ASSESSMENT OF AIRSPEED CALIBRATION METHODS ON A UTILITY HELICOPTER

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ABSTRACT

The calibration of airspeed measurement and indicating systems is an important point in the overall aircraft design, flight test and certification processes. Accurate, consistent and reliable airspeed indication is essential for the safety of the helicopter. Therefore, certification authorities dictate that an aircraft has a sufficiently accurate airspeed indicator system for different flight regimes such as level flight, climb, autorotation etc. In this paper, the airspeed calibration methods due to the position error, engaged during the development of T625 helicopter, are discussed. There are several flight test methods to determine the position error. The Horseshoe Heading (GPS) and the ORBIS methods, the methods used for level flight, depend on accurate GPS data and do not need any further instrumentation or device. The calibration results for these methods are compared with the data obtained with the Trailing Bomb method at which a probe is slung from the helicopter is to collect air data in the absent of rotor downwash.

1. NOTATION

AC	Advisory Circular
CG	Center of Gravity
CS	Certification Specification
GW	Gross Weight
HD	Density Altitude
HOGE	Hover Out-of-Ground Effect
ISA	International Standard Atmosphere
KIAS	Knots Indicated Air Speed
KTAS	Knots True Air Speed
MCP	Maximum Continuous Power
MTOW	Maximum Take-Off Weight
OAT	Outside Air Temperature
OEI	One Engine Inoperative
PEC	Pressure Error Correction
SL	Sea Level
TOP	Take-Off Power
VH	Maximum Level Flight Speed
VNE	Never Exceed Speed

2. INTRODUCTION

Helicopter airspeed calibration is a critical process that ensures the accuracy and reliability of airspeed measurements, which are essential for safe and efficient flight operations. The instruments are designed on assumption that they will be fed with pressures from the undisturbed free stream air in which the aircraft flies, but this is not the case as aircraft generates a pressure field around itself in producing aerodynamic forces. Unlike fixed wing aircraft, helicopters face unique aerodynamic challenges due to the combination of rotor induced flow, fuselage interference and the complex airflow patterns around airspeed sensors. These factors can lead discrepancies between the indicated airspeed (IAS) and the true airspeed (TAS), necessitating precise calibration methods to correct these errors [6].

Conventional airspeed indicators measure static atmospheric pressure and dynamic pressure and provide information to the pilot; the airspeed at which the aircraft would be flying at the dynamic pressure corresponding to the sea level (assuming zero position and instrument errors) [7]. The schematic representation of the pitot-static system is provided in the Figure 1.

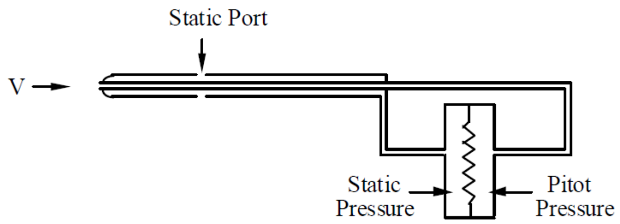

Figure 1: Schematic View of Pitot Static Sytem [7]

As mentioned, airspeed data cannot be measured directly, but it is proportional to the dynamic pressure of the air through which the aircraft flies as explained in the Bernoulli's Law (1). If the density information of flight conditions is measured, true airspeed of the aircraft can be determined from the following equation.

$$(1)\ \ P_{dynamic} - P_{static} = \frac{1}{2}\rho V^2$$

However, the instrument is calibrated using the density value of the sea level condition (ρ_0); therefore, this indicated airspeed will be equal to the true airspeed only at sea level. If this relation is substitute to the equation, the relationship between TAS and IAS can be obtained.

$$(2)\ \ P_{dynamic} - P_{static} = \frac{1}{2}\rho_0 {V_i}^2 = \frac{1}{2}\rho V^2$$

$$(3)\ \ V^2 = {V_i}^2 \frac{\rho_0}{\rho}$$

where density ratio can be defined as;

$$(4)\ \ \sigma = \frac{\rho}{\rho_0}$$

Then,

$$(5)\ \ TAS = IAS\ \frac{1}{\sqrt{\sigma}}$$

As mentioned before, deviations from the true airspeed can occur in the indicated airspeed due to the various error sources. Therefore, pitot-static system should be calibrated due to mainly following reasons;

