AN ARCHITECTURE FOR STORE SEPARATION ANALYSIS IN QUASI REAL-TIME USING PHOTOGRAMMETRY

Luiz Eduardo Guarino de Vasconcelos - MSc. {A}
Nelson Paiva Oliveira Leite - PhD. {B}
André Yoshimi Kusumoto - MSc. {C}
Cristina Moniz Araujo Lopes - PhD {D}.

Instituto Tecnológico de Aeronáutica (ITA) {A,D}
Instituto de Pesquisas e Ensaios em Voo (IPEV) {B,C}
Instituto Nacional de Pesquisas Especiais (INPE) {A}
Instituto de Aeronáutica e Espaço (IAE) {D}
du.guarino@gmail.com{A}, nelsonnpol@ipev.cta.br{B}, kusumotoayk@ipev.cta.br{C}, cmoniz77@gmail.com {D}

1. ABSTRACT

The Brazilian Air Force Instituto de Pesquisas e Ensaios em Voo ("*Flight Test and Research Institute*" - IPEV) is currently developing a new airborne near real-time Optical Tracking System (OTS) to be used for store separation flight test campaigns. Such system should determine the released store Time-Space Positioning Information (TSPI) data and send such information to be merged with the Flight Test Instrumentation (FTI) data set. With this new tool it would become possible, in near real-time, to correlate the simulated 6DoF trajectory with the real one to provide the confidence degree of the trajectory estimation model (e.g. simulation runs from CFD analysis) to provide a solid preview whereas the next separation test point is still considered safe or not and to improve test campaign efficiency without jeopardizing its safety levels. Several approaches have been highlighted in the literature to improve this particular Flight Test Campaign (FTC) efficiency and to reduce its costs. In this paper it will be presented the proposed architecture, the development and experimental evaluation of the software, the calibration process for the optical system, the determination of associated uncertainties, and the preliminary test results by static ejection test. Further developments should encompass the final system integration into the existing photogrammetric POD and its evaluation by a real FTC.

2. INTRODUCTION

The Brazilian Air Force (FAB) Flight Test and Research Institute (IPEV) is the unique governmental test range in Brazil that holds the execution of experimental Flight Test Campaigns (FTC). The execution of a test flight is considered to be successful, if and only if:

1. The physical integrity of the aircraft and crew is maintained after the flight; and
2. It was possible to gather and register accurate data from the FTI.

Some FTC are inherently unsafe, among them we have the store separation FTC. So, in this case, the flight clearance process for such FTC requires the inclusion of several engineering analysis and simulation runs (e.g. Computer Fluid Dynamics - CFD Analysis, or Wind Tunnel Tests) into the risk assessment process, to estimate the associated risk level to each Test Point (TP) to be executed.

But the models used for CFD simulations are not real, they only represent our best knowledge about the physical phenomenon, so they could be significantly incorrect. Such inconsistencies appear mostly often:

1. At the early phases of experimental FTC (i.e. When our previous knowledge about the test bed is limited), so the used model is inaccurate; and
2. In the occurrence of not predicted anomalies (e.g. Non-linearities or unpredictable aerodynamics couplings), so the used model is incomplete and incorrect.

In particular, for the store separation FTC, the mostly possible hazard condition that could occur is the store-to-rack/pylon/aircraft collisions [1], so after the flight the test range engineering staff should properly estimate the collision occurrence probability into the flying envelope by CFD analysis or wind tunnel data.

Then for each separation (Figure 1) the FTC technical staff should evaluate the correlation between the actual separation trajectory and the previewed one, so it would be possible to conclude that either:

1. The used model for CFD analysis is still accurate and therefore that the execution of the next TP is also safe; or
2. The used model should be improved for convergence and therefore the CFD simulation should be evaluated again before the execution of the next TP (i.e. Go/No-Go).

