SEA LEVEL FLIGHT PERFORMANCE TEST OVERVIEW FOR A UTILITY HELICOPTER

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ABSTRACT

T625 Gökbey helicopter finished the sea level flight test campaign, needed for certification process, in Kocaeli Cengiz Topel Airport at the beginning of 2024. Load surveys, autopilot, flight characteristics and flight performance are among the several different subjects for the test campaign. Hover, climb, autorotation, level flight, height-velocity and Category B take-off and landing tests constitute part of helicopter flight performance tests. Engine training mode is applied for both safety concerns and getting the desired engine performance for the tests requiring engine failure simulation. Flight tests provide evidence of compliance with relevant requirements and also contribute to data collection for the development of Flight Manual charts. This article aims to present details on the executed flight performance tests and highlight significant aspects all during the process. Furthermore, the certification criteria concerning general helicopter flight performance are briefly discussed.

1. NOTATION

AC	Advisory Circular
AEO	All Engines Operative
CG	Center of Gravity
CS	Certification Specification
GW	Gross Weight
HD	Density Altitude
HIGE	Hover In-Ground Effect
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
SL	Sea Level
TOP	Take-Off Power
RFM	Rotorcraft Flight Manual
VFR	Visual Flight Rules
IFR	Instrument Flight Rules
H-V	Height-Velocity
V_{99}	Optimum Cruise Speed
V_{BE}	Best Endurance Speed
V_{BR}	Best Range Speed
V_{Glide}	Maximum Glide Speed
V_H	Maximum Level Flight Speed
V_{MRoD}	Minimum Rate of Descent Speed
V_Y	Best Oblique Climb Speed

2. INTRODUCTION

T625 Gökbey is a transport category helicopter being able to execute VFR, IFR, day and night operations with twin engine, 6050 kg maximum take-off weight. Considering the MTOW of T625, it is in the large rotorcraft class and there is an on-going certification process based on CS 29. In addition, as stated in CS 29.1 [1], large rotorcrafts must be certificated in accordance with the Category A, Category B or both Category A and B requirements. The most important difference between these categories is that Category A type helicopter is allowed to fly in case of a single engine failure. Since T625 maximum weight is less than 9072 kg but with 12 passenger seats, it may be type certified as Category B with engine isolation requirements. However, the final certification is planned as a Category A helicopter.

Figure 1: T625 Gökbey Helicopter

As indicated in CS 29.21 [1], each requirement of Subpart B (Flight), which includes flight performance requirements, must be met by tests upon a rotorcraft of the type for which certification is requested, or by calculations based on, and equal in accuracy to, the results of testing. Based on this requirement, calculation method should only be used when validated with same accuracy of the flight testing. Therefore, flight test is the main compliance method for flight performance requirements.

Flight performance information of helicopter should be given throughout the entire flight envelope as temperature and altitude. As indicated in the AC 29.45 [2] flight performance data can be extrapolated or interpolated from test altitude and temperature. Altitude extrapolation limits for different flight performance data are listed below:

- $\pm$4000 ft HD → Hover, take-off & landing
- $\pm$2000 ft HD → Height – Velocity

In addition to the altitude limits, temperature effects on flight performance is required throughout the approved temperature range. Therefore, extrapolation or interpolation for temperature should not exceed 10°C below or 20°C above from tested value as specified in AC 29.45 [2]. Representation of extrapolation limit for both altitude and temperature is given in the Figure 2. It should be noted that these limits are shown for individual test condition. However, if different test conditions are evaluated together, extrapolation limits in temperature should be according to the minimum and maximum values seen in all flight tests.

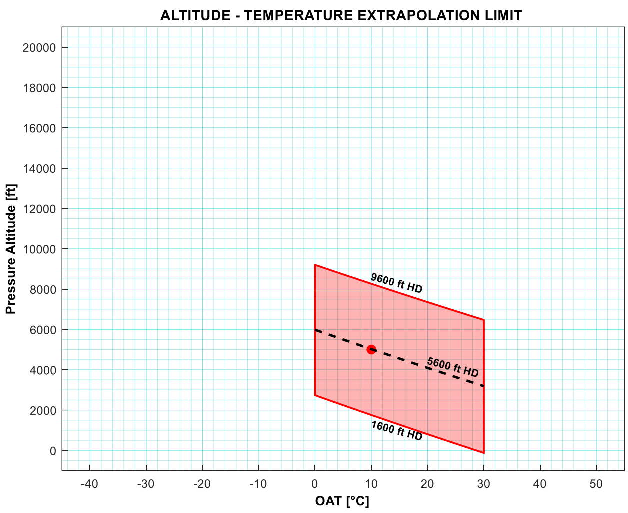

Figure 2: Altitude & Temperature Extrapolation Limit

Because of these limitations, flight tests are need to performed at different test sites to provide performance data in all flight envelope. The main concern in using different test sites, is to search for different density altitudes and temperatures. In order to investigate the flight performance of the helicopter at low density altitude, flight performance tests are carried out at Cengiz Topel Airport in Kocaeli, located at approximately sea level. The location of the airport is given in the Figure 3.

