THE VERFICATION OF FLIGHT TEST FOR AIORBORNE ELECTRO-OPTICAL DETECTING SYSTEM

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Abstract

For the principle and engineering model machines of airborne electro-optical systems or equipment, no matter how perfect or successful their designs and ground-based tests are, the practical performance and status of their systems could not finally be determined without verifying flight tests. By joining the engineering model machine with a type airplane, the key techniques of the system integration and synthesis could be really verified under airborne conditions, and the function and performance of the systems could be efficiently reflected and estimated. It is also possible to verify whether the project design of airborne electro-optical systems or equipment is completed or not, whether the engineering or application is practicable or not, and it is also possible to accumulate experience for later type airplane developing, commit few faults in designing and developing, take few risk and promote the fund benefit of cost, speed up the type design and development, so as to supply type airplanes with mature technical equipment and form powerful battle effectiveness as soon as possible.

Another question for the verification of engineering model machines of airborne electro-optical systems, which we have got to think, is how to draw up and design different schemes, methods and means of verification tests for different airborne electro optical systems or equipment. By applying scientific and optimal verifying flight test schemes and means, not only the problems involved in the engineering model machines, which couldn't be solved in ground-based test, would be determined and the verification goal would be got, but also the repeating times of flight verifying tests could be greatly reduced, and the flight test efficiency would be much raised.

1 Introduction

Both the Bay war and the Kosei war showed that modern air attack was developing in the direction of precise attracting, whole climates and instant blows. That is to say, the modern war needs the system which could run whole climates, and continuously provide the finding, sorting and identifying data for hostile targets. But to gain the functions and performances, to a great extent, depends on the airplane's capabilities of detecting targets and tracking ground-based targets. Electro-optical detecting systems, such as sight pod, were developed under such historical conditions. The U.S. pod LANTIRN is composed of a navigating pod and a sight pod. The pod LANTIRN was developed at the 70s' end, and was mainly equipped for F-15E and F-16. In America, the pod LANTIRN is being improved, at present, and made to have the ability of estimation for bomb-effect and have the ability of record for FLIR digital images. The improved system will be set to use in air force in 2002. Because of the Israeli advanced electro-optical techniques, LAFIER weapon development bureau developed its two kinds of pods, LITENING Ⅰ and LITENING Ⅱ. LITENING Ⅱ, which utilized 256×256 FPA technique, has the two functions, navigation and sight. LITENING pod has now be utilized by air forces in eight countries. The department of missile and weapon-fire of Luckheed Martin Company is now developing a new kind of sniper sight pod for America, in which there were the applications, such as medium wave band FLIR, 640×480MW Indium-antimony FPA, diode pump laser, laser-point tracker, laser indicator, CCDTV camera, blue diamond window. When Iraq aggressed on Kuwait in 1990, Britain speeded up the development of the sight pod, named after TIALD. During the Bay war, Britain arranged two TIALD pods in Saudi Arabia, for the purpose of five tornado fighters there. The two pods completed more than 100 times of tasks in the war, annihilating two targets each time averagely.

For the airborne electro-optical weapon systems as used in future fighters, it generally lasted a long time from prior-research to type research and then type equipped because of combined complex factors. To speed up the developing course, main developers and manufacturers of airborne weapon systems in the world are trying to cut short developing period, and strive to make the type products serve early the attributed weapon and systems. To adopt verifying demonstration during the course is the way, which is effective, in accordance with the law of weapon development, and more potential. The America congress, in the2001 finance year, appropriated $9,000,000 dollars to America Navy, for the integration of F-14 SAR Radar sensors in optics infrared shared reconnoiter pods and the flight-test verification so as to reduce the risk and shorten the developing periods. Boeing's X-32A and Luckheed Martin's X-35A verifying test airplanes are the air platforms which are used to verify and estimate the JSF technical performances of the JSF attack plane, which is as a contemporary typical example of determining the final developed model airplane through verifying tests.

The principle and engineering model machine of airborne electro-optical system, no matter how perfect the design and test are, cannot be sure of the real system performance without practical flight test verification. Through demonstration verification flight test with the system installed in airplane, the key techniques of the system integration and synthesis can be verified in real airborne conditions, such as whether the scheme design of *the system is* successful or not, whether the practical engineering level is reached or not, so as to accumulate experience, cut off additional courses, run less risk, increase the benefit of the cost, for later type development, and speed up the type developing course; and provide the type with mature technique equipment.