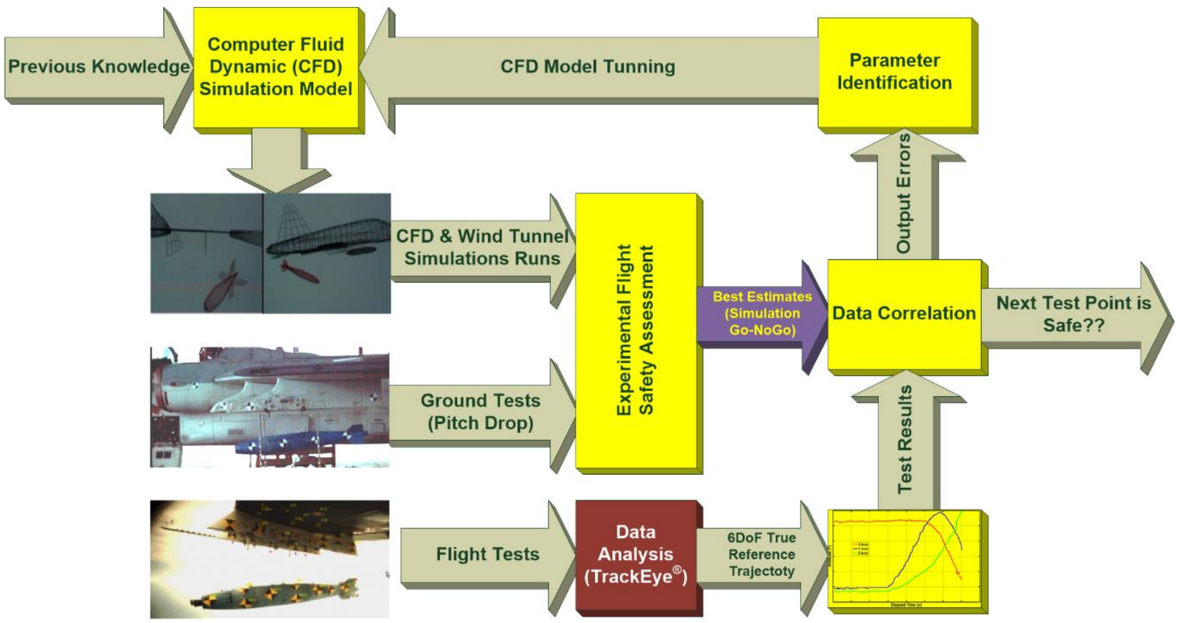

Figure 1 - Test Point Clearance Process for Store Separation Flight Test Campaign

The bottleneck for this process is the accurate measurement of the released store Time-Space Position Information (TSPI), expressed in Six Degrees-of-Freedom (6DoF) in the aircraft local reference frame (S_a). The most used process for measuring store TSPI employs the photogrammetric method [2], where 2-D pixels coordinates of a given Reference Mark (RM) measured from a picture frame is converted to horizontal and vertical angular displacements from the camera optical centerline.

Then using the measured information gathered by two or more fixed synchronized cameras placed at a known location, it is now possible to compute the 3-D position of the reference marks. A typical store separation dynamic, requires the usage of Hi-speed cameras (e.g. 400 fps) that provides hi-resolution image frames (e.g. 1024 x 768 pixels per frame - XGA), producing a data stream of 9.44 Gb/s. Nowadays most of the Custom Off-The-Shelf (COTS) cameras can only record the separation event and the store trajectory could be computed only in a post-mission operation after image downloading, by using a photogrammetric motion analysis software package (e.g. TrackEye®) [3].

Therefore, this process is very time-consuming and the test campaign becomes very ineffective and expensive because in most cases, we could only do one separation every 2 days or more.

In pursuit of the objective of improving test efficiency without jeopardizing its safety, IPEV has evaluated two possible architectures, as follows:

1. To develop and validate a data fusion application that combines inertial sensor data, measured into the released store and transmitted to the test bed with photogrammetric solution, that uses image frames with lower sampling rate (e.g. 100 fps or less), so the final 6DoF trajectory solution could be significantly speed up; or

2. To develop and validate an airborne autonomous optical tracking system, so the separation 6DoF trajectory could be computed into the camera POD and merged to the Flight Test Instrumentation (FTI) data set and transmitted in near real-time to the Ground Telemetry System (GTS).

The first solution was considered the simplest one, but its operational costs is higher, because the store instrumentation is destroyed at each launch, and its reliability is highly dependable of the data link quality between the store and the test bed.

As result IPEV has begun a long research and development process for the development of the SisTrO system, which is a near-real time optical tracking system to be used for store separation test campaigns.

3. SisTrO DESIGN

In 2009, for the development and validation of a real-time data processing tool, for the Air Data System (ADS) calibration FTC, using the tower fly-by method [4], it was required to measure in real-time the test bed altitude while flying over the tarmac. As solution, IPEV has developed an image processing application [5], to compute the test bed altitude from a single image frame (Figure 2). Such application was validated using post mission differential phase GPS measurement and the results were considered satisfactory.

The next step was to replace the single-shoot camera to a hi-speed camera and therefore to compute the test bed trajectory and speed, so a new image tracking application was developed and evaluated with a fully instrumented Helibrás H-55 Esquilo Helicopter and an EMBRAER Xavante XAT-26 Jet Aircraft, during the Brazilian 2011 class Flight Test Course (EFEV) ADS calibration FTC [6]. As result the measured altitude uncertainty for the H-55 helicopter and the XAT-26 aircraft, was respectively ±0.13m @1σ (Figure 3) and ±0.09m @1σ.

