>
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<td>Limited range of action</td>
<td>Pro-active attitude</td>
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<td>Larger number of resources assigned</td>
<td>Highly integrated test team</td>
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<tr>
<td>Narrowed Specialist FTE</td>
<td>More Generalist FTE</td>
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<tr>
<td>Aim: collect data and transfer them</td>
<td>Aim: collect data and transfer results of analysis</td>
</tr>
<tr>
<td>FT Head is responsible for department</td>
<td>FT Manager is a process owner</td>
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<td>Test success oriented</td>
<td>Program success oriented</td>
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The choice, in line with the program’s Integrated Product Team concept, was for a collaborative approach. In particular, the following areas were interested by the new approach:

- FT management: Process-oriented, linked to M346 program milestones, capable to assure:
  - Correct workflow of company internal and external contributions
- Consistency among test requirements, A/C configuration, test programs and schedules
- Overall Cost effectiveness of the test activities

- FTE group, located in the experimental department, with a larger group of engineers from the design department to support dedicated tests in specific areas
- FT data management process re-engineering, with particular emphasis on data analysis tools, both real time and post flight

The M-346 Flight Test process takes either benefit from past experience, current assets and new dedicated systems, but it can be faced only using all the company capabilities and technical resources in a collaborative way while performing the complex flight test process including: planning, scheduling, test requirements definition, in terms of measurements required, test procedures and data reduction, FTI design and realization, (both in-flight and on-ground), test A/C preparation and day-by-day operation, test conduct, test execution, data gathering and results work-out, test analysis and reporting.

Tight co-ordination, common training and detailed preparation required to perform in a safe and proficient way the test activity is a must. Each phase of the test has to be planned, executed, monitored and reported to the M-346 Program and to Company’s management.

The Core Team Members are co-located in the same site where the flight test facilities are. The Integrated Test Team (fig.3) includes:
- the Project Pilot,
- the Test Conductor and his group in charge to organize the daily flight activity and responding for short term plans, long and medium term plans,
- the ground crew and his chief,
- the flight test engineers responding for technical programs and flight data analysis and reporting,
- the FTI group, responsible for flight and ground data acquisition and recording.

The ITT is coordinated by the Flight Test Manager (FTM), who acts primarily as the process-owner for the flight test process. The FTM reports to the Product Integration Manager and, through him, to the M-346 Program Director. His primary role is to guarantee, from the functional point of view, that all the workflows that compose the flight test activity are executed in the best way. In fact, not only the technical side is controlled, but also planning, safety and procedural issues, cost-effectiveness and reporting. This approach is in line with modern quality management process and continuous improvement concept, set by new international standards.

The M-346 FTE group includes a small number of dedicated people to form the core “dedicated” team, and people from the design department to support specific test activities involving their own systems and/or areas of expertise. In this way there is the “closure of the loop” between test and design engineers, by moving the activities Centre of Gravity alternatively from flights to offices, according to the planning, sharing experience, information, tools and time.
In particular, the “dedicated” Flight Test Engineer figure:
- attends briefings and debriefings as well as monitor test flights in ground station,
- supports FTI people activity,
- process data gathered during the test flights,
- continuously develops test methods,
- participates with the design functions in establishing and issuing test requirements according to design
  specification and relevant qualification plans,
- elaborates preliminary test analysis, giving also recommendations for the foregoing activities.
- participates in test reports issuing,
- supports day by day planning of the test activities.

The team has received adequate training, both in terms of flight test instruction, by means of company internal
and external courses before the beginning of the M-346 test campaign. Obviously only the on-the-field
experience and lessons learned really help to create the proper common training, procedural, technical, inter-
personal understanding among the dedicated personnel.

3. FLIGHT TEST FACILITIES

A considerable effort has been and is still being made to bring to the program state of the art flight test analysis
capabilities, ranging from aircraft data acquisition systems to data analysis tools. Particular emphasis is being
placed on the following requirements

- Highly flexible data acquisition system
- Common formats to improve data and application sharing between the design and flight test teams
- Maximise return from real-time analysis to improve time and cost efficiency
- Minimise aircraft dependency from base airfield.