2 The purpose and significance of verifying demonstration

2.1 The purpose of the research

a. Verify the abilities of Electro-optical detecting system in finding, identifying and tracing objects at daytime;
b. Verify the abilities of Electro-optical detecting system in finding, identifying and tracing objects at night;
c. Verify the actual effective distance of the Electro-optical detecting system;
d. Verify the adaptability and match degree of Electro-optical system's connection with the type airplane;
e. Verify the correctness of Electro-optical system's connection with the type airplane in signals.

2.2 The significance of the research

a. Verify the technical feasibility, fight adaptability and financial supporting ability of Electro-optical system in airborne applying circumstance;
b. Verify whether the new developed technologies are successful and applicable or not;
c. Help research department and users accumulate experiences with interfaces, technology compatibility, adopted schemes and soon;
d. Help research department understand applying problems in practice, and keep in touch with the user's attention;
e. The users take part in the flight test and make sure whether the research or project continues its way or not, which promote competition in technology;
f. Provide scientific foundation for the evaluation of the prior-scientific-research.

3 The Contents of demonstrating Verification

Generally the airborne Electro-optical detecting system includes airborne TV system, FLIR system, Laser-ranging and directing system, Laser-capturing device, spectro-radiometer, Radiometer, Air-to-ground infrared seeker, Front-down-viewing camera measuring system and etc.

For static measuring of Electro-optical system, there are mainly the measurings such as luminance or illumination, near infrared radiation, far infrared radiation, laser power and its facula. But the dynamic measurings cover:

a. Spacial frequency varies with target contrast;
b. Special frequency varies with target temperature difference;
c. Special frequency, based on the standard target, varies with flight altitude;
d. Spacial frequency, based on the standard target, varies with fairflow velocity;
e. Stable performance;
f. Sighting and tracking accuracy;
g. Locked distances;
h. Locked periods;
i. Laser ranging and directing effective distances change with flight altitudes.

If the airborne electro-optical detecting system is supported by an airborne pod hung outside, the environment control unit inside the pod and its gyro stable platform are also verified in demonstrating flight tests.

4 The difference between demonstrating verification and type flight-tests

Demonstrating verifying flight tests are in fact to test and verify major and important technical design projects of prior-research technology and un-typed airborne products in air conditions. The Flight tests focus the attention on the effectiveness, advance and future engineering practice of the prior-research technological achievements. So in the flight test researches, the demonstrating verifying flight tests are always interested in an item or some items of technological specifications of the system designs. Rather than the type flight tests which involve every aspect of the flight test contents. The demonstrating verifying flight test ,to certain extent, is the stretch and continuity of prior-researches, and also the technology improvement on the coming type products which include software /hardware. The type flight tests are meant to test and verify the airborne systems and their related products to be typed. Within the maximized flight envelope in the whole tasks and whole technological states.

Owing to the fine classification of the type flight test, the test sorts and flight times are so more than the prior-research flight for the same system.

5 The scheme for demonstrating verifying flight tests

Omitted.

6 Testing and measuring methods

After determining the flight test programme, one main work of the demonstrating test flight for the airborne electro-optical detecting system is to design a testing scheme, to define the measuring contents and methods and to select and develop instrumentations. Actually, the verifying test flight with some success or fail depends on whether the measuring scheme is reasonable, whether the measuring method is scientific, or whether the selected instrumentations (such as its sensitivity, accuracy, signal-to-noise ratio and operating range) are suitable for the testing items. The measuring scheme and methods, and main instrumentations for the following various airborne electro-optical detecting systems during the verifying flight test will be discussed separately.

6.1 Design of multipurpose infrared target plane

Besides putting real ground objects as background targets, the system characteristics quantity testing and verifying for airborne electro-optical detecting system's dynamic tests are made by use of the accompanied test of the standard multi-function outdoor target. For the design of the multi-function infrared target plane, which is mainly used as verifying FLIR system's performance, it is necessary to fully consider the applicable characteristics of FLIR under outdoor flight conditions, and to select the measuring criteria that could reflect the systems' real performance and the measuring methods that could also be realized in the engineering. MRTD is the widely applied synthetic criteria parameter, which synthesizes the system's links and the eye's characteristics of a man and which is able to reflect the system's quality basically. The pattern of the target plane is composed of four vertical stripes in each group. The interval between stripes equals to the width of the stripe. The ratio of the length to width of the stripe is 7:1.Generally, the stripe and the background are both black body. The testing diagram of three different-groups spacial frequency is illustrated in Fig. 1. Obviously, MRTD is a function of the spacial frequency[1].