- Instrument Error
- Installation Error
  - Lag Error
  - Leakage Error
- Position Error

Instrument error can be defined as the error due to the manufacturing tolerances etc. These errors refer to inaccuracies inherent in the airspeed indicator system itself. These errors may arise from the mechanical imperfections, calibration drift or limitation in the design of the pressure measurement instruments. This error can be calibrated during cell tests by manufacturer, therefore, it is generally considered very small.

When a pressure instrument and sensor are fitted to an aircraft there are a number of problems such that system lags, blockages or leaks which can arise due to the manner in which they are installed. In an ideal system, any change in the free stream air pressure would be sensed by the pressure sensors and displayed instantaneously; however, in real case, delays may occur. Same situation may apply to blockages and leaks. The effects of this errors are fairly obvious and they can be guarded against by reducing the number of connections to a minimum, and making the radius of the tubes as large as possible. Similar to the instrument errors, installation losses can also be reduced before the system is used on the aircraft actively.

As previously mentioned, to measure airspeed by using total and static pressure, it is necessary to measure these parameters in the free stream air. In practice, the accuracy of the airspeed indicator measurement will not be perfect. Therefore, there will be errors due to the position of the sensors and this cause a difference between the indicated airspeed and calibrated airspeed. A correction known as the Pressure Error Correction, PEC, must be applied to the indicated airspeed to give the calibrated airspeed [7].

$$(6)\ \ CAS = IAS + \Delta V_{PEC}$$

The PEC, consist of two parts; static pressure error correction (SPEC) and the pitot pressure error correction PPEC. SPEC can be defined as the difference between the free stream static pressure and the measured one. It can be due to the distorted pressure field surrounding the aircraft fuselage in flight. The position of the static pressure sensor influences the magnitude of this correction. On the other hand, PPEC is the difference between the free stream pitot pressure and the recorded pitot pressure. This error mainly occurres due to the pitot tube being misaligned with the airflow. Unlike the instrument and installation errors, the effect of position errors can only be determined and corrected through flight testing.

T625 Gökbey is a transport category helicopter being able to execute VFR, IFR, day and night operations with twin engine, 6050 kg MTOW, and the subject of an on-going civil certification process. The certification requirement in CS 29 [1] states that airspeed indicating instrument must be calibrated to indicate true airspeed with a minimum practicable instrument calibration error when corresponding pitot and static pressures are applied. The error margins defined for airspeed reading is given as follows;

- 3% or 9.3 km/h (5 knots), whichever is greater, in level flight at speeds above 80% of takeoff safety speed
- 19 km/h (10 knots) in climb at speeds from 19 km/h (10 knots) below takeoff safety speed to 19 km/h (10 knots) above VY

In CS 29 [1] it is also stated that airspeed calibration should be given at 20 knots and greater for level flight and in the appropriate speed range for climb flight regimes. An example illustration of the defined error margins is shown in the Figure 2.

