TAI ROTARY WING UAV (R-300) SYSTEM DEVELOPMENT ACTIVITIES

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ABSTRACT

TAI Vertical Take-off and Landing Unmanned Aerial Vehicle Development Project (RİHA/R-300) activities have been summarised. The activities have been concentrated on Automatic Flight Control System (AFCS) Development rather than air vehicle development. An existing single seater homebuilt class helicopter has been structurally modified to install an avionics system to run the in-house developed Flight Management Software capable of full autonomous take-off, way-point navigation and landing system, with defined emergency procedures. The critical point of auto-landing is determining precise position of air vehicle with respect to landing platform. This study presents an image processing based positioning methodology which may be further developed to include moving platform landing in day and night operations. The aircraft has also been instrumented to collect in-flight data through manned flights to generate a high fidelity mathematical model of the air vehicle in parallel with the AFCS development activities. Some of the instrumentation is still on the air vehicle to collect further data during unmanned flight tests. A portable flight control ground station has also been developed which also supports payload operation and serves as engineering test station for real time data evaluation.

INTRODUCTION

An existing single seat helicopter has been converted a fully autonomous UAV system through a system identification based reverse engineering process to model the dynamics of the helicopter. The generated mathematical model has been used to develop the automatic flight control system (AFCS) which includes a stability augmentation system to support external safety pilot during remote controlled flights, an autopilot to control angular rates and the position of the helicopter, a navigation algorithm to perform way-point navigation with an emergency mode to return air vehicle to a prescribed point, and an automatic take-off and landing to system. The air vehicle has been structurally modified to support the avionics and the electrical system installations. The converted unmanned air vehicle has initially been flown for external safety pilot familiarization and stability augmentation system gain tuning after extensive pilot training in the SIL. Gain tuning flight testing for all AFCS modes has been continued until satisfactory performance has been achieved to conduct a ground generated mission plan, which may be modified during flight, composed of auto-take-off, way-point navigation and auto-landing.

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Major steps include compilation and generation of air vehicle specific data including mathematical model development, avionics, flight test instrumentation (FTI), ground control station (GCS), system integration laboratories (SIL) and AFCS architectures, and air vehicle modifications. Analysis of modifications on air vehicle and air vehicle performance including payloads are also very important. Safety precautions such as use of larger landing gear and tethered test setup and SIL testing are especially inevitable parts of the development process where air vehicle mathematical model has limitations in representing the actual helicopter.

GREEN HELICOPTER

Airframe:
The Mosquito XE, Figure 2, [1] airframe is a unibody construction made entirely of fiberglass in a vinylester matrix. Body and structure are the same to minimize weight and maximize structural efficiency.

Figure 1 The Mosquito XE Single Seater Homebuilt Helicopter in Manned Flight Testing

Engine:
Compact Radial Engine's - MZ202, 60-hp, powers The Mosquito a two cycle, two-cylinder engine with the highest power to weight ratio on the market today. This engine employs Reed Induction which yields a very flat torque curve ensuring power is delivered constantly over the required operating range. The MZ202 also has a lower operating speed of 6000 rpm when compared to other engines with similar power range that typically operate at 6500 to 7000 rpm resulting in less stress on the engine and improving reliability.
The complete engine package only weighs 69 pounds and comes with a 180-watt alternator that provides power to run the electrical system, which also features an electric start system.

Power Train:
The primary reduction is bolted directly to the engine. A centrifugal clutch on the engine crankshaft permits startup of the engine without the load of the rotor.

Power is transmitted from the clutch to the driven pulley of the reduction through an HTD cog belt, one of the highest power to weight ratio power transmission methods available. The driven pulley houses the sprage clutch which permits the rotor to overspeed the engine during autorotation. Power is transmitted to a splitter gear box at the front of the tail boom through flex couplings and a floating drive shaft. The gear box sends power to the tail rotor through a drive shaft housed in the tail boom. Another floating drive shaft then transmits power to the secondary reduction at the top of the mast which drives the main rotor through a second high capacity HTD cog belt.

Rotor System:
The main rotor is a semi-rigid configuration. Main rotor blades consist of an aluminum spar bonded to a wrapped aluminum sheet skin. Foam plugs at both ends prevent interior contamination and pumping losses. The tail rotor is also of a semi-rigid configuration with aluminum skin wrapped around a tube and foam plugs at either end. A 45 degree drag hinge is utilized to maintain tail rotor alignment.

Control Systems:
The control system is unique to the Mosquito. Main rotor control is achieved from the floor mounted joystick and collective through a control mixer in the base of the main mast, then through push tubes in the mast up to the base of the swash plate. The swash plate is contained within the mast and is supported by a push tube located in the rotor shaft. Control rods on either side of the push tube transmit inputs through the rotor shaft to the control lever on top of the rotor shaft and then down to the blade pitch horns through pitch links.The tail rotor is controlled by the foot pedals through a push pull cable to an actuating lever on the tail rotor shaft.

STRUCTURAL AND SYSTEMS MODIFICATIONS ON GREEN HELICOPTER

MIL-STD-704E [2] was used as guidance for the design of the electrical power generation, Figure 2, and distribution system. In a similar way, SAE-AS50881 [3] was used as guidance for the cable harness design. The system capacity was based on an electrical power budget with a certain amount of back-up.

Avionic equipment takes the power from 28V bus via circuit breakers. 28V bus is powered by the main battery and the newly integrated 2kw alternator at the same time. However while battery is always active, the alternator can be cut off. If the system generates a main battery hot signal, the air vehicle needs to divert the mission and land.

Engine is powered by 12 V bus. This bus is powered both the engine battery and the 28V bus. There are circuit breakers for engine and the engine starter.

The primary structure of the helicopter has been unchanged. The only modifications performed are the removal of the pilot controls, pilot seat, safety belt, and the instrument panel. Avionics equipment installation has been major structural work considering the vibration levels of the helicopter. Vibration measurements have been performed at various locations and equipment installations have been performed accordingly. The CAD model of the structural modifications and wiring harness were given in Figure 3.

The basic mechanical flight control system of the helicopter was not modified. The only modification was that the pilot controls have been removed and replaced by electrical servo motors actuated by the automatic flight control system running on the flight control computer supported with an Embedded GPS/INS (EGI) providing attitude and position of air vehicle, a Differential GPS (DGPS) providing location with 10cm accuracy and a Laser Altimeter (LALT) providing Above Ground Level (AGL) altitude. The UAV system has a double redundant link where primary link is a C-band high capacity link providing both data and video transfer and the second link is a backup only for data transfer. The remote control system also uses these links, there also exists a direct connection from remote control unit of the ground safety pilot to the air vehicle.

