THE MAIN ACTIVITIES OF RESEARCH AND DEVELOPMENT IN KARI RELATED TO RECENT UNMANNED HELICOPTER

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Abstract

Korea Aerospace Research Institute (KARI) has researched and developed several types of unmanned helicopter in recent period. The representative unmanned helicopters are Multi-Purpose Unmanned Helicopter which has MTOW 200kg (MPUH) and the First Korea Electric Unmanned Helicopter which has MTOW 125kg (K-EUH). The MPUH has payload 60kg, max speed 150km/h and flight time over 3hrs which had been developed during from 2017 to 2021. The K-EUH has payload 20kg, max speed 120km/h and flight time over 30min which had been developed during from 2019 to 2022. These unmanned helicopters were initiated to provide better vehicles to surveillance and delivery for military and also to provide future eco-friendly VTOL vehicle for urban parcel delivery service, urban passenger service as a part of Korea-UAM and also drone service market promotion in Korea. For the developing MPUH and K-EUH, KARI have applied the existing accumulated experiences and technologies obtained from the domestic helicopter development program. These programs are like Light Armed Helicopter (LAH), Light Civil Helicopter (LCH), Korean Helicopter Program (KHP). In Korea, there was no research and development activities on an electric unmanned helicopter with payload 20kg until 2019. The foreign electric helicopter examples such as battery and power system, electric motor for electric vehicle [1-3]. This electric helicopter has so many merits like and long flight distance, high payload, high cruise speed, resistance from wind relative to drone such as quadcopter type. From these merits, electric helicopter be able to service market like parcel delivery to the mountains, long offshore area and island [3]. After success of K-EUH technologies development, KARI can start the commercial program for the K-EUH to achieve real market. This paper describes main activities of the two major unmanned helicopter program which has been developed in KARI recently.

1. NOTATION

Symbols

R	Rotor radius, m
P_i	Induced power, kW
β_p	Precone angle, deg
Ω, Ω_{TR}	Main, tail rotor speed of rotation, rad/s

Acronyms:

MPUH	Multi-Purpose Unmanned Helicopter
MPUH-C	Multi-Purpose Unmanned Helicopter with CLAS
CLAS	Conformal Load-bearing Antennas
K-EUH	Korea-Electric Unmanned Helicopter
KARI	Korea Aerospace Research Institute
KHP	Korean Helicopter Program
QTP	Quad Tilt Prop
LAH	Light Armed Helicopter
LCH	Light Civil Helicopter
FCC	Flight Control Computer
GCS	Ground Control System
NATC	National Aviation Test Center
CEP	Circular Error Probability
BMS	Battery Management System

PMS	Power Management System
UAM	Urban Air Mobility
MTOW	Maximum Take-Off Weight
eVTOL	Electric Vertical Take-Off Landing
RSSI	Received Signal Strength Indicator
CDR	Critical Design Review
TRR	Test Readiness Review
FFRR	First Flight Readiness Review

2. INTRODUCTION

Helicopters or rotorcrafts have traditionally used gasoline fuel sources for internal combustion engines. But, one of the representative power sources is electric power due to eco-friendly energy and carbon neutralization. Recently, KARI had developed two types of unmanned rotorcrafts. One is the combustion engine base rotorcraft. The other is electric engine base rotorcraft. In rotorcraft. So, some rotorcraft uses hybrid engine type mixed with combustion engine and electric battery. Korea Aerospace Research Institute (KARI) has researched and developed several types of unmanned helicopter in recent period. The one of the unmanned helicopters is multi-purpose unmanned helicopter which as the MTOW 200kg. The other of the unmanned helicopters is the first Korea electric unmanned helicopter (K-EUH) with MTOW 125kg. The final flight tests of these unmanned helicopters were conducted at KARI's National Aviation Test Center (NATC). NATC was established in 2002 at Goheung County where located at southern area 300km far from Daejeon site. KARI NATC has been used until now for the all flight tests of all domestic developed manned or unmanned aircraft from airship to UAM eVTOL.

