SMART UAV RESEARCH PROGRAM STATUS UPDATE : ACHIEVEMENT OF TILT-ROTOR TECHNOLOGY DEVELOPMENT AND VISION AHEAD

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Abstract

This paper summarizes domestic technology achievements in Korea in the field of unmanned tilt-rotor air-vehicle development and smart system implementation like collision avoidance technology. Full automatic unmanned flight with small scaled version had been successfully performed in Sep 2008. The first flight of full scaled version was planned by end of 2009 which is now about to happen. What do we expect out of this technology development program will also be discussed : Opportunities and potentials of the advanced tilt-rotor concept to outbeat competing technologies in the field of the high speed VTOL UAV, VTOL Tactical UAV(VTUAV), and the multi-role VTOL manned-aircraft..

1 Introduction of the Smart UAV Program

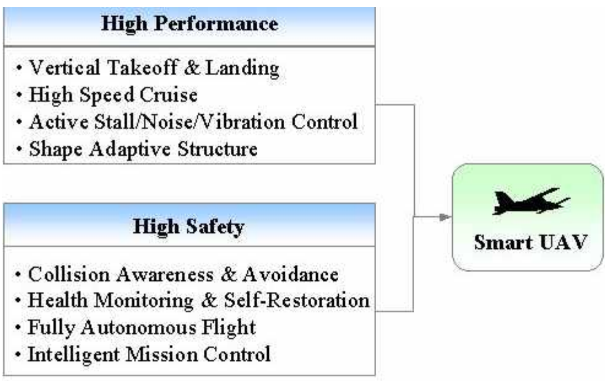

Fig. 1. Technical Features of the Smart UAV Program

8 years of research period out of 10 years of term have been successfully passed for the Smart UAV program which is sponsored by MOCIE which was MOST before 2008. It aims to enhance aircraft design and development technology of Korea to the top level of worldwide aircraft research field.

It is important to emphasize that the purpose of this program is not limited to UAV field. The technical feature of this smart UAV program will be best described in two sentence : 1) To identify & develop the technology for the high speed/advanced VTOL aircraft in the future 2) To develop & implement cutting-edge UAV system technology for the domestic aerospace industries.

To realize this end, this program started with no designated air-vehicle concept other than the top level requirements like TOGW 300kg, Max Cruise 500km/h, Max Endurance 5 Hr, Payload 40 kg, operation range 200km which were considered to be a set of revolutionary flight performance to fill the gap between the conventional VTOLs and fixed wing aircrafts.

So the phase1, first 3 years of 2002~2004, had been dedicated to the tailoring of this requirement set, and to the definition of "advanced" air vehicle concept which is expected to meet those requirements. Three major result of the phase 1 research : 1) Change of baseline aircraft concept from CRW (Canard Rotor Wing in other words, stopped rotor-wing) into tilt-rotor concept 2) Tailored and structured set of requirements. Particularly, TOGW had been tailored to 1 ton level to cope with increased payload demand including collision avoidance system and to avoid the risk of developing brand new engine that would suit

300kg size of Smart UAV 3) Preliminary design and engineering familiarization of tilt-rotor aircraft concept which led us to the risk identification and the critical mile-stone planning.

Fig. 2. 3 Development Stages of the Smart UAV Program

Phase 2, 2005~2009.3, had been dedicated to the key technology development to the level it could be verified through the flight test with small scaled "unmanned" air-vehicle, and the full-scaled system development. Three major result of the Phase 2 research : 1) Successful flight test up to full automatic unmanned tilt-rotor operation from takeoff, conversion, fixed wing flight and finally landing in its helicopter mode with small scaled version. 2) Full-scaled model development from its components (rotor system, drive system, control mechanism, on board avionic hardware including DFCC and DGNS, ground antenna tracking systems for the 200km operation range) to the system integration which is verified through extensive ground tests activities in parallel with the flight test of the small-scaled version. 3) Ground control and communication systems development. Full scaled model has been developed in cooperation with leading industries and academia to establish the domestic foundation of engineering and production capability.