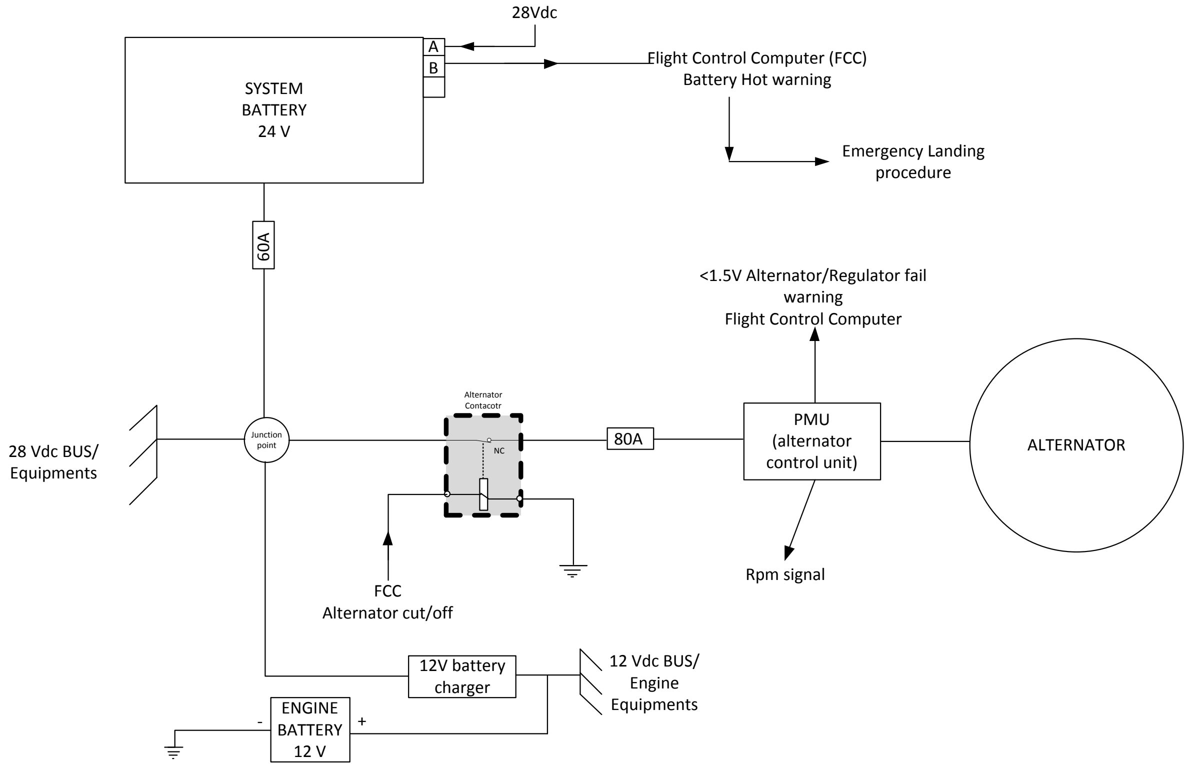

Figure 2 Electrical System

With integration of the auxiliary fuel tank, an extra fuel capacity is added to the helicopter. The auxiliary fuel tank is connected to the main tank with extra fuel lines. A pump is integrated to the system in order to be started when the level in the fuel tank is below the predefined level. The pump delivers the fuel in the auxiliary tank to the main fuel tank and is controlled either from GCS manually or it receives "low fuel level" signal from fuel level sensor and begins to pump automatically.

The avionics bay heat transfer analyses, Figure 4, have been performed to investigate the worst case heating scenarios as follows:

- Air vehicle on-ground with all systems functional (left on Figure 4)
- Air vehicle in hover (middle on Figure 4)
- Air vehicle in forward flight at 40 KEAS (right on Figure 4)

where initial conditions at air inlets were extracted from external floww analyses and in all cases, ambient air temperatue is taken as 43°C.

Figure 3 Structural Modifications and Cable Harness

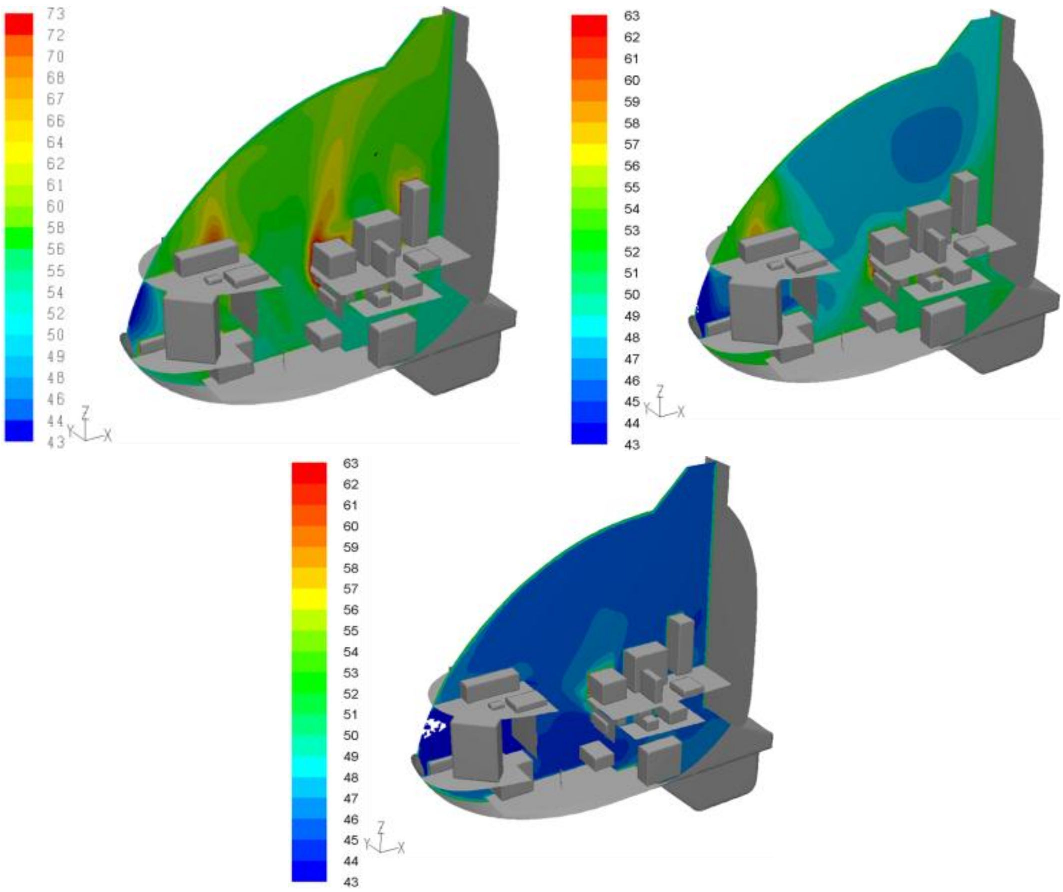

Figure 4 Heat Transfer Analyses inside the Avionics Bay

R-300 avionics architecture, Figure 5, is based on dual redundant Flight Control Computers (FCCs) on the center and dual redundant Flight Sensors, Servo Actuators, Air Vehicle Systems, dual redundant Communication Systems and Payload as peripheral systems. Owing to dual redundancy on avionics architecture, R-300 possesses high reliability and fault tolerance.