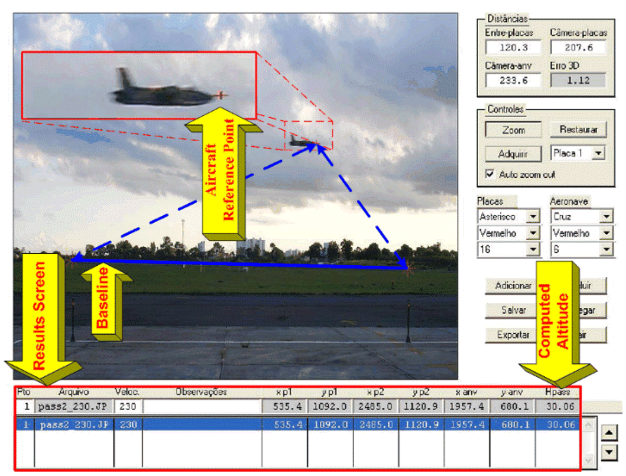

Figure 2 - Test Point Clearance Process for Store Separation Flight Test Campaign

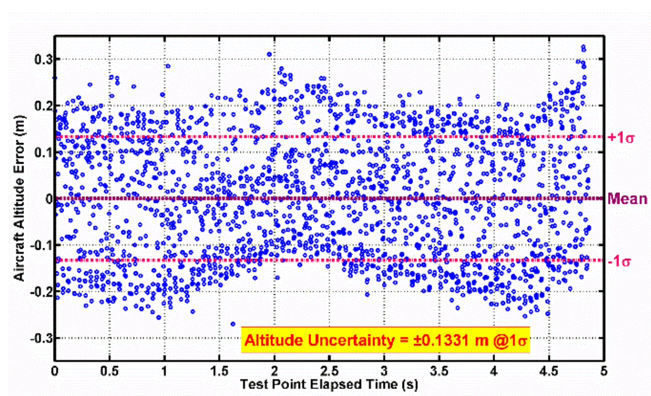

Figure 3 – Altitude Uncertainty of a test point

For such solutions, the system architecture uses a camera connected to a processing unit over a TCP-IP ETHERNET network (100/1000 Base-T), so the observed bottleneck was the additional latency of the data transmission layer which is not designed to efficiently transport hi-speed video frames (e.g. around120Gb of data for a typical 10s TP).

For improving the system performance, the “natural” solution was the integration of the optical tracking application into the hi-speed camera processor, to create a smart hi-speed camera and therefore to avoid unnecessary data transmission delays. As consequence, the next step was to embed the application into an iOS device [7], to provide a tight-coupled integration solution between the processor and the camera.

In this application, target altitude and true airspeed are computed at every valid frame and stored. After pressing Stop button, the superimposed marking can be viewed through the entire trajectory of the aircraft during the actual TP (Figure 4). Then at the end of each TP the application checks the conformance of these parameters with the specific test requirements to validate or reject the current point (Figure 5).

Figure 4 – Superimposed marks of the aircraft trajectory, after the execution of a TP

Figure 5 – TP results and its validation information

Although the observed increased performance of the iOS device solution as compared to the camera to computer transmission, such alternative cannot be used for store separation FTC, because it doesn't comply with several requirements, such as: Airborne environment (e.g. Temperature, vibration, acceleration and shock), minimum frame rate and image field-of-view.

The search for a COTS airborne hi-speed camera where the user could embed its own image processing application into the camera processor or FPGA was unfruitful due to proprietary information protection restrictions. So, the possible solution has returned to the real-time data transmission over the TCP-IP network, which is very time-consuming and inefficient.

Then the introduction of the CoaXPress Standard [8] (CXP-6) that is capable of transmitting up to 25Gb/s in up to 4 x 6,25Gb/s real-time connections, it was possible to develop hi-speed cameras and frame grabbers that withstand the required transmission bandwidth for supporting real-time image processing in near real-time.

4. SisTrO DEVELOPMENT

SisTrO development requires the integration of the following major components (Figure 6):

1. An airborne real-time hi-speed computational video imaging system composed by two or more cameras (Figure 6 A.1 and A.2) and its associated image processors (Figure 6 B.1 and B.2);
2. An airborne single board processor to compute the RM's 3-D position and the store 6DoF TSPI data (Figure 6 D);
3. An airborne data switch with IEEE-1588v2 (i.e. PTP v.2) grand master capability with GPS time source, for time synchronization and data distribution (Figure 6 E); and
4. Several software applications, to:
   a. Locate, identify and track the RM's 2-D position in pixels;
   b. To minimize the optical system (e.g. Lens and POD window) systematic errors of the measured RM's 2-D positions, using a data calibration algorithm;
   c. To compute the RM's horizontal and vertical angular displacement from the camera optical axis, using the Pin Hole model;
   d. To compute the RM's 3-D positioning using the above result (i.e. 3.c) of two or more synchronized image frames; and
   e. To convert the above result (i.e. 3.d) to store 6DoF TSPI data.