Figure 3: Cengiz Topel Airport, Kocaeli

In addition to density altitude and temperature, wind limitations dictated in AC29.45 [2], are another restrictive condition in selecting the test sites. The allowable wind conditions will vary with the type of flight test and since the effect of wind on flight tests are not determined for T625 specifically, wind limitation given for general guidance [2], is taken as reference during the performance flight tests and listed below:

- 3 kts → Hover
- 5 kts → Height - Velocity
- 10 kts → Take-off & landing

In this paper, sea level flight performance tests of the T625 helicopter are discussed. Flight performance test list is given in the below. It should be noted that some of these tests are required for certification while some of them are performed for development purposes.

- Hover performance
- Level flight performance
- Low speed performance
- Climb & descent performance
- Autorotation performance
- Height – Velocity (H-V) envelope
- Category B take-off & landing performance

3. FLIGHT PERFORMANCE TESTS

Flight performance test campaign is started with low altitude site to employ build up method. In this way, by analyzing the obtained test data, helicopter's capabilities can be assessed more accurately before conducting flight tests under more challenging conditions like hot & high field. These data can also

be used to verify and improve the accuracy of performance models used in the predictions.
In addition to the low speed tests conducted on the runway, high speed or climb/descent related flight tests have also been performed. Additionally, tests are conducted for emergency scenarios, such as single engine (OEI) or dual engine failure (Power off) situations.

3.1. Hover Performance

Hover performance is the main concern for a helicopter considering mission effectiveness. Therefore, tests are requested to determine the hovering capabilities of the helicopter. The purpose of the test is to create non-dimensional power required polar for the entire flight envelope in which the helicopter can hover. Thus, by using this polar, the required power can also be obtained for any altitude, temperature and weight condition that is not tested.
For each helicopter weight, stable hover data is obtained at different wheel heights to observe ground effect from 5 ft to 100 ft. Hover data is taken at certain weight intervals, approximately 250 kg, as a result, reference weight and power relation is obtained at sea level condition. Linear straight fit is applied to the (P/σ) vs $(GW/\sigma)^{3/2}$ change as suggested [3].

Free flight technique is used during hover tests. In this technique, after completing the test points for a specific weight, ballasts are used to quickly arrange to the next weight configuration and the tests are repeated. As previously mentioned, a wind speed limit of 3 kts is used as a reference during hover flight tests. Before each test point, confirmation is obtained from the measurement station that the wind speed is below 3 kts and also the real time wind data is provided in the post-processing as well.

Flight tests are conducted for both HOGE and HIGE at different wheel heights, such as 5ft, 10ft, 20ft, 30 ft, 100ft with the CG, centered in both the pitch and roll axes. In addition, as stated in the AC 29 [2], the effect of CG is also examined. As seen in the Figure 4, forward CG results are consistent with the trend obtained with mid CG. Therefore, it can be said that CG does not have a significant impact on hover performance as expected.

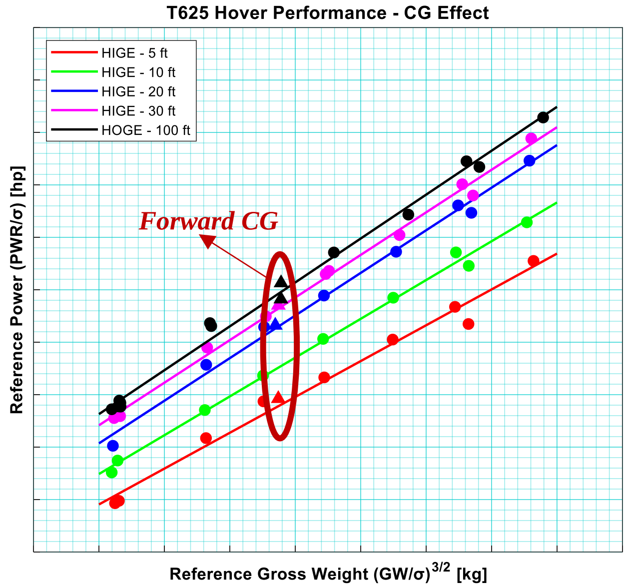

Figure 4: Hover Performance – CG Effect

Before the tests, it is estimated that due to the T625 main rotor diameter being 13.2 m, which is approximately 43 ft, the ground effect would diminish at approximately 40 ft above ground level. As seen in the Figure 5, test results also show that ground effect decreases at around 30-40 ft. Additionally, it is observed that as the weight increases, the ground affect intensifies as expected from the higher downwash of the main rotor.