The FCCs receive the attitude and position data of the air vehicle from flight sensors and provides them to the AFCS. It controls the air vehicle by commanding the servo actuators that are attached to the main and tail rotor with AFCS outputs. In addition, there is a gyro stabilised gimbal Payload for surveillance and redundant data links for communication.

The R-300 System has dual redundant WME based Flight Control Computer on which Integrity Real Time Operating System runs. The FCC is the central computer and the core of the Air Vehicle avionics system and it controls all the flight critical operations. The Operational Flight Program (OFP) is the real-time embedded software which runs on the FCC and controls all the flight operations of the aircraft; supports controlling and management of flight critical subsystems; autonomous flight through auto-pilot function and sensor data.

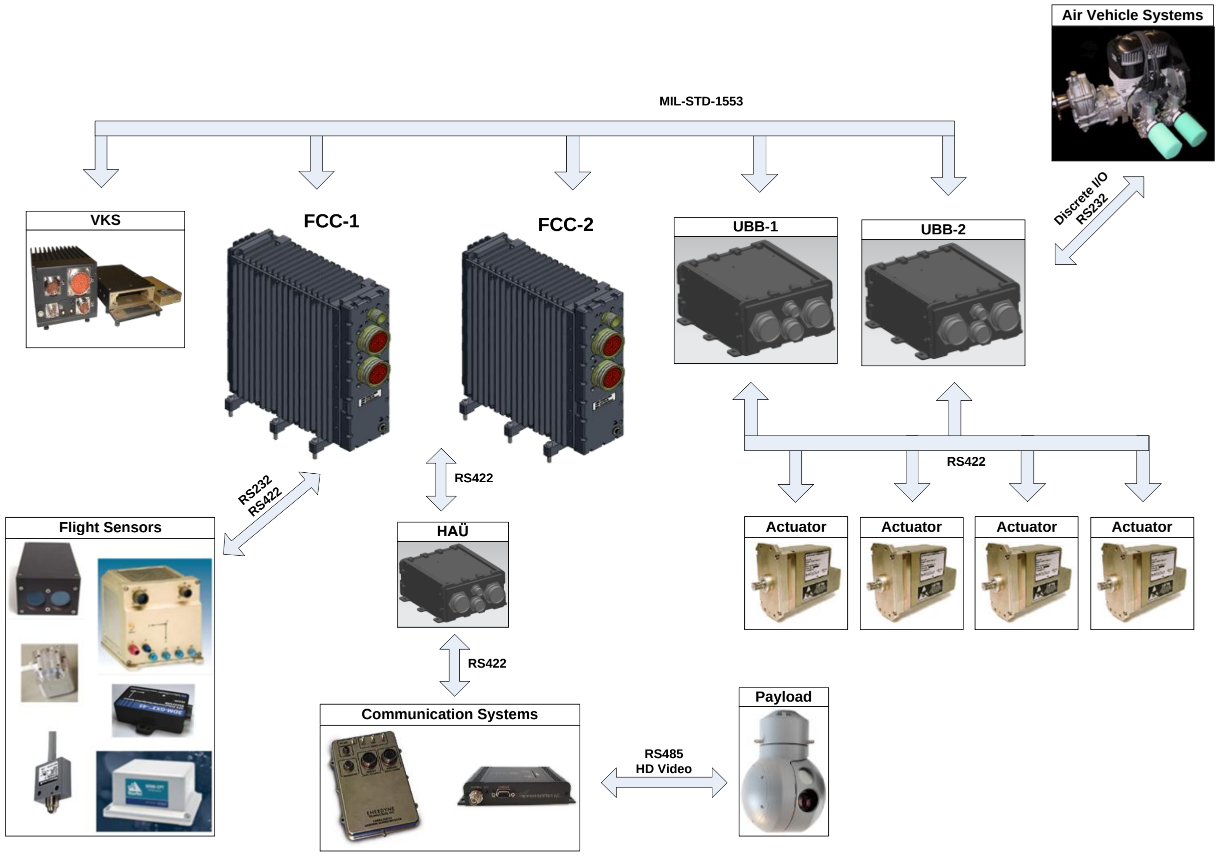

Figure 5 The Avionics Architecture

DATA ACQUISITION SYSTEM

The current data acquisition system is a part of the development phase. The system itself and the engineering data conversion together with user interfaces have been tested and verified in the System Integration Laboratory. The data is both stored on the air vehicle and has been transmitted for real time data observation to the ground, Figure 6. The basic telemetry and telecommand parameters, AFCS gain tuning parameters, IMU and GPS/D-GPS data together with some analog data such as loads and electrical current on servos are collected.

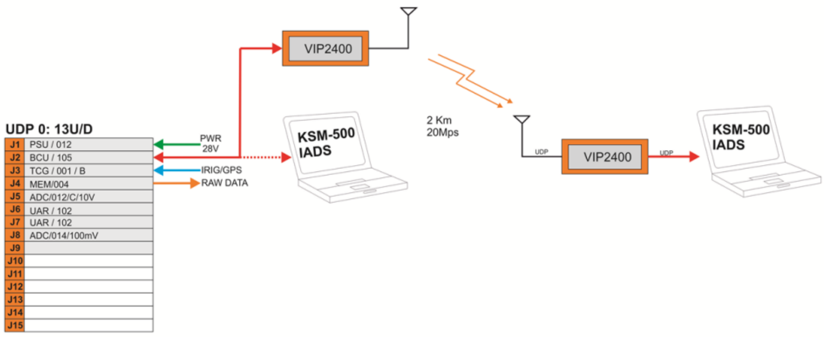

Figure 6 Basic FTI Architecture

Data Acquisition system on the air vehicle keeps recording the sensor data in FCC failure and keeps recording all data in link loss. Data Acquisition system records the data at higher frequencies than the downloaded telemetry messages. So the test results data is of higher quality for post-test data investigation especially for AFCS algorithms.

SYSTEMS INTEGRATION LABORATORY

The main purpose of the SIL (System Integration Laboratory) is to test the GCS (Ground Control Station) and FCC (Flight Control Computer) software before flight operations. Real Equipments and their Simulator versions are used for testing, Figure 7. Real Equipments are used to test the system under real working conditions and the Simulators are used to provide desired input to the FCC which cannot be provided by the real equipment in the laboratory.

Figure 7 The Systems Integration Laboratory

The REAL and SIM selection for Equipment can be performed by using “REAL/SIM Switch PANEL”. To provide multiple serial port interface between computer and FCC, there are Serial to Ethernet Converters in the SIL. SIMULATOR PC which includes the equipment and flight simulators talks to these converters over Ethernet communication protocol and the converters talk to the FCC over related serial protocols (RS232, RS422, RS485 …). By using the advantage of this architecture every input can be given to the FCC and the reaction of the FCC can be monitored to verify the software easily.

Real FCC and Real GCS can be connected directly to test the all system. The commands can be send from GCS and the simulated flight test data can be displayed, recorded and evaluated with GCS software. Pilot/operator training can be done and the test can be planned via this configuration. On the other hand, real equipments can be connected to the FCC to see the result of our commands and their returns. Some faults can be injected in the SIL during pilot/operator training. So the emergency situations can be tested and trained.