3. KARI Unmanned Helicopters

3.1. General

KARI had developed 2 types of unmanned helicopters during last 8 years. The first unmanned helicopter was called as MPUH which was Multi-Purpose Unmanned Helicopter. This MPUH was developed for reconnaissance mission as a primary mission. This MPUH was also developed for delivery mission as a secondary mission. MPUH unmanned helicopter which had payload 60kg, max speed 150km/h and flight time over 3hrs had been developed from 2017 to 2021. This helicopter was successfully developed and now was surveyed for the commercialization from the Korean army. After developing MPUH, this MPUH helicopter was used for the testbed aircraft for the CLAS (Conformal Load-bearing Antennas) project. This purpose of this CLAS project was to overcome the disadvantages of traditional protruding antennas, like high aerodynamic drag, increased radar cross section area and structural complexity. To verify this CLAS performance, MPUH was used as a testbed aircraft. The second unmanned helicopter was called as K-EUH which was Korea-Unmanned Electric Helicopter. This K-EUH which had payload 20kg, max speed 120km/h and flight time over 30min was developed for delivery mission as a primary mission. K-EUH unmanned helicopter had been developed from 2019 to 2022. This helicopter was successfully developed and now was surveyed for the commercialization from the Korean army and government service.

3.2. MPUH Unmanned Helicopter

The first unmanned helicopter was called as MPUH which was Multi-Purpose, the representative company which develop vehicle is the Sungwoo Engineering. This company was responsible for system integration (SI), airframe and sub-system development like drive train, landing gear, etc. LIGNex1 and DBrain had developed subcomponents such as FCC, avionics, ground control system (GCS). KARI had participated in design, analysis and test for the major components such as rotor blade, landing gear and fuselage. The initial basic platform of MPUH was SD-180 which was developed by Sungwoo. This helicopter has 180kg MTOW, gasoline engine and 2-blade rotor system. As the first step, This SD-180 was chosen as baseline helicopter (SD-180). This baseline helicopter was sized up to 200kg MTOW to meet the development requirements. Historically, there were a few unmanned helicopter development programs in Korea. But these programs were based on the modified development program from the existing manned helicopter which are bought from foreign country. The MPUH program was originally the first unmanned helicopter launched by government as a national project. The MPUH unmanned helicopter had many merits such as high payload, long endurance and long distance, the wind resistance compared to other drones. The major activities at MPUH program were to research on the unmanned helicopter's rotor sizing, to develop full helicopter and GCS to experience and participate in all development processes for the unmanned helicopter. It should demonstrate the achieved technologies through MPUH flight test. The initial sizing and predicting the helicopter performance was conducted as the first step. The candidate list of engines was selected and data of candidate engine performance was accumulated. These engines were compared each other based on supplier's technical sheet and internal test result if there was no technical sheet. Through these works, the critical design was conducted. After this critical design, the MPUH could entered into manufacturing step. After manufacturing, the MPUH could start to various functional tests of sub components. Through rotational test on the ground iron bird rig, the maximum rotor thrust and power were measured several times. Through endurance test on the ground iron bird, the gearbox endurance test was conducted. Through all these sub components test processes, the final SI test was conducted to check all functional capability and component interference on iron bird rig. MPUH's environmental operational test on low temperature was conducted in the temperature chamber. At the final stage, flight validation test was conducted. Through this flight test on KARI NATC, the main goals of MPUH were achieved and demonstrated such as maximum cruise flight speed 150 km/h. Other goals are achieved such as automatic landing accuracy (CEP) 3.0m and flight endurance time 3.0hrs (with payload 60kg). This paper shows the major development activities executed through this program. Figure 1. shows the configuration of MPUH. MPUH has 2-blades rigid main and tail rotor system. KARI conducted the initial sizing to meet requirement for the mission. Figure 2. shows the initial sizing of MPUH. Based on this initial sizing of MPUH, the blade platform optimization was conducted to get maximum performance with given power. Figure 3. shows the analysis result of optimal platform design of main rotor blade. This result shows the parabolic planform design has better performance than others such as rectangular or existing baseline. Figure 4. shows the MPUH system configuration and internal layout based on initial sizing and design. Figure 5. shows the structural design of main rotor blade for the special section STA 351 as an example. Total 11 sections of main rotor blade were designed using same procedure to meet each sectional property such as stiffness, weight, center of gravity, etc. Figure 6. shows the flapwise section stiffness distribution of main rotor blade. This graph shows the difference between requirement value and design value. The difference was not so big and the design was fixed after analysis. Figure 7. shows the safety wire hanging test (tie-down test) before first flight. Before flight test, each procedure was conducted such as CDR, TRR, FFRR. Figure 8. shows the initial flight test at KARI NATC. Before flight test, each procedure was conducted such as CDR, TRR, FFRR. Figure 9. Shows the one of flight test result, maximum cruise speed. ADC speed shows more bigger value rather than GPS speed. The requirement of maximum cruise speed is 150km/h. So, all speed measured from each speed sensor satisfied the requirement.