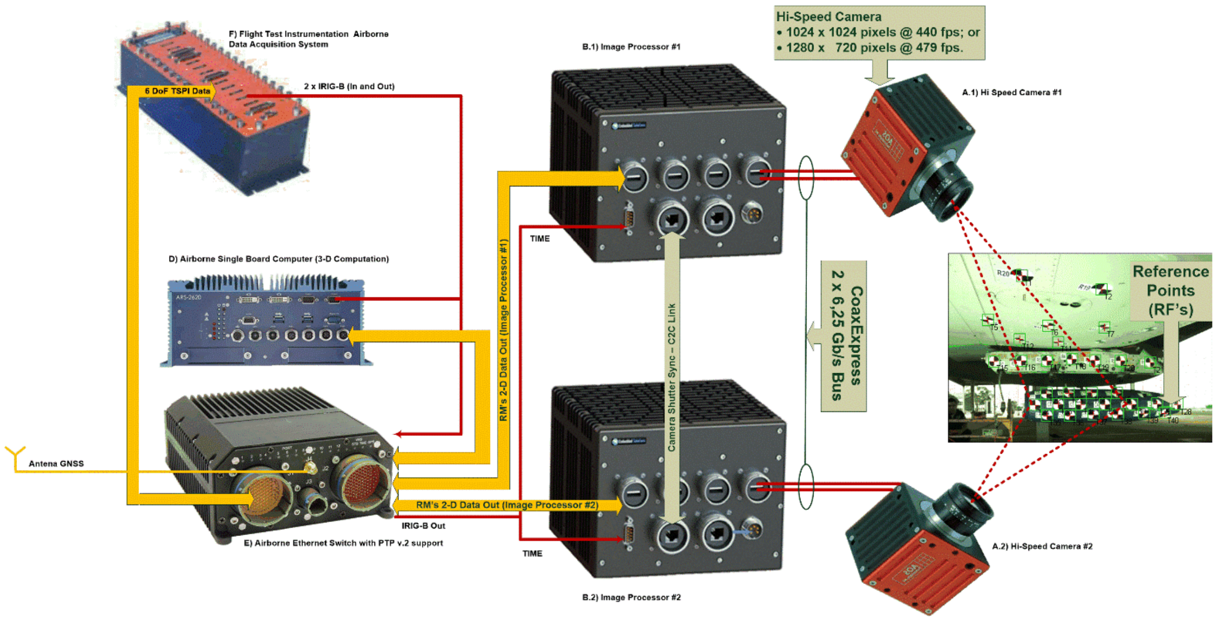

Figure 6 - SisTrO Block Diagram

SisTrO setup and operation also required the development and validation of additional tools for:

1. Performing the optical system calibration process and the identification of the systematic error compensation model coefficients; and
2. The estimation of the SisTrO uncertainties.

5. SisTrO EVALUATION

A NATO produced document [9] concentrates on compatibility, integration and separation of store separation that have to be performed during the integration of an existing or newly developed store into new or existing military aircraft. Two fundamental tests in soil separation tests (i.e. also known as static ejection or pitch drop tests) are those of evaluation of physical interfaces and electrical tests. Details of these tests are shown in [9]. These tests were also used by IPEV to experimentally validate a new solution for analysis of store separation assays.

In order to perform this type of test, the IPEV developed a method that is divided into the following steps: planning, preparation, geometry determination, camera calibration, test point realization, 2D analysis and 3D analysis with 6DOF.

5.1. Planning

As previously, photogrammetric testing offers significant and unique technical and managerial challenges. In this stage the planning of the entire flight test campaign is carried out and the following activities and information are defined: definition of the flight test period; definition of teams to participate in the test, equipment, benchmarks; elaboration of the scenario sketch; formal request for team support; definition of the number of test points and their characteristics (i.e. some determined movement in the load); reserve of equipment and test site; formalization of the campaign (i.e. preparation of the document with details of the campaign).

5.2. Preparation

At this stage, all teams and equipment must be positioned at the test site. The store must be positioned on the aircraft pylon. The adhesives are placed on the store, pylon and aircraft. The cameras are configured and their positions are determined.

The frame rate of the cameras are tested. Some releases are made in order to test the ejector, the trigger, the terminology to be used in the test, the capture of the separation by the cameras. Finally, the scenario sketching and possible adjustments are validated.

5.3. Geometry determination

For determining the geometry, it is essential to determine the longitudinal and lateral leveling of the aircraft. The aircraft leveling reference marks were used for this procedure, which was performed as instructed in the Aircraft Maintenance Manual.

For the survey of the coordinates of the points of interest described, it was necessary to establish a topographical polygon close to the aircraft to base the irradiations of the measurements. With this information, it was possible to measure the store geometry, determine the positioning and attitude of the cameras and the geometry of the aircraft.

A key component in this process is the high-speed digital camera [10]. Another item to evaluate is the camera's frame rate [10]. There are many frame rates to choose from. However, 200 frames per second is recommended as the best for store separation analysis. A typical store will travel from its initial captive position to the bottom of the camera's view in 0.2 to 0.4 seconds (i.e. depending on the distance of the camera and the lens chosen). At 200 frames per second, this will produce 40 to 80 usable frames of data.

In the tests, the Xavante 4467 registration aircraft and the Mikrotron Cube7 high speed cameras were used [11]. The cameras were configured with the frame rate at 400 frames per second (fps), mounted externally on the aircraft in a photographic POD to record movements during the release of the store. Two identical, time-synchronized cameras were used. For the tests carried out at IPEV, the Kowa 6mm C-Mount lens was used [12]. For the tests, an external fuel tank of approximately 130 kilos was also used.

5.4. Method for calibrating the cameras

There are several approaches for the correction of projective distortion, such as direct linear transformation, polynomial affine transformation, photogrammetric transformation, among others.