PRODUCT TREE

The green helicopter and unmanned systems combined together form a UAV system as follows: The basic helicopter structure and flight control system was modified slightly to support added systems, and new avionics that is sensors, FCC and data and video links were added for unmanning the system. The ground units are inevitable parts of the UAV system, however, as this is a development project, ground systems currently include some extra features which will not a part of the final product especially about the tuning of the AFCS. The integrated subsystems, ground control station, link and the modified air vehicle combined into a UAV system was given in Figure 8.

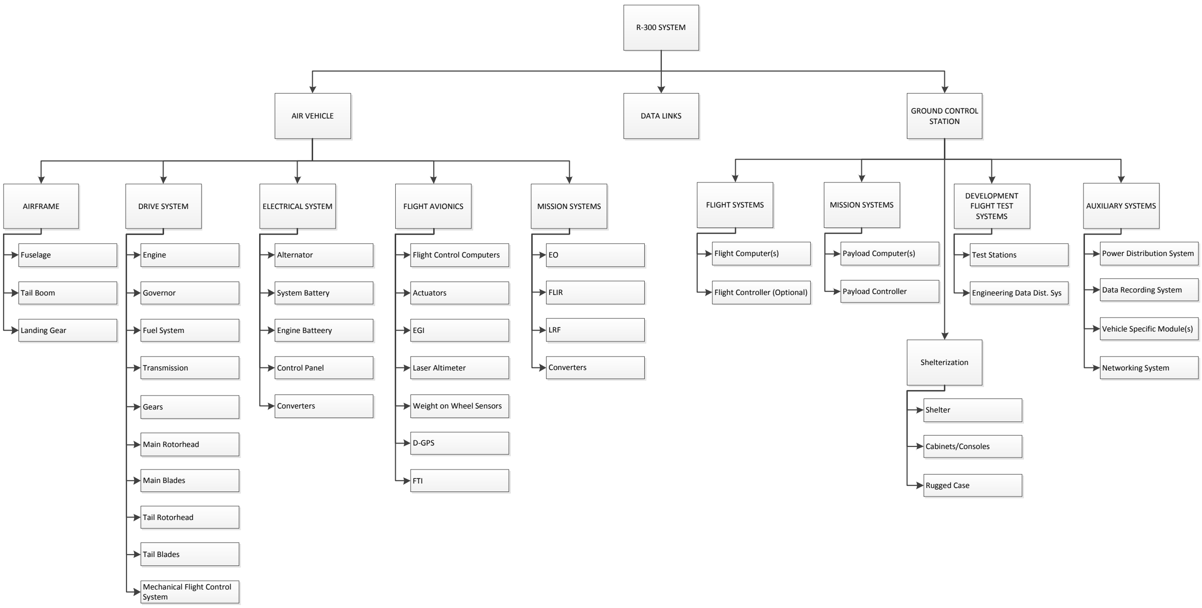

Figure 8 The Product Tree

MATHEMATICAL MODELLING

The generated non-linear mathematical model is an analytical representation of total forces experienced by the entire helicopter in six rigid body degrees of freedom. There were two main data sources for the mathematical model, namely, system identification/parameter estimation and numerical analyses, Figure 9, with empirical corrections.

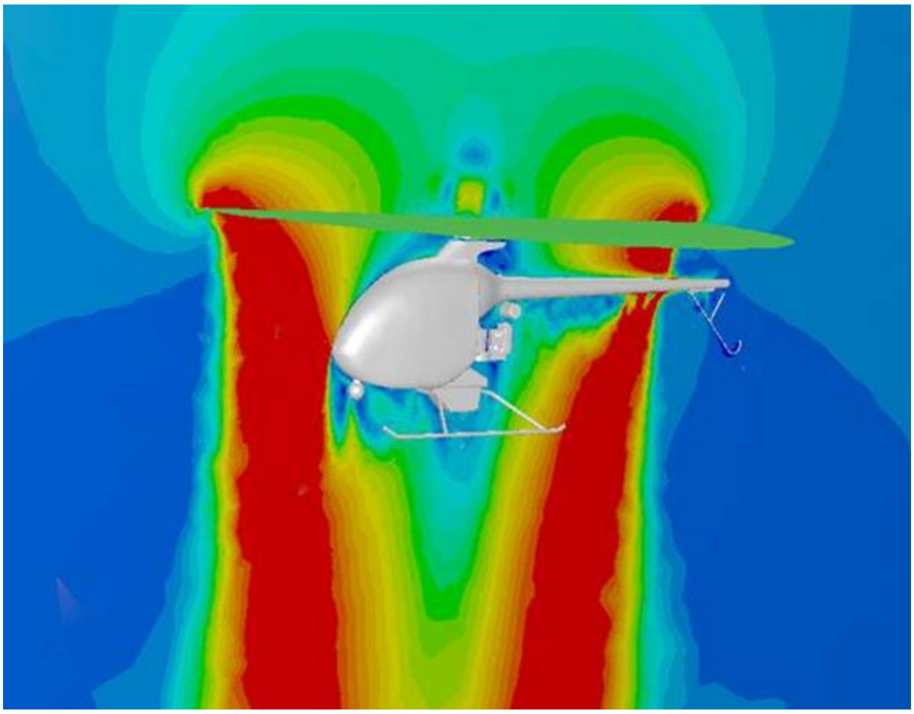

Figure 9 Fuselage Rotor Blade Interactions

The instrumented air vehicle has been flight tested to collect data in following flight regimes:

- Hover and hover taxi in and out of ground effect with vertical climb and descent
- Frequency sweeping for pilot control commands at
  - Various ground speeds
  - Various altitudes
  - Climb and descent in forward speed

to have representative air vehicle dynamic characteristics in flight performance, static longitudinal and directional stability, dynamic longitudinal and directional stability using step, sinusoidal and doublet type pilot control inputs, Figure 10. ADS-33-PRF [4] has been used as reference guide to determine the flight conditions and the data to be collected.

Modular structure of the mathematical model together with large angle consideration ensures high fidelity in both steady and maneuvering flight conditions. Computations for the main rotor aerodynamics are based on blade element theory. Each blade segment is subjected to helicopter motion together with the rotor speed and blade motion itself. Momentum theory in calculation of rotor thrust provides uniform downwash very well for the hover case. After passing it through a first order lag, azimuthal harmonic distribution as a cosine function depending on the rotor wake skew angle is taken into consideration for the existence of the forward velocity. Sideward velocity effects are also considered in a similar way.