The steps taken and the associated results are detailed in the following paragraphs.

3.1. Flight Test Instrumentation

Although the Aermacchi Flight Test Department had matured a significant experience in aircraft
instrumentation, having worked on different projects ranging from handling qualities, to safe separation, from
structural tests to avionic system monitoring, until recently it had to focus on a few specific task at a time.
The M-346 program, on the contrary, required a comprehensive flight test instrumentation system covering the
full spectrum of test disciplines at one time. The program allocated different test tasks to the two available
prototypes, with the first prototype dedicated to engines and systems tests and the second prototype dedicated to
structural and load tests. Flight control system, handling qualities and aerodynamics tests had to be shared
among the two prototype. Notwithstanding this task separation, both prototypes had to share basic loads and
system monitoring capabilities in order to maximise flexibility. This approach also resulted in the maximisation
of the return in terms of available data for system analysis. Most system analysis tasks can now be performed on
a ride-along basis while the aircraft is focusing on other tasks.

This however resulted in a fairly complex FTI system that had to be squeezed in a fairly small, twin engine and
deply equipped aircraft where space availability was of great concern. The goal was achieved by a highly
configurable system whose main characteristic are detailed below.

- IRIG standard 106 compliant.
- Highly flexible, with both hardware and software items easily reconfigurable to minimise aircraft turn-
  around and mission switching times. FTI junction boxes and data acquisition units designed to easily switch
  from one set of parameters to another (including filter re-configuration).
- Software controlled data acquisition system allows for quick system configuration (circuit set-up, ranges
  and calibrations, data acquisition format).
- Fully digital data recording system performs continuous integral recording of all aircraft buses (MIL-STD-
  1553, ARINC 429, RS 232 etc.) and of MFD video data.
- On-board computations with result presentation to the crew can be implemented.
- In-flight switching between different data acquisition system configurations.

In addition to the data acquisition and recording system a broad band telemetry link with the Aermacchi Ground
Station has been implemented. The system, with a throughput of 10 Mb/s, transmits over two different
frequencies and can operate in either data or data plus video modes.
At the time of writing, approximately 10000 parameters (all type, including digital bus) are recorded during each test flight, with 1500 of these parameters transmitted via the telemetry link, and therefore available for real-time analysis, and an average of 2000 more parameters downloaded for post-flight analysis totalling an average 10~15 GB of data per flight.

Additional FTI packages are either available or being readied. These include:

- Interim Air Data System – This system, made of a Nose pitot boom with AoA and AoS vanes and two micro air data computers, interfaces with the Flight Control System providing air data information to the pilot and the aircraft control laws.
- Flutter excitation system – This system is currently being developed and is designed to interface with the Flight Control System to provide pre-defined frequency sweep inputs to the primary control surfaces.

3.2. Telemetry, Ground Station and Real-Time data analysis

As previously mentioned, an astonishing 10 Mb/s data stream is transmitted to the ground station during each flight with approximately 40% of the throughput devoted to test data parameters and the remaining 60% devoted to the four video streams showing the three MFDs and the HUD, which proved to dramatically improve the ground crew situation awareness. All these data are received, recorded and processed real-time by the AEM Ground Station.

The facility is IRIG 106 standard compliant and, in addition, a certified Differential GPS reference station.

The telemetry receiving apparatus is made of a two-axis auto-tracking parabolic antenna and a digital receiver. The latter implements a “diversity combiner” that effectively combines the two received frequency streams in order to maximise the data/noise ratio.

A real-time front end takes care of data de-commutation and processing with an effective real-time output of one million samples per second thus guaranteeing minimal data latency.

The data is displayed in the control room where the flight test engineers have a variety of monitoring stations to follow the test flights. These include;

- 12 independent graphical front ends
- 3 strip charts
- 4 monitors displaying the aircraft three front MFDs and the HUD
- Matlab® stations with real-time in-house designed applications accessing data via a Scramnet interface
- 3 IADS™ stations

The latter have been recently introduced and represent Aermacchi next step in real-time data processing capabilities. Until recently, real-time monitoring was mainly devoted to safety of test and data quality, with most of the actual data analysis made post flight. The IADS™ software, developed by Symvionics Inc., has been adopted to move a substantial part of the analysis from post-flight to real-time, including both time domain and frequency domain based analyses, automated test summaries, integrated Caution, Advisories and Warnings for system health monitoring, just to mention a few.