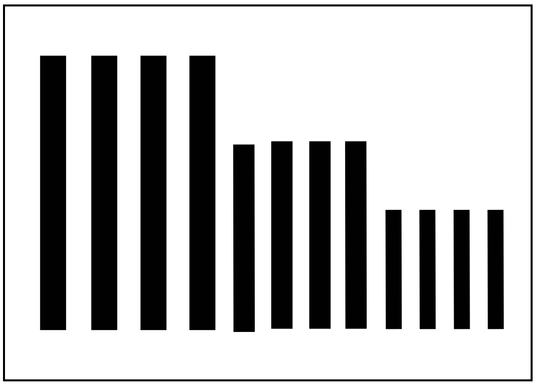

Fig.1 the testing diagram of MRTD

The system's spacial distinguishability and thermo-sensitivity decide performance limits of the FLIR sensor. The value of relative spacial distinguishability for the FLIR system is a measure of higher spacial frequency for the systems' distinguishability, while the FLIR' s relative thermo–sensitivity is a measure of lower temperature difference for the system's distinguishability. MRTD of the low spacial frequency point represents a limit of the ratio of signal-noise. The maximum spacial frequency (generally called a cut-off spacial frequency) of the high temperature difference point represents a limit of the spacial distinguishability.

Comparing to tests in laboratory or tests on ground conditions, the recorded data of airborne FLIR sensors are effected by various factors. One of the differences due to aircraft's induced vibration produces the lower cut-off spacial frequency. Other of the differences to determine the time of the spacial distinguishability is accuracy of not, which is directly effected on the confidence of continuing data procedure.

Other index measuring the airborne FLIR sensor's sensitivity characteristics is MDTD.

Fig.2 can be used for the measure of MDTD. The temperature difference between the target and the background is MDTD, when the observer can just identify the presence of the target through FLIR from a display. Therefor, MDTD is suitable to testing and evaluating of the outdoor infrared.

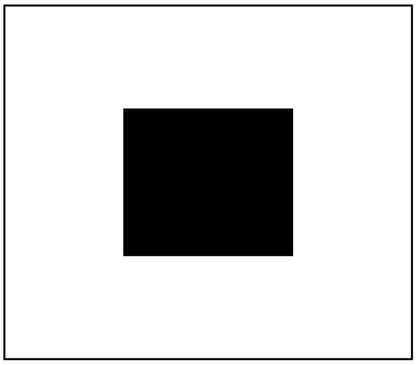

Fig.2 MDTD' s testing diagram

The study has been showed that MDTD's change is followed after change of the target's surface, temperature difference between the target and the background and thermo-interface around the target. It is preferable to select a lot of target approaches in one sortie for the measure of MDTD, and the approach in proper order for the target MDTD's measure is very advantageous, according to changing targets' size or putting different size of targets.

6.2 Test-flight verification of airborne FLIR system

During the test-flight verification of the airborne FLIR system, besides gray surface of the infrared target plate, radiation ratio of the black and white surface is 0.92 or more generally. The white surface also is diffuse-reflection surface. The gray surface can heated by electric controlling (some materials introduced that the white surface was a heating surface.), its temperature changing range is from environment temperature to 20-25 ℃ (it says 0.3-10 ℃) higher that environment. These parameters setting is to give consideration to the outdoor test-flight experiments for FLIR and TV systems.

For FLIR systems, two indexes-MRTD and MDTD need to verify during flight conditions.

Because the operating range of the forward-looking infrared is closely related to the environment conditions, air conditions, target characteristics,flight altitude, flight velocity,aircraft attitude, and measuring time. In order to conduct data processing and to compare with standard conditions, the previous parameters should be recorded in real time. In additions, to compare the effects of various environment and air conditions on the forward-looking infrared system, we should select different flight time, including mid noon, dusk and night.