Inertial			
	Data	**Unit**	**Desc**
	Phi	rad	roll attitude
	Theta	rad	pitch attitude
	Psi	rad	true heading
	u	m/s	body axis long speed
	v	m/s	body axis lat speed
	w	m/s	body axis vert speed
	p	rad/s	roll rate
	q	rad/s	pitch rate
	r	rad/s	yaw rate
	ax	m/s2	body axis long acc
	ay	m/s2	body axis lat acc
	az	m/s2	body axis vert acc
	Lat	deg	latitude
	Lon	deg	longitude
	Alt	m	altitude
Air Data			
	Data	**Unit**	**Desc**
	V	m/s	airspeed in nose direction
	AoA	deg	angle of attack
	AoS	deg	angle of sideslip
	Ps	pascal	static air pressure
	Pt	pascal	total air pressure
	OAT	Celcius	outside air temp

Inputs			
	Data	**Unit**	**Desc**
	delta_coll	deg	collective angle
	delta_lat	deg	lateral cyclic angle
	delta_long	deg	longitudinal cyclic angle
	delta_pedal	deg	pedal angle
	A0	deg	swashplate total blade angle
	A1	deg	swashplate lateral blade angle
	B1	deg	swashplate longitudinal blade angle
Propulsion			
	Data	**Unit**	**Desc**
	NR	rpm	rotor speed
	TQ	Nm	rotor torque
	FF	g/s	fuel flow
Rotor			
	Data	**Unit**	**Desc**
	tip_ax	m/s2	rotor tip axial acceleration
	tip_az	m/s2	rotor tip normal acceleration
	tip_vx	m/s	rotor tip axial speed
	tip_vz	m/s	rotor tip normal speed

Figure 10 Data to be Acquired during Manned Flight Tests

Additionally, harmonic distribution of downwash resulted from the aerodynamic hub moments exist in the calculation of downwash. After the calculation of velocity components of each blade segment, angle of attack and dynamic pressures are determined. For a wide range of angle of attack and Mach numbers, CFD results of the blade geometry are used to find corresponding aerodynamic load for each blade segment. Blade flapping and lagging motions are included in the calculation of resulting aerodynamic loads for each blade. This summation includes carrying loads from blade span axes and rotating shaft axes to the fixed shaft axes, and finalizing at the body axes of the helicopter.

Angle of attack at the fuselage is composed of free stream velocity and interference of the rotor downwash with respect to the main rotor wake skew angle. The fuselage aerodynamic loads are provided by CFD analyses for a wide range of angle of attack and sideslip angles. Airflow at the tail rotor is derived from the free stream velocity under the effect of main rotor and airframe wash. Moreover, dynamic pressure losses caused by the airframe are taken into consideration with the free stream velocity component. Bailey theory is used in order to compromise tail rotor motion in a linearized closed form. At the end, aircraft motion module gives the solution of states as the inputs of the next time step.

The mathematical model has been developed using a composite set of flight and numerical analysis data. Verification was performed against unused flight test data.

AUTOMATIC FLIGHT CONTROL SYSTEM

The control model for the autonomous helicopter consists of a low level PID control system [5], [6], [7], [8] to control attitude and position and a high level FMS (Flight Management System) for Waypoint Navigation and path planning. The cascaded PID control system controls altitude and N-E position in the outer loop based on FMS navigational position commands. There is also a FEP (Flight Envelope Protection) system that keeps the platform within the pre-determined acceleration and velocity limits while the helicopter is controlled automatically. The internal loop of the cascaded control system controls system attitude based on feedbacks on angular rate and position. The control system commands are fed into the linear model inverse of the helicopter nonlinear model with the other actual system states to create the helicopter actuator commands.

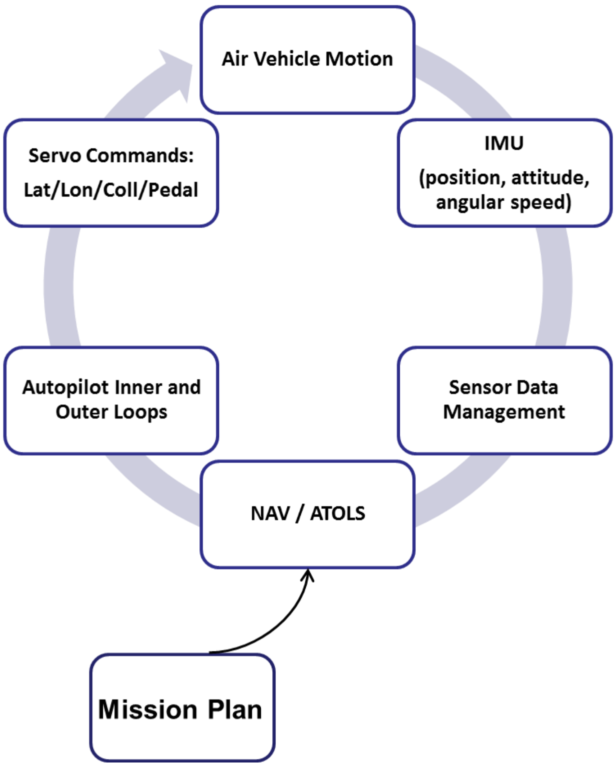

Figure 11 AFCS Logic

Waypoint Navigation, Automatic Take-off and Landing System (ATOLS) and link loss algorithms are generated in the scope of FMS. Waypoint navigation function in N-E axis includes “go to waypoint” capability which introduces arrival to the next waypoint in the shortest route while vertical trajectory following is achieved between waypoints. Mission points, cruise velocity and climb/descent velocity can be selected and arranged from Ground Control Station (GCS) during flight. Hover mode can be forced by the user at defined waypoints. Algorithms for smooth trajectory following is generated and ready to be activated in the system also for the N-E axis. ATOLS is carried out from and to a specified helipad. Ground effect compensation is added during flight tests phase. Image processing, ultrasound sensor, laser altimeter and INS/GPS data are fused and filtered for precise control of ATOLS. Link loss algorithms are formed from logical combination of Waypoint Navigation and ATOLS algorithms based on operational requirements, Figure 11.

The cascaded control structure is first developed based on a generic dynamic helicopter model in Matlab/Simulink® and verified through flight tests of a remotely piloted helicopter, R-10E. The structure is then adapted to R-300 model through flight tests. The control system is tested and verified in SIL (System Integration Laboratory) environment with Hardware in the Loop simulations and flight tests iteratively.

IMAGE PROCESSING BASED POSITION ESTIMATION

Image Processing Based Position Estimation is a key technology for fine relative positioning especially during auto-land and takeoff of an aerial vehicle. For the specific case, this system is used to estimate the position of a Rotary UAV relative to the Helipad, Figure 12. Since the pattern of the helipad is known, template matching is the main concept for these systems. In this approach, the algorithm is composed of three main stages, Shape Recognition, Template Matching and Position Estimation.

The shape of the helipad is known as a square. Therefore, in the first stage, the main idea is to extract all quadrangular regions, within the 2D captured image, which are possibly a square in 3D. In order to find required regions in different environmental conditions, day or night, an adaptive thresholding is applied before the detection and additional IR illumination is used for night conditions.