The Flight Test Department was also urged to develop a solution to support aircraft deployment and operation to different locations where direct telemetry coverage by the AEM Ground Station in Venegono cannot be achieved. Two different solutions are being developed:

- Minimal station with telemetry relay through satellite
- Full capability sheltered ground station

The first solution was successfully tested during the recent Paris Air Show at Le Bourget airport. It consists in a scaled down ground station, with full data acquisition and visualisation and reduced data analysis capabilities, that acts as monitoring station and telemetry receiving and relaying station. The receiving end is analogous to the AEM ground station, thus allowing the aircraft to operate without any change to the on-board FTI system. The telemetry relay to the AEM ground station in Venegono is achieved is through a satellite link. Fully automated radio transmissions between the AEM ground station in Venegono and the aircraft are also being implemented.

A second solution, better suited to long-term deployments will consist in a fully functional sheltered replica of the AEM ground station. On-site full test capacities would be achieved thus releasing the AEM ground station in Venegono to other activities. Flight test capacity could be demonstrated along with the aircraft and future partners involved in the test/demonstration activities. Last but not least, the high costs of a long-term satellite link hiring could be averted.

3.3. Post Flight Data Handling and Analysis

The system dedicated to download, store and analyse flight test data was heavily influenced by the adopted integrated team approach to flight testing. The main requirements driving the software packages choice and software development guidelines were the following:

- Test data had to be readily available to both flight test engineers and system specialists
- Common data formats needed to facilitate test data sharing
- Application sharing was also identified to be of paramount importance

Matlab™ was selected as the preferred analysis tool. It currently places itself among the most widely used software packages for technical computing putting together an easy to use language and interface with a wide variety of dedicated tools. The software was used in many design departments. Its choice put the flight test engineers in the position to share both data and applications with the design teams.

The flight test engineering group has undertaken a significant software design task to develop all test data analysis tools and establish itself as the primary font not just of flight test data but of flight test results.

A non-exhaustive list of the software tools developed to date is presented hereafter.

- Generation of automated flight summary reports
- Automated generation of time history plots and computation of system performance
- Data reduction for take-off and landing performance analysis
- Implementation of algorithms for the computation of derived flight parameters (Mass, CG, Calibrated Air Data)
- Plotting and flight analysis tools in support of aircraft flight display activities
- Engine thrust computation
- Lift and drag computation

In the development of the required tools particular attention has been devoted to ensure uniformity, standardisation and traceability. This was achieved through the following steps:

- CVS (Concurrent Version System) was adopted to track software development
- A release plan was drafted
- Detailed software documentation is being developed
- Standard references and computational methods are being adopted
Guidelines to software writing were adopted

As far as data download and storage is concerned, the system already in place was deemed appropriate. This system is based on a central server where flight test data is accessible as single parameter array files. These files are generated by the FTI department that decodes the tape recorded by the on board digital recorder into the proper engineering units. Once the files have been created and loaded to the server the are accessible by almost any company personal computer either directly as binary files or via a utility that converts the into ascii files. While this system allows for an incredibly broad access to test data it has three major drawbacks. It is time consuming, it requires huge amounts of data storage capacity and has limited flexibility. At the time of writing approximately 2000 of the available 10000 recorded parameters are converted into “spa” files and loaded to the server. Additional parameters required additional processing by the FTI group. This prompted for the evaluation of an extension of the current system that would result in a better compromise between flexibility and performance on one side and broad data access on the other as detailed hereafter.

- Data stored in the original unprocessed format with significant reduction in required storage space
- Configuration control maintained by the FTI group that retains control over the decoding set-up
- All parameters readily accessible via dedicated front ends by flight test engineers
- Basic data analysis tools already within the software
- Integration with current Matlab™ analysis tools
- Capability to export single parameter array files and/or ascii data files retained.