As analyzed by [2], the photogrammetric approach is the one with the smallest error, because it uses the camera projection model itself, that is, it considers the principle of the collinearity equations. In the photogrammetric process, the main task is to establish a strict geometric relation between the image and the object, so that information can be extracted from the object only through the image [13]. However, a raw image contains geometric distortions due to the influence of several intrinsic and extrinsic factors on the sensor. Thus, to obtain reliable metric information from images in the various applications, it is essential that the optical assembly (camera-lenses) be calibrated [14].

5.5. Calibration model

Calibration consists of a process for experimental determination of a series of parameters that describe the process of image formation in the camera, according to an analytical model, which relates the known coordinates of a reference grid, also called the calibration field, with the corresponding in the image. In our case, a model was developed for camera calibration that considers the pinhole model to be added to the radial [17] and tangential distortions [18].

5.6. Calibration field

There are several calibration methods that essentially differ in the type and geometry of the field, the number of necessary photographs, the camera positioning method in the field, the quantity and arrangement of distortion parameters in the mathematical model, the adjustment methodology of the model to identify the parameters, among others. Some studies address comparative studies of the various calibration methods [15, 16, 19]. At the IPEV, a geometric calibration field was set up in a room in the X-30 hangar, consisting of a three-dimensional space with 134 reference marks, as shown in Figure 7. In the calibration process, the exact 3D coordinates of the reference marks in the field must be known. Thus, a Total Topographic Station was used to determine the coordinates of the 134 reference marks.

5.7. Camera calibration

The methodology developed for the calibration in this field provides the knowledge of the external orientation of the camera, that is, its position in relation to the frames and their pointing angles. This favors convergence in the adjustment of the distortion model and the breakdown of the linear dependence between some parameters.

Photographic shots were taken with the cameras used in pitch drop testing. Only one image was required with each camera. Later, in each image were captured the line-column coordinates of the reference frames, associating with the corresponding coordinates in the field raised with Total Station, in addition to generating an image indicating the location of the frames captured.

For each reference mark, the discrepancy of the reprojection coordinate, provided by the identified model, was evaluated in relation to the corresponding real coordinate captured from the image. The result is in Figure 8, which shows a satisfactory mean square error, less than one pixel.

5.8. Test points

For the tests, all equipment must be ready. Thereafter, the test engineer to determine the start of the test point (i.e., initial frame identification in the cameras) triggers a trigger. When triggered, after 0.5 second the store was released. After the contact of the store on the "ground", the cameras were paused. The videos were then downloaded from the cameras and viewed to determine the validity of the videos. If one of the videos was inappropriate (e.g. not synchronized, loss of frames, capture catch, or any other weather), the videos were discarded. Otherwise, the videos were renamed and stored on the local computer. After that, go to the next test point, replacing the store on the pylon. 10 valid test points were carried out within 2 hours. At the end of the test day, the videos were stored on the IPEV data server.

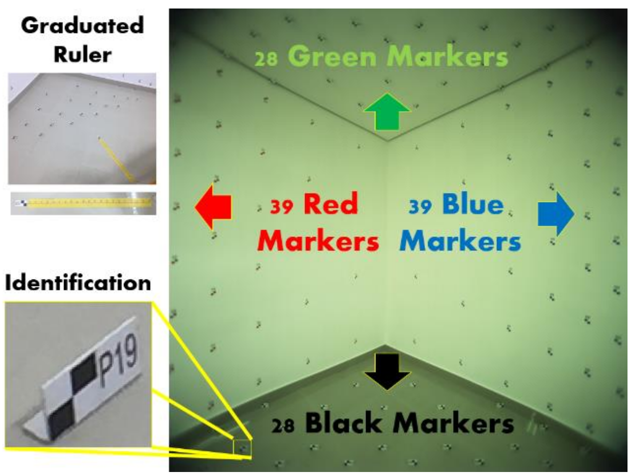

Figure 7 - IPEV Geometric Calibration Field.

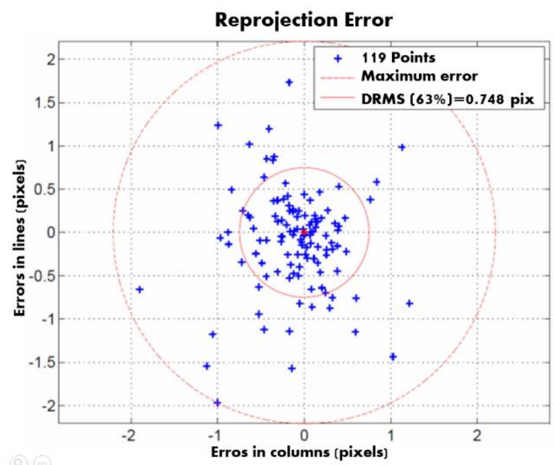

Figure 8 - Reprojection errors analysis for the rear camera.

5.9 2D Analysis

After performing the test points on the day, the IPEV photogrammetry team works on information processing.

A video of 2 seconds has an average of 2.8 GB, with each image having 3.5 MB. The camera to the left of the POD has a resolution of 1184 x 1040 pixels and the right resolution of 1248 x 968 pixels.