Figure 1: The configuration of MPUH

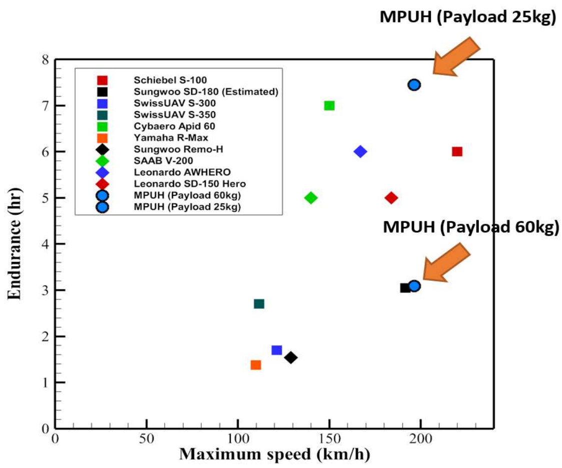

Figure 2: Initial Sizing of MPUH

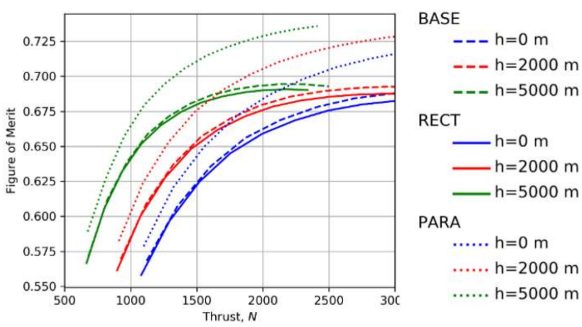

Figure 3: Platform design of main rotor blade

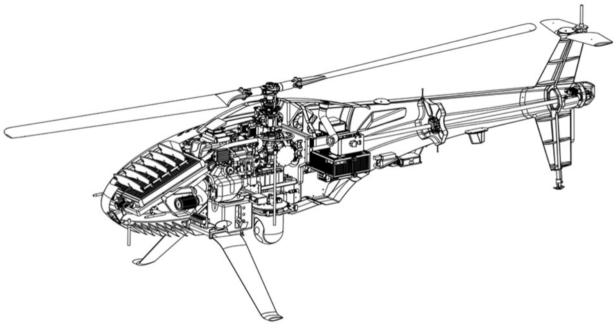

Figure 4: MPUH System Configuration and internal layout

STA			PARTS	PLY NO	PLY ANGLE	THICKNESS	MATERIAL	REMARKS
	(mm)	(r/R)			(deg)	(mm)		
5	351.0	0.1950	SKIN	1	45	0.223	CARBON FABRIC	NOSE SPAR > 20.0
				2	45	0.223		T/E STIFFENER > 5.0
				3	0	0.223		TORSION BOX > 40.0
				4	0	0.223		
				5	0	0.223		
				6	0	0.223		
					TOTAL	1.338		
			TORSION BOX	1	45	0.223	CARBON FABRIC	
				2	-45	0.223		
				3	45	0.223		
				4	45	0.223		
				5	-45	0.223		
				6	45	0.223		
					TOTAL	1.338		
			SPAR	1			GLASS UD	
					TOTAL	20.000		