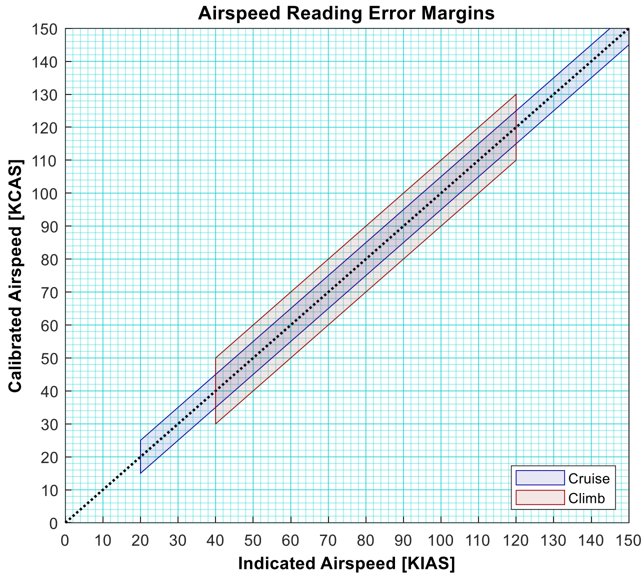

Figure 2: Airpseed Rading Error Margins

3. AIRSPEED CALIBRATION METHODS

The airspeed calibration process typically involves a series of flight tests under controlled conditions, where the helicopter's actual speed is measured and compared with the readings from its airspeed indicators. These tests are performed at different flight conditions and helicopter configurations to account for the wide range of operational environments a helicopter may encounter.

The flight tests undertaken should establish the overall errors in the system. However, prior to any flight testing it is important that the instrument and installation errors are established in order that the errors caused by positioning can be determined. As indicated before, this is usually achieved by performing lab tests before calibrating aircraft's airspeed indicator system with flight tests.

Understanding and implementing effective airspeed calibration methods are vital for helicopter to ensure that the aircraft performs optimally and safely. Most common flight test methods for airspeed calibration are listed below;

- Tower Fly-By
- Static Bomb
- Measured Course
- Radar Tracking
- Paced Car or Aircraft
- Air Data Boom

These methods can be used to calibrate both altitude and airspeed. As technology evolves, so do the methodologies for airspeed calibration, incorporating more sophisticated tools and techniques to meet increasing demand of modern helicopter requirements. This article will primarily discuss the methods used in T625 PEC tests which are listed below;

- Horseshoe Heading (GPS)
- ORBIS
- Trailing Bomb

A brief overview of these methods is provided, and the test results of each method is compared.

3.1. Horseshoe Heading (GPS)

The Horseshoe Heading method is a traditional and widely used technique for calibrating airspeed indicators for both helicopters and fixed wing aircrafts. This method is designed to determine the relationship between the IAS and TAS by performing a series of flight maneuvers that minimize wind and other external factors.

The horseshoe heading method allows the calculation of true airspeed (TAS) and wind speed by using ground speed (GS) obtained from GPS. This method is based on flying three or four different headings, which are usually perpendicular to each other for convenience. Each leg must be flown at same and constant airspeed (IAS) and altitude; therefore, true airspeed of the aircraft is taken as constant as well. In addition, by assuming wind speed and direction during performing all three legs is constant, three unknowns (true airspeed, wind speed and direction) could be found by three equation. As seen in the Figure 3, if three ground speed vectors with true headings are placed on a circle, radius of this circle gives the true airspeed and the deviation from the center results in wind speed and direction [3, 4]. As a result of the tests, differences between the IAS and TAS are tabulated to develop a correction curve. This data can be used to calibrate airspeed indicator system.

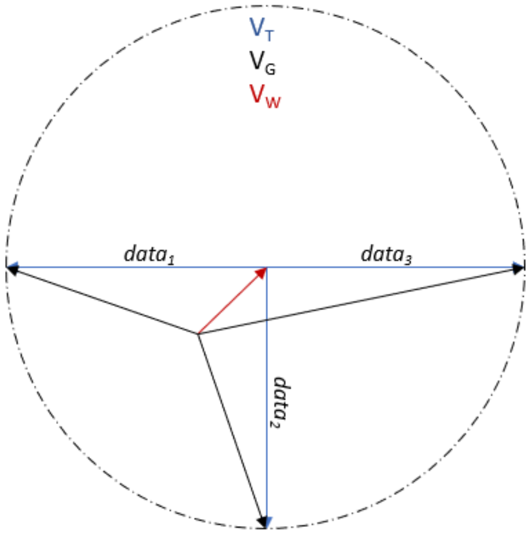

Figure 3: Horseshoe Method Vector Analysis

The main advantage of this method is that it is straightforward and does not required any complex equipment, making it a reliable choice for many aircrafts. It can be performed at any reasonable altitude and airspeed.