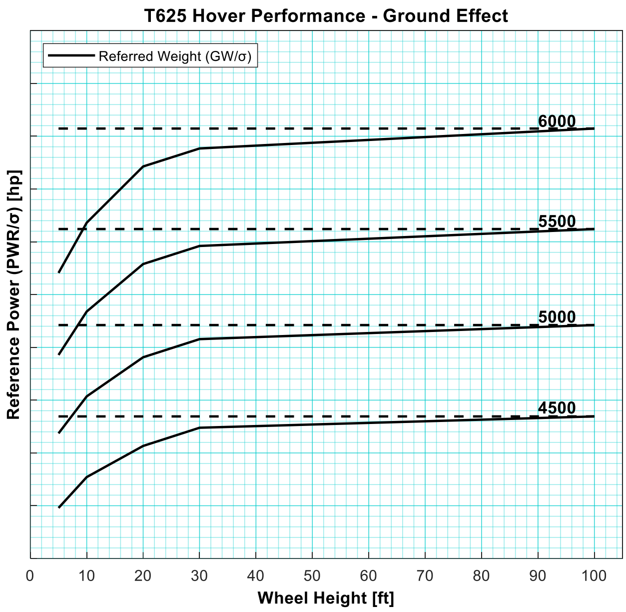

Figure 5: Hover Performance – Ground Effect

3.2. Level Flight Performance

Helicopters spend most of their life during cruise condition and to asses a helicopter's suitability for a particular mission task, power required information is needed; therefore, it is important to determine level flight performance throughout its speed range [5]. However, it should be noted that these tests are not required by the certification under the flight performance, but are conducted to obtain cruise charts in the RFM and to develop the performance model.

Similar to the hover tests, referred weight and power method is used during level flight testing. Stable data is collected at different speeds up to the maximum level flight speed. The variation in speed, altitude and vertical speed at a test point that is considered as stable is shown as an example in the Figure 6.

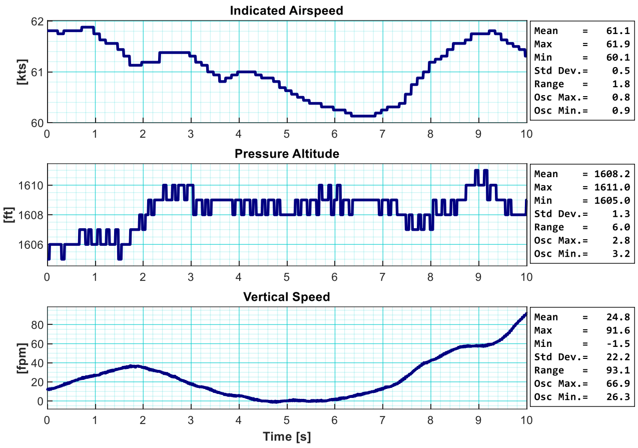

Figure 6: Level Flight Stable Data

The important point here is to conduct the speed sweep at a constant reference weight. Since the weight decreases as fuel is burned, the referred weight is kept constant by gaining altitude as required. As seen in the Figure 7, results are obtained for three referred weight and tests are performed as close to the sea level as possible to reach minimum referred weight.

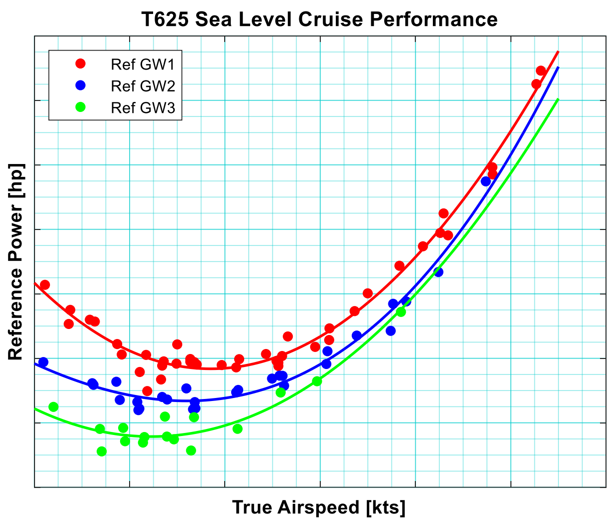

Figure 7: Level Flight Test Results

The performance parameters related to level flight, such that maximum level flight speed, best endurance speed, best range speed, are also obtained as a result of these tests. Another important point of these tests is the speed (V_Y), at which climb tests will be performed, has been determined. According to the CS 29 [1], the steady climb rates at SL, ISA condition need to be provided at V_Y speed.