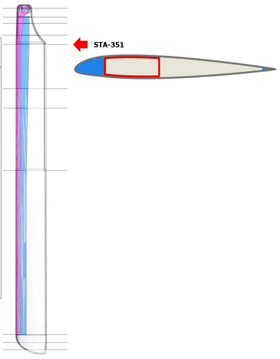

Figure 5: Structural design of main rotor blade

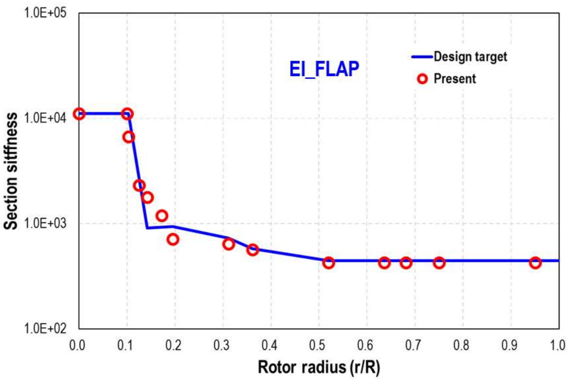

Figure 6: The flapwise section stiffness distribution of main rotor blade

Figure 7: Safety wire test before MPUH flight test

Figure 8: MPUH flight test on KARI National Aviation Test Center

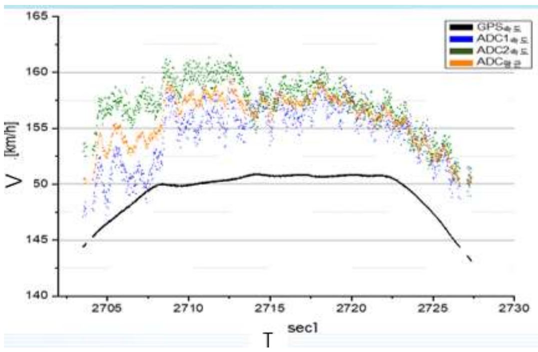

Figure 9: Flight test result (maximum cruise speed) of MPUH

3.3. CLAS Project with MPUH (MPUH-C)

In parallel with KARI MPUH development, KARI had started the CLAS Project. This CLAS Project had aims to establish and validate an innovative concept of carbon composite structure. This project was based on CLAS integrating communication antennas. These antennas are for the C-band (5.03 ~ 5.15 GHz) used for unmanned aircrafts. These aircrafts are made with carbon composite airframe. In CLAS project, MPUH was selected as a unmanned aerial vehicle because MPUH was developed by domestic company with KARI. So, it can be effectively modified and could be conducted for performance flight test to validate requirement. The detail of CLAS project was not described in this paper. The brief results were described. Helicopter has basically vibration and impact load. These characteristics were good for validation of CLAS and communication of MUM-T (Manned-Unmanned Teaming) system. Table 1. shows the requirements for CFRP based CLAS. Figure 10 shows MPUH-C design concept and modification parts. This bottom of tail boom was replaced with CLAS parts. Figure 11. shows Figure 11. shows parts and key technologies for CFRP based CLAS. Figure 12. shows specimens of ground test and fight test for CLAS. Figure 13. shows general figure of MPUH-C modified with embedded antenna. Figure 14. shows the RSSI relative to elevation angle at the hover flight. Also, this figure shows the elevation angle of antennas results measured at in-place flight test. The RSSI had confirmed that signal strength of the communication maintained with a high reception strength (-70 dBm) or less at from 5 deg to 54 deg elevation angle. Additionally, it was confirmed that reception strength exceeds a certain level. It was even at higher elevation angles through forward flight tests. Figure 15. shows antenna 3d beam pattern comparison.

Table 2. Requirements for CFRP based CLAS.

Requirement		Value	Remark
System	Weight Reduction	> 10 %	vs. Conventional
	Part Reduction	> 50 %	protruding antenna
Structure	Compressive Strength	> 1,667 N/cm	300mm X 300mm (> 50 kN)
	Impact Resistance	> 5.36 J	ASTM D7136
Antenna	Freq. Range	5.03 ~ 5.15 GHz	C-band
	Return Loss	< -10 dB	S-parameter
	Elevation Angle	0 to 90 deg	
	Azimuth Angle	0 to 360 deg	