4. TEST DATA MANAGEMENT

With a target of 800 test flights scheduled on two prototypes and on one pre-series aircraft to support the aircraft development and type certification process, the M-346 programme represents a new and unique challenge in the history of Aermacchi. A flight test programme of this magnitude and complexity, put together with the state of the art and highly sophisticated aircraft systems, prompted the Flight Test department for a broad review of its procedures and practices.

Efficient management of the massive amount of data to be handled became essential in order to maximise the return from the flight test activity, an activity that makes up for a considerable part of an aircraft development budget. For the M-346 program a set of data management tools, mainly databases, has thus been developed to allow for an easier, more precise and efficient handling of all the data associated with the flight test activity, covering activities that range from handling of test requirements to test planning and tracking, from aircraft configuration management to annual report generation. Their main characteristics are summarised hereafter.

- All the tools have been developed “in house” by the flight test staff and are therefore tailored to the specific needs of the test department.
- A distributed approach was chosen for the following reasons:
  - A broader range of subjects can be covered and linked together, giving a better global picture and planning capabilities
  - Each module can be customised to the needs of its main users
  - Modules can be developed independently, provided common standards and interfaces are used
  - Once the core system is in place, each single module can be phased in independently from the others, with a dramatic reduction of the activity backlog and better prioritisation
- All tools are under continuous review to best adapt to the increasing data management requirements.
- Standardisation of procedures and practices among different departments was achieved.
- The databases are designed to easily integrate with data acquisition and data analysis tools in order to automate the data feeding process and hence minimise the requirement for user inputs. Any database, in fact, no matter how well designed, can only be as good as the stored data.
- To maximise the tools benefits a web browser based interface was developed. In such a way, test data is readily accessible and searchable not only by the flight test personnel, but by all of the staff involved in the M-346 program.
5. ACHIEVEMENTS

At the time of writing a total of approximately 90 flights had been carried out (more than 75 with the first prototype and about 15 with the second one). The active collaboration between the flight test and design teams allowed for a quick and effective feedback from test results into design updates thus allowing the aircraft testing to proceed at a sustained steady pace. The main achievements to date are detailed hereafter.

- Second prototype first flight on schedule and within less than one year after first prototype first flight. Both prototypes now in flight test activity.
- Envelope expansion in FCS phase 1 configuration (non-production standard) completed with the aircraft cleared to a maximum airspeed of 325KCAS/0.65M, a maximum altitude of 35 kft, a load factor range of -2 to 5 g and an Angle of Attack range of –5 to 20 deg.
- Engines with dual FADEC control functional qualification
  In accordance to the risk mitigation policy adopted, the above envelope expansion was performed with the engines mounting basic Engine Control Units. Full Authority Digital Engine Control units (FADEC) were the installed and successfully completed all functional tests including in-flight windmill and cross-bleed engine restarts.
- Flutter, Buffet and aerodynamic model matching
  Validation and matching of the flutter and buffet aircraft models were successfully completed. Combined with the results of the Parameter Identification (PID) activity, aimed at validating the aerodynamic data set, this allowed to funnel revised and more reliable data into the next design phase.
- Handling qualities assessment of the bare aircraft showed good aircraft flying characteristics allowing the aircraft to be successfully demonstrated at the Paris Air Show at Le Bourget.
- Interim air Data system calibration and series ADS (IMFP) data gathering.
  The interim air data system was calibrated and showed optimum and reliable performance with errors well within MIL requirements. The system, linked to the FCS, allowed for safe flight while gathering data for the production air data system calibration (4 skewed Integrated Multi Function Probes).
- General systems functional tests completed.
  Functional qualification of general systems including Hydraulics, Electrical system, ECS, OBOGS was completed. Braking and Steering systems were tuned and optimised for best ground handling performance.
- Communications
  VHF and UHF radio tests were completed showing excellent radio performance with maximum range of ~200 nm at FL 300, slightly exceeding the optical range.
- EMC and HIRF activity completed for flight activity at home and abroad.
- APU installation and ground testing completed.
  APU ground testing has been successfully completed allowing re-deployment of the aircraft with no need for ground assistance.