Each video has, in general, 0.5 second of images that precede the beginning of the separation and 0.5 second of images after the contact of the store on the "ground".

The cameras provide RGB-standard images. Therefore, you have to turn the image into grayscale. After that, the equalization of the histogram of the image is performed in order to improve the brightness and contrast ratio of the image. The next step is to define the center of each reference marker (considering markers in the store, pylon and wing) so that they can be tracked during separation. An identification algorithm scans the image, looking for corners. It can be observed in Figure 9 that 39 reference marks were found (red dots) in the store, pylon and wing, considering the camera that is left in the POD. In Figure 10, it is possible to observe the reference markers that were tracked during the test point. For a 3D solution, two or more cameras are used to quantify the error.

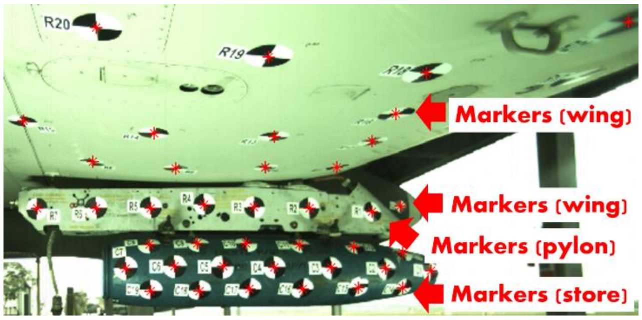

Figure 9 - Image with reference markers identified in cargo, pylon and aircraft.

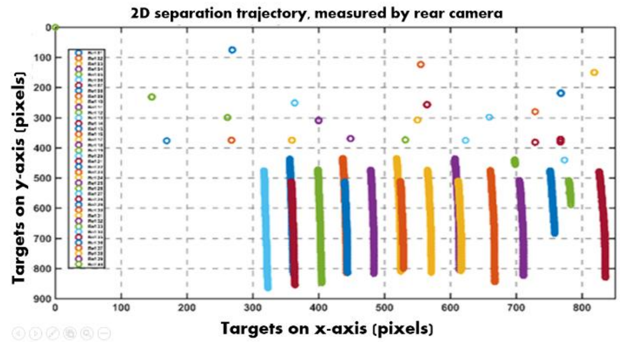

Figure 10 - 2D separation trajectory measured by the rear camera.

5.10. 3D Analysis

Given the 2-D frames of each camera, the problem of solving the position (x, y, z) of each frame is solved using least squares. Each reference marker is defined by the intersection of two lines, generated by the line of sight of each camera. Each line in space is represented by two equations in x, y and z, so that with two straight lines (four equations), we have an over-determined system, which is solved by least squares (4 equations and 3 unknowns). With a third camera, we have two more equations. It could quickly determine, by means of determinant, if there is intersection between two lines in space, which will hardly occur in the experimental measurements. However, a middle ground can be obtained by resolution in the least squares (a point that belongs to no straight line, but is closest to both simultaneously).

Suppose we are given the coordinates of a number of points measured in two different Cartesian coordinate systems [20]. The photogrammetric problem of recovering the transformation between the two systems from these measurements is called absolute orientation [20]. This problem occurs in many contexts.

The transformation between two Cartesian coordinate systems can be thought of as the result of a rigid movement of the body and can thus be decomposed into a rotation and a translation. In stereophotogrammetry, moreover, the scale may not be known. There are obviously three degrees of freedom for translation. The rotation has another three (direction of the axis in which the rotation occurs plus the angle of rotation around this axis). Scaling adds one more degree of freedom. Three known points in both coordinate systems provide nine constraints (three coordinates each), more than enough to allow determination of the seven unknowns (3 translations, 3 rotations and 1 scale).

Discarding two of the constraints, seven equations in seven unknowns can be developed to allow parameter recovery.

The algorithm implemented by [20] uses all available information to obtain the best possible estimate (i.e., least squares). In addition, it is preferable to use it for center point estimation, rather than relying on single point measurements. This algorithm is used in this work. The main purpose of 3D analysis is to obtain 6DoF data.

Figure 11 shows an example of 3D tracking of five frames of store. Figure 12 shows the frame-by-frame position error determination.