Phase 3, 2009~2011, will be dedicated to capstone Smart UAV research program by implementing "smart" technology into the Smart UAV and enhance its performance and system completeness to the level that no other precedent aircraft ever been able to reach. (See Fig. 3)

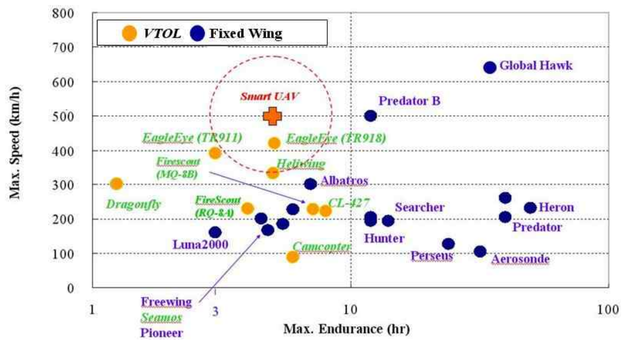

Fig. 3. Outstanding Performance Target of Smart UAV

2 Technology development Status

To realize tiltrotor platform, lots of high level design technologies are required. Items in the list below are the key technologies that have been developed and implemented in Smart UAV program.

2.1 Advanced VTOL UAV Design Technology

Tiltrotor platform requires lots of high level design technologies that haven't been tried before. Items in the list below are the key technologies that have been developed and implemented in Smart UAV program.

- Sizing and aerodynamic flight performance prediction/evaluation.
- CATIA based 3D Design and Digital Mock-up technology to realize compact size and internal layout for light weight configuration design.
- Rotor aero-elastic analysis & Load analysis considering dual RPM operation mode to achieve stable rotor system in high speed and conversion mode. (Fig. 4)
- Aerodynamic analysis & Design for optimum blade and wing design for both rotor mode and propeller mode. [1]

- Dual RPM engine control by DFCC to enhance aerodynamic performance in terms of high speed and endurance.
- Stable rotor hub & Rotor control system design which is key to realize tilt rotor vehicle.
- Nacelle conversion system & Automatic conversion flight.
- High performance & Low weight drive system development.
- Flight control : Automatic flight control and mode conversion logic / system development for full automatic operation from lift-off to landing.
- Differential left & right rotor pitch control with optimum control mixing for rotor mode and propeller mode.
- Dual-system architecture implementation & H/W development for reliable flight control system design.

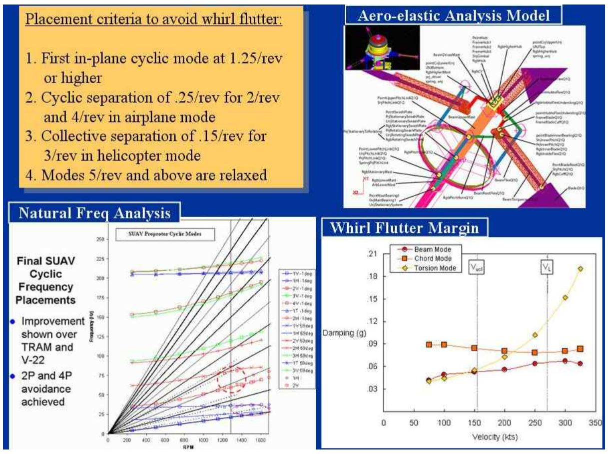

Fig. 4. Eample of Advanced VTOL Design : Dynamic Analysis & Design to avoid Whirl Flutter

All of these technologies have been successfully developed during past few years and will be tested and validated through current on-going component/system level ground tests to be ready for first flight.

Fig 4 shows the technical achievement example in the case of rotor aero-elastic analysis technology which had been implemented to optimize the stiffness of rotor design, hub design, and wing design for whirl flutter elimination in mission range. Smart UAV rotor system, control system, and supporting structure have been evaluated to have sufficient whirl flutter margin even at the speed of 300 kts (555 km/h) as is shown in Fig. 4.

2.2 Advanced UAS Technology

On top of the advanced VTOL UAV design technologies, wide range of state-of-the-art UAS technologies have been challenged and implemented through this program.

