# Testing of Simsek High Speed Target Drone

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## *ABSTRACT*

*In the last few decades, the global market for unmanned systems has grown significantly and major aeronautical companies shifted their focus to unmanned platforms, especially for ISR missions. Target drones, which are being used for aerial defense systems testing and personnel training, have a much longer history than ISR systems, and still keep its market share.*

*Getting well trained in peacetime is the key for being ready for war, and air defense is not an exception for this. Realism and cost are two important factors to balance for training solutions. Time has proven that using target drones is perhaps the best solution for almost all aspects, such as realism, cost, operational simplicity, thus overall training effectiveness.*

*TAI has been providing target drone solutions for Turkish Armed Forces (TAF) for more than a decade with products such as Turna still in service. By 2009, TAF expressed its needs for a higher speed, higher maneuverability and low cost target solution for surface-to-air and air-to-air defense systems training. Based on this, TAI has designed, manufactured and tested its High Speed Target Drone (HSTD) System dubbed "Simsek". Simsek is capable for simulating many different high speed aerial threats such as missiles and fighter aircraft, with its different payload options and high maneuverability. The system is completely autonomous from launch to recovery and thus easy to operate.*

*This paper summarizes the design and test cycles followed for Simsek development. The methods applied for verifying and improving the design by means of simulation, development, ground and flight testing are presented. Test cycles, techniques, procedures and lessons learned topics are covered. A special emphasis is given on automatic flight control laws development and testing.*

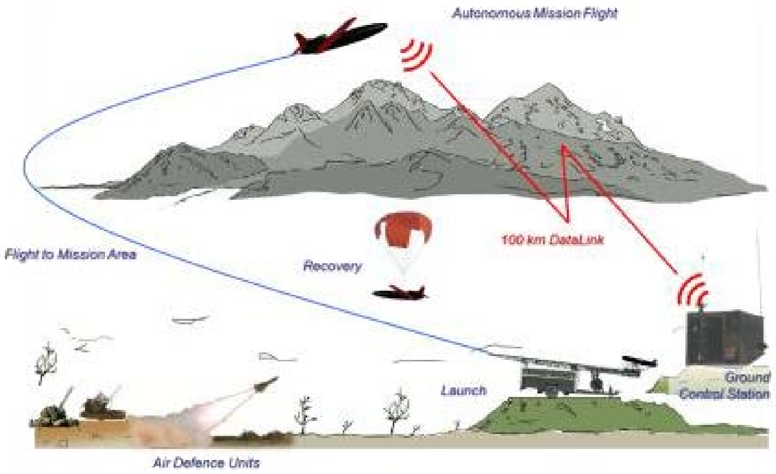
# 1.0 SIMSEK HIGH SPEED TARGET DRONE SYSTEM INTRODUCTION

**Figure 1: Simsek HSTD take-off**

Simsek System capabilities and technical specifications are;

- Low cost, expendable, modular, easy to operate and easy to maintain system,
- Full autonomous flight & navigation capability that can be programmable before and/or during the flight,
- Preprogrammed maneuvers,
- Flare, Passive Radar Augmenter and Jet Engine lets IR, Radar & Optically guided missile systems to perceive,
- MDI (Missed Distance Indicator) on the A/C measures the missed distance and transmit the score to the GCS (Ground Control Station),
- Smoke for tracking the A/C,
- Maximum speed of 350 knots (650 km/hr),
- Maximum endurance of 60 minutes,
- Flight altitude between 100ft (30m) to 15000 feet (4500 m) (ASL),
- 100 km Data Link Range,
- Maximum Take-off Weight 75kg,
- Take-off with pneumatic launcher, recovery by parachute.

Figure 2: Simsek HSTD mission Scenario




Simsek System is primarily tested at simulation model while each system is tested on ground as development tests. After development tests, ground tests are applied on integrated system of systems. All the ground tests are followed by flight tests while simulation model trials are continuing in parallel. Following chapters explain these procedures.