In addition to the high speed conditions, lower speed points are targeted as well. Flight tests are conducted at speeds from 10 kts to 40 kts. Since the airspeed indicator system on the helicopter does not work properly at low speeds, pilot cannot read the reference speed at these conditions. For this reason, a pace car is used to keep the speed and the helicopter follows it on the runway.

As well as the level flight tests, test results for low speeds are evaluated by using reference weight and power method. A complete power curve can be obtained by combining the results of these tests. The power carpet obtained from all level flight and low speed performance tests can be seen in the Figure 8.

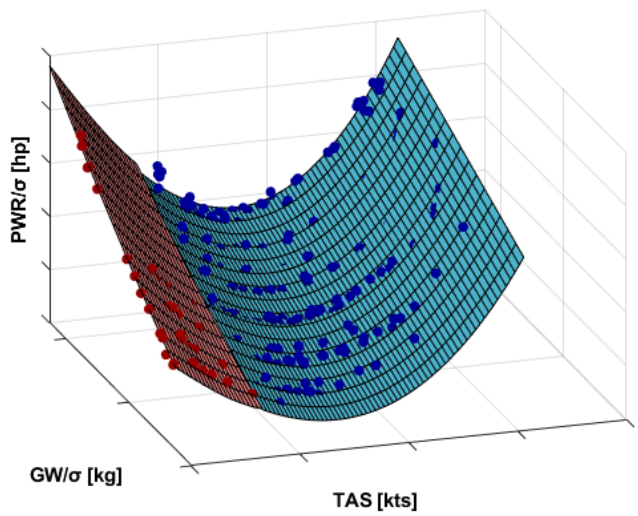

Figure 8: T625 Power Carpet

3.3. Climb & Descent Performance

As required in CS 29 [1], maximum climb rate that can be achieved with V_Y speed should be determined for the entire flight envelope. V_Y speed can be defined as the speed where the power requirement is minimum, thus climb rate will be maximum. As stated by AC 29 [2] two methods are used generally to determine this speed. In the first method, Sawtooth climbs may be used to determine the best rate-of-climb airspeed. In this technique increments of climb power are applied up to maximum allowable at various airspeeds to evaluate the resultant climb rate. The second method that can be used to determine V_Y speed is to use the level flight performance results, as applied in this test campaign.

Another important point for climb performance is determining the critical CG. AC 29 [2] states that the rotorcraft should be ballasted to the desired gross weight and the critical center of gravity. As seen in the Figure 9, climb tests at most forward and aft cg configurations are performed. Since there is no significant difference between two cases in terms of performance perspective, aft cg, which is a critical configuration for helicopter controllability and pilot visibility, is used during performance tests.

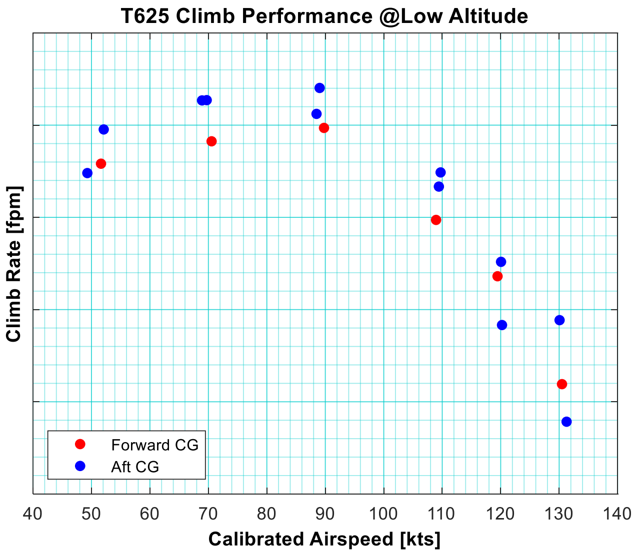

Figure 9: Maximum Climb Rate w.r.t. CG Configurations

Tests are performed by climbing and descending within the 1000 ft altitude band. Firstly, test condition is trimmed in level flight and then targeted torque is increased by approximately 10% until the maximum power is reached. Climb efficiency database is obtained by using the test results. Similar procedure is applied for the descent points, where this time aimed target is decreased 10% until autorotation.