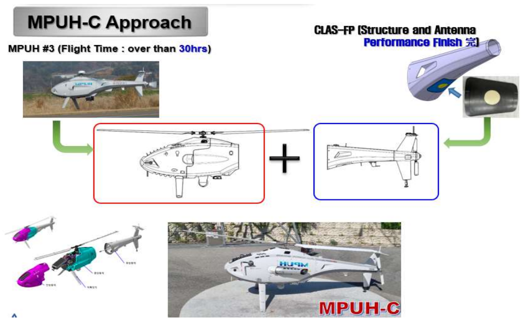

Figure 10: MPUH-C Design Concept and Modification Parts

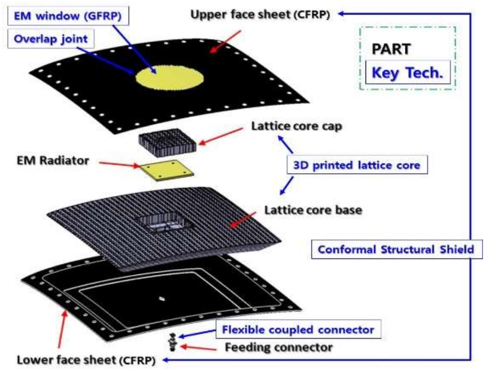

Figure 11: Parts and key technologies for CFRP based CLAS

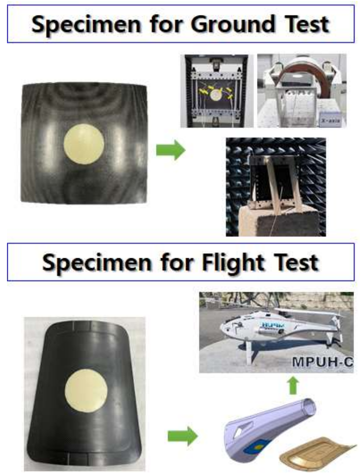

Figure 12: Specimens of GT and FT for CLAS

Figure 13: MPUH modified with Embedded Antenna (MPUH-C)