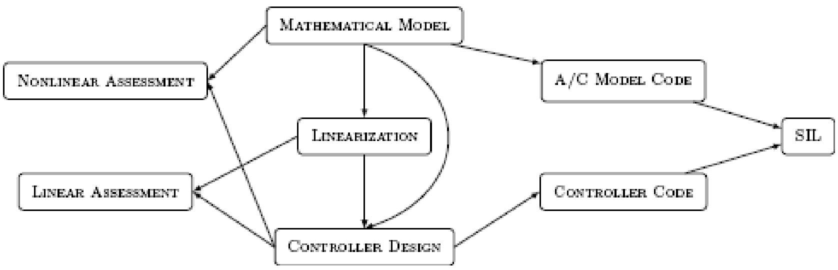
## 2.0 MODELLING AND SIMULATION

In the context of development and flight testing of UAS, Modeling and Simulation serves to the purposes of:

- Model based controller design: Designing control system using mathematical model available with estimates about uncertainties in the model.
- Generating real-time code of A/C mathematical model for concurrent testing of software and system behavior in SIL (System Integration Laboratory).
- Obtaining opinions of pilots, by SIL simulations, about controller and HMI (Human Machine Interface), thereby taking necessary actions, if possible.
- Planning of flight tests using SIL facility, for safe trajectory, for safe time and fuel budgets.
- Preparing for flight test using SIL facility: all flight test pilot and monitoring crew go over the planned test scenario before flight test.

Figure below depicts the role of mathematical model in development.

Figure3: Mathematical model of UAS and its usage in development



## 3.0 DEVELOPMENT TESTS

Development tests are the test phase before ground tests that covers technical requirements and interface verification of sub-systems. All units from software to hardware, from components to equipments are first tested to verify the requirements and analysis. Testing of different kinds of production methods, production materials, equipments and method of sub-systems working principles are covered. Test plans and test results are reported for every step. Some of the development tests applied on Simsek System are as follows:

Structural Tests

Material selection tests: different kind of manufacturing material such as epoxy, carbon, kevlar, fiber-glass and prepreg clothes are tested to select the best material for every component separately. Test specimens are produced for every combination and every specimen are tested for compression (strength and modulus) and ILSS (Interlaminar Shear Strength) values with dynamic test devices.

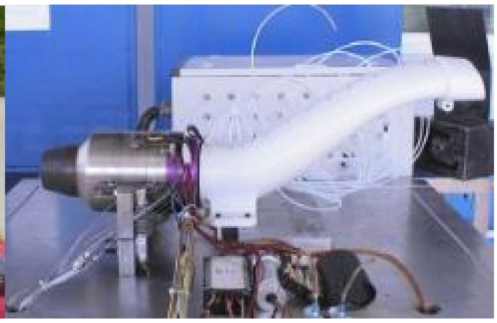
Wing and Spar loading tests: Evaluation of aircraft wing, wing spar and wing-fuselage connection resistance under calculated design loads. Components are loaded until fracture which occurred above %100 loading in all tests.

Sledge impact tests: Sledge shape and material is tested for recovery impact condition to determine the component behavior during these loads.

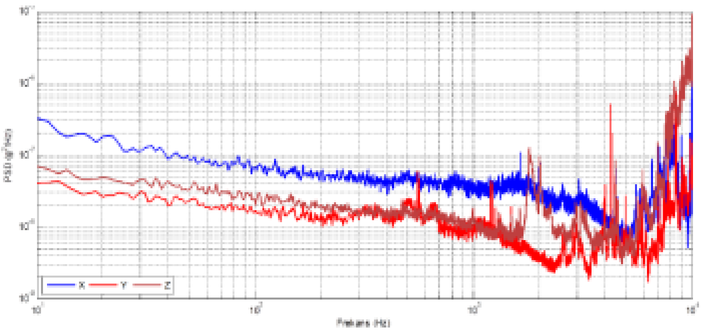
Structural tests on rapid prototype components: Parts produced in 3D rapid prototype are tested for maximum loads and limits.