The climb efficiency values are obtained from the tests, depending on varying climbing speeds and helicopter weight. As seen in the Figure 10, while the difference is more pronounced with varying weight, the efficiency value does not change as much with climbing speed. It should be noted that these climb efficiency values are obtained at V_Y speed.

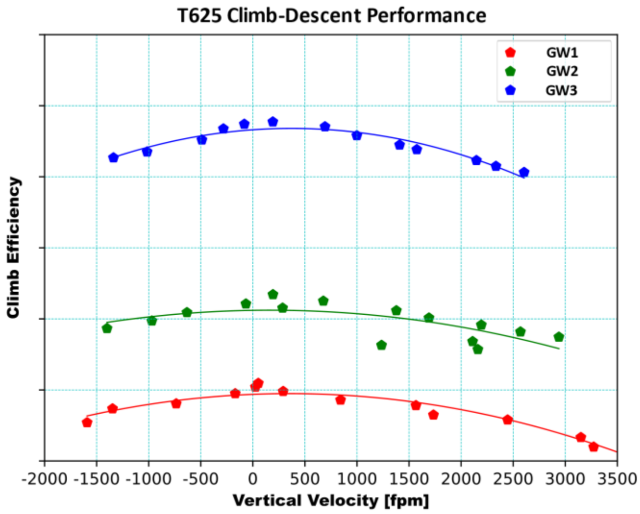

Figure 10: Climb Efficiency at Low Altitude

3.4. Autorotation Performance

The main purpose of autorotation tests in terms of flight performance is to determine critical speeds for autorotation as indicated in CS 29 [1] and AC 29 [2]. These speeds can be defined as speeds for minimum rate of descent and best glide angle. But firstly, the critical CG is determined for mid weight, just like in the climb tests as depicted in Figure 11.

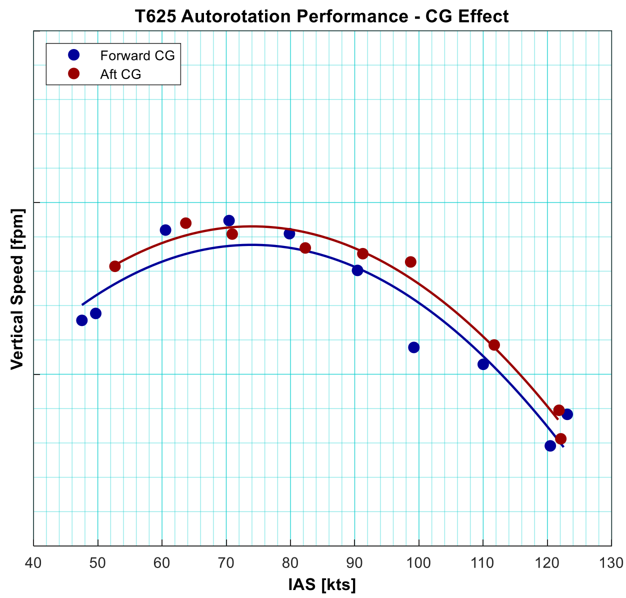

Figure 11: Autorotation Descent Rate with Different CG

Although the lowest possible altitude is aimed as in other tests, it is performed at a slightly higher altitude due to safety concerns. The altitude band, at which the trimmed data is collected, is slightly higher than the climb/descent tests. Autorotation tests are performed at different speeds for three different weights and the rate of descent variation with forward speed is obtained.

3.5. Height – Velocity Envelope

In case of a power failure, the ability of a helicopter to perform a safe autorotative or OEI landing is limited by the structural and aerodynamic design of the helicopter. Power loss inside the dangerous region bounded by height from ground level and airspeed combinations may result in severe damage to the rotorcraft [4]. The main purpose of Height – Velocity envelope flight tests is to determine an area of height – velocity combinations that safe landing after an engine failure cannot be made. This envelope must be provided for all pressure altitude and ambient temperature conditions in an envelope where takeoff and landing are approved. The flight conditions that will allow safe entry and recovery of the helicopter are summarized in the form of a Height-Velocity diagram as seen in the Figure 12. Since T625 is a multi-engine helicopter and meets Category A engine isolation requirements, there is no need to examine high speed region and it is only required to establish the one engine inoperative (OEI) H-V envelope for the RFM.