On the other hand, this method can be affected by atmospheric conditions, especially if the wind speed and direction is variable during the test. Stable wind conditions is required for better results. Additionally, since average values are used when solving equations, the helicopter heading and airspeed should be kept constant throughout the maneuver. Therefore, since it is not very feasible for the pilot to maintain a precise climb rate at the same time, it is very difficult to use this method during climb and descent flight regimes.

3.2. ORBIS

This method provides wind speed and direction by flying on a circular path with constant airspeed and altitude. While aircraft is turning with steady bank angle throughout the flight path, heading and ground speed are recorded. In order to reduce the effect of wind variation, turn rate should be one that flight area as small as possible [5]. With this method, high number of flight test data might be used depending on measurement frequency, which reduces the impact of test uncertainties, such as noise, turbulence or pilot sensitivity, on data quality. Vectoral forms of true airspeed, ground speed and wind speed are presented in the Figure 4. Ground speed is decomposed by North and East elements at each point throughout flight path, and the deviation of circle from the origin gives both wind speed and direction.

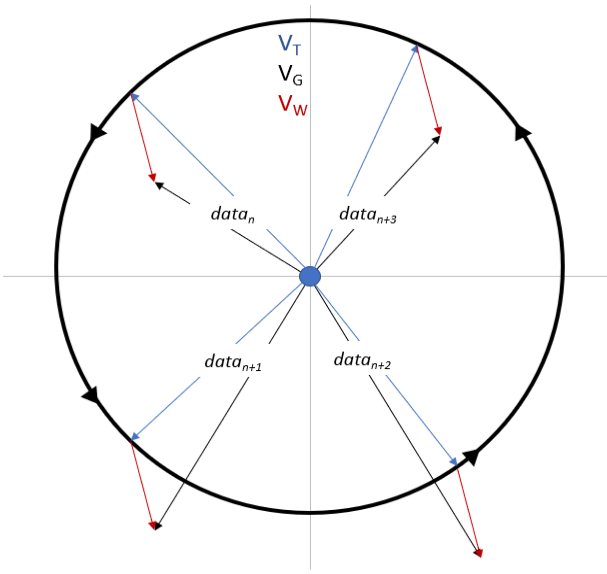

Figure 4: ORBIS Speed Circle

One of the primary benefits of the ORBIS method is that it is easier to eliminate the wind effect since data can be collected from any point along the circular path. Additionally, by increasing the data cloud, the margin of error caused by different factors is also reduced. Similar to the Horseshoe method, it is requiring only standard flight instrumentation and GPS for ground speed measurement. It does not require complex or specialized equipment.

The success of the ORBIS method depends on the ability of the pilot to maintain circular flight path with constant airspeed. Any deviations from these parameters can introduce errors into the calibration results. In addition, it is assumed that atmospheric conditions are stable in this method like Horseshoe method. Therefore, turbulence or any rapid change in the air can reduce the accuracy of this method.

3.3. Trailing Bomb

The Trailing Bomb method is an airspeed calibration technique that involves the use of specially designed device, often referred to as a trailing bomb device to measure the true airspeed of an aircraft. This method is known for its high accuracy and is typically used in the flight test environments during development and certification of an aircraft.

In this method, trailing bomb is taken as reference system to calibrate aircraft airspeed indicator system. Trailing bomb is a streamlined, small, and aerodynamically shaped device that contains its' own airspeed measurement like pitot-static tube. It is attached to the aircraft with a long cable. During the calibration test, trailing bomb is deployed from the aircraft. It is released from a specific point on the aircraft and towed behind it at a considerable distance.

As the aircraft flies, trailing bomb remains in a undisturbed airflow, which allows it to measure true airspeed accurately. Then true airspeed obtained from trailing bomb can be compared with the indicated airspeed shown on the aircraft instruments. An example of the test result is given in the Figure 5.