Aircraft System Tests

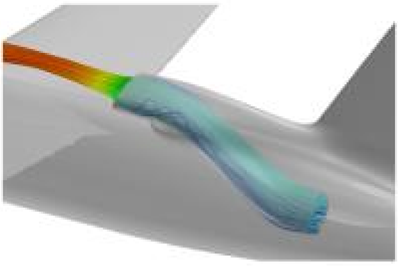
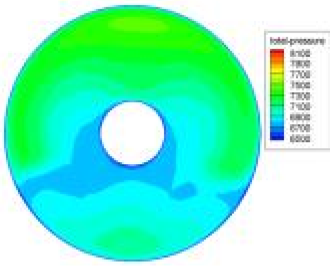
Power system tests: These tests are the longest and most comprehensive tests of all. Jet engine and Engine Control Unit (ECU) are separately tested. Tests include; idle rpm, different level throttle, heat in different rpm, current consumption in different rpm, flowmeter, thrust, different engine strap, endurance, compressor choke, engine cover heat at maximum rpm and ECU-engine operational tests. Engine model is updated based on test results.

Engine vibration tests: Vibration measurement in different rpm with vibration sensors connected on engine straps.

Engine inlet air flow tests: After flow analysis, selected inlet geometry is tested with air flow in different rpm levels to determine any flow separation or spoilage.

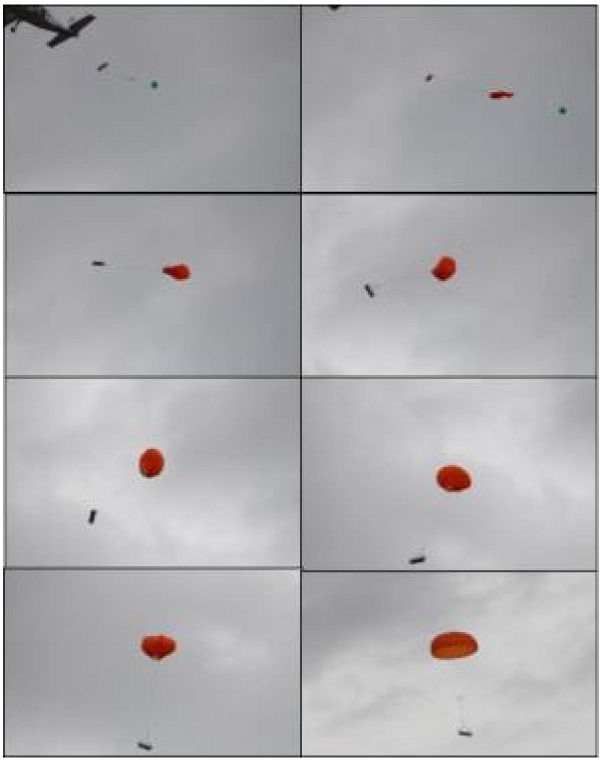



Payload Smoke tests: Smoke payload is generated by pumping smoke oil to the exit of engine exhaust. Systems operation and different kinds of oil for denser smoke is tested during these tests.

Fuel system tests: Fuel tank and its accessories are tested for operability. System is tested for different attitudes of flight conditions as maximum roll and maximum pitch where current and fuel flow is recorded.

Fuel system leakage tests: Bladder tank is pressurized to determine leakage.

Parachute tests: One of the most comprehensive test sequences to determine performance of newly developed parachute system. Tests are realized by releasing the parachute with dummy weight from a manned aircraft and a manned paraglide. In all the tests; main riser load, sink rate and swing angle are recorded to compare with design requirements. All tests are realized for different altitudes, temperatures, speeds and dummy weights.