The next step of the flight test campaign will see the extensive testing of the FCS phase 2 CLM (reversionary production mode), flutter and buffet tests and a loads campaign that will support the envelope expansion to 572KCAS/0.95M, an altitude of 40 kft and a maximum loading of –3 to 7g. A/C performance will also be thoroughly assessed and the engines fully qualified.
6. **LESSONS LEARNED**

In this paragraph some lessons learned in the first period of the test activity are presented.

**Combine flight test and design teams throughout the test activity**

The involvement of the test team in the ground testing phases greatly improved the team knowledge of the aircraft and of the designers needs in terms of test results. On the other side, involvement of the design teams in the test activity greatly improved their knowledge of the operational requirements. The overall result has been to have better

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

The M-346 program implemented several risk reduction policies, the most significant being the following:

a) An FCS Phase 1 Control Laws Mode, with limited capabilities, was developed. This allowed to test the fly-by-wire flight control system without the uncertainties of complex control laws entering the loop. The aircraft could also be flown earlier allowing for systems set-up and data gathering for the production system design.

b) An Interim Air Data System was selected as the primary air data source during the FCS phase 1 test flights. Simplicity of design and accuracy guaranteed a reliable air data source within the limits of the initial target flight envelope thus ensuring safe flight and calibration of the complex production air data system.

c) An interim engine control system, already extensively tested and flown, was adopted, minimising engine test times and ensuring flight tests could commence swiftly. In addition, the design of the production FADEC could benefit from data gathered during engine flight tests.

**Flight test activity is a process.**

As other M-346 activities, the flight test part of the project takes advantage of the program “flat” organization, thus allowing data collection and analysis in the same time in order to transfer test results and not only valid data to designers, for immediate decisions and relevant actions.

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.

FTE are not only responsible for FTI/data acquisition/test procedure, but they are truly “test designer”, combining requirements coming from Design Dept, operational and procedural aspects, taking also into account certification needs and professional rules/standards.

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

A collaborative approach has been adopted within the company and with partners.

An independent, third-party certifying agency has been established within Italian MOD to follow all the process leading to the M-346 aircraft type certification. A working group composed by both M-346 specialists and Italian MOD personnel has been charged to drive the certification process. Meanwhile the certifying Agency has been given full visibility on the program and the associated test results. The participation of IAF test engineers and test pilots to the flight test activity has also been forseen.

**Implement innovative, state of the art IT to improve overall test cost-effectiveness**

Large use of Information Technology aids is made within the Flight Test Department. This is not limited to traditional areas such as test data processing, but was extended to all areas of test management, from test planning to data analysis to final reporting.

A mixture of COTS items and home developed software was implemented aiming at best balancing the needs for customization, development times, interoperability and costs. In particular the standardisation of software tools used by the test and design teams allowed for an extensive exchange of data, information and applications with greatly improved efficiency.

A big effort is now underway to move a good deal of the data processing activity to real-time, thus reducing the average workload per test and minimise response times.
7. CONCLUSIONS

The M-346 represents a completely new generation of trainer aircraft, with state of the art leading edge technology that matches more complex and extensive aircraft development programs such as the Eurofighter Typhoon and the JSF. For the first time in many years an Italian company faces the challenge of thoroughly testing such an aircraft with a test activity that will see the Company involved in areas ranging from avionics to buffet, from engines to aircraft agility.

To cope with such a challenge Aermacchi has undergone a deep review of its established test organisation. All test processes went under deep review in order to make best use of the design and flight test resources. An extensive effort has also been made to re-engineer the test tools available, from test management to data acquisition and processing. A considerable emphasis has been put into building a highly skilled team that could merge experience, enthusiasm and creativity. To date the test team has achieved a competence unthinkable just a few years ago.

The results obtained from the almost 100 flight test performed so far have been promising, showing the goodness of the aircraft design. A long way still lies ahead. The success will ultimately depend on the skills of all those involved in the test activity.

BIBLIOGRAFY