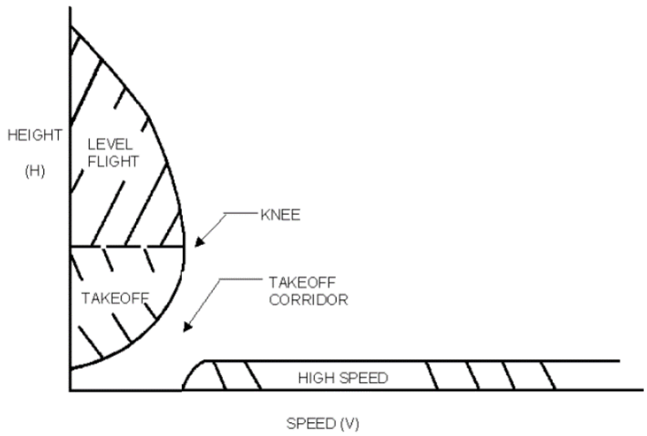

Figure 12: Height-Velocity (HV) Diagram [2]

In order to simulate OEI condition, engine training mode is used during H-V flight tests. Targeted power levels are achieved through training mode, which means total torque of the high and low engine should be equal to contingency rating, in this case it is 30 sec. OEI. As indicated in the AC 29 [2] power should be limited to minimum specification values on the operating engine. The turbine engine power does not vary directly with density altitude and at a specific HD, the turbine engine power available also varies with ambient temperature. Therefore, if one test sequence is to be utilized for a given HD, it would be appropriate to restrict test power to the lowest value attainable from a deteriorated engine through the approved ambient temperature range at the density altitude of the test. This method is used as it is planned to generate T625 H-V charts.

Before starting to H-V tests, it is required to show that OEI training mode has similar transient characteristics with the real engine failure. In AC 29 [2], it is stated that;

"For all tests to examine behavior following an engine failure, usually the failure of the engine is simulated in some way…. For rotorcraft equipped with a FADEC, and particularly those with a 2 minute/30 second OEI rating structure, it is common practice to simulate an OEI condition by using reduced power on all engines by means of a flight test tool. In every case, it must be demonstrated that all aspects of rotorcraft and powerplant behavior are identical to those that would occur in the event of an actual engine failure with the remaining engine developing minimum-specification power. Of particular concern are "dead engine" power decay characteristics, "live engine" acceleration characteristics, and rotor RPM control."

Therefore, comparison is made for different torque sharing values of training mode with real one engine case at sea level condition. As a result of this study, it has been assessed that using the training mode is appropriate since the NR and engine torque decay rates are similar to the actual OEI condition as seen in the Figure 13. The difference in the minimum NR values is insignificant.

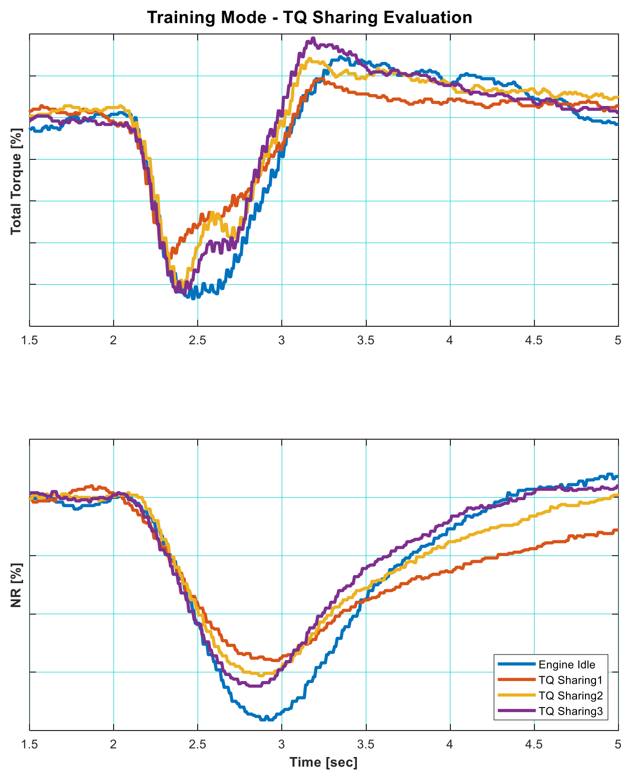

Figure 13: Engine Training Mode Evaluation

After showing that the training mode is appropriate to simulate one engine failure, H-V tests start with the easiest scenario, which is minimum weight, as a part of the built-up test methodology. The H-V chart is divided in to three sections; low hover, high hover and