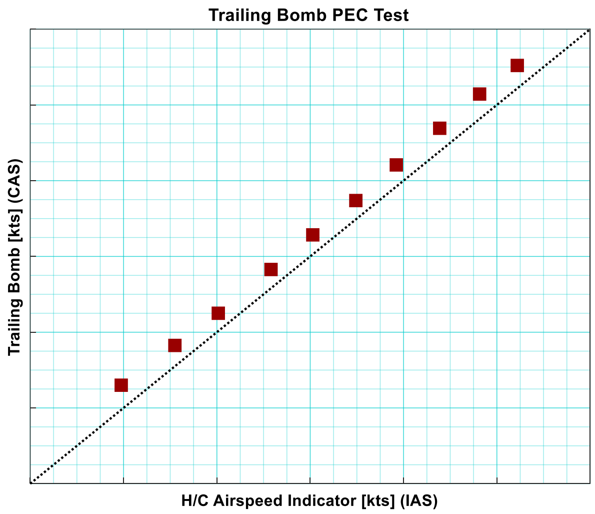

Figure 5: Trailing Bomb Airspeed Calibration

The most important advantage of this method is that since the trailing bomb is connected to the helicopter with a long cable, it is assessed that there is no interaction with rotor downwash; therefore, it is one of the most accurate airspeed calibration methods. In addition, unlike the other methods that require indirect measurements or calculations, airspeed correction could be performed at once and test results can be interpreted more easily since measured data is used directly in this method. More importantly, this method can be used in all flight regimes such as level flight, climb, descent and autorotation. It allows for calibration in any flight condition as long as data can be obtained in a stable state.

Although, trailing bomb can provide good results for all flight speeds, there are risks and difficulties with trailing bomb installation and usage. During flight tests, it requires extra attention of flight crew, especially at take-off and landing. During T625 flight test campaign, safety is ensured by continuously receiving feedback from the ground crew during takeoff and landing, as well as from a chase helicopter while in the flight. In addition, since trailing bomb has a long cable, it can become unstable as helicopter accelerates. Especially during high speed flights or in conditions with high descent rates, it becomes more challenging for the trailing bomb to remain stable. Therefore, stabilization must be made with weight placements along the cable. Before starting the calibration tests with the trailing bomb in the T625 test campaign, additional flight tests are conducted to determine the appropriate placement and amount of weights that should be attached to specific locations on the cable.

4. TEST RESULTS & EVALUATION

T625 pressure error correction tests are performed with the methods mentioned in the previous section. As stated in the certification [1, 2], calibration errors for airspeed are obtained for different flight regimes which are listed below:

- Level Flight
- Climb / Descent
- Autorotation

In addition to the flight regimes, tests are also conducted for different helicopter configurations as well. Since the pitch attitude will change depending on the helicopter's weight and center of gravity (CG), the angle of the airflow encountered by the pitot-static system also changes. Therefore, the test points are conducted for the different weight and CG configurations, including the low weight with forward CG and the high weight with aft CG, which are considered as the most critical ones.

Firstly, results are obtained with different configurations in level flight using the Horseshoe (GPS) method. This method is performed with 4 leg to reduce the effect of the test uncertainties and increase the data cloud. Additionally, this method allows checking that the wind direction and speed do not change during the test point by using 4 leg instead of 3. In Figure 6, each combination of these legs at 80 KIAS level flight, resulted wind and true airspeed vectors are presented. By using three ground speed vectors, a circle can be obtained and the radius of this circle equals to the true airspeed (TAS) of the helicopter. Conducting a vector calculation with TAS and GS, the wind vector is found. In addition, it is seen that similar results for wind are obtained at four different combinations, which shows that the wind speed and direction is stable and the test results are reliable. According to these results, airspeed calibration error obtained by GPS-Four Leg method is approximately 4.5 kts at 80 KIAS with the weight and cg configuration used during flight test.