- Reliable and long range data link systems with low power and light weight features.
- Dual channel data link using Ku-band and UHF band with dual antenna for each data link.
- Real time data link monitoring and automatic reconfiguration/switching of data link.
- Real time display of geographic data, flight information, system monitoring information upto 200 km range.
- Collision awareness and automatic avoidance flight management systems based on ADS-B system.
- UAV in the manned airspace issue : See & Avoid capability with ADS-B, transponder(C), VRT, flight termination systems

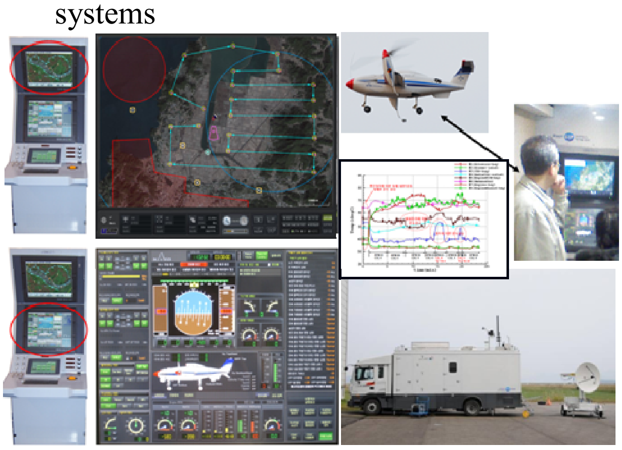

Fig. 5. GCS Example : Real Time data display & interface

2.3 Systematic Design & Validation Technology

Establishing an effective validation system is a key element for the success of innovative systems development program like the smart UAV. KARI led the systems engineering activities like UAS functional analysis, requirement flow down, configuration management, design integration and trade off issue control, TPM & CPM management for risk control, etc. in parallel with core technology development & validation efforts. Out of those systems engineering efforts, "One-stop flight test environment" is highlight of the systematic & effective validation technology of KARI.

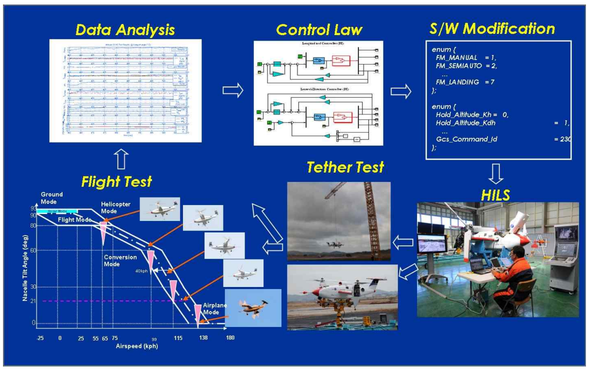

Fig 6. One-Stop Flight Test Environment

With this environment, all the activities related with flight control law changes or anomalies identified through flight test are evaluated and corrected at the same site for the next ground/flight tests on the same day.

2.4 Program Status of Smart UAV Development

The conceptual, preliminary and detailed design of the Smart Unmanned Aircraft System(UAS) were finished by early 2006. And the development and qualification tests of its parts, subsystems, and even air-vehicle level system integration tests have been being completed. After a tiltrotor concept was selected as the Smart Unmanned Air Vehicle(UAV) platform among several candidates, an extensive studies have been done to build-up key technologies required for tilt-rotor development and to come up with highly reliable and effective UAV.

A turbo-shaft engine was selected to drive two side-by-side rotors, and the rotor system was designed to utilize a constant-velocity joint gimbaled hub. Lots of wind tunnel tests were performed in 2005, and several 40%-scaled (when rotor diameter compared to the full-scale version) vehicles were produced to be used for flight control logic validation and air-vehicle flight dynamics understanding. On September 2008, KARI made a historic full automatic flight with demo version (40% scale version). On December 2009, full scale version made a quasi-first flight (holding hovering altitude with self power with MTOW configuration) in the tether test environment.

3 Vision with tiltrotor technology

Although, there are lots of technical traits in the Smart UAV program other than tiltrotor technology, this paper will discuss the vision related with tiltrotor technology only.

3.1 Tiltrotor concept for Multirole VTOL Aircraft

For the manned aircraft program level, two remarkable decisions had been made in the middle of controversial arguments between tiltrotor technology and advanced helicopter technology. 1) In 2005, US DoD granted full production of V-22 Osprey program while dropping the Comanche program in 2004 which was already entered into flight test phase. 2) In 2007, advanced tiltrotor concept had been selected as a next generation heavy weight transport aircraft for both US Army and Air Force following the concepts evaluation study started in 2005.