Parachute cover tests: Parachute cover is tested for 100 times consecutive correct openings.

Servo Tests: Servo is loaded with the calculated maximum load to determine any failure.

Servo function and error tests: These tests are applied on servo system to determine the function loss error during command loss and different amplitude commands.

Elevator and Aileron load tests: Validation of analysis by loading elevators and ailerons with dummy load. Results gained from feedback are compared with analysis.

Avionic Tests

Data Link Tests: Line of Sight (LOS) data link range test on ground between Ground Control Station (GCS) and data link system mounted on test vehicle. Later, test is repeated while the data link system is mounted on manned test aircraft.

Data link performance tests: Frequency interference tests and Bi-amp performance tests are applied on data link system at System Integration Laboratory.

Data Link capacity allocation tests: Data link tests to determine and arrange the limit of %80 safe data capacity usage.

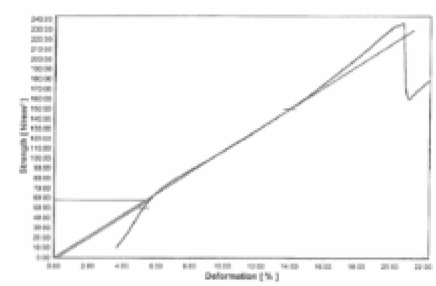
Electrical load and power supply capacity tests: Determination of required power capacity of each sub-system / equipment and comparison of assembled power with electric power usage in different operation conditions.

Battery tests: Determination of battery characteristics that supply all the aircraft system's energy.

Ground control Station UPS tests: Test to determine the maximum and safe time that UPS can supply alone.

Launcher Tests

Launcher strap tests: Straps of hydraulic launcher is tested for maximum pull and stop loads for operational capability and limits.




Launcher dummy tests: After analysis of launch, many dummy launches are made with launcher for different dummy weights, launch speeds, launch accelerations and launch angles.

Environmental Conditions Tests

Temperature and humidity tests: All avionic equipments and sensors are tested for temperature and humidity limits based on MIL-STD-810F.

Equipment EMI/EMC tests: All aircraft equipments are checked for EMI and EMC separately and together as a system based on MIL-STD-464A (system level), MIL-STD-461E and/or RTCA/DO-160E (equipment level).

## 4.0 GROUND TESTS

Simsek system design is tested for each subsystem on ground. After sub system tests, aircraft is assembled and ground tests are applied in two categories; Installation tests and ground functional tests.

Installation Tests

Basic geometrical checks: After the aircraft comes out from the production line, initial dimension control with check list and basic dimension control with CMM.

Engine installation check: Engine installation is checked with CMM since thrust line is very important parameter for a high maneuverable drone.

Test boom installation check: Test boom needed for performance flights is checked for right alignment with CMM (Coordinate Measuring Machine).

Fuel tank leak test: Pressurized air is applied in fuel tank.

Electrical continuity check: All harness are controlled pin to pin.

Weight and balance check: Weight and balance after all installation tests are finished to determine empty and maximum takeoff weight (with balance weight).

Ground Functional Tests

Aircraft first power-up tests: Voltage levels are checked and first energy is supplied to aircraft.

EGI calibration and test: EGI is calibrated on aircraft in an open air no metal area.

Air data system ground test: Speed and Altitude controls with air data tester in a specific tolerance.

Servo ground tests: All 5 servo’s maximum deflection are measured and checked from feedback values.

Integrated avionics ground test: All functionality of the system is checked with respect to procedure.

Autopilot ground test: All autopilot functionality is checked with respect to procedure.