knee point. For the low hover point, altitude is gradually increased until the helicopter's limits are reached. On the other hand, for the high hover point, altitude is decreased starting from high altitudes until the limits are reached. At this point, different from low hover section, as mentioned in AC 29 [2], a minimum 1-second time delay between power failure and initial control actuation is utilized. After completing the hover points, test points are conducted to determine knee portion. As descending from high hover point, the speed is initially high and then reduced until the limits are reached. The important point here is to change only one parameter (altitude or speed) at a time for safety reasons and also to be consistent with the built-up test technique.
Parameters of a test segment executed at the high hover point in the Figure 14 are provided as an example. After the training mode activated, pilot waits for the reaction time and then decreases the pitch angle with longitudinal cyclic to accelerate helicopter. As mentioned in AC 29 [2], the target for minimum pitch angle is not more than 15-20 degrees. At the same time, by lowering the collective, the NR is prevented from dropping further, ensuring that sufficient kinetic energy remains in the rotor for use during cushion. This procedure is an example for the high hover point; different maneuvers are defined for both low hover and knee portions.

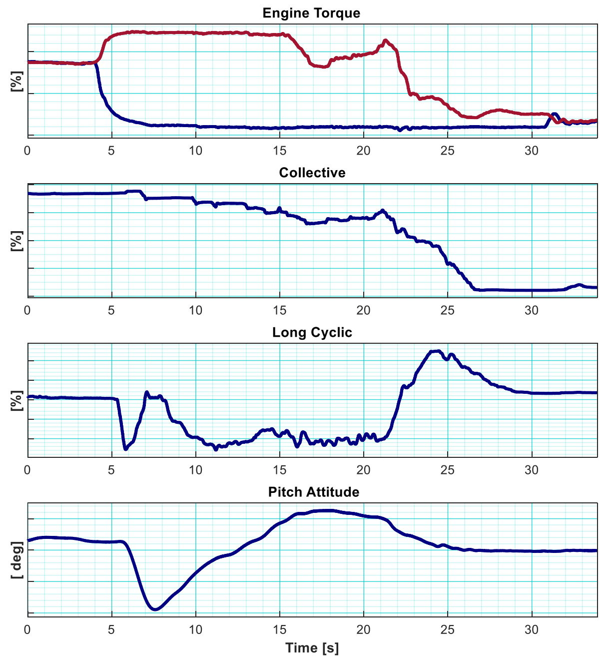

Figure 14: H-V Test Point Sample

For each test segment, wind and maneuver parameters are checked to determine whether adequate conditions for flight have been satisfied. As previously mentioned, the H-V curve is dependent on structural and aerodynamic limits. Therefore, NR and sinking speed during landing is evaluated. In order to evaluate these two parameters together, H-V index parameter is defined as follows;

$$(1)\ \ HV_{index} = \frac{Min\ NR}{NR}\, x\, \frac{V_Z}{Max\ V_Z}$$

Min NR is the minimum main rotor OEI speed while Max V_Z is the maximum normal landing speed. The test condition is considered as acceptable when H-V index is lower than 1. However, a lower H-V index, approximately 0.6, is targeted to apply a safety margin. In addition to the structural limits, pilot workload evaluation is also taken into account at each test condition. In the Figure 15, H-V envelope obtained is shown along with the test points considered valid and invalid for a given helicopter weight.