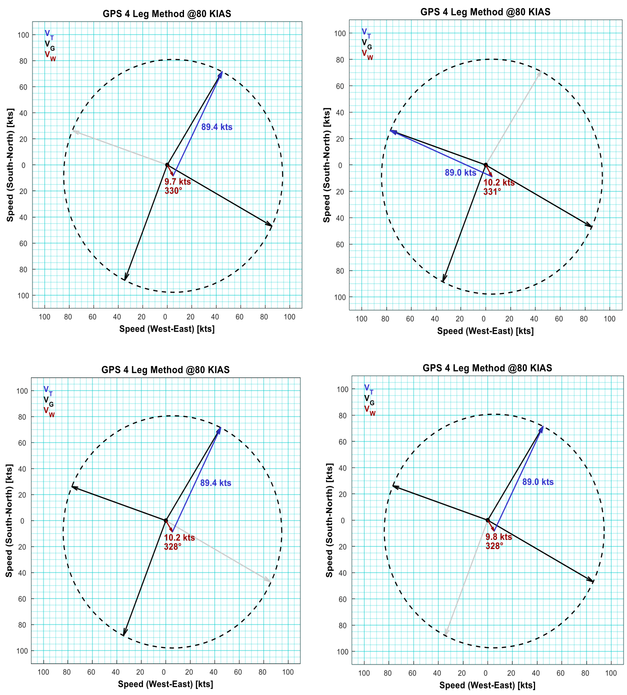

Figure 6: Horseshoe (GPS 4-Leg) Test Result Evaluation

Same vector analysis is performed for each speed at which flight test results are obtained. As seen in the Figure 7, there is a linear error that decreases with increasing airspeed for mid weight mid cg configuration. Additionally, the test points are repeated with a different configuration to observe the effect of the helicopter pitch attitude. It is seen that with the change in helicopter configuration, the calibration error in the airspeed reading shifts by a similar amount. Another important point from these tests is that, since the method is applied with 4 leg, it is possible to monitor whether the wind speed or direction is changed during each segment. Despite the wind being high, approximately 11 kts, it is observed that consistent results could be obtained as long as the wind speed and direction is stable during the tests.

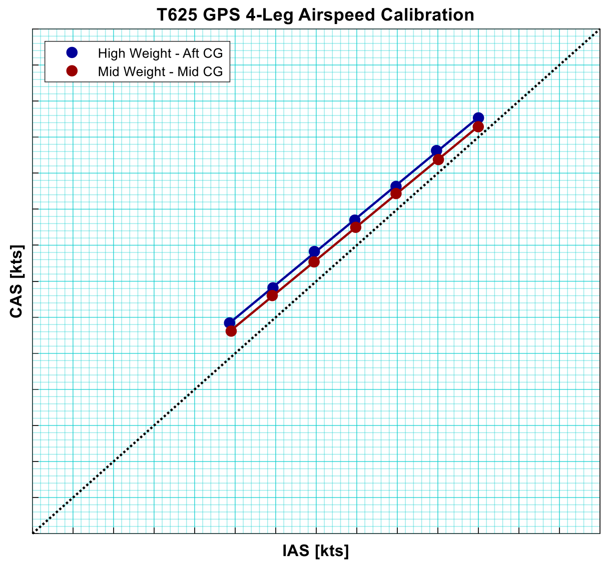

Figure 7: Horseshoe (GPS 4-Leg) Test Results

For the same condition and configuration which is mid weight and cg, ORBIS method is applied as well. The purpose of these tests is not to perform a full airspeed calibration but rather to experiment with a new method and examine its consistency with other methods. A full circle is flown at a speed of 80 and 100 KIAS with keeping the altitude constant. As indicated before, throughout the maneuver, heading and ground speed can be measured at each time step. The Figure 8 shows that the indicated airspeed and ground speed values during the maneuver conducted across 360 degrees of helicopter heading.