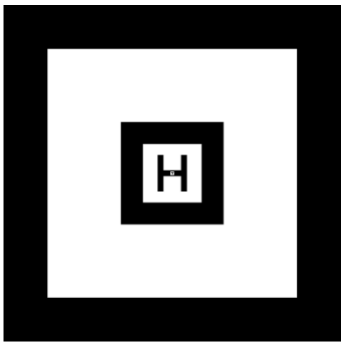

Figure 12 Helipad used for Image Processing

Finding a correct match within the candidate quadrangular regions is the next step. Used helipad is composed of a predefined binary (black&white) pattern, such as an **H** character, in a black square shaped frame. Therefore, Distance-Space is suitable for template matching. For the purpose, Distance Transformation is applied to interior of each candidate quadrangle before the matching. Then, predefined distance-transformed-template of helipad is reshaped by Perspective Transformation, in order to ensure that, all corners of candidate and the template coincide. Finally, the candidate, having a lower Normalized Square Difference value than the threshold, is decided to be the matched target.

The last stage is the geometry and mathematics. The problem definition is to find 3D body coordinates of each corner of the helipad using their known 2D coordinates on the image plane. The knowledge of camera parameters, dimensions of the helipad and the fact that the z-coordinate of the corners must be positive makes the problem converge to one exact solution. Using the 3D coordinates of the corners, necessary positional and angular data can be calculated.

At the end, system outputs are:

- 3D fine coordinate of the center of helipad relative to the aerial vehicle,
- Pitch, yaw and roll angles of helipad relative to the aerial vehicle.

The controller of air vehicle is fed with these outputs for a successful auto-land/takeoff purpose, even for non-stable helipads.

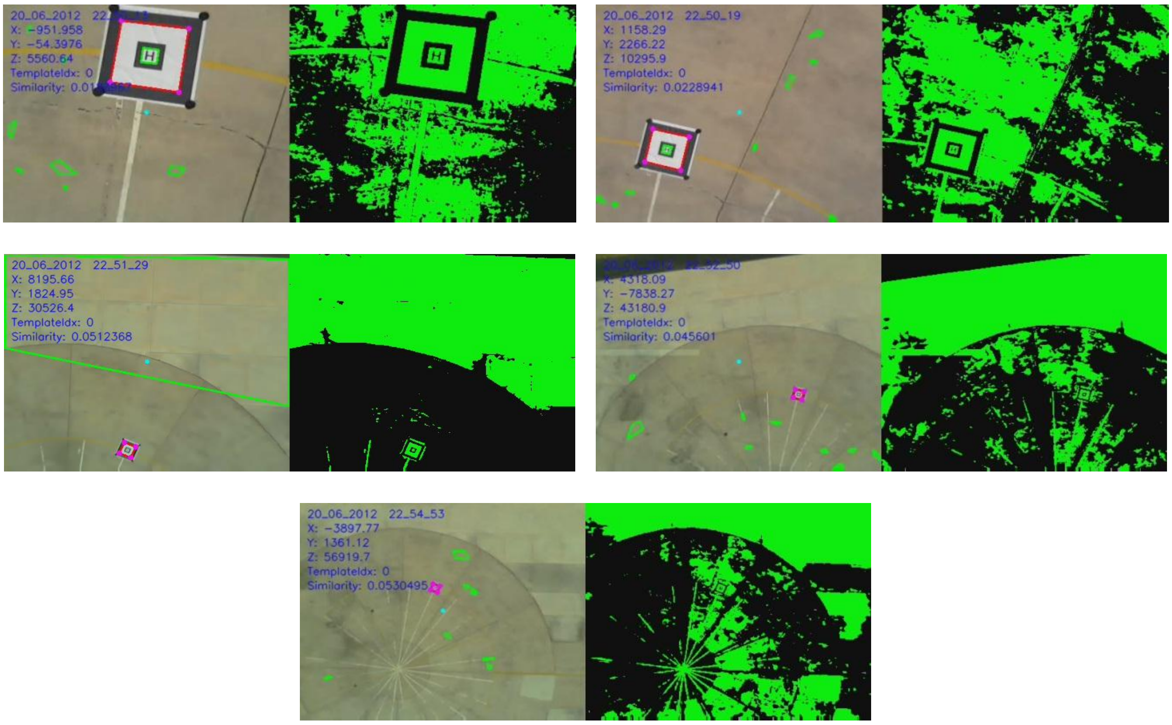

Figure 13 Position Estimations at 5.5, 10.3, 30.5, 43.2 ve 56.9 m altitudes (units in milimeters in pictures)

The helipad used in the tests was a square with 1.5 m x 1.5 m. dimensions. Various flight test measurements were given in Figure 13. The estimated horizontal position with respect to helipad center has a 1.5cm offset when the air vehicle is flying 10m above the helipad. The same figure becomes 4.9cm when the air vehicle is at 30m close to the visual limits.

Again using the same helipad, the difference between barometric altitude and the current image processing system is 1.7m when the air vehicle is flying 30m above the helipad. At lower altitudes the difference goes down to a few centimeters, Figure 14.

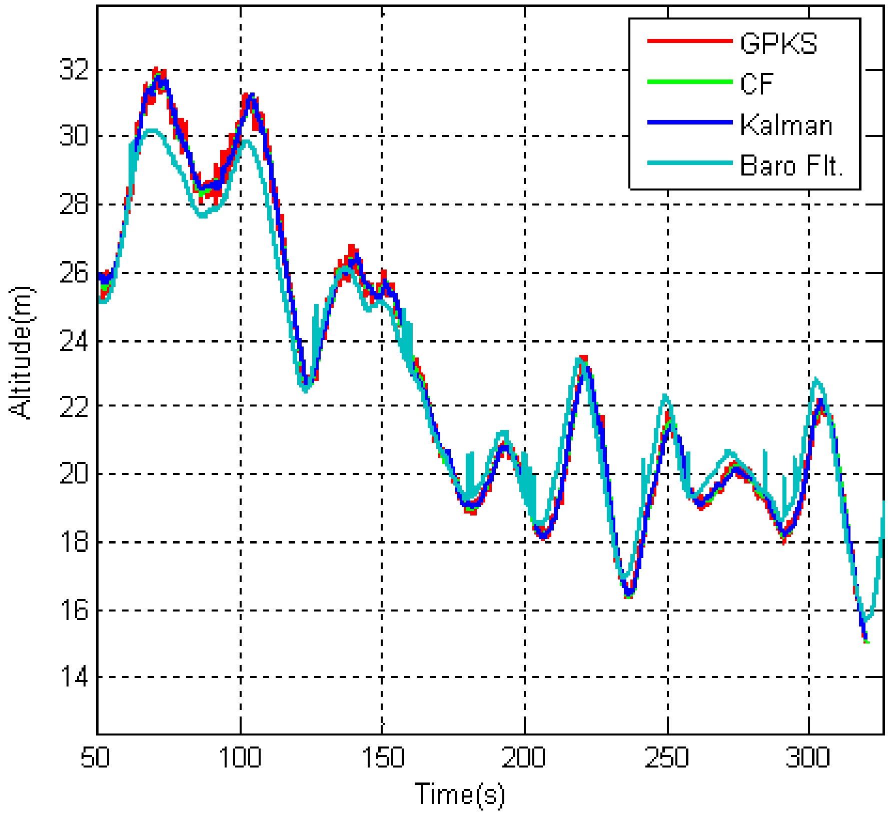

Figure 14 Comparison Various Altitude Measurement Methods

GROUND FLIGHT CONTROL and ENGINEERING TEST STATION

R-300 GCS, Figure 16, is compatible with Stanag 4586 [9], and provides user interfaces needed to control the air vehicle, visualized air vehicle and equipment data to Operator, and data recording and replay capability.