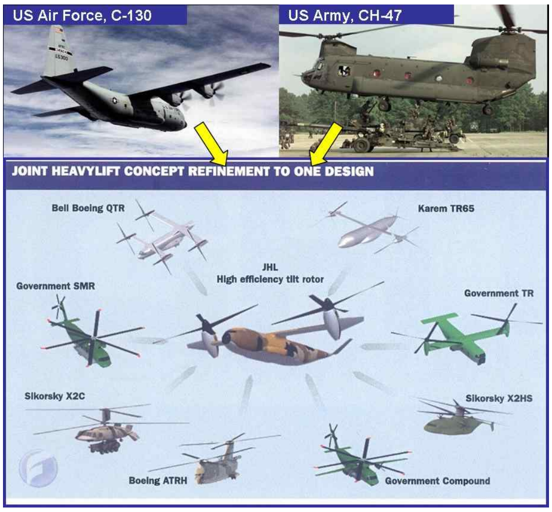

Fig. 7. Next Generation Vehicle Concept Consolidation : Joint Heavy Lift (JHL) Program for US Army and Air Force

3.2 Tiltrotor concept for VTOL Tactical UAV

Even after V-22 Osprey's successful debut into the service with full rate production decision in 2005, various concept studies are still on-going to find more suitable and advanced VTOL solution other than tilt-rotor concept especially in the Tactical UAV regime. Most of those programs are targeting to achieve higher speed, and low development risk & cost while maintaining VTOL capability. Recent research: Aurora Excalibur program(tilt-jet concept with hybrid engine supported by electric power at takeoff), Sikorsky X2 program(coaxial concept with pusher), Karem advanced tilt-rotor program, mono tilt-rotor program, and tip-jet concept with variable rotor rpm.

In addition, conventional VTOL concept still maintains strong position in the current market as in the case of Firescout(Northrop Grumman) which has been chosen and about enter into service as a Class IV UAV for the US Army. Hummingbird is another promising successor of conventional VTOL concept implementing propulsion system modulation idea. Common traits of these two programs are the long endurance and the payload capability to compensate for the low speed and shorter range characteristics.

Will tiltrotor concept find a applicable place in VTUAV? A sound review on basic design & sizing features together with the performance characteristics will be a good starting point in quest for an eligible answer.

3.3 Concept Feature : Tiltrotor vs Helicopter

- Vehicle Design & Sizing Feature Comparison

	Tiltrotor	Helicopter	Notes on Tiltrotor Concept
Disc Loading	13 ~ 20	5 ~ 12	Pros : Much better cruise perf. Cons : Less payload perf. & energy Autorotation inertial
	See Fig. 8		
Power	4 ~ 10	5 ~ 18	Cons : More takeoff power
	See Fig. 8		
Hover F.M.	> 0.8	~ 0.8	Pros : Less takeoff power due to blade twist > 35 degree
Hovering Tip Speed	> M 0.71	< M0.65	Pros : Less takeoff power Cons : Strong downwash
Empty Weight Ratio	< 0.65	< 0.6	Cons : Less payload ratio due to system complexity
Lift to Drag Ratio in Cruise Flight	> 8	< 5	Pros : Much less fuel burn & Higher cruise speed
	See Fig. 9		
Advance Speed Ratio, J	> 0.55	< 0.25	Pros : Much higher fwd speed Aeroelastic stability in high speed flight regime

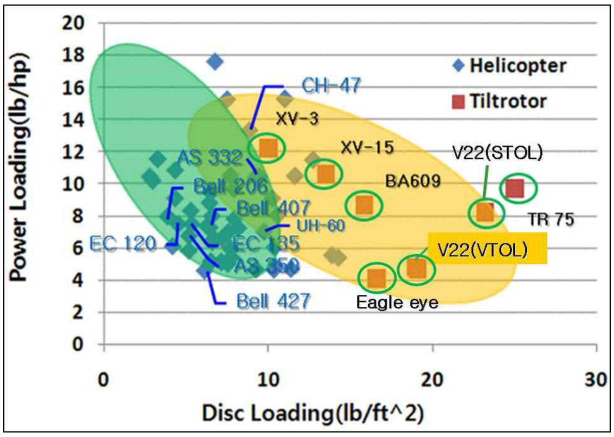

Fig. 8. Power Loading and Disc Loading Trends Comparison

TR75 the advanced tiltrotor proposed by Karem for the JHL program.