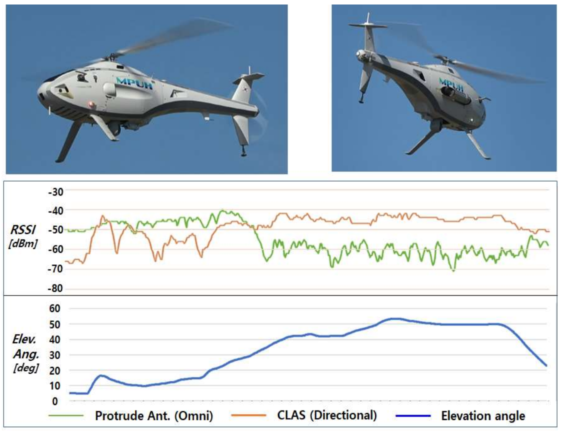

Figure 14: Antenna RSSI with respect to Elevation Angle @ Hover Flight

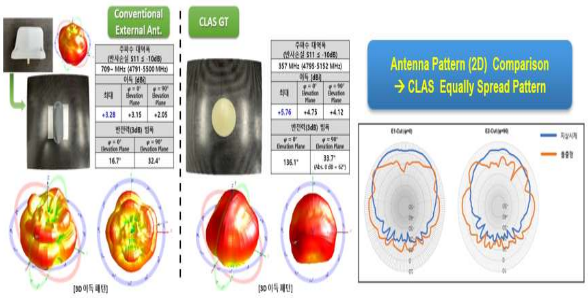

Figure 15: Antenna 3D beam pattern comparison

3.4. K-EUH Unmanned Helicopter

KARI had leaded this K-EUH electric unmanned helicopter development which had the responsibility to system integration, analysis, ground and flight test. Other companies such as Sungwoo Eng. and DBrain had involved the development responsibility of airframe structure, FCC, avionics, ground control system. As the first step, K-EUH was sized to meet the development requirements with payload 20kg, 60km flight distance. The K-EUH program was officially started on the 1st of April in 2019 and finished on March in 2022 (36 months). The final target of this program is developing the pure battery system and power management system for the electric unmanned helicopter with payload 20kg, flight distance 60km. This electric system should verify and validate technologies achievement through these several validation tests. Finally, this program should demonstrate the achieved electric unmanned helicopter technologies through flight test. KARI had executed the design and analysis of unmanned helicopter system including the rotor system, airframe, electric power system, battery management system and landing gear. Also, KARI had executed the rotor sizing, performance analysis, dynamic analysis, rotor test. KARI also supported the technology demonstration during flight test at KARI NATC site. Maximum take-off weight, payload, endurance time, flight distance, maximum cruise speed, maximum power capability and automatic landing accuracy capabilities are the basic requirements of K-EUH. The core technologies including battery management system and power management system need to be satisfied with program requirements. After several iteration from preliminary design to critical design, the K-EUH could be entered into fabrication. After this fabrication, K-EUH could enter into various functional tests of sub components. Through rotational test on the ground iron bird rig, the maximum rotor thrust and power were measured. At the third step, the major sub-system integration tests on the ground were conducted by their own test rigs. Through iron bird test rig, the major system integration test was conducted to check and validate all functional role and interference effects. K-EUH's environmental operational test for the low temperature was conducted at the temperature chamber in KARI. At the fourth step, flight validation test was finished at KARI NATC. The performance test results of K-EUH were shown and validated such as 100 km/h maximum cruise flight speed, automatic landing accuracy 3.0m and flight endurance 0.5hrs. These performance results were conducted with payload 20kg. Figure 16 shows the work flow chart of design methodology of K-EUH. Figure 17 shows blade platform design of main rotor blade. Figure 18 shows the main rotor system design of K-EUH. Figure 19 shows the K-EUH configuration. Figure 20 show the ground rig test to measure maximum thrust and battery performance. Figure 21 shows K-EUH flight test on KARI National Aviation Test Center. Figure 22 shows the K-EUH flight test (Race track) for long distance at KARI NACT. Figure 23 shows the maximum speed measured from GPS from flight test (Ref.2-4)

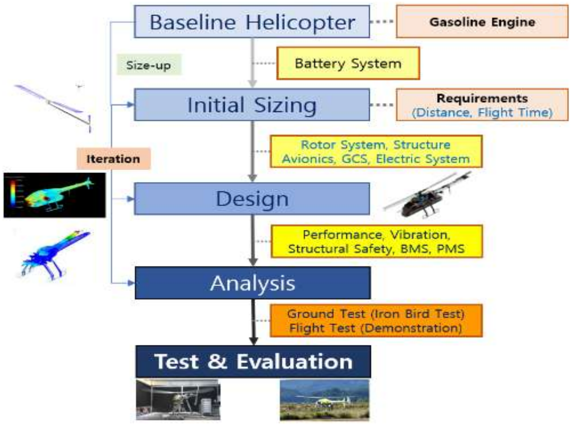

Figure 16: The Work Flow Chart of Design Methodology of Unmanned Helicopter Development