As the current GCS is being used in a development project, it includes special features such as:

- gain tuning parameters,
- engine, governor, fuel system, main and engine battery health status
- flight mode selector with intermediary AFCS modes
    - AP Inner,
    - AP Outer
    - Direct Drive (Remote Control + SAS)

The GCS is composed of two main units:

- The Core UAV Control System (CUCS) computer
- The Vehicle Specific Module

Vehicle Specific Module (VSM) converts the Air to Ground and Ground to Air messages to the standard messages as defined in Stanag4586. VSM sends the Air to Ground messages to the Core UAV Control System computer and Ground to Air messages to the UAV via specific data link. CUCS computer includes the all GCS screens that the operator needs. Operator does not need to use different CUCS computer for different UAVs. Operator selects only UAV configuration and the necessary screens (Figure 15) are displayed. Also CUCS computer provides the all data received and transmitted to the test station computers via multicast. All test data can be monitored via Data Monitor software which is in test station computer. Extra test stations can be connected to CUCS computer via an ethernet switch.

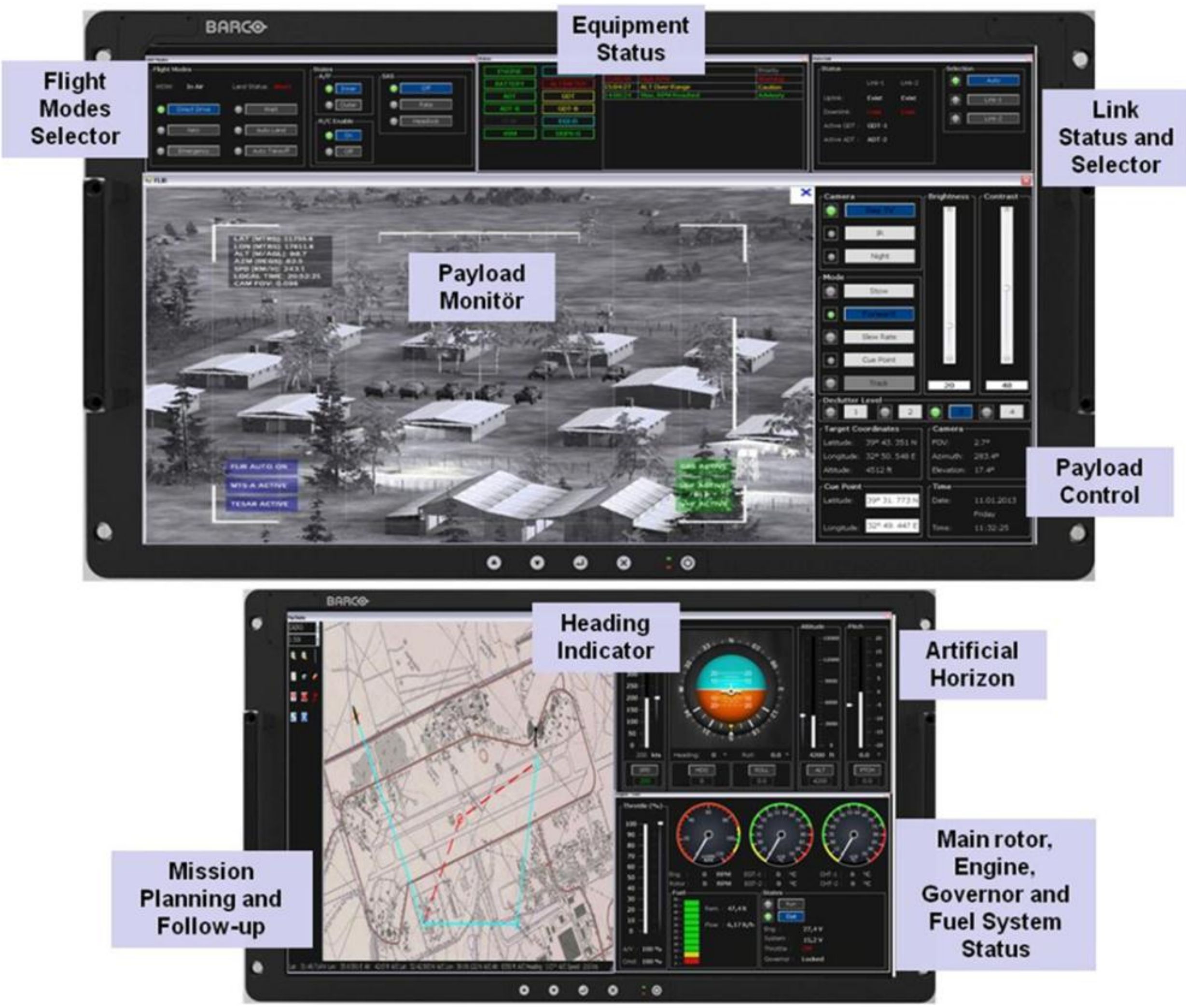

Figure 15 View of the Ground Flight Control Station

SOFTWARE VERIFICATION and CHANGE MANAGEMENT METHODOLOGIES

The high level requirements defining capabilities to be achieved in this in-house financed development project determined the basic AFCS requirements and the functional structure. The AFCS model, the mathematical model and GCS have been integrated using operational requirements specifications (ORS) and functional requirements specification (FRS) documents. This integrated flight and ground systems were activated in the Systems Integration Laboratory for the first time for verification before installing on the air vehicle. The software verification tests were conducted, any incompliances or mistakes were corrected through a change implementation system. The change requests are evaluated by a group of engineers and the best solution alternative is selected for resolution of the problem. Similar methodology starting with SIL testing is valid for any modification or upgrade to improve the existing system.

Any Project team member is authorised to make “Change Requests” (CR). The request is managed through CR Management System as follows: Any Project engineer can create a CR any time during software development/modification process. CR is then directed to the design engineer in charge of the system/equipment to be analysed to clarify the proposal and the solution.

CR’s accepted through analysis process are evaluated in CCB (change board) with the participation of Project team members and related functional organisation lead engineers. CR’s approved in this meeting are addressed to the software version where they will take place, and the related requirement specification (FRS – functional requirement specification) is updated by the design engineer. The design engineer implements the proposed solution in the FRS as defined in the CCB meeting and sends for verification to CR creator. At this step the CR creator checks whether the FRS is prepared as defined in CCB meeting and sends to software engineer if he verifies the FRS. The software engineer checks the applicability/codability of the FRS and initiates the coding process. After the verification of the change in the SIL, the change is completed and CR is closed.