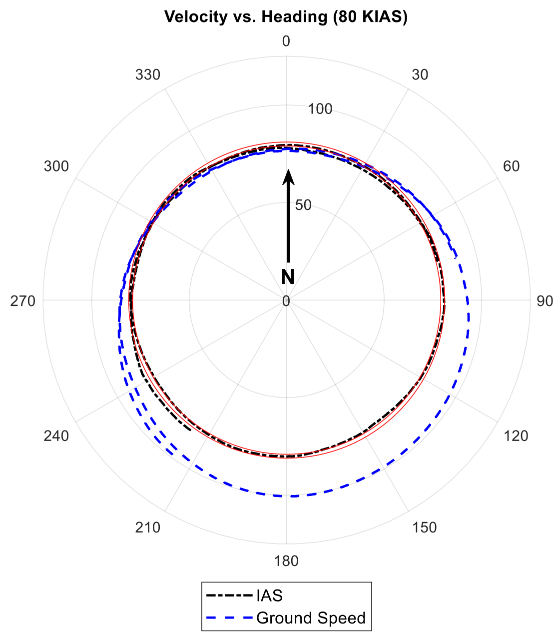

Figure 8: ORBIS Method at 80 KIAS

Similar to the previous method, GPS-Four Leg, ground speed vector components are drawn to obtain a full circle, and the distance of the center of this circle from the origin result in wind speed and direction as given in the Figure 9. By using these results, it is calculated that the airspeed correction at 80 KIAS is approximately 4.4 kts which is very close to the horseshoe heading result. Similar results are observed for the 100 KIAS condition, where the correction error difference between Horseshoe method and ORBIS is less than 0.5 kts.

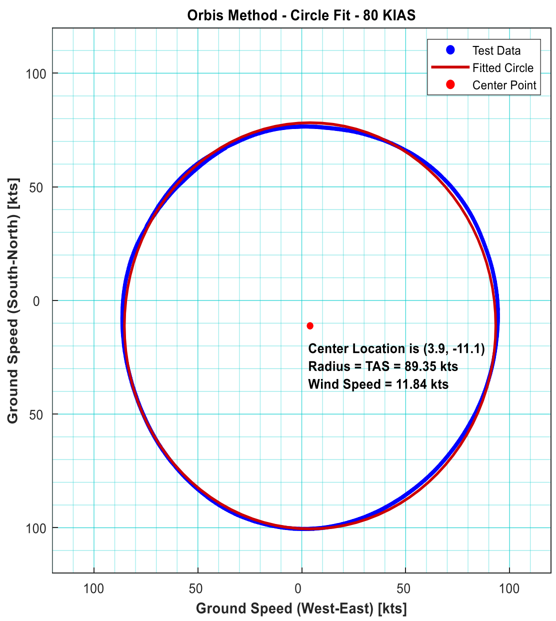

Figure 9: ORBIS Test Result at 80 KIAS

Finally, a significant portion of the test campaign is completed by using trailing bomb. In addition to level flight tests similar to those conducted with other methods, PEC tests are also performed for different flight regimes such as climb, descent and autorotation. A special test campaign is planned since there are risks in the set up and usage of the trailing bomb. Firstly, while weight and cg configuration are kept similar with the previous flight tests, in which horseshoe heading and ORBIS methods are used, test results are compared and consistency of the results are evaluated. As previously mentioned, the configuration of the trailing bomb itself is optimized to obtain more stable data, with focusing on the amount and position of the weights on the cable. Then, calibration data is collected under level flight conditions with mid weight and CG configuration. 80 KIAS flight test results in a time domain is seen in the Figure 10. ADC values are the indicated airspeed shown on the helicopter while trailing bomb values can be taken as calibrated airspeed. As a result, a calibration error of 5.1 kts is observed, and this value is consistent with the results obtained from the other methods.

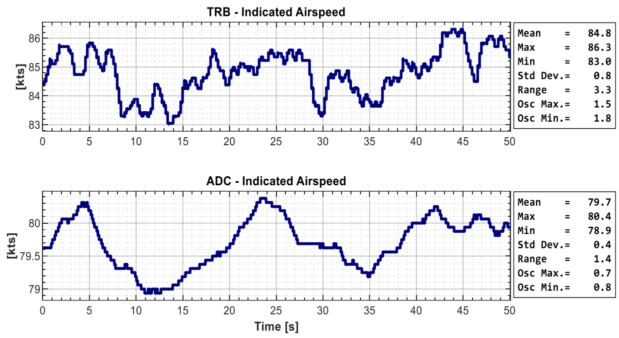

Figure 10: Trailing Bomb Test Result at 80 KIAS

Similar results are obtained for other speeds during level flight as well. The comparison of the correction curves obtained for both Trailing Bomb and Horseshoe method is shown in the Figure 11. From this, it is evaluated that these two methods provide consistent results with each other for the level flight condition. Additionally, it is determined that trailing bomb provides reliable data, making it suitable for the use in other flight test as well.