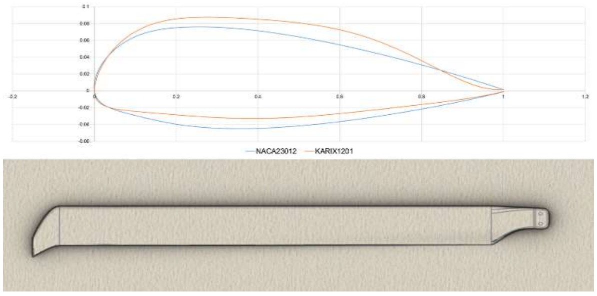

Figure 17: Blade Planform Design on K-EUH

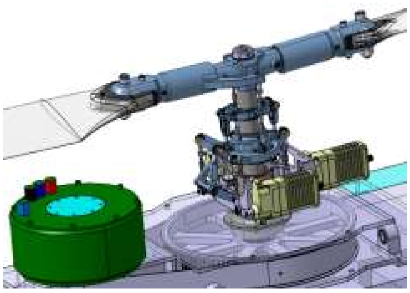

Figure 18: Main rotor system design of K-EUH

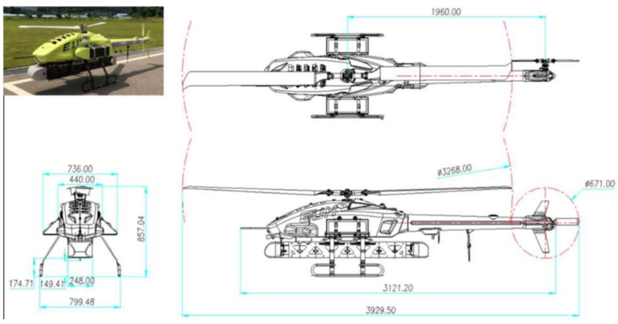

Figure 19: K-EUH Configuration

Figure 20: K-EUH performance test on ground rig

Figure 21: K-EUH flight test on KARI National Aviation Test Center

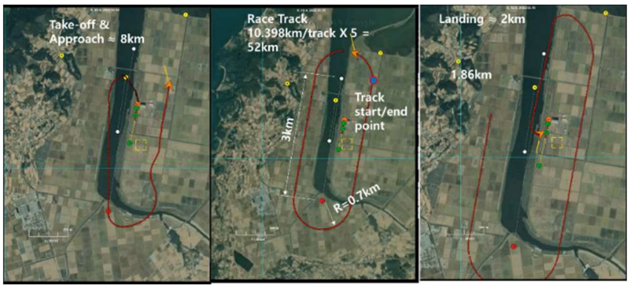

Figure 22: K-EUH flight test (Race track) for long distance at KARI National Aviation Test Center

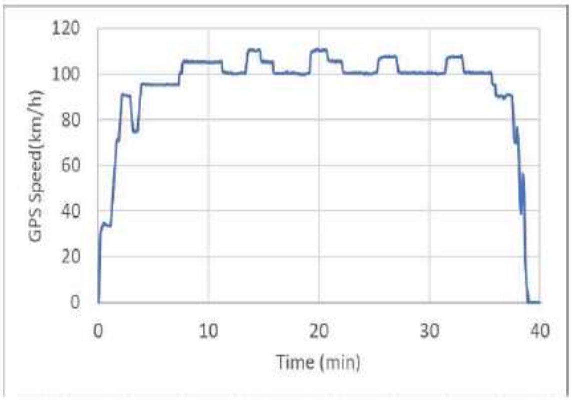

Figure 23: K-EUH flight test result on performance

3.5. National Aviation Test Center (NATC)

KARI NATC had established at Goheung-gun county 300km far from Daejeon South Korea in August, 2002. At that time, the first 700m runway was built. In 2006, The airship test building & small aircraft test building was built to conduct national aircraft development project. In 2010, helicopter test facilities such as rotor whirl tower & L/G drop test building was built. In 2022, The second 1.2km runway and 2 taxiways and landing strip was built. In 2023, K-UAM Grand Chanllenge-1st Stage Demonstration Facility was finished. In 2028, Airfield Flight Safety Monitoring System will be finished to monitor several aircrafts simultaneously with safety. Figure 24-28 shows the representative flight test of developed in KARI or Korea at KARI NATC

Figure 24: Drone photo of KARI NATC (Dec 2024)

Figure 25: Airship flight test at KARI NATC (Oct. 2019)

Figure 26: OPPAV flight test at KARI NATC (Dec. 2023)

Figure 27: EAV-4 flight test at KARI NATC (April 2025)

Figure 28: flight test of Major aircraft at KARI NATC

4. Conclusions

As the Conclusion, this paper described the main activities of the two major unmanned helicopter program which has been developed in KARI recently. From this unmanned helicopter program, the core technologies of unmanned helicopters. The MPUH-C flight test was done and shown the performance capability of the embedded antenna structure on MPUH at KARI NATC. Through MPUH-C flight tests, stable communication performance was verified at various elevation and azimuth angle and flight attitude, and applicability to unmanned helicopters was confirmed through the development of a CLAS prototype for flight tests.

Second, this paper described the overview of development of the first Korea Electric Unmanned Helicopter (K-EUH). The K-EUH has payload 20kg, max speed 120km/h and flight time over 30min which had been developed during from 2019 to 2022. Finally, KARI NATC was briefly introduced where major flight test of domestic developed aircraft such as drone, multicopter, evtol, rotary wing aircraft, fixed wing aircraft, etc.

5. ACKNOWLEDGMENTS

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