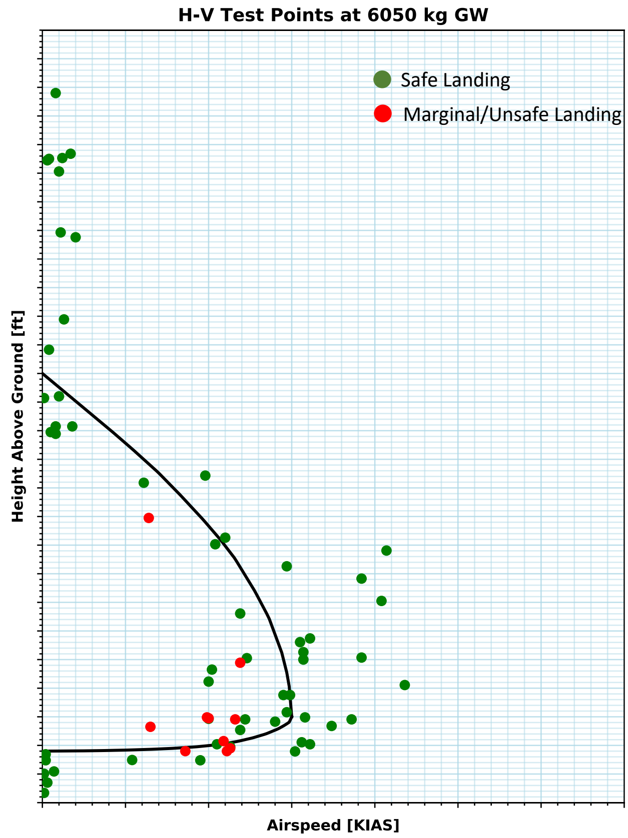

Figure 15: H-V Test Results

3.6. Cat B Take-Off & Landing Performance

The main purpose of Category B Take-off flight tests is to determine takeoff distance of helicopter under different altitude, temperature and gross weights at critical CG condition. Cat B takeoff distance can be defined as the horizontal distance calculated from a starting location to a point 50 ft above take-off surface with all engines operative. The important point in these tests is that the takeoff profile should be defined considering the H-V diagram. As stated in the AC 29 [2], there should be minimum margin of 5 kts between the H-V diagram and take-off profile. In addition, to ensure that the takeoff profiles are repeatable, it is crucial to conduct the tests multiple times. This allows for consistent results under different conditions, thereby increasing the reliability of the test. The examples of the takeoff profiles, performed, are shown in the Figure 16.

Another important point to be considered during these tests are the usage of DGPS for more precise distance and speed measurement. Additionally, although the allowable wind speed for the tests is 10 kts, corrections are applied to the distances based on measured wind speed.

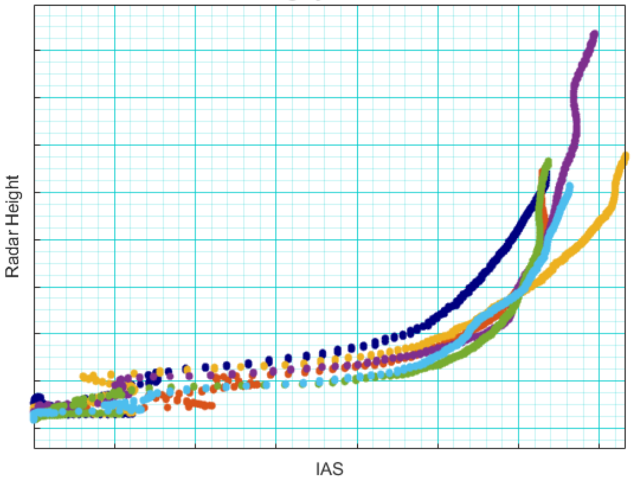

Figure 16: Category B Take-Off Profiles

On the other hand, Cat B landing is defined by a profile wherein the distance to clear a 50 ft obstacle height with one engine inoperative [OEI] case. Similar to H-V tests, the engine training mode is used to simulate a single engine failure situation during Cat B landing. Same concerns during take-off are also applicable for landing, and examples from the test points conducted are provided in the Figure 17.

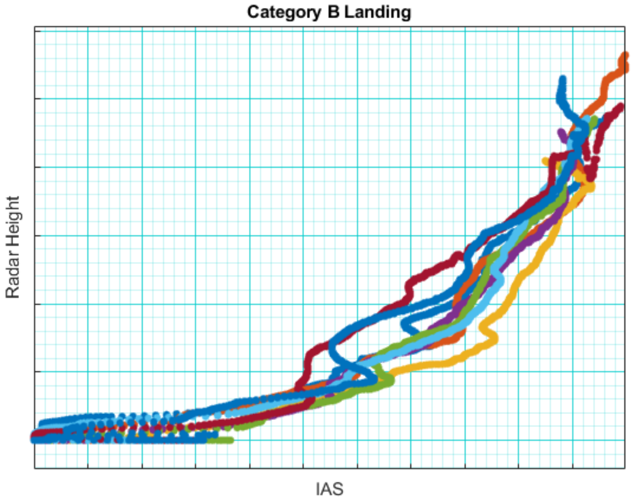

Figure 17: Category B Landing Profiles

4. CONCLUDING REMARKS

The low-altitude flight tests of the T625 helicopter were completed at Cengiz Topel Airport in Kocaeli. These tests, which encompassed performance assessment as part of the certification and development process, laid the groundwork for subsequent testing in more diverse and challenging flight conditions. Specific test methods were developed for each type of performance evaluation. Overall, the test campaign highlighted critical areas, particularly single-engine failure tests; H-V and Category B landing, which require increased focus on safety and testing techniques.

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