GROUND AND FLIGHT TESTS

The modified air vehicle, structures and avionics have been subjected to extensive ground functionality testing. The SIL and tethered flight are the ground parts of the test process. The testing sequence was given in the chart below, Figure 16. The order in this chart is for a cold start. At the very beginning of flight testing for a manned-to-unmanned conversion project, the flight with remote control (RC) is a very important tool which is also very difficult due to the fact the RC pilot is outside of the air vehicle and is trying to fly an air vehicle he didnot fly before. Therefore, SIL training, tethered flights and safety landing gears are extremely important for RC pilot familiarization. After this stage is over, SIL testing is still the first step to be taken after an OFP update, however, tethered flights and safety landing gear flights are no longer needed.

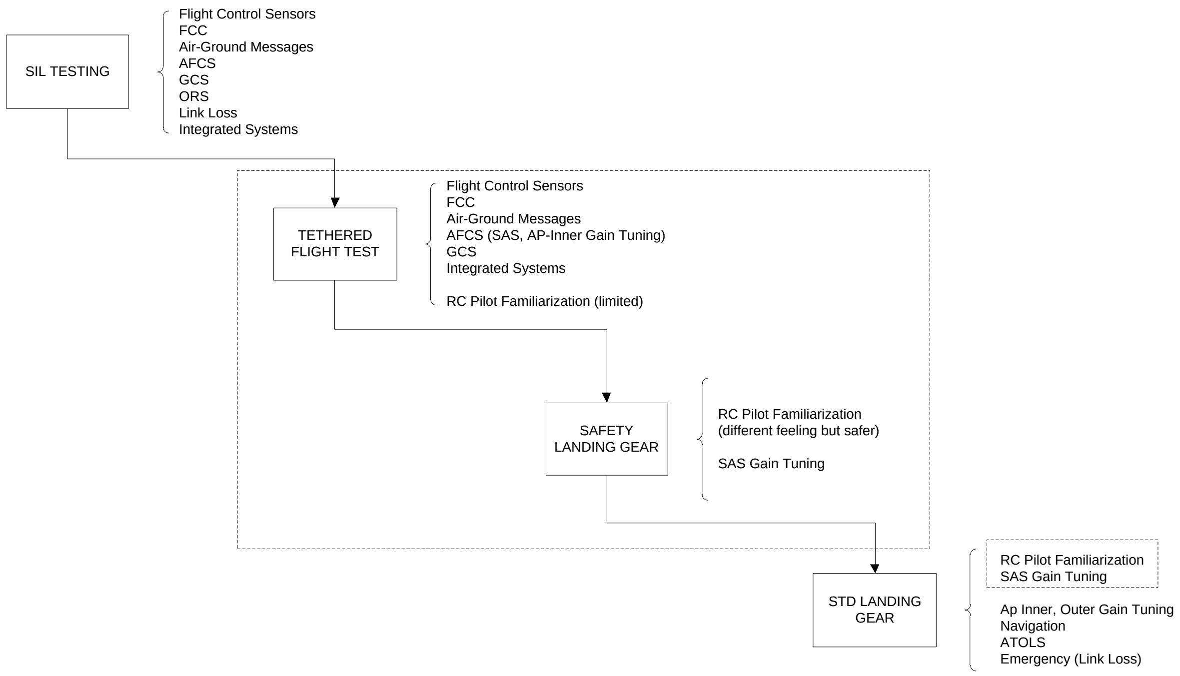

Figure 16 Ground and Flight Test Flow

SIL testing is the most important tool to verify that the OPS is free of faults before transfer to air vehicle. UAV system components has been tested on the Systems Integration Laboratory (SIL) using one-to-one matching avionics. The AFCS has also been tuned in SIL using the developed and partially verified mathematical model. Air vehicle flight control sensors, the flight control computer, the air-to-ground and ground-to-air messages, AFCS modes including link loss, flight mode transitions, GCS functions and UAV system integrated tests are performed in the SIL.

The tethered flight tests have been performed on a six-degrees-of-freedom tethered flight test setup, Figure 17. Using this setup, remote control pilot and the engineers had opportunities to observe the impact of structural, avionics modifications on air vehicle, and vice versa, the air vehicle response to control inputs of the human pilot and autopilot. Due to the nature of the tethering not all AFCS functions can be verified, however, basic air air vehicle and GCS functions, all messages can be tested as in flight. The pilot familiarization is limited but is very good starting point before free flight tests using large landing gear.

Figure 17 R-300 on Tethered Test Setup for System Functionality Testing

The free flight tests have been initiated with ground safety pilot familiarization and SAS gain tuning using a larger landing gear, Figure 18, to help pilot especially for take-off and landing. The difficulties regarding the remote control of the converted helicopter made it compulsory to use a SAS to stabilize the helicopter in pitch and roll, and to keep heading fixed unless pilot commands a certain heading using the remote control unit.

Using large landing gear, pilot familiarization and SAS gain tuning have been peformed concurrently and familiarization have been completed under the given conditions, i.e., large landing gear and SAS tuned for large landing gear.

The flight tests have progressed with standard landing gear, Figure 19. RC Pilot familiarization and SAS gain tunign have again been performed at the same time. Landing gear change has resulted in minor variations in gain parameters in SAS. RC Pilot familiarization process has been continued until the pilot feels safe to recover the helicopter from dangerous situations during AFCS verification flight tests. The autopilot, core of the AFCS, inner and outer loops have been tuned to control the air vehicle attitude and position respectively.

During the flight tests, RC pilot supported by SAS has had very important functions where inner and outer loops have been activated and and tested for their responses until satisfactory convergence was reached. The tuned autopilot was the starting point for the high level modes of the AFCS, i.e., the automatic take-off and landing, way-point navigation and emergency modes.

Figure 18 Air Vehicle in Hover for Pilot Familiarization and SAS Gain Tuning with Safety Landing Gear

During the course of the flight testing period, the avionics architecture for R-300 has been modified to a redundant system. The double redundant system has been implemented on first prototype, and work is in progress for the second prototype with some further improvements on the architecture. The third prototype will be the same as the second prototype. When the R-300 projects activities were suspended for upgrade, the AFCS improvement work has been initiated again.

To this end, R-10E has been reinstated to its pioneering role for full functionality AFCS development and verification. The flight envelope for the R-10E system has been expanded further espeially for forward speed through the use of a feedforward algorithm to establish forward speed-collective correlation.

The R-10E system has also been used to perform the activities given in Image Processing based Position Estimation section. This capability will be used for precise automatic landing of air vehicle especially for shipboard landing both daytime and nighttime. A 5 degrees-of-freedom ship motion simulator, Figure 20, has been developed for the verification of the system. The simulator only excludes the heading control, all other rotational and translational motions are available.

Figure 19 Air Vehicle in Hover with Standard Landing Gear for AP Gain Tuning

Figure 20 The 5-degrees-of-freedem Ship Motion Simulator

Acknowledgement

This paper summarizes the work done in the last 1.5 half year in the company funded in-house infrastructure development project (RİHA / R-300) to increase the technology readiness levels for the development of high capacity Rotary Wing Unmanned Systems capable of shipboard landing. In spite of the fact that there only 5 writers mentioned in the paper, the work has been performed by the TAI Project Team composed of many specialists from various disciplines organised in an Integrated Product Team methodology to develop the current system.

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