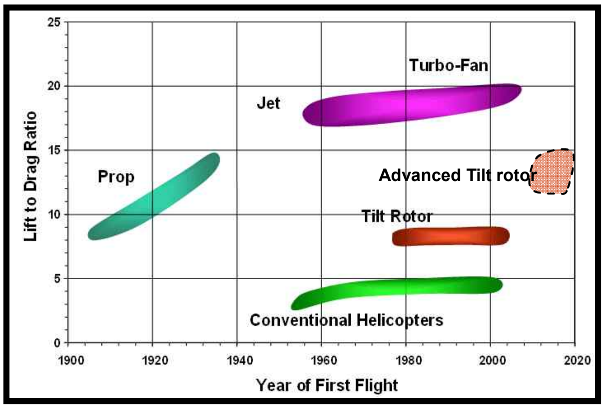

Fig. 9. Life to Drag Ratio Comparison

With these major design/sizing characteristics, flight performance is quite different as follows.

- Flight Performance & Operation Feature Comparison

	Tiltrotor	Helicopter	Notes on Tiltrotor Concept
Max Cruise Speed	350	< 170 kts	Double in cruise speed means 2 times in mission radius and 4 times in mission range
	See Fig. 10		
Altitude with > 100 kts speed	> 25,000 ft	< 12,000 ft	High altitude performance has crucial survivability importance for & to for wide range operation UAV make sure or LOS data link
	See Fig 11		
Payload Ratio	30 ~ 35%	20 ~ 50%	In case of helicopter, more fuel to payload trade is possible for wider range mission operation.
Container Volume	App. 50 ~ 80	100 (Ref.)	Less volume is important for ship deck operation
Noise	App. 75 ~ 85 dB	85 ~ 95 dB (Ref)	Less noise approximately 10 dB (MTOW more than 1 ton)

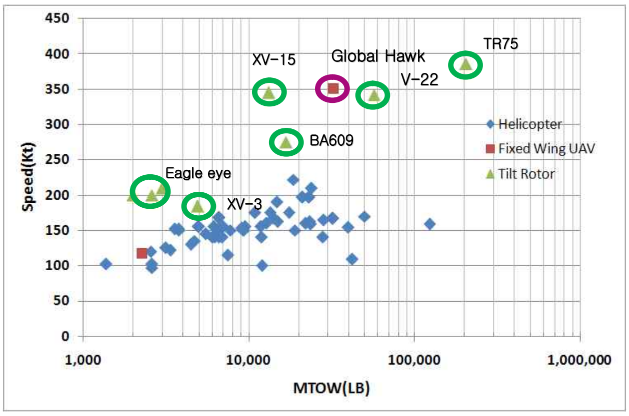

Fig. 10. Maximum Speed vs MTOW Trends Comparison

Theoretically, maximum cruise speed for conventional helicopter is limited to 170 kts. To fly more than this speed, sophisticated systems are required like rotor RPM control and/or additional pusher propeller which can be implemented into tiltrotor concept more effectively. So, for the concept comparison purpose, it would be more reasonable to consider 170 kts as the limit speed of helicopter concept

Fig. 11 is based on the XV-15 flight test data and the UH60 flight manual. Altitude and speed performance of helicopter drops quickly with the takeoff weight increase as the bigger portion of rotor power will be shared for lift.