6.2.1 MRTD' s test-flight measuring

The verifying test aircraft is flying to the plate's course at a constant speed and altitude and closing on the target plate. During each closing target testing and data acquiring, let keep constant temperature difference between the target plate's four-strip shape and the background. Data acquiring includes the local air transparency, real-time record of the target plate's temperature difference and image record of the airborne approaching target. In order to get the mean statistics of the tested data, the test-flight measuring process should repeat again and again. After getting each statistics data set of MRTD' s test-flight measurement, the temperature difference of the target plate adjusts its value to another value and then conduct the next MRTD test-flight measuring process. Based on flight conditions and application modes of the airborne forward infrared system; it can complete the test-flight measuring, combining with multi-parameters and various application modes, including different flight altitudes, different flight airspeeds,different infrared FOVs, multi-polarities (white-thermo/black-thermo), and various infrared operatings (automatic/manual). For the forward infrared system with gyro stability tracing platform, the performace of the platform tracing system should be verified by use of banking the target and circling the target.

6.2.2 MDTD's test-flight measuring

MDTD's outdoor test-flight measuring is effected by various thermo-disturbance. This flight measuring is completed by the target exploring and identifying flight tests at various ground–body backgrounds and thermo–interface geographical positions. The various thermo-reverse-difference target plates put beforehand in the test area and apply a measurable target thermo-source. In order to processing the late data and digitally analyzing, FLIR's images, the measuring at the same FOV direction as FILR system's FOV during the flight measuring should be gathered distributed data of a same target thermo-source by a calibrated temperature thermo-imaging system (or thermo–image meter). After getting the distributed data of the same direction and same target thermo-source, the strip charts from the calibrated thermo-image system can compare with FLIR's digitized video signals, so that it can decide. The minimum dynamic range of FLIR's sensors and MDTD curves at different background conditions.

6.3 Test-flight verification of airborne laser ranging and illuminating (directional) system

The main devices of the laser measuring field include the Light-spot measuring point specified, light power meter and high-reflectivity white-Lambert-body Laser target. The measuring contents mainly include the maximum laser range, laser illuminating energy, laser illuminating light-spot shape, divergence and pointing accuracy. The maximum Laser range mainly is the received laser return signal which was solved in real-time after the airborne laser shoot to the given target at a certain flight altitude. The laser illuminating energy is reflecting energy, measuring from the light power meter. Early EG&E Company's 580 Model radiator can measure visible and near-infrared-zone the coherent radiation. This radiator made a mean of all energy at 0.35um to 1.15 um and can measure the pulse energy from laser or other light sources (known pulse repeat frequencys) by an integrating method. The laser Light-spot measuring point specified can measure the laser incident light-spot shape and buffeting. For example, the TV camera with a silicon-matrix vidicon tube can observe the visible and near-infrared-zone laser incident image. This vidicon tube can respond to 1.1 um laser. It is ideal to use for observing the system's image of the gallium arsenate (Ga-As) and neodymium-yttrium-aluminum-garnet (NYAG).

7 Data processing scheme

7.1 Atmosphere transmission ratio calculation

During airborne flight environment conditions, the effective acting-range measure of the ground-based target detecting and identifying slant-range for the forward looking infrared system is related to multi-interface, in which the atmosphere transmission ratio is a main effective element. Therefore, to define the slant-range transmission factor is an important mid-parameter to finally determine the acting range of forward-looking-infrared actual space. Based on the flight altitude, zenith angle, visibility, initial/end wave length horizontal transfer distance, field temperature, relative humidity, the actual atmosphere transmission ratio of the flight sortie is calculated by use of LOWTRAN and HITRAN model (AGARDS military target signature R&A model). The LOWTRAN's calculation rule is the wave's number as a variable from 350 to 40,000 cm^{-1} (0.25~28.5um). Each step is $0.5cm^{-1}$. The atmosphere transmission ratio and radiance are calculated by solving a mean at intervals of $20cm^{-1}$ wave number . For sorbing molecules, the single–parameter spectral band model is used, including effects of continual absorbing, molecule's scattering and dulling of gas sol. In the slant air path, these rules include effects of refracting and Earth's curvature. There are representative air and gas sol models and parameters of various area. Customers can select them based on local environment conditions. They can re-select, derive and measure parameter instead of previous parameters, and then establish new edition for them. All these works provide a reliable theory basis for test-flight and data processing of the airborne electro-optical sensors system's real operating range.