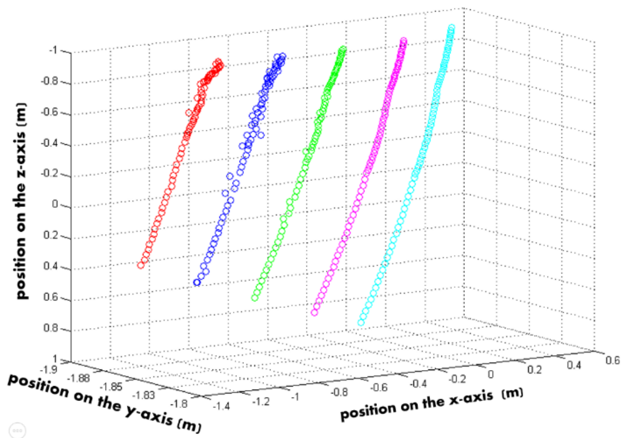

Figure 11 - 3D chart for analysis of a test point

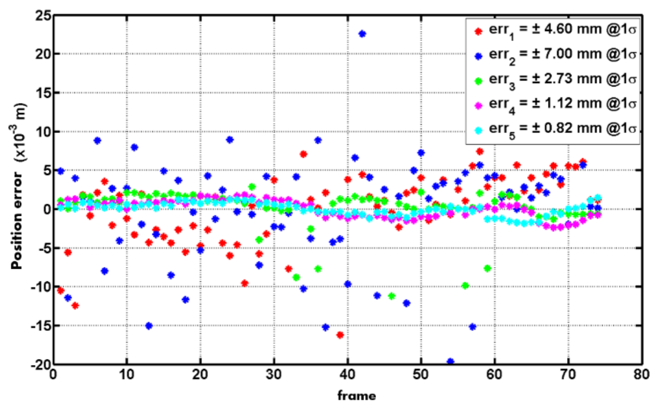

Figure 12 - Frame-by-frame position error.

All the algorithms developed were made in Matlab.

6. LESSONS LEARNED

The main lessons learned from this work were:

- The positioning of the reference markers influences the result and the uncertainties;
- The use of the calibration field facilitates the step of calibrating cameras with a single shot; and
- Calibrating the cameras is essential.

7. CONCLUSIONS

This work aimed at presenting the proposed architecture, the development and experimental evaluation of the software, the calibration process for the optical system, the determination of associated uncertainties, and the preliminary test results by static ejection test, performed by the Brazilian Air Force.

Performing pitch drop and analysis using photogrammetric solution requires significant managerial and technical efforts.

The reduction and analysis of data performed were considered satisfactory.

8. ACKNOWLEDGEMENTS

The authors thank the colleagues from the Instituto de Pesquisas e Ensaios em Voo (IPEV) and Instituto Tecnológico de Aeronáutica (ITA), for supporting the flight tests. In addition, we would like to thank FINEP and FUNCATE under agreement 01.12.0518.00 that funded the development of this work.

9. REFERENCES

[1] Stephen R. Perillo, Donald J. Atkins. Challenges and Emerging Trends in Store Separation Engineering – an Air Force SEEK EAGLE Office. 47th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition. 2009.

[2] Lima, S. A.; Brito, J. L. N. S. Estratégias para retificação de imagens digitais. Em: COBRAC 2006 - Congresso Brasileiro de Cadastro Técnico Multifinalitário, UFSC, Florianópolis, 2006. Anais, Artigos, n. 90, p. 1-14, 2006.

[3] IMAGE SYSTEMS. 6DoF Stores Release. Available in http://www.imagesystems.se/index.php/download/public/brochures/TRACKEYE-6D-STORE-SEPARATION-BROCHURE-2017.pdf. Acessed on August, 20th, 2018.

[4] ARANTES, R. M., “Introdução a Aerodinâmica Técnicas de Ensaios em Vôo - Calibração, Documento nº E-B11”, Chapter 2.3, Grupo Especial de Ensaios em Vôo, 2003.
[5] LEITE, N. P. O.; LOPES, L. M. F.; LIMA, W. O.; ROBERTO, L. The Development of a Quasi-Real Time Data Processing Tool for the Calibration Flight Test Campaign of an Air Data System. In: European Test & Telemetry Conference (ETTC), Toulouse: ETTC 2009. pp. 130-135.
[6] VASCONCELOS, L. E. G.; LEITE, N. P. O.; PINHEIRO, C. A. M.; CARPINTEIRO, O. A. S.; Development of a Hi-Speed Near Real-Time 720i Image Processing Application for Flight Test. In: European Test & Telemetry Conference (ETTC), Toulouse: ETTC 2011. pp. 67-72.
[7] VASCONCELOS, L. E. G.; LEITE, N. P. O.; Development of an Image Processing Application for Air Data System Calibration using iOS Mobile Devices, Proceedings of the European Test and Telemetry Conference ETTC 2013, Toulouse: ETTC 2013.
[8] JIAA; JIIA CXP-001-2015 CoaXPress Standard, The Standardization Committee CoaXPress Working Group, Japan Industrial Imaging Association (JIIA), 2015, Available at: http://jiia.org/wp-content/themes/jiia/pdf/standard_dl/coaxpress/CXP-001-2015.pdf, accessed on August, 20th, 2018.
[9] NATO. Aircraft/Stores Compatibility, Integration and Separation Testing. North Atlantic Treaty Organization. STO AGARDograph 300. Flight Test Technique Series – Volume 29. AG-300-V29. Published September 2014.
[10] R.J.Arnold and CS.Epstein. AGARD Flight Test Techniques Series on Store Separation Flight Testing. Volume 5. NATO. No.300. Published April 1986. ISBN 92-835-1523-4.
[11] Mikrotron.Mikrotron Cube7-Datasheet.Available in https://mikrotron.de/fileadmin/Data_Sheets/High-Speed_Recording_Cameras/mikrotron_motionblitz_eosens_cube7_datasheet.pdf. Accessed on August 20th, 2018.
[12] Kowa. Lenses 6mm Kowa – Datasheet. Available in http://www.rmaelectronics.com/content/Kowa-Lenses/LM6HC.pdf. Accessed on August, 20th, 2018.
[13] Mikhail, Edward M., James S. Bethel, and J. Chris McGlone. Introduction to Modern Photogrammetry. Hoboken: Wiley, 2001. 479p. ISBN 978-81-265-3998-7.
[14] Gruen, A.; Huang, T. S. Calibration and orientation of cameras in computer vision. Berlin: Springer, 2001. 235 p. ISBN (3-540-65283-3).
[15] Clarke, T.A.; Fryer, J.F. The development of camera calibration methods and models Photogrammetric Record, 1998, 16(91): pp 51-66.
[16] Remondino, F.; Fraser, C. Digital camera calibration methods - Considerations and comparisons ISPRS Commission V Symposium 'Image Engineering and Vision Metrology', Germany, 2006.
[17] Heikkila, J. Camera Calibration Toolbox for Matlab. Available in http://www.vision.caltech.edu/bouguetj/calib_doc. Accessed on August, 20th, 2018.
[18] Brown, D.C. Decentering Distortion and the Definitive Calibration of Metric Cameras. 29 ed, Washington DC, pp 444-462, March 1965. Annual Convention of the American Society of Photogrammetry.
[19] Hieronymus, J. Comparison of methods for geometric camera calibration In: International Congress for Photogrammetry and Remote Sensing, 22, 2012, Melbourne, Australia. Proceedings Melbourne: International Society of Photogrammetry and Remote Sensing (ISPRS), 2012. P.595-599. Vol XXXIX-B5. ISSN (16821750).
[20] Horn, B. K. P. Closed-form solution of absolute orientation using unit quaternions. Vol. 4, No. 4/April 1987/J. Opt. Soc. Am. A.