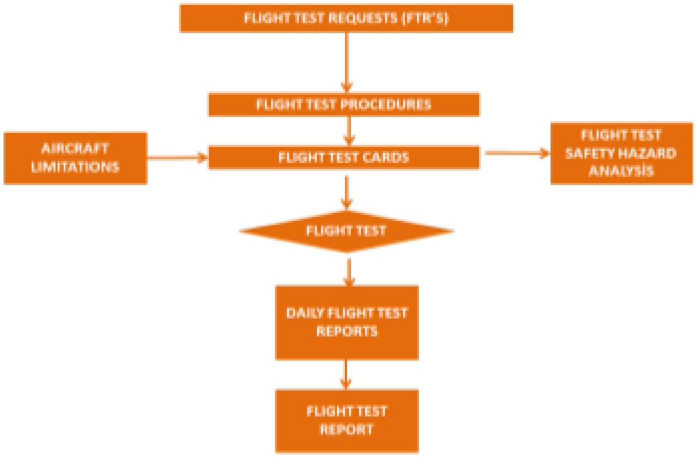
Engine ground test: All engine functionality is checked with respect to procedure.

EMI-EMC test: EMI and EMC tests are applied for one time.

## 5.0 FLIGHT TESTS

For Simsek and other independent research & development projects, safety and effectivity of flight test, the major steps are common process which is mentioned below.

**Figure 4: Flight Tests Process**




During flight tests; internal pilot, flight test manager, flight test engineer and control specialist which adjust the gains during flight perform test points at Ground Control Station (GCS). While in the Engineering Test Station (ETS); aerodynamics, avionic, ground systems, aircraft systems, data link engineers are watching flight parameters real-time and giving feed-back to GCS when necessary.

After test flight, all test points, observations, findings, comments and critical data analyses are reported.

### 5.1 FLIGHT SUMMARY OF SIMSEK

Following the process mentioned above, Simsek System has flown 26 sorties for flight tests up to date. With these flight tests, System has proved its system's operability, autopilot capability and ability of carrying payloads.

During flight tests campaign, roll, pitch, speed and altitude hold modes' gain adjustments were performed and Navigation mode and high speed tests were executed.

## 5.2 FLIGHT TESTS

Progress of Autopilot Flight Tests:

In 1st flight pitch-rate and roll-rate CAS (Control Augmentation System) controllers are employed, to increase external pilot relief as much as possible by providing attitude sustainment on zero-command and automatic trim capabilities of rate CAS. In following flights, attitude hold autopilots are activated at safe altitudes of flight test. After gaining confidence in autopilot, Simsek is launched with roll and pitch attitude autopilots on and gains are tuned at various flight conditions. At this stage, also external pilot became internal pilot, since flight distances go beyond the visual limits of pilot. In later phases, altitude hold, speed hold autopilot mode and waypoint navigation modes are tested.

Autopilot Tuning

Autopilot gains are tuned online via uplink messages. Control engineer views commanded and sensor data online judges the performance of autopilot and sends the new candidate of tune factor to UAS. Also, recorded flight test data is evaluated for control performance. To this purpose, command tracking performance measures are devised and evaluated offline. Offline analysis of test data results in autopilot gains of next flight test, if related tests are not concluded.

Performance Tests

Performance tests are performed to determine actual speed, range and altitude limits. Some performance tests are performed with air data tester payload mounted on the nose of the drone. These tests allow to calibrate air speed transducers, aerodynamic calculations and also aerodynamic and engine performance verification.

Assessment of Flight Test Data:

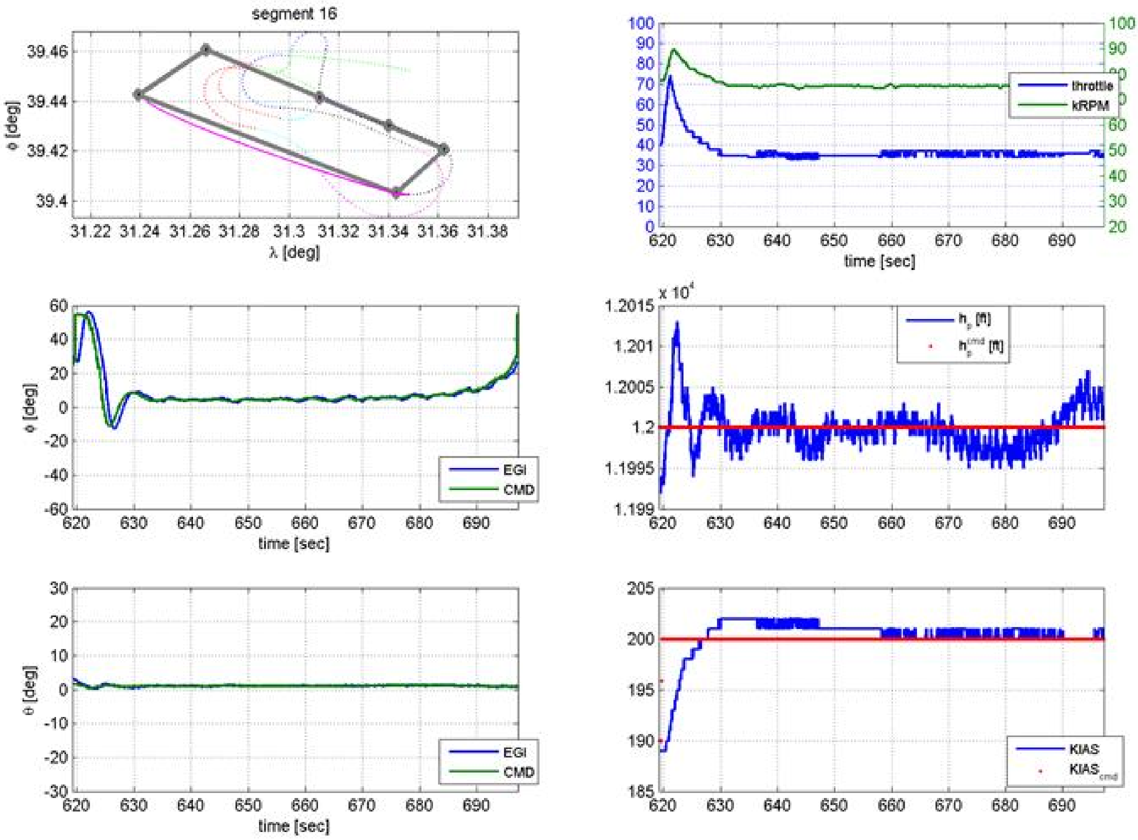
For controller performance assessment, closed loop linear models (ARX, ARMAX,&c.) for longitudinal and lateral motions are estimated offline, to represent nominal response of test configuration of A/C. Nominal identification model serves to determine time domain characteristics (overshoot, rise and settling times) in more systematic manner. Also, deviations of test data from nominal identification model are used to quantify the amplitude and frequency of persistent oscillations (if any).

Vibration problems are recognized better in higher frequency airborne data recording which is utilized in recent flight test campaign. Temporal vibration phenomena are analyzed by Time-Frequency Analysis (TFA) tools (Gabor transform/STFT) helping to locate specific time instances at which a vibration problem starts or ends (e.g. heavy turbulence, loose components).

In some offline re-constructive computations (like aerodynamic force/moment estimations) where first and second derivatives are of noisy data is required, Savitzky-Golay filter is employed giving satisfactory (data compatible) results.

Sample Plots from a Flight Test

**Figure 5: Navigation Mode: guidance to a waypoint (AH+SH+lateral navigation)**




## 6.0 FUTURE OF SIMSEK PROGRAM

Simsek Target System has reached initial operational capability status and is already planned to give service during military training exercises in 2015. These operational experiences are expected to generate new requirements to be implemented. There are already pre planned product improvements including different payloads and automated maneuvers. Existing manufacturing methods and systems will also be reviewed to exploit any possibility to reduce unit costs. With its low cost and high performance, Simsek target system is already attracting interest from other countries as well and is expected to have a good market share.