7.2 Slant-range calculation between aircraft and ground-based target

If an aircraft is flying horizontally to the target plate at constant ground velocity and constant altitude, when the target can just be found and identified by FLIR or tracing TV, the pilot begins to calibrate the target, press the Top button and record the present flight altitude and velocity. When the aircraft is flying just over the target, pressing the TOP button again and recording the present flight altitude and velocity again. The slant-range between the aircraft and target will be calculated by the following formula (1) :

$$R1=(((AGV)*(\Delta T))^2+(AALT)^2)^{0.5} \qquad (1)$$

Where R1-slant-range between aircraft and target;

AGV-means aircraft ground speed between two indicative time intervals;

△t- two indicative time intervals;

AALT-means flight altitude between two indicative time intervals.

If horizontal flight AOA of the aircraft is α ,The pitching angle of the motion platform of the electro-optical system is θ , and other conditions are as previous conditions. The slant range can be calculated by formula(2).

$$R2=(ALT-ALTO)/SIN(\theta-\alpha) \qquad (2)$$

Where R2- slant-range (m) between detector and target;

ALT-pressure altitude (m);

ALTO-local pressure altitude (m).

7.3 Conversion of actual operating range

Based on the relationship between the detecting range and the ratio of signal-noise derived from the developable source target and the irradiancy produced from the target at the infrared detective element, the operating range's relation(3) of infrared detecting system depending on energy rule can be calculated:

$$r=1/\beta*\ln(MD_0\tau_0 NAD^*\Omega^{0.5}/2SNR\Delta f_R^{0.5} \qquad (3)$$

Where: r- actual operating rang (m) of detection.

β - radiation attenuation coefficient of air.

M- radiation of target at $\lambda_1-\lambda_2$ wave band.

D_0- effective aperture of optical system.

τ_0- light spectrum transmittance of optical system.

N_A- digital aperture of optical system.

D^*- detectivity of detector.

Ω - instantaneous FOV of detection.

SNR- ratio of signal-noise (or signal to noise ratio).

$\triangle f_R$- equivalent bandwidth of noise.

From formula (3), without considering the factors of optical parts of infrared system, detectors and signal characteristics and processing, the operating range of the infrared system is mainly relative to air characteristics. In order to quantitatively evaluate the airborne infrared system as well as other electro-optical devices, during data post processing, the actual data of outdoor should be converted to the conditions of the standard atmosphere and target signature, so that the evaluative results for the infrared and other electro-optical sensors can be attained consistently and they can be compared with other same kind systems. During the flight verifying tests of the electro-optical detectors (including FLIR, TV, laser, and so on), processing and converting the contents and methods for the outdoor measuring data are:

a. Apparent operating range gained from flight test data;
b. FLIR's MRTD/MDTD drawn from flight test data and apparent temperature difference;
c. Operating range converts spatial frequency;
d. Atmosphere attenuation, FLIR's equivalent target's temperature difference and operating range are calculated by use of LOWTRAN model;
e. Laser's equivalent operating range is calculated by HITRAN model;
f. Atmosphere attenuation and TV's equivalent operating range are calculated by LOWTRAN or MODTRAN model.

8 Problems and suggestions

The airborne electro-optical detecting system is regard as auxiliary equipment of aviation weapon systems. Besides themselves characteristics and different applications, the full play of their functions and performances is through interfaces between airborne avionics and fire-control and arm system. Therefore, the flight verifying tests for airborne electro-optical detecting systems, besides verifying the necessary specifications of electro-optical detecting systems, are to verify and validate their compatibility, reliability and systems' composite performance. Because the open loop verification for the electro-optical detecting system itself could not find some defects in their designs, the closed loop for all systems could reveal the inherent relationship in the engineering design.

9 Conclusion

Based on the test flight, the technique feasibility operational suitability and budget supporting capacity for the airborne electro-optical detecting system could be verified during the real environment conditions. This approach is an important means for tackling key problems of prototype aircraft and for predicting results.

It has contributed to new technique developing and verifying various interfaces, technique compatibility and operational schemes for different departments.

References

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