10. BIOGRAPHY

Luiz Eduardo Guarino de Vasconcelos is a Software Engineer with 16 years of experience. PhD Student in Space Sciences and Technologies at Aeronautics Institute of Technology (ITA). Master in Computer Science and Technology from the Federal University of Itajubá (UNIFEI). He has been working in the Science and Technology career since 2002. He work at Brazilian Air Force Flight Test and Research Institute (IPEV/DCTA) for 16 years in flight tests, developing applications for real-time analysis involving image processing, sensor calibration and techniques of software engineering. In the last 5 years has been dedicated to the development of computational solutions for store separation analysis. He has been working for 3 years at National Institute for Space Research (INPE) with software development related to the weather forecast. He has dozens international publications. Professor at Faculty of Technology (FATEC Guaratinguetá) working mainly in the courses of web programming, database, security and distributed systems. Professor in the postgraduate on Projects and Development of Web and Mobile Applications (at UNIFATEA) working in the courses of agile methodologies, application security, software testing, web development and mobile. Participation in startups and in research projects.

Andre Kusumoto is a Senior Technologist at Brazilian Air Force Flight Test and Research Institute (IPEV/DCTA) at São José dos Campos, Brazil. IT Projects Manager, head of Software Development Team and researcher in the Institute's research projects, Andre currently working on the development of real-time processing tools for telemetry stations using computer vision techniques. He completed his Master's Degree in Space Sciences and Technologies at Aeronautics Institute of Technology (ITA) and has experience in Computer Science, working mainly in the following subjects: Digital Image Processing, Computer Vision and Computational Systems Analysis. In addition, Andre is a Professor of Computer Graphics, Image Processing and Software Engineering at Universidade Paulista (UNIP).

Cristina Lopes is a PhD in Chemistry at State University of Campinas (UNICAMP, 2003) with a sandwich period at the Institut für Makromolekulare Chemie / Albert-Ludwigs Universität Freiburg, Germany. Master in Chemistry at UNICAMP (1997) and Graduate in Technological Chemistry at UNICAMP (1994). She is currently a Researcher at the Department of Aerospace Science and Technology (DCTA), working at the Institute of Aeronautics and Space (IAE). Permanent Professor of the postgraduate program in Space Sciences and Technologies (ITA / IAE / IEAv). She is Coordinator of the area of Space Systems, Tests and Launches. President of the Academic Programs Council of IAE. Representative of Scientific Initiation of IAE with CNPq. Has experience in the area of materials, with specialization in polymers, aerospace materials, nanocomposites, hybrid composites, ballistic shielding, and electromagnetic shielding.

Nelson Paiva Oliveira Leite, in 1981 he got his electronic engineering degree and later in the same year he was hired as junior engineer by the Research and Development Institute (IPD) Flight Test Subdivision (PAR-V), which nowadays became the Flight Test and Research Institute (IPEV) is a flight test engineer at the Flight Test and Research Institute (IPEV) of the Brazilian Air Force. Currently, his main activities are focused on the development of a flight simulator to be used primarily for the training of the Flight Test Course students.