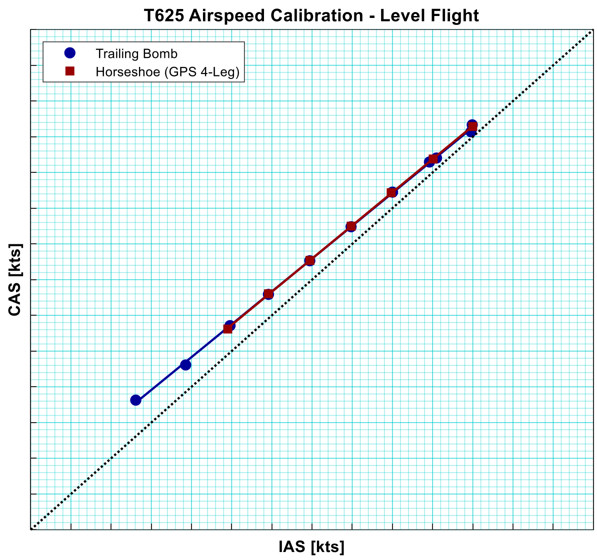

Figure 11: Airspeed Calibration Comparison for Level Flight

As previously mentioned, calibration test are conducted with trailing bomb at different climb and descent rates, as well as at autorotation condition. As seen in the Figure 12, results for two different configurations are compared. For these conditions, as given in the Figure 2, there is a 10 kts margin of airspeed reading error defined in de CS 29 [29]. However, when the test points are individually examined, it is observed that there are points exceeding this limit. Therefore, a correction needs to be applied to the airspeed reading instrument. This correction is determined such a way that it brings all flight conditions and configuration results within the defined limits.

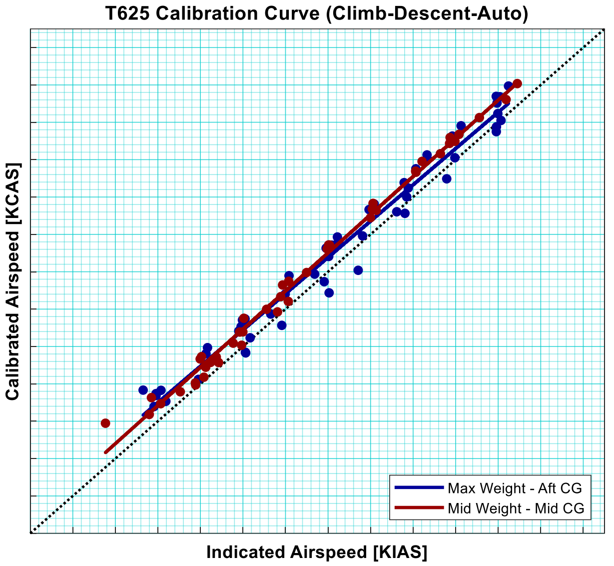

Figure 12: Calibration Curve for Climb, Descent & Autorotation

Finally, after the correction is applied to the airspeed indicating system, tests are conducted at different conditions and configurations for validation purposes, demonstrating that the system calibration error is within the certification defined limits.

5. CONCLUDING REMARKS

T625 airspeed calibration tests with Horseshoe (GPS), ORBIS and trailing bomb methods has provided a comprehensive assessment of the accuracy and reliability of the airspeed measurement systems. Each method has its own unique advantages and disadvantages under different flight conditions. The combination of these three methods ensured a precise calibration of the helicopter's airspeed system. The data obtained has been analyzed to create a detailed correction chart, which will be used to adjust the airspeed indicators and ensure accurate readings across the full range of operational conditions.

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