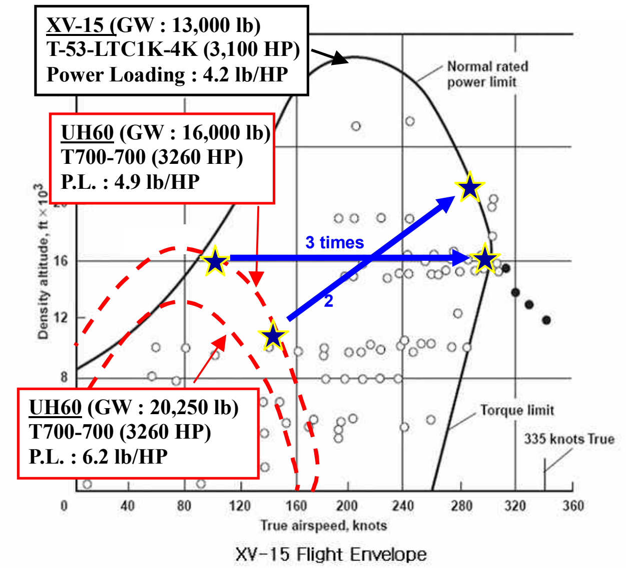

Fig. 11. Flight Envelop Comparison

So, when it comes to flight performance comparison between tiltrotor and helicopter, reference takeoff weight has to be checked. In most cases, the maximum altitude of helicopter performance is based on empty weight condition which is impractical in operation.

3.4 Validity of Tiltrotor Concept Solution as a next generation Advanced VTOL platform

Speed and altitude performance are crucial elements for the survivability of air-vehicle. Although the speed and the altitude performace of tiltrotor are less appreciated than manned multi-role aircraft, the survivability is crucial issue even more for small VTUAV due to low speed design characteristics.(Fig. 12) This became more important with the proliferatioin of hand-carry missle system Furthermore, for the wide range operation of VTUAV, high altitude capability is mandatory to ensure line of sight data link.

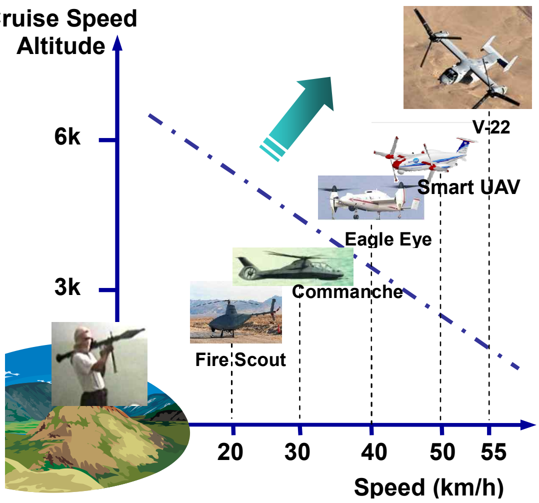

Fig. 12. Survivability as function of speed and altitude

In addition, tiltrotor concept draws strong interest as a baseline concept for PAV (Personal Air Vehicle) as has been presented by UK's Falx Air Vehicles[2] with hybrid-electric tiltrotor concept. Electric power system is much easier to implement in case of tiltrotor concept as its devided power source in two instead of one big motor. Furthermore, with this conceopt, no need for the drive train and cross shaft through the wing. Thereby, it is reasonable to expect the substatial reduction in system complexity and weight which ensures the enhancement of vehicle system reliability and flight performance.

4 Summary

4.1 The Smart UAV Development Status

The Smart UAV Program is well on track for the realization of challenging and innovative VTOL flight performance targets like high speed and long endurance in the form of tiltrotor system. Tiltrotor concept is selected as the result of extensive and internationally colaborated study on the advanced VTOL concepts. Key technologies and critical hardwares have been successfully developed and integrated during past 6 years. Subsystem level tests and air-vehicle level integrated ground test have been completed. Flight tests of 40% scaled model had successfully been completed in 2008 including full automatic flight. Full scaled version will demonstrate full automatic flight from takeoff to landing, automatic collision avoidance[3], 5 Hrs of endurance, 500km/h of flight speed, more than 5 km of flight altitude and 200km of operation range, and highly reliable systems with the duplex flight control and communication system architecture.

4.2 Vision & Future tasks

Tiltrotor technology has just begun to enter into service. Advanced tiltrotor development decision of US's JHL program, V-22 full rate production decision, Falx's research of hybrid-electric tiltrotor are the good evidence that tiltrotor technology would be strong contender in the near future to fill the broad range of market need. In case of wide range VTUAV application, high altitude capability of tiltrotor will become core trait not only for data link, but also for survivability. As the UAV systems become more complex and expensive survivability issue will become the primary agenda in down selecting the vehicle concept. On the other hand, improving endurance performance, empty weight reduction, aerodynamic performance improvement for both high speed cruise and heavy weight hovering condition, refinement of system reliability and complexity need to be pursued in parallel with a future research on the advanced tiltrotor technology.

5 References

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